Department of Wood Science & Engineering
40th Annual Report
2020

Prepared By

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EXECUTIVE SUMMARY

This year's report summarizes progress on several longstanding field studies at the Peavy Arboretum. In addition, significant progress has been made on fire testing, where the testing apparatus has been refabricated into what is believed to be its final form for standardized tests. A new section, 1.4.1 has been added describing efforts to identify suitable dry climate accelerants for dazomet. In addition, the UPRC has initiated several efforts to study DCOI as a utility pole preservative in western wood species, including a post test at the Peavy Arboretum site as well as the Madras, Oregon dry climate research site (section 3.4.1). This effort also includes a planned stake test and soil bottle test to investigate the efficacy of different solvent systems for DCOI (section 3.3.2).

Objective I examines the performance of internal remedial treatments for utility poles in a variety of lab and field studies. This objective also includes work dedicated to improving remedial treatments. The long-term study to measure the performance of dazomet with copper-based accelerants in penta-treated Douglas-fir poles was sampled for the second year after retreatment. MITC levels were abnormally low in year two (23 years after study start) compared to previous studies and the different treatments could not be differentiated from one another. This suggests there may be an issue with continued sampling of this project (section 1.1.1). Efforts to evaluate potassium dithiocarbamate as an internal remedial treatment relative to metam sodium continued at the Peavy arboretum with the second year of sampling for this project. MITC levels were also abnormally low for this study and the two in year 2 and it is unclear why as these data deviate from prior observations (section 1.1.2).

The full-scale internal remedial treatment study initiated in 2008 was sampled again in 2020 (149 months) and results continued along the lines of previously identified trends (section 1.3.1). Metam sodium-based treatments continued to show low levels of MITC which continues to support its ability to produce effective levels of MITC only in the first few years after treatment. MITC-FUME treatments also contained low MITC levels in this year's sampling, supporting its utility in providing a high initial impulse of MITC in the first few years after treatment which dissipates before the 10-year inspection cycle is complete. After 149 months, dazomet-based treatments showed MITC levels hovering around the effective threshold, particularly for samples taken at or below groundline. Powdered dazomet treatments appeared to provide higher levels of MITC at this late sampling point and inner pole sections had higher MITC levels generally. Overall, dazomet provides long-lasting MITC production above or just below effective inhibitory thresholds past the typical 10-year inspection cycle, particularly close to the groundline. Chloropicrin levels in wood were well past the effective threshold throughout wood samples taken from poles, but were reduced somewhat compared to previous years in the samples taken above groundline. Chloropicrin treatment continued to show its ability to produce effective inhibitory levels of chemical in wood well past the 10-year inspection cycle. Boron levels in poles treated with Impel rods or Pol saver rods were highest for both treatments at or below groundline after 149 months. The Impel rod treatments had generally higher levels of boron than the Pol saver treatments, however the Impel rod treatments tended to contain more decay fungi at this sampling point. These results support previous results indicating boron's dependence on water for diffusion in wood.

The effects of metam sodium on boron rod performance was measured for a second year (section 1.3.2). Boron levels continued to be generally higher in the pole interior and in the areas close to or below groundline. Interestingly, the metam sodium plus boron rod treatment began to have higher boron concentrations farther up the pole sections, which suggests there may be a positive impact on boron migration from co-treatment that must be investigated with subsequent samplings. MITC levels in metam sodium + boron rods were generally very low and below threshold levels as was seen in section 1.1.2. It is unclear why this was observed.

A new initiative was undertaken in 2020 to identify effective dazomet accelerants for dry climates using small-scale reactions to screen the performance of chemical combinations under different conditions (section 1.4.1). Several divalent metals including copper sulfate were tested for their ability to accelerate dazomet decomposition at three different moisture conditions and metal/dazomet ratios. Copper sulfate was the most effective dazomet accelerant at low moisture conditions and a molar ratio of metal: copper of around 1/10 caused similar amounts of MITC production than a higher ratio, indicating that further saturation would not be effective. Ferrous sulfate performed well as a dazomet accelerant at higher moisture contents but was not effective at low moisture contents. Water was shown to be the strongest factor driving dazomet decomposition, although at lower moisture contents, copper proved to be an effective accelerant.

Objective II seeks to identify chemicals for protecting exposed wood surfaces in utility pole. Recent efforts in this area done by the UPRC focused on examining how boron migrates in poles pretreated with boron and then over-treated with copper naphthenate. Section 2.1.1 describes the 7th year sampling of boron pretreated pole sections over-treated with copper naphthenate. In this year's sampling, inward migration of boron was not detected relative to levels seen in the previous year. However, overall boron loss to the environment appeared to slow or stop entirely. Section 2.1.2 describes the fourth-year sampling of boron pretreated poles with a penta, copper naphthenate or ACZA overtreatment. Inward migration of boron was not noticeably different than the previous year. Total boron loss to the environment also appeared to slow in most treatments, except for above groundline samples taken from ACZA poles where boron loss continued relative to the previous year.

Objective III seeks to discover improved specifications for utility poles. Section 3.1.1 describes impacts of pole capping systems on pole moisture content. The 2020 sampling will be done in December 2020 and will be included in the final draft of this report. Section 3.1.2 describes the use of polyurea caps to modulate moisture content in utility poles. The 2020 data for this section will be gathered in December 2020. Section 3.1.3 describes the impacts of pole top orientation on moisture uptake by utility poles and the 2020 data for this study will not be taken until December 2020. Section 3.1.5 describes the impact of polyurea coatings on the performance of untreated or penta-treated crossarms that have been exposed in Hilo, HI for 128 months. Two penta-treated and one untreated crossarm were sampled and destructively analyzed. The coating on one of the penta-treated crossarms was is much better condition than the untreated crossarm as was the wood underneath the crossarm. The second penta-treated crossarm's coating was heavily damaged on the upper surface and only low amounts of penta were detected in the wood. One of two penta-treated crossarms were sound while the other had significant amounts of decay. Only two instances of decay fungi were found in the undecayed penta-treated crossarm whereas they were much more abundant in the untreated. Dematiaceous fungi were abundant in the decayed penta-treated crossarm.

Section 3.2.1 describes progress on the development of a standard test method for assessing the performance of utility pole fire retardant treatments. In 2020, significant changes were made to the testing apparatus and a second heating element was added to facilitate more complete burning of the pole sections. The existing setup costs about $1000 in materials to set up without including a power source in the calculation. Initial tests were done on untreated poles to develop a standard procedure to be used on other pole treatments. Loss in circumference, surface temperature, maximum char depth and check widening were measured as parameters to discern treatment efficacy. Burning untreated poles showed a relatively large variability in circumference losses, indicating that the test may require a high number of replicates per treatment to resolve treatment effects. The fire test was also adapted to test treated crossarms, using a titanium dioxide-based coating as an initial test. The coating performed well and served as a sacrificial layer, preventing wood beneath from igniting and charring. Overall, the current testing apparatus performs well as a cost-effective testing apparatus and the current effort will be continued to generate baseline data for an AWPA standard.

This report also contains the 70-month evaluation of a stake test designed to measure the impact of various solvent systems on the performance of pentachlorophenol and copper naphthenate. Copper naphthenate stakes treated with 100% biodiesel tended to have lower ratings than those treated with diesel oil alone. The 70-month time-point has shown the largest divergence between the biodiesel stakes and diesel stakes for copper naphthenate to date and the difference is most pronounced in a forest-covered site as compared to an open field site. The same pattern was not observed with penta, although there was some divergence between different penta treatments. The UPRC also plans on expanding the efforts to test solvent system efficacy to DCOI and we have planned a soil bottle test and a stake test to measure the impact of solvent systems on the performance of DCOI. These proposed studies are summarized in section 3.3.2.

The UPRC has initiated a post test that will measure the performance of DCOI, copper naphthenate and penta-treated Douglas-fir poles at two field sites, the Peavy Arboretum pole farm and a field site in Madras, Oregon. This study has been installed at the Peavy Arboretum and will be installed at the Madras site soon (section 3.4.1).

Objective IV seeks to measure the performance of external groundline preservative systems that can be utilized to protect utility poles. The only active study in this object currently is the impact of Biotrans field liners on pole moisture content. This study was not sampled in 2020.

Objective V seeks to measure the performance of copper naphthenate as a utility pole treatment in western wood species. The 30-year evaluation of western redcedar stakes treated with copper naphthenate is reported in section 5.1.1. Copper naphthenate continued to provide protection to unweathered stakes, whereas the weathered stakes treated with copper naphthenate were in worse condition after 30 years. The lower retention weathered stakes had several failures by this time. The results indicate that copper naphthenate is an effective treatment for western redcedar.

OBJECTIVE I:

DEVELOP SAFER CHEMICALS FOR CONTROLLING INTERNAL DECAY OF WOOD POLES

The initial preservative treatment in the manufacture of utility poles yields a product that resists decay by wood destroying organisms effectively for decades beyond the effective lifespan of an untreated pole. However, the preservative treatment slowly loses efficacy over time and decay fungi can move into the pole past the preservative treated shell and cause internal decay. Pole life can be extended further by the application of internal remedial treatments as either fumigants or water-soluble compounds that either kill or inhibit the growth of decay fungi. Application of fumigants on a regular treatment cycle can extend the life of a utility pole for decades and is therefore an economical method to maintain utility pole integrity (Morrell 2016). That said, the development and testing of internal remedial treatments is of great interest to utilities. The UPRC has been involved in internal remedial treatment research since its inception and continues to work to help develop effective internal remedial treatments and application methods and specifications for existing treatments. The below sections describe progress on research in this topic area in 2020.

1.1.0 Develop Improved Fumigants for Controlling Internal Decay of Wood Poles

Fumigants have been shown to be effective in controlling decay fungi in wood since the mid-20th century and since have become widely used for the control of internal decay in utility poles in North America (Ruddick 1983). Early treatments used included two liquid fumigants were registered to preserve wood; metam sodium (33% sodium n-methyldithiocarbamate) and chloropicrin (96% trichloro-nitromethane), of which chloropicrin was most effective. These are both liquid fumigants which are prone to spillage and represent a hazard to applicators. Solid fumigants were identified by the UPRC and developed as fumigants for internal remedial treatment of utility poles which had the advantage of being much easier and safer to apply. Now there are a variety of liquid and solid fumigants commercially available from several different providers (Table 1.1.1). The UPRC has continued performance evaluations for these products under a variety of conditions aimed at identifying factors that affect performance and developing appropriate retreatment protocols for each.

Table 1.1.1. Characteristics of internal remedial treatments for utility poles in North America.

Trade Name	Active Ingredient	Concentration (%)	Manufacturer
TimberFume	trichloronitromethane	97	Osmose Utilities Services, Inc.
WoodFume	sodium n-methyldithiocarbamate	33	Osmose Utilities Services, Inc.
SMDC-Fume			Copper Care Wood Preservatives, Inc.
MITC-FUME	methyl isothiocyanate	97	Osmose Utilities Services, Inc.
Super-Fume	Tetrahydro-3,5-dimethyl-2H-1,3,5-thiodiazine-2-thione	98-99	Pole Care Inc.
UltraFume			Copper Care Wood Preservatives, Inc.
DuraFume II			Osmose Utilities Services, Inc.
Impel Rods	Disodium Octaborate	100	Intec, Inc.
Bor8 Rods		97	Wood Care Systems
Cobra Rods	Disodium Octaborate, Copper Hydroxide, Boric Acid	88-91, 1.5-3, 4-8	Genics, Inc.

1.1.1 Performance of Dazomet With or Without Copper-based Accelerants

Dazomet functions as a fumigant by decomposing into methylisothiocyanate (MITC) gas which permeates the wood ultrastructure and kills or inhibits decay fungi. However, when applied alone in rod or powdered form, dazomet decomposition does not produce enough MITC to effectively fumigate Douglas-fir poles (Forsyth 1998). Addition of divalent metals to dazomet accelerates its decomposition to MITC (Forsyth and Morrell 1992). Previous studies have shown that application of dazomet with a copper-based accelerant improves its decomposition to MITC (Forsyth et al. 1993; Love et al. 2010). Copper naphthenate solution can also serve as a source of copper for use as a dazomet accelerant and it is already widely applied as a remedial treatment to field dress damaged poles. The UPRC completed a 20-year field study to test the effectiveness of copper naphthenate as a dazomet accelerant in penta-treated Douglas-fir poles which was completed and summarized in the 2017 annual report. Copper sulfate was included in this study because of its known ability to accelerate dazomet decomposition, despite its lack of use in practice. We have retreated these poles with a second remedial treatment of the same type in 2018 and will continue monitoring MITC production and the development of decay fungi in these poles over an extended period.

The original treatment holes were reopened and treated a second time for this study. Holes were probed for residual chemical and re-bored prior to the addition of chemical. Two hundred grams of dazomet were equally distributed among the three holes. One set of three poles received no additional treatment, three poles received 20 g of copper sulfate powder equally distributed among the three holes, and three received 20 g of liquid copper naphthenate (2% metallic copper) in mineral spirits, also equally distributed among the three holes. Holes were then plugged with wooden dowels.

Chemical distribution was assessed annually after treatment by removing increment cores from three equidistant points around each pole at sites 0.3, 1.3, and 2.3 m above groundline. Because of the high volume of sampling holes from the 20-year study, sampling holes for the current round of sampling were drilled approximately 6 inches lower than the holes drilled for the first

20-year time series. The outer 25 mm of each core was discarded. The next 25 mm, and the 25 mm section closest to the pith, of each core were placed into vials containing 5 mL of ethyl acetate (Figure 1.1.1). The cores were stored at room temperature for 48 hours to extract any MITC in the wood, then the increment core was removed, oven-dried, and weighed. The oven dried weight of each core section was used to calculate chemical content on a wood weight basis (µg/g wood). The ethyl acetate extracts were injected into a Shimadzu gas chromatograph equipped with a flame photometric detector with filters specific for sulfur (a component of MITC). MITC levels in the extracts were quantified by comparison with prepared standards and results were expressed on a µg MITC/oven dried g of wood basis (Table 1.1.2). Each core at each sampling location was analyzed for MITC to produce the heat maps (Figure 1.1.2).

The remainder of each core was then placed on the surface of a 1.5% malt extract agar petri dish and observed for evidence of fungal growth. Any fungi growing from the cores were examined for characteristics typical of Basidiomycetes, a class of fungi containing important wood decay taxa.

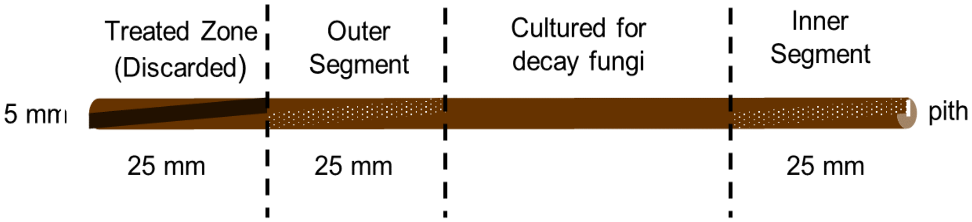


Figure 1.1.1. Schematic of core processing for fumigant analysis and fungal culturing.

MITC levels in poles during the first 20-year treatment cycle are provided for reference (Table 1.1.2; Figure 1.1.2). MITC levels after the first year following retreatment were generally low for all treatments in all core sections taken above 0.3 m above groundline (Table 1.1.2). There were no sections above that level that had MITC levels above threshold and all but one (dazomet + copper sulfate inner 1.3 m) had MITC levels below detection levels. The only sections above threshold were at 0.3 m (Table 1.1.2). Poles treated with dazomet alone generally showed the lowest MITC levels and only core sections 0.3 m above groundline closest to the pith were above threshold levels. MITC levels were below threshold in outer core sections. Dazomet plus copper sulfate treated poles showed higher MITC levels and values were above threshold 0.3 m above groundline in the outer and inner core sections. Poles treated with dazomet plus copper naphthenate had lower MITC levels than those treated with dazomet plus copper sulfate, but both core sections taken from 0.3 m above groundline were still above threshold levels.

The second year after retreatment (year 23) showed very low average MITC levels across all treatments. The only MITC levels above threshold were from dazomet + either accelerant at 0.3 m above groundline and no samples taken from dazomet alone treatments were above threshold levels. This result is unusual for the second year after treatment for dazomet and it is unclear what happened here. Extensive sampling has introduced numerous holes into the poles and these may serve as avenues for the escape of MITC gas which can confound results. However, we expect that MITC has the capacity to bind to wood and we would expect to see at least some in these samples at this time point.

The remaining core sections not extracted for MITC were cultured for decay fungi. Isolations were somewhat infrequent across all pole types and for the first two years after retreatment (Table 1.1.3)(Figure 1.1.3). The only sections where decay fungi were isolated from were cores taken 1.3 m above groundline from poles treated with dazomet alone or dazomet plus copper sulfate in year 1 after retreatment. In year 2 decay fungi were only found in dazomet alone treatments and 11 and 22% of cores cultured contained decay fungi 0.3 and 1.3 m from groundline. No decay fungi were isolated from any cores taken from dazomet plus copper naphthenate in year 1 or 2 after retreatment.

Table 1.1.2: Residual MITC in Douglas-fir pole sections 1 to 20 years after treatment with dazomet with or without copper sulfate or copper naphthenate. Poles were retreated after 20 years with the same chemicals. Year 22 (1) indicates the first year after retreatment (gray).Year 23 (2) indicates 2020, the current sampling year (green).

Copper Treatment	Year sampled	Residual MITC (µg/g of wood)[a]					
		0.3 m		1.3 m		2.3 m	
		inner	outer	inner	outer	inner	outer
None	1	**21** (14)	18 (37)	0 (0)	0 (0)	0 (0)	3 (8)
	2	**72** (47)	**36** (33)	0 (0)	0 (0)	0 (0)	0 (0)
	3	**57** (27)	**32** (42)	0 (0)	0 (0)	0 (0)	0 (0)
	4	**50** (41)	**32** (32)	6 (5)	6 (6)	0 (0)	0 (0)
	5	**67** (31)	9 (8)	12 (4)	10 (29)	0 (0)	0 (0)
	8	**21** (26)	16 (21)	**22** (24)	17 (28)	**21** (23)	**26** (39)
	10	10 (13)	6 (12)	19 (34)	12 (21)	13 (22)	4 (6)
	12	**35** (38)	**20** (22)	4 (5)	1 (4)	2 (6)	0 (0)
	15	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	20	**33** (9)	6 (15)	0 (0)	0 (0)	0 (0)	0 (0)
	22 (1)	**38** (31)	3 (4)	0 (0)	0 (0)	0 (0)	0 (0)
	23 (2)	14 (9)	16 (15)	0 (0)	0 (0)	0 (0)	0 (0)
20 g Copper sulfate ($CuSO_4 \cdot 5H_2O$)	1	**103** (78)	**55** (86)	4 (6)	0 (0)	0 (0)	0 (0)
	2	**101** (36)	**32** (17)	7 (7)	3 (7)	0 (0)	0 (0)
	3	**78** (25)	**29** (17)	7 (7)	5 (8)	0 (0)	0 (0)
	4	**95** (61)	**40** (20)	20 (21)	**21** (27)	**25** (35)	**23** (33)
	5	**87** (12)	**21** (6)	18 (15)	3 (6)	7 (10)	0 (0)
	8	**35** (43)	14 (20)	**26** (29)	12 (21)	**29** (36)	**24** (40)
	10	16 (24)	7 (9)	**28** (41)	5 (8)	**30** (46)	4 (6)
	12	**40** (16)	**21** (16)	13 (6)	1 (2)	4 (6)	0 (0)
	15	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	20	**31** (14)	3 (20)	0 (0)	0 (0)	0 (0)	0 (0)
	22 (1)	**274** (288)	**34** (23)	12 (22)	0 (0)	0 (0)	0 (0)
	23 (2)	19 (14)	12 (20)	0 (0)	0 (0)	0 (0)	0 (0)
20 g Copper naphthenate (2% Cu in mineral spirits)	1	**34** (19)	**43** (54)	0 (0)	0 (0)	2 (5)	6 (19)
	2	**94** (45)	**94** (64)	6 (7)	5 (11)	0 (0)	0 (0)
	3	**110** (29)	**59** (46)	7 (7)	4 (8)	0 (0)	0 (0)
	4	**89** (33)	**73** (24)	18 (9)	9 (7)	1 (2)	0 (0)
	5	**102** (18)	**41** (39)	**23** (7)	1 (2)	2 (3)	0 (0)
	8	**27** (26)	**22** (23)	**26** (35)	20 (24)	**26** (26)	**38** (55)
	10	19 (28)	11 (13)	**24** (37)	4 (9)	**28** (43)	9 (18)
	12	**57** (17)	**29** (14)	8 (30)	2 (4)	3 (6)	0 (0)
	15	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	20	**42** (22)	10 (20)	0 (0)	0 (0)	0 (0)	0 (0)
	22 (1)	**65** (50)	**24** (17)	0 (0)	0 (0)	0 (0)	0 (0)
	23 (2)	16 (22)	**20** (20)	1 (2)	0 (0)	0 (0)	0 (0)

[a] Values in bold type represent chemical levels at or above the fungal threshold. Numbers in parentheses represent one standard deviation.

Table 1.1.3. Percentage of increment cores containing decay and non-decay fungi 1 to 23 years after application of dazomet with or without copper sulfate or copper naphthenate. Poles were retreated after 20 years with the same chemicals. Year 22 (1) indicates the first year after retreatment (gray). Year 23 (2) indicates 2020, the current sampling year (green).

Copper Treatment	Years after treatment	Isolation Frequency (%)[a]		
		0.3 m	1.3 m	2.3 m
None	1	0^{11}	0^{11}	0^{11}
	2	0^{0}	0^{33}	0^{33}
	3	0^{0}	0^{33}	0^{0}
	4	0^{11}	0^{33}	0^{56}
	5	0^{0}	0^{0}	0^{100}
	8	0^{0}	0^{11}	0^{56}
	10	0^{0}	0^{33}	0^{0}
	12	0^{0}	11^{0}	0^{22}
	15	0^{0}	22^{0}	0^{11}
	20	33^{11}	33^{22}	33^{44}
	22 (1)	0^{11}	11^{33}	0^{0}
	23 (2)	11^{11}	22^{33}	0^{33}
20 g Copper sulfate ($CuSO_4 \cdot 5H_2O$)	1	0^{11}	22^{33}	0^{44}
	2	0^{0}	44^{56}	0^{33}
	3	0^{0}	11^{11}	0^{33}
	4	0^{11}	22^{33}	11^{33}
	5	0^{0}	0^{67}	0^{89}
	8	0^{0}	0^{22}	0^{44}
	10	0^{0}	11^{44}	0^{11}
	12	0^{0}	0^{0}	0^{33}
	15	0^{11}	0^{44}	0^{0}
	20	0^{0}	11^{56}	0^{56}
	22 (1)	0^{33}	11^{44}	0^{11}
	23 (2)	0^{11}	0^{33}	0^{0}
20 g Copper naphthenate (2% Cu in mineral spirits)	1	33^{33}	0^{22}	0^{44}
	2	0^{0}	0^{0}	0^{67}
	3	0^{0}	0^{0}	0^{22}
	4	0^{0}	0^{0}	0^{67}
	5	0^{0}	11^{11}	0^{78}
	8	0^{11}	0^{0}	0^{33}
	10	0^{0}	0^{11}	0^{44}
	12	0^{0}	0^{11}	0^{22}
	15	0^{0}	0^{22}	0^{0}
	20	0^{22}	0^{33}	0^{56}
	22 (1)	0^{22}	0^{56}	0^{33}
	23 (2)	0^{22}	0^{67}	0^{89}

[a] Values represent the average of nine cores containing decay fungi. Superscripts represent average of non-decay fungi in the same cores.

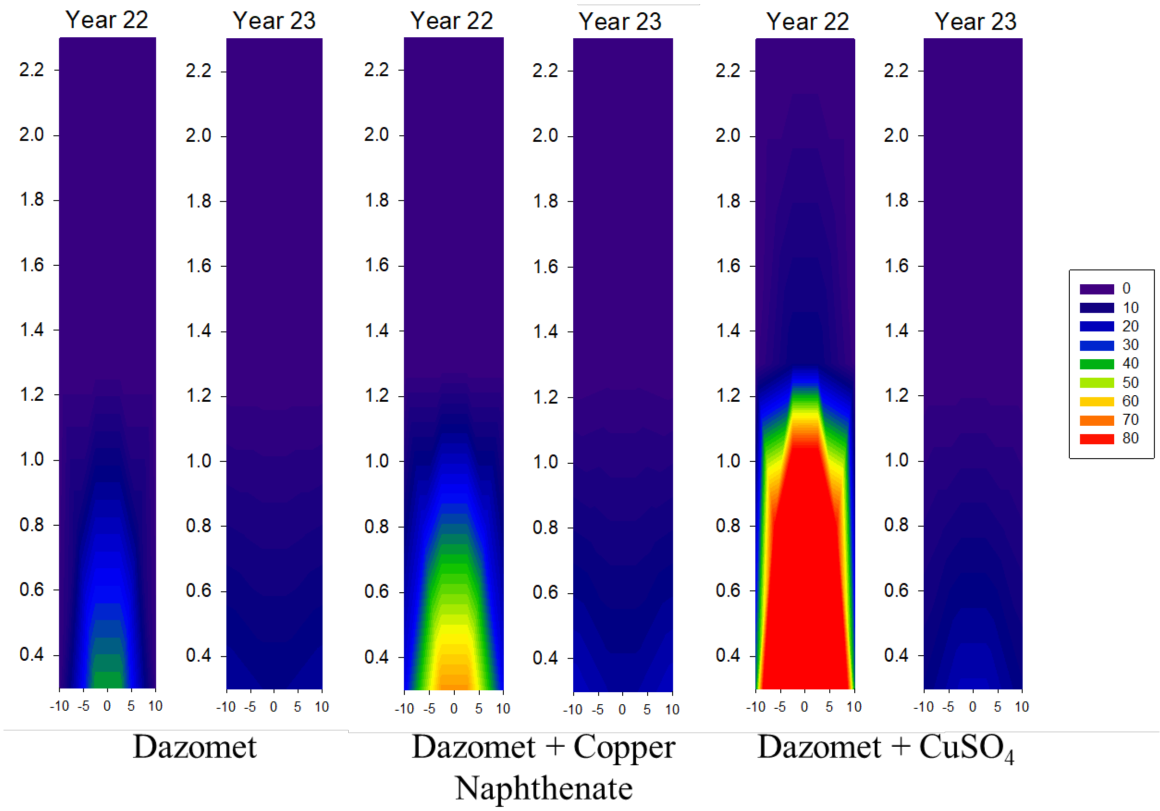


Figure 1.1.2. Residual MITC distribution in Douglas-fir pole sections one year (year 22) and two years (year 23) after retreatment with 200 g of dazomet without accelerant, 200 g of dazomet plus 20 g of copper naphthenate, or 200 g of dazomet plus 20 g of copper sulfate. Purple and dark blue indicate MITC levels below threshold, whereas other colors are above threshold.

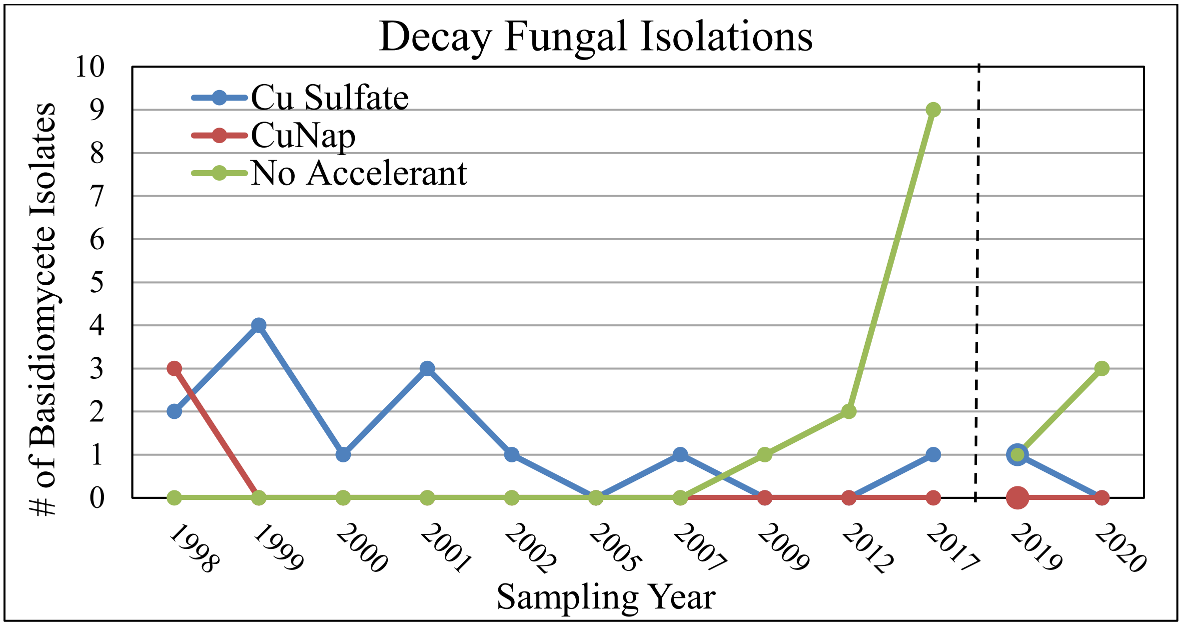


Figure 1.1.3. Decay fungal isolations during the 20-year original treatment cycle and the first two years after retreatment. Poles were retreated in 2018 (vertical dotted line).

1.1.2 Effect of Potassium N-methyldithiocarbamate (KMDC) as an Internal Remedial Treatment

Sodium n-methyldithiocarbamate (NaMDC) has been used for decades as a utility pole fumigant (Graham 1973). However, NaMDC typically only provides protective levels of MITC for less than 10 years (Konkler et al. 2019). This may be due in part to the fact that NaMDC is applied as a 32.7% aqueous solution, meaning the majority of the mass does not serve as a source of fumigant (Morrell and Corden 1986). Potassium N-methyldithiocarbamate (KMDC) is available in more concentrated form (~54%) but has not been previously explored for this application. A field study at the Peavy Arboretum was initiated to study the efficacy of KMDC as a fumigant and compare its performance to NaMDC. This study was sampled in 2020 and the results of the analysis are presented below.

Douglas-fir pole sections (283-340 mm in diameter by 3 m long) were pressure treated with pentachlorophenol in P9 Type-A oil before being set to a depth of 0.6 m at our Peavy Arboretum field test site. Three steeply downward-sloping holes were drilled into the poles beginning at groundline and moving upward at 150 mm intervals with each hole offset from the last 120 degrees. The poles were treated with 500 mL of 32.7% NaMDC solution or 54% KMDC solution and the holes were plugged with tight fitting plastic plugs. Each treatment was replicated on 5 poles for a total of 10 poles.

Poles are being sampled at regular intervals by removing increment cores from three equidistant points around each pole at 150 mm below groundline, groundline, and at 150 mm, 300 mm, 450 mm, 600 mm, and 1000 mm above groundline. Cores were processed by first discarding the outer treated shell and then reserving the outermost and innermost 25 mm sections for MITC extraction in ethyl acetate. MITC was quantified in extracts using GC-MS equipped with a flame-photometric detector. The remaining core segment between the outer and inner 25 mm sections was reserved for culturing to assess the presence of viable decay fungi. These poles were evaluated for the first time in April 2019 and will be sampled annually thereafter.

The first year of sampling showed MITC levels varied widely across poles in both KMDC and NaMDC treatments. KMDC-treated poles tended to have higher overall MITC levels (Table 1.1.4). For NaMDC-treated poles, MITC levels were below inhibitory threshold levels (20 µg/g) in at least one zone in all five poles sampled, but the majority of sampling locations had MITC levels above threshold (Figure 1.1.1). KMDC-treated poles showed a wide range of MITC levels as well, but three of these poles had MITC levels much higher than threshold levels close to the groundline (Figure 1.1.4). MITC levels were higher closer to ground level for all treatments.

MITC levels in year 2 for both NaMDC and KMDC-treated poles were dramatically lower than those found in year one and there were only sporadic, irregular occurrences of MITC levels above the effective inhibitory threshold (Table 1.1.5; Figure 1.1.5). MITC levels were still

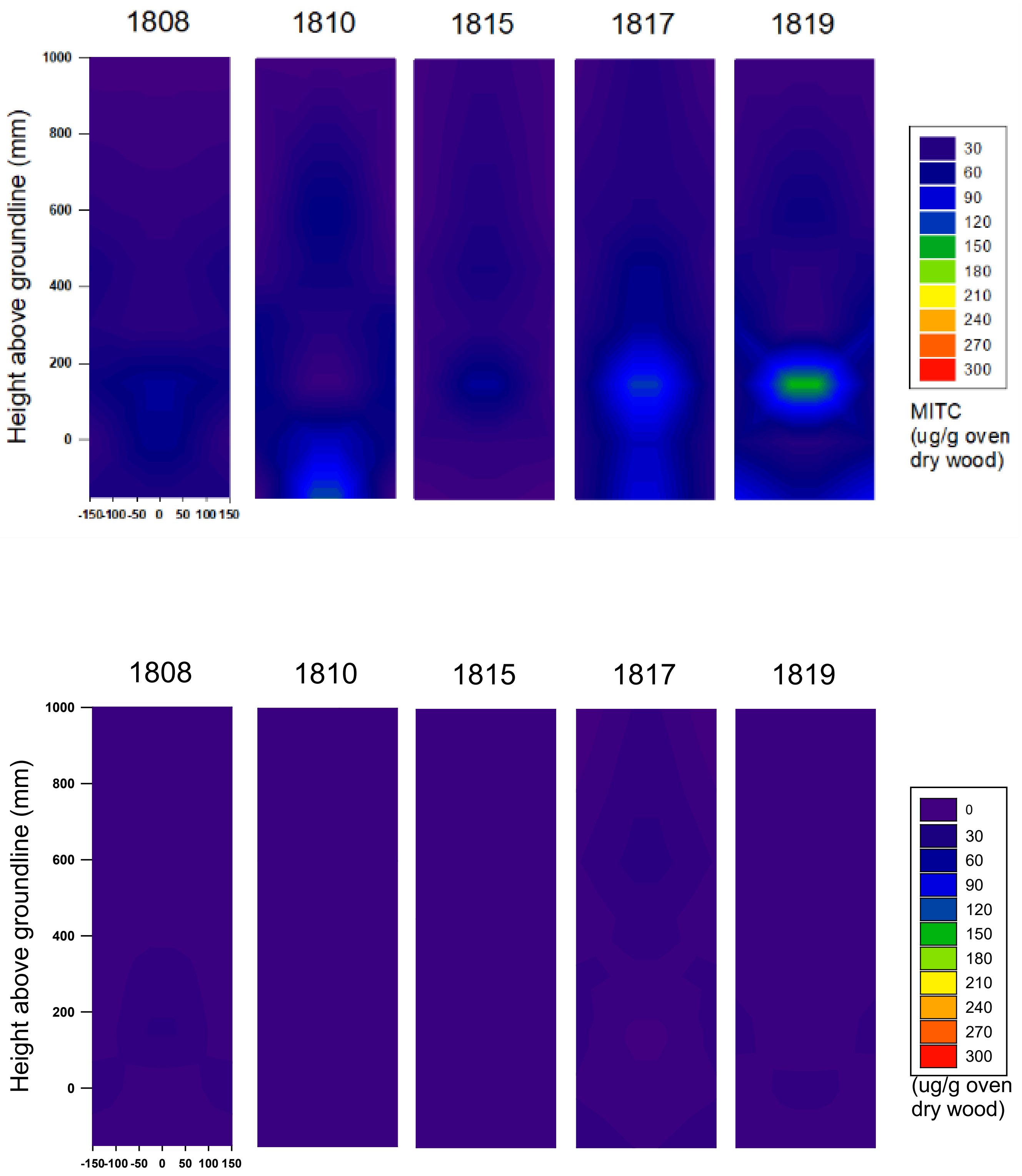


Figure 1.1.4: MITC evolution from poles treated with Metam Sodium (NaMDC) one year (top) and two years (bottom) after application at our Peavy Arboretum test site. Numbers above each heat map indicate the specific pole identifier.

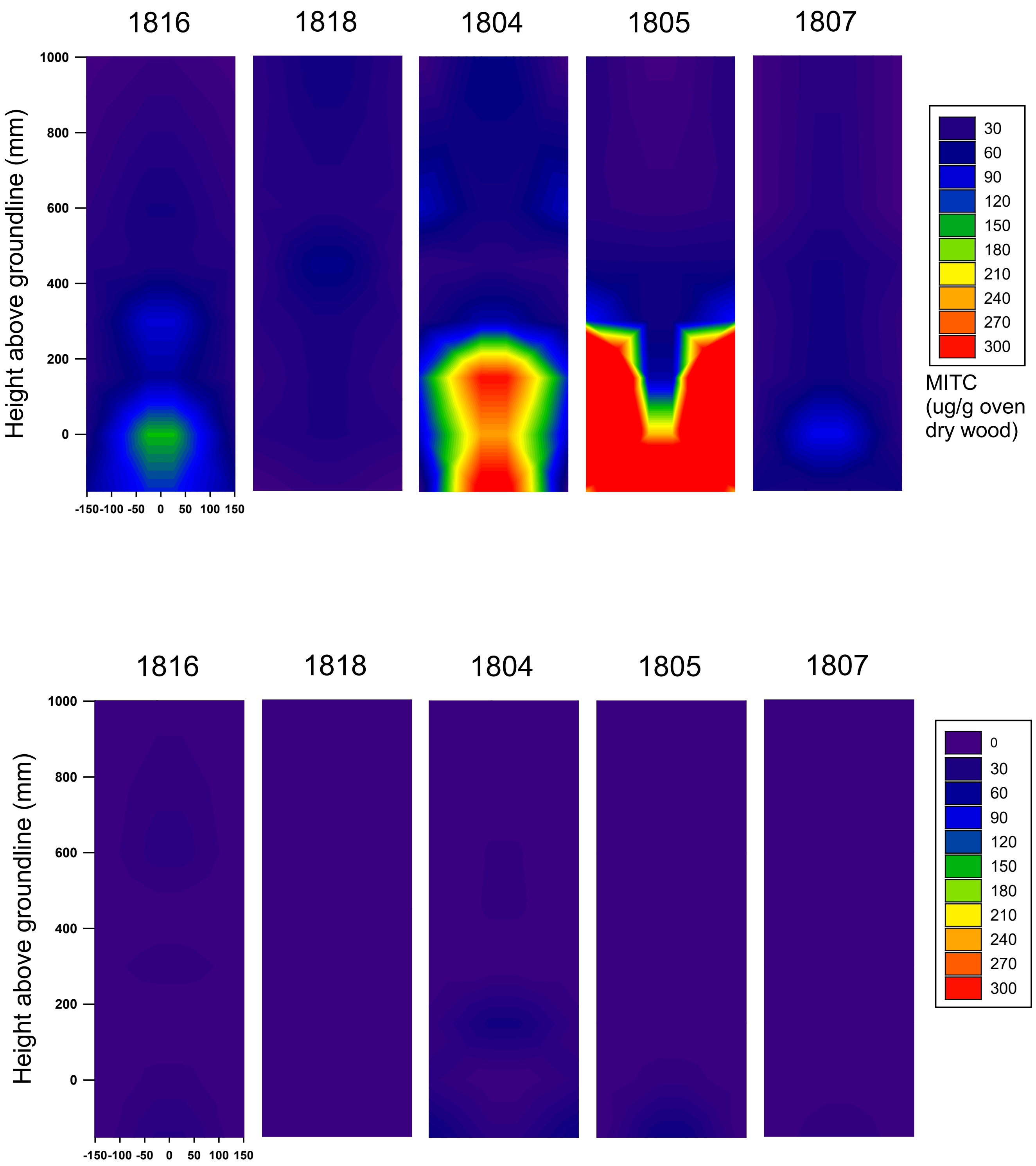
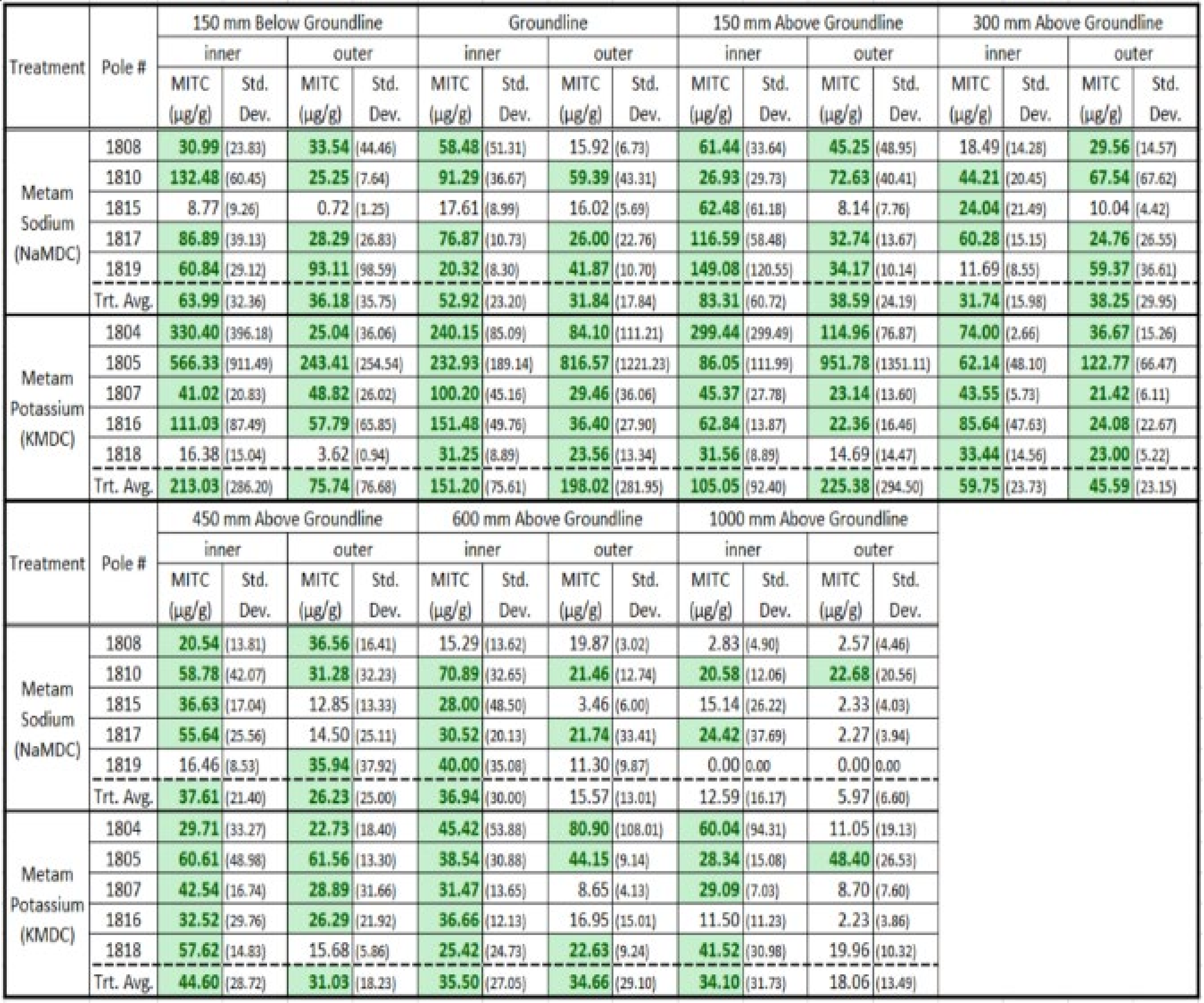


Figure 1.1.5: MITC evolution from poles treated with Metam Potassium (KMDC) one year (top) and two years (bottom) after application at our Peavy Arboretum test site. Numbers above each heat map indicate a specific pole identifier.

somewhat higher closer to the groundline or below, but there were still many examples of core samples at or below groundline that did not have any MITC. These low MITC levels are an aberration from previous studies with NaMDC and it is unclear why the MITC levels were so much lower here. We intend to resample in year three to see if this was only an aberration or if there truly is no chemicals remaining in the poles.

