Oregon State University
Utility Pole Research Cooperative
(UPRC)

Department of Wood Science & Engineering

39th Annual Report
2019

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COOPERATORS

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Bonneville Power Administration

Brooks Manufacturing Inc.

Clark Public Utilities

Copper Care Wood Preservatives Inc.

BASF Wolman, GMBH

Fortis Alberta

Genics Inc.

Idaho Power

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Lonza

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EXECUTIVE SUMMARY

The Cooperative currently operates under five objectives and the progress under each objective will be summarized below.

Objective I primarily examines the performance of the various internal remedial treatments. We have established a variety of field and laboratory tests to develop new and evaluate new internal remedial treatments for utility poles. We continue to evaluate studies that are in place at the Peavy Arboretum and have summarized the data for these studies in the section below. The goal of these tests is to evaluate all available remedial treatments in the same environment so they can be compared. Last year we completed a 20-year trial on the performance of dazomet with different types of accelerant and retreated these poles with the same accelerant combinations. One year after retreatment showed that only dazomet + accelerant, including copper naphthenate, consistently produced MITC levels above inhibitory threshold levels. MITC levels were most consistently reached at the closest sampling point to groundline.

We have continued to evaluate new remedial treatment combinations including poles treated with both metam sodium and boron rods and a comparative study between potassium dithiocarbamate and metam sodium. Co-treatment of penta-treated Douglas-fir poles with metam sodium and boron rods was sampled for the first time this year and results show that boron and MITC levels were generally higher when boron rods were absent from the treatment. Boron levels did not appear to be affected by the presence of metam sodium and were generally higher in the inner pole segments closer to groundline or below. Treatment of poles with potassium dithiocarbamate appeared to produce higher average levels of MITC than metam sodium, primarily at groundline or below. MITC values that were above threshold were typically at or below groundline for both treatments. However, each treatment also had more than one pole with MITC below threshold levels in a majority of the sampling area.

Laboratory tests of boron movement through treated wood show that boron diffusion is much slower through an oil treated shell. 2019 was the final year of data collection for this test and it is concluded as of this year.

We also continue to examine the performance of remedial treatment in dry climates. MITC production in dazomet and metam sodium treatments were hampered by low moisture conditions over the entire 102-month period while MITC-FUME performed well only in the first 36 months of the study. Boron diffusion from rods was minimal in dry climates and only reached above inhibitory levels in a few samples at or below groundline over a 102-month period. We will continue to monitor the performance of these treatments at dry sites and seek to add more in-service poles to our study.

Objective II examines methods for limiting internal decay above ground. The primary tests under this objective are two large field trials examining boron pre-treatments followed by an over treatment with either pentachlorophenol, copper naphthenate, or ammoniacal copper zinc arsenate. Boron levels continue to be highest in the outermost pole sections and much lower, often below threshold levels farther to the interior. There is not yet any clear pattern of inward diffusion in the first 6 and 3 years of these studies and we will continue to monitor boron diffusion in these poles over time.

Objective III examines a variety of methods to improve wood performance in utility systems including fire retardants, pole top caps, and selection of cross arms. Cap tests continue to show that water shedding caps markedly reduce internal moisture content of poles in service. Osmose caps continue to effectively reduce pole moisture content 142 months after installation and polyurea caps were effective at reducing moisture content at all sampling points except the 90-month sampling. Our study of pole top configuration continue to show that capped pole tops are most effective at consistently reducing moisture ingress, while the moisture content of pitched and double-pitched tops varied more widely depending on the sampling season. Collectively, the results illustrate the benefits of using water shedding caps to reduce internal moisture content and create conditions less conducive to fungal attack.

Fire continues to be a major problem for utilities with lines running through forested areas, particularly in arid or seasonally-dry climates. We continued to develop a novel fire test method as a preliminary screening tool to evaluate potential utility pole fire retardants and have utilized the prototype to test the performance of three arrangements of Genics Fire Mesh wraps. Our results indicate that double wrapping with the fire mesh was most effective and the square-cut mesh wrap orientation was least effective at preventing char on test poles. We plan to continue to develop this test as a standardized rapid testing protocol for AWPA.

The field stake trial examining the effects of solvents on performance of pentachlorophenol and copper naphthenate is continuing. The results show that all penta stakes are largely performing well regardless of solvent. Stakes treated with Cu-Nap in biodiesel appear to be trending towards higher levels of decay than diesel-treated Cu-Nap stakes, but the average decay ratings are not statistically different in these two treatments.

Crossarms are an important, but often overlooked, part of the overhead electrical transmission and distribution system. Douglas-fir is the primary species used for crossarms and the grading rules used to select arms are quite rigorous. In 2018, we examined the properties of 250 arms representing 50 arms that were considered acceptable according to the current grading rules and 200 that had been rejected for various reasons, primarily for knots. Almost all of the acceptable arms met the minimum ANSI value of 7800 psi (49/50), but over 80% of the rejected crossarms met this standard as well. This study indicates that grading based on visual characteristics alone could not effectively differentiate between crossarms with adequate and inadequate strength properties.

Objective IV examines the performance of external barriers applied below groundline on poles. We continue to examine the effect of Biotrans barriers at two different heights on moisture ingress into pole stubs at our Peavy Arboretum site. After 116 months of sampling it appears that barriers may cause slightly elevated moisture levels compared to unwrapped poles.

Objective V examines the performance of copper naphthenate as a preservative for utility poles. The long-term fungus-cellar trial shows that copper naphthenate-treated western redcedar stakes continue to perform well under high decay hazard conditions. We evaluated in-service utility poles in Washington State in the Clark County PUD and Snohomish County PUD that were treated with copper naphthenate using either a biodiesel or petrodiesel carrier. Copper naphthenate retention levels were generally higher in petrodiesel-treated poles at the 2015 and 2019 sampling times. Soft rot was slightly less prevalent in petrodiesel-treated poles than the biodiesel-treated poles in the Clark PUD, whereas the opposite was true in the Snohomish PUD. We will continue to monitor these poles at 4-5 year intervals to assess the relative performance of biodiesel copper naphthenate treatment.

OBJECTIVE I:
DEVELOP SAFER CHEMICALS FOR CONTROLLING INTERNAL DECAY OF WOOD POLES

Remedial treatments continue to play a major role in extending the service life of wood poles. Early forms of remedial treatments tended to consist of broadly toxic chemicals that readily volatilize into the wood anatomical structure. Further development of remedial treatments led to treatments composed of solids that are more safely applied and slowly diffused around the treatment area, in some cases with the aid of water. Each system offers advantages and disadvantages and may perform differently under specific environmental conditions. Our goal has been to elucidate which conditions each remedial treatment performs best so utilities may choose the most effective methods of pole life extension on a case-by-case basis. In addition, we aim to improve remedial treatment formulations that are more effective at preventing and arresting fungal growth within poles. Here we describe progress toward these goals completed in 2019.

A. Develop Improved Fumigants for Controlling Internal Decay of Wood Poles

While numerous methods are employed to control internal decay, fumigants are widely used in North America. Initially, 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. Both fumigants are prone to spilling during application, exposing the user to health risks. Two alternatives that are solid at room temperature were identified by the UPRC to reduce applicator exposure, methyl isothiocyanate (MITC sold as MITC-FUME) and dazomet (sold as Super-Fume, UltraFume, and DuraFume) (Table I-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 I-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. 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
Circumference @ GL (avg., max., min.)	84, 104, 65 cm

Dazomet powder was originally used in agriculture as a soil fumigant to reduce pathogen pressure on crops prior to planting. It was formulated into a pelletized form by the UPRC and tested as a pole fumigant. It was eventually formulated as a solid rod (BASF Wolman GmbH) for easy application into bore holes, however the reduced surface:volume of dazomet rods compared to powder raised questions as to its ability to adequately decompose to MITC. To test this, we performed a field trial to measure the performance of dazomet rods versus a powdered formulation alone or in the presence of a copper-based accelerant. MITC distribution was monitored over the course 15 years to determine whether, and for how long, each treatment provided adequate protection against decay fungi. These data are detailed in the 2015 annual report.

2. Performance of Dazomet With or Without Copper-based Accelerants

In the early development of dazomet as a remedial treatment, it was shown to decompose to the active fumigant, MITC, too slowly to be effective against decay fungi. Previous studies by Malcom Corden under the Coop indicated certain bivalent metals, such as copper, could markedly accelerate dazomet decomposition and further work by Paul Forsyth showed that mixtures of copper sulfate and dazomet produced excellent decomposition to MITC in the lab and performed well in field trials. However, EPA registration of the copper sulfate-based treatment proved too high a hurdle to its commercialization. We are not aware of any efforts to commercialize the copper sulfate as a dazomet accelerant. Copper naphthenate was explored as an alternative copper-based accelerant which was already approved for the field treatment of poles, but is a less concentrated form of copper than copper sulfate. The UPRC initiated 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 (Figure I-2-4)(Table 2). 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 I-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. Each core at each sampling location was analyzed for MITC to produce the heat maps (Figures I-2-5).

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.

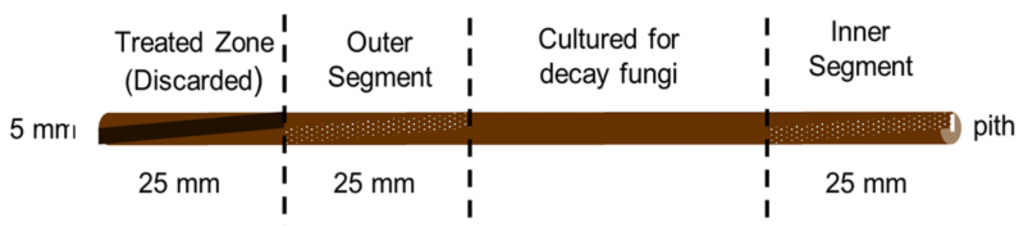


Figure I-1. Schematic of core processing for fumigant analysis and fungal culturing.

MITC levels in poles during the first 20-year treatment cycle are provided for reference (Table I-2; Figures I-2, I-3, I-4). 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 I-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 (Figure I-5).

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.

Table I-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).

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** (31)	6 (4)	0 (0)	0 (0)	0 (0)	0 (0)
	22 (1)	**38** (31)	3 (4)	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** (288)	3 (23)	0 (0)	0 (0)	0 (0)	0 (0)
	22 (1)	**274** (288)	**34** (23)	12 (22)	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** (50)	10 (17)	0 (0)	0 (0)	0 (0)	0 (0)
	22 (1)	**65** (50)	**24** (17)	0 (0)	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 with three replicates/height/depth/year.

The remaining core sections not extracted for MITC were cultured for decay fungi. Mostly, isolations were infrequent across all pole types and sampling heights (Table I-3)(Figure I-6). 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. No decay fungi were isolated from any cores taken from dazomet plus copper naphthenate. Of those sections where fungi were isolated, 11% contained decay fungi. These reapplied remedial treatments will continue to be sampled in the years to come.

Table I-3. Percentage of increment cores containing decay or non-decay fungi 1-20 years after dazomet application 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).

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}
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}
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}

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

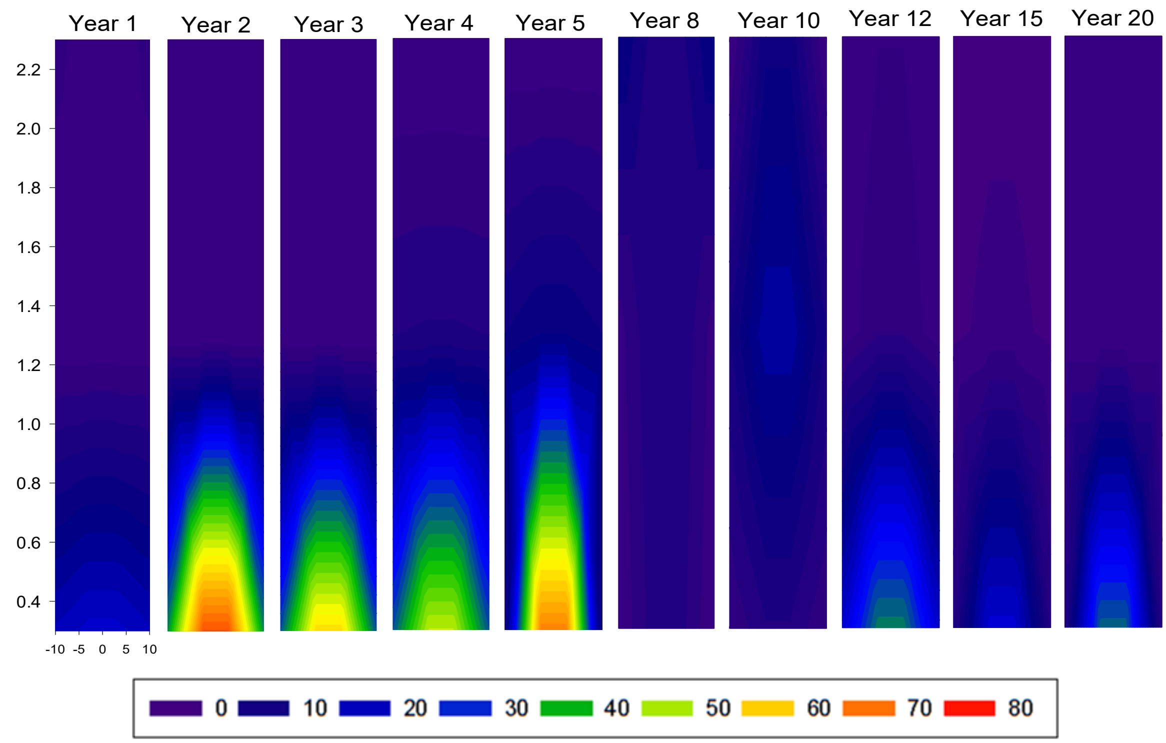


Figure I-2. Distribution of residual MITC in Douglas-fir pole sections 1 to 20 years after treatment with 200 g of dazomet. Dark blue indicates MITC levels below the threshold. Light blue and all other colors indicate MITC levels above that level.

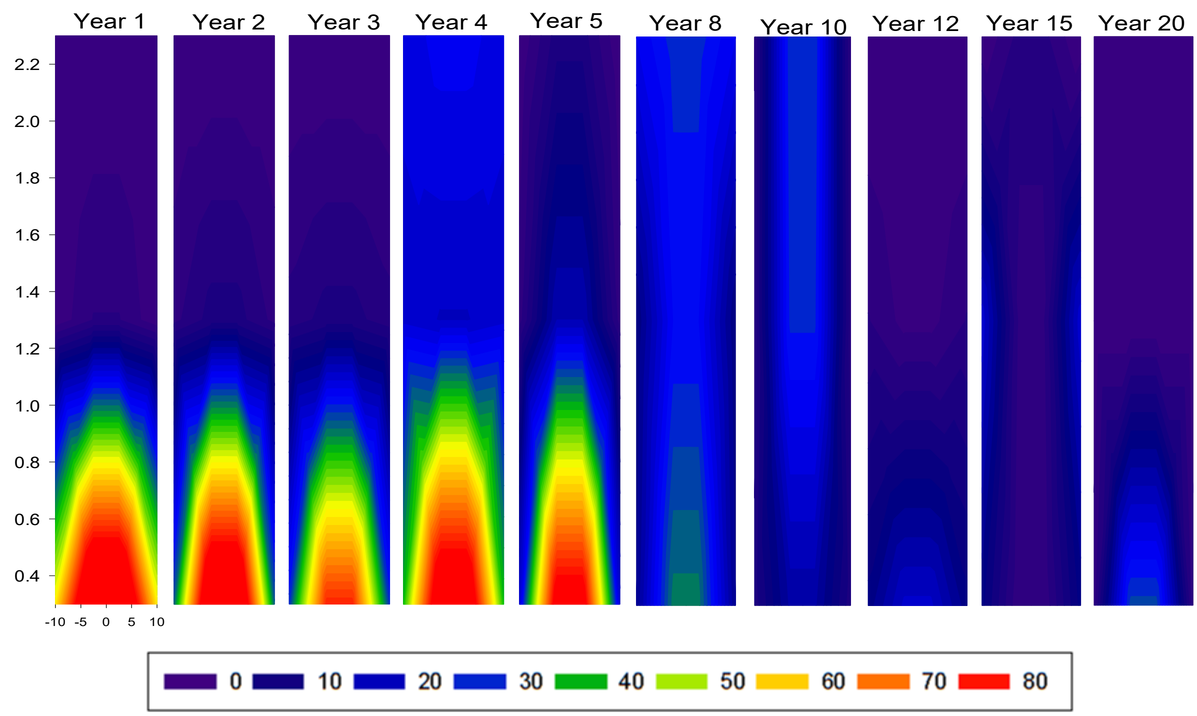


Figure I-3. Distribution of residual MITC in Douglas-fir pole sections 1 to 20 years after treatment with 200 g of dazomet plus 20 g of copper sulfate. Dark blue indicates MITC levels below the threshold. Light blue and all other colors indicate MITC levels above that level.