Efforts to culture fungi from the interior sections of the MITC cores yielded no viable fungi from any core in the first year (Table 1.1.6). In the second year after treatment only one new non-decay fungus was observed from all poles, indicating that decay fungi remained very low. This is in line with previous fumigant studies where fungal isolates are typically not found for several years after treatment with fumigant.

Table 1.1.4. MITC concentration in poles treated with Metam Sodium (NaMDC) or Metam Potassium (KMDC) 15 months after application in Corvallis, OR. MITC levels above the protective threshold of 20 µg/g are indicated with bold green boxes.



Treatment	Pole #	150 mm Below Groundline				Groundline				150 mm Above Groundline				300 mm Above Groundline			
		inner		outer		inner		outer		inner		outer		inner		outer	
		MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.
Metam Sodium (NaMDC)	1808	**30.99**	(23.83)	**33.54**	(44.46)	**58.48**	(51.31)	15.92	(6.73)	**61.44**	(33.64)	**45.25**	(48.95)	18.49	(14.28)	**29.56**	(14.57)
	1810	**132.48**	(60.45)	**25.25**	(7.64)	**91.29**	(36.67)	**59.39**	(43.31)	**26.93**	(29.73)	**72.63**	(40.41)	**44.21**	(20.45)	**67.54**	(67.62)
	1815	8.77	(9.26)	0.72	(1.25)	17.61	(8.99)	16.02	(5.69)	**62.48**	(61.18)	8.14	(7.76)	**24.04**	(21.49)	10.04	(4.42)
	1817	**86.89**	(39.13)	**28.29**	(26.83)	**76.87**	(10.73)	**26.00**	(22.76)	**116.59**	(58.48)	**32.74**	(13.67)	**60.28**	(15.15)	**24.76**	(26.55)
	1819	**60.84**	(29.12)	**93.11**	(98.59)	**20.32**	(8.30)	**41.87**	(10.70)	**149.08**	(120.55)	**34.17**	(10.14)	11.69	(8.55)	**59.37**	(36.61)
	Trt. Avg.	**63.99**	(32.36)	**36.18**	(35.75)	**52.92**	(23.20)	**31.84**	(17.84)	**83.31**	(60.72)	**38.59**	(24.19)	**31.74**	(15.98)	**38.25**	(29.95)
Metam Potassium (KMDC)	1804	**330.40**	(396.18)	**25.04**	(36.06)	**240.15**	(85.09)	**84.10**	(111.21)	**299.44**	(299.49)	**114.96**	(76.87)	**74.00**	(2.66)	**36.67**	(15.26)
	1805	**566.33**	(911.49)	**243.41**	(254.54)	**232.93**	(189.14)	**816.57**	(1221.23)	**86.05**	(111.99)	**951.78**	(1351.11)	**62.14**	(48.10)	**122.77**	(66.47)
	1807	**41.02**	(20.83)	**48.82**	(26.02)	**100.20**	(45.16)	**29.46**	(36.06)	**45.37**	(27.78)	**23.14**	(13.60)	**43.55**	(5.73)	**21.42**	(6.11)
	1816	**111.03**	(87.49)	**57.79**	(65.85)	**151.48**	(49.76)	**36.40**	(27.90)	**62.84**	(13.87)	**22.36**	(16.46)	**85.64**	(47.63)	**24.08**	(22.67)
	1818	16.38	(15.04)	3.62	(0.94)	**31.25**	(8.89)	**23.56**	(13.34)	**31.56**	(8.89)	14.69	(14.47)	**33.44**	(14.56)	**23.00**	(5.22)
	Trt. Avg.	**213.03**	(286.20)	**75.74**	(76.68)	**151.20**	(75.61)	**198.02**	(281.95)	**105.05**	(92.40)	**225.38**	(294.50)	**59.75**	(23.73)	**45.59**	(23.15)

Treatment	Pole #	450 mm Above Groundline				600 mm Above Groundline				1000 mm Above Groundline			
		inner		outer		inner		outer		inner		outer	
		MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.
Metam Sodium (NaMDC)	1808	**20.54**	(13.81)	**36.56**	(16.41)	15.29	(13.62)	19.87	(3.02)	2.83	(4.90)	2.57	(4.46)
	1810	**58.78**	(42.07)	**31.28**	(32.23)	**70.89**	(32.65)	**21.46**	(12.74)	**20.58**	(12.06)	**22.68**	(20.56)
	1815	**36.63**	(17.04)	12.85	(13.33)	**28.00**	(48.50)	3.46	(6.00)	15.14	(26.22)	2.33	(4.03)
	1817	**55.64**	(25.56)	14.50	(25.11)	**30.52**	(20.13)	**21.74**	(33.41)	**24.42**	(37.69)	2.27	(3.94)
	1819	16.46	(8.53)	**35.94**	(37.92)	**40.00**	(35.08)	11.30	(9.87)	0.00	0.00	0.00	0.00
	Trt. Avg.	**37.61**	(21.40)	**26.23**	(25.00)	**36.94**	(30.00)	15.57	(13.01)	12.59	(16.17)	5.97	(6.60)
Metam Potassium (KMDC)	1804	**29.71**	(33.27)	**22.73**	(18.40)	**45.42**	(53.88)	**80.90**	(108.01)	**60.04**	(94.31)	11.05	(19.13)
	1805	**60.61**	(48.98)	**61.56**	(13.30)	**38.54**	(30.88)	**44.15**	(9.14)	**28.34**	(15.08)	**48.40**	(26.53)
	1807	**42.54**	(16.74)	**28.89**	(31.66)	**31.47**	(13.65)	8.65	(4.13)	**29.09**	(7.03)	8.70	(7.60)
	1816	**32.52**	(29.76)	**26.29**	(21.92)	**36.66**	(12.13)	16.95	(15.01)	11.50	(11.23)	2.23	(3.86)
	1818	**57.62**	(14.83)	15.68	(5.86)	**25.42**	(24.73)	**22.63**	(9.24)	**41.52**	(30.98)	19.96	(10.32)
	Trt. Avg.	**44.60**	(28.72)	**31.03**	(18.23)	**35.50**	(27.05)	**34.66**	(29.10)	**34.10**	(31.73)	18.06	(13.49)

Table 1.1.5: MITC concentration in poles treated with Metam Sodium (NaMDC) or Metam Potassium (KMDC) 27 months after application in Corvallis, OR. MITC levels above the protective threshold of 20 µg/g are indicated with bold green boxes.

Treatment	Pole #	150 mm Below Groundline				Groundline				150 mm Above Groundline				300 mm Above Groundline			
		inner		outer		inner		outer		inner		outer		inner		outer	
		MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.
Metam Sodium (NaMDC)	1808	1.45	(2.52)	1.03	(1.78)	2.12	(3.66)	9.96	(11.77)	12.66	(21.92)	1.24	(2.16)	9.59	(7.16)	0.00	0.00
	1810	5.37	(4.79)	0.00	0.00	4.11	(7.12)	0.00	0.00	5.11	(7.12)	0.05	(0.09)	0.00	0.00	2.12	(3.68)
	1815	0.00	0.00	0.00	0.00	5.47	(4.84)	0.00	0.00	1.18	(2.05)	0.00	0.00	2.03	(2.43)	0.00	0.00
	1817	17.86	(6.67)	**22.31**	(29.17)	13.77	(1.57)	17.14	(11.72)	10.30	(7.26)	19.90	(14.88)	17.08	(3.44)	19.17	(3.20)
	1819	0.00	0.00	0.00	0.00	8.86	(15.22)	1.19	(2.05)	0.00	0.00	8.65	(12.75)	1.26	(2.18)	4.06	(7.03)
	Trt. Avg.	4.94	(2.80)	4.67	(6.19)	6.87	(6.48)	5.66	(5.11)	5.85	(7.67)	5.97	(5.98)	5.99	(3.04)	5.07	(2.78)
Metam Potassium (KMDC)	1804	15.09	(26.14)	**42.68**	(73.92)	0.00	0.00	13.83	(23.95)	**32.66**	(36.16)	8.59	(8.10)	1.10	(1.90)	0.00	0.00
	1805	**37.42**	(53.82)	0.00	0.00	9.44	(16.34)	0.52	(0.89)	0.00	0.00	0.00	0.00	4.13	(7.16)	0.00	0.00
	1807	11.08	(19.19)	0.00	0.00	1.92	(3.33)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1816	18.95	(13.28)	0.00	0.00	8.24	(6.11)	0.00	0.00	0.00	(0.00)	2.04	(3.53)	8.54	(1.86)	3.55	(3.09)
	1818	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Trt. Avg.	16.51	(22.49)	8.54	(14.78)	3.92	(5.16)	2.87	(4.97)	6.53	(7.23)	2.13	(2.33)	2.75	(2.18)	0.71	(0.62)

Treatment	Pole #	450 mm Above Groundline				600 mm Above Groundline				1000 mm Above Groundline			
		inner		outer		inner		outer		inner		outer	
		MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.
Metam Sodium (NaMDC)	1808	1.51	(2.62)	0.00	0.00	1.91	(3.31)	0.00	0.00	0.00	(0.00)	0.00	0.00
	1810	0.00	0.00	1.02	(1.77)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1815	0.00	0.00	0.00	0.00	2.03	(1.80)	0.00	0.00	2.55	(4.42)	0.00	0.00
	1817	**20.20**	(3.55)	13.02	(13.16)	**26.14**	(10.89)	17.35	(15.05)	18.54	(11.38)	6.20	(10.74)
	1819	1.54	(2.66)	1.96	(3.40)	1.51	(2.61)	0.00	0.00	0.00	0.00	0.00	0.00
	Trt. Avg.	4.65	(1.77)	3.20	(3.67)	6.32	(3.72)	3.47	(3.01)	4.22	(3.16)	1.24	(2.15)
Metam Potassium (KMDC)	1804	6.97	(5.37)	0.00	0.00	6.45	(11.18)	2.27	(3.93)	0.00	0.00	1.01	(1.75)
	1805	4.82	(8.36)	0.00	0.00	0.00	0.00	0.00	0.00	0.57	(0.99)	0.00	0.00
	1807	0.53	(0.92)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1816	1.88	(3.26)	0.00	0.00	15.17	(4.32)	0.00	0.00	3.22	(5.57)	0.00	0.00
	1818	0.00	0.00	0.00	0.00	0.62	(1.07)	0.00	0.00	0.69	(1.19)	0.00	0.00
	Trt. Avg.	2.84	(3.58)	0.00	0.00	4.45	(3.31)	0.45	(0.79)	0.90	(1.55)	0.20	(0.35)

1.1.3 Performance of Dazomet in Powdered and Rod Forms in Douglas-fir Pole Sections

Date Established:	March 2000
Location:	Peavy Arboretum, Corvallis, OR
Pole Species; Treatment; Size	Douglas-fir; Penta; n/a
Circumference @ GL (avg., max., min.)	84, 104, 65 cm

Since it was developed for use as an internal remedial treatment, dazomet has been formulated into first pelletized and then rod form (BASF Wolman GmbH) for easy application into bore holes. Rods have a relatively lower surface:volume than powdered forms which raised concerns of reduced efficacy due to lower contact with water and accelerants. A field test at the Peavy Arboretum field site was initiated in 2000 to test the performance of dazomet rods versus powdered forms alone or in the presence of a copper-based accelerant. MITC distribution was monitored over the course 15 years to determine how well each treatment combination would prevent fungal growth.

This study progressed through and entire treatment cycle and was not sampled in 2020. Results from the most recent sampling are summarized in the 2015 report.

1.2.0 Performance of Water Diffusible Preservatives as Internal Treatments

Common fumigants used as remedial treatments are toxic and pose a health hazard to those tasked with applying them to poles. Boron is a less toxic alternative that can be easily applied to poles as a solid rod with little risk of direct chemical exposure to the applicator. Boron has been used as a treatment for freshly sawn lumber to prevent insect attack for decades and is desirable because of its low toxicity towards humans and its ability to diffuse through wet wood. Boron's ability to diffuse in water make it mobile in moist conditions near groundline where decay hazard is highest, increasing its effective zone of inhibition well beyond the initial site of application. However, the relatively high mobility of boron also causes it to leach out of wood into the surrounding soil under high moisture conditions. Here we describe progress on studies aimed at studying water diffusible preservatives, namely boron, as an internal remedial treatment.

1.2.1 Performance of Copper Amended Fused Boron Rods

Date Established:	November 2001
Location:	Peavy Arboretum, Corvallis, OR
Pole Species; Treatment; Size	Douglas-fir; Penta and Creosote; n/a
Circumference @ GL (avg., max., min.)	78, 102, 66 cm

This test will not be sampled again until 2021, 20 years after initial treatment.

1.3.0 Tests Including Both Fumigants and Diffusible Remedial Treatments

Internal remedial treatment may employ fumigants or water-diffusible chemicals which inhibit the growth of decay fungi. Fumigants volatilize within the wood ultrastructure and become widely distributed in wood as a gas which kills and inhibits the growth of decay fungi. Diffusible internal treatments require water to move within wood which limits their diffusion but are potentially longer-lasting than fumigants. These properties suggest these two treatment types may have complimentary functionality and dual treatments with fumigants and water-based treatments may improve the overall performance of internal remedial treatment. Below we describe progress on studies evaluating both fumigants and diffusible remedial treatments.

1.3.1 Full Scale Field Trial of All Internal Remedial Treatments

Date Established:	March 2008
Location:	Peavy Arboretum, Corvallis, OR
Pole Species; Treatment; Size	Douglas-fir; Penta; n/a
Circumference @ GL (avg., max., min.)	102, 117, 86 cm

The UPRC has performed a variety of field trials since its inception to assess the performance of internal remedial treatments. These have all tested different remedial treatments at different times and as slightly different treatments. These include both fumigants which form a gas that permeates the wood ultrastructure and diffusible remedial treatments which rely on water to spread the active chemical throughout the wood to inhibit the growth of fungi. Because of the slight variations in methodologies between studies and general environmental conditions year to year, the results from these studies are not entirely comparable. We addressed this issue by establishing a single large-scale test of all the EPA registered internal remedial treatments at our Corvallis test site (Table 1.3.1).

Table 1.3.1. Internal remedial treatments evaluated on Douglas-fir poles at the Peavy Arboretum test site.

Product Name	Dosage/pole	Additive	Common name	Active Ingredient
DuraFume	280 g	CuNap	dazomet	Tetrahydro-3,5-dimethyl-2H-1,3,5-thiadiazine-2-thione
SUPER-FUME	280 g	CuNap	dazomet	Tetrahydro-3,5-dimethyl-2H-1,3,5-thiadiazine-2-thione
UltraFume	280 g	CuNap	dazomet	Tetrahydro-3,5-dimethyl-2H-1,3,5-thiadiazine-2-thione
Basamid	280 g	CuNap	dazomet	Tetrahydro-3,5-dimethyl-2H-1,3,5-thiadiazine-2-thione
Basamid rods	264 g	CuNap	dazomet	Tetrahydro-3,5-dimethyl-2H-1,3,5-thiadiazine-2-thione
MITC-FUME	120 g	none	methylisothiocyanate	methylisothiocyanate
WoodFume	475 ml	none	metam sodium	Sodium N-methyldithiocarbamate
SMDC-Fume	475 ml	none	metam sodium	Sodium N-methyldithiocarbamate
Pol Fume	475 ml	none	metam sodium	Sodium N-methyldithiocarbamate
Chloropicrin	475 ml	none	chloropicrin	trichloronitromethane
Impel rods	238 g (345 g BAE)	none	boron rod	Anhydrous disodium octaborate
FLURODS	180 g	none	fluoride rod	sodium fluoride
PoleSaver rods	134 g	none	fluoride rod	disodium octaborate tetrahydrate, sodium fluoride

Penta-treated Douglas-fir pole stubs (280-300 mm in diameter by 2.1 m long) were set to a depth of 0.6 m. Three (for poles treated with diffusible rods) and four (for poles treated with fumigants) steeply sloping treatment holes (19 mm x 350 mm long) were drilled into the poles beginning at groundline and moving upward 150 mm and around the pole 120 degrees. The various remedial treatments were added to the holes at the recommended dosage for a pole of this diameter (Table 1.3.1). The treatment holes were then plugged with removable plastic plugs. Copper naphthenate (2% Cu) was added to all dazomet treatments. The accelerant was poured onto the top of the dazomet in the treatment holes until the visible fumigant appeared to be saturated. No attempt was made to quantify the amount of copper naphthenate added to each treatment hole.

Chemical movement in the poles was assessed 18, 30, 42, 54, 89, 125 and 149 months after treatment by removing increment cores from three equidistant sites beginning 150 mm belowground, then 0, 300, 450 and 600 mm above groundline. An additional height of 900 mm above groundline was sampled for fumigant treated poles only. The outer, preservative-treated shell was removed, and then the outer and inner 25 mm of each core was retained for chemical analysis using treatment appropriate methodology. The fumigants were analyzed by gas chromatography. Chloropicrin was detected using an electron capture detector while MITC based systems were analyzed using a flame-photometric detector. Inhibitory threshold level for MITC and chloropicrin for decay fungi used in this study is 20 µg/g of oven dried wood and is based on prior observations from fungal culturing of fumigant-treated poles. The remainder of each core was plated on malt extract agar and observed for fungal growth. Boron based systems were analyzed using the Azomethine-H method and the effective inhibitory threshold against decay fungi used here is 0.6 kg/m^3, a conservative level based on previous observations (Freitag and Morrell 2005). Fluoride based systems were analyzed using neutron activation analysis.

For fumigants chemical levels in most poles were elevated 18 months after treatment and then gradually declined to lower levels seen at 149 months after treatment (Table 1.3.2). Fumigant levels tended to be highest toward the center of the poles at a given height, reflecting the tendency for the sloping holes to direct chemical toward the center. Fumigant levels were also highest at or below groundline and then typically declined with distance upward, indicative of proximity to treatment holes, and more stable environmental conditions that may slow the loss of gasses from the wood.

This study included three fumigants containing sodium n-methyldithiocarbamate (NaMDC) (Pol-Fume, SMDC-Fume, and WoodFume). These formulations contain 32.1 % NaMDC in water. The NaMDC decomposes in the presence of organic matter (e.g. wood) to produce a range of sulfur containing compounds including carbon disulfide, carbonyl sulfide, and, most importantly, MITC. At the initial 18-month sampling point contained MITC levels that were 3 to 5 times the inhibitory threshold. MITC levels declined steadily out to the 42-month sampling point where for most NaMDC-based treatments they were close to the inhibitory threshold at all sampling locations. After 54 months, MITC levels had dropped below the inhibitory threshold for all of these treatments at all sampling locations. MITC levels have continued to decline and are all uniformly below the threshold level 54 months after treatment. MITC remained below threshold for all subsequent sampling points and remained near zero. The theoretical decomposition rate of NaMDC to MITC is 40% of the original 32.1%, but numerous tests suggest that the rate in wood is actually nearer to 20% of the original treatment. As a result, NaMDC is expected to produce much lower levels of chemical in the wood and their retention should be relatively short. Some users of these treatments have raised concerns about the potential for this shorter protective period to allow decay fungi to re-colonize the poles and cause renewed damage before the next treatment cycle (which should be 10 years). However, there is evidence that decay fungi do not re-colonize the poles very quickly and, in some cases, they never reach the levels at which they were present prior to treatment. For this reason, there is a substantial time lag between loss of chemical protection and re-colonization that permits the use of this treatment.

MITC-FUME treated poles contained the highest levels of MITC of any treatment 18 months after treatment, with levels approaching 100 times the threshold 150 mm below groundline and 300 mm above groundline. MITC levels declined precipitously after the initial sampling and reached levels closer to the inhibitory threshold, 3.5-30 times the inhibitory level. MITC levels were higher in the pole interior and in samples taken from below or at groundline. By the 89-month time point MITC levels dropped below threshold levels in all sampling locations except those from at or below groundline. In all sampling times beyond 89 months, MITC levels were below threshold in all locations in the pole sections. These results illustrate how MITC-FUME produces a large initial impulse of fumigant that is widely distributed in poles. Inhibitory levels of MITC remain widely distributed to a time between 54 and 89 months, where after they remain elevated for some time in high-risk areas at or below groundline. These data are in line with original field trials showing that protective levels remained in Douglas-fir poles 7 years after treatment. These results indicate that MITC-FUME should provide protection against renewed fungal attack for 10 years considering there is a delay in fungal reinvasion after fumigation.

This study included five dazomet-based fumigants (dazomet powder, dazomet rods, DuraFume, Super-Fume tubes and Ultrafume). Dazomet-based fumigants are increasingly commonly used as remedial treatments for utility poles because they have shown to be effective and are safer for the applicator to handle than liquid fumigants. Dazomet decomposes to produce a range of sulfur containing compounds including the active fumigant MITC. Dazomet decomposition is much more efficient in the presence of water and therefore higher pole moisture content expected at or below groundline and toward the pole interior should accelerate MITC production. In addition, copper-containing accelerants have been shown to increase dazomet decomposition and it has become common practice to add copper naphthenate solution into the treatment hole with the dazomet treatment. Therefore, all dazomet treatments assessed here had copper naphthenate solution added.

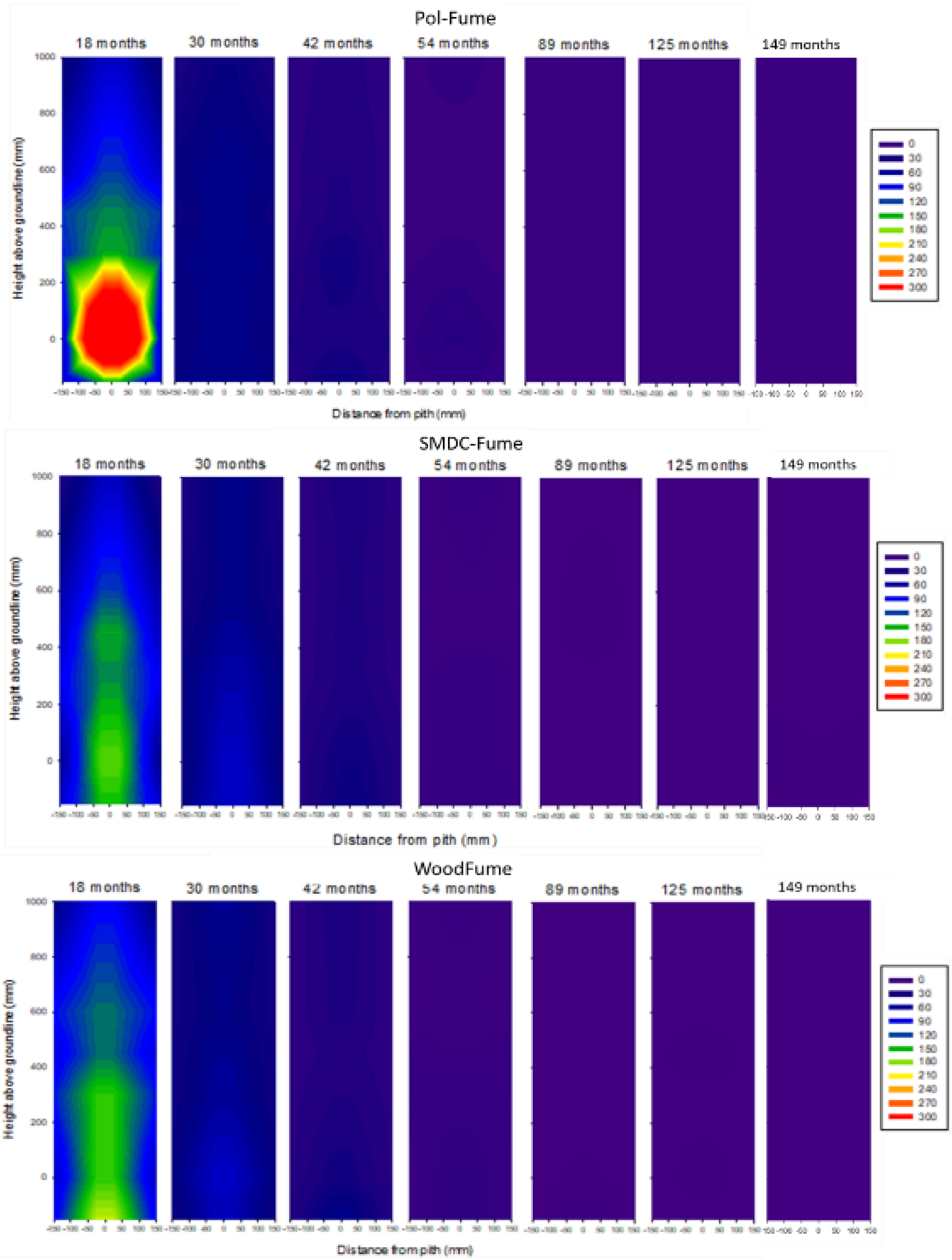


Figure 1.3.1. Distribution of MITC in Douglas-fir pole sections 18 to 149 months after treatment with metam sodium-based fumigants, Pole Fume, SMDC Fume or Wood-Fume. Dark blue signifies little or no chemical while increasingly light blue to green or yellow signifies MITC levels above the threshold. Charts are extrapolated from individual MITC analyses at assay locations described in Table 1.3.2.

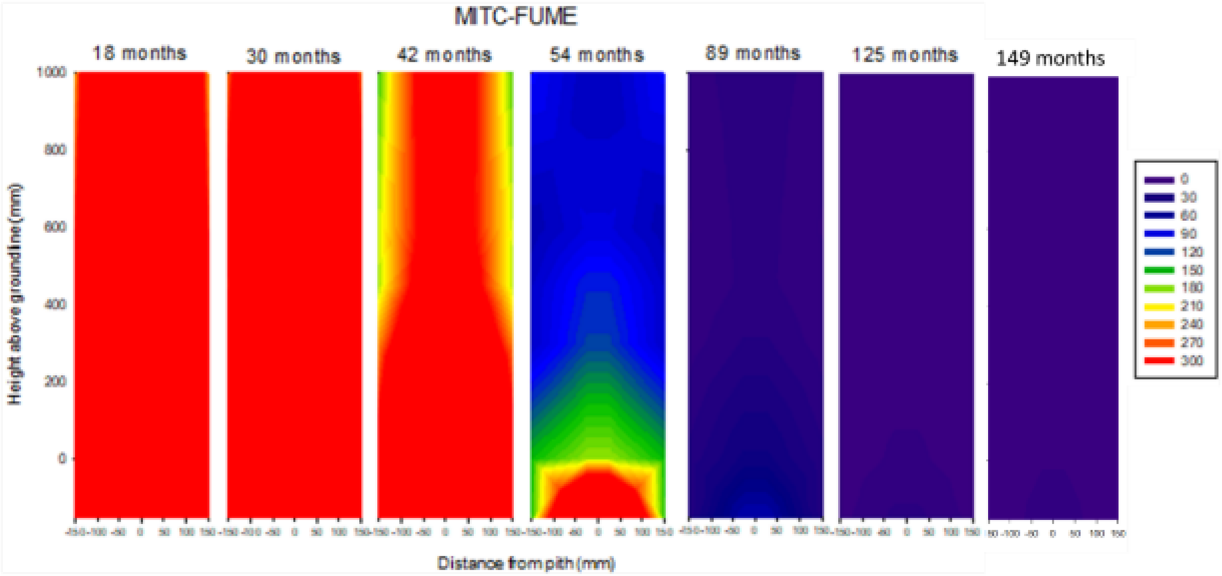


Figure 1.3.2: Distribution of MITC in Douglas-fir pole sections 18 to 125 months after treatment with MITC-Fume. Dark blue signifies little or no chemical while increasingly light blue to green or yellow signifies MITC levels above the threshold. Charts are extrapolated from individual MITC analyses at assay locations described in Table 1.3.2.

At the initial 18-month sampling point, MITC levels in poles receiving dazomet powder (dazomet, DuraFume, or UltraFume) were above or well above (0.95-16.8-fold) effective thresholds in nearly all sampling locations with higher MITC levels generally below groundline. At the next two sampling points (30 and 42 months) many of the sampling locations, especially in the pole interior, had higher MITC levels than at the first sampling point which is a result of the ability of this treatment to continue to degrade to MITC over time. MITC levels 54 months after treatment were above the threshold at all sampling locations for dazomet powder treatments and only began to drop below the effective threshold in samples taken over 300 mm above groundline after 89 months. MITC levels remain above the inhibitory threshold 149 months after application of all three products in samples taken below or at groundline. Periodic surges in MITC levels were observed in dazomet powder-treated poles, which may be attributable to rain events. We have attributed these increases to periods of elevated rainfall that increased the wood moisture content, thereby enhancing decomposition of residual dazomet in the treatment holes. These results are also consistent with previous field trials and indicate this system will provide at least the 10-year protective period used by most utilities in their inspection and treatment cycles.

At the initial 18-month sampling point, MITC levels in poles receiving either dazomet in rod form or in tubes (Super-Fume tubes) tended to be lower than levels found in poles receiving powdered treatments, but were still above the threshold at all sampling points except for near the pole surface 900 mm above groundline. Chemical levels near the surface at 900 mm above groundline less consistently above threshold than in the powdered treatments (Figure I-24). The rods and tubes both may restrict contact between the wood and the chemical, creating the potential for reduced decomposition, however if this is the case, there may be potential for a longer release period for rod treatments which we will continue to monitor over time. MITC levels remained above threshold levels in samples below 900 mm for rod and tube-based dazomet treatments. By the 149-month sampling points, MITC levels were below threshold levels in most sampling locations for dazomet rods and tube treatments. However, these results indicate that the level of protection provided by these treatments, especially at or near groundline is sufficient to provide protection for the typical 10-year inspection cycle. The results of all MITC-based treatments have supported previous tests done on individual systems as they were developed. In general, the results show that metam sodium provides the shortest protective period, while MITC-FUME and the dazomet treatments provide longer term protection that is consistent with the typical pole retreatment cycle.

For chloropicrin-treated poles, the initial 18-month sampling point showed chloropicrin levels in the pole sections were 4.3-1800 times above the effective threshold. Levels steadily declined in subsequent sampling points except for at the 900 mm above groundline samples which saw increases in subsequent sampling points. Chloropicrin levels were well above threshold at all time-points included so far. Sampling at the 149-month showed chloropicrin levels remained high in the poles as was previously observed (Figure 1.3.5-most recent data to be included in final report). These data indicate that chloropicrin is well-suited to prevent fungal growth throughout the normal 10-year inspection cycle.

Two boron-based internal remedial treatments consisting of fused borate rods were included in this test as well, Impel Rods and Pol Saver rods. Boron levels were measured from the inner and outer sections of cores taken at five different heights, up to 600 mm above groundline. At the initial 18-month sampling point boron levels were highest for borate rod treatments in the inner pole sections and at or below groundline. This is likely due to the sloping angle of the holes combined with higher moisture content present in areas at or below groundline and this pattern was seen at time-points through 149 months. Boron levels were generally below the inhibitory threshold levels 300 mm or above groundline, except for one sample. In subsequent sampling points, boron levels tended to remain above threshold inhibitory levels at or below groundline in the inner pole sections for both treatment types and increased at subsequent time-points in some sections (Table 1.3.3). At the 149-month sampling point, samples at or below groundline for Polesaver treatments dropped below the effective threshold whereas they remained above threshold for impel rods (Figure 1.3.6). Above groundline, both treatments had all (Pol Saver) or a large majority of (Impel rods) sampling areas with boron levels under the effective threshold level and above 300 mm all samples had boron levels below threshold. At groundline or below for all time-points, Pol Saver treatments had a total of 7 core sections from different sampling points under threshold, whereas Impel Rod treatments only had 3. After 149 months, at or below groundline samples had average boron levels above threshold for Impel rods, whereas ¾ of these samples were below threshold for Polesaver rods. In addition, several equivalent samples

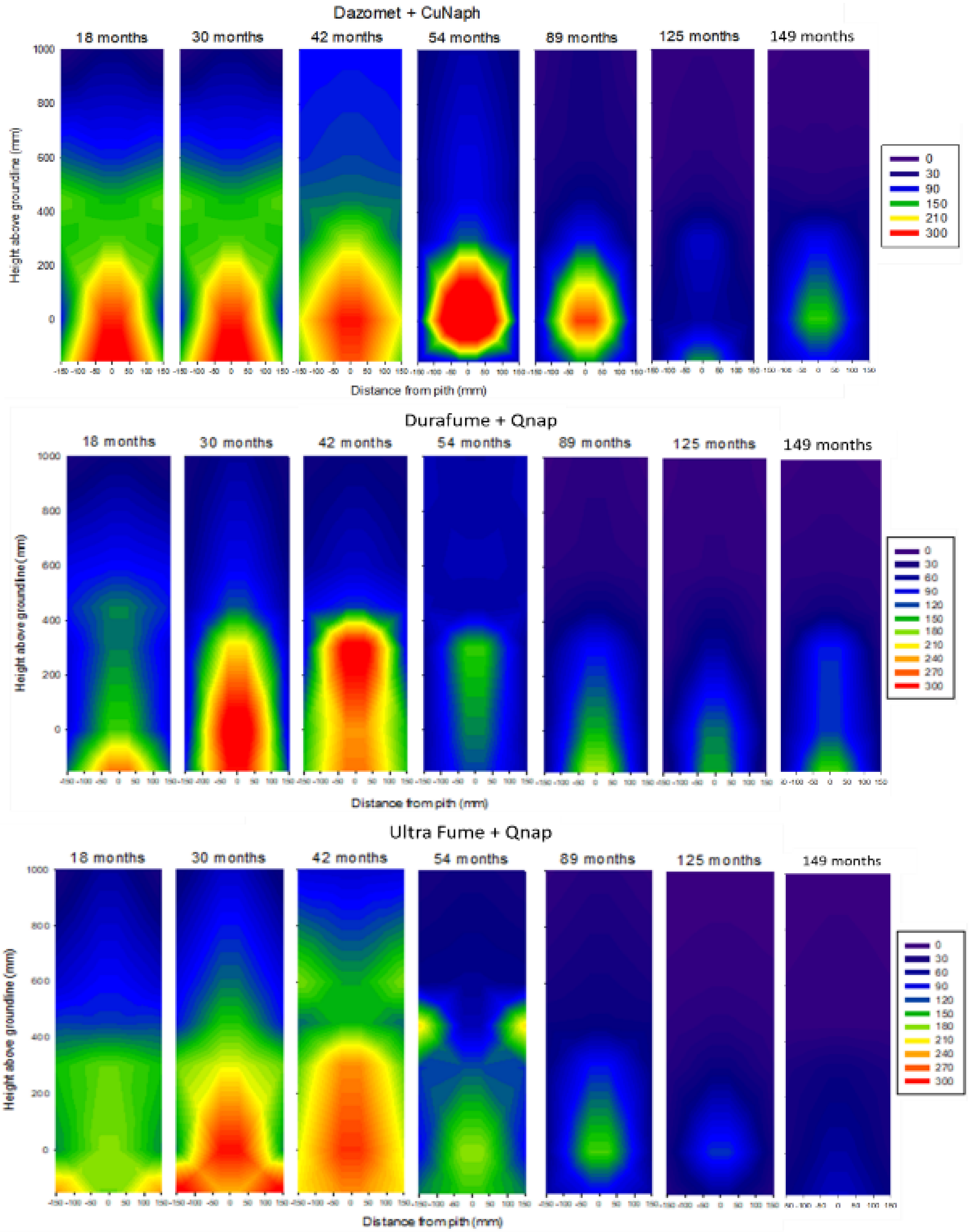


Figure 1.3.3. Distribution of MITC in Douglas-fir pole sections 18 to 149 months after treatment with dazomet, DuraFume or UltraFume plus copper naphthenate. Dark blue signifies little or no chemical while increasingly light blue to green or yellow signifies MITC levels above the threshold. Charts are extrapolated from individual MITC analyses at assay locations described in Table 1.3.2.

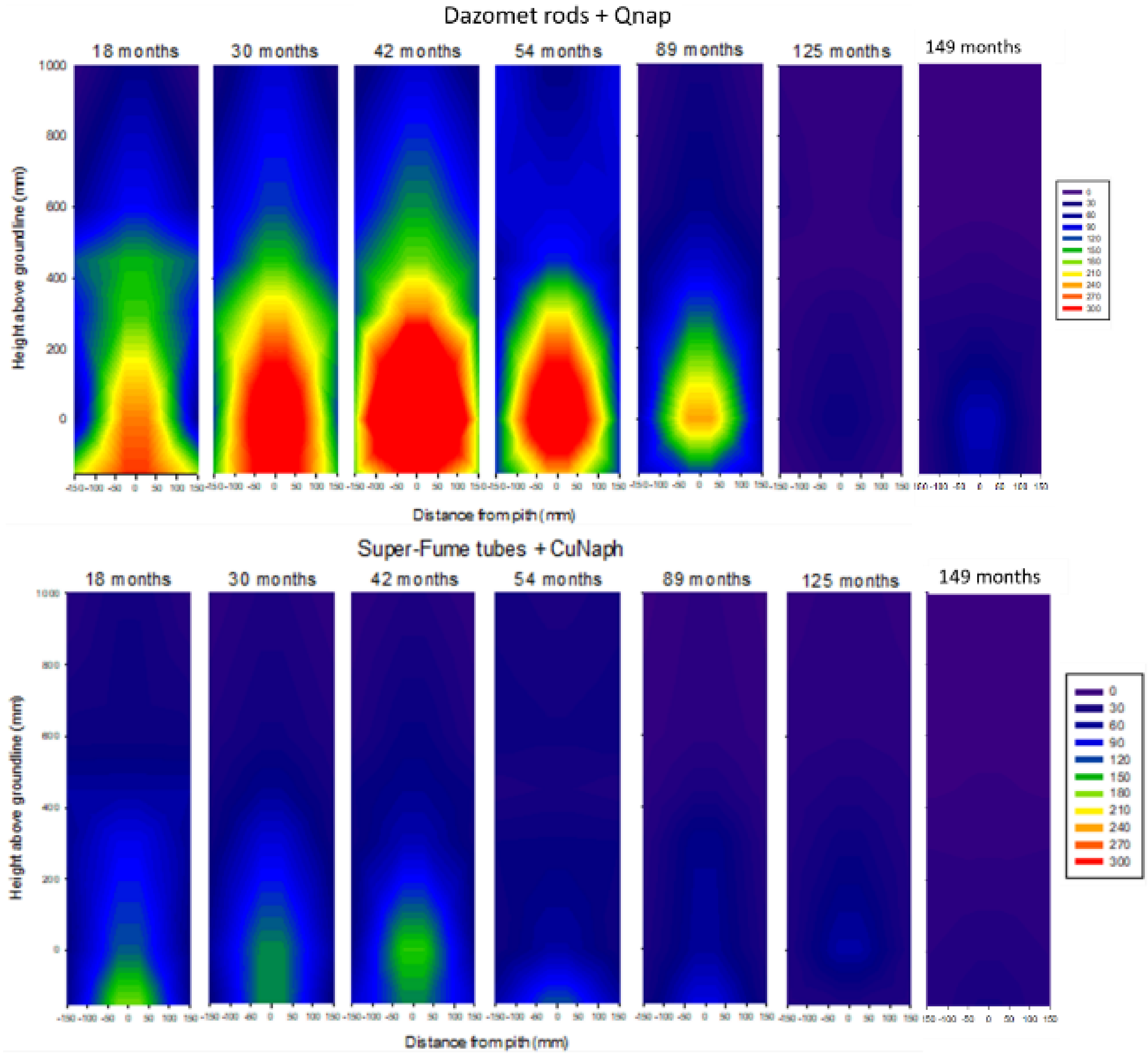


Figure 1.3.4: *Distribution of MITC in Douglas-fir pole sections 18 to 149 months after treatment with dazomet rods or SuperFume tubes plus copper naphthenate. Dark blue signifies little or no chemical while increasingly light blue to green or yellow signifies MITC levels above the threshold. Charts are extrapolated from individual MITC analyses at assay locations described in Table 1.3.2.*

locations in the last five sampling points for Impel rods had at least double the boron concentration as the Pol Saver treatment. This is likely due to the density of Impel Rods being higher than Pol Saver rods, meaning they have more boron to deliver to the wood overall. However, both systems provided protection at or below groundline for the entire treatment cycle, particularly in the inner pole sections.

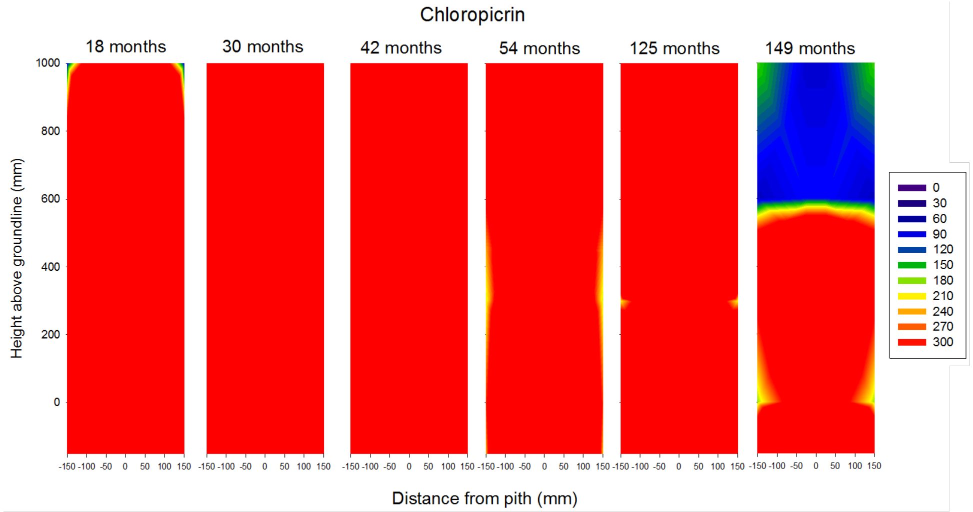


Figure 1.3.5: Distribution of chloropicrin in Douglas-fir pole sections 18 to 149 months after treatment with chloropicrin. Dark blue and purple signify little or no chemical while increasingly light blue to green, yellow or red signifies MITC levels above the threshold. Charts are extrapolated from individual MITC analyses at assay locations described in Table 1.3.2.

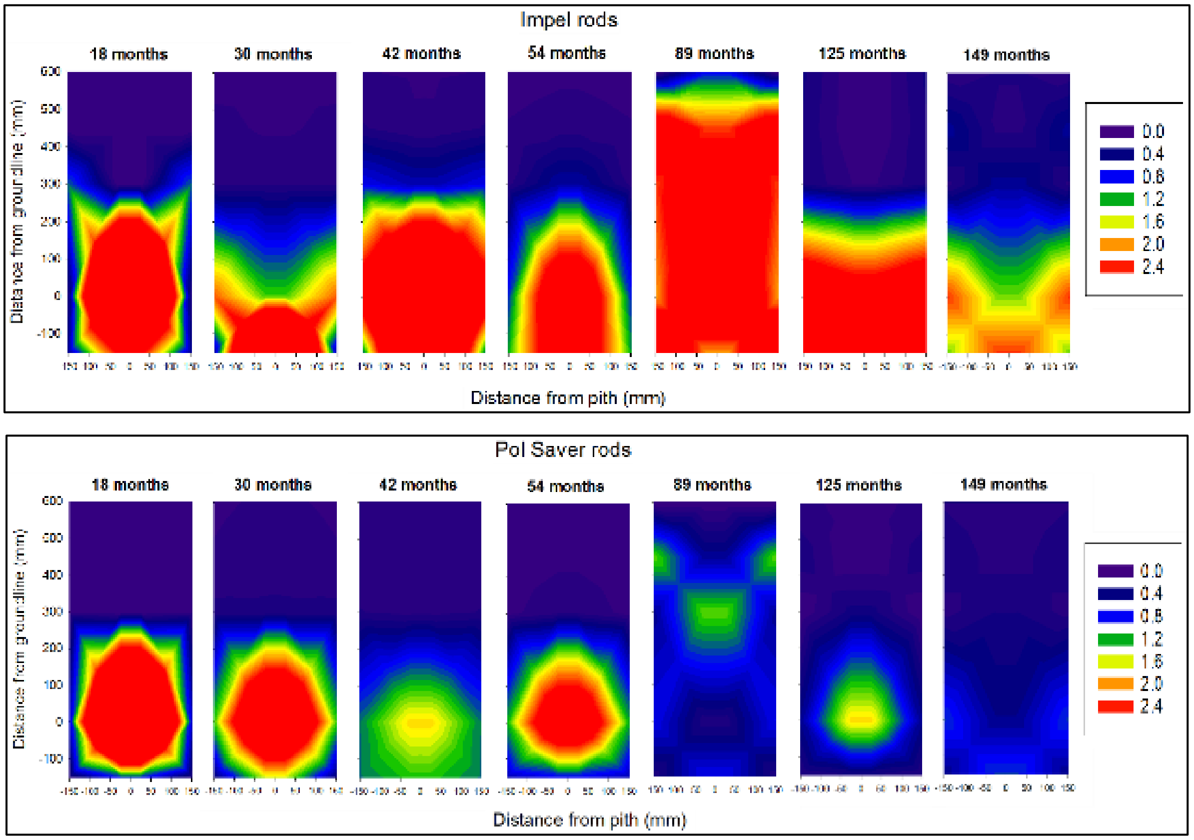


Figure 1.3.6. Distribution of boron in Douglas-fir pole sections 18 to 149 months after treatment with Impel or PolSaver Rods. Dark blue signifies little or no chemical while increasingly light blue to green or yellow signifies boron levels above the threshold. Charts are extrapolated from individual boron analyses at assay locations described in Table 1.3.3.

Boron is known to have a limited ability to diffuse upward in poles, because of the downward sloping angle of the treatment holes and that groundline and below groundline pole sections are likely to have consistently higher moisture content than above groundline sections. These results are consistent with previous tests showing that uniform boron movement requires several years. If these trends continue, we would expect elevated boron levels in the poles for several more years. The inner zone is likely to present a more moisture-stable environment that would facilitate boron movement over time. While higher moisture contents at-or-below groundline may facilitate boron diffusion throughout the pole, it may also facilitate boron loss to the surrounding soil during wet winters at Peavy Arboretum. This may be another reason why the core sections closer to the pole surface have lower boron concentrations than the inner sections.

Discussion of fungal colonization data was not included until the 89-month sampling point due to the small amount of isolations found in the pole sections in earlier data (Table 1.3.4 and Table 1.3.5). Incidence of decay fungi was relatively high among poles not treated with remedial treatments at or below groundline. The incidence of decay fungi was fairly high in the non-remedially treated control poles especially at or below groundline. Among the fumigants, fungal isolation was more prominent among metam sodium systems from the 125-month sampling point onward, particularly in Pole Fume and Wood Fume samples, but also in MITC-FUME samples. Powdered dazomet treatments began to show decay fungi in the groundline or near groundline samples taken from 125 months onward, just past the 10-year mark. This is consistent with the relatively short-term protection afforded by metam sodium. Decay fungi isolations remained high in metam sodium treatments after 149 months. Decay fungi were also isolated sporadically from poles treated with Super-Fume tubes or Dura-Fume. SuperFume treatments showed some decay fungi isolated in above ground samples, whereas the below groundline samples showed relatively more decay funding in the DuraFume samples at the 149-month time-point. UltraFume treatments showed generally low amounts of fungi in samples taken from these poles until the 149-month sampling point, where some of the above groundline samples began to show the presence of decay fungi.

Isolations of decay fungi from cores removed from water diffusible-treated poles were initially infrequent at or below groundline. More recent sampling at 89, 125 and 149 months showed a relatively high incidence of decay fungi in Impel Rod-treated poles above groundline. This is consistent with the low boron levels seen in above groundline sections of boron-treated poles. However, it is unusual that higher decay fungi isolation rate was only seen in Impel rod-treated pole sections given that boron levels were also low in Pole Saver-treated pole sections at the same heights. Rates of isolation of non-decay fungi were very high across diffusible treatments above ground and it’s possible that non-decay fungi are outcompeting decay fungi in the above groundline sections of Pole Saver and Flurod treated poles. Regardless, fungal isolations tended to be lower in groundline and below groundline sections until the 149-month time point with Impel Rods, which is consistent with the higher boron concentration in these areas.

Table 1.3.2: Residual MITC levels in Douglas-fir poles 18 to 149 months after application of selected remedial treatments at heights -150 mm, groundline, and 300 mm.

Treatment	Cu Naph	months after treatment	Chemical Level (µg/g)					
			Height above groundline (mm)					
			-150		0		300	
			inner	outer	inner	outer	inner	outer
Control	-	18	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
		30	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
		42	11 (16)	5 (8)	8 (13)	4 (6)	5 (8)	4 (7)
		54	1 (1)	0 (1)	6 (13)	1 (2)	1 (1)	1 (1)
		89	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
		125	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
		149	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Dazomet	+	18	**337** (266)	**158** (196)	**289** (322)	**102** (105)	**163** (112)	**151** (119)
		30	**253** (257)	**78** (73)	**366** (278)	**78** (60)	**201** (139)	**109** (77)
		42	**270** (297)	**165** (146)	**299** (281)	**196** (176)	**181** (212)	**121** (69)
		54	**102** (86)	**63** (45)	**472** (662)	**76** (74)	**123** (116)	**57** (36)
		89	**139** (126)	**55** (35)	**279** (237)	**62** (57)	**100** (65)	**35** (19)
		125	**138** (365)	**38** (41)	**61** (66)	**47** (59)	**76** (128)	**22** (27)
		149	**96** (55)	**55** (43)	**158** (195)	**54** (37)	**89** (124)	**37** (32)
Dazomet rods	+	18	**283** (260)	**181** (347)	**254** (166)	**51** (73)	**159** (66)	**95** (115)
		30	**348** (292)	**149** (169)	**391** (394)	**115** (122)	**220** (90)	**134** (201)
		42	**315** (198)	**171** (145)	**691** (1128)	**176** (129)	**253** (139)	**118** (74)
		54	**233** (256)	**107** (104)	**413** (564)	**107** (95)	**201** (311)	**66** (50)
		89	**113** (62)	**66** (64)	**238** (192)	**61** (77)	**120** (67)	**46** (39)
		125	**27** (28)	6 (11)	**40** (43)	15 (27)	**24** (30)	12 (18)
		149	**61** (62)	14 (17)	**71** (68)	16 (20)	**24** (21)	**21** (28)
DuraFume	+	18	**255** (164)	**126** (118)	**160** (87)	**83** (95)	**131** (81)	**82** (79)
		30	**297** (232)	**106** (88)	**333** (359)	**79** (55)	**212** (201)	**72** (44)
		42	**256** (199)	**152** (171)	**243** (150)	**143** (117)	**329** (536)	**87** (43)
		54	**116** (122)	**60** (59)	**134** (131)	**55** (32)	**158** (209)	**54** (44)
		89	**185** (198)	**48** (36)	**146** (104)	**47** (33)	**98** (61)	**41** (39)
		125	**145** (136)	**23** (33)	**130** (108)	**40** (70)	**60** (74)	12 (11)
		149	**163** (246)	**47** (44)	**112** (95)	**44** (46)	**107** (225)	**27** (32)
Super-Fume Tubes	+	18	**173** (152)	**50** (77)	**121** (85)	**46** (46)	**91** (72)	**54** (47)
		30	**138** (160)	**42** (42)	**135** (104)	**58** (73)	**83** (40)	**38** (26)
		42	**132** (150)	**72** (60)	**157** (244)	**50** (38)	**68** (23)	**39** (26)
		54	**120** (211)	**63** (84)	**61** (44)	**36** (18)	**43** (20)	**42** (32)
		89	**87** (100)	**33** (33)	**57** (46)	**25** (40)	**53** (59)	18 (25)
		125	**27** (28)	**21** (27)	**62** (65)	**25** (29)	**39** (49)	**21** (24)
		149	**31** (27)	17 (20)	**23** (21)	17 (20)	10 (9)	12 (12)
UltraFume	+	18	**174** (92)	**239** (324)	**175** (115)	**136** (183)	**168** (83)	**151** (208)
		30	**229** (188)	**318** (821)	**300** (198)	**136** (162)	**195** (85)	**170** (204)
		42	**246** (267)	**206** (163)	**283** (236)	**194** (187)	**246** (152)	**166** (105)
		54	**158** (116)	**131** (126)	**179** (81)	**97** (59)	**119** (89)	**113** (150)
		89	**91** (62)	**59** (57)	**163** (131)	**50** (38)	**102** (102)	**47** (42)
		125	**54** (44)	**21** (25)	**111** (112)	**34** (42)	**41** (33)	19 (22)
		149	**73** (64)	**45** (39)	**60** (56)	**34** (34)	**40** (32)	**27** (30)
MITC-FUME	-	18	**1868** (1682)	**207** (219)	**24710** (88693)	**560** (1335)	**2085** (1906)	**372** (430)
		30	**1773** (1871)	**565** (435)	**2328** (1945)	**535** (461)	**1318** (1176)	**412** (323)
		42	**1210** (1243)	**712** (1569)	**794** (617)	**334** (187)	**491** (311)	**246** (136)
		54	**612** (1472)	**155** (115)	**180** (123)	**150** (155)	**115** (83)	**78** (61)
		89	**66** (75)	**20** (18)	**37** (35)	20 (23)	18 (21)	9 (10)
		125	13 (19)	4 (10)	7 (8)	3 (7)	4 (7)	1 (4)
		149	9 (12)	0 (2)	5 (10)	1 (2)	2 (5)	0 (0)
Pol Fume	-	18	**132** (74)	**63** (56)	**661** (1539)	**69** (36)	**149** (104)	**120** (168)
		30	**53** (30)	**47** (49)	**52** (36)	**40** (37)	**50** (23)	**47** (24)
		42	**38** (28)	**21** (14)	**27** (17)	**24** (21)	**34** (24)	16 (7)
		54	14 (20)	8 (12)	18 (22)	11 (18)	8 (15)	3 (1)
		89	1 (2)	0 (0)	1 (2)	0 (0)	0 (1)	0 (0)
		125	1 (2)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
		149	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
SMDC-Fume	-	18	**152** (75)	**74** (55)	**168** (132)	**50** (22)	**135** (75)	**90** (77)
		30	**76** (50)	**48** (27)	**75** (41)	**40** (19)	**64** (28)	**45** (24)
		42	**39** (28)	20 (9)	**36** (21)	**20** (10)	**25** (8)	14 (3)
		54	11 (8)	6 (6)	11 (13)	4 (3)	10 (18)	5 (4)
		89	0 (1)	0 (1)	0 (1)	0 (0)	0 (0)	0 (0)
		125	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
		149	1 (5)	0 (0)	1 (2)	1 (4)	0 (0)	0 (0)
WoodFume	-	18	**187** (125)	**91** (120)	**157** (106)	**74** (54)	**156** (107)	**103** (99)
		30	**68** (52)	**38** (32)	**75** (61)	**45** (45)	**57** (40)	**37** (24)
		42	**53** (24)	20 (22)	**33** (21)	17 (19)	**24** (21)	15 (16)
		54	16 (13)	6 (5)	15 (11)	5 (5)	9 (8)	8 (9)
		89	2 (7)	0 (0)	1 (1)	0 (0)	0 (0)	0 (0)
		125	0 (0)	0 (0)	1 (2)	0 (0)	0 (0)	0 (0)
		149	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Chloropicrin	-	18	**37096** (134096)	**6052** (11848)	**16347** (24851)	**18001** (25506)	**22498** (27167)	**12951** (16512)
		30	**12749** (22396)	**4900** (8571)	**1149** (2837)	**1071** (1895)	**6516** (6511)	**1585** (1853)
		42	**6488** (6654)	**2904** (3671)	**4606** (3245)	**1257** (2437)	**3438** (2753)	**4059** (5007)
		54	**2317** (1768)	**267** (413)	**1808** (1503)	**331** (375)	**1023** (1088)	**226** (295)
		89						
		125	**3492** (3965)	**3243** (6665)	**1335** (1210)	**889** (2074)	**723** (749)	**337** (507)
		149	**1721** (1423)	**711** (1398)	**607** (742)	**440** (558)	**419** (676)	**101** (87)

[a] Numbers in parentheses represent one standard deviation around the mean of 15 replicates. Numbers in bold type are above the toxic threshold, 20µg MITC/g dry wood, 20µg chloropicrin/g dry wood.

[a] Numbers in parentheses represent one standard deviation around the mean of 15 replicates. Numbers in bold type are above the toxic threshold, 20µg MITC/g dry wood, 20µg chloropicrin/g dry wood.

Table 3.1.2 cont. Residual MITC levels in Douglas-fir poles 18 to 149 months after application of selected remedial treatments at heights 450 mm, 600 mm, and 900 mm.

Treatment	Cu Naph	months after treatment	Chemical Level (µg/g)					
			Height above groundline (mm)					
			450		600		900	
			inner	outer	inner	outer	inner	outer
Control	-	18	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
		30	0 (0)	0 (0)	0 (0)	0 (0)	1 (4)	0 (0)
		42	8 (13)	5 (8)	5 (8)	5 (7)	7 (10)	5 (7)
		54	3 (5)	2 (4)	1 (1)	1 (1)	1 (1)	0 (1)
		89	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
		125	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
		149	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Dazomet	+	18	**148** (112)	**167** (205)	**107** (99)	**123** (206)	**47** (30)	19 (12)
		30	**165** (102)	**93** (55)	**142** (110)	**106** (95)	**75** (38)	**48** (46)
		42	**128** (66)	**125** (108)	**114** (58)	**106** (103)	**99** (63)	**96** (144)
		54	**90** (70)	**49** (26)	**87** (67)	**51** (39)	**65** (48)	**42** (56)
		89	**54** (28)	**27** (15)	**34** (21)	**25** (28)	**31** (23)	10 (8)
		125	**32** (44)	14 (24)	18 (17)	9 (9)	12 (12)	9 (12)
		149	**25** (18)	**35** (37)	13 (14)	15 (20)	9 (7)	4 (6)
Dazomet rods	+	18	**147** (55)	**118** (168)	**97** (53)	**53** (69)	**49** (36)	9 (21)
		30	**153** (55)	**84** (64)	**114** (52)	**72** (82)	**79** (37)	**29** (23)
		42	**170** (53)	**118** (98)	**138** (79)	**85** (71)	**77** (32)	**35** (21)
		54	**105** (96)	**59** (47)	**83** (58)	**80** (82)	**49** (39)	**89** (99)
		89	**77** (51)	**42** (58)	**51** (31)	**24** (24)	**34** (11)	7 (9)
		125	10 (9)	7 (10)	7 (10)	**21** (37)	8 (18)	11 (23)
		149	13 (14)	7 (16)	3 (6)	2 (5)	1 (3)	0 (0)
DuraFume	+	18	**132** (59)	**105** (109)	**99** (86)	**90** (134)	**45** (22)	**27** (37)
		30	**120** (73)	**57** (37)	**92** (51)	**49** (23)	**58** (34)	**32** (18)
		42	**111** (52)	**88** (73)	**76** (38)	**56** (44)	**46** (26)	**36** (29)
		54	**60** (32)	**67** (64)	**68** (54)	**64** (88)	**60** (53)	**68** (97)
		89	**46** (33)	**26** (31)	**21** (20)	17 (18)	16 (12)	3 (5)
		125	**36** (29)	13 (12)	13 (16)	8 (12)	10 (14)	3 (6)
		149	**37** (49)	19 (24)	16 (24)	14 (24)	8 (18)	3 (6)
Super-Fume Tubes	+	18	**60** (22)	**60** (44)	**39** (17)	**38** (30)	**35** (72)	16 (19)
		30	**54** (21)	**31** (15)	**37** (19)	**24** (22)	**25** (10)	12 (11)
		42	**53** (33)	**40** (32)	**44** (21)	**23** (10)	**24** (13)	11 (8)
		54	**30** (12)	**26** (21)	**37** (29)	**40** (67)	**27** (31)	**33** (54)
		89	**28** (26)	13 (18)	16 (19)	9 (14)	13 (19)	4 (7)
		125	**26** (18)	19 (19)	17 (11)	14 (26)	14 (23)	9 (16)
		149	7 (9)	5 (7)	4 (6)	3 (6)	3 (5)	1 (2)
UltraFume	+	18	**112** (51)	**113** (134)	**98** (72)	**77** (65)	**59** (69)	**26** (20)
		30	**156** (79)	**103** (112)	**127** (74)	**87** (64)	**76** (47)	**39** (24)
		42	**150** (63)	**125** (81)	**143** (57)	**175** (187)	**78** (47)	**82** (80)
		54	**69** (36)	**211** (530)	**55** (24)	**52** (31)	**39** (19)	**30** (29)
		89	**44** (23)	**42** (37)	**37** (20)	**30** (40)	**20** (15)	10 (10)
		125	**20** (14)	13 (12)	11 (9)	8 (8)	2 (4)	0 (1)
		149	12 (15)	10 (11)	11 (11)	7 (9)	3 (5)	0 (1)
MITC-FUME	-	18	**1574** (2239)	**360** (332)	**840** (673)	**283** (214)	**848** (764)	**235** (208)
		30	**882** (932)	**292** (236)	**904** (1066)	**330** (279)	**662** (589)	**261** (250)
		42	**389** (281)	**184** (107)	**350** (284)	**189** (106)	**369** (250)	**165** (117)
		54	**107** (70)	**77** (50)	**85** (41)	**68** (51)	**73** (50)	**98** (104)
		89	13 (13)	7 (7)	14 (13)	5 (7)	15 (14)	9 (11)
		125	1 (4)	1 (3)	1 (2)	1 (2)	1 (3)	1 (3)
		149	0 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Pol Fume	-	18	**136** (76)	**123** (111)	**118** (61)	**78** (58)	**65** (29)	**35** (26)
		30	**51** (26)	**39** (20)	**53** (26)	**45** (23)	**41** (22)	**23** (19)
		42	**25** (18)	15 (7)	**24** (17)	16 (8)	**20** (9)	14 (7)
		54	3 (2)	3 (2)	3 (1)	4 (2)	8 (13)	4 (2)
		89	0 (0)	0 (0)	1 (3)	0 (0)	0 (0)	0 (0)
		125	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
		149	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
SMDC-Fume	-	18	**144** (112)	**71** (52)	**114** (89)	**61** (47)	**72** (51)	**24** (23)
		30	**56** (26)	**37** (19)	**49** (20)	**31** (16)	**52** (37)	**25** (15)
		42	**26** (12)	13 (4)	**24** (10)	13 (5)	**27** (15)	13 (13)
		54	4 (2)	4 (2)	5 (3)	3 (2)	9 (19)	3 (3)
		89	1 (2)	0 (1)	1 (3)	0 (0)	0 (0)	0 (0)
		125	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
		149	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
WoodFume	-	18	**127** (79)	**85** (112)	**129** (62)	**100** (112)	**95** (48)	**46** (60)
		30	**53** (34)	**35** (21)	**48** (25)	**33** (26)	**55** (28)	**32** (30)
		42	20 (15)	14 (16)	**25** (24)	13 (13)	**26** (17)	12 (12)
		54	6 (5)	8 (13)	5 (5)	4 (3)	6 (4)	4 (4)
		89	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
		125	1 (5)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
		149	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Chloropicrin	-	18	**9263** (14788)	**6772** (13209)	**3429** (6239)	**606** (853)	**795** (780)	**86** (181)
		30	**424** (1009)	**2307** (5072)	**3582** (4241)	**1129** (1819)	**3691** (11390)	**278** (339)
		42	**1546** (1472)	**1363** (1131)	**1720** (1489)	**678** (837)	**1639** (1990)	**310** (560)
		54	**867** (931)	**276** (376)	**984** (1040)	**381** (621)	**387** (509)	**604** (1219)
		89						
		125	**1324** (2516)	**369** (619)	**613** (780)	**345** (393)	**202** (219)	**451** (411)
		149	**177** (229)	**74** (85)	**721** (1128)	**80** (92)	**329** (687)	**160** (206)

[a] Numbers in parentheses represent one standard deviation around the mean of 15 replicates. Numbers in bold type are above the toxic threshold, 20µg MITC/g dry wood, 20µg chloropicrin/g dry wood.

[a] Numbers in parentheses represent one standard deviation around the mean of 15 replicates. Numbers in bold type are above the toxic threshold, 20µg MITC/g dry wood, 20µg chloropicrin/g dry wood.

Table 1.3.3: Boron levels at various distances above and below groundline in Douglas-fir poles 18-149 months after treatment.

Treatment	months after treatment	Height above groundline (mm)[a]					
		-150		0		300	
		inner	outer	inner	outer	inner	outer
Control	18	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	30	0.07 (0.02)	0.07 (0.02)	0.07 (0.02)	0.06 (0.00)	0.08 (0.03)	0.08 (0.04)
	42	0.18 (0.24)	0.19 (0.23)	0.21 (0.28)	0.18 (0.25)	0.21 (0.27)	0.20 (0.28)
	54	0.00 (0.00)	0.04 (0.02)	0.03 (0.04)	0.01 (0.01)	0.00 0.00	0.00 0.00
	89	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	125	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	149	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Impel rods	18	**2.59** (1.44)	0.37 (0.35)	**7.68** (10.11)	0.16 (0.20)	0.02 (0.03)	**0.97** (2.17)
	30	**6.67** (8.01)	0.39 (0.40)	**1.30** (0.47)	**2.14** (3.60)	0.16 (0.13)	0.15 (0.14)
	42	**5.49** (5.77)	**0.98** (0.88)	**6.30** (7.76)	**3.09** (3.91)	**0.53** (0.74)	**0.72** (1.25)
	54	**3.34** (2.06)	**1.12** (1.42)	**3.57** (2.76)	**0.84** (0.46)	0.47 (0.87)	0.13 (0.18)
	89	**1.91** (2.45)	**3.95** (7.06)	**3.16** (2.94)	**2.25** (2.56)	**0.76** (1.13)	0.00 (0.01)
	125	**4.38** (3.39)	**3.42** (5.97)	**3.38** (5.70)	**3.78** (3.65)	0.45 (0.25)	**0.52** (0.24)
	149	**2.36** (2.14)	**0.91** (1.16)	**2.27** (1.68)	**1.38** (1.42)	0.44 (0.46)	0.14 (0.16)
Pol Saver rods	18	**0.84** (0.11)	0.14 (0.24)	**7.50** (4.55)	**0.61** (0.74)	0.00 (0.00)	0.04 (0.08)
	30	**1.54** (1.98)	0.31 (0.18)	**4.44** (4.86)	**1.28** (0.57)	0.18 (0.01)	0.18 (0.11)
	42	**1.24** (0.79)	**1.02** (0.49)	**1.73** (1.10)	**1.03** (0.31)	0.13 (0.09)	0.16 (0.09)
	54	**0.74** (0.67)	**0.53** (0.49)	**3.56** (3.90)	**1.17** (0.93)	0.15 (0.05)	0.05 (0.04)
	89	**0.72** (0.84)	0.18 (0.31)	**1.34** (1.88)	0.44 (0.50)	0.01 (0.01)	0.00 (0.00)
	125	**0.61** (0.54)	0.43 (0.18)	**0.65** (0.52)	**0.69** (0.71)	**2.10** (4.10)	0.24 (0.18)
	149	0.49 (0.38)	0.19 (0.18)	**0.90** (1.02)	0.41 (0.44)	0.24 (0.33)	0.12 (0.10)

Treatment	months after treatment	Height above groundline (mm)[a]			
		450		600	
		inner	outer	inner	outer
Control	18	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	30	0.10 (0.03)	0.06 (0.01)	0.08 (0.00)	0.07 (0.02)
	42	0.19 (0.29)	0.21 (0.26)	0.21 (0.23)	0.08 (0.02)
	54	0.00 (0.00)	0.01 (0.00)	0.00 (0.00)	0.03 (0.04)
	89	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	125	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	149	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Impel rods	18	0.02 (0.03)	0.02 (0.03)	0.02 (0.04)	0.00 (0.01)
	30	0.07 (0.04)	0.10 (0.09)	0.07 (0.03)	0.05 (0.02)
	42	0.09 (0.09)	0.17 (0.18)	0.07 (0.02)	0.08 (0.03)
	54	0.12 (0.13)	0.09 (0.14)	0.06 (0.08)	0.04 (0.05)
	89	0.06 (0.08)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	125	0.38 (0.23)	**0.51** (0.23)	0.24 (0.11)	**0.54** (0.85)
	149	0.17 (0.19)	0.11 (0.15)	0.24 (0.27)	0.13 (0.12)
Pol Saver rods	18	0.02 (0.04)	0.06 (0.06)	0.02 (0.03)	0.03 (0.04)
	30	0.12 (0.01)	0.09 (0.03)	0.09 (0.03)	0.07 (0.03)
	42	0.11 (0.05)	0.11 (0.06)	0.13 (0.01)	0.11 (0.03)
	54	0.06 (0.08)	0.03 (0.05)	0.05 (0.03)	0.00 (0.00)
	89	0.08 (0.14)	0.00 (0.00)	0.00 (0.00)	0.07 (0.12)
	125	0.36 (0.26)	0.50 (0.22)	0.44 (0.34)	0.38 (0.15)
	149	0.10 (0.09)	0.15 (0.10)	0.08 (0.08)	0.28 (0.53)

[a] Numbers in parentheses represent one standard deviation around the mean of 3 (control and Pol Saver) or 5 (Impel rods) replicates. Numbers in bold type are above the toxic threshold.

Table 1.3.4. Degree of fungal colonization (%) in Douglas-fir poles 18 to 149 months after internal remedial treatment with water diffusible rods or fumigants.[a]

Treatment	Cu Naph	Months After Treatment	Height above groundline (mm)						Pole
			-150	0	300	450	600	1000	
Fumigant Control	-	18	33^{17}	17^{0}	0^{0}	0^{0}	0^{0}	0^{0}	8^{3}
		30	33^{50}	33^{50}	17^{17}	0^{17}	0^{17}	0^{0}	14^{25}
		42	50^{50}	50^{50}	50^{50}	33^{50}	33^{17}	0^{50}	36^{44}
		54	22^{11}	33^{0}	11^{0}	33^{0}	33^{0}	22^{0}	26^{2}
		89	33^{56}	56^{56}	56^{33}	56^{11}	44^{22}	22^{44}	44^{37}
		125	67^{100}	67^{89}	56^{22}	44^{56}	44^{78}	0^{56}	46^{67}
		149	56^{56}	67^{67}	56^{67}	67^{78}	44^{78}	0^{67}	48^{69}
Dazomet	+	18	0^{7}	0^{0}	7^{13}	0^{7}	0^{7}	0^{7}	1^{7}
		30	0^{0}	0^{0}	0^{0}	0^{7}	0^{0}	0^{0}	0^{1}
		42	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}
		54	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}
		89	0^{0}	0^{7}	0^{0}	0^{0}	0^{0}	0^{7}	0^{2}
		125	0^{20}	7^{20}	7^{0}	0^{0}	0^{13}	0^{13}	2^{11}
		149	0^{27}	13^{20}	13^{27}	0^{0}	0^{7}	0^{27}	4^{18}
Dazomet rods	+	18	0^{0}	0^{7}	0^{0}	0^{0}	0^{0}	0^{7}	0^{2}
		30	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}
		42	0^{0}	0^{7}	0^{0}	0^{0}	0^{0}	0^{0}	0^{1}
		54	0^{0}	0^{0}	0^{0}	0^{0}	0^{7}	0^{0}	0^{1}
		89	0^{7}	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}	0^{1}
		125	0^{33}	0^{13}	0^{0}	0^{0}	0^{7}	0^{7}	0^{10}
		149	0^{60}	0^{20}	0^{20}	0^{0}	0^{0}	0^{20}	0^{20}
DuraFume	+	18	0^{7}	0^{7}	0^{0}	0^{0}	0^{7}	0^{7}	0^{4}
		30	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}
		42	0^{0}	0^{7}	0^{0}	0^{7}	0^{0}	0^{0}	0^{2}
		54	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}
		89	0^{0}	0^{7}	0^{7}	7^{7}	0^{0}	0^{0}	1^{3}
		125	13^{33}	0^{7}	0^{20}	0^{0}	0^{13}	0^{0}	2^{12}
		149	27^{20}	0^{13}	0^{20}	0^{20}	0^{20}	0^{7}	4^{17}
MITC-FUME	-	18	0^{0}	0^{13}	0^{0}	0^{0}	0^{0}	0^{0}	0^{2}
		30	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}
		42	0^{0}	0^{7}	0^{0}	0^{0}	0^{0}	0^{0}	0^{1}
		54	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}
		89	0^{7}	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}	0^{1}
		125	7^{40}	0^{33}	0^{33}	7^{40}	7^{33}	0^{7}	3^{31}
		149	7^{60}	0^{60}	20^{40}	13^{47}	20^{60}	0^{47}	10^{52}
Pol Fume	-	18	0^{0}	0^{7}	0^{7}	0^{13}	0^{0}	0^{20}	0^{8}
		30	0^{0}	0^{13}	0^{0}	0^{0}	0^{0}	0^{7}	0^{3}
		42	7^{7}	0^{0}	7^{7}	0^{7}	7^{7}	0^{0}	3^{4}
		54	0^{7}	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}	0^{1}
		89	0^{60}	0^{87}	27^{27}	40^{27}	27^{7}	0^{40}	16^{41}
		125	33^{47}	40^{47}	33^{33}	33^{53}	33^{40}	33^{60}	34^{47}
		149	47^{67}	47^{67}	20^{40}	20^{47}	40^{60}	13^{53}	31^{56}
SMDS-Fume	-	18	0^{0}	0^{13}	0^{7}	0^{7}	0^{13}	0^{7}	0^{8}
		30	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}
		42	0^{0}	0^{0}	0^{7}	0^{0}	0^{0}	0^{0}	0^{1}
		54	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}
		89	0^{67}	7^{73}	0^{13}	0^{27}	0^{40}	0^{20}	1^{40}
		125	0^{87}	7^{73}	20^{53}	7^{47}	0^{40}	0^{73}	6^{62}
		149	0^{67}	13^{67}	20^{33}	20^{40}	0^{47}	7^{47}	10^{50}

[a] Values represent percentage of cores containing decay fungi. Superscript values represent percent of cores containing non-decay fungi.

Table 1.3.4. cont. Degree of fungal colonization (%) in Douglas-fir poles 18 to 149 months after internal remedial treatment with water diffusible rods or fumigants.[a]

Treatment	Cu Naph	Months After Treatment	Height above groundline (mm)						Pole
			-150	0	300	450	600	1000	
Super-Fume Tubes	+	18	0^{0}	0^{0}	0^{13}	0^{7}	0^{0}	0^{7}	0^{4}
		30	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}
		42	0^{7}	0^{0}	0^{7}	0^{7}	0^{7}	0^{0}	0^{4}
		54	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}
		89	7^{0}	0^{0}	0^{20}	0^{13}	0^{0}	0^{0}	1^{6}
		125	0^{20}	0^{20}	0^{13}	0^{0}	7^{0}	0^{7}	1^{10}
		149	0^{27}	0^{33}	0^{20}	13^{7}	13^{0}	0^{0}	4^{14}
UltraFume	+	18	0^{0}	0^{0}	0^{20}	0^{7}	0^{7}	0^{0}	0^{6}
		30	0^{0}	0^{0}	0^{0}	0^{7}	0^{0}	0^{7}	0^{2}
		42	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}
		54	0^{0}	0^{0}	0^{0}	0^{7}	0^{0}	0^{0}	0^{1}
		89	0^{13}	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}	0^{2}
		125	0^{7}	0^{7}	0^{13}	0^{7}	0^{7}	0^{20}	0^{10}
		149	0^{27}	0^{7}	27^{33}	0^{0}	0^{20}	0^{33}	4^{20}
WoodFume	-	18	0^{0}	0^{0}	0^{0}	0^{0}	0^{20}	0^{7}	0^{4}
		30	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}
		42	0^{0}	0^{0}	0^{0}	0^{20}	0^{7}	0^{0}	0^{4}
		54	0^{0}	0^{7}	0^{0}	0^{0}	0^{0}	0^{0}	0^{1}
		89	0^{47}	0^{33}	7^{27}	13^{13}	0^{27}	7^{7}	4^{26}
		125	13^{67}	7^{67}	13^{73}	33^{60}	7^{60}	7^{47}	13^{62}
		149	13^{80}	20^{53}	13^{47}	13^{60}	20^{47}	20^{47}	17^{56}
Chloropicrin	-	18	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}
		30	0^{7}	7^{0}	0^{0}	0^{0}	0^{0}	7^{0}	2^{1}
		42	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}
		54	0^{27}	0^{7}	0^{7}	0^{0}	0^{0}	0^{0}	0^{7}
		89	0^{13}	0^{13}	0^{0}	0^{0}	0^{7}	0^{13}	0^{8}
		125	0^{60}	0^{33}	7^{33}	0^{40}	0^{20}	0^{33}	1^{37}
		149	0^{47}	0^{47}	7^{47}	0^{33}	7^{40}	0^{20}	2^{39}
Diffusible Control	-	18	0^{0}	14^{0}	0^{0}	0^{0}	0^{0}	n/a	3^{0}
		30	22^{56}	33^{11}	0^{22}	0^{0}	0^{22}		11^{22}
		42	33^{67}	33^{67}	33^{33}	22^{44}	0^{44}		24^{51}
		54	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}		0^{0}
		89	0^{67}	0^{56}	11^{22}	0^{56}	11^{56}		4^{51}
		125	17^{67}	33^{50}	0^{33}	0^{50}	0^{17}		10^{36}
		149	50^{50}	17^{33}	33^{50}	33^{50}	33^{50}		33^{47}
Impel rods	-	18	0^{7}	0^{8}	0^{18}	0^{8}	0^{7}	n/a	0^{10}
		30	7^{47}	0^{7}	0^{27}	7^{33}	0^{47}		3^{32}
		42	0^{67}	0^{27}	7^{60}	13^{60}	7^{60}		5^{55}
		54	0^{0}	0^{0}	7^{0}	0^{0}	0^{0}		1^{0}
		89	0^{60}	0^{27}	20^{67}	40^{40}	7^{53}		13^{49}
		125	0^{40}	0^{20}	33^{47}	27^{47}	13^{53}		15^{41}
		149	7^{47}	13^{47}	27^{47}	33^{33}	20^{33}		20^{41}
Pol Saver rods	-	18	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}	n/a	0^{0}
		30	0^{67}	0^{0}	0^{33}	0^{44}	0^{44}		0^{38}
		42	0^{78}	0^{56}	0^{78}	0^{78}	0^{78}		0^{73}
		54	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}		0^{0}
		89	0^{44}	0^{56}	0^{22}	0^{44}	11^{33}		2^{40}
		125	0^{22}	0^{22}	0^{56}	0^{67}	0^{56}		0^{44}
		149	0^{56}	0^{44}	0^{67}	0^{33}	0^{44}		0^{49}
FLUROD	-	18	0^{0}	0^{0}	0^{20}	0^{40}	0^{13}	n/a	0^{15}
		30	0^{13}	0^{0}	0^{47}	0^{60}	0^{60}		0^{36}
		42	0^{20}	0^{20}	0^{33}	0^{20}	0^{53}		0^{29}
		54	0^{0}	0^{0}	0^{0}	0^{7}	0^{0}		0^{1}
		89	0^{47}	0^{20}	0^{27}	0^{13}	7^{20}		1^{25}
		125	7^{60}	0^{60}	0^{53}	0^{53}	7^{40}		3^{53}
		149	n/a	n/a	n/a	n/a	n/a		n/a

[a] Values represent percentage of cores containing decay fungi. Superscript values represent percent of cores containing non-decay fungi.

1.3.2 Effect of Metam Sodium on Boron Rod Performance

One of the combination treatments considered for the internal remedial treatment of utility poles is the combination of boron rods with metam sodium (NaMDC). The combination of the two has potential to function as a dual action remedial treatment with fumigant properties and also the longer-lasting water-soluble treatment while reducing the number of treatment holes needed per treatment cycle. Additionally, metam sodium is thought to act as an accelerant and stimulate faster boron diffusion into poles. The UPRC initiated a field trial at the Peavy Arboretum site in 2019 to test the combination of these two chemicals as a remedial treatment. This study was sampled in 2020 and will be sampled annually hereafter.

Douglas-fir pole sections (283-340 mm in diameter by 3 m long) were pressure treated with pentachlorophenol in P9 Type-A oil before being set to a depth of 0.6 m at our Peavy Arboretum field test site; there were 5 replicates/treatment for a total of 20 poles. Three steeply sloping holes were drilled into each pole beginning at groundline and moving upward with each subsequent hole 150 mm, each offset 120 degrees from the previous hole.

Each of the treatment holes had one of the following treatments applied for a total of three treatment holes per pole: (1) fused borate rod alone, (2) fused borate rod plus 500 mL of water as a control liquid addition, (3) fused borate rod plus 500 mL of metam sodium. Two, 100 mm long x 12 mm wide Bor-8 rods were added to each hole where necessary. Data from an ongoing remedial treatment trial using metam sodium alone was used as a control for metam sodium without boron. A description of this study is included in section 1.3.1 of this report. All poles were left uncapped in this study.

These poles were sampled for both MITC and boron content by removing increment cores from three equidistant points around each pole at -150 mm below ground, groundline, 150 mm, 300 mm, 450 mm, 600 mm, and 1000 mm above groundline. The 600 and 1000 mm above ground zones were not sampled for boron. These cores were processed as described earlier to produce inner and outer 25 mm segments for ethyl acetate extraction. The resulting extracts were analyzed for MITC as described earlier. Parallel cores were removed and hot water extracted for boron and analyzed for boron using the Azomethine H method.

After one year of sampling, boron concentrations were highest below groundline, reaching the 0.6 kg/m^3 inhibitory threshold level 150 mm below groundline when inner and outer pole core sections were averaged (Table 1.3.5). Average boron generally declined as the distance above groundline increased. Boron levels tended to be higher in the inner core sections, congruent with the downward sloping treatment holes and outer core sections were below threshold for boron in all sampling locations. Outer core sections had boron levels below threshold levels at all sampling locations across all treatments. Boron levels among the different treatments were similar at equivalent sampling locations and no effect of metam sodium or water was obvious.

Year two sampling showed similar patterns, with the inner core sections showing higher boron concentrations and boron levels generally decreasing with increasing height above groundline (Table 1.3.5). Boron levels in most core sections at or below groundline were above the effective threshold. In the second year, many samples taken from 150 mm above groundline showed boron levels above threshold, indicating boron migration was progressing. Boron levels were generally higher in year 2 than year one, especially boron rods treated with a metam sodium solution. Boron levels in the pole interior reached well above the effective threshold up to the 450 mm above groundline sampling point. This is an early indication that the boron-metam sodium co-treatment may have a positive impact on boron diffusion, however we will continue to monitor this study to determine if the increased boron diffusion is a durable phenomenon.

MITC levels measured from 150 mm below groundline to 1000 mm above groundline in poles treated with metam sodium alone (section 1.3.1) or metam sodium plus a boron rod. In year 1 and two, most cases for both treatments, MITC levels were higher in the inner pole sections (Table 1.3.6). Additionally, poles that were treated with metam sodium alone had generally higher MITC levels at all sampling locations. After 2 years, the metam sodium alone treatment showed reduced MITC levels compared to the previous sampling point, but levels were generally above the effective threshold at nearly all sampling locations. MITC levels in metam sodium + boron poles were much lower than the previous year as was seen in section 1.1.2. All sampling locations for the metam sodium plus boron treatment had MITC levels below the effective threshold. It is unclear why MITC levels were so low at this point and it is unusual compared to other studies using metam sodium.

No fungi were isolated from metam sodium-treated poles in year 1, but there were sporadic isolations of decay fungi from poles treated with boron rods alone with or without water addition (Table 1.3.7). Most of the isolations occurred in cores below groundline. In year two, boron only poles contained decay and non-decay fungi in both aboveground and belowground samples (Table 1.3.8). Some of the poles in this group contained more widespread instances of decay fungi, while at least one pole (1802, did not contain any. Poles treated with boron plus metam sodium contained similar amounts of decay fungi overall, although they tended to be more prevalent in the at-or-below groundline samples (Table 1.3.9). There were three instances of decay fungi originating from above groundline samples and these were limited to two of the replicate poles. These isolations do not necessarily indicate the immanent loss in structural integrity in poles treated with boron rods. Boron is fungistatic and can prevent the growth of decay fungi found in poles with boron rods, provided boron levels remain above the effective threshold. These early results are somewhat promising for the efficacy of the dual treatment, however further sampling points will tell whether the treatment remains so for an extended period.

Table 1.3.5: Boron concentration from 2019 and 2020 in poles combining both assay zones, and with the inner and outer assay zones separated. Boron levels above the protective threshold of 0.6 kg/m3 BAE are indicated with bold green boxes.

Treatment	Pole Zone	Sampling Year	150 mm Belowground		Groundline		150 mm Aboveground		300 mm Aboveground		450 mm Aboveground	
			[Boron] kg/m^3 BAE	Std. Dev.	[Boron] kg/m^3 BAE	Std. Dev.	[Boron] kg/m^3 BAE	Std. Dev.	[Boron] kg/m^3 BAE	Std. Dev.	[Boron] kg/m^3 BAE	Std. Dev.
B Rods	Whole Pole	2019	**0.623**	(0.61)	0.467	(0.57)	0.492	(0.61)	0.175	(0.17)	0.143	(0.17)
		2020	**2.574**	(4.85)	**1.537**	(2.26)	**1.907**	(2.20)	0.294	(0.37)	0.021	(0.03)
	Interior	2019	**0.946**	(0.67)	0.407	(0.52)	**0.693**	(0.75)	0.213	(0.18)	0.165	(0.22)
		2020	**5.004**	(5.93)	**2.846**	(2.58)	**2.671**	(2.02)	0.425	(0.44)	0.013	(0.01)
	Exterior	2019	0.300	(0.37)	0.527	(0.67)	0.290	(0.43)	0.137	(0.17)	0.121	(0.13)
		2020	0.145	(0.25)	0.229	(0.35)	**1.143**	(2.11)	0.162	(0.24)	0.030	(0.04)
B Rods + H_2O	Whole Pole	2019	0.583	(0.56)	**0.672**	(0.72)	0.414	(0.48)	0.120	(0.14)	0.053	(0.03)
		2020	**2.161**	(2.43)	**0.829**	(1.35)	**1.020**	(1.63)	0.287	(0.56)	0.054	(0.04)
	Interior	2019	**0.807**	(0.54)	**1.115**	(0.74)	0.549	(0.46)	0.190	(0.18)	0.068	(0.04)
		2020	**3.829**	(2.36)	**1.588**	(1.59)	**1.967**	(1.87)	0.498	(0.73)	0.068	(0.03)
	Exterior	2019	0.359	(0.53)	0.229	(0.36)	0.279	(0.51)	0.051	(0.02)	0.037	(0.02)
		2020	0.493	(0.81)	0.071	(0.06)	0.072	(0.09)	0.077	(0.08)	0.040	(0.04)
B Rods + NaMDC	Whole Pole	2019	**0.608**	(0.83)	0.455	(0.54)	0.370	(0.53)	0.125	(0.11)	0.202	(0.41)
		2020	**1.243**	(2.27)	**3.231**	(2.90)	**2.452**	(2.72)	0.580	(1.29)	0.525	(1.36)
	Interior	2019	**0.704**	(1.09)	**0.667**	(0.70)	0.561	(0.71)	0.175	(0.12)	0.336	(0.57)
		2020	**2.349**	(2.79)	**4.778**	(2.42)	**4.431**	(2.56)	**1.010**	(1.71)	**0.962**	(1.81)
	Exterior	2019	0.512	(0.58)	0.244	(0.24)	0.179	(0.19)	0.075	(0.08)	0.069	(0.04)
		2020	0.136	(0.13)	**1.683**	(2.48)	0.473	(0.62)	0.149	(0.16)	0.088	(0.12)

Table 1.3.6. MITC levels in poles treated with metam sodium alone or with metam sodium + a fused boron rod.

Treatment	Year	150 mm Below Groundline				Groundline				300 mm Above Groundline			
		inner		outer		inner		outer		inner		outer	
		MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.
NaMDC + Fused Boron Rod	2019	77.80	(38)	45.05	(44)	61.74	(27)	35.79	(21)	36.76	(18)	45.31	(36)
	2020	4.94	(3)	4.67	(6)	6.87	(6)	5.66	(5)	5.99	(3)	5.07	(3)
NaMDC Alone	2019	94.24	(55)	45.61	(46)	92.99	(38)	38.47	(22)	88.02	(57)	62.76	(69)
	2020	39.59	(26)	26.42	(22)	40.57	(27)	25.19	(20)	34.30	(18)	25.86	(14)

Treatment	Year	450 mm Above Groundline				600 mm Above Groundline				1000 mm Above Groundline			
		inner		outer		inner		outer		inner		outer	
		MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.
NaMDC + Fused Boron Rod	2019	42.90	(25)	29.57	(28)	42.35	(34)	18.59	(15)	15.74	(20)	7.46	(8)
	2020	4.65	(2)	3.20	(4)	6.32	(4)	3.47	(3)	4.22	(3)	1.24	(2)
NaMDC Alone	2019	81.31	(53)	55.76	(55)	72.12	(42)	47.76	(43)	46.47	(26)	21.08	(22)
	2020	32.27	(17)	22.14	(12)	29.95	(14)	21.80	(13)	29.56	(17)	15.90	(13)

Table 1.3.7: Results of culturing for decay and non-decay fungi after 1 year of exposure. Metam sodium poles were completely devoid of fungi.