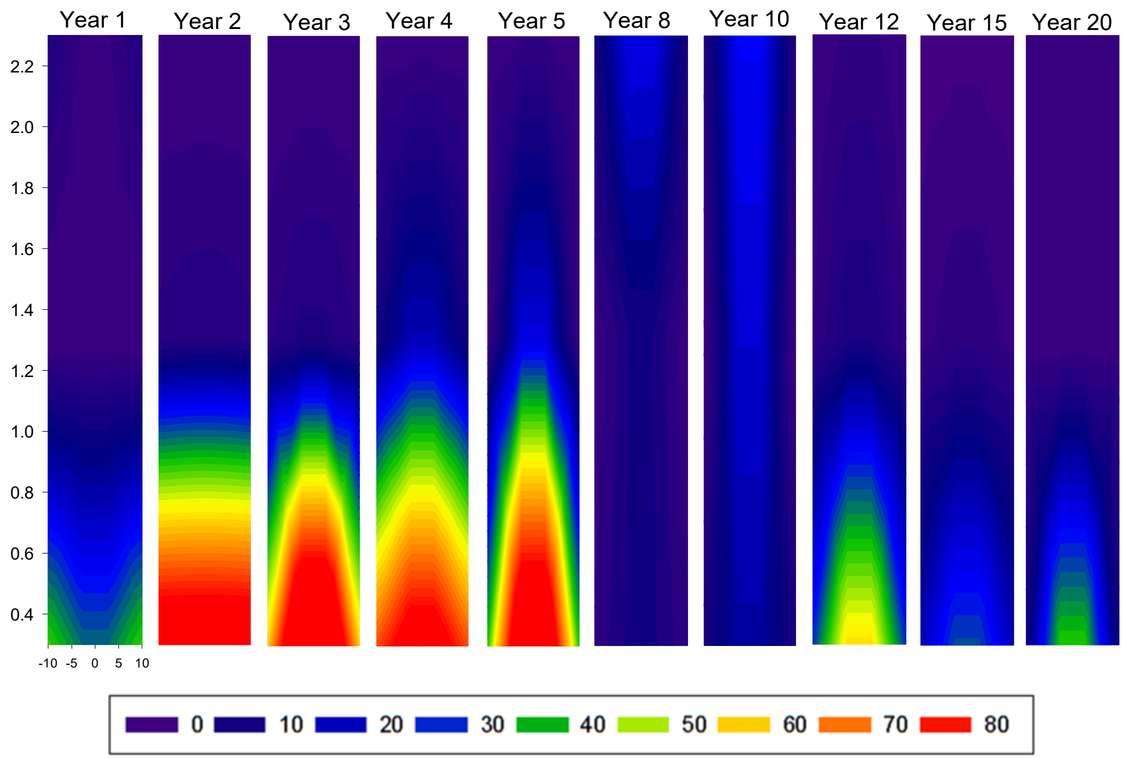


Figure I-4. Distribution of residual MITC in Douglas-fir pole sections 1 to 20 years after treatment with 200 g of dazomet plus 20 g of copper naphthenate. Dark blue indicates MITC levels below the threshold. Light blue and all other colors indicate MITC levels above that level.

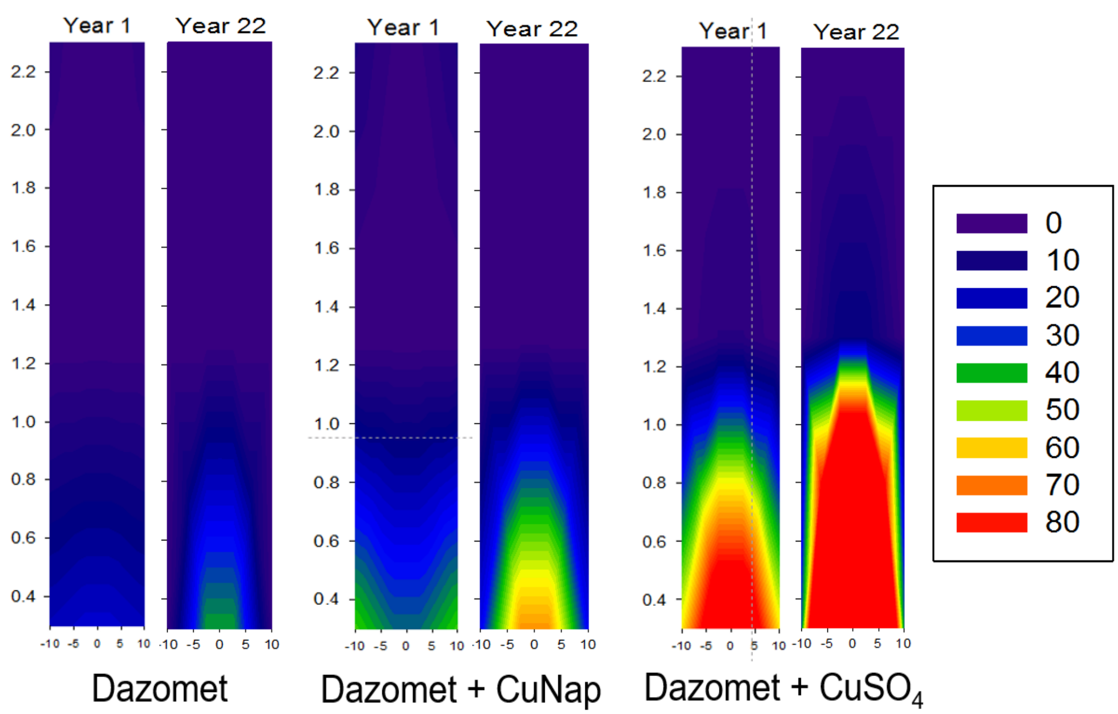


Figure I-5. Residual MITC distribution in Douglas-fir pole sections following initial treatment (year 1) and retreatment (year 21) with 200 g of dazomet without accelerant, 200 g of dazomet plus 20 g of copper naphthenate, or 200 g of dazomet plus 20 g of copper sulfate. Purple and dark blue indicate MITC levels below threshold, whereas other colors are above threshold.

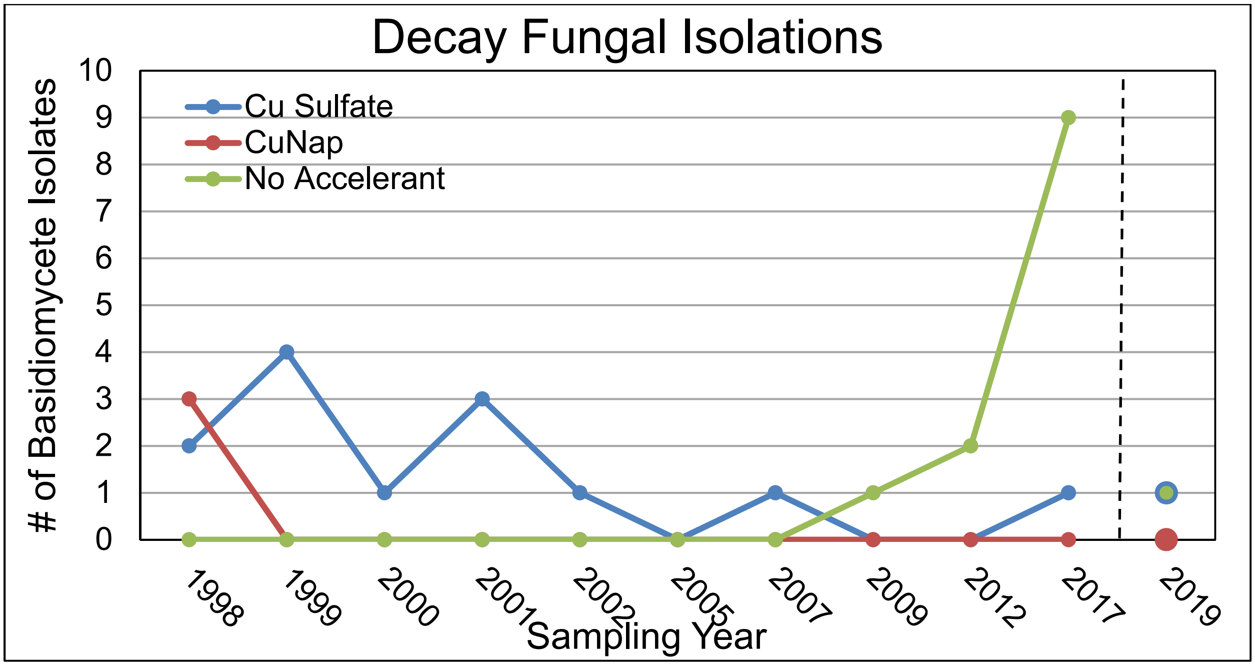


Figure I-6. Decay fungal isolations during the 20-year original treatment cycle and the first year after retreatment (2019). Poles were retreated in 2018 (vertical dotted line).

3. Effect of Metam Sodium on Boron Rod Performance

Some of our members have expressed an interest in testing the combination of metam sodium and boron as a remedial treatment. Metam sodium decomposes into MITC which diffuses as a gas through wood offering rapid protection from decay fungi, whereas boron requires moisture to move through wood causing a slow-release effect over 10-15 years. The combination of the two has potential to function as a dual action remedial treatment ultimately reducing the number of times utilities need to treat a single pole and reduce the number of treatment holes that need to be drilled in each pole. Additionally, metam sodium may act as an accelerant and stimulate faster boron diffusion into poles. The UPRC initiated a field trial at the Peavy Arboretum site to test the combination of these two chemicals as a remedial treatment.

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. Three steeply sloping holes were drilled into each pole beginning at groundline and moving upward 150 mm and around the pole 120 degrees.

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. To see how metam sodium performed without boron rods, please refer to the 2018 Annual Report (Page 19; I.C.1; Full Scale Field Trial of All Internal Remedial Treatments). 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. These poles were sampled for the first time in 2019 and will be sampled annually thereafter.

After one year of sampling, boron concentrations were highest in the below groundline samples, reaching the 0.6 kg/m^3 inhibitory threshold level 150 mm below groundline when inner and outer pole core sections were averaged (Table I-4). Average boron generally declined as the distance from groundline increased with the exception of the boron + water treatment at groundline which showed increased average boron levels compared to below groundline. When boron levels from inner and outer core sections were analyzed independently, the same general trend of decreasing boron concentration with increasing height was seen for both inner and outer sections. However, inner core sections had generally higher boron concentrations which remained above threshold in most treatments until 300 mm above groundline (Table I-4). 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.

MITC levels were also measured from 150 mm below groundline to 1000 mm above groundline in poles treated with metam sodium alone or metam sodium plus a boron rod. In most cases for both treatments, MITC levels appeared to be higher in the inner pole sections (Table I-5). Additionally, poles that were treated with metam sodium alone had generally higher MITC levels at all sampling locations. No fungi were isolated from metam sodium-treated poles, but there were sporadic isolations of decay fungi from poles treated with boron rods with or without water addition (Table I-6)(Figure I-7). Most of the isolations occurred in cores below groundline. 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. OSU will continue to sample these pole sections to establish the long-term performance characteristics of a combination of metam sodium and fused boron rods.

Table I-4: Boron concentration 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	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	**0.623**	(0.61)	0.467	(0.57)	0.492	(0.61)	0.175	(0.17)	0.143	(0.17)
	Pole Interior	**0.946**	(0.67)	0.407	(0.52)	**0.693**	(0.75)	0.213	(0.18)	0.165	(0.22)
	Pole Exterior	0.300	(0.37)	0.527	(0.67)	0.290	(0.43)	0.137	(0.17)	0.121	(0.13)
B Rods + H_2O	Whole Pole	0.583	(0.56)	**0.672**	(0.72)	0.414	(0.48)	0.120	(0.14)	0.053	(0.03)
	Pole Interior	**0.807**	(0.54)	**1.115**	(0.74)	0.549	(0.46)	0.190	(0.18)	0.068	(0.04)
	Pole Exterior	0.359	(0.53)	0.229	(0.36)	0.279	(0.51)	0.051	(0.02)	0.037	(0.02)
B Rods + NaMDC	Whole Pole	**0.608**	(0.83)	0.455	(0.54)	0.370	(0.53)	0.125	(0.11)	0.202	(0.41)
	Pole Interior	**0.704**	(1.09)	**0.667**	(0.70)	0.561	(0.71)	0.175	(0.12)	0.336	(0.57)
	Pole Exterior	0.512	(0.58)	0.244	(0.24)	0.179	(0.19)	0.075	(0.08)	0.069	(0.04)

Table I-5. MITC concentration in poles treated with Metam Sodium (NaMDC) alone or Metam Sodium + a fused boron rod 15 months after application at our Peavy Arboretum test site in Corvallis, OR. MITC levels above the protective threshold of 20 µg/g are indicated with bold green boxes.

Treatment	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	**77.80**	(38)	**45.05**	(44)	**61.74**	(27)	**35.79**	(21)	**36.76**	(18)	**45.31**	(36)
NaMDC Alone	**94.24**	(55)	**45.61**	(46)	**92.99**	(38)	**38.47**	(22)	**88.02**	(57)	**62.76**	(69)
Treatment	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	**42.90**	(25)	**29.57**	(28)	**42.35**	(34)	**18.59**	(15)	15.74	(20)	7.46	(8)
NaMDC Alone	**81.31**	(53)	**55.76**	(55)	**72.12**	(42)	**47.76**	(43)	**46.47**	(26)	**21.08**	(22)

Table 1-6. Results of culturing for decay and non-decay fungi. Metam sodium poles were completely devoid of fungi.

Sample (pole) Number	Treatment Name	Height (mm)	Pole Side	Non-Decay	Decay
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
1809	B Rods + H2O	150	C	1	1
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
1813	B Rods + H2O	0	B	1	0
1813	B Rods + H2O	0	C	1	0
1814	B Rods	-150	C	1	1
1814	B Rods	0	C	1	0
1820	B Rods	-150	B	0	1

Figure I-7. Cultured decay fungi from boron rod poles.

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

Metam sodium has been used for over 55 years for controlling internal decay in utility poles. One disadvantage of this chemical is that it is mostly water (32.7% NaMDC) and it has poor decomposition. Potassium N-methyldithiocarbamate (KMDC) is available in more concentrated form (~54%), but has not been previously explored for this application. We sought to test the efficacy of KMDC as a fumigant and compare its performance to NaMDC. To do this we initiated a field trial at our Peavy Arboretum site using penta-treated pole sections as a medium for comparing these two fumigants.

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 sloping holes were drilled into the poles beginning at groundline and moving upward 150 mm and around the pole 120 degrees. The poles were treated with 500 mL of NaMDC or KMDC and the holes were plugged with tight fitting plastic plugs. Each treatment was replicated on 5 poles.

These poles were sampled for MITC levels 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 removing the outer and inner 25 mm sections for MITC extraction in ethyl acetate according to standard procedures. 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 with KMDC trending toward higher overall MITC levels (Table I-7). For NaMDC-treated poles, MITC levels were below threshold inhibitory levels (20 µg/g) in at least one zone in all five of the poles sampled (Figure I-8). One pole, 1815, had MITC levels below threshold in the majority of the pole area. MITC levels were higher closer to ground level across all poles. 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. As with NaMDC, MITC levels tended to be higher near the groundline, but one KMDC-treated pole, 1818, had uniformly low MITC levels throughout, although above threshold in some portions of the pole near groundline (Figure I-9). These initial results indicate the range of MITC levels generated by KMDC is much wider, reaching higher levels than NaMDC. However, the variability of both treatments is high leaving some poles with more areas with MITC levels above threshold than others. It is too early to tell how these treatments will perform against one another in the long-term.

Efforts to culture fungi from the interior sections of the MITC cores yielded no viable fungi from any core. Sampling will continue annually for the next 10 years to determine the relative long-term efficacy of these two treatments.