Sample (pole) Number	Treatment Name	Height (mm)	Pole Side	Non-Decay	Decay	Decay Morphogroup
1801	B Rods + H2O	0	C	1	0	
1802	B Rods	-150	C	1	0	
1806	B Rods + H2O	0	C	1	0	
1809	B Rods + H2O	-150	C	0	1	3
1809	B Rods + H2O	150	C	1	1	3
1809	B Rods + H2O	0	B	1	0	
1811	B Rods + H2O	450	C	1	0	
1811	B Rods + H2O	0	B	1	0	
1812	B Rods	-150	A	1	0	
1812	B Rods	-150	B	1	0	
1813	B Rods + H2O	150	A	0	1	3
1813	B Rods + H2O	0	B	1	0	
1813	B Rods + H2O	0	C	1	0	
1814	B Rods	-150	C	1	1	2
1814	B Rods	0	C	1	0	
1820	B Rods	-150	B	0	1	3

Table 1.3.8: Results of culturing from poles treated with boron rods alone after 2 years of exposure. Decay and non-decay fungi were totaled.

Sample (pole) Number	Treatment Name	Height (mm)	Pole Side	Non-Decay	Decay	Decay Morphogroup
1802	B Rods	150	C	1	0	
1802	B Rods	300	B	1	0	
1802	B Rods	450	C	1	0	
1803	B Rods	-150	C	1	0	
1803	B Rods	0	A	1	0	
1803	B Rods	0	C	1	0	
1803	B Rods	150	B	1	0	
1803	B Rods	300	A	0	1	3
1803	B Rods	300	B	1	0	
1803	B Rods	300	C	1	0	
1803	B Rods	450	A	1	0	
1803	B Rods	450	B	1	1	3
1803	B Rods	450	C	1	0	
1812	B Rods	-150	A	1	1	3
1812	B Rods	-150	B	1	0	
1812	B Rods	-150	C	1	0	
1812	B Rods	0	A	1	0	
1812	B Rods	0	B	1	1	3
1812	B Rods	0	C	1	0	
1812	B Rods	150	A	1	0	
1812	B Rods	450	C	1	1	3
1814	B Rods	-150	A	0	1	2
1814	B Rods	-150	B	1	0	
1814	B Rods	0	B	0	1	1
1814	B Rods	0	C	0	1	1
1814	B Rods	150	A	0	1	2
1814	B Rods	300	B	1	0	
1814	B Rods	300	C	0	1	1
1814	B Rods	450	B	1	0	
1814	B Rods	450	C	1	0	
1820	B Rods	-150	A	1	0	
1820	B Rods	-150	B	1	0	
1820	B Rods	-150	C	1	0	
1820	B Rods	0	A	1	0	
1820	B Rods	0	C	1	1	3
1820	B Rods	150	A	1	0	
1820	B Rods	150	B	1	0	
1820	B Rods	150	C	1	0	
1820	B Rods	300	A	1	0	
1820	B Rods	300	B	1	1	3
1820	B Rods	300	C	1	0	

Table 1.3.9: Results of culturing boron + water or boron + metam sodium poles after 2 years of exposure. Decay and non-decay fungi were counted.

Sample (pole) Number	Treatment Name	Height (mm)	Pole Side	Non-Decay	Decay	Decay Morphogroup
1801	B Rods + H2O	300	C	1	0	
1806	B Rods + H2O	-150	B	0	1	5
1806	B Rods + H2O	-150	C	1	0	
1806	B Rods + H2O	0	A	1	1	1
1806	B Rods + H2O	0	C	1	1	1
1806	B Rods + H2O	150	C	1	0	
1806	B Rods + H2O	300	A	1	0	
1806	B Rods + H2O	300	B	1	0	
1806	B Rods + H2O	450	A	1	0	
1806	B Rods + H2O	450	B	1	0	
1809	B Rods + H2O	-150	B	0	1	3
1809	B Rods + H2O	-150	C	1	0	
1809	B Rods + H2O	0	B	1	0	
1809	B Rods + H2O	0	C	1	1	3
1809	B Rods + H2O	150	B	1	0	
1809	B Rods + H2O	150	C	1	0	
1809	B Rods + H2O	450	B	1	0	
1809	B Rods + H2O	450	C	1	0	
1811	B Rods + H2O	150	B	1	0	
1811	B Rods + H2O	300	A	1	0	
1811	B Rods + H2O	300	B	1	0	
1813	B Rods + H2O	-150	A	1	0	
1813	B Rods + H2O	-150	B	1	0	
1813	B Rods + H2O	-150	C	1	0	
1813	B Rods + H2O	0	A	1	0	
1813	B Rods + H2O	0	C	0	1	3
1813	B Rods + H2O	300	A	1	0	
1813	B Rods + H2O	300	B	1	1	3
1813	B Rods + H2O	450	A	1	0	
1813	B Rods + H2O	450	B	1	0	
1813	B Rods + H2O	450	C	1	1	3
1808	B Rods + Metam Sodium	-150	B	0	1	5
1808	B Rods + Metam Sodium	0	B	1	0	
1808	B Rods + Metam Sodium	150	B	1	0	
1808	B Rods + Metam Sodium	300	A	1	0	
1808	B Rods + Metam Sodium	300	C	1	0	
1808	B Rods + Metam Sodium	450	A	0	1	4
1808	B Rods + Metam Sodium	450	C	1	0	
1808	B Rods + Metam Sodium	600	A	1	0	
1815	B Rods + Metam Sodium	450	A	1	0	
1819	B Rods + Metam Sodium	300	A	1	0	
1819	B Rods + Metam Sodium	450	C	1	0	

1.4.0 Identification of accelerants to improve the decomposition of dazomet in dry climates

The UPRC has played a central role in developing dazomet as an internal remedial treatment for decades. Originally used as a soil fumigant in agriculture, dazomet in its commercial formulations has proven to be an effective fumigant for the control of internal decay in utility poles with some distinct advantages including greater ease and safety of application when compared to liquid fumigants. Dazomet decomposes into methylisothiocyanate (MITC), hydrogen sulfide, methyl amine, formaldehyde and other minor components (Forsyth 1994). MITC serves as the active fumigant and it volatilizes within wood and effectively inhibits fungal growth. On its own, dazomet decomposes slowly and MITC production is insufficient to become effectively distributed throughout the wood. However, decomposition to MITC can be increased under certain conditions and with the addition of accelerants. Copper-based accelerants have proven very effective in increasing MITC production from dazomet and as a result it is now common practice to apply dazomet powder or rods to treatment holes with a solution of copper naphthenate.

The presence of water is essential to the decomposition of dazomet to MITC and a high moisture content is perhaps the greatest factor leading that enables the production of MITC (Forsyth and Morrell 1995). Moisture contents of around 30%, which are regularly found at or below groundline in utility poles, is enough to allow sufficient decomposition of dazomet. There are also seasonal effects found in UPRC data where wetter periods lead to greater MITC production. The close relationship with MITC production and moisture content is a major impediment to the effective use of dazomet in dry climates. Ongoing assessment of internal remedial treatments in in-service poles in Utah (150-200 mm annual rainfall) has shown that MITC production from dazomet-based remedial treatments is low relative to observations in our Corvallis, Oregon field site (~1041 mm annual rainfall). While this study is ongoing, we can intuit from the existing data that MITC levels will remain relatively low in dazomet-treated poles in dry climates.

In the absence of moisture, MITC must be produced by a dazomet accelerant, which is typically a copper naphthenate solution (2% metal) added into treatment holes along with dazomet. Early development of dazomet accelerants identified copper sulfate as an excellent dazoment accelerant (Forsyth and Morrell 1992; Forsyth et al. 1998). These lab-based studies led to field trials where copper sulfate and copper naphthenate accelerants were shown to improve MITC production from dazomet (Love et al. 2010). However, these studies did not vary moisture content in combination with different accelerants and further study of dazomet accelerants in low moisture conditions can help improve its performance in dry climates. We’ve initiated an effort to identify more effective accelerants for dazomet in low moisture conditions. The initial lab-based screening study is described here.

1.4.1 Lab-based screening of metal compounds for the ability to decompose dazomet to MITC in dry conditions

Laboratory-based experiments were designed and executed to determine the relative performance of several metal compounds as dazomet accelerants under three different moisture conditions and three different molar ratios between dazomet and accelerant. The reaction chambers consisted of 20 ml airtight vials with a septum for leak-free sampling. About 1 g of oven dried Douglas-fir wood sawdust was added to each vial. The sawdust was moistened to one of three moisture contents, 12, 30 or 60% by adding water to the vials. Dazomet powder was added to the vials alone or in combination with one of seven metal compounds at one of three molar ratios with dazomet to try to identify at which range diminishing returns are reached. The treatments tested in this study are summarized in table 1.4.1.

Table 1.4.1: Reaction components, ratios of metal added and moisture content of Douglas-fir wood sawdust for dazomet accelerant assays.

Chemical	DF Sawdust (g)	Dazomet mass (mg)	Dazomet: Metal molar ratio	Moisture Content
None (control)	~1	N/A	N/A	N/A
Dazomet alone	~1	162.27	N/A	12%, 30%, or 60%
Copper Sulfate Anhydrous	~1	162.27	1:1, 1:10, or 1:100	12%, 30%, or 60%
Copper Sulfate Pentahydrate	~1	162.27	1:1, 1:10, or 1:100	12%, 30%, or 60%
Ferrous Sulfate Heptahydrate	~1	162.27	1:1, 1:10, or 1:100	12%, 30%, or 60%
Colbalt Sulfate Heptahydrate	~1	162.27	1:1, 1:10, or 1:100	12%, 30%, or 60%
Zinc Sulfate Heptahydrate	~1	162.27	1:1, 1:10, or 1:100	12%, 30%, or 60%
Nickel Sulfate Hexahydrate	~1	162.27	1:1, 1:10, or 1:100	12%, 30%, or 60%
Magnesium Sulfate Anhydrous	~1	162.27	1:1, 1:10, or 1:100	12%, 30%, or 60%
Water (Heptahydrate control)	~1	162.27	1:1, 1:10, or 1:100	12%, 30%, or 60%

The headspaces of the reaction vials were sampled for volatilized methylisothiocyanate (MITC) using a 3 ml syringe at three time points, 1 week, 2 weeks and one month. The headspace sample was directly injected into a GC-MS and MITC was quantified and expressed as mg MITC per ml of air.

Results showed generally lower MITC levels in all dry (12%), and copper sulfate was the best accelerant out of those tested at low moisture levels. Higher moisture levels, 30 and 60%, as expected, showed much higher MITC levels generally (Table 1.4.2-4). The addition of a water control, particularly at the higher wood moisture contents produced similar amounts of MITC as the copper compound accelerants (Figure 1.4.1-9). However, at lower moisture contents, copper-containing compounds tended to produce higher MITC concentrations than the water controls, especially at lower metal to dazomet ratios. At the higher moisture contents, copper sulfate still performed better than any of the other metal compounds, but the gap between dazomet alone and with metal accelerants narrowed at 60% moisture content due to the essential role played by water in producing MITC. Ferrous sulfate heptahydrate appeared to perform similarly to copper sulfate compounds at the 60% moisture content, indicating it was capable of reacting with dazomet, but was more difficult to mobilize in solution to come into contact with dazomet. Most other metal compounds performed considerably poorer than copper sulfate.

The ratio of metal to dazomet was also an important factor in determining MITC production, particularly in the low moisture reactions. In most cases, the lowest MITC levels were seen in the 0.01 metal to dazomet ratio. However, in some sampling points MITC levels were lower when the ratio was 1 in reactions at the 1-week sampling point, but this changed as the incubation period went on. In low moisture conditions, raising the metal ratio from 0.01 to 0.1 generally increased MITC levels, sometimes by an order of magnitude. A further increase to a ratio of 1 in dry conditions increased MITC levels in most cases, but the increase was not as dramatic from 0.01 to 0.1, indicating that saturation may have been reached. This indicates that maintaining sufficient accelerant levels available for dazomet is important in dry conditions, but adding excess may not benefit MITC production and could be wasteful.

MITC production was generally steady throughout the 1-month incubation period for most treatments and samples taken at 1 week, 2 weeks, or 1 month had similar MITC levels (Table 1.4.2-4). This indicated that for most treatments there did not appear to be a benefit of the longer incubation period between the 2 week and 1-month sampling points compared to the other incubation periods. This may indicate the headspace reaching equilibrium for some treatments, or a consumption of the accelerant's oxidative capacity which causes slowing of dazomet oxidation in the later incubation periods.

Copper sulfate pentahydrate did not perform as well as anhydrous copper sulfate in lower moisture conditions at metal:dazomet ratios below 1. It is possible that this could be an issue of access to metal ions, where the hydration shell around copper ions did not allow contact between copper ions and dazomet in low moisture conditions where they crystals did not find enough free water to dissolve. This may suggest that ion contact could partially modulate accelerant effectiveness and systems that seek to facilitate as much contact as possible between copper and dazomet would increase MITC production from dazomet. In subsequent studies we will seek to utilize a scaled-up testing system which allows us to study ways to improve contact between dazomet and the accelerant.

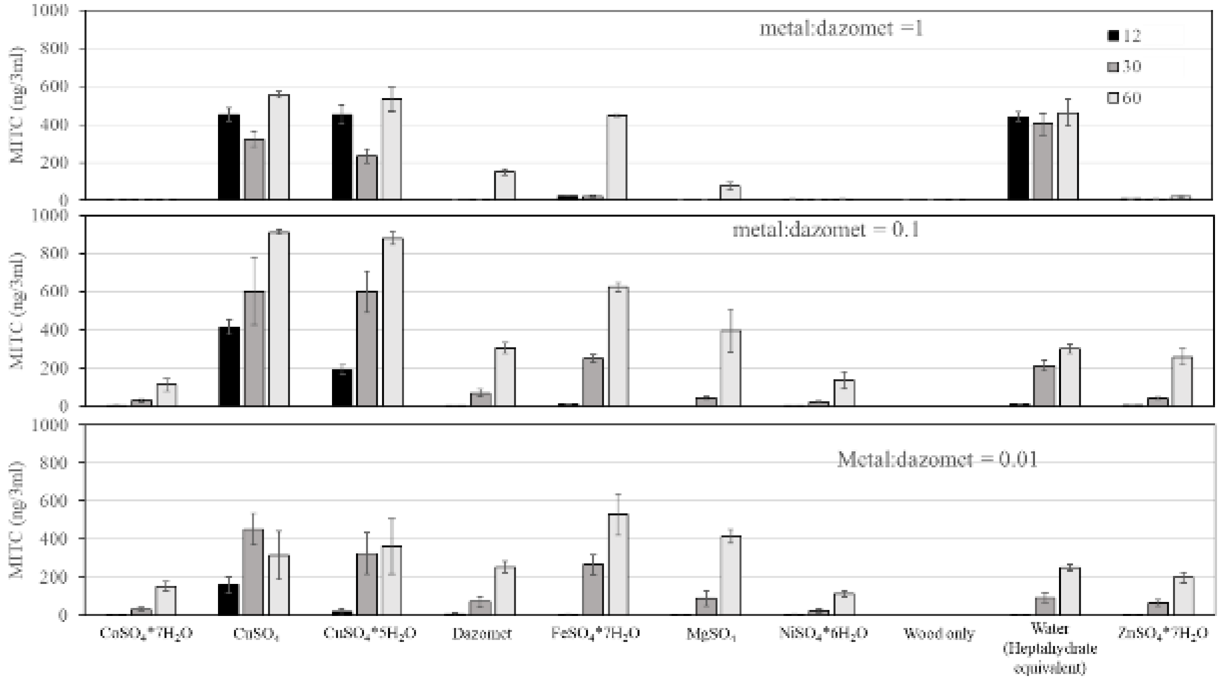


Figure 1.4.1: MITC levels in the headspace of reaction vials (ng/3ml) taken after 1 week of incubation for different metal-dazomet combinations at three moisture content percentages (12, 30 and 60%) and three metal ratios.

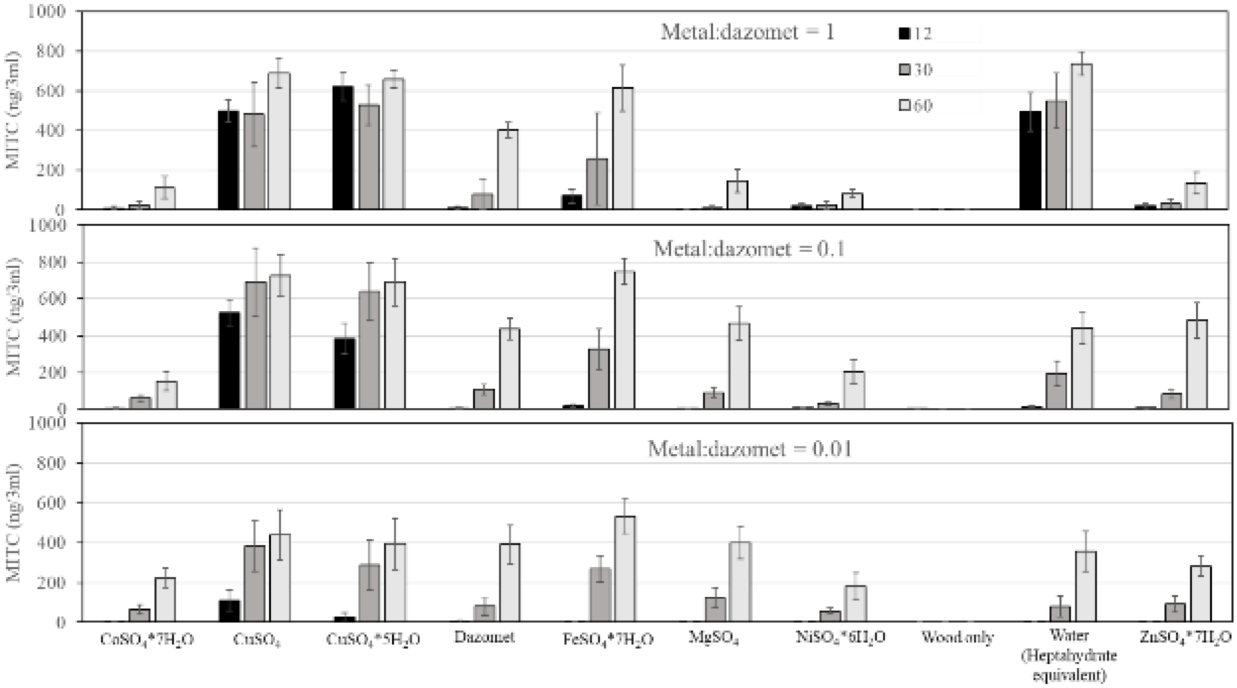


Figure 1.4.2: MITC levels in the headspace of reaction vials (ng/3ml) taken after 2 weeks of incubation for different metal-dazomet combinations at three moisture content percentages (12, 30 and 60%) and three metal ratios.

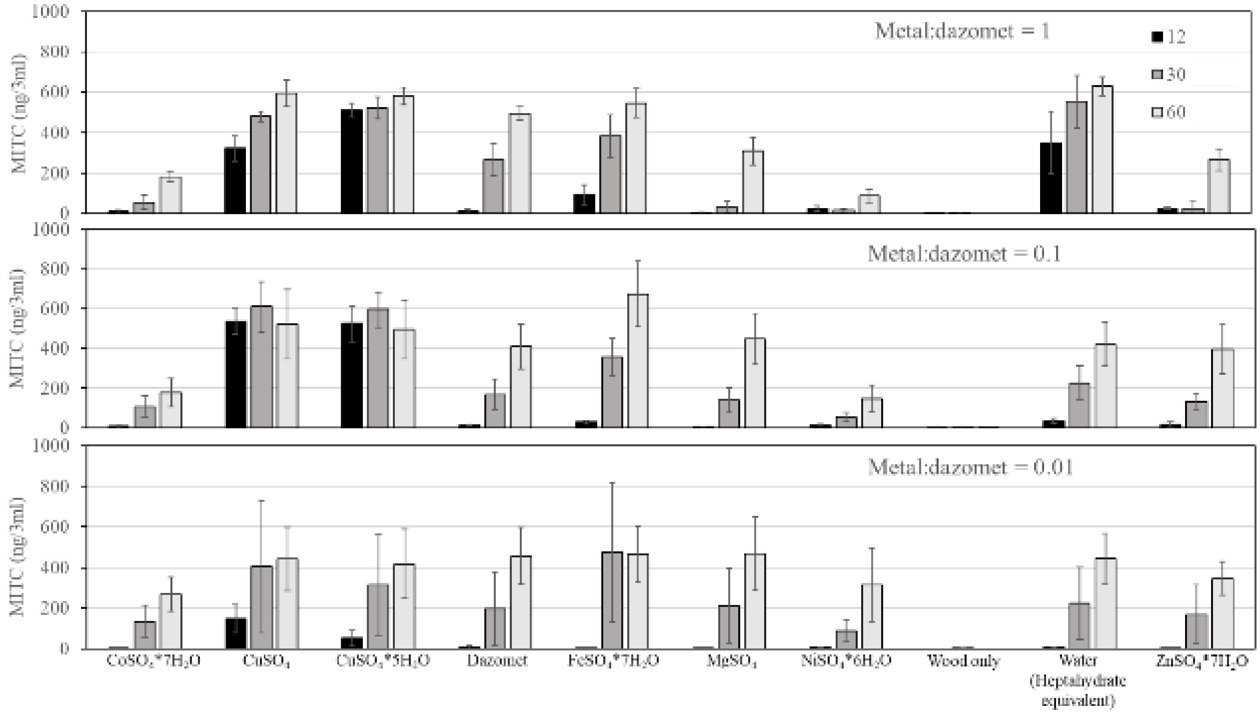


Figure 1.4.3: MITC levels in the headspace of reaction vials (ng/3ml) taken after 1 month of incubation for different metal-dazomet combinations at three moisture content percentages (12, 30 and 60%) and three metal ratios.

Table 1.4.2: Average mass of MITC (ng) per 3 ml sample of headspace after one week of incubation at room temperature.

	MITC ng/3 ml of headspace								
	Metal:Dazomet = 1			Metal:Dazomet = 0.1			Metal:Dazomet = 0.01		
Metal Compound or control	12%	30%	60%	12%	30%	60%	12%	30%	60%
Cobalt Sulfate Heptahydrate	2.4	2.0	4.4	2.9	29.0	112.6	2.0	30.7	151.2
Copper Sulfate Anhydrous	450.2	320.2	552.8	413.0	602.3	912.2	160.3	450.1	313.9
Copper Sulfate Pentahydrate	449.7	233.6	530.9	192.5	601.3	881.8	20.8	323.4	360.5
Dazomet control	0.0	3.5	148.6	1.7	69.7	304.9	5.1	69.6	251.4
Ferrous Sulfate Heptahydrate	22.8	20.5	445.2	10.0	249.5	624.0	3.1	264.8	528.5
Magnesium Sulfate Anhydrous	0.0	0.0	74.1	0.0	45.4	394.5	0.9	87.8	413.3
Nickel Sulfate Hexahydrate	6.2	4.7	5.3	2.6	21.5	137.9	2.4	22.9	111.3
None	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0
Water (Heptahydrate control)	440.2	401.3	461.3	10.2	212.9	302.6	2.6	92.1	247.8
Zinc Sulfate Heptahydrate	6.9	4.7	20.0	4.6	41.6	258.1	2.5	64.3	198.2

Table 1.4.3: Average mass of MITC (ng) per 3 ml sample of headspace after two weeks of incubation at room temperature.

	MITC ng/3 ml of headspace								
	Metal:Dazomet = 1			Metal:Dazomet = 0.1			Metal:Dazomet = 0.01		
Metal Compound or control	12%	30%	60%	12%	30%	60%	12%	30%	60%
Cobalt Sulfate Heptahydrate	10.0	23.5	113.4	5.6	62.4	152.7	1.3	63.9	223.4
Copper Sulfate Anhydrous	497.1	482.0	689.6	523.1	690.6	727.5	109.8	381.7	441.1
Copper Sulfate Pentahydrate	620.2	528.4	657.5	383.6	640.2	691.7	27.2	289.3	394.6

Dazomet control	10.0	78.2	402.8	5.5	109.1	438.8	3.4	81.9	391.1
Ferrous Sulfate Heptahydrate	71.4	257.6	613.6	19.4	327.1	749.9	1.8	269.1	534.1
Magnesium Sulfate Anhydrous	1.8	10.2	145.3	1.9	90.2	466.1	0.8	126.7	398.7
Nickel Sulfate Hexahydrate	20.7	23.7	82.0	6.8	32.8	204.1	1.5	56.4	182.3
None	0.0	1.2	0.0	0.4	0.0	0.0	0.0	0.0	0.0
Water (Heptahydrate control)	493.3	549.2	736.4	16.7	195.3	440.7	2.1	79.9	357.3
Zinc Sulfate Heptahydrate	20.6	30.3	136.0	7.8	82.6	483.5	1.6	91.8	283.1

Table 1.4.4: Average mass of MITC (ng) per 3 ml sample of headspace after one month of incubation at room temperature.

	MITC ng/3 ml of headspace								
	Metal:Dazomet = 1			Metal:Dazomet = 0.1			Metal:Dazomet = 0.01		
Row Labels	12%	30%	60%	12%	30%	60%	12%	30%	60%
Cobalt Sulfate Heptahydrate	11.1	53.9	182.7	9.8	107.5	177.6	3.2	134.3	267.7
Copper Sulfate Anhydrous	321.2	480.9	594.5	536.1	608.8	522.3	146.9	404.2	440.9
Copper Sulfate Pentahydrate	510.4	520.0	581.3	524.3	595.1	494.6	50.4	312.0	416.1
Dazomet control	11.9	266.5	493.2	13.1	168.4	410.3	5.1	195.9	456.6
Ferrous Sulfate Heptahydrate	93.7	383.0	545.5	28.5	356.9	673.5	3.3	475.1	464.1
Magnesium Sulfate Anhydrous	3.7	30.9	308.0	4.3	140.6	448.2	2.4	210.4	467.3
Nickel Sulfate Hexahydrate	23.5	15.4	85.5	13.2	52.0	148.9	3.7	88.8	313.5
None	0.2	1.0	0.0	2.2	1.8	0.0	0.0	0.2	0.0
Water (Heptahydrate control)	350.1	555.3	626.9	33.3	225.4	420.6	4.4	223.7	443.7
Zinc Sulfate Heptahydrate	24.2	23.5	266.1	16.5	133.3	396.0	3.7	168.6	344.9

1.5.0 Performance of Internal Remedial Treatments in In-Service Utility Poles

The UPRC has performed extensive testing of internal remedial treatments in more controlled conditions either in the laboratory or at the Peavy Arboretum field site. These studies have provided valuable information on the performance of internal remedial treatments and has aided in the development of several commercial products for the improvement of utility poles. However, the ultimate test of performance is in in-service poles and remedial treatments must be finally be assessed for their efficacy in utility networks in a variety of environments to show their merit. The UPRC has partnered with utilities over the decades to monitor the performance of internal remedial treatments in in-service utility poles. This section summarizes our efforts in this area of research this year.

1.5.1 Performance of Internal Remedial Treatments in Arid Climates: Rocky Mountain Power Test

Date Established:	August 2010
Location:	Utah
Pole Species; Treatment; Size	Pine, Cedar, Douglas-fir; Penta, Creo, Cellon; n/a
Circumference @ GL (avg., max., min.)	87, 107, 71 cm

This test was not sampled in 2020 for its 102-month sampling point. The study will be sampled again in xxx depending on pandemic restrictions.

1.6.0 References for Objective I

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OBJECTIVE II:

IDENTIFY CHEMICALS FOR PROTECTING EXPOSED WOOD SURFACES IN POLES

Effective pressure treatment of utility poles with preservatives extends their effective service life decades beyond what it would be without the preservative treatment. Pressure treatment impregnates the sapwood with chemicals that prevent the destructive activity of decay fungi, many wood destroying insects, and marine borers, creating a barrier from attack originating outside of the pole surface. The preservative treated shell only functions in this capacity if it remains intact, otherwise disruption of this barrier can expose susceptible and untreated wood. Damage that occurs after pole treatment such as checking, bolt holes or injury from equipment can allow entry of degradative organisms, obviating the protective capacity of preservative treatment (Graham and Helsing, 1979). Damaged poles can be treated with surface-applied preservative solutions to help restore the protective barrier and this is recommended for any holes made during inspection or other modifications (Morrell, 2012). However remedial surface treatments can never fully replace the pressure treatment imparted on the pole initially. That said, there is a perennial interest from utilities in developing effective means to protect exposed wood surfaces in poles. The UPRC has undertaken numerous research projects in this area starting before its inception (Graham et al. 1981). This report section describes current efforts to identify chemicals for protecting exposed wood surfaces.

2.1.0 Effect of Boron Pretreatment on the Performance of Preservative Treated Douglas-fir Poles

External field treatments with preservative solutions and pastes is commonly used to remediate damage done to the preservative treated shell in in-service poles. However, practical application can only be done in limited areas of the pole, typically after field-drilling bolt holes and other forms of damage can expose untreated heartwood. Deep checking and splitting can expose large areas of untreated wood in in-service utility poles and the application of external pastes over a large area is not practical or effective in these cases. In addition, external preservative application may be too late to be effective as the fungi may have had time to colonized the exposed wood before application.

Imparting decay resistance to the heartwood in the initial manufacture of the pole would help mitigate decay risk in these scenarios where heartwood is exposed. However, heartwood is notoriously difficult to treat, especially in refractory species such as Douglas-fir. Methods such as through boring and deep incising are commonly used methods to distribute preservative solution deep within the heartwood. These methods are typically used to facilitate greater preservative penetration in the zone bracketing the groundline only and do not protect exposed heartwood in aboveground portions of the pole exposed via drilling or other damage.

Water soluble preservatives have properties that make them an attractive potential treatment for preserving heartwood. Water soluble preservatives such as borates or fluorides tend to migrate in wood once they are pressure treated. This makes them less well-suited for exposure to the elements as they tend to leach out of treated wood. However, mobility also means they have the potential to migrate throughout the wood ultrastructure and may be able to migrate into the heartwood, impacting decay resistance deep within a pole. An initial pressure treatment with borates followed by an overtreatment with an oil-borne preservative typically used to treat poles may enable the migration of preservative to the heartwood while preventing borate leaching from the pole.

Pole pretreatment with water soluble preservatives has been studied previously by the UPRC. Dip-treatment of poles with either ammonium bifluoride (Morrell et al. 1989) or disodium octaborate tetrahydrate (Morrell et al. 1991) was assessed as a measure to prevent the growth of decay fungi during air seasoning. Treatments were successful in preventing colonization initially after exposure. However, effectiveness waned after several years which may have been due to preservative migration out of the poles. These studies highlighted the need for a method to help retain water soluble preservatives in the treated poles.

Boron has been successfully used as a pretreatment for railroad ties prior to treatment with creosote or copper naphthenate (Lloyd et al. 2020). Green ties are either hot dip-treated or pressure treated with borates prior to creosote or copper naphthenate treatment. The rapid application of borates helps to prevent the ingress of decay fungi during seasoning which can result in early strength loss and premature failure of the ties.

Overtreatment with an oil-borne preservative after treatment with a water-soluble pretreatment is one potential avenue to facilitate better retention and allow preservative migration into the heartwood. The studies described in this section are designed to track the migration of boron in borate-pretreated Douglas-fir poles or pole sections which are over-treated with an oil-borne or waterborne preservative. These studies measure boron concentration at different distances from the pole surface and in combination with different manufacturing process variations (section 2.1.1) or different preservative overtreatments (section 2.1.2). A similar sampling regime for boron-pretreated poles in service (section 2.1.3) was not sampled this year, but is ongoing.

2.1.1 Boron Pre-treatment Followed by Copper Naphthenate Pressure Treatment of Douglas-fir Poles

Freshly peeled Douglas-fir pole sections (2.4 m long by 250-300 mm in diameter) were pressure treated with a 7% solution (BAE) of DOT, then six increment cores were removed from two sides near the middle of each pole to determine initial borate retention. Cores were divided into 25 mm segments from surface to pith and combined by depth for each pole. Combined cores were ground to pass a 20-mesh screen before extraction in hot water and boron analysis according to AWPA Standard A2, Method 16. There is no AWPA borate retention specified for utility pole pre-treatment, however the standard for pre-treatment of ties specifies 2.7 kg/m^3 of boron (as B_2O_3, equal to 4.9 kg/m^3 BAE). Previous studies have shown that the boron threshold for protecting Douglas-fir from internal decay is much lower than this, and can be as little at 0.4-0.44 kg/m^3 (Freitag and Morrell 2005). Since these values were determined a value or 0.6 kg/m^3 has been used in subsequent research as a threshold level for borates to prevent internal decay and will be used here.

Table 2.1.1. Boron levels in Douglas-fir poles immediately after pressure treatment with disodium octaborate tetrahydrate and prior to drying/treatment. ***Bold*** *values are above threshold.*

Pole #	Boron Retention (kg/m^3 BAE)					
	0-25 mm	25-50 mm	50-75 mm	75-100 mm	100-125 mm	125-150 mm
758	**15.17**	**8.85**	0.36	0.30	**5.85**	**7.95**
759	**10.30**	0.21	0.16	0.08	0.73	0.11
760	**7.22**	0.09	0.12	0.06	0.11	0.02
761	**10.29**	0.10	0.03	0.03	0.08	0.03
762	**7.47**	0.11	0.11	0.07	0.09	0.05
763	**10.24**	0.23	0.06	0.08	0.05	0.08
764	**4.56**	0.12	0.05	0.04	0.08	0.06
765	**7.23**	0.11	0.08	0.08	0.08	0.31
766	**10.57**	0.14	0.07	0.05	0.02	0.03
767	**11.66**	0.19	0.08	0.00	0.16	0.11
770	**8.42**	0.15	0.02	0.02	0.00	0.05
786	**5.90**	0.05	0.00	0.03	0.00	0.05
787	**7.16**	0.16	0.00	0.07	0.00	0.35
788	**14.21**	0.24	0.16	0.08	0.07	0.00
789	**9.71**	0.11	0.04	0.10	0.00	0.03
Average	**9.34**	0.72	0.09	0.07	0.49	0.61
Standard deviation	2.93	2.25	0.09	0.07	1.49	2.03

Five poles not subjected to further treatment were set aside to air-dry. Five of the remaining ten poles were kiln dried to 25% MC, 50 mm from the surface, and were pressure treated with copper naphthenate to the AWPA U1 UC4B target retention of 0.095 pcf (as Cu). The remaining five poles were pressure treated with copper naphthenate to the same retention, but the poles were seasoned in the cylinder using the Boulton process. Following treatment, all poles were returned to OSU, sampled and analyzed for boron content as described above. Eight additional cores were taken from each copper naphthenate-treated pole so the outer 6 to 25 mm could be assayed for copper by x-ray fluorescence spectroscopy.

Boron retentions (as kg/m^3 BAE) were highest in the outer 25 mm of each pole, ranging from 4.56 to 15.17 kg/m^3 immediately after treatment but before drying (Table 2.1.1). With the exception of one pole, retentions were extremely low in the next 25 mm inward and remained low toward the pole center. These results are typical of any short-term pressure treatment of Douglas-fir poles. If all boron in pole sections immediately after treatment was considered, poles would contain an average of 2.36 kg/m^3 BAE, or about half the level required for boron pretreatment of railroad ties, albeit not evenly distributed throughout the pole. These values are skewed by one pole that had high boron levels in 4/6 assay zones. The remaining poles had much lower boron levels and, in all poles, boron was largely confined to the outer 25 mm.

After kiln drying, boron levels remained elevated in the outer 25 mm of pole sections (Table 2.1.2), but were lower than directly after treatment, sometimes substantially (Table 2.1.3). If total boron levels were averaged across each pole section, it would equate to 1.02 kg/m^3 BAE, far below the specified level, but still above the effective inhibitory threshold. Some of these reductions may be attributed to differences in sampling locations at different time points as well as to movement of boron into the next 25 mm from the surface, but the levels of loss also suggest some of the boron was lost from the wood during drying. The results suggest that drying will have to be optimized for this application as it is a major point of boron loss.

Poles not treated with an oil borne overtreatment were sampled for boron after pressure treatment and then again after 2 months of air seasoning. Boron levels in poles 2 months after treatment averaged 2.14 kg/m^3 BAE, and levels were slightly higher in the 25 to 50 mm zone (Figure 2.1.1). However, boron levels in four of the five poles in this treatment group remained very low 50 mm or further inward, though technically above the effective inhibitory threshold. The overall shape of the preservative gradient changed only slightly after 2 months (Figure 2.1.1). This suggests that the majority of boron remained in the outer pole zones.

Five Boulton seasoned and copper naphthenate treated poles, and five kiln-dried and copper naphthenate poles were set to a 0.6 m depth at Peavy Arboretum in Corvallis, OR. Boron content was assessed in one-year intervals starting one year after treatment by removing increment cores from three equidistant points around each pole at groundline and 1.2 m. Coring holes were plugged with tight-fitting wooden dowels. Increment cores were divided into 25 mm segments from the outside towards the center. Core segments from a given height and zone were combined and ground to pass a 20-mesh screen. Ground wood was analyzed for boron.

Boron levels in the outer 25 mm of poles that had undergone either seasoning type one year after treatment had declined (Figure 2.1.2; 2.1.3 and Tables 2.1.4; 2.1.5). The field site receives ~1041 mm of rainfall per year and tends to be extremely wet during the winter which may have resulted in boron leaching from the outermost layer. Previous tests revealed that interior pole moisture content at groundline tends to be above 30% most of the year, but only reaches that level above groundline near the end of winter. The higher moisture content at groundline would be expected to cause greater boron loss to the surrounding soil in that zone and indeed average boron levels across both treatment types are higher than at groundline (Figure 2.1.2). However, boron levels in the above ground sampling zone also had reduced boron levels compared to their pre-installation levels (Figure 2.1.3), which indicates rainwater leaching is responsible for some loss. Boron levels were similar or slightly lower in the inner 25 to 150 mm at both heights, suggesting there had been relatively little inward movement after installation. In addition, outside of the first 50 mm below the pole surface, few samples had boron concentrations above the 0.6 kg/m^3 inhibitory threshold level.

Table 2.1.2. Boron levels in Douglas-fir poles immediately after pressure treatment with disodium octaborate tetrahydrate and drying/treatment. Bold values are above threshold.

Pole #	Boron Retention (kg/m^3 BAE)					
	0-25 mm	25-50 mm	50-75 mm	75-100 mm	100-125 mm	125-150 mm
759	3.21	0.42	0.01	0.02	0.12	**1.80**
760	4.22	**0.60**	0.06	0.00	0.01	0.05
762	**6.60**	0.14	0.03	0.00	0.00	0.06
763	4.04	0.12	0.01	0.01	0.02	0.03
764	3.37	0.26	0.02	0.03	0.08	0.07
766	3.50	0.07	0.01	0.01	0.00	0.01
767	3.74	0.15	0.08	0.03	0.01	0.02
770	4.30	**1.06**	0.12	0.06	0.31	0.13
788	**14.82**	**0.63**	0.03	0.01	0.00	0.00
789	**6.17**	0.45	0.04	0.00	0.02	0.02
Average	**5.40**	0.39	0.04	0.02	0.06	0.22
Std. Dev.	(3.50)	(0.31)	(0.03)	(0.02)	(0.10)	(0.56)

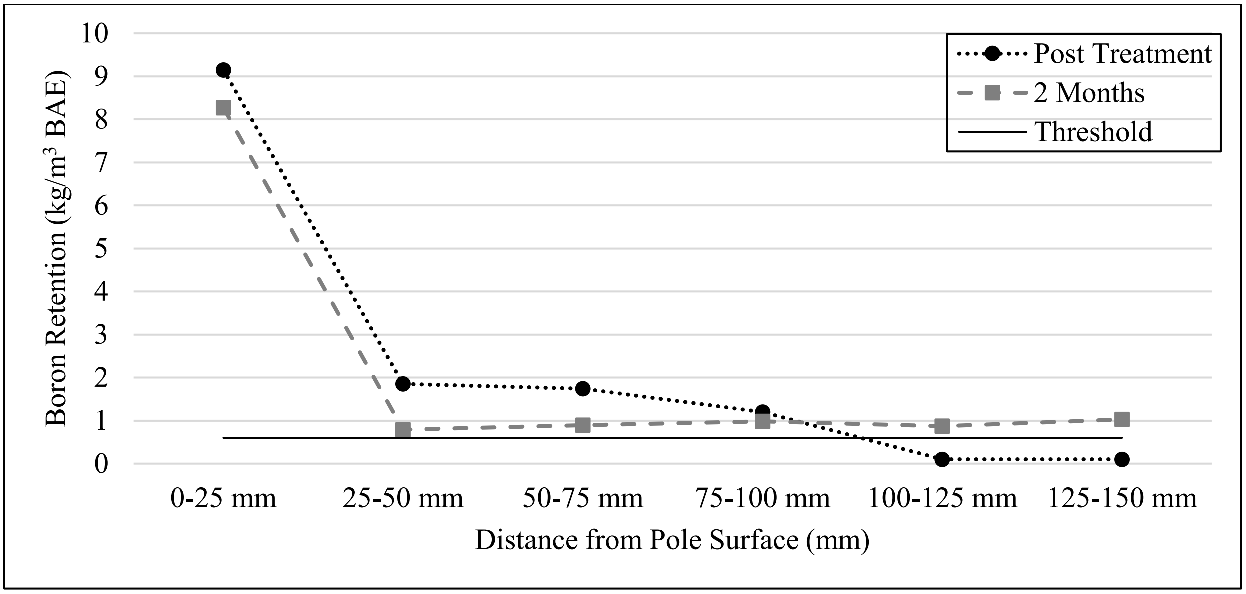

Figure 2.1.1. Boron retentions in 25 mm increments inward from the surface in Douglas-fir poles immediately after pressure treatment with disodium octaborate tetrahydrate and again 2 months later. These poles were not treated with an over treatment.

The initial assays done here indicate that boron levels should be higher to be effective. Initial boron application levels could be increased by using a stronger treatment solution. Pole sections were treated with a process typically used on lumber for the Hawaiian market and solution concentrations might have been somewhat lower than needed. Other treaters have made us aware that solutions of DOT used in commercial pretreatment of poles are typically 20% for pressure treatment and 30% for dip treatment prior to copper naphthenate overtreatment. This is a significant difference in solution strength compared to the 7% solution (BAE) as DOT used in this study and may explain why inward boron migration was limited here. A future study using poles pretreated to boron (as DOT) retentions of at least 0.25 pcf (4.0 kg/m^3) prior to

Table 2.1.3. Differences in boron retentions in the outer 25 mm of poles immediately after treatment and after kiln drying. Bold values are above threshold.

Pole #	Boron Retention (kg/m^3 BAE) in the outer 25 mm		
	Pre-Drying	Post-Drying	Difference
759	**10.30**	3.21	7.09
760	**7.22**	4.22	3.00
762	**7.47**	**6.60**	0.87
763	**10.24**	4.04	6.20
764	4.56	3.37	1.19
766	**10.57**	3.50	7.07
767	**11.66**	3.74	7.92
770	**8.42**	4.30	4.12
788	**14.21**	**14.82**	-0.61
789	**9.71**	**6.17**	3.54

overtreatment would be useful to measure boron migration in poles treated using common standards.