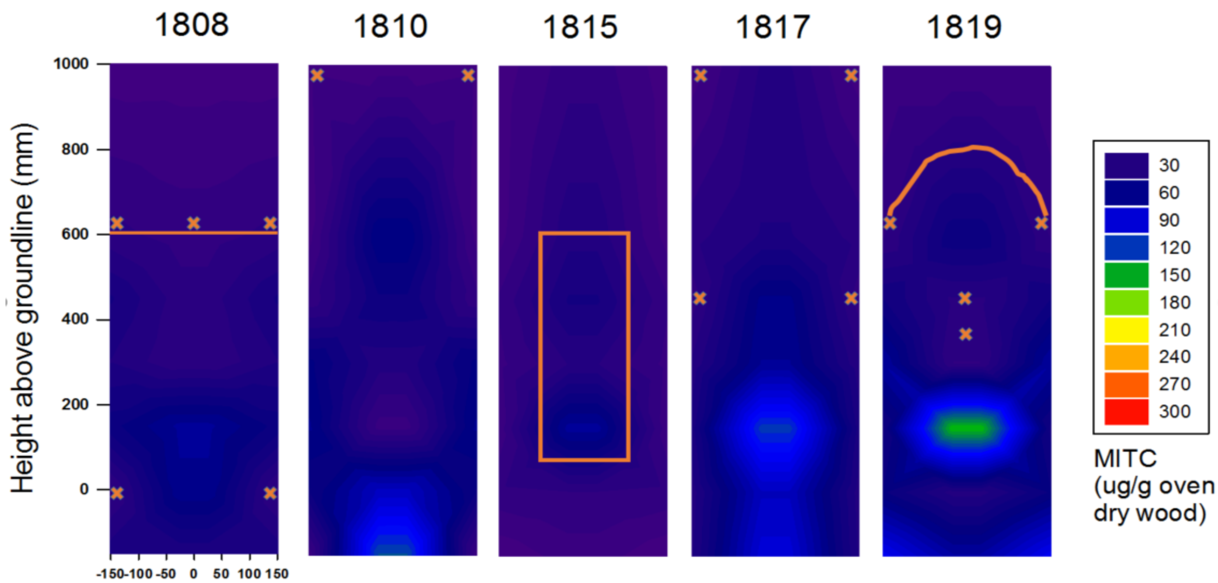


Figure I-8. MITC evolution from poles treated with Metam Sodium (NaMDC) one year after application at our Peavy Arboretum test site. Sections marked with an orange "x" or lines and in purple were below the protective threshold of 20 µg/g MITC. Numbers above each heat map indicate the specific pole identifier.

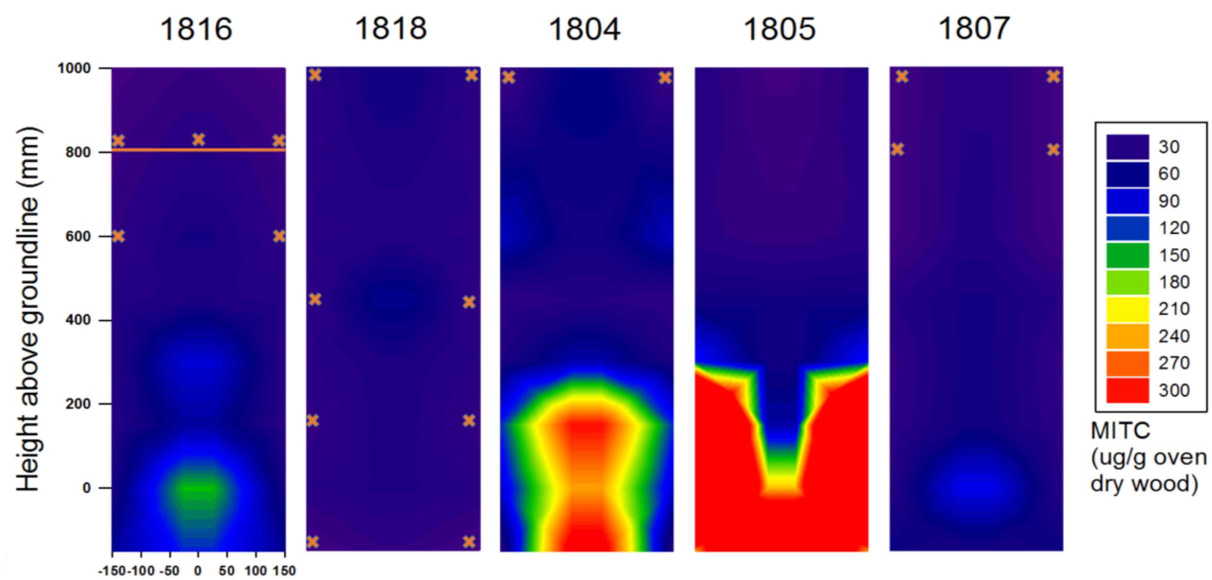


Figure I-9. MITC evolution from poles treated with Metam Potassium (KMDC) one year after application at our Peavy Arboretum test site. Sections marked with an orange "x" or lines and in purple were below the protective threshold of 20 µg/g MITC. Numbers above each heat map indicate a specific pole identifier.

Table I-7. 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)

B. 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 alternatives 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 a 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.

Remedial treatments with boron usually consist of a solid fused boron rod inserted into a drill hole at the desired treatment site. Exposure to water causes the boron to diffuse into the surrounding wood, spreading fungicidal activity. The UPRC has performed several field trials at the Peavy arboretum aimed at finding ways to increase boron mobility in wood. We have also initiated a study to determine how the presence of other common preservatives in wood interacts with the ability of boron to migrate. Our most recent efforts are described below.

1. Effect of Glycol on Movement of Boron from Fused Borate Rods

Date Established:	March 1995
Location:	Peavy Arboretum, Corvallis, OR
Pole Species, Treatment, Size	Douglas-fir, penta
Circumference @ GL (avg., max., min.)	84, 104, 65 cm

This test has been completed. Please consult the 2015 Annual Report for final data.

2. 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
Circumference @ GL (avg., max., min.)	78, 102, 66 cm

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

3. Diffusion of Boron Through Preservative Treated Wood

Several years ago, we examined the levels of remedial treatment below groundline in poles at the Peavy test site. Results were surprising because we found relatively little boron in this zone, despite moisture levels that should have encouraged diffusion through a wider area of the wood. One possible reason for this loss would be diffusion through the external preservative treated shell into the soil. In earlier studies, we examined the possibility of fumigants, notably MITC, diffusing through a treated shell. These results indicated that MITC strongly sorbed to the treated shell but did not diffuse through it. However, we have not explored the potential movement of boron through a treated shell. Work at Mississippi State University developed diffusion coefficients for boron applied as disodium octaborate tetrahydrate, but these tests did not include any oil-treated materials.

We have previously reported on efforts to determine a mass balance for the amount of remedial treatment applied vs the amount found within wood. The first attempt was made with boron rods and it suggested large amounts of boron were unaccounted for. We then examined boron levels in belowground portions of poles receiving boron rods, but this still did not account for boron levels recovered. One further possibility is that boron is diffusing to and through the preservative treated shell and into the surrounding soil. However, adjacent soil analyses did not show elevated boron levels, but the overall amount of boron moving into the soil was likely to be substantially diluted. While boron diffusion through wood has been well-studied, the potential for the preservative treated shell to retain boron has received little attention.

We should note here, these data do not address whether boron can or cannot move through a preservative treated shell (as is the case with external pastes). Rather, it attempts to establish a rate at which boron diffuses through a preservative treated shell in a controlled laboratory setting. To measure this, we created an apparatus capable of monitoring fluid flow through wood discs. Different preservative treatments could then be applied to the discs to measure their impact on migration of boron through preservative shells.

Douglas-fir lumber was used to create 25 mm diameter discs oriented so the wide surface presented either a radial or tangential face. These discs were conditioned to a stable moisture content at 23°C and 65% relative humidity before being pressure treated to a target retention of 112 kg/m^3 with biodiesel oil.

Non-treated and oil treated discs were then inserted in a diffusion apparatus constructed using 100 mm diameter PVC piping with one chamber on either side of the disk. The disc was held in place using a threaded connector that effectively sealed each chamber so that any movement would have to occur through the wood. One chamber contained a 4% boric acid equivalent (BAE) solution, while the other contained distilled water. Each chamber had a sampling port that allowed for solution to be removed for analysis of boron concentration (Figure I-10).

A wood disc was placed into the apparatus and appropriate solutions were added to each side. The assembly was placed on its side and maintained at room temperature (21°C to 24°C). At intervals, 2 mL of solution were removed from the distilled water side of each apparatus and tested for boron concentration. Distilled water was added back into the chambers so they remained full. The experiment was monitored until boron concentrations in the receiving side (distilled water side) stabilized.

Two years ago, we reported on tests that included radially oriented specimens with and without diesel treatment. The experiment was monitored on a regular basis for over 100 days. Boron movement was initially limited in both treated and control samples, but concentrations in control samples with no oil treatment increased at a much more rapid rate after 40 days of exposure (Figure I-11). Concentrations on the receiving ends of control samples continued to increase at a much faster rate than treated samples. This trial was discontinued because leaks in several chambers led to concerns about spurious results.

Figure I-10. Photograph of five of the diffusion apparatuses used to assess boron movement through non-treated or diesel oil-treated Douglas-fir lumber. A 25 mm diameter wood sample is resting on the fourth chamber to provide a measure of scale.

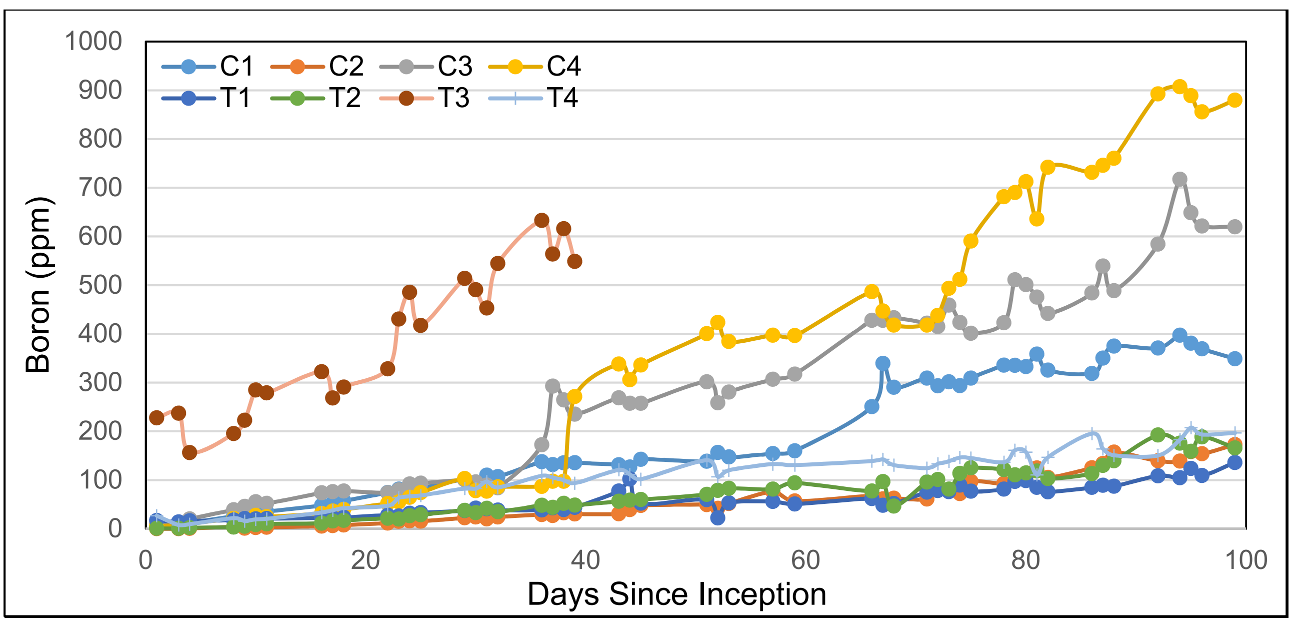


Figure I-11. Detail of boron concentrations early in the time-course on the receiving end of diffusion tests using radially oriented Douglas-fir sapwood with or without a biodiesel treatment, where C= no treatment and T= diesel treated samples. The T-3 sample developed a leak and was dropped from the test.

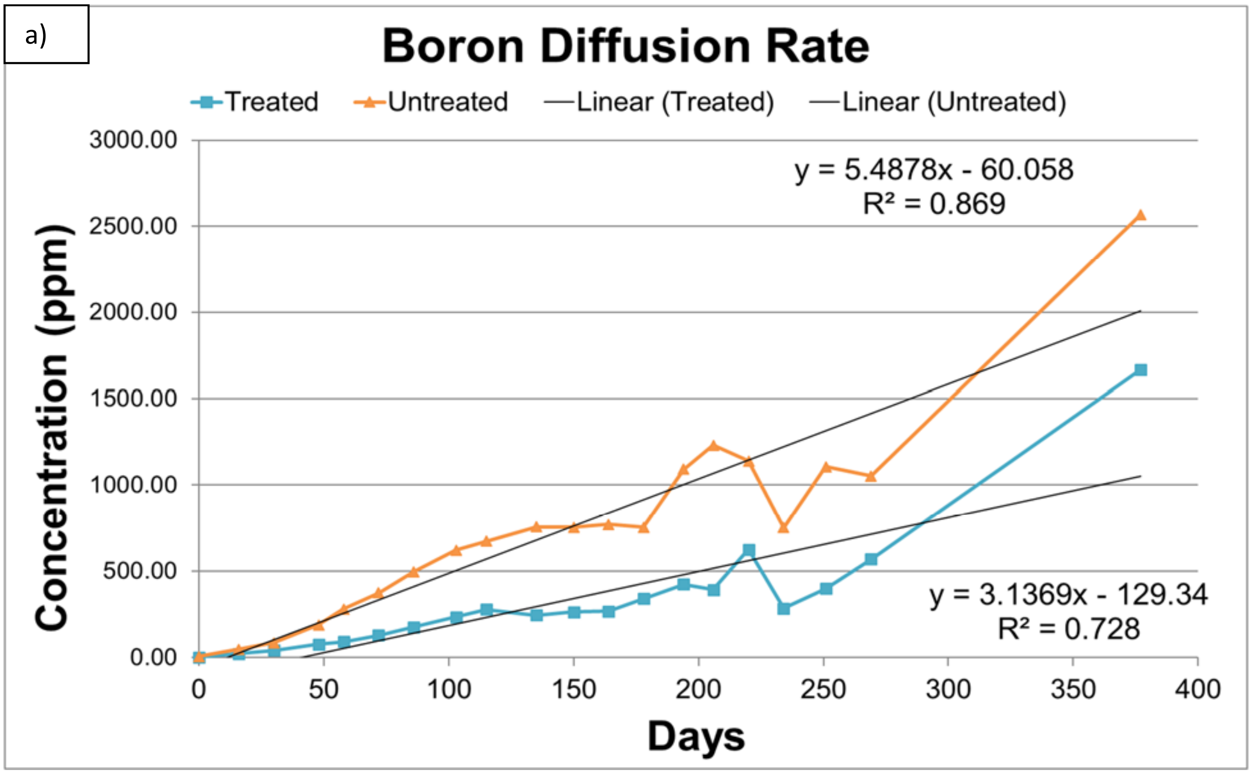
A second test was established last year using a similar set up with better seals. Boron was detected on the receiving (distilled water) side of the chambers within 25 days for both treated and non-treated samples, and levels detected were higher in chambers with untreated samples. Boron levels continued to increase with time in both sets of chambers; however, boron concentrations increased much more rapidly in chambers with untreated wood (Figure I-12). Initially, it appeared that boron concentrations in the receiving chamber were reaching an equilibrium state; however, boron levels have continued to gradually increase at points past about 269 days, suggesting this is not the case. At 269 days, boron levels in chambers containing oil-treated wood were just 67% of those in chambers containing non-treated wood. Chambers with oil-treated wood maintained lower boron concentrations into the later sampling times as levels for all chamber types increased out to 377 days. These results indicate that boron moves through wood treated with oil less efficiently than untreated wood. Therefore, oil is a barrier to boron migration, but an incomplete one that still allows diffusion.

We can infer from these lab-based data that low boron levels in poles at the Peavy site may be a function of the extremely high winter water table, which leads to boron leaching into the surrounding soil. Previous studies of railroad ties dipped in boron prior to air-seasoning and creosote over-treatment have shown creosote helps retain boron in railroad tie interiors for decades after treatment, even when ties are installed in track. Our test site is far wetter than the conditions a tie would be exposed to in a track on a well-drained ballast.

This diffusion test suggests boron losses are slowed by preservative treated shells, even when continuously exposed to liquid water. The data can then be used to model boron movement from poles and, hopefully, help explain the results obtained from sampling below-ground boron treated poles in the large scale internal remedial treatment test.

After this experiment ran for 377 days, we detected a seal leak in the diffusion chambers. The chambers were continually sampled past this point out to 495 days. Boron levels decreased in both chamber types at the 495-day sampling point (Figure I-12). After the leak at the 495-day time point, chambers with untreated wood were much more variable, causing a much larger overlap in boron values between the two treatment types (Figure I-13). It is unclear why boron levels dropped at this point, but there may have been an issue with the leaking apparatus that caused this decline. This experiment is now complete and will not yield further results in future reports.

a)



b)

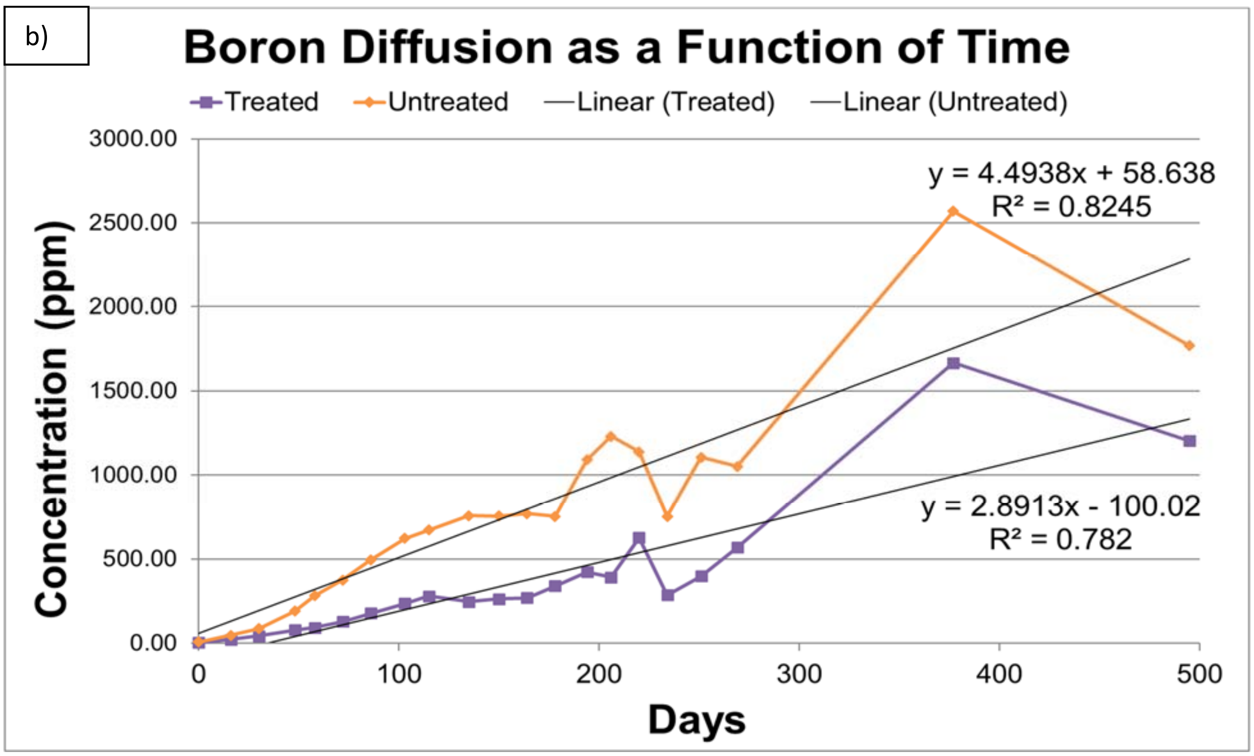


Figure I-12. Boron concentrations over time on the receiving end of diffusion tests using radially oriented Douglas-fir sapwood with biodiesel (treated) or without biodiesel (untreated). Panel a) rate of boron diffusion prior to suspect seal leak between 377 and 495 days. Panel b) rate of boron diffusion after suspect seal leak between 377 and 495 days.

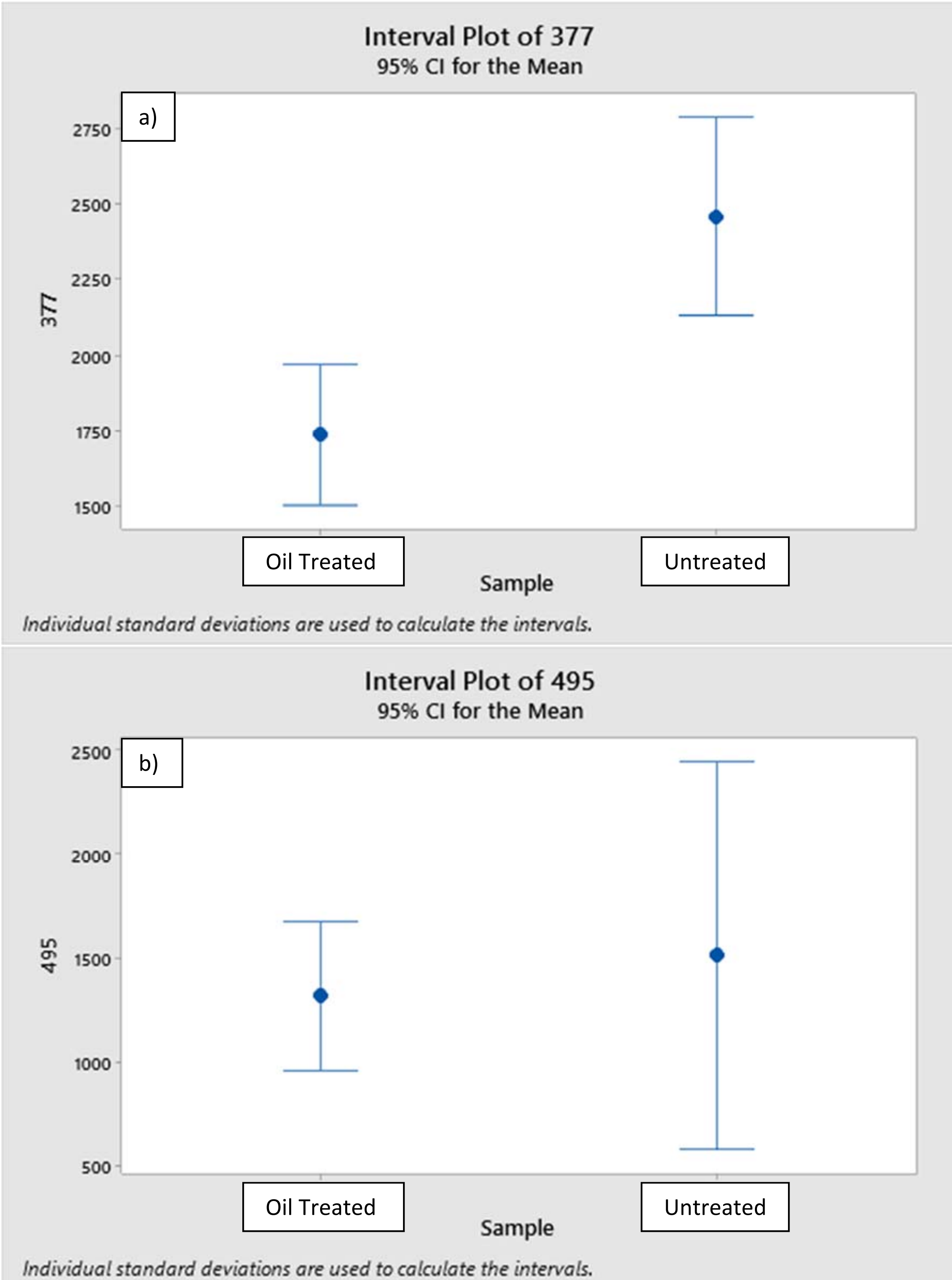


Figure I-13. Boron concentration variation on the receiving end of diffusion tests to highlight seal leakage. Panel a) significantly decreased boron diffusion across oil-borne preservative-treated shells. Panel b) no difference in boron concentration after seal leaks.

C. Tests Including Both Fumigants and Diffusibles

1. Full Scale Field Trial of All Internal Remedial Treatments

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

We have established numerous field trials to assess the efficacy of a wide variety of internal remedial treatments. Slight variations in methodologies over time disallow the use of these temporally segregated studies in “apples to apples” comparisons among all remedial treatments tested. To address this problem, we initiated a single large-scale test of all the EPA-registered internal remedial treatments in penta-treated Douglas-fir pole stubs at our Corvallis test site. This experiment was completed last year and details about the report are summarized in the 2018 report (Page 19; I.C.1; Full Scale Field Trial of All Internal Remedial Treatments). In brief, chemical levels in most poles were elevated 18 months after treatment, and gradually declined over the 125 month test, in line with typical remedial treatment cycles in North America. Fumigant levels tended to be highest toward the center of the poles at a given height, and at or below groundline. Many of the treatments tested were effective in keeping below groundline samples above the minimum inhibitory threshold of 20 µg/g dry wood through the 10-year period, although some retained higher levels than others, resulting in fewer fungal isolations from cores.

2. 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
Circumference @ GL (avg., max., min.)	87, 107, 71 cm

Internal treatments are widely used to arrest internal fungal decay in poles. These treatments have proven to be extremely effective, rapidly eliminating fungi and protecting against reinvasion for 7 to 10 or more years. While these treatments are highly effective, nearly all testing has been performed in wet, temperate climates. There are few data on the efficacy of these treatments in dry conditions common to most of the western United States. While decay risk is also lower in these locations, the absence of moisture in wood at the time of treatment can result in inadequate release of fungicidal compounds. Moisture can be a critical requirement for decomposition of dazomet to produce MITC and it is essential for diffusion of boron from fused boron rods. Performance of internal remedial treatments was assessed on Douglas-fir, western redcedar, and lodgepole pine poles located 220 kilometers (136 miles) south of Salt Lake City, Utah (Table I-8). Poles were selected on the basis of accessibility and absence of prior internal treatment. This high desert site receives little rainfall (Salt Lake gets an average of 400 mm of rain and 1400 mm of snow/year); approximately 150-200 mm of precipitation, primarily as snow, per year.

Each pole was sounded, then inspection/treatment holes were drilled beginning at groundline adjacent to the largest check and moving around the pole 120 degrees and upward 150 mm. Poles were treated with one of the following treatments according to the manufacturer's instructions: dazomet, dazomet with 1% copper naphthenate (10% w/w), MITC-FUME, metam sodium, fused borate rods (one 75 mm long rod/hole) with water (10% w/w), fused borate rods without water or were left untreated. Treatment holes were sealed with tight fitting plastic plugs.

Applied Treatments:

- Dazomet with accelerant (2% elemental copper)
- Dazomet with no accelerant
- MITC-FUME
- Metam sodium
- Fused boron rods with water
- Fused Boron rods without water
- Non-treated control

Poles were sampled 14, 36, 60, and 102 months after treatment by removing increment cores from three equidistant locations around a pole at heights of 150 mm below groundline, at groundline, as well as 300, 450, 600, and 900 mm above groundline. The treated shell was discarded and the outer and inner 25 mm was removed. The outer and inner 25 mm long core segments from poles treated with dazomet, metam sodium or MITC-FUME were placed into a glass vial and sealed with a Teflon lined cap. The remainder of the core was placed into a plastic drinking straw, labeled with the pole #/sampling height, location and stapled shut. For poles treated with fused boron rods, the entire core was placed in a drinking straw. Vials and straws were returned to Oregon State University for processing.

Table I-8. Characteristics of poles evaluated in the Rocky Mountain Power System.

OSU Pole #	RMP Pole #	Species	Primary Treatment	YI	Class	Length	Treatment
301	196502	L. pine	penta	1981	5	40	Dazomet
308	193501	L. pine	penta	1981	5	35	
315	191505	L. pine	penta	1981	4	40	
322	301701	cedar	creosote	1999	4	40	
331	303900	Douglas-fir	cellon (penta)	1996	5	35	
336	197705	cedar	penta	1999	4	40	
303	195501	L. pine	penta	1971	4	35	Dazomet + CuNap
310	193500	L. pine	penta	1980	5	35	
317	191503	L. pine	penta	1983	4	35	
324	301702	cedar	creosote	1999	5	30	
329	301906	Douglas-fir	penta	1999	4	30	
338	197700	Douglas-fir	penta	2008	4	35	
306	194501	L. pine	penta	1981	5	40	Metam Sodium
320	191600	L. pine	penta	1983	4	40	
332	194406	Douglas-fir	penta	2000	5	30	
334	199406	cedar	penta	2005	4	40	
341	194901	cedar	penta	2002	4	45	
307	194508	L. pine	penta	1971	5	35	Control
321	197504	L. pine	penta	1981	5	40	
335	199312	cedar	penta	2007	3	40	
305	195503	L. pine	penta	1984	4	40	MITC-FUME
312	192500	L. pine	penta	1981	5	35	
319	191500	L. pine	penta	1983	5	40	
326	301930	Douglas-fir	penta	1995	4	35	
328	301905	cedar	creosote	1999	5	30	
340	186200	cedar	penta	2006	4	35	

In the lab, cores were transferred to individual tubes containing 5 mL ethyl acetate and extracted at room temperature for a minimum of 48 hours. After extraction, the cores were oven-dried and weighed. Extracts were analyzed for MITC by gas chromatography. MITC was expressed on a µg MITC/oven dried gram of wood basis. Outer and inner 25 mm core segments from boron treated poles were combined from three cores from the same pole height, ground to pass a 20 mesh screen and hot water extracted. The resulting extract was analyzed by the Azomethine H method. Results were expressed as kg/m^3 boric acid equivalent (BAE).

Remaining center sections of all cores were briefly flamed to reduce the risk of surface contamination and then placed on 1% malt extract agar in plastic petri dishes. Cores were observed for evidence of fungal growth on the agar and any growth was examined for characteristics typical of wood decay fungi.

Previous studies have shown that the fungal protection threshold for MITC is approximately 20 µg/g, and the boron threshold is approximately 0.5 kg/m^3 BAE. These values were used as benchmarks to estimate the degree of protection provided by remedial treatments due to chemical migration in the wood.

No MITC was detected and only background levels of boron were present in poles not receiving treatment. The presence of some boron in the wood is consistent with our previous results and these are presumed to be naturally occurring. These levels do not measurably affect fungal growth. MITC-FUME treatment (Figure I-14) was the most effective at increasing MITC levels. After 14 months, MITC levels were elevated 3 to 345 times the inhibitory threshold (20 µg/g) in all core segments except for four located 900 mm above groundline in Douglas-fir and pine poles (Table I-9) MITC levels declined markedly at all three sampling heights 36 months after treatment, but remained well above (1-65 times) the inhibitory threshold in all core sections except for 900 mm above groundline in the inner core section of Douglas-fir poles. The outer section of Douglas-fir cores at this height increased above threshold values at this point. 60 months after MITC-FUME treatment, MITC levels decreased further with sections above threshold value ranging from 1.5 to 6.5-fold above threshold. Seven core sections dropped below threshold values that were above it at 36 months. After 102 months, only a single core section, inner core of pine poles at groundline, remained slightly above threshold MITC values. MITC levels tended to be 80 to 90% lower in the outer zones than in the inner zones of the same poles at a given location, but for the most part were still above threshold levels in the inner zone as well.

Western red cedar poles were the only poles to show effective treatment 900 mm above groundline across inner and outer core sections. This suggests that MITC-FUME may more readily migrate in western redcedar than Douglas-fir or pine poles. However, further replication and controlled cradle-to-grave field trials are needed to conclusively state any differences among species. MITC levels well above threshold values are consistent with prior observations of MITC-FUME treatments. MITC-FUME rapidly moves at very high levels throughout wood. Declines in MITC levels over time are more rapid than what has previously been observed in prior studies at the Peavey Arboretum, but the levels observed here are still consistent with effective treatment.

Metam sodium (Figure I-15) increased MITC levels in 22 of 30 core segment types above threshold 14 months after treatment. MITC levels ranged from 1 to 25 times the threshold level in these samples. Samples that were below threshold at 14 months ranged in location from outer core section below ground (cedar), outer core 300 mm above groundline (Pine), outer core sections 450 mm above groundline (Douglas-fir), outer core sections at 900 mm above groundline, and both sections 900 mm above groundline (Douglas-fir and Pine). At 36 months MITC levels decreased in most core sections and only 10 of 30 sample types remained above threshold levels. MITC levels ranged from 1 to 5 times threshold levels in these samples. Interestingly, all samples at or below groundline dropped below threshold except one (inner pine groundline). Conversely, inner sections 300 to 900 mm above groundline remained above threshold levels. After 60 months, MITC levels in several at or below groundline core sections increased to above threshold levels, particularly in the Douglas-fir pole which had only one outer core section 450 mm above groundline that was below threshold levels at this time point. All core sections from pine and cedar poles except for one in each species were below threshold at 60 months. Threshold levels were surpassed in 11 of 30 core section types and MITC levels in these ranged from 1 to 5.5 times the threshold level. At 102 months, there were no core sections among all species treated with metam sodium that had MITC levels above threshold.

In metam sodium treatments, as was observed in the MITC-FUME treatments, outer sections tended to have much lower MITC levels than inner sections. MITC levels tended to be higher in Douglas-fir poles than either western redcedar or lodgepole pine. Metam sodium tends to release high levels of MITC shortly after treatment. Then chemical levels decline within 2-3 years. Results at 14 and 36 months are consistent with these performance characteristics. More rapid loss of MITC from pine is consistent with the higher degree of permeability of this wood species. Western redcedar; however, is relatively impermeable and would be expected to retain MITC for longer periods.