In the six subsequent sampling years 2-7, the overall trends seen after the first year's sampling continued. Boron levels were generally highest in the first 25 mm from the surface, rapidly tapering off deeper in the pole (Figure 2.1.2 and 2.1.3). Total boron levels in the outermost section showed a steady decrease year to year. This combined with the fact that internal boron levels remained fairly constant indicate that the majority of boron loss is a result of loss to the soil rather than migration to the pole interior. Boron levels also remained somewhat higher in the outermost core samples taken from 1.2 m above ground throughout the 7-year sampling. Boron levels in sections taken from 25 mm or deeper below the surface were more similar between the two heights which suggests that groundline leaching does not impact boron levels in the heartwood very much if at all. Samples greater than 50 mm below the surface tended to have boron levels below the effective threshold at all sampling points except for year 1.

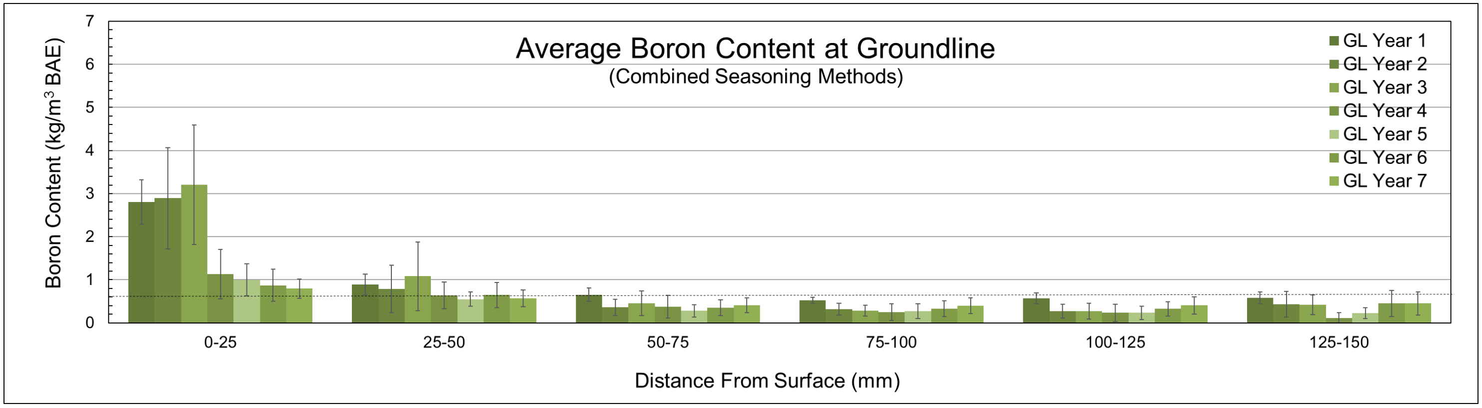

Figure 2.1.2. Boron content at groundline (GL) in 25 mm increments from Douglas-fir pole surface 1-7 years after pre-treatment with disodium octaborate tetrahydrate followed by either kiln drying or Boulton seasoning and CuNap treatment. Both kiln and Boulton seasoning are combined for each year. Dotted line indicates 0.6 kg/m^3 BAE, the threshold for decay prevention.

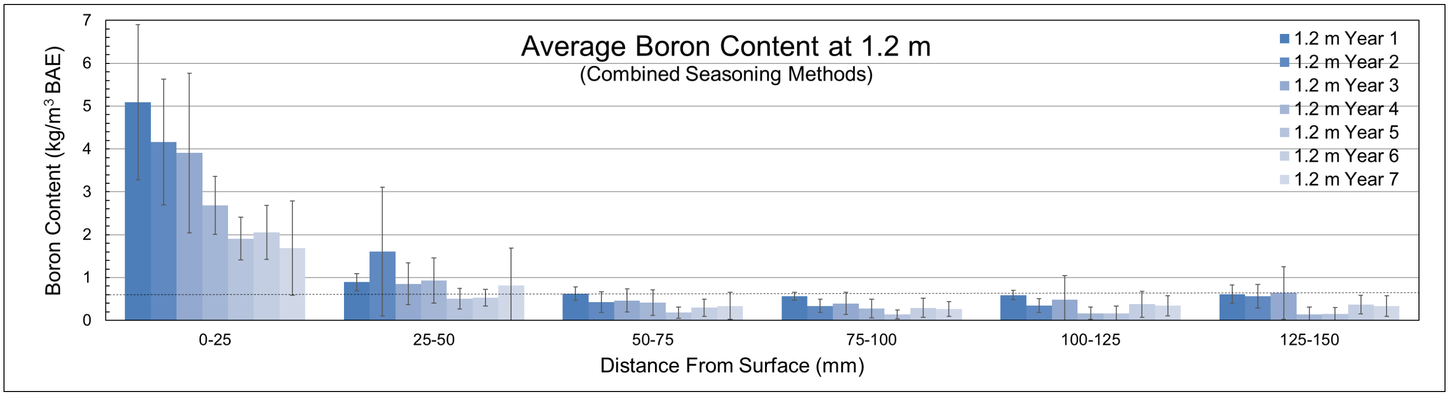

Figure 2.1.3. Boron content 1.2 m above groundline in 25 mm increments from Douglas-fir pole surface 1-7 years after pre-treatment with disodium octaborate tetrahydrate followed by either

kiln drying or Boulton seasoning and CuNap treatment. Both kiln and Boulton seasoning are combined for each year. Dotted line indicates 0.6 kg/m^3 BAE, the threshold for decay prevention.

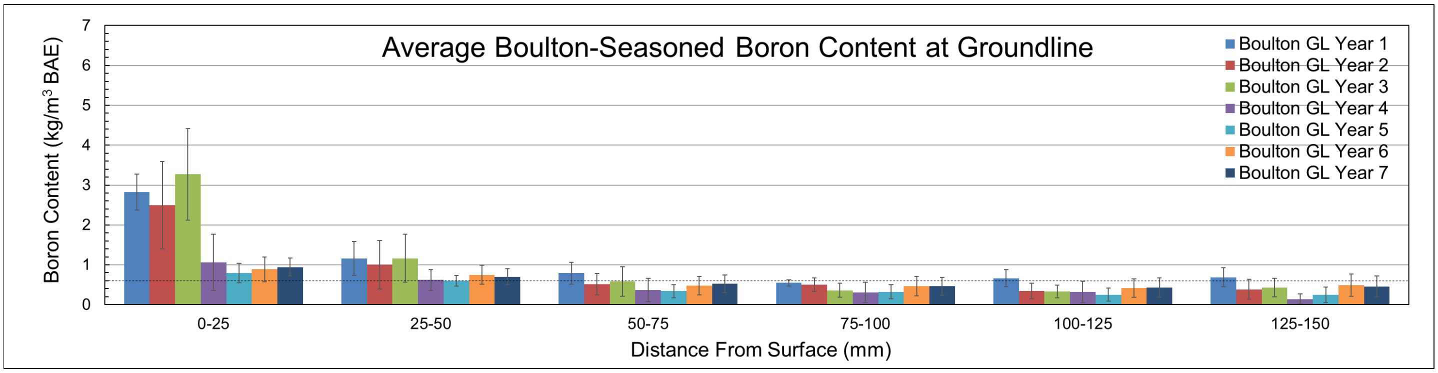

Figure 2.1.4. Boron content in 25 mm increments from Douglas-fir pole surface taken at groundline 1-7 years after pre-treatment with disodium octaborate tetrahydrate followed by Boulton seasoning and CuNap treatment. Dotted black line indicates 0.6 kg/m^3 BAE, the threshold for decay prevention.

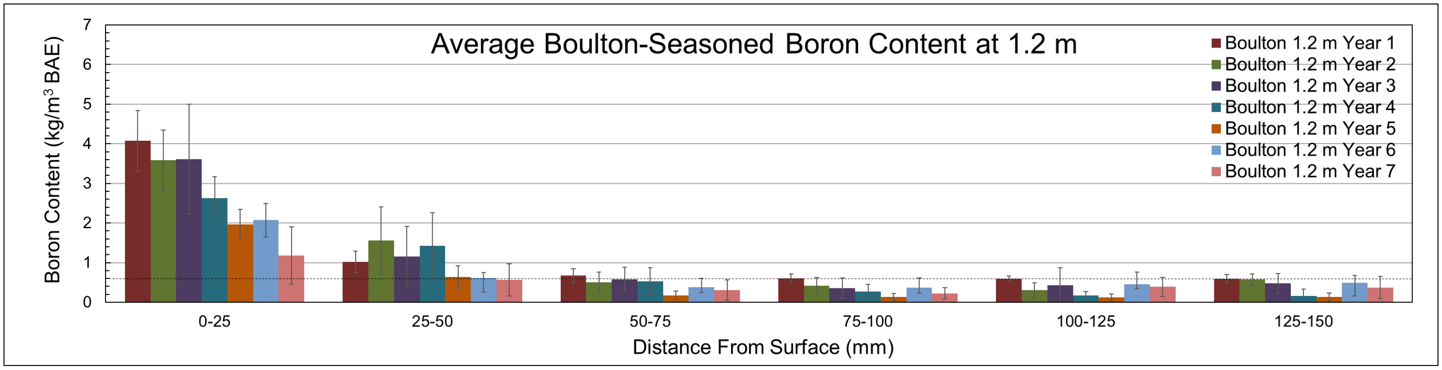

Figure 2.1.5. Boron content in 25 mm increments from Douglas-fir pole surface taken 1.2 m above groundline 1-7 years after pre-treatment with disodium octaborate tetrahydrate followed by Boulton seasoning and CuNap treatment. Dotted black line indicates 0.6 kg/m^3 BAE, the threshold for decay prevention.

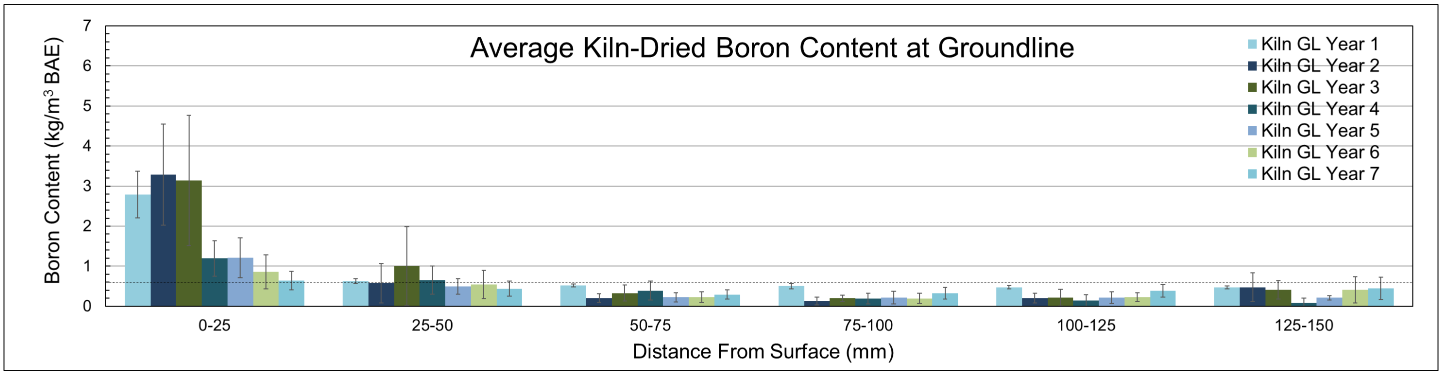

Figure 2.1.6. Boron content in 25 mm increments from Douglas-fir pole surface taken at groundline 1-7 years after pre-treatment with disodium octaborate tetrahydrate followed by kiln drying and CuNap treatment. Dotted black line indicates 0.6 kg/m^3 BAE, the threshold for decay prevention.

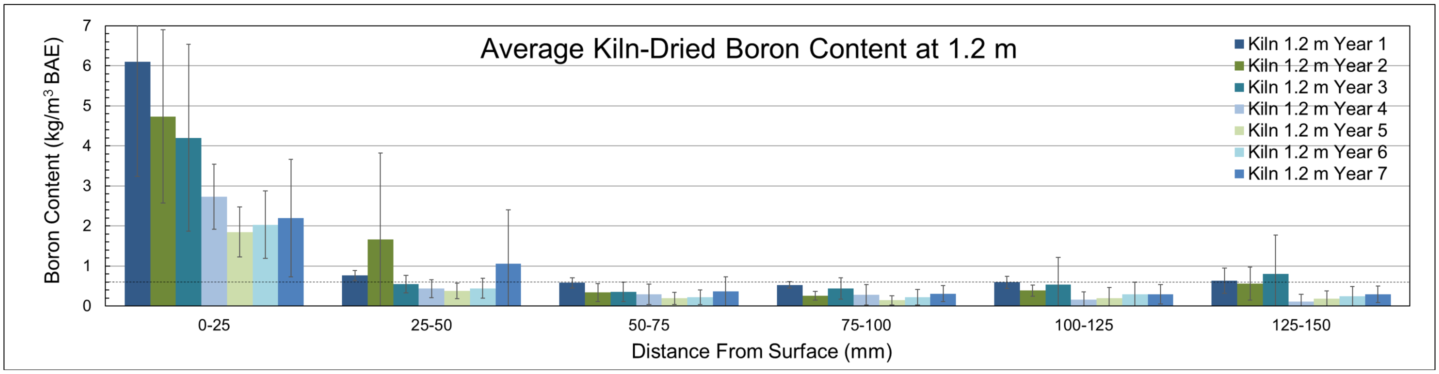

Figure 2.1.7. Boron content in 25 mm increments from Douglas-fir pole surface taken 1.2 m above groundline 1-7 years after pre-treatment with disodium octaborate tetrahydrate followed by kiln drying and CuNap treatment. Dotted black line indicates 0.6 kg/m^3 BAE, the threshold for decay prevention.

When the data for the two treatment types, Boulton seasoning or kiln drying, were viewed separately, both treatment types showed similar patterns in line with those described above and performed similarly to each other except for a few differences in early sampling (Figure 2.1.4; 2.1.5; 2.1.6; and 2.1.7). Boulton-seasoned poles generally had lower boron content 0-25 mm from the surface 1.2 m above groundline in the first three years of sampling than equivalent locations on kiln-dried poles. These differences were eliminated after the third year of sampling as boron was depleted from the outermost pole layer. Boron levels 25 mm below the surface or deeper were similar between the two treatment types at all sampling points. Boron levels at a few sampling points taken at 25-50 mm below the pole surface at 1.2 m above groundline appeared to be higher but were a deviation from the other replicate samples taken at that time. The differences between Boulton-seasoned and kiln-dried treatments were not consistent at different sampling heights and the only real difference between the two was in the first three years in the surface samples taken at 1.2 m. This suggests that the main influence on boron concentration in these poles is ground contact, which appears to be causing the outer pole sections to lose boron relative to above ground sections.

Deeper than 50 mm below the pole surface boron content was generally below the inhibitory threshold on average in nearly all poles of both treatment types. However, in year 6 and 7 there appeared to be an uptick in boron concentration in the inner sections of a few Boultonized poles which pushed boron content above the inhibitory threshold. In addition, one kiln dried pole in year 7 also saw several sections greater than 50 mm under the pole surface rise above the threshold levels (Table 2.1.4; 2.1.5). It is unclear if this is due to inward migration or spatial differences in boron distribution within the pole, however it is encouraging that in the Boulton seasoned poles, some of the increases were maintained for two years straight. It will become clearer as these poles are sampled into the future.

Total average boron concentrations calculated from all samples taken each year are shown to illustrate total boron depletion over time (Figure 2.1.8). Boron losses were higher from the groundline, but were also quite large from the above groundline as shown by the large difference between initial boron retentions and the year 1 sampling point. Average boron levels decreased each year until year 6 where they increased and remained stable in year 7. This increase may be due to uneven boron distribution at different sampling locations which may have driven up concentrations in the more recent sampling points. These results suggest that the pool of boron available for inward diffusion may have stabilized.

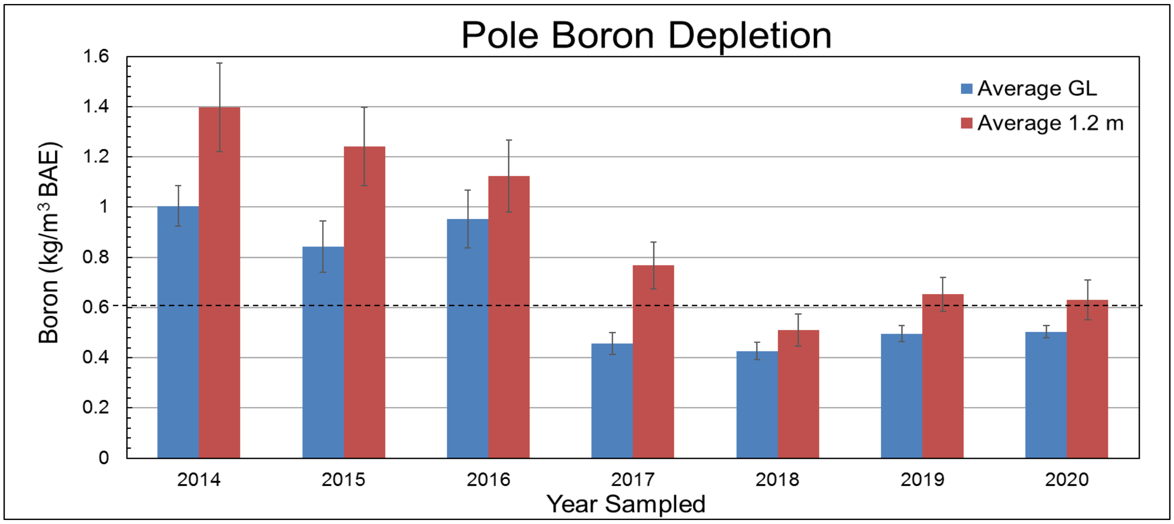

Figure 2.1.8. Average of total pole boron content of Douglas-fir poles after pre-treatment with disodium octaborate tetrahydrate followed by kiln drying and CuNap treatment. Dotted black line indicates 0.6 kg/m^3 BAE, the threshold for decay prevention. Initial average pole boron concentrations after treatment were 9.44 kg/m^3 BAE (pre-drying) and 5.40 kg/m^3 BAE (post-drying). Values for 2014 represent 1-year exposed in the field and highlight the faster loss of total pole boron at groundline than 1.2 m above ground. Bars represent standard error.

The results illustrate an inherent difficulty in using water-borne solutions of boron to deliver a sufficient load in the outer sapwood to allow diffusion inward at levels capable of preventing fungal attack. This problem is exacerbated by greater pole diameter. These results differ from those in railroad ties, where boron remains at elevated levels for many years after initial treatment followed by a creosote over-treatment. However, there are several important differences between the service applications of ties and poles. First, ties are typically installed over a well-drained ballast which reduces the potential for excessive wetting that leads to boron loss. In addition, overall boron levels in these poles were much lower than those typically placed into an air-seasoning tie. This occurred because the poles were pressure treated with a solution intended for lumber. Thus, initial loadings were lower than desired given the larger volume of wood that needs to be protected. The lower loadings, led to a lower concentration gradient between the outer and inner pole sections which may have led to a lower rate of diffusion between the two zones. However, our results illustrate that even with lower boron retentions, there are heavy losses to the surrounding soil which suggests interior boron levels in pretreated poles may benefit from the installation of impermeable barriers at the groundline.

Wood species may also have affected the results and boron diffusion through Douglas-fir tends to be much slower than through hardwoods used for railroad ties. The railroad tie research was performed on hardwoods. Boron movement through Douglas-fir tends to be much slower than in other species, and this may have something to do with the slow to non-existent inward diffusion seen here. The results from this study led us to undertake a more comprehensive study of boron treatment that is described in the next section.

Table 2.1.4. Boron content in increment cores removed from groundline or 1.2 m above groundline of Douglas-fir poles 1-7 years after pre-treatment with disodium octaborate tetrahydrate followed by Boulton seasoning and pressure treatment with copper naphthenate.

Pole #	Kiln/ Boulton	Boron Retention (kg/m^3 BAE)[a]											
		0-25 mm		25-50 mm		50-75 mm		75-100 mm		100-125 mm		125-150 mm	
		gl	1.2 m	gl	1.2 m	gl	1.2 m	gl	1.2 m	gl	1.2 m	gl	1.2 m
759	Boulton Year 1	2.37	4.57	1.12	1.12	0.67	0.72	0.58	0.72	0.54	0.72	0.58	0.72
760		2.51	3.09	1.66	1.39	1.12	0.99	0.67	0.72	0.63	0.58	0.63	0.49
762		3.00	4.52	0.81	0.76	0.49	0.54	0.45	0.49	0.49	0.58	0.54	0.72
763		3.63	4.97	0.58	0.67	0.54	0.49	0.54	0.45	0.58	0.54	0.54	0.49
764		2.60	3.23	1.61	1.16	1.12	0.63	0.49	0.63	1.08	0.54	1.16	0.54
Mean		2.82	4.08	1.16	1.02	0.79	0.67	0.55	0.60	0.66	0.59	0.69	0.59
(SD)		(0.45)	(0.77)	(0.43)	(0.27)	(0.28)	(0.17)	(0.08)	(0.11)	(0.21)	(0.07)	(0.24)	(0.10)
759	Boulton Year 2	3.22	4.49	1.35	1.12	0.49	0.36	0.38	0.41	0.32	0.39	0.23	0.36
760		2.89	2.90	1.77	1.57	0.81	0.92	0.69	0.73	0.69	0.47	0.33	0.71
762		3.26	3.73	0.44	0.85	0.44	0.15	0.45	0.53	0.10	0.49	0.09	0.71
763		0.34	4.28	0.15	3.19	0.06	0.57	0.27	0.27	0.28	0.02	0.45	0.60
764		2.79	2.51	1.32	1.07	0.76	0.54	0.70	0.17	0.34	0.17	0.82	0.48
Mean		2.50	3.58	1.00	1.56	0.51	0.51	0.50	0.42	0.34	0.31	0.38	0.57
(SD)		(1.09)	(0.77)	(0.61)	(0.85)	(0.27)	(0.26)	(0.17)	(0.20)	(0.19)	(0.18)	(0.25)	(0.14)
759	Boulton Year 3	1.89	6.00	1.55	2.26	0.52	0.88	0.27	0.41	0.44	1.25	0.25	0.86
760		3.09	2.20	1.52	1.80	0.54	0.98	0.29	0.78	0.13	0.46	0.73	0.49
762		3.10	2.66	0.34	0.89	0.11	0.23	0.12	0.17	0.20	0.20	0.10	0.39
763		2.90	4.34	0.55	0.23	0.49	0.47	0.61	0.02	0.32	0.01	0.60	0.08
764		5.39	2.88	1.87	0.62	1.25	0.31	0.50	0.39	0.57	0.23	0.48	0.57
Mean		3.27	3.61	1.16	1.16	0.58	0.57	0.36	0.35	0.33	0.43	0.43	0.48
(SD)		(1.15)	(1.39)	(0.60)	(0.76)	(0.37)	(0.30)	(0.18)	(0.26)	(0.16)	(0.44)	(0.23)	(0.25)
759	Boulton Year 4	0.69	3.07	0.73	1.35	0.70	0.45	0.39	0.15	0.40	0.17	0.26	0.06
760		0.68	1.84	0.53	1.19	0.49	0.87	0.43	0.54	0.37	0.26	0.30	0.07
762		0.26	3.13	0.18	0.51	0.00	0.05	0.00	0.03	0.00	0.00	0.00	0.00
763		2.26	2.97	0.66	3.00	0.03	0.34	0.05	0.20	0.08	0.13	0.00	0.49
764		1.42	2.12	0.99	1.08	0.60	0.96	0.67	0.42	0.76	0.28	0.14	0.19
Mean		1.06	2.63	0.62	1.43	0.36	0.53	0.31	0.27	0.32	0.17	0.14	0.16
(SD)		(0.70)	(0.54)	(0.27)	(0.84)	(0.29)	(0.34)	(0.25)	(0.19)	(0.27)	(0.10)	(0.13)	(0.17)
759	Boulton Year 5	0.64	2.13	0.62	0.89	0.33	0.22	0.46	0.08	0.33	0.13	0.20	0.11
760		0.61	2.13	0.60	1.07	0.51	0.33	0.50	0.23	0.41	0.12	0.45	0.20
762		0.54	2.26	0.38	0.39	0.11	0.09	0.06	0.12	0.01	0.07	0.02	0.05
763		1.11	2.09	0.59	0.43	0.21	0.02	0.15	0.00	0.11	0.02	0.07	0.00
764		1.06	1.22	0.80	0.42	0.54	0.20	0.46	0.24	0.41	0.26	0.51	0.29
Mean		0.79	1.97	0.60	0.64	0.34	0.17	0.33	0.13	0.25	0.12	0.25	0.13
(SD)		(0.24)	(0.38)	(0.14)	(0.28)	(0.17)	(0.11)	(0.18)	(0.09)	(0.16)	(0.08)	(0.20)	(0.10)
759	Boulton Year 6	0.62	2.35	0.88	0.77	0.47	0.44	0.75	0.64	0.54	0.73	0.81	0.57
760		1.18	1.82	1.05	0.79	0.80	0.77	0.61	0.68	0.58	0.91	0.55	0.32
762		0.62	2.47	0.39	0.52	0.24	0.19	0.16	0.24	0.15	0.30	0.14	0.53
763		0.67	1.38	0.84	0.52	0.67	0.30	0.62	0.23	0.69	0.21	0.77	0.78
764		1.34	2.35	0.56	0.45	0.22	0.18	0.18	0.02	0.13	0.15	0.20	0.26
Mean		0.89	2.07	0.75	0.61	0.48	0.38	0.46	0.36	0.42	0.46	0.49	0.49
(SD)		(0.31)	(0.41)	(0.24)	(0.14)	(0.23)	(0.22)	(0.25)	(0.26)	(0.23)	(0.30)	(0.28)	(0.19)
759	Boulton Year 7	0.73	2.28	0.68	0.83	0.52	0.31	0.56	0.22	0.64	0.26	0.65	0.22
760		1.03	1.78	0.78	1.21	0.70	0.79	0.68	0.39	0.55	0.43	0.77	0.44
762		0.66	0.38	0.46	0.29	0.26	0.16	0.19	0.15	0.16	0.77	0.17	0.19
763		1.03	0.73	0.54	0.07	0.31	0.02	0.18	0.00	0.11	0.03	0.14	0.13
764		1.26	0.70	1.03	0.42	0.83	0.26	0.68	0.36	0.69	0.44	0.57	0.89
Mean		0.94	1.17	0.70	0.57	0.52	0.31	0.46	0.22	0.43	0.39	0.46	0.37
(SD)		(0.22)	(0.72)	(0.20)	(0.41)	(0.22)	(0.26)	(0.23)	(0.14)	(0.25)	(0.24)	(0.26)	(0.28)

[a] Cells in red signify boron retentions above the threshold for protection against internal fungal attack. SD = Standard deviation.

Table 2.1.5. Boron content in increment cores removed from groundline or 1.2 m above groundline of Douglas-fir poles 1-7 years after pre-treatment with disodium octaborate tetrahydrate followed by kiln drying and pressure treatment with copper naphthenate.

Pole #	Kiln/ Boulton	Boron Retention (kg/m^3 BAE)[a]											
		0-25 mm		25-50 mm		50-75 mm		75-100 mm		100-125 mm		125-150 mm	
		gl	1.2 m	gl	1.2 m	gl	1.2 m	gl	1.2 m	gl	1.2 m	gl	1.2 m
766	Kiln Year 1	2.20	3.58	0.54	0.58	0.54	0.54	0.45	0.49	0.49	0.54	0.49	0.54
767		2.28	4.12	0.63	0.63	0.54	0.49	0.49	0.54	0.45	0.49	0.40	0.45
770		3.00	3.63	0.63	0.85	0.54	0.81	0.63	0.67	0.49	0.90	0.49	1.25
788		3.81	9.27	0.72	0.85	0.54	0.45	0.49	0.45	0.40	0.54	0.49	0.40
789		2.64	9.90	0.63	0.90	0.45	0.63	0.45	0.49	0.54	0.49	0.49	0.54
Mean		2.79	6.10	0.63	0.76	0.52	0.58	0.50	0.53	0.47	0.59	0.47	0.64
(SD)		(0.59)	(2.86)	(0.06)	(0.13)	(0.04)	(0.13)	(0.07)	(0.08)	(0.05)	(0.15)	(0.04)	(0.31)
766	Kiln Year 2	1.85	2.89	0.12	0.42	0.33	0.34	0.07	0.29	0.05	0.34	0.53	0.13
767		2.95	3.73	0.57	0.24	0.29	0.07	0.04	0.07	0.32	0.24	0.28	0.24
770		5.53	3.68	1.52	1.04	0.15	0.73	0.28	0.41	0.24	0.36	0.33	1.30
788		3.61	8.94	0.34	5.94	0.04	0.34	0.04	0.25	0.06	0.66	0.11	0.54
789		2.49	4.45	0.34	0.65	0.22	0.20	0.22	0.24	0.33	0.33	1.14	0.60
Mean		3.28	4.74	0.58	1.66	0.21	0.34	0.13	0.26	0.20	0.39	0.48	0.56
(SD)		(1.26)	(2.16)	(0.49)	(2.16)	(0.11)	(0.22)	(0.10)	(0.11)	(0.12)	(0.14)	(0.36)	(0.41)
766	Kiln Year 3	0.85	1.24	0.27	0.31	0.27	0.63	0.07	0.27	0.12	0.07	0.60	0.03
767		2.17	4.88	0.57	0.29	0.26	0.12	0.15	0.07	0.04	0.04	0.15	0.09
770		5.54	1.83	2.93	0.77	0.70	0.65	0.27	0.84	0.59	0.58	0.75	1.20
788		4.24	7.40	0.90	0.56	0.11	0.26	0.27	0.58	0.05	1.84	0.38	2.54
789		2.92	5.65	0.34	0.80	0.30	0.11	0.23	0.44	0.27	0.12	0.18	0.15
Mean		3.14	4.20	1.00	0.55	0.33	0.35	0.20	0.44	0.21	0.53	0.41	0.80
(SD)		(1.63)	(2.33)	(0.99)	(0.22)	(0.20)	(0.24)	(0.08)	(0.26)	(0.20)	(0.68)	(0.24)	(0.97)
766	Kiln Year 4	0.55	1.51	0.52	0.23	0.30	0.16	0.15	0.14	0.03	0.00	0.00	0.00
767		1.12	2.25	0.25	0.29	0.19	0.14	0.10	0.06	0.07	0.04	0.06	0.01
770		1.71	2.75	1.32	0.85	0.79	0.80	0.44	0.77	0.41	0.51	0.33	0.48
788		0.93	3.25	0.58	0.33	0.15	0.21	0.07	0.32	0.04	0.16	0.04	0.05
789		1.66	3.89	0.59	0.49	0.51	0.18	0.22	0.13	0.17	0.12	0.00	0.00
Mean		1.20	2.73	0.65	0.44	0.39	0.30	0.19	0.29	0.14	0.17	0.09	0.11
(SD)		(0.44)	(0.82)	(0.35)	(0.23)	(0.24)	(0.25)	(0.13)	(0.26)	(0.14)	(0.18)	(0.12)	(0.19)
766	Kiln Year 5	0.41	1.06	0.29	0.38	0.13	0.16	0.09	0.15	0.07	0.07	0.12	0.11
767		1.49	1.81	0.31	0.10	0.10	0.08	0.11	0.04	0.15	0.04	0.24	0.03
770		1.07	1.31	0.78	0.71	0.43	0.48	0.52	0.36	0.49	0.73	0.20	0.53
788		1.92	2.30	0.67	0.34	0.27	0.20	0.19	0.11	0.18	0.14	0.29	0.25
789		1.14	2.76	0.44	0.36	0.18	0.06	0.19	0.06	0.17	0.01	0.21	0.00
Mean		1.21	1.85	0.50	0.38	0.22	0.20	0.22	0.14	0.21	0.20	0.21	0.18
(SD)		(0.50)	(0.62)	(0.20)	(0.19)	(0.12)	(0.15)	(0.16)	(0.12)	(0.14)	(0.27)	(0.05)	(0.20)
766	Kiln Year 6	0.35	1.08	0.15	0.12	0.10	0.07	0.04	0.03	0.06	0.03	0.08	0.03
767		0.80	1.59	0.26	0.24	0.06	0.11	0.09	0.05	0.18	0.12	0.20	0.02
770		1.22	2.54	1.12	0.52	0.29	0.57	0.33	0.44	0.37	0.35	0.42	0.50
788		1.47	3.43	0.73	0.84	0.40	0.17	0.37	0.48	0.21	0.86	0.32	0.58
789		0.46	1.52	0.46	0.48	0.30	0.18	0.15	0.13	0.32	0.12	1.03	0.09
Mean		0.86	2.03	0.54	0.44	0.23	0.22	0.20	0.23	0.23	0.29	0.41	0.24
(SD)		(0.43)	(0.85)	(0.35)	(0.25)	(0.13)	(0.18)	(0.13)	(0.20)	(0.11)	(0.30)	(0.33)	(0.24)
766	Kiln Year 7	0.21	0.53	0.17	0.10	0.14	0.07	0.11	0.07	0.14	0.11	0.00	0.16
767		0.75	1.55	0.39	0.27	0.27	0.13	0.27	0.15	0.36	0.17	0.51	0.13
770		0.90	0.84	0.71	4.82	0.50	3.70	0.54	1.08	0.56	0.63	0.84	0.70
788		0.73	2.64	0.57	0.56	0.32	0.33	0.38	0.41	0.56	0.42	0.57	0.41
789		0.63	1.44	0.36	0.68	0.24	0.23	0.33	0.30	0.29	0.07	0.30	0.10
Mean		0.64	1.40	0.44	1.29	0.29	0.89	0.33	0.40	0.38	0.28	0.44	0.30
(SD)		(0.23)	(0.73)	(0.18)	(1.78)	(0.12)	(1.41)	(0.14)	(0.36)	(0.16)	(0.21)	(0.28)	(0.23)

[a] Cells in red signify boron retentions above the threshold for protection against internal fungal attack. SD = Standard deviation.

2.1.2 Effect of Boron Pre-treatment on Performance of Douglas-fir Poles Treated with Pentachlorophenol, Copper Naphthenate, or Ammoniacal Copper Zinc Arsenate

The initial trial to evaluate the potential for pre-treatment with borates produced somewhat anomalous results. There were several delays in processing that might have affected the outcome. In order to develop better data, additional poles were obtained for a larger trial.

Class 3, 40-foot long Douglas-fir poles were cut into twenty-four, 2.4 m long sections and allocated to one of three treatments. Twelve poles were tagged and sent to be commercially treated with a 10% solution of disodium octaborate tetrahydrate (DOT) as part of a lumber charge. After treatment, the poles were commercially treated to the AWPA UC4C retention with copper naphthenate (2.4 kg/m^3) or pentachlorophenol (9.6 kg/m^3). The remaining six pole sections were impregnated with a DOT/ammoniacal copper zinc arsenate solution. Following treatment, increment cores were taken at 300 mm increments along the pole length. These cores were divided into 25 mm segments and 8 segments from a given depth were combined for each pole. Core segments were oven-dried, ground to pass a 20-mesh screen, and hot water extracted. The hot water extract was analyzed for boron using the Azomethine H method. Initial preservative retention was determined by additional coring. The outer 6 mm of each increment core was discarded and the next 19 mm was retained. These segments were ground to pass a 20-mesh screen and analyzed by x-ray fluorescence. We experienced interference with the ACZA samples in our XRF unit. Instead, these samples were microwave digested and analyzed by inductively coupled plasma optical emission spectroscopy for copper, zinc, arsenic, and boron.

Average boron levels were elevated at all depths in the ACZA-treated poles, but there was wide variation in boron levels within and among poles (Table 2.1.6). For example, boron levels ranged from the limit of detection (0.04 kg/m^3 BAE) to 7.64 kg/m^3 BAE in the 25-50 mm zone. Average boron levels in copper naphthenate-treated poles were lower in the outer 3 zones than they were in two innermost sampling zones, which was unusual considering our previous results. Boron was only detectable in the outermost zone of one of six copper naphthenate poles. Boron was detectable in the two innermost sections of all of the copper naphthenate poles and one pole had much higher levels than the others. Boron levels were only above the protective threshold in 6 of 30 sections in copper naphthenate poles. Similarly, boron levels in penta-treated poles were highly variable, ranging from below the detection limit to 7.34 kg/m^3 BAE. Boron levels were again only above the protective threshold in 7 of 30 assays. Boron levels in the outermost section were generally low except for two poles which were above the effective threshold. One pole showed much higher boron levels in the innermost sections which was surprising considering previous observations. Other than this one pole, boron levels were below the effective threshold in the innermost sections. Variations in chemical distribution are to be expected in wood, but the range observed for boron here is extreme and suggests that process parameters may need to be changed to accommodate Douglas-fir pole sections to deliver more consistent treatment.

Table 2.1.6. Boron levels at 25 mm increments inward from the surface of Douglas-fir poles dual-treated with DOT and copper naphthenate, pentachlorophenol, or ACZA measured shortly after pressure treatment.

Treatment	Rep	Boron retention (kg/m^3 BAE)				
		0-25 mm	25-50 mm	50-75 mm	75-100 mm	100-125 mm
ACZA	1	-----	**6.80**	**1.07**	**6.88**	**2.03**
	2	-----	0.54	0.22	0.16	0.00
	3	-----	0.04	0.03	0.21	**1.36**
	4	-----	**0.64**	0.13	0.37	0.31
	5	-----	**7.64**	0.50	**0.92**	**4.25**
	6	-----	**3.69**	**4.25**	XXX	**6.13**
Mean (SD)		-----	**3.22** (3.07)	**1.03** (1.48)	**1.71** (2.60)	**2.35** (2.19)
CuNap	1	0.00	0.29	0.42	**1.72**	0.26
	2	0.00	0.00	0.00	**0.90**	0.42
	3	0.00	0.09	0.52	0.31	0.44
	4	**1.12**	0.49	0.00	0.52	0.27
	5	0.00	0.53	0.00	0.10	0.24
	6	0.00	0.16	**1.22**	**5.68**	**3.14**
Mean (SD)		0.26 (0.42)	0.26 (0.20)	0.36 (0.44)	**1.54** (1.92)	**0.85** (1.05)
Penta	1	0.00	0.47	0.34	0.23	0.09
	2	0.34	0.00	0.00	0.01	0.01
	3	0.00	**0.85**	**7.34**	**2.08**	**5.52**
	4	**1.76**	0.23	0.00	0.00	0.05
	5	**1.66**	**0.86**	0.09	0.21	0.00
	6	0.13	0.04	0.00	0.08	0.22
Mean (SD)		0.65 (0.76)	0.41 (0.35)	**1.29** (2.71)	0.44 (0.74)	**0.98** (2.03)

*Numbers in bold text represent values above the threshold to prevent fungal attack.

Boron pre-treatment is not intended to provide initial protection against fungi. Rather, it is used to protect untreated heartwood that is exposed as the poles season in service and develop checks. As a result, the presence of sub-threshold levels at this point is not as important, although it is important to have a sufficient total loading in the pole so subsequent diffusion creates a well-protected core. We would expect boron to continue to distribute more evenly as the poles wet and dry.

The poles were sampled in each of four years after installation by removing increment cores from three locations around each pole at groundline and 1.2 m above groundline. Each core was divided into 25 mm long segments. Core segments from a given location on each pole were combined and ground to pass a 20-mesh screen. The resulting ground wood was hot water-extracted and analyzed for boron via the Azomethine H method. Results were expressed on a kg/m^3 boric acid equivalent (BAE) where the threshold for fungal protection is considered to be equal to, or greater than 0.6 kg/m^3 BAE.

At the first-year sampling, boron levels at groundline and 1.2 m above groundline for the most part did not differ markedly from each other one year after treatment for all treatments, but there were some exceptions (Table 2.1.7-9). Boron levels were higher in the outer 25 mm at 1.2 m in copper naphthenate-treated poles while groundline boron levels trended higher in the outer 25 mm in Penta-treated and ACZA-treated poles (Figure 2.1.9-11). In sampling from 2 years onward, groundline samples tended to have equivalent or lower boron in the outermost core sections.

Average boron levels were above the threshold in the outer 25 mm at both groundline and 1.2 m in all treatments throughout all four years of sampling (Figure 2.1.9-11). This is in contrast to the patterns observed in the initial sampling before installation where boron content in the outermost sections were lower on average than those observed deeper beneath the pole surface (Table 2.1.6). Average boron levels declined sharply to the inside of the outermost 25 mm section, but stayed above threshold levels in the 25-50 mm section in most of the year 1 samples. All boron levels 25 mm or farther inside the pole in year 2 onward were below threshold. Differences between all samples taken from all treatments greater than 50 mm below the pole surface were slight and have remained so through the 4th year sampling.

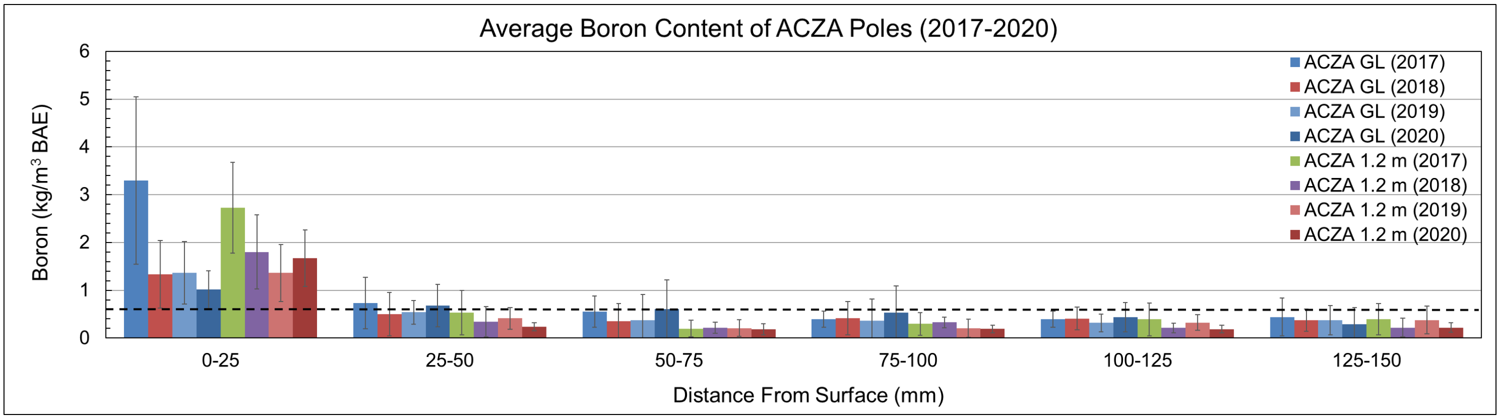

Figure 2.1.9. Boron levels in Douglas-fir poles subjected to an ACZA/boron dual pressure treatment for the first 4 years of sampling. Dotted black line indicates 0.6 kg/m^3 BAE, the threshold for decay prevention

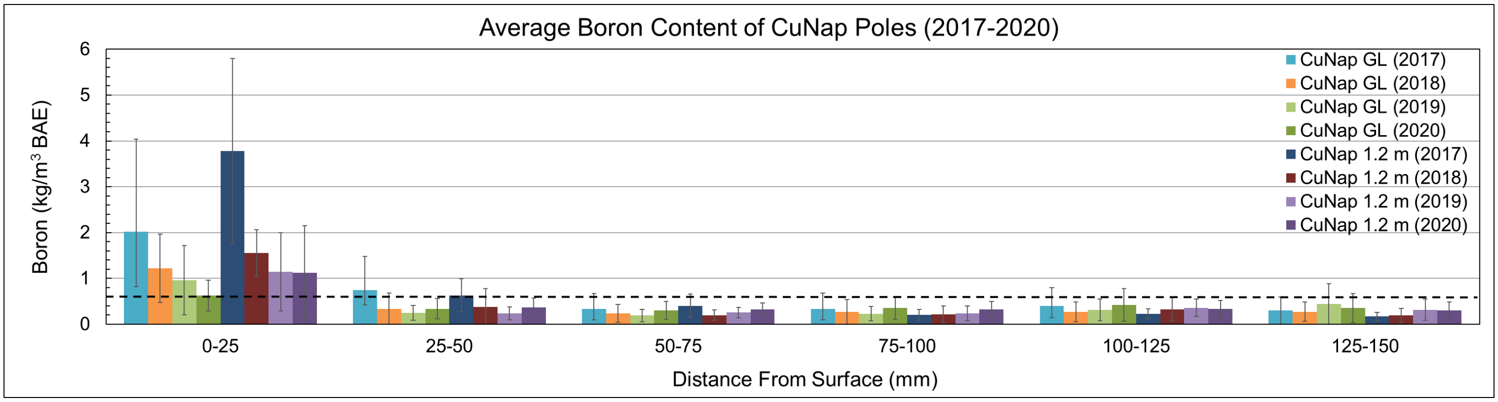

Figure 2.1.10. Boron levels in Douglas-fir poles subjected to a boron pre-treatment followed by over-treatment with copper naphthenate for the first 4 years of sampling. Dotted black line indicates 0.6 kg/m^3 BAE, the threshold for decay prevention

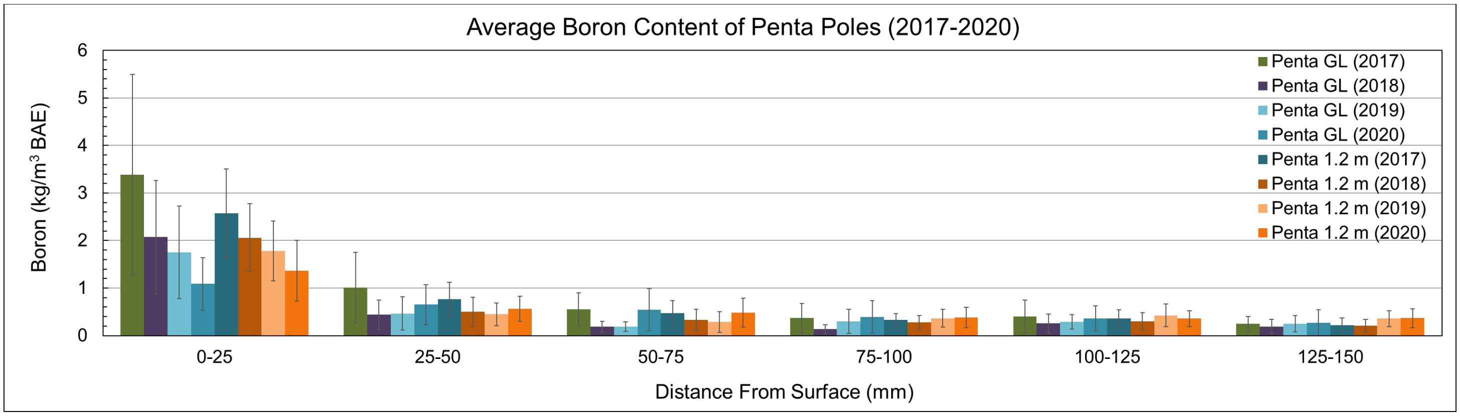

Figure 2.1.11. Boron levels in Douglas-fir poles subjected to a boron pre-treatment followed by over-treatment with Pentachlorophenol the first four years of sampling. Dotted black line indicates 0.6 kg/m^3 BAE, the threshold for decay prevention.