Poles treated with dazomet alone contained levels of MITC much lower than those found in all other treatments after 14 months and no core sections exceeded threshold levels at this time point. After 36 months, only three core section types were 1 to 2 times threshold levels and surprisingly, these were all at groundline or above. At 60 months, 11 of 30 core section types were 1 to 10.5 times above threshold levels. Most of the increases in MITC levels seen at 60 months were in Douglas-fir and Pine in 150 mm below groundline, groundline, and 300 mm above groundline samples. At 102 months, only one outer core section 450 mm above groundline in the Douglas-fir pole was above threshold levels.

MITC levels were below threshold in most samples below groundline at 14 and 36 months, despite these having generally higher moisture levels conducive to dazomet decomposition (Figure I-16). There was a spike in MITC levels at 60 months for some samples at groundline and below, but these subsided again at 102 months. Results indicate that conditions were not suitable for dazomet decomposition when no copper accelerant was added. As seen with all other treatments, MITC levels tended to be highest in the inner zones, which reflects both the tendency for the sloping treatment holes to direct chemical in this direction as well as the reduced likelihood of diffusion outward from these zones. MITC distribution throughout poles; however, was spotty and barely above threshold where threshold levels were reached. MITC levels were highest in pine poles. Where effective levels of MITC were reached in the poles tested, it took five years for the dazomet treatment to decompose enough to generate threshold levels of MITC. This extended lag time between treatment and effective prevention would allow a wide window for decay to occur. These results indicate that applying dazomet to poles in drier regions without an accelerant does not result in an adequate release of active ingredient.

MITC levels in poles treated with dazomet plus copper naphthenate as an accelerant were higher than those found with dazomet alone 14 months after treatment, but much lower than those found with either metam sodium or MITC-FUME (Figure I-17). At 14 months, only 5 of 30 predominantly below or at groundline core section types were above threshold, ranging from 1.5 to 8 times MITC threshold levels. At 36 months, MITC levels increased dramatically in Douglas-fir poles and all sections in this species contained MITC levels above threshold. Pine and cedar showed some increases in MITC at this time point in inner cores 150 mm belowground. At this time point about half (14 of 30) of core section types were 2 to 34 times above MITC threshold levels. At 60 months, 8 of 30 core section types were 1 to 4 times the MITC threshold level. MITC levels in Douglas-fir poles decreased dramatically and only remained above threshold below groundline. Pine poles were above threshold values at groundline and below. Cedar poles had only one outer section below groundline with MITC values above threshold. At 102 months, Pine was the only species tested to have core sections above MITC threshold levels. Interestingly, inner core sections 450 and 900 mm above groundline showed MITC values above threshold levels at this time point.

These results illustrated the benefits of copper naphthenate accelerant for improving dazomet decomposition to MITC, but they also indicated that the resulting chemical levels were much lower than levels found in previous studies in wetter locations. The spotty distribution of MITC in poles over the course of the test suggests that even the addition of an accelerant does not produce rapid decomposition typically found in wetter climates. Results suggest that alternative methods need to be developed for applying dazomet under drier regimes. For example, increasing the amount of copper available to accelerate decomposition might improve performance. One utility had proposed a step wise treatment whereby smaller amounts of copper naphthenate and dazomet were alternately introduced into treatment holes to improve the degree of copper/dazomet interaction, however this would increase treatment time. Another approach might involve using less dazomet and more copper. This approach might be useful since field trials have shown that dazomet in wetter climates continues to release MITC that remains at threshold levels for over a decade in Douglas-fir. The fact that metam sodium is effective even though MITC only remains at fungitoxic levels for 3-5 years after treatment suggests that a lower amount of dazomet might still result in protective levels being present for a typical retreatment cycle. This might allow dazomet to be used under drier conditions. Another alternative would be to drill treatment holes further below groundline to place chemical where moisture levels are likely to be more suitable for both fungal attack and dazomet decomposition. However, this increases inspection costs because of additional digging.

In addition to substantial differences in MITC levels between the four fumigant treatments, MITC levels in outer zones were far lower than those in the interior. While an inner/outer gradient is consistent with previous studies showing the tendency of angled treatment holes to direct chemical toward the pole center, the differences observed were far greater than those observed in studies in wetter climates. The reasons for these differences are unclear, although they may reflect the presence of much drier wood or the high summer temperatures to which these poles were exposed. Elevated temperatures could increase chemical movement out of the pole. Regardless of the cause, results indicate that dazomet is ineffective without added accelerant and is unlikely to be useful when applied aboveground in these regions.

Boron levels in poles treated with fused boron rods alone tended to be extremely low over the 102 months in test (Table I-10). Only 7 core sections taken at any time point during this study had boron levels above the protective threshold and these were all at or near groundline. Boron levels in one of these samples (inner Douglas-fir at groundline, 36 months) had unreasonably high boron levels (6.23 kg/m^3), which suggests it may have come in contact with boron rod and is not an accurate representation of chemical migration in wood. The addition of water to treatment holes at the time of application in theory should have improved boron migration, however this was not observed. Boron levels remained well below threshold in most core sections analyzed at all time-points. Because boron requires moisture to migrate in wood, these data indicate that pole moisture levels were too low to allow boron movement from rods. If boron-based materials are used in poles in drier climates, it will be important to place the chemicals well below groundline where there is a potential for subsurface moisture to create conditions suitable for boron diffusion to occur. This may require a reconsideration of treatment patterns used.

Results indicate that MITC movement from MITC-FUME and metam sodium-treated poles was not affected by low moisture levels in poles in a dry climate. Dazomet and boron rods were both substantially affected by low pole moisture contents, which suggests the need for changes in how these systems are employed in drier climates. Placement of dazomet or boron rods in holes above groundline is not advisable in these poles unless there is evidence that external wetting occurs. These systems are only likely to be effective in higher moisture conditions that exist below the 150 mm below groundline sampling point tested in these studies. However, given the low levels of replication in this study, we recommend that further field testing in dry climates be done before conclusive recommendations be given.

No decay fungi were isolated from any poles over the course of testing. Decay fungi can be difficult to isolate from western redcedar and pine poles, but it is unclear why no fungi were isolated from non-treated Douglas-fir. While no decay fungi were isolated, a variety of non-decay fungi were isolated (Table I-11). These fungi play a variety of roles in wood including conditioning wood to enhance growth of decay fungi or inhibiting attack by other decay fungi. In this case, they can serve as indicators for suitable fungal growth. Very few fungi were isolated 14 months after treatment, perhaps reflecting the treatments applied to poles. Fungi were increasingly prevalent in the 36 and 60 month sampling points. At 102 months frequency of isolation showed a mixture of increases and decreases among core sections that had fungi, however there was no clear pattern. Fungi tended to be more common in Douglas-fir poles, but there was considerable variation in isolation frequency.

*Table I-9. MITC levels at selected distances above or below the groundline in western redcedar, Douglas-fir or lodgepole pines poles 14, 36, 60, & 102 months after application of MITC-FUME, metam sodium, or dazomet with/without an accelerant. **Bold** values are above threshold for fungal protection (20 µg/g).*

Trt.	Spp.	n	Time (Mo)	MITC Level (ug/g of wood)																			
				-150 mm				0				300 mm				450 mm				900 mm			
				inner		outer		inner		outer		inner		outer		inner		outer		inner		outer	
Control	cedar	1	14	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	8	(14)	0	(0)	0	(0)
			36	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
			60	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
			102	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
	pine	2	14	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
			36	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
			60	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
			102	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
Dazomet	cedar	2	14	10	(12)	1	(3)	16	(25)	3	(8)	9	(17)	0	(0)	5	(7)	3	(4)	2	(4)	0	(0)
			36	10	(16)	2	(5)	**39**	(72)	2	(4)	7	(11)	2	(5)	**25**	(57)	2	(6)	1	(4)	0	(0)
			60	**47**	(104)	13	(25)	8	(19)	**51**	(124)	17	(43)	2	(4)	**23**	(47)	4	(10)	1	(3)	8	(19)
			102	0	(0)	2	(5)	2	(5)	0	(0)	0	(0)	0	(0)	0	(0)	4	(6)	0	(0)	0	(0)
	DF	1	14	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
			36	0	(0)	0	(0)	1	(2)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
			60	**215**	(372)	13	(22)	**37**	(41)	10	(18)	**52**	(50)	14	(24)	16	(28)	16	(27)	**27**	(25)	12	(21)
			102	0	(0)	0	(0)	0	(0)	0	(0)	6	(10)	4	(8)	6	(8)	**83**	(143)	0	(0)	0	(0)
	pine	3	14	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	2	(5)	0	(0)	1	(3)	0	(0)
			36	6	(12)	3	(5)	15	(13)	4	(7)	5	(8)	1	(4)	0	0	0	(1)	**27**	(64)	4	(9)
			60	**23**	(67)	**34**	(41)	19	(32)	**30**	(39)	**26**	(60)	16	(29)	3	(7)	12	(30)	4	(9)	7	(13)
			102	14	(28)	0	(0)	12	(32)	0	(0)	5	(4)	0	(1)	13	(15)	1	(2)	6	(16)	2	(5)
Dazomet + Cu	cedar	1	14	19	(12)	0	(0.0)	**33**	(14)	0	(0.0)	11	(13)	9	(16)	**158**	(193)	0	(0)	14	(24)	0	(0)
			36	**341**	(559)	0	(0)	10	(4)	0	(0)	12	(11)	9	(16)	98	(153)	6	(11)	0	(0)	0	(0)
			60	3	(3)	**33**	(51)	0	(0)	0	(0)	0	(0)	0	(0)	1	(2)	10	(17)	0	(0)	0	(0)
			102	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	20	(34)
	DF	2	14	**67**	(72)	12	(24)	**54**	(69)	1	(3)	18	(7)	3	(7)	10	(6)	0	(0)	0	(0)	0	(0)
			36	**679**	(757)	**75**	(97)	**323**	(513)	**153**	(337)	**145**	(159)	**75**	(118)	**35**	(52)	**91**	(188)	74	(139)	164	(235)
			60	**23**	(26)	**32**	(43)	20	(24)	10	(11)	19	(21)	2	(4)	12	(15)	8	(9)	0	(0)	0	(0)
			102	13	(14)	13	(20)	16	(16)	4	(5)	13	(14)	5	(9)	11	(15)	7	(13)	6	(9)	2	(3)
	pine	3	14	17	(17)	7	(21)	**31**	(27)	0	(0)	2	(3)	2	(6)	0	(0)	0	(0)	0	(0)	0	(0)
			36	**43**	(58)	8	(9)	**52**	(73)	1	(2)	12	(16)	0	(0)	5	(14)	0	(0)	2	(5)	1	(2)
			60	**32**	(48)	**83**	(143)	**27**	(30)	**23**	(26)	20	(36)	3	(5)	3	(6)	**29**	(53)	4	(7)	1	(2)
			102	**24**	(35)	9	(9)	**30**	(28)	18	(44)	14	(20)	6	(10)	**23**	(26)	18	(38)	**55**	(81)	7	(7)
Metam Sodium	cedar	2	14	**155**	(215)	15	(12)	**64**	(34)	**29**	(21)	**148**	(18)	**48**	(44)	**239**	(127)	**34**	(36)	**34**	(30)	9	(15)
			36	7	(3)	0	(0)	10	(6)	2	(3)	**36**	(27)	3	(6)	**34**	(19)	3	(5)	**39**	(26)	2	(4)
			60	**60**	(104)	17	(30)	16	(36)	13	(20)	7	(10)	3	(5)	15	(23)	20	(29)	0	0	3	(7)
			102	3	(7)	0	(0)	5	(6)	0	(0)	13	(24)	0	(0)	2	(4)	0	(0)	3	(8)	0	(0)
	DF	1	14	**290**	(355)	**37**	(5)	**124**	(54)	**76**	(50)	**96**	(82)	**88**	(137)	**497**	(306)	5	(8)	19	(14)	0	(0)
			36	8	(9)	0	(0)	6	(5)	7	(8)	**104**	(86)	**23**	(14)	**78**	(20)	7	(7)	**44**	(44)	4	(6)
			60	**63**	(12)	**49**	(11)	**114**	(51)	**52**	(12)	**56**	(33)	**44**	(16)	**72**	(19)	19	(17)	**30**	(9)	**21**	(14)
			102	0	0	0	0	0	0	0	0	0	0	0	0	2	(3)	0	(0)	3	(6)	0	(0)
	pine	3	14	**158**	(165)	**169**	(336)	**108**	(75)	**48**	(53)	**181**	(209)	14	(21)	**23**	(25)	**48**	(44)	0	(0)	6	(12)
			36	5	(8)	0	(0)	**44**	(40)	3	(4)	**105**	(155)	4	(6)	**35**	(34)	2	(5)	11	(28)	3	(7)
			60	1	(1)	19	(21)	**65**	(54)	6	(11)	17	(37)	3	(7)	0	(0)	0	(0)	1	(1)	0	(0)
			102	2	(4)	2	(6)	7	(13)	0	(0)	4	(9)	5	(12)	3	(8)	0	(0)	0	(0)	0	(0)
MITC-FUME	cedar	2	14	**1537**	(887)	**227**	(255)	**2954**	(3080)	**439**	(890)	**3902**	(2648)	**527**	(594)	**3019**	(2235)	**557**	(556)	**183**	(158)	**94**	(201)
			36	**222**	(126)	**28**	(30)	**297**	(84)	**91**	(69)	**387**	(370)	**193**	(162)	**488**	(554)	**217**	(224)	**234**	(283)	**197**	(125)
			60	19	(22)	**64**	(69)	**85**	(43)	**112**	(51)	**60**	(42)	**88**	(40)	6	(11)	10	(12)	**32**	(32)	19	(15)
			102	9	(8)	6	(7)	6	(5)	4	(6)	0	(0)	2	(3)	18	(21)	0	(0)	8	(2)	6	(7)
	DF	1	14	**3616**	(2938)	**420**	(530)	**6911**	(2969)	**332**	(381)	**2136**	(1589)	**178**	(304)	**462**	(783)	**67**	(62)	0	(0)	0	(0)
			36	**840**	(340)	**323**	(414)	**1316**	(234)	**173**	(151)	**369**	(82)	**162**	(91)	**273**	(243)	**54**	(53)	13	(12)	**27**	(47)
			60	**106**	(26)	**128**	(35)	**78**	(53)	**75**	(32)	**59**	(54)	6	(11)	**46**	(17)	**48**	(33)	15	(13)	10	(14)
			102	10	(9)	1	(2)	8	(9)	3	(6)	3	(6)	0	(0)	13	(6)	2	(3)	0	(0)	0	(0)
	pine	3	14	**1549**	(1454)	**149**	(130)	**5647**	(7469)	**195**	(239)	**833**	(1278)	**85**	(218)	**60**	(157)	**487**	(1371)	1	(2)	0	(0)
			36	**557**	(377)	**300**	(412)	**755**	(556)	**263**	(288)	**543**	(336)	**145**	(195)	**133**	(180)	**37**	(58)	2	(4)	2	(3)
			60	**109**	(87)	**72**	(40)	**114**	(35)	**30**	(33)	8	(14)	0	(0)	**54**	(80)	**55**	(107)	1	(3)	0	(0)
			102	16.3	(13)	4.7	(7)	**27**	(34)	3	(4)	16.6	(41)	2.3	(5)	14.8	(19)	6.2	(8)	9.7	(13)	2.8	(5)