Boron depletion from the poles was most pronounced in the first year and after that the rate of loss decreased and even stopped in some of the treatments (Figure 2.1.12). Interestingly, the different treatments showed different patterns of boron depletion and were apparently affected differently by soil contact and rainwater. ACZA treated poles, for example, showed greater loss of boron in the 1.2 m samples than was seen at the groundline. Conversely, Penta and copper naphthenate-treated poles showed greater depletion over time at the groundline. These differences were not always great enough to be considered significant with 95% confidence, but the data trends in the stated direction.

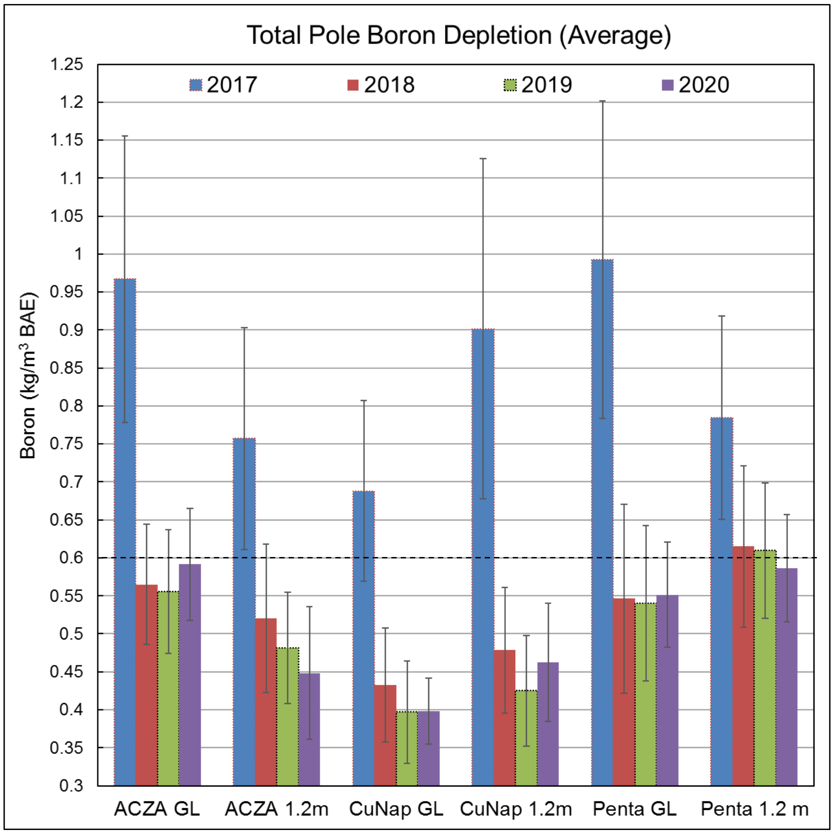

Figure 2.1.12. Average of total pole boron content of Douglas-fir poles subjected to either a boron pre-treatment followed by over-treatment with copper naphthenate, pentachlorophenol, or an ACZA/boron pressure treatment after 4 years. Dotted black line indicates 0.6 kg/m^3 BAE, the threshold for decay prevention. Initial average pole boron concentrations after treatment are unknown. Values for 2017 represent 1-year exposed in the field. Bars represent standard error.

Boron levels were generally low in poles in this study, but it is important to stress that the results do not necessarily mean that boron is not performing a function. Research on railroad ties showed trace amounts of boron protected the wood for over 20-years after treatment, and we would expect the results to be similar in utility poles. While higher boron loadings would be preferable, it does not take much boron to inhibit the germination of fungal spores. There is still a relatively higher boron pool in the areas closest to the pole surface and therefore still potential for inward migration. We will continue to monitor these poles to determine how boron redistributes in the interior of the poles.

Table 2.1.7: Boron levels at 25 mm increments inward from the surface at groundline and 1.2 m above groundline in Douglas-fir poles one, two, three and four years after dual treatment with boron plus ACZA.

Primary Treatment	Depth (mm)	GL		1.2 m	
		(kg/m^3 BAE)	Std. Dev.	(kg/m^3 BAE)	Std. Dev.
ACZA (2017)	0-25	3.29	(1.92)	2.73	(1.04)
	25-50	0.73	(0.59)	0.53	(0.51)
	50-75	0.55	(0.36)	0.20	(0.19)
	75-100	0.40	(0.19)	0.30	(0.26)
	100-125	0.39	(0.18)	0.39	(0.38)
	125-150	0.44	(0.43)	0.40	(0.36)
ACZA (2018)	0-25	1.33	(0.78)	1.80	(0.85)
	25-50	0.50	(0.50)	0.34	(0.34)
	50-75	0.36	(0.41)	0.21	(0.12)
	75-100	0.42	(0.38)	0.33	(0.12)
	100-125	0.41	(0.26)	0.21	(0.11)
	125-150	0.37	(0.26)	0.22	(0.21)
ACZA (2019)	0-25	1.37	(0.71)	1.36	(0.65)
	25-50	0.54	(0.27)	0.41	(0.25)
	50-75	0.38	(0.58)	0.21	(0.19)
	75-100	0.37	(0.49)	0.21	(0.21)
	100-125	0.32	(0.20)	0.32	(0.18)
	125-150	0.37	(0.34)	0.38	(0.32)
ACZA (2020)	0-25	1.01	(0.39)	1.67	(0.59)
	25-50	0.68	(0.44)	0.24	(0.09)
	50-75	0.60	(0.62)	0.18	(0.11)
	75-100	0.53	(0.56)	0.19	(0.08)
	100-125	0.44	(0.30)	0.19	(0.08)
	125-150	0.28	(0.35)	0.22	(0.10)

Table 2.1.8: Boron levels at 25 mm increments inward from the surface at groundline and 1.2 m above groundline in Douglas-fir poles one, two, three and four years after dual treatment with boron plus CuNap.

Primary Treatment	Depth (mm)	GL		1.2 m	
		(kg/m^3 BAE)	Std. Dev.	(kg/m^3 BAE)	Std. Dev.
CuNaph (2017)	0-25	2.02	(1.32)	3.78	(2.22)
	25-50	0.74	(0.35)	0.63	(0.40)
	50-75	0.34	(0.27)	0.40	(0.28)
	75-100	0.34	(0.27)	0.20	(0.13)
	100-125	0.40	(0.29)	0.22	(0.12)
	125-150	0.30	(0.32)	0.17	(0.10)
CuNaph (2018)	0-25	1.22	(0.81)	1.55	(0.56)
	25-50	0.34	(0.37)	0.38	(0.44)
	50-75	0.24	(0.21)	0.20	(0.12)
	75-100	0.26	(0.30)	0.22	(0.20)
	100-125	0.27	(0.24)	0.33	(0.28)
	125-150	0.27	(0.23)	0.20	(0.17)
CuNaph (2019)	0-25	0.96	(0.83)	1.15	(0.93)
	25-50	0.25	(0.17)	0.24	(0.16)
	50-75	0.19	(0.15)	0.25	(0.12)
	75-100	0.23	(0.17)	0.24	(0.18)
	100-125	0.31	(0.26)	0.36	(0.21)
	125-150	0.45	(0.48)	0.32	(0.26)
CuNaph (2020)	0-25	0.62	(0.33)	1.13	(1.03)
	25-50	0.34	(0.22)	0.37	(0.21)
	50-75	0.31	(0.20)	0.33	(0.14)
	75-100	0.35	(0.24)	0.32	(0.17)
	100-125	0.42	(0.36)	0.33	(0.18)
	125-150	0.35	(0.32)	0.30	(0.19)

Table 2.1.9: Boron levels at 25 mm increments inward from the surface at groundline and 1.2 m above groundline in Douglas-fir poles one, two, three and four years after dual treatment with boron plus Penta.

Primary Treatment	Depth (mm)	GL		1.2 m	
		(kg/m^3 BAE)	Std. Dev.	(kg/m^3 BAE)	Std. Dev.
Penta (2017)	0-25	3.39	(2.31)	2.58	(1.02)
	25-50	1.01	(0.82)	0.76	(0.39)
	50-75	0.55	(0.39)	0.47	(0.30)
	75-100	0.37	(0.34)	0.33	(0.15)
	100-125	0.40	(0.38)	0.36	(0.21)
	125-150	0.24	(0.17)	0.22	(0.17)
Penta (2018)	0-25	2.07	(1.30)	2.06	(0.78)
	25-50	0.44	(0.34)	0.51	(0.33)
	50-75	0.19	(0.13)	0.33	(0.25)
	75-100	0.13	(0.10)	0.28	(0.15)
	100-125	0.26	(0.22)	0.30	(0.20)
	125-150	0.19	(0.16)	0.21	(0.15)
Penta (2019)	0-25	1.75	(1.07)	1.78	(0.69)
	25-50	0.46	(0.38)	0.45	(0.26)
	50-75	0.19	(0.11)	0.28	(0.24)
	75-100	0.30	(0.27)	0.36	(0.21)
	100-125	0.29	(0.17)	0.42	(0.26)
	125-150	0.25	(0.19)	0.36	(0.18)
Penta (2020)	0-25	1.09	(0.56)	1.37	(0.64)
	25-50	0.65	(0.42)	0.56	(0.27)
	50-75	0.55	(0.45)	0.48	(0.31)
	75-100	0.39	(0.34)	0.38	(0.21)
	100-125	0.36	(0.26)	0.36	(0.17)
	125-150	0.27	(0.27)	0.37	(0.20)

2.1.3 Effect of Boron Pretreatment on the Performance of In-Service Utility Poles: SnoPUD System

Boron pretreatment of oil-borne preservative treated poles has shown promise in preventing heartwood decay in small scale and field studies performed at OSU and elsewhere. However, utilities have an interest in monitoring how these treatments perform when they are implemented in a real-world scenario. The UPRC has initiated a long-term field sampling effort in conjunction with Snohomish County PUD to monitor the impact of boron pretreatments on the performance of copper naphthenate-treated utility poles over the long term. The study also monitors boron migration throughout the pole sections to determine whether boron pretreatment leads to inward boron migration in in-service poles as was predicted by smaller-scale studies. The pole treatments that are being monitored for this study are summarized in table 2.1.8.

Poles monitored in this study were installed in 2014 and were first sampled 2019 and the results of this sampling are described in the 2019 report. There was no sampling done this year. The sampling schedule for this project will be re-assessed once travel restrictions are lifted and logistics can be determined.

Table 2.1.8. Total number of poles sampled for each treatment.

Treatment	Poles (#)
CuNap Only	19
Dual Treatment	24
Dual Treatment + Field Liner	5
Total Poles in Study	48

2.2.0 References for Objective II

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OBJECTIVE III:

EVALUATE PROPERTIES AND DEVELOP IMPROVED SPECIFICATIONS FOR WOOD POLES

Objective III aims to develop new primary treatment methods, explore the potential for new wood species, assess various inspection tools, and explore methods to produce more durable wood poles.

3.1.0 Effect of coatings, pole caps and pole top orientation on the performance of above ground portions of utility poles.

Most of the efforts taken up by the UPRC focus on preventing decay at or around groundline whether it be through the improvement of initial pole treatments or through internal remedial treatments. However, decay further up the pole and on utility pole crossarms is also a concern for the lifetime performance of the utility infrastructure. Invade poles more slowly at higher elevations, but over time the ingress of moisture, especially at the pole end grain, increase the risk of decay and consequent failure.

Preservative treatment can penetrate through the end of the pole for distances ranging from 150 to 450 mm depending on the species. While this level of protection is far greater than is seen farther away from the ends, checks and splits that develop as the pole seasons can still disrupt the preservative barrier. This results in the ingress of moisture and decay organisms which may lead to early replacement. Remedial treatment of this type of damage is difficult and the best approach is prevention through the application of a water shedding cap.

The UPRC has long advocated for utilities to use water shedding caps to protect the tops of utility poles. However, there were insufficient data showing the effects of capping on pole condition. In this section, we will present data on three tests examining the effects of capping as well as pole top shape on moisture content. Moisture content has been used as an indirect indicator of decay risk because poles that become wet are likely to be at tacked by decay fungi.

Similar issues of above ground decay plague crossarms, and while decay may not be as rapid as at groundline, crossarms are still susceptible to decay and moisture ingress, particularly if checking has occurred and the preservative-treated shell is penetrated. Crossarms carry essential distribution equipment and therefore the function of the entire pole rides on the integrity of the crossarms. Like pole tops, decay prevention can play an important role in ensuring long-term performance for crossarms and coatings which exclude moisture and slow the ingress of fungal hyphae can help facilitate this.

3.1.1 Effect of Conventional Capping on Pole Moisture Content:

Ten Douglas-fir poles that had been removed from service were cut into 2.5 m lengths and set in the ground to a depth of 0.6 m. The poles were cut so that the top was at least 150 mm away from any pre-existing bolt hole. The original bolt holes on the pole sections were then plugged with tight fitting wood or plastic plugs to retard moisture entry. Five of the poles were left without caps while the remainder received Osmose pole caps.

Initial moisture contents for each pole were determined during installation from increment cores taken 150 mm below the top of the pole. The outer treated zone was discarded (about 15 mm), and the inner and outer 25 mm of the remainder of the core were weighed, oven-dried, and re-weighed to determine wood MC.

Cap effect on MC was assessed 4 to 153 months after installation by removing increment cores from just beneath the pole cap or at an equivalent location on the non-capped poles (Table 3.1.1). The cores were processed as described above. Moisture contents were initially higher in capped poles, but have since declined to a range of 7.0% to 25.6% over the 153 months since installation. The moisture level generally considered necessary for fungal attack is 28.0%-30.0%. Thus, wood in the area beneath the caps is below the level required for fungal growth (Table 3.1.1). Moisture contents of poles without caps were initially lower than the capped poles, but levels have steadily increased over time. Moisture contents were very high after 90 months of exposure and there was some decay evident in cores. Moisture contents dropped in subsequent sampling of uncapped poles averaging 29.5%, 17.9%, 13.8% and 30.8% the inner segments after 113, 126, 142 and 153 months, respectively. Moisture levels closer to the surface during this period were lower than the inner portion of the poles, ranging from 10.4%-21.5% (Table 3.1.1). The higher moisture levels in the center are consistent with previous results. These results suggest that uncapped poles are more susceptible to moisture impulses that may temporarily increase moisture levels well above those necessary for fungal growth. During this time the caps remained sound and free of damage that might allow moisture to intrude into the wood (Figure 3.1.1). The results clearly show the benefits of capping in terms of reducing internal moisture content. Ultimately, reducing the time when conditions are suitable for fungal growth should translate into improved performance.

Figure 3.1.1. Example of the condition of water-shedding caps at the start of exposure and after 126 and 142 months of exposure in Corvallis, OR.

Table 3.1.1. % Moisture contents in Douglas-fir poles with or without water shedding caps as determined over 153 months

Exposure (mo)	Sampling Month	Control		Pole Cap	
		inner	outer	inner	outer
0	February	20.1	16.8	28.4	19.7
4	June	25.2	18.9	19.0	18.3
12	February	37.5	26.1	14.2	16.4
28	June	60.7	27.4	15.5	15.9
32	October	29.3	17.4	13.6	13.5
40	June	99.3	35.5	13.6	16.1
44	October	53.1	21.5	14.7	14.1
52	June	85.1	22.0	-	-
56	October	41.7	23.3	9.8	9.4
64	June	48.4	13.0	8.8	8.3
90	August	83.6	28.2	13.3	11.0
113	July	29.5	21.5	18.1	16.3
126	August	17.9	10.4	7.7	7.0
142	December	13.8	12.9	10.2	10.6
153	November	30.8	20.9	25.6	19.4

3.1.2 Use of Polyurea Caps to Limit Moisture Intrusion on Douglas-fir Pole Tops

Polyurea barriers have proven to be durable on crossarm sections in sub-tropical exposures in Hilo, Hawaii (See section 3.1.5). Given good performance in high decay hazard environments, these coatings are likely to perform well as moisture barriers in other applications as well. The

UPRC initiated a study to investigate polyurea coatings as a pole capping system. Six penta-treated Douglas-fir pole sections (3.0 m long) were coated with polyurea from the tip to approximately 0.9 m below that zone (Figure 3.1.2). The poles were set to a depth of 0.6 m at a test site on the OSU campus. Increment cores were removed from the non-coated section of the pole and divided into inner and outer 25 mm sections as described above. Each core section was weighed immediately after removal from the pole, oven-dried, and re-weighed. The difference was used to determine MC. The sampling hole was covered with a patch of seal-fast tape (Mule-Hide Products, Beloit, WI). Moisture contents at the time of installation for the coated poles for the inner and outer zones were 23.8% and 19.0%, respectively (Table 3.1.2). The poles, installed in the spring of 2011, were sampled after 4, 12, 16, 24, 50, 73, 86, 90 and 101 months of exposure to assess the effect of the coating on internal moisture. Increment cores were removed in the same manner as previously described and MC was determined for each pole. Non-coated, non-capped poles from the previously-installed moisture-shedding pole cap study served as controls. The condition of the surface coating was also visually monitored for evidence of adhesion with the wood as well as the development of surface degradation.

Figure 3.1.2: Example of a polyurea capped pole top during installation in 2011.

The caps remain sound and free of damage 8 years after installation (Figure 3.1.3). Moisture contents of non-coated poles were generally higher than capped poles from the 12-month to the 86-month sampling point. At most of these sampling points the inner pole core segment had a moisture content above 30% in the uncapped poles, indicating conditions were amenable to fungal growth. The outer pole segments were generally below the 28.0%-30.0% threshold for fungal growth. Moisture contents ranged from 10.4%-85.1% in all portions of uncapped poles in the 12 to 90-month period. During this same period the polyurea-coated poles had generally lower moisture levels and remained mostly below the threshold for fungal growth ranging from 4.6%-34.4% in this period. In most cases the inner pole core segments had a higher moisture levels than the outer pole segments. At the 78 and 90-month sampling points, the uncapped pole cores dropped in moisture content below or about equal to the polyurea-coated poles. At the 101-month timepoint, uncapped poles started to show higher moisture levels than capped poles again, although the difference was not as dramatic as the earlier timepoints in the study.

Table 3.1.2. Moisture content beneath the tops of Douglas-fir poles with and without a water-shedding polyurea coating as determined over 101 months.

Exposure (mo)	Sampling Month	Coated Poles		Control[1]	
		inner	outer	inner	outer
0	June	23.8	19.0	99.3	35.5
4	October	21.6	13.2	53.1	21.5
12	June	4.6	8.3	85.1	22.0
16	October	17.9	16.2	41.7	23.3
24	June	17.8	14.0	48.4	13.0
50	August	17.3	18.3	83.6	28.2
73	July	34.4	24.2	29.5	21.5
86	August	15.0	16.0	17.9	10.4
90	December	18.3	12.0	13.8	12.9
101	November	12.3	10.5	25.6	19.4

[1] Moisture content data from the controls from the Osmose capping study are included here for comparison.

Figure 3.1.3. Condition of polyurea coatings on the tops of Douglas-fir pole sections after 73 months (left) and 90 months (right) of exposure in Corvallis, OR.

3.1.3 Effect of Pole Top Configuration on Moisture Uptake in Poles

In previous tests, we have explored the benefits of capping poles at the time of installation to retard moisture uptake and limit the potential for pole top decay. These tests have shown dramatic differences in moisture content between poles with and without caps. One other aspect of a pole specification is variation in the shape of the pole top. Some utilities specify a flat top, while others require sloping or roofed tops. The presumption is that the slope encourages water to run off the wood more quickly, thereby reducing the risk of water uptake that creates conditions conducive to fungal attack. However, sloping surfaces expose a greater wood surface area to wetting, thereby potentially increasing the risk of moisture uptake. This becomes especially important as poles season and check in service. Preservative treatment imparts some moisture resistance to wood, but continuous wetting and drying can lead to checking and greater moisture uptake over time. This increased moisture content swells the wood. Stresses develop as the wood dries which lead to the development of micro-checks on the upper surface that act as conduits for moisture to penetrate into the wood, potentially beyond the original depth of preservative treatment. There are, however, no data examining differences in moisture uptake on pole tops with differing roofing patterns. In 2017, we established a study to test the effect of pole top orientation on moisture content.

Douglas-fir poles were cut into twenty-four, 0.9 m long sections which were allocated to four different treatment groups. Two groups were left with their tops cut perpendicular to the length. The tops of one set of pole sections were cut at 30-degree angles while the final set was cut with two sloping sides coming to a point (Figure 3.1.4).

Poles were then pressure treated with penta in P9 Type-A oil in a commercial cylinder. Half of the poles with their tops cut perpendicular to the longitudinal direction received a commercial water shedding cap, while the remaining pole sections received no cap. In our previous capping tests, we removed increment cores from poles at varying intervals. These cores were weighed, oven dried, and re-weighed. Differences were used to determine wood moisture content. This process, while accurate, was time consuming and created a tremendous number of holes in each section that could become pathways for moisture ingress. In the current test, we used weight gain of each section as an indirect moisture change measure. Each section was weighed to record a starting weight, then placed upright on a rack. The rack was exposed outside and samples were periodically weighed to assess effects of pole top configuration on moisture uptake.

Sample moisture contents varied somewhat at the time of installation and the resulting changes in mass as the samples dried made it difficult to delineate differences associated with roofing style. To deal with this issue, the mass of the samples at the end of the summer was used as the initial starting point for assessing future moisture changes. This time was chosen because the pole sections had ample time to dry during the hot, rain-free summer months. As a result, differences measured by weight changes do not reflect absolute moisture content, but relative changes to our selected start time.

Figure 3.1.4. Examples of the different pole top roofing patterns assessed for their ability to resist moisture ingress.

Table 3.1.3. Mass changes of Douglas-fir pole sections with different top configurations as determined by weighing over a 39-month exposure period in western Oregon.

Exposure Time (Months)	Average Moisture Content (%)			
	Double Pitch	Flat	Flat w/Cap	Single Pitch
9/20/2017	0.0 (0.0)	1.8 (1.8)	1.2 (1.4)	1.5 (1.8)
10/25/2017	2.2 (1.5)	3.3 (0.9)	0.7 (1.3)	2.3 (1.6)
12/21/2017	6.8 (2.1)	7.5 (1.1)	3.3 (2.7)	6.2 (3.0)
4/2/2018	5.2 (1.6)	6.2 (1.4)	3.3 (1.4)	4.7 (2.0)
5/7/2018	3.9 (2.2)	4.2 (1.6)	1.2 (1.4)	3.1 (0.3)
8/14/2018	0.0 (0.0)	0.9 (1.3)	1.4 (1.6)	0.0 (0.0)
9/19/2018	2.7 (1.0)	2.6 (0.9)	2.6 (0.3)	4.4 (2.9)
10/15/2018	-1.4 (1.7)	0.0 (0.0)	0.2 (2.1)	-3.1 (0.3)
11/18/2018	6.8 (2.1)	7.5 (1.1)	3.3 (2.7)	6.2 (3.0)
1/15/2019	5.2 (1.6)	6.2 (1.4)	3.3 (1.4)	4.7 (2.0)
2/18/2019	5.2 (1.6)	6.5 (0.8)	2.6 (0.3)	5.4 (1.8)
3/18/2019	1.3 (1.5)	3.2 (0.8)	1.4 (1.6)	2.3 (1.6)
4/17/2019	3.7 (1.3)	5.0 (0.7)	1.2 (1.4)	3.1 (0.3)
5/20/2019	-0.8 (1.6)	1.5 (1.4)	-0.6 (1.1)	0.9 (1.7)
7/8/2019	-0.8 (1.6)	0.0 (0.0)	-0.7 (1.5)	-0.7 (1.5)
8/8/2019	0.0 (0.0)	1.0 (1.3)	1.9 (1.3)	3.8 (1.4)
12/12/2019	1.9 (2.4)	5.0 (0.9)	2.6 (0.3)	3.1 (0.3)

12/11/2020	0.8 (3.1)	3.0 (2.1)	2.5 (1.8)	8.3 (14.4)

[a] *Values represent means of 4 or 5 replicates per roof style. Figures in parentheses represent one standard deviation.*

The results over the first year (2017-2018) showed that mass changes were greatest during the December to April period, then declined over the next 5 months (Table 3.1.3). Pole sections with a flat top and cap had the lowest mass gains over the test period, while mass changes in the other pole sections were similar to one another. The initial results do not show dramatic differences among the various roofing designs; however, this may change as the poles weather over several more wetting and drying cycles.

The second year of sampling (2018-2019) showed only small differences in the relative moisture contents among the different treatment types on the order of only a few percentage points at maximum. The double-pitched pole tops tended to run slightly drier after the summer months than the flat uncapped configuration, but these differences were mostly statistically indistinguishable. The flat capped configuration tended to remain slightly drier than the others during the wetter months. One interesting sampling point was our most recent sampling in December 2019. The flat uncapped configuration had a higher relative moisture gain than all of the other configurations. This may have been caused by the unseasonably dry conditions in November 2019, which may have allowed increased drying for high surface area configurations. At the December 2020 sampling, one of the single pitch replicates was much heavier (~30%) than it was at the start of the study indicating substantial moisture uptake which increased the group average substantially. Other replicates with this orientation did not see large increases in moisture content. The other orientations did not show weight changes that were dramatically different than the previous sampling, although the smallest year-on-year change was the flat capped treatment, which suggests capping may stabilize moisture content to a greater degree than the other orientations. We will continue to monitor these sections to determine if pole top configuration ultimately affects moisture uptake. The poles, as they appeared in December 2019, are included in Figure 3.1.5.

Figure 3.1.5. Status and appearance of pole top configuration poles in December of 2019.

3.1.4 Effect of Capping and Supplemental Chemical Treatment on Marine Pile Decay

Capping clearly reduces the risk of moisture entry into pole tops, creating conditions that are less conducive to fungal attack. However, we have largely limited our assessments to moisture measurements beneath caps as an indirect measure of decay risk. In the 2018 Annual Report, we reported on a long-term trial that examined the benefits of capping on marine pilings at the South Beach Marina in Newport, OR. The overall results highlight the benefits of capping to prevent fungal decay and further details of this study are summarized in the 2018 Annual Report.

3.1.5 Performance of Polyurea-Coated Douglas-fir Crossarm Sections Exposed in Hilo Hawaii: 128-month report

Preservative treated Douglas-fir resists decay in above ground applications such as utility pole crossarms. However, Douglas-fir has a notably difficult to treat heartwood and as a result preservative penetration is not very deep and checks on the surface can expose untreated wood, leading to the ingress of decay organisms. Coatings can provide an additional layer of protection against moisture and decay organisms and can help provide protection for areas where preservative treated shell has been penetrated and untreated heartwood is exposed. One alternative is to coat the exterior of the arm to retard moisture entry and presumably limit fungal and insect entry. Polyurea coatings have been employed to protect a variety of surfaces and appear to have potential as wood coatings in non-soil contact. Polyurea coatings were evaluated for their capacity to protect penta-treated and untreated Douglas-fir crossarm sections in above ground exposure in Hilo, HI.

Douglas-fir cross arm sections were either left non-treated or pressure treated to the AWPA Use Category requirement with pentachlorophenol (penta) in P9 Type-A oil. Half of the arms from each treatment group were then coated with polyurea. The arms were then shipped to Hilo, Hawaii, where they were exposed on test racks 450 mm above the ground. The site receives approximately 5 m of rainfall per year and the temperature remains a relatively constant 24-28 °C. The site has an extreme biological hazard (280 on the Scheffer Climate Index Scale which normally runs from 0 (low) to 100 (high) decay risk within the continental U.S.) and a severe UV exposure. Non-treated pine sapwood exposed aboveground normally fails within 2 years at this site, compared to 4 to 5 years in western Oregon. The cross arms were installed in June 2009. Primarily visual assessment consisted of examining coating condition on the upper (exposed) and lower surfaces (Figure 3.1.6). Additional coated samples were exposed in June, 2011.

Figure 3.1.6: Polyurea coated and non-coated samples shortly after exposure in Hilo Hawaii.

After 4 years of exposure the non-treated, non-coated Douglas-fir samples began to experience decay on the sides and undersides where moisture collected and there was evidence of fungal fruiting bodies in the untreated samples (Figure 3.1.7). These samples had an average rating of 7.0 on a scale of 10 (perfectly sound, no evidence of biological attack) to 0 (complete failure). Non-coated penta treated samples had some weathering on the upper surfaces, but remained sound and free of decay. All of the penta treated, non-coated samples rated 10.

Figure 3.1.7. Example of a non-treated, non-coated wood sample after 4 years of exposure in Hilo, Hawaii, showing evidence of fungal decay and fruiting bodies

Polyurea coated samples are challenging to evaluate without damaging the coating, therefore periodic destructive sampling of a single sample from each treatment was done to assess the condition of crossarm sections. One to two samples from each treatment were removed and dissected to determine the degree of damage inside the coating after 48, 72 and 128 months of exposure and results through the 72-month sampling are described in Konkler et al. 2019. Samples were visually examined for damage at the field site in years between these sampling dates. Penta treated samples were sound and free from obvious decay, although there were differences in coating thickness on the upper, UV-exposed surface and the bottom that had not been exposed to sunlight (Figure 3.1.8). Penta had also migrated through the surfaces of the polyurea coated samples to a limited extent, but the samples otherwise appear to be free of attack. The non-treated, but coated samples also appeared to be free of fungal attack, but there were a few differences in appearance. The upper coated surfaces on these samples were more heavily degraded (Figure 3.1.9). Cutting revealed the sample had decay pockets immediately beneath the coating. These results suggest the coating was not a complete barrier against fungal attack (Konkler et al. 2019).

Figure 3.1.8. Example of lower, non-UV exposed surface of a coated, penta treated section showing evidence of oil migration towards the surface after 6 years of exposure in Hilo, Hawaii

Figure 3.1.9. Photos of the upper surfaces of coated, non-treated control samples after 6 years of exposure in Hilo, Hawaii showing erosion of the coating and complete loss of coating on the corner.

Once crossarm pieces were destructively sampled, coatings were carefully separated from the wood and the thickness was measured on upper and lower surfaces. Coatings were then tension-tested to determine peak load. Results from the four-year sampling suggested coatings on non-treated wood experienced thickness loss on the UV exposed surface whereas these losses were less with penta-treated crossarms (Table 3.1.4). The lower effect on penta-treated samples was likely due to migration of oil from the original penta treatment through coating and to the surface which likely provided some UV protection.

Table 3.1.4. Condition of polyurea coatings removed from the upper (UV exposed) and lower (non-UV exposed) surfaces of non-treated and penta treated Douglas-fir sections exposed for 48 months in Hilo, Hawaii.[a]

Treatment	Top/Bottom	Thickness (mm)	Density (g/cm^3)	Peak Load (N)
None	Top	0.89	0.88	257
	Bottom	1.85	0.99	455
Penta	Top	1.68	0.94	533
	Bottom	1.85	1.05	709

[a]Values represent means of 2 samples per material exposure.

Samples collected after 72 months were cut lengthwise in approximately four equal sections so that the upper (UV) and lower (non-UV) surfaces were exposed. The sections were examined for evidence of decay. Penta-treated samples were sound and exhibited no evidence of visible decay or discoloration. Non-treated samples had small pockets of decay on both the upper and lower surfaces immediately adjacent to the coating. This was interesting because we might expect to see fungal attack on the upper surface where the coating had thinned to the point where fungal hyphae could penetrate into the wood, but the coating on the lower surface was thick enough to provide a barrier against fungal attack (Figure 3.1.9). One possibility is that the fungi grew around the timbers along the wood/coating interface so that attack was occurring all around the timber.

Figure 3.1.10. Interior of a coated, untreated Douglas-fir section after 6 years of aboveground exposure in Hilo, Hawaii.

The coatings on the upper and lower surface were separated from the 72-month samples and thickness was measured with digital calipers. The results are summarized in Table 3.1.5. Coating thickness declined in the upper and lower surfaces of non-treated samples and only the upper surface on treated samples relative to the 48-month sampling point. For both treated and untreated samples, the coating on the upper, UV-exposed surface was thinner than the lower surface, indicating UV damage (Table 3.1.5). The upper surface of untreated sections was heavily discolored and thinned.

Table 3.1.5. Thickness of polyurea coatings on non-treated and penta treated Douglas-fir timbers after 72 months of above-ground exposure near Hilo, Hawaii.

Replicate	Coating Thickness (mm)			
	Non-Treated		Treated	
	Upper Surface	Lower Surface	Upper Surface	Lower Surface
1-1	0.90	1.17	1.54	2.47
1-2	0.86	1.06	1.54	2.40
1-3	0.97	1.08	1.76	2.37
1-4	0.99	1.12	1.75	2.18
1-5	0.92	1.10	1.82	2.15
2-1	0.19	1.53	1.16	2.01

2-2	0.26	1.77	1.18	2.42
2-3	0.46	1.38	1.42	2.02
2-4	0.30	1.40	1.66	1.66
2-5	0.40	1.48	1.94	2.16
3-1	0.84	1.40	1.22	1.30
3-2	0.84	1.36	1.13	1.18
3-3	1.03	1.37	1.06	1.35
3-4	1.00	1.34	0.76	1.54
3-5	0.50	1.38	0.68	1.48
Average (SD)	0.70 (0.31)	1.33 (0.19)	1.37 (0.38)	1.91 (0.45)

The sectioned samples were cultured for decay fungi by sampling small fragments from different locations on the four sections. The plates were examined for evidence of growth of basidiomycetes and the results were summarized in Table 3.1.6. A variety of fungi were isolated from both treated and non-treated sections, with more than 140 fungi were isolated from 120 samples removed from non-treated arms, and 94 fungi were isolated from 101 samples from penta treated arms (Table 3.1.6). Only 3 decay fungi were isolated from penta treated arms, while 43 decay fungi were isolated from non-treated arms. The difference reflects the efficacy of penta as a preservative but also the benefits provided by a thicker polyurea coating which remained more intact on penta-treated crossarms. The frequency of dematiaceous fungi was higher in penta treated arms. Dematiaceous fungi are typically more tolerant of preservatives and many are capable of producing soft rot decay. While no decay was evident in the penta treated samples, the presence of these fungi might eventually cause wood damage. Interestingly, decay was not located directly beneath the thinned barrier but rather on the lower surface where the barrier was thickest. The upper surface may have been a less hospitable environment for fungi because of its direct exposure to sunlight and no doubt higher average temperatures during the daylight hours. Oil in penta treated arms diffused into the coating and was visible on the bottom surface of the crossarms and this material might have protected helped protect the crossarms from intrusion of decay fungi as well as protected the coating from UV light degradation.

Table 3.1.6: Fungi isolated from non-treated and penta treated Douglas-fir timbers coated with polyurea and exposed above ground near Hilo Hawaii from 84 months.

Fungus	Non-treated	Treated
Attempts	120	101
Decay Fungi	43	3
Non-Decay Fungi	102	91
Dematiaceous Fungi	31	82

Three exposed crossarm pieces were sampled from the above ground decay site in Hilo, HI after 128 months of exposure, two penta-treated and one untreated sample. The samples were photographed and the surface condition assessed before slicing the crossarms into four longitudinal sections (Figure 3.1.10-11). The remaining coating was removed and coating thickness was measured as above. The untreated sample was heavily degraded and had significant areas of exposed wood where decay was easily identified. One penta-treated sample (penta 1) had intact coatings on both upper and lower surfaces and showed heavy oil deposits on the bottom surface. The interior of the penta 1 sample exhibited no obvious signs of decay while the untreated sample showed extensive decay and parts of the wood readily was friable (Figure 3.1.11). The second penta sample (Penta 2) had extensive damage to the polyurea coating on the upper surface and in sections, much of it was gone (Figure 3.1.10). The bottom surface also had oil deposits similar to the other penta-treated sample.

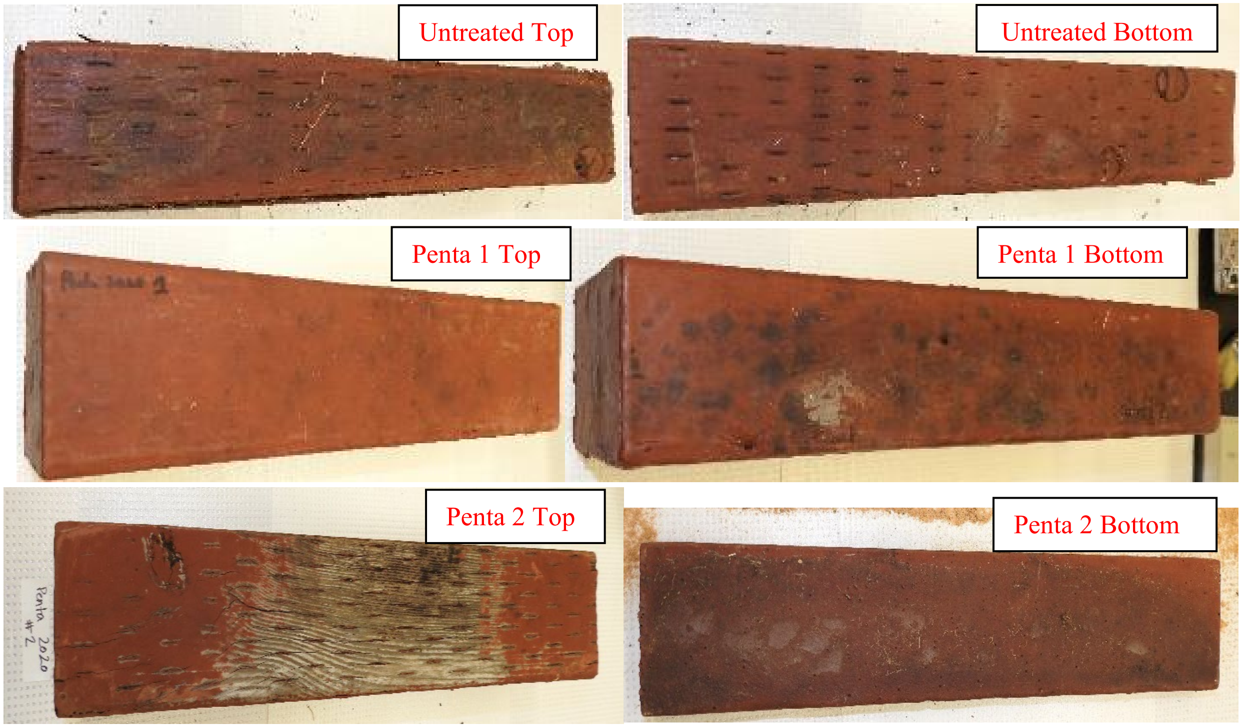

Figure 3.1.10: Top and bottom surfaces of untreated (top) and penta-treated (middle and bottom) Douglas-fir crossarms.


Untreated


Penta 1

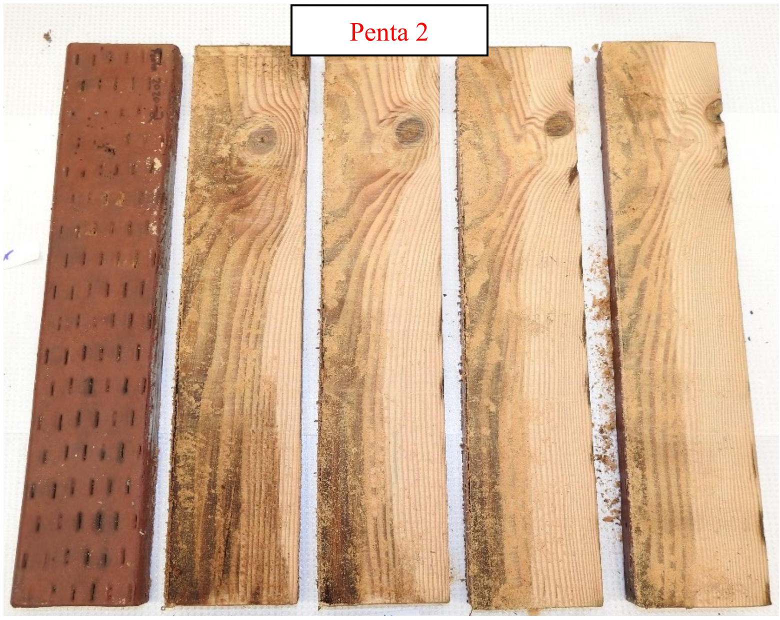

Figure 3.1.11: Sectioned crossarm sections of the untreated crossarm (top) and penta-treated (middle and bottom) coated crossarms pieces.

Coating thickness measurements showed a similar pattern to data from previous sampling points where the coating thickness for the penta-treated crossarm showed greater thickness than the untreated crossarm, particularly for the Penta 1 sample. The coating from the penta 2 sample on the upper surface was take from locations where the coating could still be sampled as over a large area of the top surface the coating had deteriorated. The untreated sample showed heavy decay where the surface had started to fragment and fall away from the wood. These results may indicate that the coatings of the untreated and penta 2 samples were penetrated by abiotic factors and was subsequently invaded by fungal hyphae, leading to the decomposition of the wood. The data from the penta 1 sample showed that both the penta treatment and the polyurea coating were successful at protecting the wood within. The penta 2 sample also exhibited signs of decay when it was sectioned which is a significant departure from the penta 1 sample (Figure 3.1.11). When assayed for pentachlorophenol retention, the penta 2 sample contained only about 0.4 kg/m^3 indicating that either significant depletion occurred, or the samples were undertreated to begin with. This indicates that the likely reason for the poor performance of one of the two penta samples analyzed at after 128 months of exposure was due to low levels of penta in the wood.

Table 3.1.7: Coating thickness measurements for penta-treated and untreated, coated Douglas-fir crossarms exposed in above ground contact in Hilo, HI for 128 months.