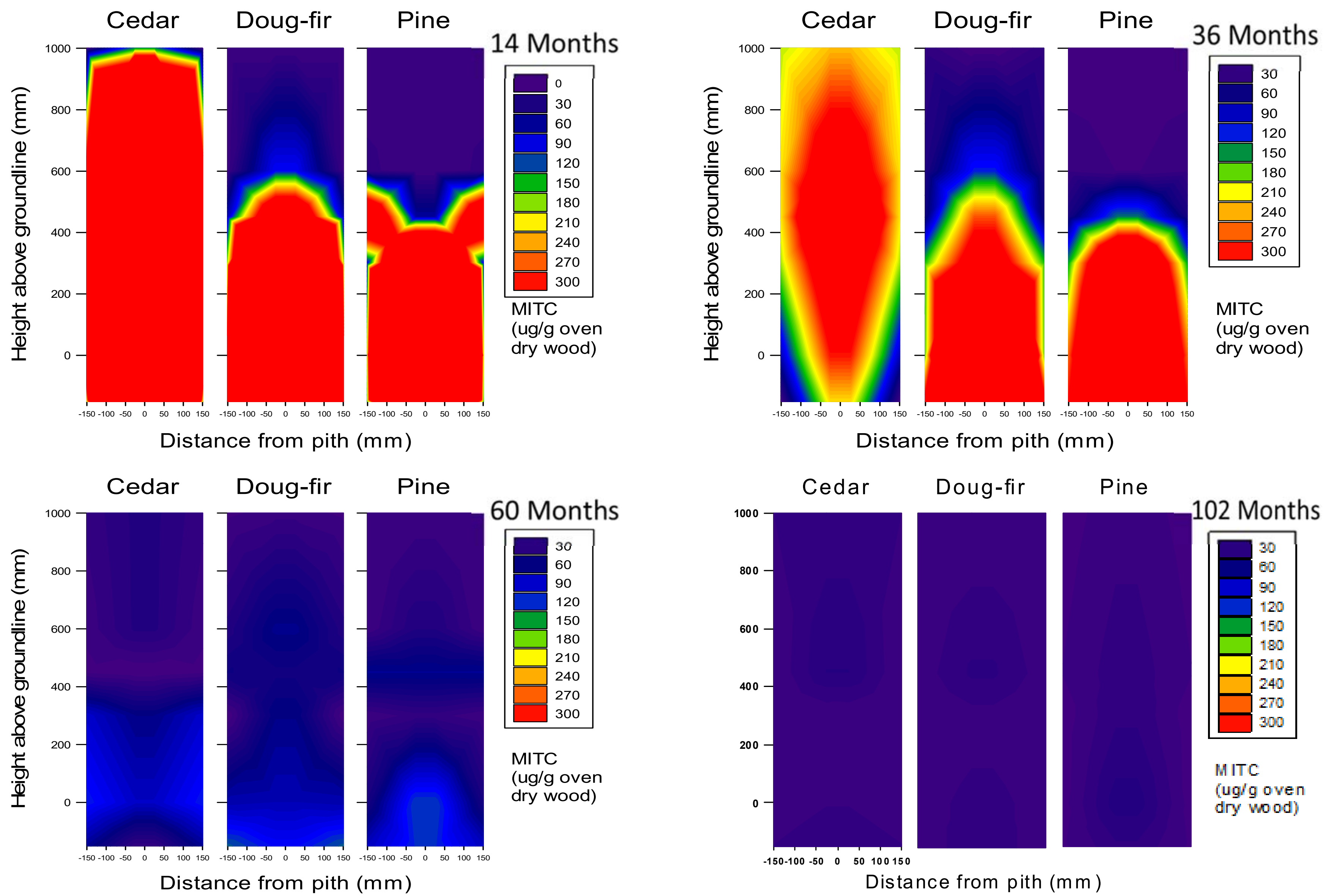


Figure I-14. *Diagram showing MITC levels in poles 14, 36, 60, or 102 months after application of MITC-FUME. Red colors indicate MITC levels well above the toxic threshold of 20 µg/g. Only deep purple colors are below threshold.*

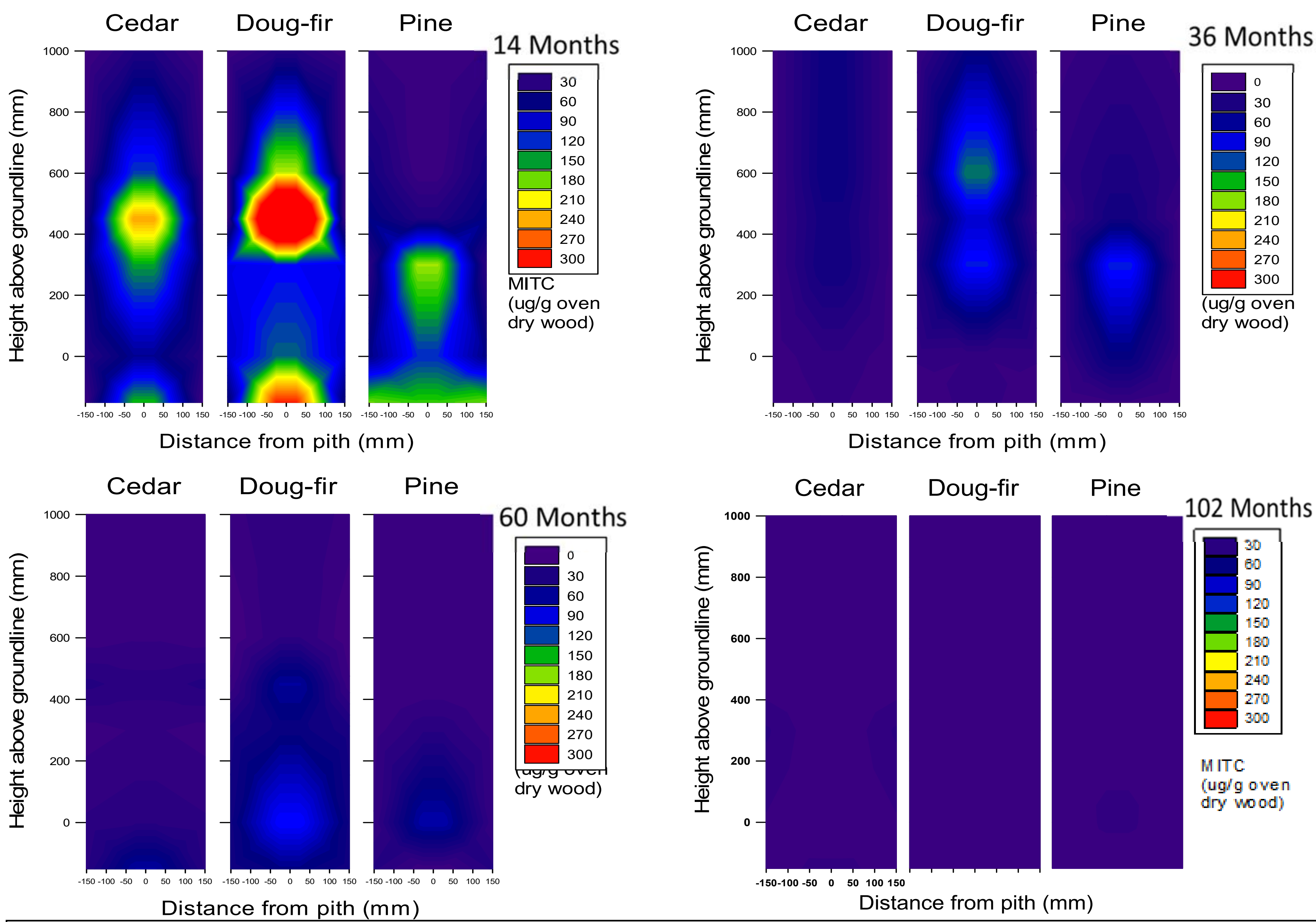


Figure I-15. Diagram showing MITC levels in poles 14, 36, 60, or 102 months after application of Metam Sodium. Red colors indicate MITC levels well above the toxic threshold of 20 µg/g. Only deep purple colors are below threshold.

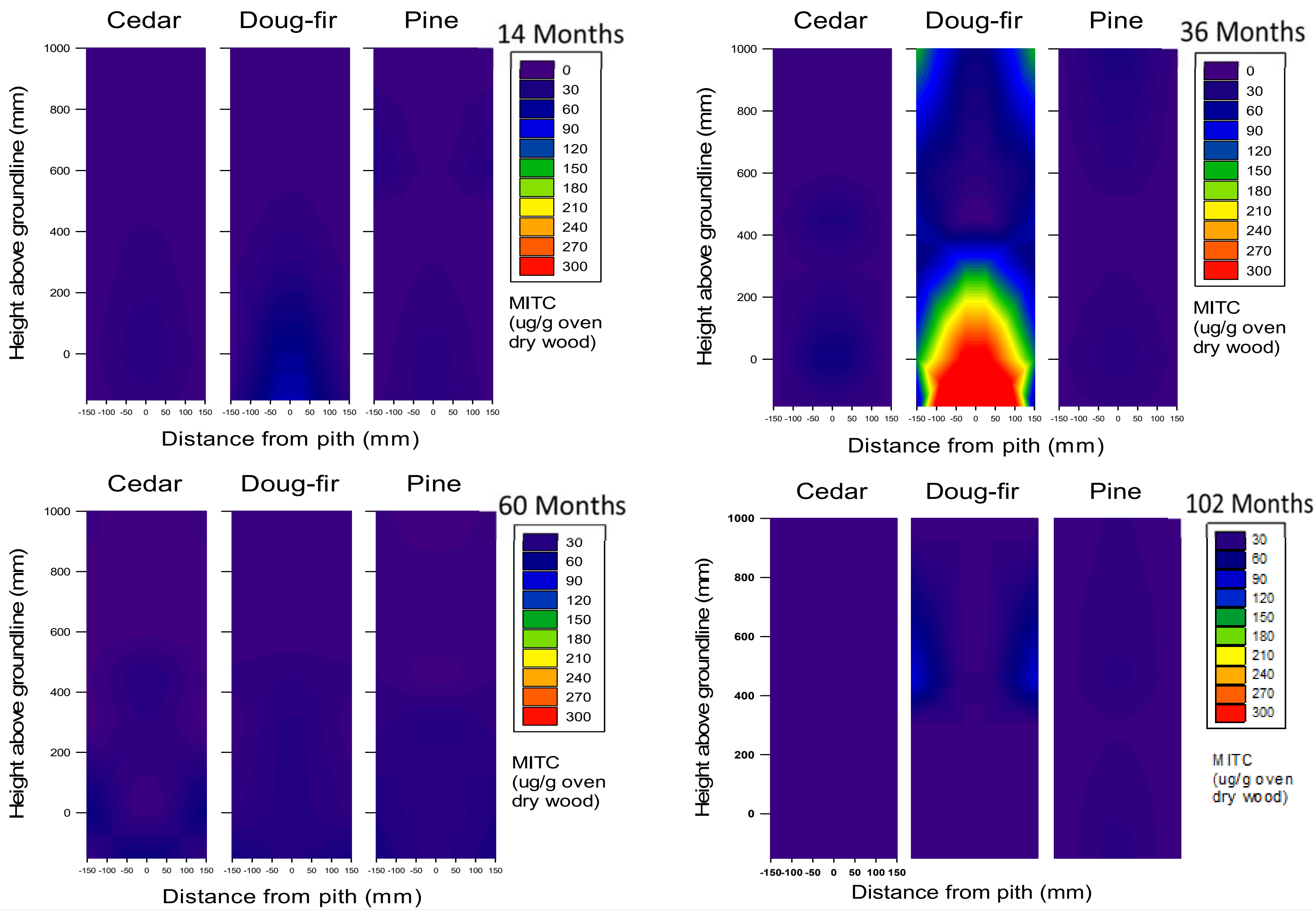


Figure I-16. Diagram showing MITC levels in poles 14, 36, 60, or 102 months after application of Dazomet without accelerant. Red colors indicate MITC levels well above the toxic threshold of 20 µg/g. Only deep purple colors are below threshold.

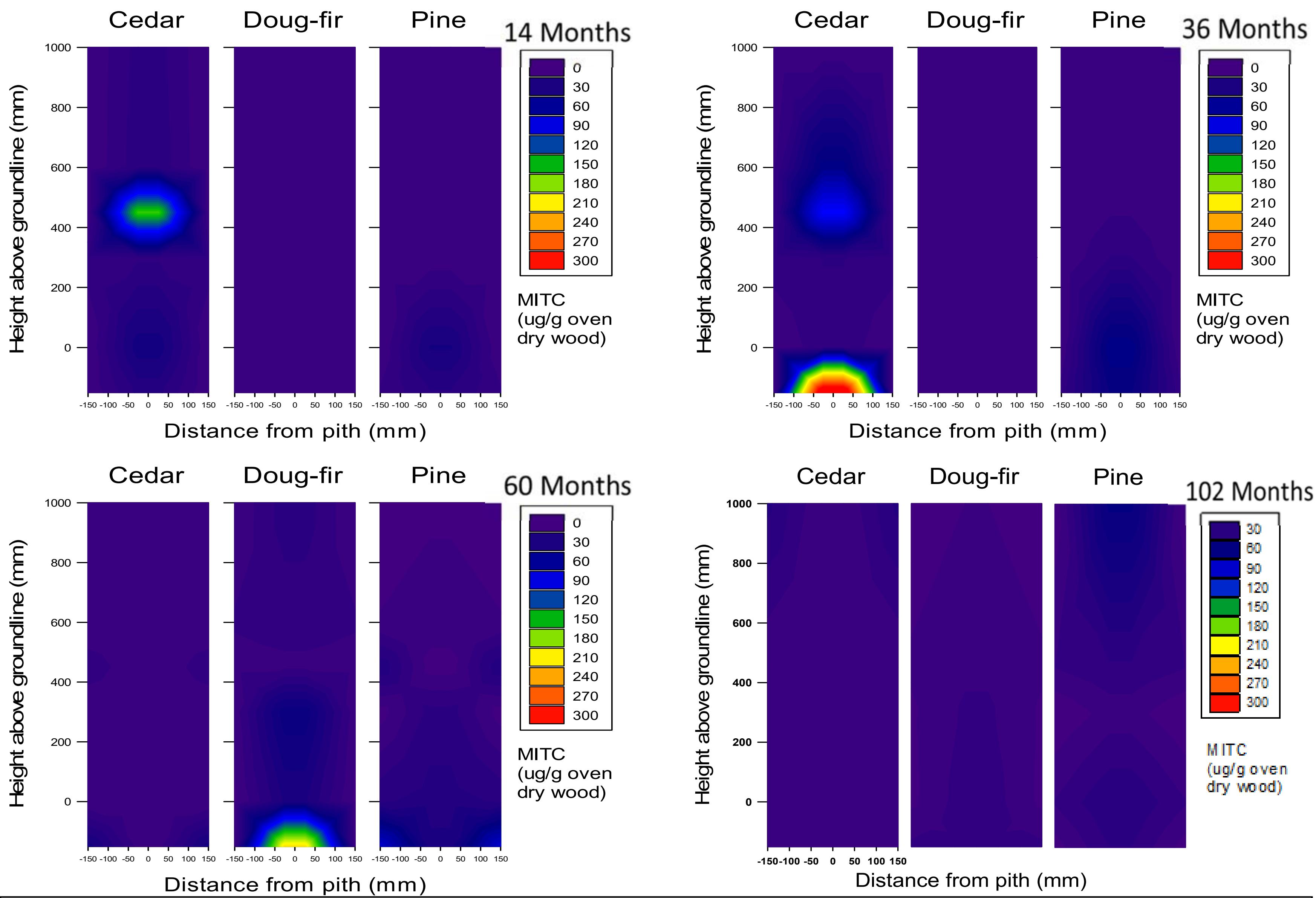


Figure I-17. Diagram showing MITC levels in poles 14, 36, 60, or 102 months after application of Dazomet with CuNap accelerant. Red colors indicate MITC levels well above the toxic threshold of 20 µg/g. Only deep purple colors are below threshold.

Table I-10. Boron levels (kg/m³ BAE) at selected distances above or below the groundline of western redcedar, Douglas-fir or lodgepole pine poles 14, 36, 60, and 102 months after application of fused borate rods with or without added water.

Treatment	Species	n	Time (Months)	Height above groundline (mm)												Average Boron in Pole
				-150 mm		0		300 mm		450 mm		600 mm		900 mm		
				inner	outer	inner	outer	inner	outer	inner	outer	inner	outer	inner	outer	
Control	cedar	1	14	0.03	0.01	0.00	0.04	0.00	0.06	0.01	0.03	0.05	0.02	0.03	0.08	0.03
			36	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
			60	0.00	0.02	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			102	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	DF	1	14	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			36*	*	*	*	*	*	*	*	*	*	*	*	*	*
			60*	*	*	*	*	*	*	*	*	*	*	*	*	*
			102*	*	*	*	*	*	*	*	*	*	*	*	*	*
	pine	1	14	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00
			36	0.01	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.01
			60	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
			102	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
Fused boron rods	cedar	2	14	0.04	0.02	0.00	0.01	0.01	0.02	0.01	0.04	0.00	0.06	0.00	0.05	0.02
			36	0.02	0.53	0.01	0.14	0.00	0.18	0.00	0.10	0.01	0.16	0.00	0.17	0.11
			60	**2.09**	**0.72**	0.15	0.02	0.02	0.09	0.02	0.02	0.01	0.02	0.00	0.02	0.27
			102	0.00	0.00	0.00	0.49	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
	DF	1	14	0.00	0.02	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00
			36	0.07	0.00	**6.13**	0.00	0.04	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.53
			60	0.00	0.00	0.12	0.00	0.00	0.00	0.00	0.17	0.00	0.16	0.00	0.00	0.04
			102	0.00	0.00	**2.39**	**0.70**	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.26
	pine	3	14	0.24	0.00	0.03	0.00	0.04	0.02	0.00	0.00	0.00	0.01	0.01	0.01	0.03
			36	0.05	0.00	0.00	0.09	0.03	0.00	0.00	0.00	0.04	0.00	0.16	0.00	0.03
			60	0.36	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.02	0.07	0.04
			102	**1.50**	**0.68**	0.41	0.00	**0.60**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27
Fused boron rods + water	cedar	1	14	**0.72**	0.00	0.03	0.04	0.00	0.27	0.01	0.00	0.01	0.01	0.02	0.03	0.10
			36	0.38	0.29	0.31	0.21	0.09	0.22	0.18	0.27	0.20	0.20	0.07	0.21	0.22
			60	0.29	0.03	0.04	0.09	0.04	0.02	0.06	0.02	0.06	0.03	0.06	0.01	0.06
			102	**0.75**	0.03	0.00	0.01	0.00	0.06	0.07	0.13	0.00	0.00	0.00	0.04	0.09
	DF	2	14	0.04	0.20	0.05	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.03
			36	0.28	0.05	0.00	0.21	0.00	0.05	0.00	0.07	0.02	0.03	0.00	0.06	0.06
			60	**0.76**	0.06	0.23	0.18	0.06	0.09	0.01	0.02	0.02	0.02	0.02	0.08	0.13
			102	**5.22**	0.08	**2.20**	0.20	0.00	0.00	0.00	0.19	0.00	0.00	0.00	0.29	**0.68**
	pine	3	14	0.57	0.02	0.10	0.02	0.01	0.03	0.03	0.01	0.03	0.02	0.02	0.02	0.07
			36	0.08	0.12	0.00	0.00	0.03	0.14	0.03	0.15	0.09	0.09	0.04	0.16	0.08
			60	0.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.03
			102	0.35	0.40	0.00	0.50	0.00	**0.69**	0.00	**0.66**	0.00	0.00	0.22	0.16	0.25

* Pole failure (not sampled in 2013, 2015, or 2019).
Note I: Standard deviations removed for final chart because of low replication and unpredictable numbers.
Note II: After careful reanalysis of raw data, corrections were made to previous year numbers. These are the final Boron data. Please disregard previous RMP Annual Reports.
Note III: Numbers in **bold** are above threshold for fungal attack (**0.6** kg/m³ BAE)

Table I-11. Frequency of non-decay fungi in western redcedar, Douglas-fir and pine poles 14 to 102 months after application of various remedial treatments. Transparent green ovals indicate the only treatments at 102 months with isolated decay fungi.