Polyurea Crossarm coating thickness (mm)		
ID	untreated	
	top	bottom
Untreated 1	1	1

Untreated 1	1	1
Untreated 1	0.8	1
Untreated 1	0.8	0.9
Untreated 1	0.8	1
Average (stddev)	0.88 (0.11)	0.98 (0.04)
Penta 1	1.75	1.5
Penta 1	1.5	1.5
Penta 1	1	1.75
Penta 1	2	2
Penta 1	1.5	2.1
Average (stddev)	1.55 (0.37)	1.77 (0.28)
Penta 2	1	1
Penta 2	1	1.2
Penta 2	1	0.9
Penta 2	1.25	2
Penta 2	1	1.8
Average (stddev)	1.05 (0.11)	1.38 (0.49)

Fungal culturing results supported observations of the sectioned crossarms. The heavily decayed untreated crossarms contained more decay fungi than the penta-treated crossarms, although two isolates from penta 1 and three from penta 2 appeared to be decay fungi (Table 3.1.8). The untreated crossarms also contained far more dematiaceous fungi than the penta 1 sample. Penta 2 contained the most dematiaceous fungi of the three samples, suggesting that soft rot may be an issue in this sample. While the number of decay fungi isolated from penta-treated crossarms was low it was not zero, indicating that the intact coating on the penta-treated crossarm did not entirely exclude decay fungi. This suggests that the fungi may be able to grow through the polyurea barrier, or there were existing decay fungi existing in the penta-treated samples that survive the treating process.

Table 3.1.8: Number of fungal isolates found in wood samples taken from treated and untreated polyurea-coated crossarms.

Treatment	Decay fungi	Non-decay fungi	Dematiaceous
Untreated	8	16	18
Penta 1	2	18	2
Penta 2	3	37	32

3.2.0 Developing Data on the Ability of Various Systems to Protect Poles from Wildfire

In North America, wildfires in the western regions are predicted to increase in size and severity moving into the future due to a combination of factors. Hands-off forest management practices as well as large beetle outbreaks in public forest land has led to an excess of fuel buildup and greater risk of large fires. This situation is exacerbated by the projected more extreme periods of drought forecast into the future. This causes an increased risk of damage to or loss of utility assets which has drawn the attention of utilities throughout western North America.

Wood poles have in-built susceptibility to wildfire and system hardening to reduce the risk of fire damage may include replacement with more fire-resistant materials such as steel. However, it is unclear how steel poles would perform in a wildfire under load and replacing wood poles with steel eliminates other positive benefits of using wood poles in utility systems such as a reduced environmental impact compared to steel or concrete (Bolin & Smith, 2011; Smith, 2014). Additionally, utilities have existing networks largely built with wood poles and therefore have an interest in preventing the damage of wood poles by wildfires.

Utilities have begun exploring the use of fire retardants and other fire-protective barriers on wood poles and there are many examples of pre-installation and post-installation methods to protect poles from fire. Some of these include pressure treatments, spray on or paint-on treatments, or physical barriers and mesh wraps that are available from a variety of sources. As more fire-retardant systems are developed for wood poles, utilities must have methods of testing these treatments to verify their efficacy. However, certified materials testing facilities capable of fire testing are prohibitively expensive to use for each experimental treatment and can total in the tens of thousands of dollars to test a single treatment. At this price, official testing would need to be reserved for a nearly finished product and experimental treatments would need to be screened out before this stage. Many utilities have devised their own small-scale tests for screening fire retardant treatments, however these vary from utility to utility and no standard method exists for rapid, low-cost screening that can be used across all utilities.

The OSU UPRC has made strides to develop a standard method for pole fire retardant testing that is inexpensive and can be constructed and carried out with readily available materials. Fire testing has been done at OSU periodically since the late 1990s and since 2014 has been a regular component of the research done annually in the UPRC (Morrell, 1999, 2014). Now we intend to continue to develop our testing capabilities with the end goal of standardizing a testing method to be included in the American Wood Protection Association (AWPA) Book of Standards.

There have been three types of fire tests done on fire retardant treatments for poles in the UPRC each using different heat sources. Earlier testing starting in the late 1990s trialed pole treatments using bags of straw leaned against pole sections as fuel for an open flame (Morrell, 1999). Later iterations of this method utilized straw stacked up around the circumference of poles to achieve a more complete burn (Morrell, 2006). The use of straw fuel and an open flame to test fire retardant treatments suffered from several deficiencies that made these types of test difficult to reproduce. While it was generally considered beneficial that the pole sections would be exposed to an open flame, the fire intensity was not reproducible year to year due to variations in the ambient conditions. Heterogeneity in the fuel source is another issue for this method and variations in the moisture content and quality of the straw fuel led to variation in the testing conditions year-to-year.

To address these issues, a fire test was develop which employed a weed burner as an ignition source (Morrell, 2014). This test allowed the heat level to be controlled and was more reproducible than straw bale-based tests, but it represented a rather intense flame exposure that may not be representative of real-world conditions. The testing apparatus also only exposed one side of the pole sections to flame.

The latest testing apparatus uses ceramic heating panels directly under a hot wire bracketed by a steel heat shield which wraps around the pole surface (Morrell, 2015). An early version of this apparatus was affixed to a tripod where it could be moved and put directly against the pole surface. The heat panel design has several advantages include the consistent and reproducible application of heat which will allow the comparison of different treatments done at different locations. The test is more controlled compared to straw bale-based tests and there is no open flame until the ignition of the test pole itself which makes it safer to operate. Finally, the system is portable and easily constructed with readily available materials which is necessary if a standard method is to be developed that can be used by separate entities.

The heat panel testing apparatus has been used to test several spray-on or paint-on fire retardant treatments in addition to several protective barriers and mesh wraps. The results of these tests can be found in previous reports (Morrell, 2015, 2018; Presley, G.N., Cappellazzi, J., Konkler, M., and Sinha, 2019). The original design of the fire testing apparatus had some significant drawbacks. It only allowed a small portion of the pole surface to be burned, and therefore limited to the testing area to a small portion of the total surface area. This caused a deficiency in measuring damage because total circumference loss as a measure of fire damage was not useful in this test. Instead depth of char and total surface area burned was used as a measure of fire damage. Circumference loss can be used to calculate estimated strength loss so as a practical matter it is a more useful for determining the impact on pole performance. The small area bracketed by the heat shield in the original design also allowed excessive heat loss to the surrounding and greater protection of the heat source of the apparatus was needed to expose the poles to a more rigorous evaluation.

3.2.1 Modification of the fire testing apparatus

In this year's report we describe modifications to the fire testing apparatus that we believe will be its final iteration before standardization by AWPA. The initial design was expanded to include three ceramic heating panels affixed below a hot wire shielded under a piece of sheet metal (Figure 3.2.1). The heating elements were bracketed by a large piece of 5-sided sheet metal that extended out so that the ends of the sheet would reach around a pole. The entire apparatus was affixed to a small dolly so it could be rolled around. Two identical units were constructed and would be used together to encompass the entire circumference of a pole section and retain heat (Figure 3.2.2). All subsequent tests were performed using two units simultaneously applying to two faces of the pole section. The surface temperature of the poles was also monitored during the burns using an 18″ Hastelloy thermocouple affixed to the surface of the pole section at the base using a loosely attached staple. Temperature was measured on one surface directly facing the ceramic heat panels.

Figure 3.2.1: Modified fire ceramic panel-based testing apparatus made in 2020 in face view and profile.

Figure 3.2.2: Orientation of two identical burn units during a fire test at different stages, during heating and then after combustion.

One of the goals of this effort is to design a testing apparatus that is low-cost and can be fabricated readily by many different users. The testing apparatus made here was partially fabricated in a metal shop which utilized equipment to bend, cut and drill sheet metal. Most other components were used as purchased except the dollies, which were slightly modified using and angle grinder blade. Table 3.2.1 summarizes the total cost of components used in constructing these units and a brief description of the tools needed to fabricate them.

Table 3.2.1: Cost estimates for fires test components.

Item	Specs	Supplier	Quantity	Cost	Total
Hastelloy Thermocouple	18-inch, plain, Type-K	Chemglass	1	104.45	104.45
Thermocouple Extension Cord	Type-K	Chemglass	1	61.29	61.29
Thermocouple Reader/Data Logger		Chemglass	1	242.05	242.05
Robert Shaw hot surface igniter	LP/NG, 120V AC, 4 1/2 in L., Silicon Carbide	zoro	2	15.16	30.32
Tempco IR heaters	240V, 1000W	zoro	6	21.64	129.84
Plugs + Cord	220 V, 30 amp, 35'	zoro	2	81.51	163.02
Extension Cord	50'	zoro	2	45	90
Hand Truck		zoro	2	62.42	124.84
Sheet metal		TBD		TBD	N/A
Generator		TBD	1	TBD	500 (est)
Total Costs					**1445.81**

3.2.2 Initial tests using the updated fire testing apparatus on treated and untreated Douglas-fir pole sections

The modified fire testing apparatus was used to burn treated and untreated poles to provide baseline data on the resistance of common utility pole treatments. A standard protocol was employed to test all treatments. Poles were exposed to heating from both heating racks simultaneously until pole ignition as shown in 3.2.2. The heat was continuously applied for 10 minutes after ignition before it was removed by wheeling away the heating racks. Temperature at the pole surface facing one of the heating panels was monitored throughout the heating period using an 18″ Hastelloy thermocouple. The poles were allowed to burn for another 10 minutes followed by a 2-hour smolder before quenching (Figure 3.2.3). While the poles are too small to test flexural strength loss, section modulus can be calculated from the original and final circumference to determine calculated percentage loss to compare among treatments.

Figure 3.2.3: Examples of untreated poles with checks smoldering. Checks acted like chimneys and extended caused vigorous smoldering during the smoldering period.

After the burns were completed, the damage was assessed to determine performance. Maximum char depth and loss in circumference was measured for each pole by scraping away char and measuring circumference at the point of exposure and subtracting it from the original diameter. When checks were present, they tended to act like chimneys, and allowed a vigorous smolder throughout the smoldering period (Figure 3.2.3). Increase in check size was measured and was used as a parameter to compare treatments among poles that had checks in the burn area.

The only treatment tested to date in 2020 is the untreated control. Six untreated poles were burned and the loss in circumference, maximum char depth and check size increase was determined (Table 3.2.2). Temperature was monitored throughout the heating period (Figure

3.2.5). Temperature steadily increased throughout the heating period until ignition where a characteristic sharp spike indicated ignition. Temperature remained high as long as heat was applied. After the panels were removed, the temperature at the pole surface declined steadily, but remained high as long as the pole was burning. After the fire extinguished, the temperature declined rapidly for the remaining smoldering period.

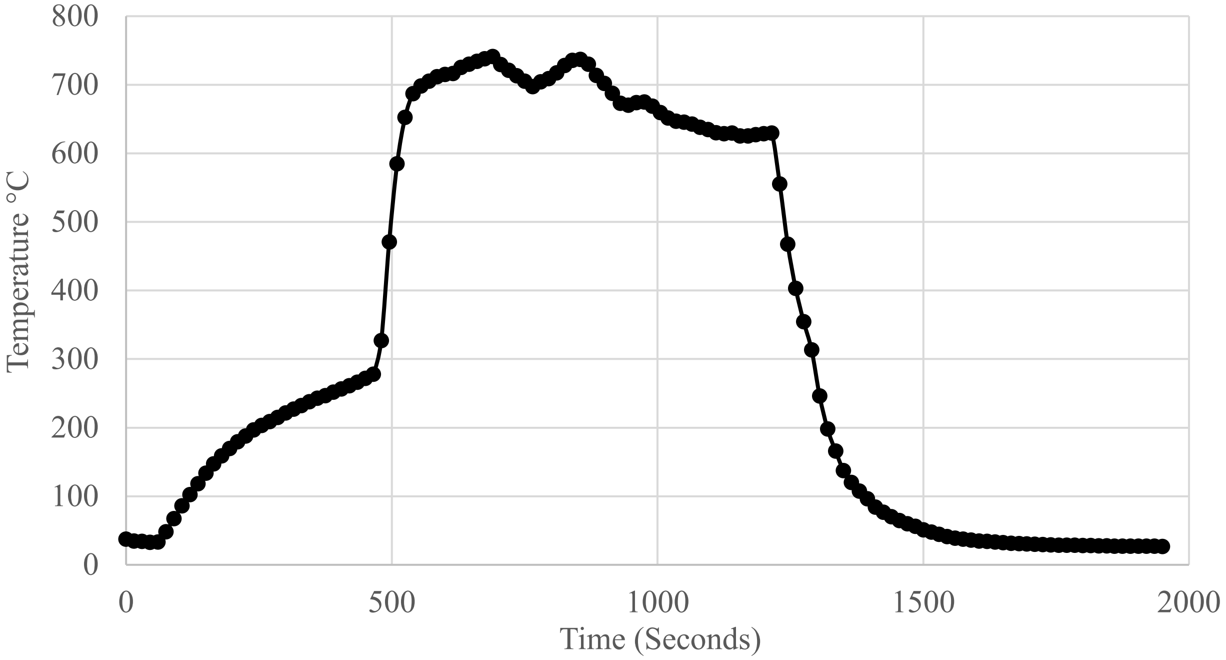

Figure 3.2.5: A typical heating curve for untreated poles. Note the sharp spike in temperature with the ignition of the poles.

Circumference loss, maximum temperature, maximum char depth and increase in check size for 6 untreated poles are shown in Table 3.2.2. Surface temperatures reached a maximum of between 665 and 741°C during the burn. Untreated poles lost between 12.7 and 66.7 mm in circumference and check widening ranged widely (3.2-92.1 mm), likely due to differences in location on the different poles. Data from untreated poles show that the new fire testing apparatus causes extensive damage to untreated poles, much greater than that produced by previous iterations of this test. This suggests that treatments will be able to be resolved from untreated controls. However, it is important to note that this test likely does not simulate real-world fire conditions that are most commonly encountered by utility infrastructure. Conditions tested here are more intense than flame exposure poles would receive from brush fires and a second test utilizing burning straw may better simulate some of the real-world conditions and be a useful companion test to develop as well.

Check widening and circumference loss were quite variable in this sample, which indicates that the test is quite variable and may require a large number of replicate burns to distinguish treatments, unless the differences are stark among treatments.

Table 3.2.2: Data collected from burning 6 untreated Doug-fir pole sections in 2020.

Pole #	Max surface Temp (°C)	Circumference loss (mm)	Max char depth (mm)	Check widening (mm)
5	741.2	12.7	5	9.5
6	671.5	50.8	7	52.1
7	676.3	38.1	4	76.2
8	718.2	38.1	6	3.2
9	761.7	38.1	10	85.7
10	665.1	66.7	9	92.1

3.2.3 Adaptation of the fire testing apparatus for testing fire-retardant treated crossarms

The fire testing racks were adapted to test crossarms and various fire-retardant treatments applied to them. The heating racks were designed for poles so the smaller size of the crossarms did not enable heating on two sides. The tests were done by placing crossarms in close proximity to one of the heating elements on a heating rack while enclosing the crossarm with the opposing heating rack on the other side (Figure 3.2.6). Heat was applied until ignition and another 10 minutes after ignition with a 2-hour smoldering period after. If ignition did not take place, the crossarms were exposed to heat for a full 20 minutes before removing. After the burn the loss in diameter was measured and any damage to coatings or other protective barriers was assessed.

Figure 3.2.6: Fire testing apparatus adapted to testing crossarms and fire-retardant treatments for crossarms. Two racks were used to enclose the space around the test crossarm. The crossarm was placed close to one of the heating elements and the burn was initiated.

In 2020, penta-treated crossarms coated with a titanium dioxide-based coating (named FPC) were tested for fire resistance using the testing apparatus. Uncoated controls will be tested but are not included in this report. The coated crossarms prevented the crossarms from burning and they did not ignite during the duration of the test. As a result, the damage was limited to a small area where the heating element was exposed. The coating was heavily damaged where it was exposed to heat and it appeared to serve as a sacrificial layer (Figure 3.2.7). After the burn the coating was charred and bubbled off of the crossarm surface. The char was easily removed and the wood surface was generally not heavily damaged. While not widespread, the damaged coating area was very fragile and if exposed to the elements the remainder of the protective coating would have likely easily flaked off.

Figure 3.2.7: Coated crossarms after burning with and without remaining char layer from the coating.

The heating curve for the coated crossarms diverges sharply from the curves of test material that combusted (Figure 3.2.8). Surface temperatures of the coated crossarms typically reached a maximum temperature in the low 300°C as compared to test material that combusted which saw temperature spikes over 700°C after combustion. This indicates the coating was successful in protecting the test material.

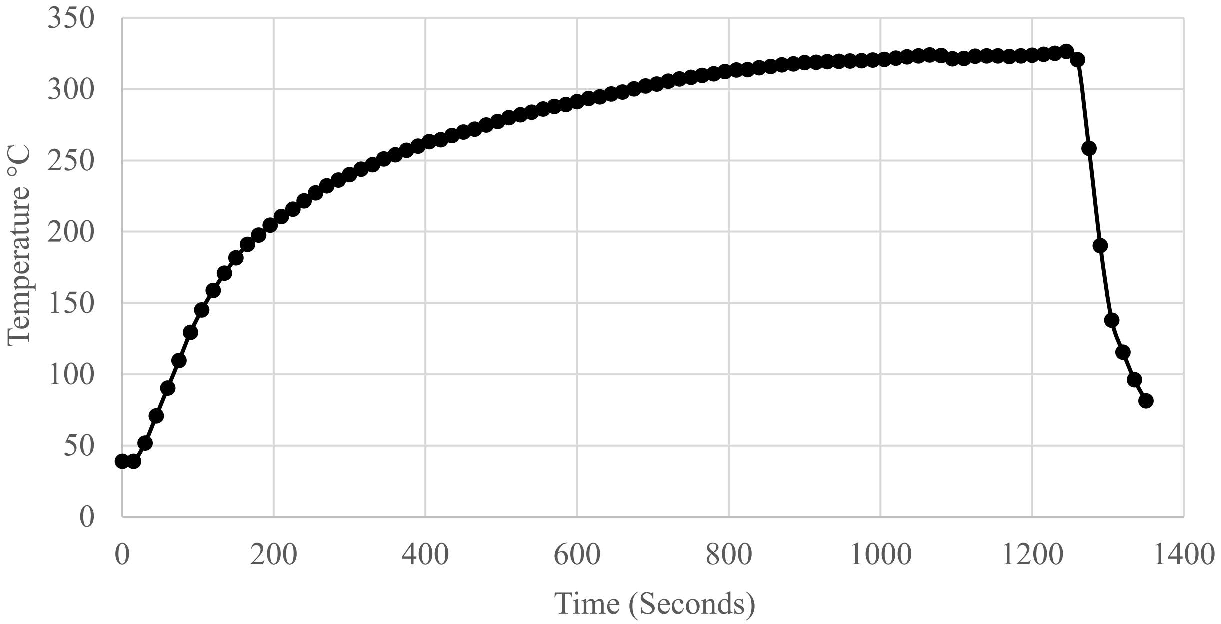

Figure 3.2.8: Typical heating curve for coated crossarms exposed to the fire testing apparatus.

3.3.0 Effect of Solvents on the Performance of oil borne preservative systems

Oilborne preservative systems are widely used for the protection of utility poles because they offer some distinct advantages over waterborne alternatives such as providing water resistance to poles and making poles easier for line personnel to climb. However, the use of hydrophobic solvents introduces another variable into the treatment process. Solvents have an impact on preservative performance in oilborne systems because oilborne preservatives do not fix to wood and instead are immobilized in oil deposits within the wood. This makes the solvent characteristics essential in determining the preservative performance (Arsenault 1970; Arsenault et al 1984). The oils themselves have a biocidal character and determine the mobility of the preservative in the wood, which modulates depletion rate. Faster preservative depletion leads to a lower concentration of active ingredient and a less effective treated wood product. Issues associated with solvent performance have led the American Wood Protection Association to require that changes to solvent systems for a given preservative be tested for their performance.

The UPRC has performed extensive testing on the performance both copper naphthenate and penta. The work originally began because of changes in the solvents commonly used to solubilize penta for Douglas-fir treatment. Changes in the availability of petroleum-based solvents has left treaters with petroleum oils that are poorer solvents for penta. This caused treaters to consider diesel oil for Douglas-fir treatment which comes with strong odors and is difficult to utilize for Boulton seasoning. Some of these negative characteristics can be mitigated by including biodiesel in a blend with diesel oil. Biodiesel is a better solvent for penta that diesel oil and greatly reduces odors. The mixture could still meet the AWPA Solvent Standard P9 Type

A; however, there was concern among some treaters about the efficacy of biodiesel as a solvent for penta compared to conventional petroleum-based oil. However, there were still concerns about the impacts of the inclusion of biodiesel on the performance of penta-treated Douglas-fir poles.

To address these concerns, the UPRC performed extensive laboratory and field studies were undertaken to evaluate the efficacy of penta and other preservative systems in conventional and biodiesel solvents. Some preliminary studies done in other research groups showed there may be some negative impacts of biodiesel on penta performance (Langroodi et al. 2012), while studies done at Oregon State University showed biodiesel did not have an impact on DCOI performance (Hua-Kang et al. 2013). These studies required validation in larger scale experiments and the UPRC has since initiated field scale stake tests and is currently proposing to start tests on DCOI in different solvents (section 3.4.2). AWPA E10 soil bottle tests on blocks treated with copper naphthenate using diesel oil blended with various types of biodiesel showed higher protective threshold levels against decay fungi than blocks treated with diesel alone, indicating reduced efficacy of the biodiesel formulas (Morrell et al. 2010). Results from the UPRC research indicated that biodiesel likely has a negative impact on the performance of copper naphthenate. This led treaters to voluntarily stop the use of biodiesel in copper naphthenate treatment and the initiation of a larger scale stake test and field assessments of poles treated with copper naphthenate in a biodiesel solvent by two utilities. Below we describe progress on an AWPA E7 stake test designed to measure the impact of solvent systems on the performance of copper naphthenate and pentachlorophenol. In addition, we describe two new planned studies on the performance of DCOI-treated wood in different solvent systems.

3.3.1 Effect of biodiesel-containing solvents on the performance of Copper Naphthenate and Pentachlorophenol

Douglas-fir lumber was collected from a local mill shortly after sawing. The lumber was primarily sapwood free of knots, splits and other defects and was cut into standard stakes prior to treatment. The samples were weighed and allocated to treatment groups so that each group contained stakes and blocks with approximately similar density distributions. The samples were then treated with combinations of copper naphthenate or penta in mixtures of diesel alone or amended with 30, 50, 70, or 100% biodiesel using an empty cell process. The same commercially available soy-based biodiesel (FP9-HTS) was used to treat both penta and copper naphthenate treatments. In addition, each biocide was tested in an aromatic oil, a paraffinic oil, FPRL oil, and penta concentrate concurrently with biodiesel treatments. Penta target retentions were 2.4, 4.8, 6.4, and 9.6 kg/m^3, copper naphthenate retentions were 0.66, 0.99, 1.33, and 1.66 kg/m^3 as Cu.

Samples were conditioned to 65% relative humidity and weighed prior to treatment and subjected to 30 psi of initial air pressure. Treatment solution was pumped into the vessel and pressure was raised to 150 psi and held for 2 hours. Pressure was released and a 2 to 4-hour vacuum was drawn to relieve internal pressure and recover residual preservative. Stakes continued to lose solvent after treatment and were allowed to stabilize for 2 weeks before being re-weighed to determine net solution uptake (Figure 3.3.1). The net weight gain was used to estimate residual preservative retention which was used to allocate stakes or blocks to given treatment groups. Samples with excessively high or low retentions were not included.

Figure 3.3.1. Stakes drying under cover after treatment with copper naphthenate (bottom) or penta (top).

We included two test sites in this study. One was an open field and one was a mature forest, adjacent to each other at our Peavy test site. Each site offers a unique microclimate for fungal decay, with the forest naturally harboring more wood-decay fungi. Stake condition was evaluated at 22, 34, 46, 58 and 70 months. Each stake was removed from the soil, wiped clean and probed with an awl for evidence of softening. Stake condition was rated on a scale from 10 to 0 as described in AWPA Standard E7 where:

Grade No.	Description of Condition
10	Sound. Suspicion of decay permitted
9	Trace decay to 3% of cross section
8	Decay from 3 to 10% of cross section
7	Decay from 10 to 30% of cross section
6	Decay from 30 to 50% of cross section
4	Decay from 50 to 75% of cross section
0	Failure

Stakes in the open field tended to have consistently lower degrees of fungal attack than those in the wooded area. Untreated controls for the grassy meadow site only started to show heavy decay after 58 months, whereas similar levels were seen in the controls from the forest site after only 34 months (Table 3.3.1 and 3.3.2). Microclimates at each of the two sites were notably different as indicated by the fact that stakes in the open field site were very dry when evaluated in the summer months, while those in the forest approximately 200 meters away were moist. Year-round moist conditions are more conducive fungal attack. Both sites are extremely wet during the winter, but the lower temperatures likely result in a lower decay rate during that time of year.

Stakes treated with solvent but no biocide were in slightly better condition than untreated controls, especially at the forest site, but differences were slight and they are expected to disappear over time. Stakes at the open field site were in good condition 34 months after installation, with ratings averaging above 9.00, while stakes in the forest site experienced more aggressive decay. Many of the solvent-treated and lower preservative retentions began to show decay from 46 months onward, particularly in the forest site. Untreated control stakes began to fail in the forest site after 46 months of exposure, which continued to have much heavier decay than the field site. Penta-treated stakes exposed at the forest site remained in good condition after 46-months with ratings around 9.00. Copper naphthenate treatments with different solvents began to diverge at 46 months at the forest site, although not statistically significantly. 100% biodiesel-treated copper naphthenate stakes in the forest plot started to show more signs of decay (avg. 7.84) than diesel only treated stakes (avg. 9.26). Ratings remained high for both types of treatments at the field site.

After 58 months most of the untreated stakes at the forest site had failed, whereas many still remain intact, although heavily decayed, at the field site. At the field site, stakes treated with Copper naphthenate or penta dissolved in different solvent systems remained relatively close to one another, and average ratings were generally within one point of one another. The forest site showed more dramatic divergence in treatments and 100% biodiesel-copper naphthenate stakes were noticeably more degraded (average rating 6.43) than petroleum-copper naphthenate-treated stakes (average rating 7.89) (Figures 3.3.2 to 3.3.5). However, at this sampling point the differences among copper naphthenate treatments were not statistically significant. The same divergence between biodiesel-treated and diesel-treated was not seen in penta-treated stakes.

After 70 months many of the same trends persisted. At the field site, different solvent treatments for both penta and copper naphthenate remained fairly close, with average values for each treatment remaining within 1 point of the other solvent systems for the preservative (Figure 3.3.2; 3.3.4). At the forest site, some of the solvent treatments diverged in the lowest penta retention level, namely the 30% biodiesel treatment was a full 2 points lower on average compared to the diesel only treatment. However, there was not a consistent pattern because the highest average ratings for penta biodiesel/diesel mixtures was the 50% biodiesel blend (Table 3.3.3). Copper naphthenate stakes on the other hand showed consistently lower ratings for high percentage (50-100%) biodiesel treatments compared to diesel only treatment (Figure 3.3.3).

Many stakes, particularly at the forest site are experiencing advanced decay after 70 months and the site may provide functional data for only a few more years. Pictures of the sites (Figure 3.3.6) and some recently rated stakes (Figure 3.3.7) are included below. It is important to note that one of our members pointed out an error in previous year's data regarding the average ratings for "all retentions" listed in tables 3.3.1 and 3.3.2. Previously, these were erroneously calculated using the solvent-only treatment in addition to the different retention levels where they should have only been calculated with the different retention levels for each preservative. These have been corrected in this year's data and the current table should serve as the most accurate depiction of the stake test data.

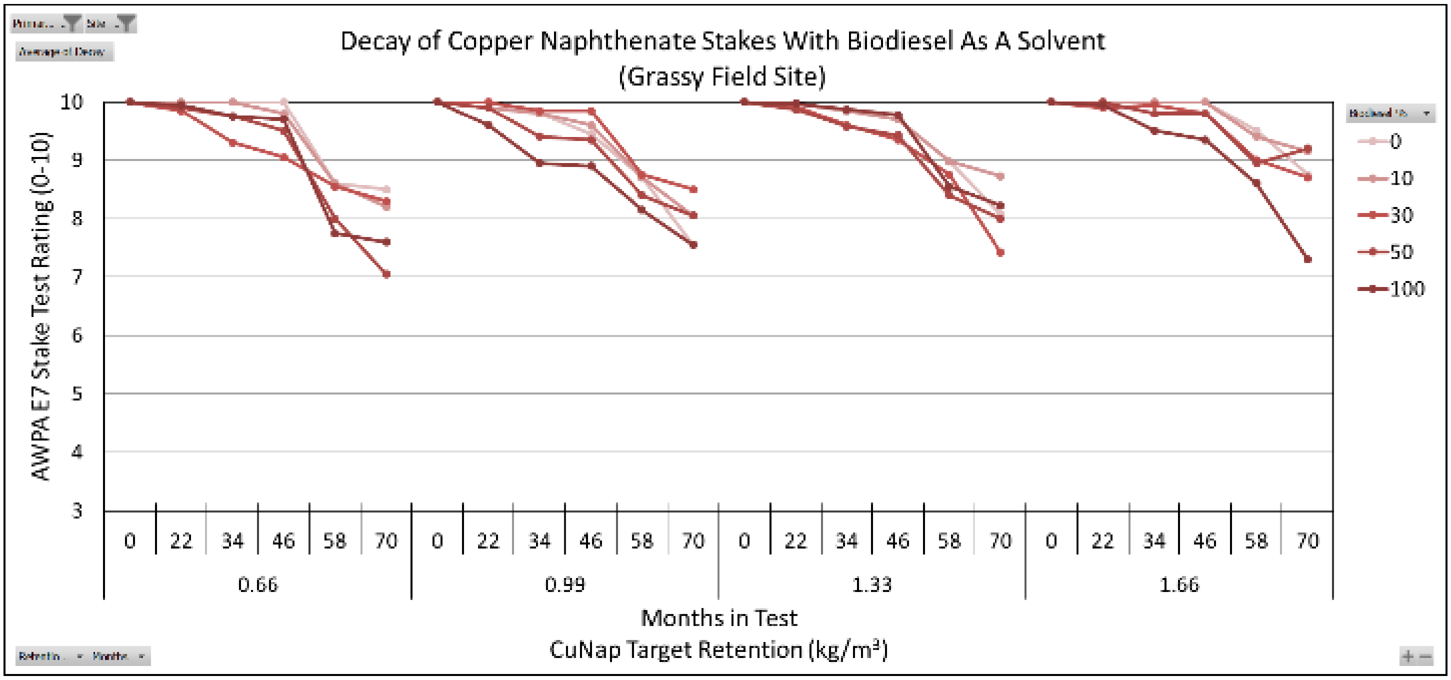

Figure 3.3.2: Average ratings of stakes treated with copper naphthenate using biodiesel and diesel-containing solvents for 70 months at an open field site.

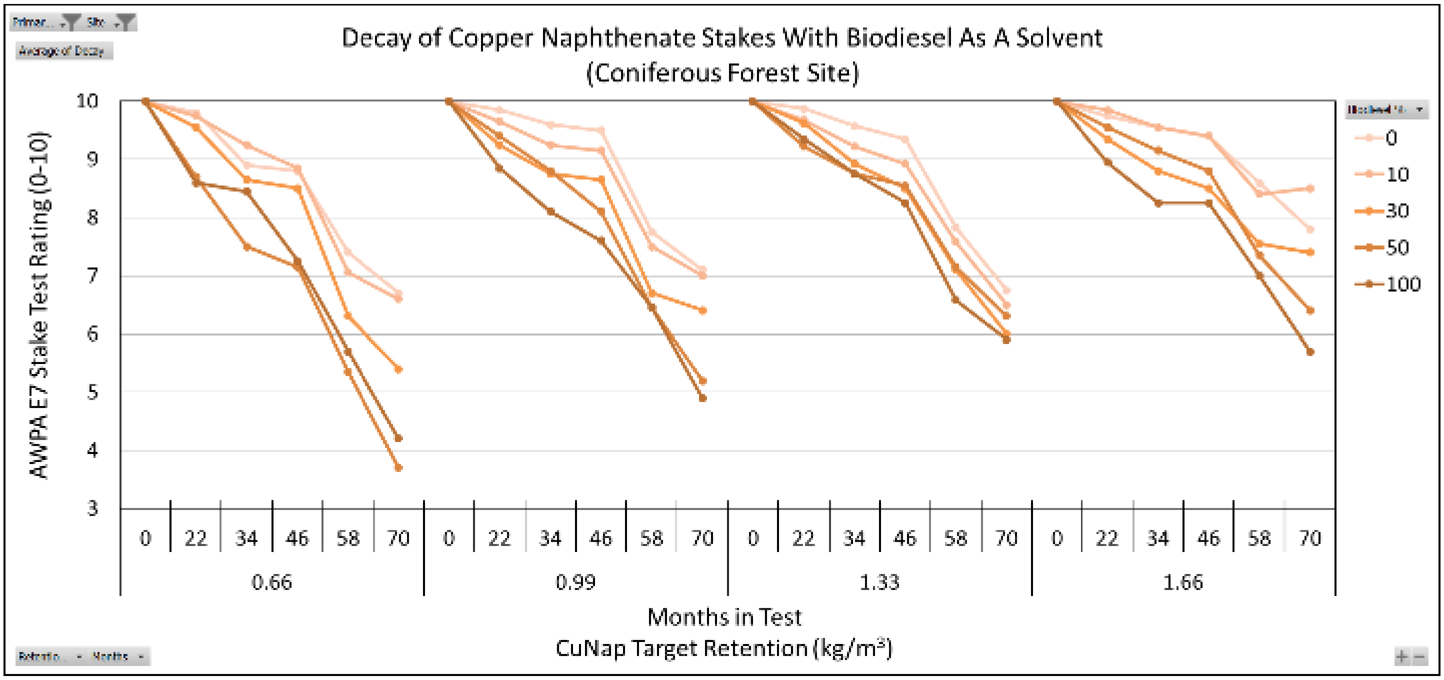

Figure 3.3.3: Average ratings of stakes treated with copper naphthenate using biodiesel and diesel-containing solvents for 70 months at a forested site.

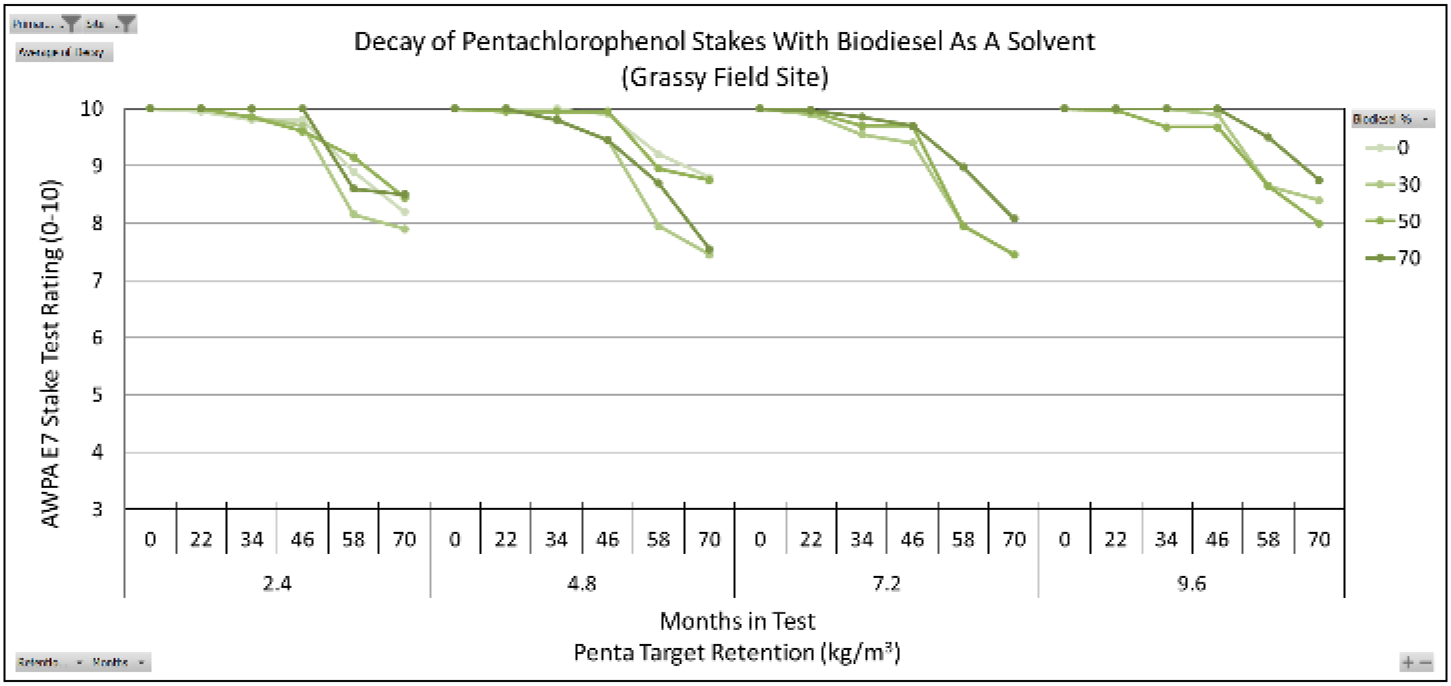

Figure 3.3.4: Average ratings of stakes treated with pentachlorophenol using biodiesel and diesel-containing solvents for 70 months at an open field site.

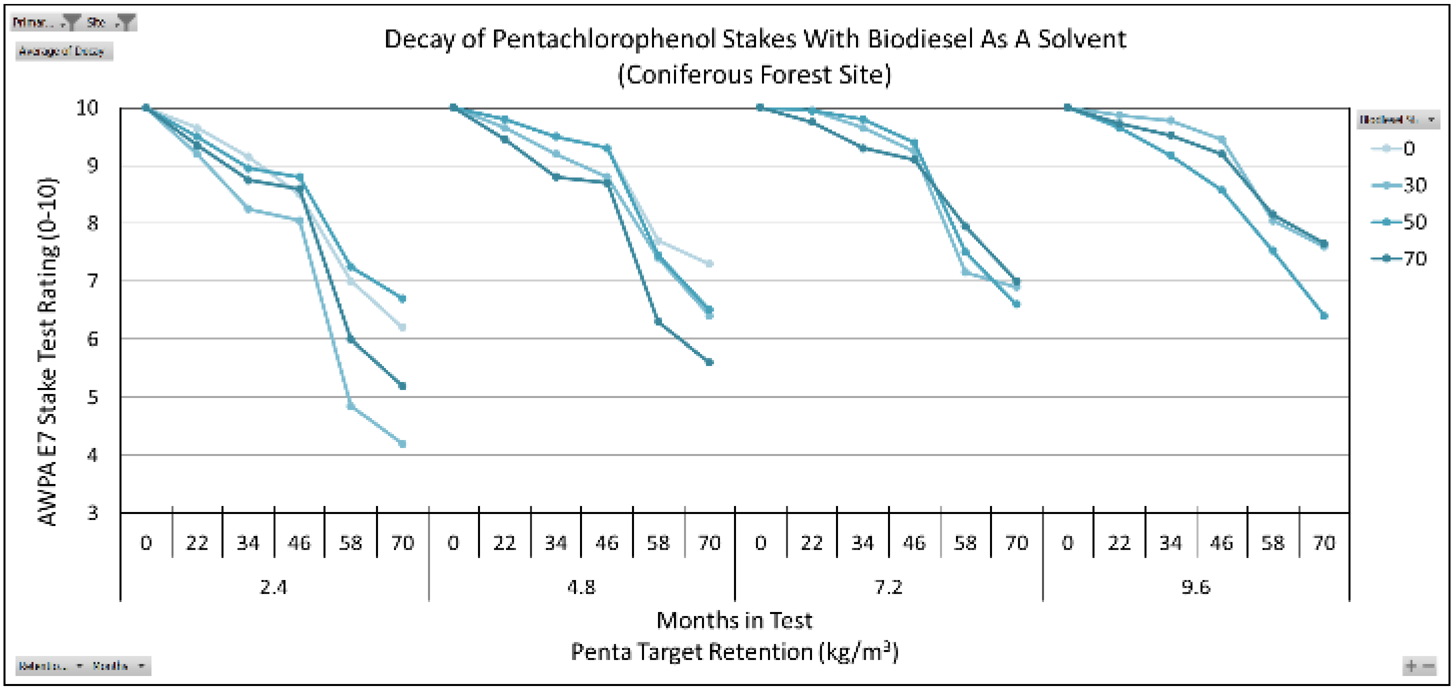

Figure 3.3.5: Average ratings of stakes treated with pentachlorophenol using biodiesel and diesel-containing solvents for 70 months at an open field site.

Figure 3.3.6: Field sites used in this study, open field site (left) and forest site (right).

Figure 3.3.7: Stakes rated at the 70-month sampling. Stakes that failed in 2020, predominantly due to brown-rot (top left).

Table 3.3.1: Condition of Douglas-fir sapwood stakes treated with pentachlorophenol or copper naphthenate in various solvents and exposed for 70 months at a grassy meadow site near Corvallis, Oregon.

Treatment		Months	Average Stake Condition						
			Target Retentions (kg/m³)						
Pentachlorophenol Carrier	Biodiesel %		**Water (UTC)**	**0**	**2.4**	**4.8**	**7.2**	**9.6**	**All Retentions**
Water (UTC)	-----	22	9.90 (0.3)						9.90
		34	9.25 (1.3)						9.25
		46	8.80 (1.6)						8.80
		58	6.08 (3.4)						6.08
		70	**3.35** (3.7)						**3.35**
Diesel	0*	22		9.95 (0.2)	9.95 (0.2)	10.00 (0.0)			9.98
		34		9.65 (0.5)	9.80 (0.3)	10.00 (0.0)			9.90
		46		9.35 (0.9)	9.80 (0.3)	9.90 (0.3)			9.85
		58		8.60 (0.8)	8.90 (0.8)	9.20 (0.6)			9.05
		70		8.10 (0.8)	8.20 (0.7)	8.80 (1.0)			**8.50**
	30	22		10.00 (0.0)	10.00 (0.0)	10.00 (0.0)	9.90 (0.2)	10.00 (0.0)	9.98
		34		9.75 (0.6)	9.85 (0.5)	9.80 (0.6)	9.55 (0.8)	10.00 (0.0)	9.80
		46		9.50 (0.9)	9.70 (0.6)	9.45 (0.9)	9.40 (1.1)	9.90 (0.4)	9.61
		58		7.95 (2.3)	8.15 (1.6)	7.95 (1.4)	7.95 (1.4)	8.65 (1.1)	8.18
		70		7.15 (2.7)	7.90 (1.6)	7.45 (1.4)	7.45 (1.4)	8.40 (1.2)	**7.80**
	50	22		9.90 (0.2)	10.00 (0.0)	9.95 (0.2)	9.95 (0.2)	9.98 (0.1)	9.97
		34		9.35 (1.1)	9.85 (0.5)	9.95 (0.2)	9.70 (0.7)	9.68 (0.7)	9.79
		46		9.15 (1.3)	9.60 (0.7)	9.95 (0.2)	9.70 (0.7)	9.68 (0.7)	9.73
		58		8.60 (1.0)	9.15 (0.7)	8.95 (1.5)	7.95 (1.2)	8.65 (0.9)	8.68
		70		**7.15** (2.3)	**8.45** (1.2)	**8.75** (1.3)	**7.45** (1.3)	**8.00** (1.1)	**8.16**
	70	22		9.70 (0.9)	9.95 (0.2)	9.95 (0.2)	10.00 (0.0)	10.00 (0.0)	9.98
		34		9.25 (1.4)	9.65 (0.8)	9.75 (0.6)	9.75 (0.5)	9.90 (0.3)	9.76
		46		9.25 (1.4)	9.35 (0.9)	9.65 (0.9)	9.75 (0.5)	9.90 (0.3)	9.66
		58		7.80 (1.8)	8.45 (1.3)	8.85 (1.1)	8.55 (1.1)	8.95 (0.8)	8.70
		70		**7.60** (1.6)	**7.80** (1.2)	**8.50** (1.6)	**7.95** (1.3)	**8.53** (0.9)	**8.19**
Aromatic Oil	0	22		10.00 (0.0)	10.00 (0.0)	9.90 (0.3)	10.00 (0.0)	10.00 (0.0)	9.98
		34		10.00 (0.0)	9.90 (0.3)	9.90 (0.3)	10.00 (0.0)	9.93 (0.2)	9.93
		46		10.00 (0.0)	9.80 (0.4)	9.90 (0.3)	10.00 (0.0)	9.85 (0.3)	9.89
		58		8.70 (0.9)	8.55 (1.4)	8.15 (1.3)	8.45 (1.1)	8.55 (1.1)	8.43
		70		**8.45** (1.0)	**8.05** (1.6)	**7.80** (1.5)	**8.05** (1.1)	**8.125** (1.2)	**8.01**
Naphthenic Oil	30	22		10.00 (0.0)	9.95 (0.2)	9.95 (0.2)	9.95 (0.2)	9.98 (0.1)	9.96
		34		9.35 (0.9)	9.85 (0.3)	9.95 (0.2)	9.95 (0.2)	9.90 (0.3)	9.91
		46		9.20 (0.9)	9.85 (0.3)	9.95 (0.2)	9.95 (0.2)	9.83 (0.7)	9.89
		58		6.90 (1.7)	8.50 (0.9)	8.60 (1.1)	8.75 (0.9)	8.425 (1.2)	8.57
		70		**6.60** (2.0)	**8.05** (1.0)	**8.10** (1.1)	**8.35** (1.0)	**8.00** (1.3)	**8.13**
Paraffinic Oil	30	22		9.95 (0.2)	10.00 (0.0)	10.00 (0.0)	10.00 (0.0)	10.00 (0.0)	10.00
		34		9.30 (1.5)	9.40 (0.9)	9.90 (0.3)	9.70 (0.5)	9.90 (0.3)	9.73
		46		9.20 (1.8)	9.25 (1.0)	9.90 (0.3)	9.70 (0.5)	9.90 (0.3)	9.69
		58		6.90 (2.2)	7.10 (2.6)	8.45 (0.6)	8.50 (1.0)	8.60 (0.6)	8.16
		70		**6.65** (2.1)	**6.50** (2.6)	**8.10** (0.7)	**7.80** (1.1)	**8.25** (0.6)	**7.66**
FPRL Oil	0	22		9.95 (0.2)	9.90 (0.2)	10.00 (0.0)	10.00 (0.0)	9.98 (0.1)	9.97
		34		9.70 (0.6)	9.55 (0.6)	9.90 (0.3)	9.90 (0.3)	9.83 (0.6)	9.79
		46		9.70 (0.6)	9.35 (0.8)	9.90 (0.3)	9.80 (0.6)	9.80 (0.7)	9.71
		58		7.30 (1.5)	7.40 (1.4)	8.20 (1.5)	8.10 (1.7)	8.85 (0.9)	8.14
		70		**6.85** (1.7)	**6.80** (1.5)	**7.85** (1.7)	**7.70** (1.9)	**8.375** (1.0)	**7.68**
Ketone Bottoms	0	22		9.90 (0.2)	9.90 (0.3)	9.95 (0.2)	10.00 (0.0)	9.95 (0.2)	9.95
		34		9.45 (1.0)	9.75 (0.5)	9.90 (0.3)	9.95 (0.2)	9.80 (0.5)	9.85
		46		9.15 (1.8)	9.35 (1.2)	9.80 (0.6)	9.95 (0.2)	9.73 (0.6)	9.71
		58		7.50 (2.7)	7.55 (2.0)	8.50 (1.2)	8.15 (1.1)	8.675 (1.1)	8.22
		70		**7.10** (2.6)	**7.15** (1.9)	**8.00** (1.5)	**7.65** (1.1)	**8.225** (1.2)	**7.76**
Copper Naphthenate Carrier	Biodiesel %	Months		**0**	**0.66**	**0.99**	**1.33**	**1.66**	**All Retentions**
Diesel	0	22		9.95 (0.2)	10.00 (0.0)	10.00 (0.0)	9.98 (0.1)	10.00 (0.0)	9.99
		34		9.65 (0.5)	10.00 (0.0)	9.80 (0.5)	9.85 (0.6)	10.00 (0.0)	9.91
		46		9.35 (0.9)	10.00 (0.0)	9.45 (0.8)	9.70 (0.8)	10.00 (0.0)	9.79
		58		8.60 (0.8)	8.60 (0.7)	8.70 (1.1)	8.98 (1.4)	9.50 (0.4)	8.94
		70		**8.10** (0.8)	**8.50** (0.7)	**7.55** (1.2)	**8.08** (2.0)	**8.75** (0.9)	**8.22**
	10	22		9.90 (0.2)	10.00 (0.0)	9.90 (0.2)	9.98 (0.1)	10.00 (0.0)	9.97
		34		9.90 (0.3)	10.00 (0.0)	9.80 (0.2)	9.85 (0.5)	10.00 (0.0)	9.91
		46		9.85 (0.5)	9.80 (0.6)	9.60 (0.6)	9.70 (0.7)	10.00 (0.0)	9.78
		58		7.40 (0.8)	8.60 (1.0)	8.70 (0.7)	8.98 (1.3)	9.40 (0.7)	8.92
		70		**6.90** (0.8)	**8.20** (1.2)	**8.05** (1.0)	**8.73** (1.6)	**9.15** (0.9)	**8.53**
	30	22		10.00 (0.0)	9.85 (0.3)	10.00 (0.0)	9.93 (0.2)	9.90 (0.3)	9.92
		34		9.75 (0.6)	9.30 (1.1)	9.85 (0.3)	9.60 (0.8)	9.95 (0.2)	9.68
		46		9.50 (0.9)	9.05 (1.2)	9.85 (0.3)	9.35 (1.1)	9.80 (0.6)	9.51
		58		7.95 (2.3)	8.55 (1.3)	8.75 (1.5)	8.75 (1.3)	9.00 (1.3)	8.76
		70		**7.15** (2.7)	**8.30** (1.5)	**8.50** (1.4)	**7.43** (2.2)	**8.70** (1.3)	**8.23**
	50	22		9.90 (0.2)	9.90 (0.3)	9.90 (0.2)	9.88 (0.3)	10.00 (0.0)	9.92
		34		9.35 (1.1)	9.75 (0.6)	9.40 (0.7)	9.58 (0.7)	9.80 (0.5)	9.63
		46		9.15 (1.3)	9.50 (0.7)	9.35 (0.8)	9.43 (0.8)	9.80 (0.5)	9.52
		58		8.60 (1.0)	8.00 (2.1)	8.40 (1.0)	8.40 (1.7)	8.95 (0.4)	8.44
		70		**7.15** (2.3)	**7.05** (2.3)	**8.05** (1.1)	**8.00** (1.9)	**9.20** (0.7)	**8.08**
	100	22		9.95 (0.2)	9.95 (0.2)	9.60 (0.9)	9.98 (0.1)	9.95 (0.2)	9.87
		34		9.50 (1.0)	9.75 (0.8)	8.95 (1.3)	9.88 (0.3)	9.50 (1.0)	9.52
		46		8.95 (1.7)	9.70 (0.9)	8.90 (1.4)	9.78 (0.6)	9.35 (1.3)	9.43
		58		7.15 (2.8)	7.75 (1.1)	8.15 (1.6)	8.55 (1.4)	8.60 (1.5)	8.26
		70		**7.00** (3.0)	**7.60** (1.4)	**7.55** (1.6)	**8.23** (1.5)	**7.30** (2.5)	**7.67**

Values represent means of 10 stakes per treatment.

Figures in parentheses represent one standard deviation.

Ratings for non-treated controls averaged 9.90 (0.30), 9.25 (1.3), 8.80 (1.7), 6.08 (3.5), and 3.35 (3.7) after 22, 34, 46, 58, and 70 months of exposure, respectively.

Copper naphthenate values are as Cu metal.

*All retention averages for Penta with 0% biodiesel are lower than expected because the two highest retentions were not tested.

Table 3.3.2: Condition of Douglas-fir sapwood stakes treated with pentachlorophenol or copper naphthenate in various solvents and exposed for 70 months at a forest site near Corvallis, Oregon.

Treatment		Months	Average Stake Condition						
			Target Retentions (kg/m^3)						
Pentachlorophenol Carrier	Biodiesel %		**Water (UTC)**	**0**	**2.4**	**4.8**	**7.2**	**9.6**	**All Retentions**
Water (UTC)	-----	22	8.00 (1.9)						8.00
		34	5.45 (2.1)						5.45
		46	4.23 (2.4)						4.23
		58	1.83 (1.7)						1.83
		70	**0.60** (1.4)						**0.60**
Diesel	0*	22		8.75 (1.0)	9.65 (0.6)	9.80 (0.3)			9.73
		34		7.45 (1.4)	9.15 (1.1)	9.50 (0.5)			9.33
		46		7.30 (1.2)	8.50 (1.3)	9.30 (0.6)			8.90
		58		4.75 (1.9)	7.00 (2.7)	7.70 (2.2)			7.35
		70		**3.90** (2.4)	**6.20** (2.6)	**7.30** (2.0)			**6.75**
	30	22		8.70 (1.4)	9.20 (0.8)	9.65 (0.3)	9.95 (0.2)	9.88 (0.4)	9.67
		34		8.35 (1.9)	8.25 (1.7)	9.20 (0.7)	9.65 (0.6)	9.78 (0.6)	9.22
		46		7.80 (2.0)	8.05 (1.6)	8.80 (1.0)	9.25 (0.8)	9.45 (0.9)	8.89
		58		4.85 (2.7)	4.85 (3.1)	7.40 (2.5)	7.15 (2.0)	8.05 (1.8)	6.86
		70		**4.20** (2.7)	**4.20** (2.7)	**6.40** (2.0)	**6.90** (1.9)	**7.60** (1.6)	**6.28**
	50	22		9.05 (0.9)	9.50 (0.4)	9.80 (0.2)	9.95 (0.2)	9.65 (0.5)	9.73
		34		8.00 (1.1)	8.95 (0.8)	9.50 (0.5)	9.80 (0.3)	9.18 (1.1)	9.36
		46		7.60 (1.1)	8.80 (0.7)	9.30 (0.5)	9.40 (0.7)	8.58 (1.4)	9.02
		58		4.60 (1.9)	7.25 (1.4)	7.45 (1.6)	7.50 (2.6)	7.53 (1.7)	7.43
		70		**3.70** (2.2)	**6.70** (1.3)	**6.50** (1.6)	**6.60** (2.2)	**6.40** (2.1)	**6.55**
	70	22		8.95 (0.9)	9.35 (0.7)	9.45 (0.6)	9.75 (0.3)	9.73 (0.5)	9.57
		34		8.40 (1.1)	8.75 (1.2)	8.80 (0.9)	9.30 (0.7)	9.53 (0.6)	9.09
		46		8.00 (1.6)	8.60 (1.4)	8.70 (1.0)	9.10 (0.7)	9.20 (0.8)	8.90
		58		6.00 (2.5)	6.00 (1.7)	6.30 (2.1)	7.95 (2.2)	8.15 (1.6)	7.10
		70		**5.00** (3.2)	**5.20** (2.1)	**5.60** (1.9)	**7.00** (1.6)	**7.65** (1.5)	**6.36**
Aromatic Oil	0	22		9.80 (0.3)	9.85 (0.3)	9.95 (0.2)	9.85 (0.5)	9.93 (0.2)	9.89
		34		9.50 (0.6)	9.70 (0.5)	9.85 (0.3)	10.00 (0.0)	9.83 (0.4)	9.84
		46		9.50 (0.6)	9.50 (0.5)	9.60 (0.5)	9.95 (0.2)	9.48 (0.5)	9.63
		58		8.40 (0.9)	8.40 (1.1)	8.45 (1.2)	8.70 (0.6)	8.83 (0.7)	8.59
		70		**7.90** (0.9)	**7.80** (1.1)	**7.80** (1.0)	**8.30** (0.9)	**8.15** (1.0)	**8.01**
Naphthenic Oil	30	22		9.45 (0.7)	9.70 (0.5)	9.85 (0.2)	9.90 (0.3)	9.90 (0.3)	9.84
		34		7.80 (1.7)	9.30 (1.0)	9.60 (0.4)	9.75 (0.5)	9.68 (0.8)	9.58
		46		7.00 (1.4)	8.80 (1.3)	9.05 (0.7)	9.15 (1.0)	9.30 (0.8)	9.08
		58		3.75 (1.7)	5.75 (2.4)	7.20 (2.3)	7.45 (2.5)	7.45 (1.7)	6.96
		70		**2.70** (2.2)	**4.70** (2.8)	**6.50** (2.1)	**6.90** (2.1)	**7.10** (1.4)	**6.30**
Paraffinic Oil	30	22		9.35 (0.6)	9.30 (1.2)	9.95 (0.2)	9.90 (0.2)	9.70 (0.6)	9.71
		34		8.65 (1.3)	8.45 (2.0)	9.55 (0.8)	9.75 (0.4)	9.45 (0.8)	9.30
		46		8.00 (1.6)	8.10 (1.9)	9.30 (0.8)	9.35 (1.0)	9.40 (0.7)	9.04
		58		5.60 (2.7)	6.35 (2.4)	7.55 (2.2)	7.65 (1.2)	8.03 (1.7)	7.39
		70		**4.20** (3.2)	**5.40** (3.0)	**6.90** (2.0)	**6.10** (2.2)	**7.45** (1.5)	**6.46**
FPRL Oil	0	22		9.25 (0.4)	9.60 (0.4)	9.95 (0.2)	9.70 (0.6)	9.98 (0.1)	9.81
		34		8.30 (1.1)	9.05 (0.9)	8.70 (1.0)	9.30 (1.1)	9.88 (0.4)	9.23
		46		7.60 (1.0)	8.35 (1.0)	8.50 (1.0)	9.05 (1.0)	9.53 (0.7)	8.86
		58		5.40 (2.4)	5.85 (1.9)	6.90 (2.1)	7.50 (1.6)	8.13 (1.6)	7.09
		70		**3.70** (2.8)	**4.90** (2.6)	**6.20** (2.7)	**7.00** (1.4)	**7.40** (1.5)	**6.38**
Ketone Bottoms	0	22		9.25 (0.8)	9.70 (0.5)	9.90 (0.2)	9.40 (0.7)	9.95 (0.2)	9.74
		34		8.35 (1.0)	9.05 (0.9)	9.65 (0.6)	9.20 (0.9)	9.85 (0.5)	9.44
		46		7.75 (1.2)	8.70 (1.0)	9.05 (1.1)	9.15 (0.7)	9.58 (0.5)	9.12
		58		4.50 (1.3)	7.20 (1.7)	7.35 (1.7)	7.50 (1.5)	8.13 (1.2)	7.54
		70		**3.90** (1.9)	**4.90** (2.8)	**6.50** (1.7)	**6.60** (2.1)	**7.40** (0.7)	**6.35**
Copper Naphthenate Carrier	Biodiesel %	Months		**0**	**0.66**	**0.99**	**1.33**	**1.66**	**All Retentions**
Diesel	0	22		8.75 (1.0)	9.80 (0.3)	9.85 (0.3)	9.88 (0.3)	9.75 (0.4)	9.82
		34		7.45 (1.4)	8.90 (1.0)	9.60 (0.7)	9.58 (0.7)	9.55 (0.7)	9.41
		46		7.30 (1.2)	8.80 (1.1)	9.50 (0.6)	9.35 (0.9)	9.40 (0.7)	9.26
		58		4.75 (1.9)	7.40 (2.1)	7.75 (1.9)	7.83 (2.0)	8.60 (1.4)	7.89
		70		**3.90** (2.4)	**6.70** (1.6)	**7.10** (1.5)	**6.75** (2.4)	**7.80** (1.1)	**7.09**
	10	22		8.85 (0.9)	9.75 (0.5)	9.65 (0.3)	9.68 (0.5)	9.85 (0.2)	9.73
		34		7.65 (1.3)	9.25 (0.9)	9.25 (0.8)	9.23 (0.9)	9.55 (0.4)	9.32
		46		7.30 (1.0)	8.85 (1.0)	9.15 (0.7)	8.93 (0.9)	9.40 (0.4)	9.08
		58		4.65 (1.4)	7.05 (1.6)	7.50 (1.9)	7.58 (1.9)	8.40 (0.7)	7.63
		70		**2.90** (2.6)	**6.60** (1.6)	**7.00** (1.5)	**6.50** (2.3)	**8.50** (0.9)	**7.15**
	30	22		8.70 (1.4)	9.55 (0.4)	9.25 (0.7)	9.63 (0.5)	9.35 (0.6)	9.44
		34		8.35 (1.9)	8.65 (1.3)	8.75 (0.7)	8.93 (1.1)	8.80 (0.5)	8.78
		46		7.80 (2.0)	8.50 (1.3)	8.65 (0.7)	8.50 (1.1)	8.50 (0.7)	8.54
		58		4.85 (2.7)	6.30 (1.9)	6.70 (1.7)	7.10 (1.9)	7.55 (1.1)	6.91
		70		**4.20** (2.7)	**5.40** (2.1)	**6.40** (1.7)	**6.00** (2.5)	**7.40** (0.9)	**6.30**
	50	22		9.05 (0.9)	8.70 (0.9)	9.40 (0.7)	9.23 (0.8)	9.55 (0.5)	9.22
		34		8.00 (1.1)	7.50 (1.4)	8.80 (1.2)	8.75 (1.0)	9.15 (0.9)	8.55
		46		7.60 (1.1)	7.15 (1.2)	8.10 (1.2)	8.55 (0.9)	8.80 (0.9)	8.15
		58		4.60 (1.9)	5.35 (1.7)	6.45 (1.9)	7.15 (1.8)	7.35 (2.2)	6.58
		70		**3.70** (2.2)	**3.70** (2.8)	**5.20** (2.3)	**6.30** (2.2)	**6.40** (3.1)	**5.40**
	100	22		8.60 (1.5)	8.60 (1.1)	8.85 (1.1)	9.35 (0.7)	8.95 (1.2)	8.94
		34		7.25 (2.3)	8.45 (1.3)	8.10 (1.8)	8.75 (1.1)	8.25 (1.5)	8.39
		46		6.55 (2.5)	7.25 (1.6)	7.60 (1.7)	8.25 (1.1)	8.25 (1.5)	7.84
		58		4.15 (3.2)	5.70 (2.0)	6.45 (2.5)	6.58 (2.2)	7.00 (2.0)	6.43
		70		**3.50** (3.3)	**4.20** (3.0)	**4.90** (3.3)	**5.90** (2.0)	**5.70** (2.2)	**5.18**

Values represent means of 10 stakes per treatment.

Figures in parentheses represent one standard deviation.

Ratings for the non-treated control averaged 8.00 (1.9), 5.45 (2.1), 4.23 (2.4), 1.83 (1.7), and 0.60 (1.4) after 22, 34, 46, 58, and 70 months of exposure, respectively.

Copper naphthenate values are as Cu metal.

*All retention averages for Penta with 0% biodiesel are lower than expected because the two highest retentions were not tested.

3.3.2 Effect of solvent systems on the performance 4,5-dichloro-2-n-octyl-isothiazolin-3-one (DCOI): Study designs and implementation plan

Recent developments have led to the sole manufacturer of pentachlorophenol (penta) in North America to plan to discontinue its production by the end of 2021 (Tullo 2020). Penta is the most commonly used wood preservative for utility poles and as much as 60% of poles in the United States are treated with penta (Gulliford, 2008). The loss of this preservative means a combination of other oil borne treatments will have to fill the void. Two of the major oil borne alternatives to penta for pole treatment are copper naphthenate and DCOI. The performance of copper naphthenate has been extensively studied in the UPRC for decades and has shown to be an effective preservative comparable to penta. DCOI on the other hand has received less research attention from our cooperative.

We have received considerable interest from utility members for research on the long-term performance of DCOI as a utility pole treatment. DCOI is not a new chemical and has been a proven effective wood preservative since the 1980s (Nicholas et al. 1984; Greenley and Hegarty 1988). However, more information on the long-term performance of this chemical as a utility pole treatment in a variety of environments would help utilities make informed decisions about which chemicals would be best suited for specific environments within their network. More information on the performance of DCOI in Douglas-fir would also be valuable for western utilities.

We have initiated an effort to study the efficacy of DCOI as a utility pole treatment for Douglas-fir poles in a series of studies at different scales. We are initiating two studies on the impacts of solvent systems on the efficacy of DCOI as a preservative system. DCOI has been standardized in a variety of solvents previously as described in a data packaged submitted to the P3 committee in 2005 (AWPA 2005). However, many solvent systems are currently available for DCOI that have not been tested with this system.

The first test proposed here is an AWPA E10 soil bottle test to be performed on Douglas-fir and Southern pine 19 mm blocks treated with one of three solvent systems, HBB-30 oil, RHT-70 oil, or #2 diesel (AWPA 2020). Biodiesel has previously been shown to have no significant impact on the performance of DCOI in AWPA E10 tests, so it will not be tested here (Hua-Kang et al. 2013). Blocks will be treated to one of three retentions listed in Table 3.3.3. Retentions selected will be the UC4B AWPA standard retention for either species, 0.5 kg/m^3 based on the effective threshold determined for DCOI against decay fungi (Greenley and Hegarty 1984), and 50% of the threshold level. Blocks will be assessed for preservative retention prior to leaching according to the protocol described in the AWPA E10 standard (AWPA 2020).

Table 3.3.3 Retentions, solvent systems and wood species to be used in AWPA E10 soil bottle test on DCOI.

Preservative	Retentions (kg/m^3)	Solvent	Species
DCOI	2.1	RHT-70, HBB-30, or #2 Diesel	Southern Pine
DCOI	2.4	RHT-70, HBB-30, or #2 Diesel	Douglas-fir
DCOI	0.5	RHT-70, HBB-30, or #2 Diesel	Southern Pine or Douglas-fir
DCOI	0.25	RHT-70, HBB-30, or #2 Diesel	Southern Pine or Douglas-fir
None	N/A	RHT-70, HBB-30, or #2 Diesel	Southern Pine or Douglas-fir

After leaching, blocks will be sterilized by gamma irradiation and exposed to two brown rot fungi, (*Gloeophyllum trabeum* and *Postia placenta*) and one white rot fungus (*Trametes versicolor*) for 4, 8 and 16 weeks. Mass losses will be assessed and used as an indicator of resistance to fungal decay relative to control. This project is intended to describe the performance of solvent systems available in the present day for treating with DCOI in delivering the chemical to Douglas-fir or Southern pine wood and retaining the chemical through simulated weathering.

The second test proposed here will be an AWPA E7 stake test testing the same solvent systems for DCOI plus biodiesel-containing mixtures of the #2 diesel treatment. The stake tests will be done at two field sites concurrently, at the Peavy Arboretum (~41″ annual rainfall) and our field site at Madras, Oregon (~11″ annual rainfall). Douglas-fir and Southern pine stakes will be treated with DCOI to three different retentions (Table 3.3.4) using one of five different solvent systems (Table 3.3.5). Stakes will also be treated with copper naphthenate in #2 diesel or pentachlorophenol in HBB-30 oil at three different retentions as controls. Depletion will be assessed with the highest retention for copper naphthenate and penta and all retentions for DCOI for 5 time points during the study.

Table 3.3.4: Target retention levels for treatment of Southern pine and Douglas-fir stakes

Retention Groups	DCOI Kg/m^3		CuNap Kg/m^3		Penta Kg/m^3	
	Doug-fir	S. pine	Doug-fir	S. pine	Doug-fir	S. pine
UC4B Retention 1	2.40	2.10	1.52	1.28	7.20	6.08
Retention 2	1.20	1.05	0.76	0.64	3.60	3.04
Retention 3	0.60	0.53	0.38	0.32	1.80	1.52

Table 3.3.5: Solvents used to treat stakes with DCOI, copper naphthenate or pentachlorophenol

Preservative	**Solvent**
DCOI	RHT-70
DCOI	HBB-30
DCOI	#2 diesel
DCOI	30% biodiesel
DCOI	50% biodiesel
Copper Naphthenate	#2 diesel
Penta	HBB-30

Each unique treatment will contain 10 replicate stakes for annual assessment in addition to the stakes used for depletion analysis. Assessments will be done according to the grading criteria described in the AWPA E7 standard (AWPA 2020). The study will be assessed until solvent system performance can be resolved.

3.4.0 Performance of DCOI as a treatment for Douglas-fir utility poles

As described in section 3.3.2 of this report, the future lack of availability of pentachlorophenol as a preservative for utility poles has stimulated a lot of questions from western utilities about what alternative treatments will be for their utility networks. DCOI and copper naphthenate are positioned to play a much larger role as utility pole treatments in western utilities once penta is no longer available. Copper naphthenate has a long history of successful use as a treatment for utility poles. DCOI, while not a new preservative, has not been standardized for utility poles until relatively recently and most of the literature supporting its efficacy utilizes southern pine. DCOI's performance in western species such as Douglas-fir have primarily been tested in a few smaller-scale trials and western utilities have requested more information about its performance in Douglas-fir in environments relevant to their utility networks. To address this, we've initiated a field study to study the relative performance of DCOI as a preservative treatment for Douglas-fir utility poles in two different environments, a dry site and a wet temperate site. In 2020, the UPRC has initiated a long-term study of the performance of DCOI relative to other common utility pole treatments for Douglas-fir in two different climate conditions.

3.4.1 Performance of DCOI as a treatment for Douglas-fir utility poles in two climactic conditions

The UPRC has recently obtained a dry climate field research site research in Madras, Oregon as an addition to our field research site at Peavy Arboretum. The Madras site will allow the UPRC to test the performance of utility pole treatments of various types in a low moisture environment (~11″ annual rainfall) in parallel with the Peavy Arboretum site which receives about 41″ of annual rainfall.

Table 3.4.1 Metadata for oilborne preservative two-climate study.

Description	DCOI, Qnap, penta two-climate post test					
Site(s)	Peavy Arboretum			Mardras, Oregon		
Installation date	October 2020			TBD		
Species	Douglas-fir			Douglas-fir		
Treatments	DCOI	Qnap	Penta	DCOI	Qnap	Penta
Number of Poles	5	5	5	5	5	5
Circumference at groundline (cm)	109.1	109.9	90.0			
Average Retentions (kg/m^3)	2.37	1.49	9.49			

Douglas-fir pole sections, 5′ x 12-14″ diameter were obtained from treating facilities in the Oregon/Washington region. Ten poles of each of three treatments, DCOI, CuNap, and penta, were obtained for this study. Each pole was cored at three equidistant locations at the center and these cores were pooled and assayed for retention using AWPA standard procedures (AWPA, 2020). The poles were installed at the Peavy Arboretum site in October 2020 and will be installed at the Madras Oregon site as soon as is possible.

Figure 3.4.1 Peavy Arboretum site for the DCOI pole test.

Background soil samples have been taken from the site to serve as controls in case any soil migration studies will be initiated in the future. This will be done at the Madras site as well. Poles were capped and will be left undisturbed until year 5 where they will be sampled for retention and the presence of fungi.

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OBJECTIVE IV:

PERFORMANCE OF EXTERNAL GROUNDLINE PRESERVATIVE SYSTEMS

4.1.0 Effectiveness of external barriers on pole performance

Initial preservative treatments done during utility pole manufacture lose efficacy over time and this loss can result in external decay on the outer pole surfaces, particularly from soft rot fungi. Extensive external decay can result in the loss of effective shell and pole strength causing the need for pole replacement. Surface decay can be prevented by the addition of preservative pastes and wraps that impart supplemental biocides to the pole surfaces at and below groundline. This helps slow or stop the growth of soft rot fungi at the pole surface and prevent the invasion of soft rot fungi in these areas. Wraps can also be used as a water impermeable barrier to prevent the ingress of moisture into poles at and below groundline where the risk of decay is highest and prevent the migration of preservative from poles into the environment.

External supplementary preservative treatments typically contain known preservative chemicals including borate, copper, or fluoride. Over the past 20 years, the UPRC has established a number of field trials for external groundline preservative pastes and barrier wraps on pole stubs at our Peavy Arboretum field site or poles in active utility lines. Most of these trials have been completed and a summary of past studies can be found in Table 4.1.1 along with references to the Annual Report in which results are presented.

4.1.1 Performance of Biotrans field liners in preventing moisture ingress to utility poles

In 2007, a set of penta-treated Douglas-fir pole stubs were encased in the newest generation of Biotrans liner and set into the ground at our Peavy Arboretum research site (Figure 4.1.1). The poles were each sampled prior to installation to determine chemical penetration and retention and baseline MC. Five poles received a Biotrans liner that extended 150 mm above groundline; five received a Biotrans liner that extended 300 mm above groundline and eleven poles were left without liners. The 2019 report summarizes data up to the 116th month of sampling. The study was not sampled this year and is being considered for finishing.

Figure 4.1.1: Example of a Biotrans liner at the OSU Peavy Arboretum test site.

Table 4.1.1. Summary of completed tests evaluating external groundline preservatives.

Location	Year Initiated	Wood Species	Primary Treatment	Treatments tested	Manufacturer	Final Report
Corvallis, OR	1989	Douglas-fir	none	CuNap-Wrap	Tenino Chem. Co (Viance)	1996
				CuRap 20 II	ISK Biosciences	
				Pol-Nu	ISK Biosciences	
				Cop-R-Wrap	ISK Biosciences	
				CRP 82631	Osmose Utilities Services, Inc.	
Corvallis, OR	1990	Douglas-fir	none	CuRap 20	ISK Biosciences	1993
				Patox II	Osmose Utilities Services, Inc.	
				CuNap-Wrap	Viance	
Merced, CA	1991	Douglas-fir W. redcedar S. pine	penta	CuNap-Wrap	Viance	2002
				CuRap 20	ISK Biosciences	
				Patox II	Osmose Utilities Services, Inc.	
Binghamton, NY	1995	W. redcedar S. pine	penta creosote	CuRap 20	ISK Biosciences	2003
				CuNap-Wrap	Viance	
				Cop-R-Wrap	ISK Biosciences	
Corvallis, OR	1998	Douglas-fir	none	Propiconazole	Janssen Pharm.	2003
				Dr. Wolman Cu/F/B	BASF	
				CuRap 20	ISK Biosciences	
Beacon, NY	2001	S. pine	penta	COP-R-PLASTIC	Osmose Utilities Services, Inc.	2009
				PoleWrap	Osmose Utilities Services, Inc.	
				Dr. Wolman Wrap Cu/F/B	BASF	
				Dr. Wolman Wrap Cu/B	BASF	
				Cobra Wrap	Genics, Inc.	
				Cobra Slim	Genics, Inc.	
Douglas, GA	2004	S. pine	creosote	CuBor (paste and bandage)	Copper Care Wood Preserving, Inc.	2010
				CuRap 20 (paste and bandage)	ISK Biosciences	
				Cobra Wrap	Genics, Inc.	
				COP-R-PLASTIC	Osmose Utilities Services, Inc.	
				PoleWrap (Bandage)	Osmose Utilities Services, Inc.	
Corvallis, OR	2007	Douglas-fir	Penta	BioTrans Pole Sleeves	BioTrans	2018 (penta migration Final), 2019 (moisture content)
Washington, Snohomish PUD	2014	Douglas-fir	CuNap with or without boron pre-treatment	Barrier wraps		2019 first sampling

4.2.0 References for Objective IV

OBJECTIVE V:

PERFORMANCE OF COPPER NAPHTHENATE TREATED WESTERN WOOD SPECIES

5.1.0 Use of Copper naphthenate as a preservative treatment for western species

Copper naphthenate (CuNap) has been available as a wood preservative since the 1940s and it was used as a creosote extender during the Second World War. Since then CuNap has gained widespread use as a stand-alone treatment. CuNap is currently listed as a non-restricted use pesticide, meaning applicators do not require special licensing to apply this chemical. As a result, some utilities have sought to replace more heavily-restricted chemicals with CuNap in an effort to cultivate a more environmentally-friendly image. As pentachlorophenol becomes less available and eventually unavailable as a utility pole treatment, the use of CuNap for the treatment of utility poles is likely to increase, therefore western utilities have an interest in understanding its performance in western wood species in a variety of conditions.

The UPRC has performed extensive testing designed to investigate the suitability of CuNap system for use on western wood species. Early studies in the UPRC examined the condition of Douglas-fir poles treated with copper naphthenate using diesel as the primary solvent. Both lab and field-based studies were used to investigate the performance of this system over the years and generally these support the use of CuNap as a treatment for western species. Described below are current efforts to measure the performance of CuNap as a utility pole treatment in western species.

5.1.1 Performance of Copper Naphthenate Treated Western Redcedar Stakes in Soil Contact

The test described below was initiated 30 years ago to provide continuous exposure data under realistic decay conditions. Western redcedar sapwood stakes (12.5 by 25 by 150 mm long) were cut from both freshly sawn lumber or the outer surfaces of the above-ground portions of utility poles in service for approximately 15 years. Poles were butt-treated but did not have any other above-ground treatments applied. Stakes cut from poles were included to test the ability of copper-naphthenate to retreat western redcedar poles.

Stakes were conditioned to stable weight at 23°C and 65% relative humidity (12% moisture content and weighed. Freshly cut and weathered stakes were pressure treated with copper naphthenate diluted in diesel oil to produce target retentions of 0.8, 1.6, 2.4, 3.2, and 4.0 kg/m^3, with 10 replicates for each stake type. Sets of 10 stakes or each type treated with diesel oil alone or completely untreated served as negative controls.

Stakes were then exposed in a fungus cellar maintained at 30°C and approximately 90% relative humidity. Soil moisture cycled between wet and slightly dry to avoid favoring soft rot attack (which tends to dominate in soils that are maintained at high moisture levels). Stake condition was visually assessed on an annual basis using a scale from 10 (completely sound) to 0 (completely destroyed).

In 2007, the decay chambers experienced and interruption in function and were replaced. This caused some drying of the soil medium during this period which slowed decay and shows up in the data as stalled declines in stake ratings. Once the chambers were fixed decay proceeded as before and stake ratings began declining more rapidly.

Freshly sawn stakes continue to out-perform weathered stakes at all retention levels (Figures 5.1.1 and 5.2.2). Non-treated stakes failed within 180 months while stakes treated with diesel alone have virtually all failed by the current rating at 360 months. At 360 months, all freshly sawn stakes treated with copper naphthenate to retentions of 4.0 kg/m^3 continue to provide excellent protection with average ratings of 7.1 (Figure 5.1.1). While some decay is present, it remains relatively minor and the wood is still serviceable. The conditions of stakes treated at the two lowest retentions (0.8 and 1.6 kg/m^3) continued to decline over the past 3-years and both treatments have average ratings of 2.5 and 3.7, indicating the presence of substantial decay and some failures. The average decay rating for the intermediate retention (2.4 kg/m^3) was just 4.7, while the second highest retention (3.2 kg/m^3) averaged about 6.2. The exposure conditions used in this test are designed to encourage soft rot and decay of this type was evident on several of the stakes as shown by an hourglass taper at the tip of decayed stakes (Figure 5.1.3). This suggests conditions were more suitable for decay deeper in the soil. Stake tests similar to this one are typically run for much shorter periods, but these results support copper naphthenate as an effective treatment to prevent soft rot in western redcedar over multiple decades.

Weathered stakes have consistently exhibited greater degrees of damage at a given treatment level than stakes made from freshly cut wood. The condition of these stakes continues to decline and all treatment levels would be non-serviceable in their current condition. The non-treated and diesel-treated controls were destroyed after 200 months. At 360 months, the three lowest retentions (0.8, 1.6, and 2.4 kg/m^3) had average ratings below 1.0, indicating the presence of substantial external decay and failure (Figure 5.1.2). Stakes treated to 3.2 or 4.0 kg/m^3 had average ratings of 2.6 and 3.8, respectively after 360 months. While weathering clearly reduced the service life of treated stakes, treatment with copper naphthenate to higher retentions shows potential for extending the life of weathered wood. The performance of weathered wood treated to 3.2 or 4.0 kg/m^3 showed similar resistance to decay as fresh cut wood treated to the lowest retention, 0.8 kg/m^3.

As noted, weathered wood was included in this test because the cooperating utility planned to remove poles from service for re-treatment and reuse. While this process remains possible, it is clear that the performance characteristics of weathered, retreated material differed substantially from freshly sawn material. Even if the outer, weathered wood were to degrade over time, this zone is relatively shallow on western redcedar and would not markedly affect overall pole properties. Copper naphthenate should continue to protect weathered western redcedar sapwood above-ground, allowing utility personnel to safely climb these poles. Any slight decrease in aboveground protection would probably take decades to emerge given the prolonged performance of this material in soil contact. As a result, retreatment of western redcedar still appears feasible for avoiding pole disposal and maximizing the value of the original investment.

A more reasonable approach might be to remove weathered wood and treat the poles. This process would be very similar to processes that have been used for removing sapwood on freshly peeled poles to produce a so-called “redbird” pole. Since weathered wood is already physically degraded, it likely has little strength and contributes little to overall material properties. Thus, treatment of a weathered outer layer serves little practical purpose. Removal of this more permeable, weaker wood would effectively reduce the pole class, but might result in a better performing pole. Resulting treatments on shaved poles would be shallower given the resistance of western redcedar to preservative treatment, but any gaps in the treatment barrier would only expose durable heartwood.

The results with freshly sawn and treated western redcedar clearly show good performance. These results are consistent with field performance of this preservative on western species. We continue to seek copper naphthenate treated Douglas-fir poles in the Northwest so that we can better assess the field performance of this system.

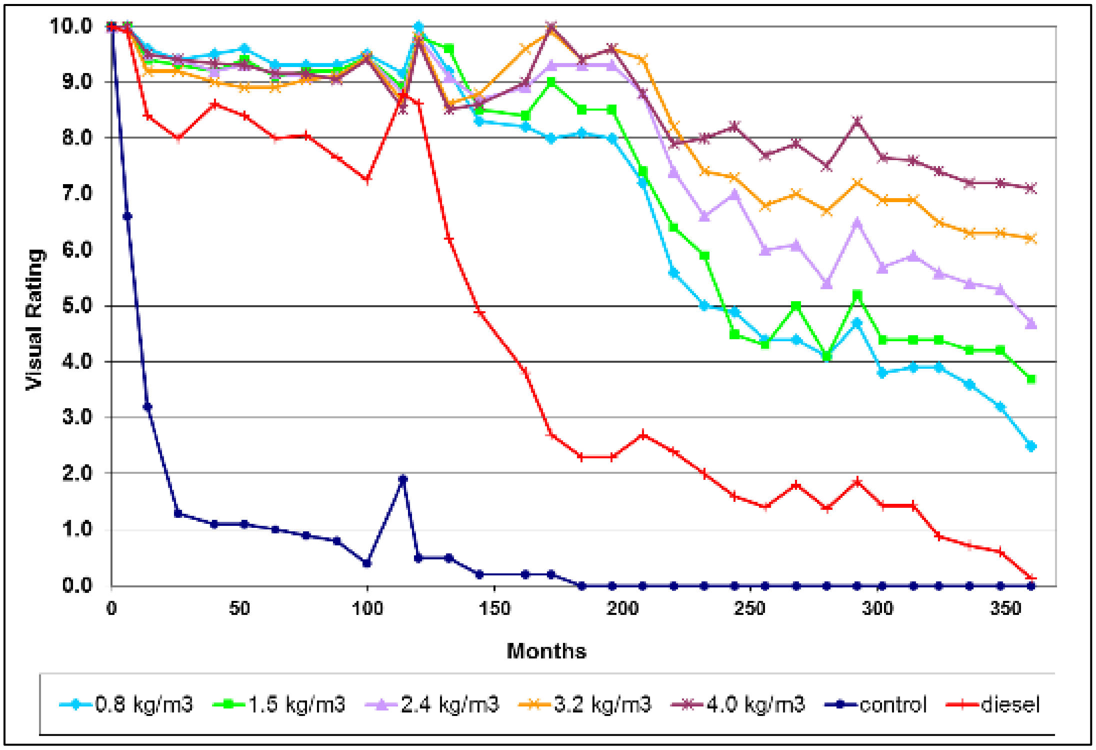

Figure 5.1.1: Condition of freshly sawn western redcedar sapwood stakes treated with selected retentions of copper naphthenate in diesel oil and exposed in a soil bed for 360 months.

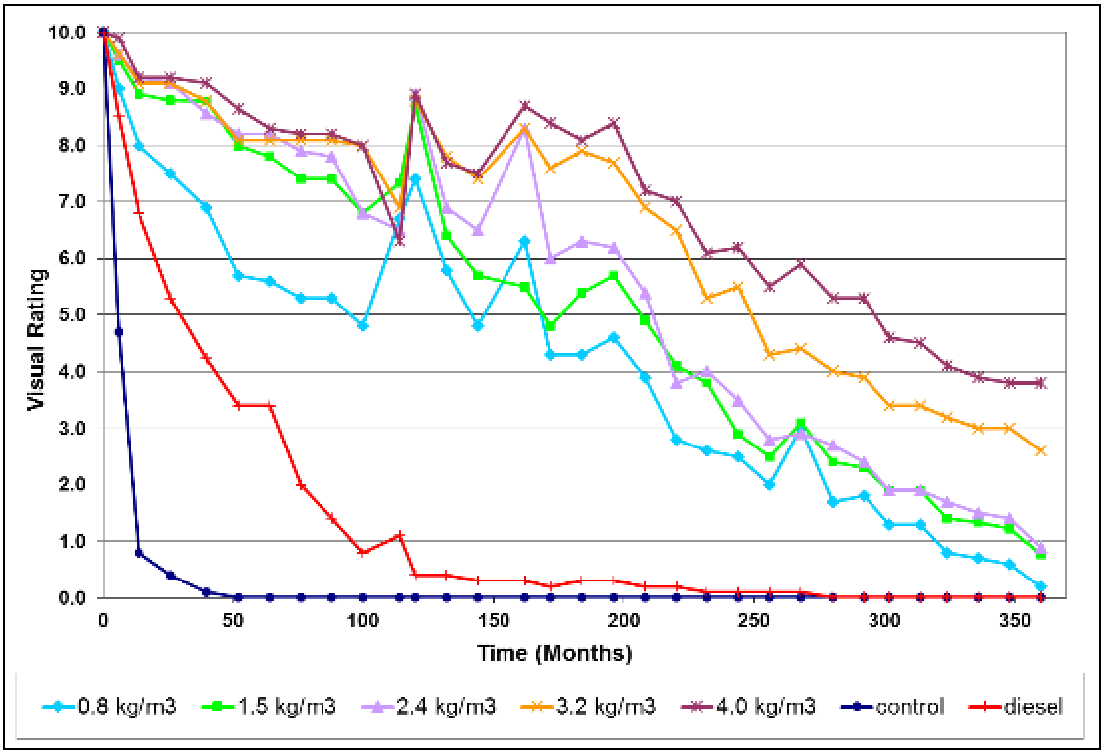

Figure 5.1.2: Condition of weathered western redcedar sapwood stakes treated with selected retentions of copper naphthenate in diesel oil and exposed in a soil bed for 360 months.

Figure 5.1.3: Examples of western redcedar stakes cut from weathered poles (top) and freshly sawn lumber (bottom) showing a tendency for wood to decay towards the lower end of the samples. Photos were taken in 2020.

5.1.2 Condition of Douglas-fir poles Treated with Copper Naphthenate in Diesel or Biodiesel Blends (SnoPUD/PSE Systems)

In our 2016 and 2017 Annual Reports we described a comparative study of copper naphthenate-treated poles in service using petroleum diesel or biodiesel as a carrier solvent. These poles were last sampled in 2019 where they were analyzed for copper retention, copper penetration, the presence of soft rot decay, and the presence of soft rot fungi and basidiomycete decay fungi. As a part of our evaluation of copper naphthenate performance, we had previously inspected 64 copper naphthenate-treated Douglas-fir poles in the Puget Sound area described in the 2012 and 2013 Annual Reports (Table V-1 in these reports). These poles had been treated with either biodiesel or a conventional petrodiesel solvent. Initial inspections determined preservative penetration and retention and identified whether soft rot decay was occurring at a faster rate in poles treated with a biodiesel vs petrodiesel carrier. These poles would then be monitored over the next decade to detect any early issues associated with the use of biodiesel. In 2015, we added an additional population of poles into this database (See 2016 Annual Report Table V-1).

These poles were not sampled in 2020 and they will be returned to in a later sampling point to be determined.

5.2.0 References for Objective V