Treatment	Species	Cores with Fungi (%)															
		-150 mm below GL				Groundline				300 mm above GL				450 mm above GL			
		14 mo	36 mo	60 mo	102 mo	14 mo	36 mo	60 mo	102 mo	14 mo	36 mo	60 mo	102 mo	14 mo	36 mo	60 mo	102 mo
Boron/H_2O	Cedar	0	100	100	67	0	17	0	0	0	0	0	0	0	0	0	0
	Doug-fir	0	100	100	89	0	89	78	78	0	44	29	33	0	56	14	33
	pine	0	67	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Impel Rods	Cedar	0	63	83	67	0	0	0	17	0	0	0	17	0	0	0	0
	Doug-fir	56	100	100	78	44	100	86	100	0	67	71	56	0	89	63	67
	Pine	67	100	100	67	0	67	67	33	0	100	33	33	0	67	33	67
Dazomet	Cedar	0	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Doug-fir	0	67	67	33	0	44	56	33	0	11	44	44	0	56	56	33
	Pine	100	67	100	100	100	67	100	100	33	67	100	100	33	100	100	67
Dazomet/Cu	Cedar	0	0	0	0	0	0	0	0	0	0	0	0	0	33	0	0
	Doug-fir	22	33	44	33	0	33	67	0	0	56	78	11	0	33	56	0
	Pine	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Metam Sodium	Cedar	0	0	0	33	0	0	0	0	0	0	0	33	0	0	0	0
	Doug-fir	0	50	55	67	0	33	33	50	0	33	67	67	0	50	67	33
	Pine	0	0	-	100	0	0	-	0	0	0	-	33	0	0	-	33
MITC-FUME	Cedar	0	0	0	0	0	0	0	17	0	17	0	17	0	33	0	17
	Doug-fir	0	33	38	44	0	22	44	11	0	33	56	11	0	44	22	33
	Pine	0	67	0	67	0	0	0	67	0	0	0	33	0	0	0	0
Control	Cedar	0	67	100	67	0	34	50	100	0	0	34	0	0	0	0	0
	Doug-fir	0	67	100	67	0	100	0	67	0	100	67	67	0	50	100	67
	Pine	75	55	58	100	50	50	67	83	0	50	67	100	0	83	67	83

OBJECTIVE II: IDENTIFY CHEMICALS FOR PROTECTING EXPOSED WOOD SURFACES IN POLES

Preservative treatment of utility poles prior to installation provides an excellent barrier against fungal, insect, and marine borer attack; however, this barrier remains effective only while intact. A variety of post-treatment modifications, both unintended and necessary, can break this barrier and provide an entrance for decay fungi. Most utility standards recommend that all field damage to treated wood should have supplemental protection with copper naphthenate solutions. While this treatment will never be as good as the initial pressure treatment, it provides a thin barrier that can be effective aboveground, provided it is actually implemented by field crews which it is often not. In 1980, the UPRC initiated a series of trials to assess the efficacy of various treatments for protecting field drilled bolt holes, non-treated western redcedar sapwood and non-treated Douglas-fir timbers above groundline. The prevention of aboveground decay is still a major issue for utilities despite progress in mitigation techniques. Moreover, post-treatment modifications will become increasingly important as utility poles become more heavily used as sites for next generation telecommunication distribution hardware. The UPRC will continue to perform research aimed at mitigating the negative impacts of post-treatment utility pole modification.

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

Douglas-fir heartwood has a well-deserved reputation for being difficult to impregnate with preservatives. Through-boring, radial drilling, and deep incising can all improve treatment, but their application is generally limited to groundline. While this represents the area with greatest risk of internal decay, fungi can attack non-treated heartwood above this zone and aboveground decay likewise must be prevented to extend pole life. Attaching equipment to poles is almost universally done by field-drilling attachment holes. Non-treated, field-drilled holes represent access paths into non-treated heartwood for decay fungi. While progression of fungal attack and decay is slower aboveground, these field-drilled holes eventually become decay sites, especially in climates with high annual rainfall and decay hazard. Under Objective II, we have examined simple methods for treating holes with boron compounds and evaluated the potential for using preservative-coated bolts. None of these practices have been adopted or have led to changes in practices.

Another approach to reduce decay risk in non-treated heartwood is to initially treat poles with water diffusible chemicals such as boron or fluoride prior to seasoning and treatment. Diffusible chemicals could move into the heartwood as poles dry, and be over-treated with conventional oil-borne preservatives such as copper naphthenate, penta, or creosote to help retain boron.

We explored this possibility in the 1980s to reduce the risk of fungal colonization during air-seasoning, first with ammonium bifluoride (fluoride) and later with disodium octaborate tetrahydrate (DOT). Results with fluoride were initially promising. Poles were flooded with a 20% solution of ammonium bifluoride and exposed at four sites in the Pacific Northwest and California. Fungal colonization was assessed over a three-year period by removing increment cores for culturing. Initially, the percentage of cores containing basidiomycetes was low at all sites, but steadily increased at the wetter sites (Table II-1). Results indicated fluoride could initially limit fungal colonization, but eventually a more weather-resistant treatment would be required.

Table II-1. Basidiomycete isolations from Douglas-fir pole sections with or without an ammonium bifluoride treatment after 1 to 3 years of exposure in various locations in the Pacific Northwest (from Morrell et al., 1989).

Seasoning Location	Cores Containing Basidiomycetes (%)					
	Non-Treated			Fluoride Treated		
	1 Year	2 Year	3 Year	1 Year	2 Year	3 Year
Arlington, WA	39	74	71	14	38	69
Scappoose, OR	27	56	76	14	36	45
Eugene, OR	36	52	72	12	19	35
Oroville, CA	29	39	37	8	11	12

In a follow-up study near Corvallis, OR, Douglas-fir pole sections were either dipped for 3 minutes in a 20% BAE solution of DOT or sprayed at 6-month intervals with a 10% solution of DOT and exposed for 3 years. Dip-treated pole sections contained much lower basidiomycete levels 1-year after treatment than non-treated controls, while isolation levels were similar after 2-years of exposure (Table II-2). Spray treatments followed similar patterns, even when sprays were applied at 6-month intervals. Results indicate boron and fluoride inhibit fungal attack, but their protection was limited and needs to be followed by over-treatment with traditional non-diffusible wood preservatives.

The potential for boron as a pre-treatment has also been explored on railroad ties in the southern U.S. Extensive studies at Mississippi State University have clearly demonstrated that dip or pressure treatment with boron followed by air seasoning and creosote treatment markedly improved performance of ties; this approach is now widely used by railroads. Boron may also have value as a pre-treatment for utility poles, and to test this we have designed and implemented a field trial that test the efficacy of boron dip and spray treatments in preventing decay in Douglas-fir poles.

Table II-2. Basidiomycete isolations from Douglas-fir pole sections with or without a disodium octaborate tetrahydrate treatment after 1 to 3 years of exposure in various locations in the Pacific Northwest (from Morrell et al., 1991).

Treatment	Cores Containing Basidiomycetes (%)		
	Year 1	Year 2	Year 3
Control	23	59	87
Dip	9	47	30
Sprayed (0/6 mo.)	19	43	61

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. 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. No AWPA borate retention is specified for utility pole pre-treatment. The current AWPA Standard for borate pre-treatment of ties specifies 2.7 kg/m^3 of boron (as B_2O_3, equal to 4.9 kg/m^3 BAE); however, our data suggest the boron threshold for protecting Douglas-fir from internal decay is far lower (0.6 kg/m^3). Clearly, a proper treatment level will need to be determined. For the purposes of this discussion the tie level will be used, although it is probably much higher than necessary.

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 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 II-3). 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 half the required level. These values are skewed by one pole that had extremely high boron levels in 4/6 assay zones. The remaining poles had much lower boron levels. Boron was largely confined to the outer 25 mm.

After kiln drying, boron levels were elevated in the outer 25 mm of pole sections, but declined sharply inward (Table II-4). Boron levels, if averaged across the entire pole cross section, would average 1.02 kg/m^3 BAE, far below the specified level. Boron levels in the outer 25 mm were lower after drying in nine of the ten pole sections and, in some cases, the differences were substantial (Table II-5). 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 schedules will have to be adjusted to reduce boron loss.

Boron should become more uniformly distributed over time as it diffuses inward from the pole surface. 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 II-1). However, boron levels in four of the five poles in this treatment group remained very low 50 mm or further inward. The overall shape of the preservative gradient changed only slightly after 2 months (Figure II-1). This suggests that the majority of boron remained in the outer pole zones.

Treated poles were set to a 0.6 m depth at Peavy Arboretum, Corvallis OR. Five Boulton seasoned and copper naphthenate treated poles, and five kiln-dried and copper naphthenate poles were installed. Boron content was assessed one, two, and three years after treatment by removing increment core pairs 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.

Table II-3. 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

Boron levels in the outer 25 mm of poles one year after treatment had declined (Figure II-2; Tables II-6, II-7). The field site receives ~1200 mm of rainfall per year and tends to be extremely wet during the winter. 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. Elevated moisture contents are expected to help boron diffuse and distribute evenly. Declines suggest boron is moving out of poles and into surrounding soil. Boron levels in the outer 25 mm of wood 1.2 m above groundline were higher than at groundline, suggesting boron moved at the same rate out of soil contact. 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.

It is important to remember that the 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 overtreatment would be useful to measure boron migration in poles treated using common standards.

Table II-4. 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)

Table II-5. 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

Boron levels in poles 2 years after installation had declined in the outer 25 mm of the poles at both groundline and 1.2 m above that level (Figure II-2; Figure II-3; Tables II-6, II-7). Boron levels in the outer zone tended to be much higher 1.2 m above the groundline, suggesting some boron was leaching from poles in soil contact (Figure II-3). Levels further inward remained similar to those found after one year. These results suggest boron lost from the outer 25 mm zone is predominantly lost to the soil and is substantially moving inward.

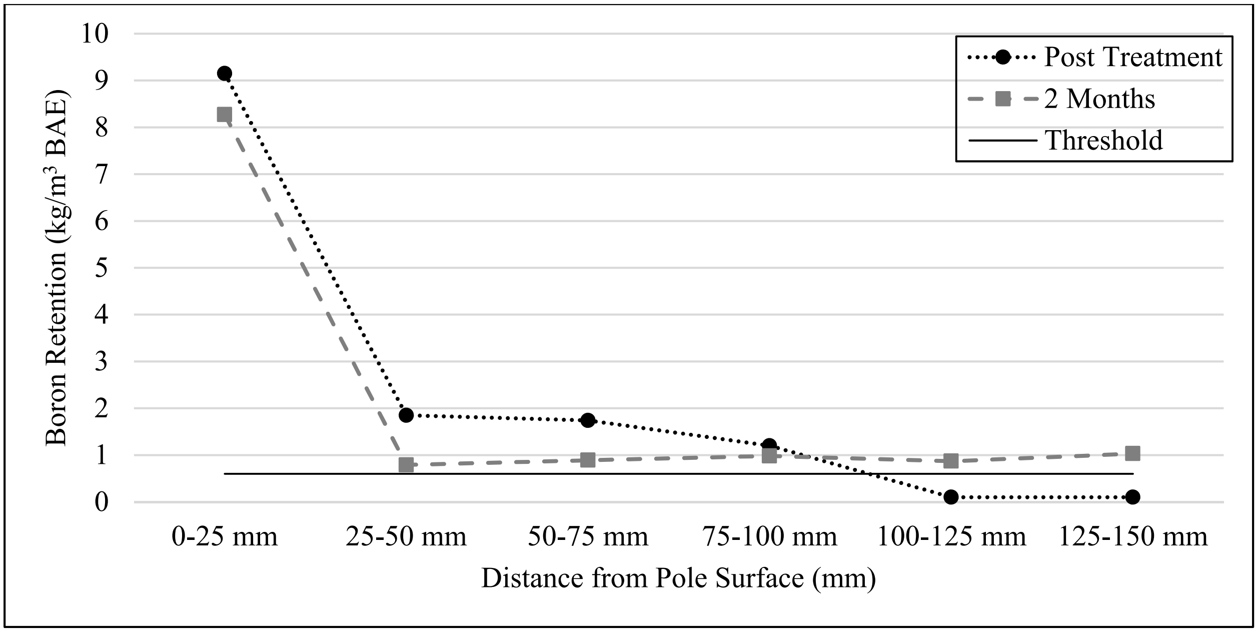


Figure II-1. Boron retentions in 25 mm increments inward from the surface in Douglas-fir poles immediately after pressure treatment with disodium octaborate tetrahydrate and again 2 months later.

Boron levels in poles 3 years after treatment continue to remain elevated near the surface but are much lower further inward (Figure II-2; Figure II-3). Boron levels more than 75 mm from the surface tended to vary widely and were often below threshold. The failure of boron to become more evenly distributed is perplexing, especially near groundline where moisture levels should be more than adequate for diffusion to occur.

Boron levels in poles 4 years after treatment continue to remain above the threshold in the outer 75 mm of the poles that were Boulton seasoned during treatment, but more variable deeper in the pole (Figure II-4). Boron was detectable at the innermost sampling point, albeit at low levels. Boron levels in poles that were air-seasoned prior to treatment were above the threshold in the outer 50 mm, and were detectable in inward samples but generally below threshold levels.

Sampling 5 years after installation yielded similar results. Boron levels are at or near the threshold in the outer pole zones but slightly below in the pole interior for Boulton seasoned and kiln dried poles. There is little to no difference in boron levels in poles that had been Boulton seasoned vs those that had been kiln dried prior to treatment at this sampling point (Tables II-6, II-7).

Sampling 6 years after installation showed very similar results to previous years for kiln dried poles. Boron levels were again mostly above the 0.6 kg/m^3 threshold in the outermost 25 mm of kiln-dried poles, except for two groundline samples. Boulton seasoned poles similarly showed highest boron levels at the outermost 25 mm sections, with all sections at and 1.2 m above groundline showing levels above threshold. However, boron levels rose relative to the previous year's sampling in a few poles 25-150 mm to the pole interior, pushing some of these sections above threshold levels. There was no consistent pattern in these increases and it did not occur in all Boulton seasoned poles. When all Boulton seasoned poles were averaged, boron retention was still below threshold levels, however it is still interesting that some of the poles showed increases in boron levels at the inner sections. As was seen at earlier sampling points for kiln dried and Boulton seasoned poles, the outermost 25 mm groundline samples had generally lower boron levels than above groundline samples, reflecting higher moisture content and diffusion rates at groundline.

Lower boron levels deeper in poles might suggest treatment failure; however, it is unclear how much boron is required for protection against spore germination, particularly in moderately durable heartwood. The results illustrate an inherent difficulty in using conventional water-borne solutions of boron to deliver a sufficient load in the outer sapwood to allow continued diffusion inward at levels capable of preventing fungal attack. This problem will increase with pole diameter. There are other systems that allow for higher boron concentration that might be suitable for this treatment approach.

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, however, should not have affected overall diffusion as evidenced by the absence of gradually increasing boron levels further away from the outer 25 mm zone. The results suggest higher loadings alone may not be sufficient to produce the desired internal boron concentrations. Wood species may also have affected the results. The railroad tie research was performed on hardwoods. Boron movement through Douglas-fir tends to be much slower than in other species, although it also appeared to remain in the wood for longer periods of time.

The results from this study led us to undertake a more comprehensive study of boron treatment that is described in the next section.

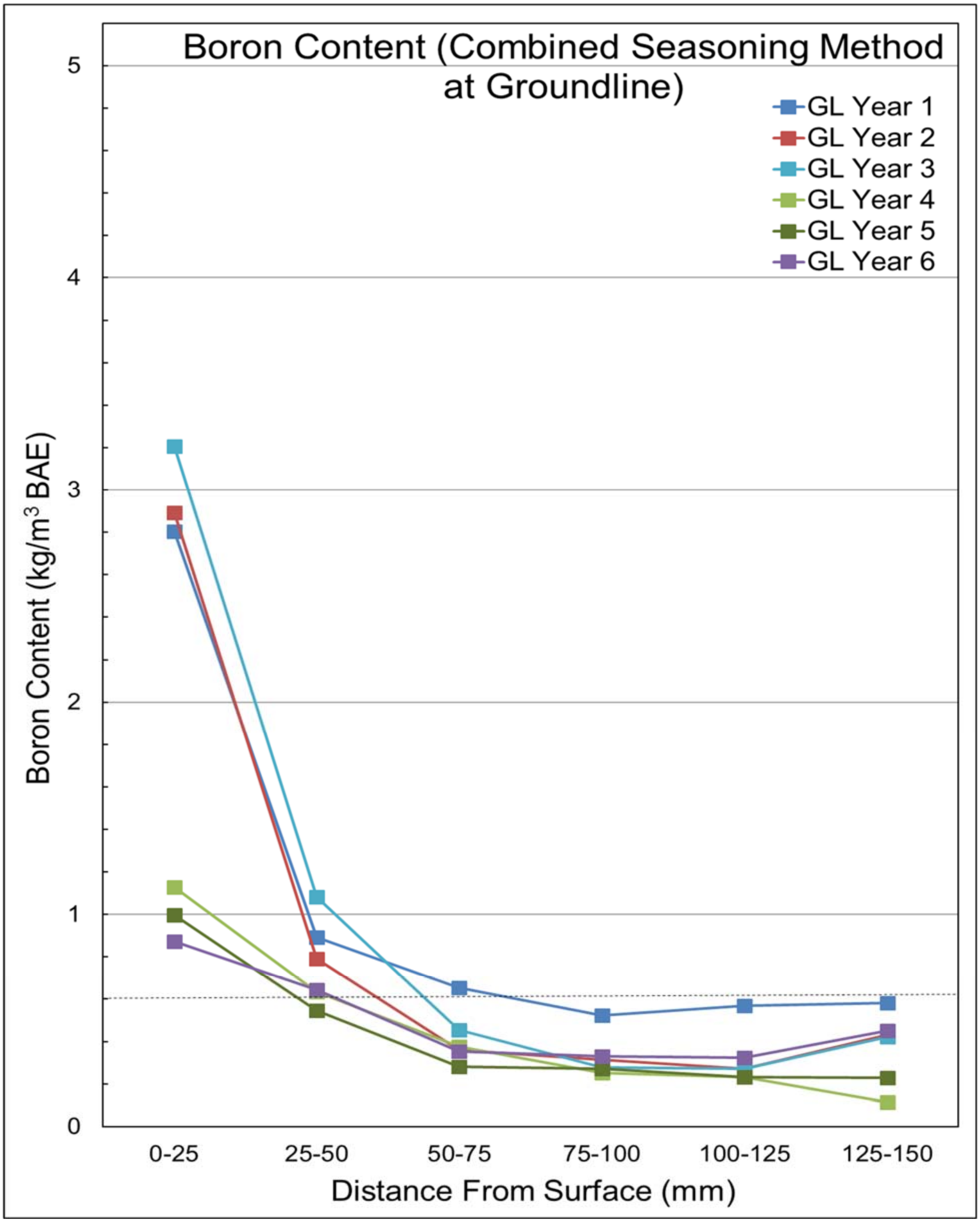


Figure II-2. Boron content at groundline (GL) in 25 mm increments from Douglas-fir pole surface 1-6 years after pre-treatment with disodium octaborate tetrahydrate followed by either kiln drying or Boulton seasoning and CuNap treatment. Both kiln and Boulton seasoning are combined for each year. Dotted line indicates 0.6 kg/m^3 BAE, the threshold for decay prevention.

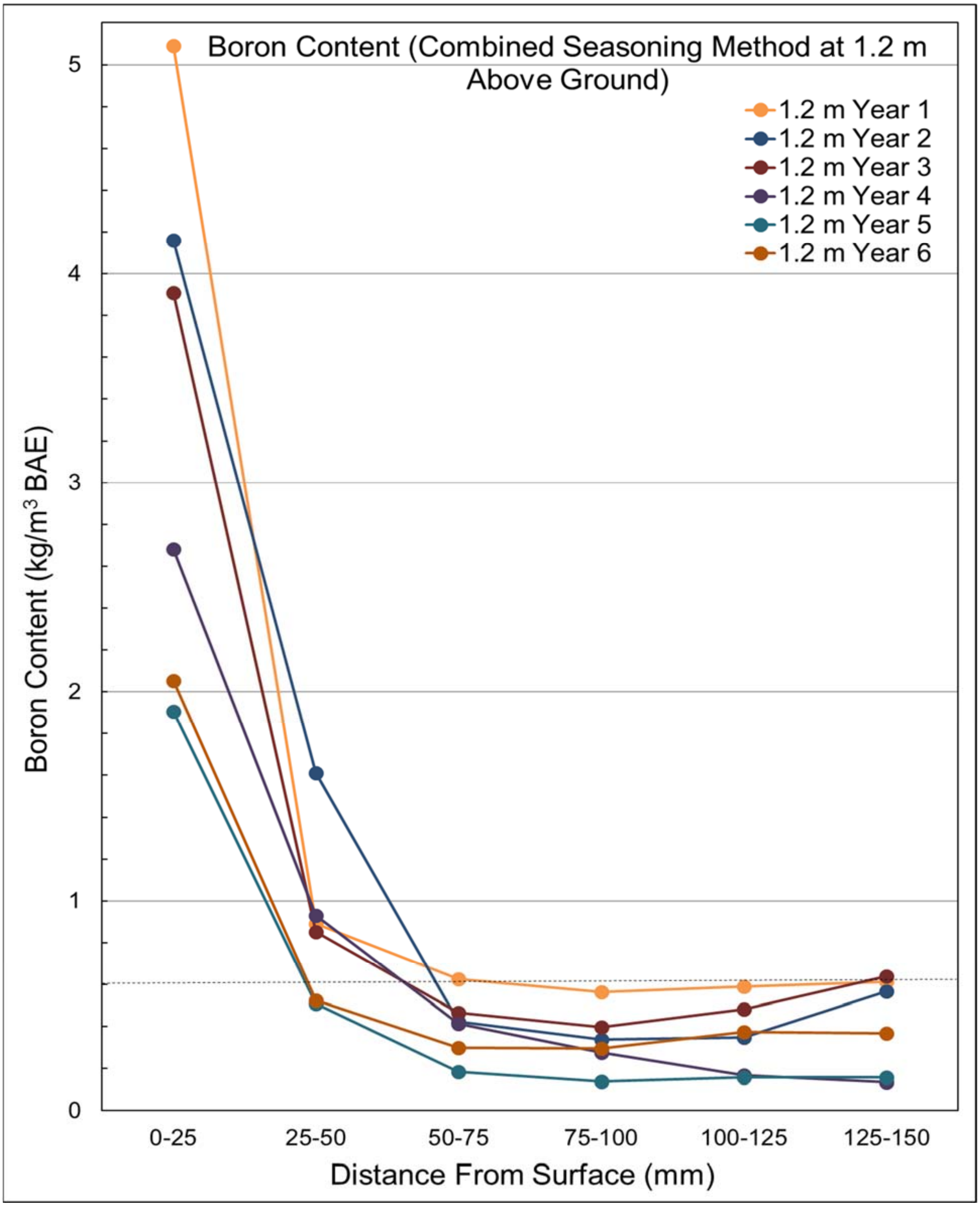


Figure II-3. Boron content 1.2 m above groundline in 25 mm increments from Douglas-fir pole surface 1-6 years after pre-treatment with disodium octaborate tetrahydrate followed by either kiln drying or Boulton seasoning and CuNap treatment. Both kiln and Boulton seasoning are combined for each year. Dotted line indicates 0.6 kg/m³ BAE, the threshold for decay prevention.

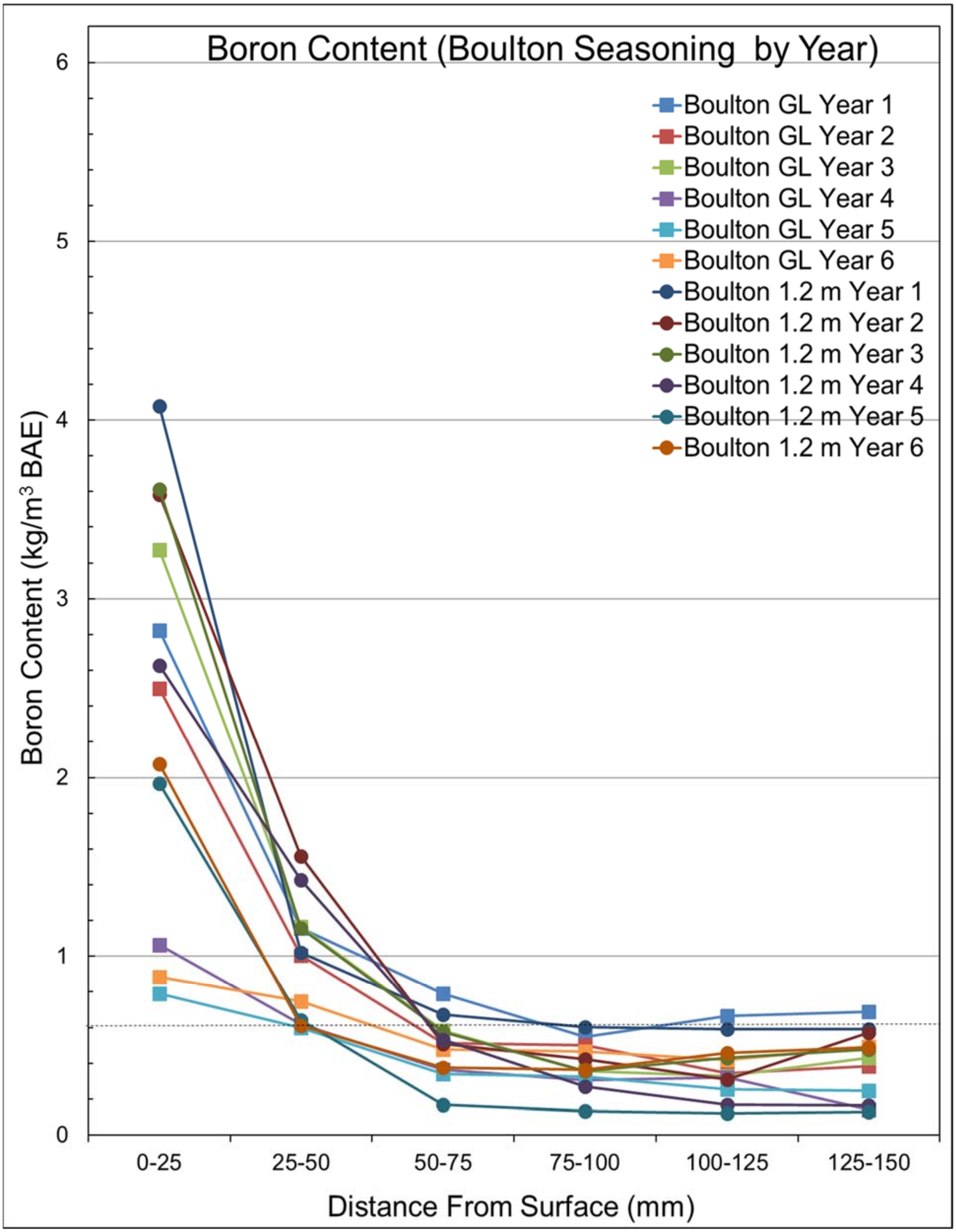


Figure II-4. Boron content in 25 mm increments from Douglas-fir pole surface 1-6 years after pre-treatment with disodium octaborate tetrahydrate followed by Boulton seasoning and CuNap treatment. Dotted black line indicates 0.6 kg/m³ BAE, the threshold for decay prevention.

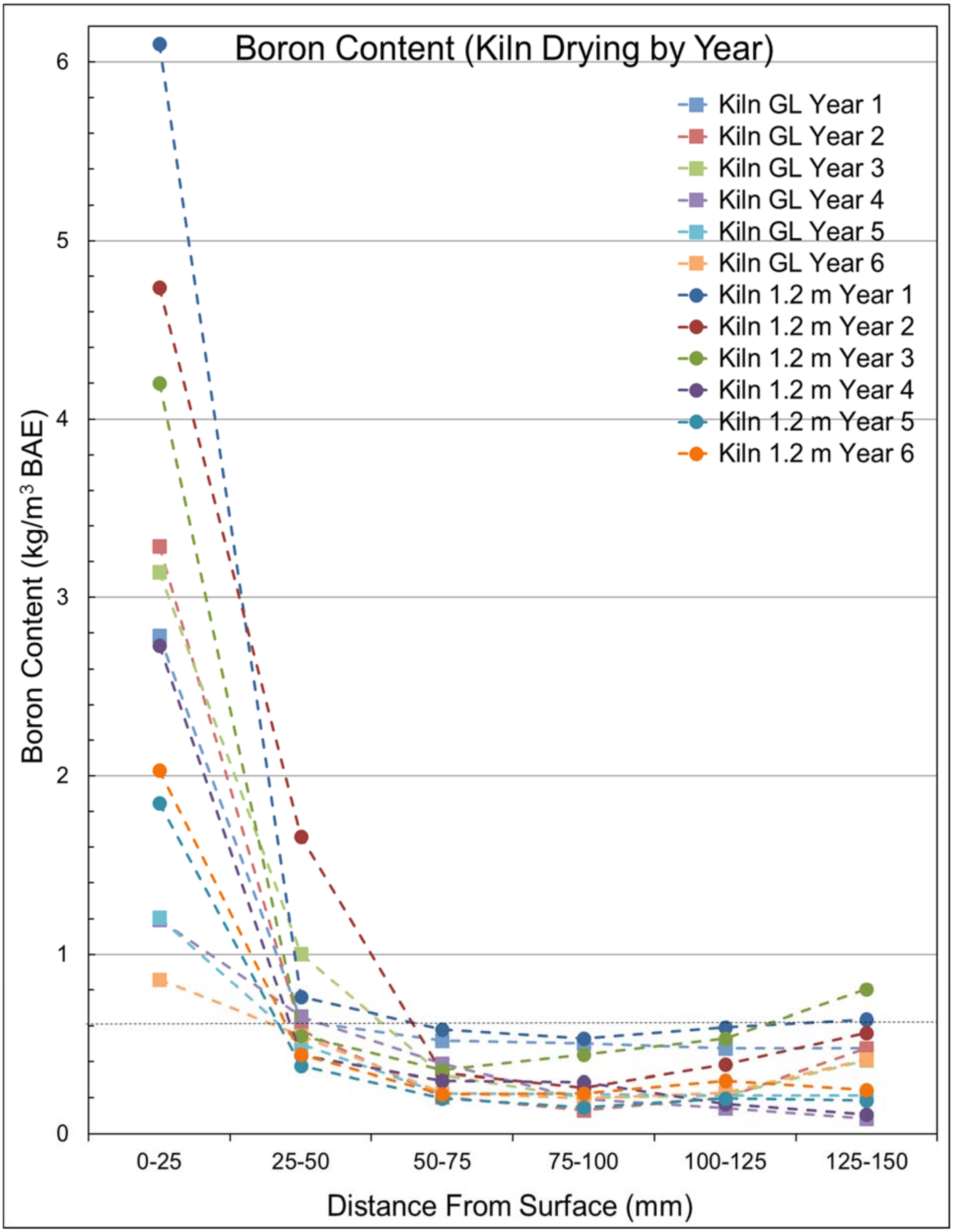


Figure II-5. Boron content in 25 mm increments from Douglas-fir pole surface 1-6 years after pre-treatment with disodium octaborate tetrahydrate followed by kiln drying and CuNap treatment. Dotted black line indicates 0.6 kg/m^3 BAE, the threshold for decay prevention.

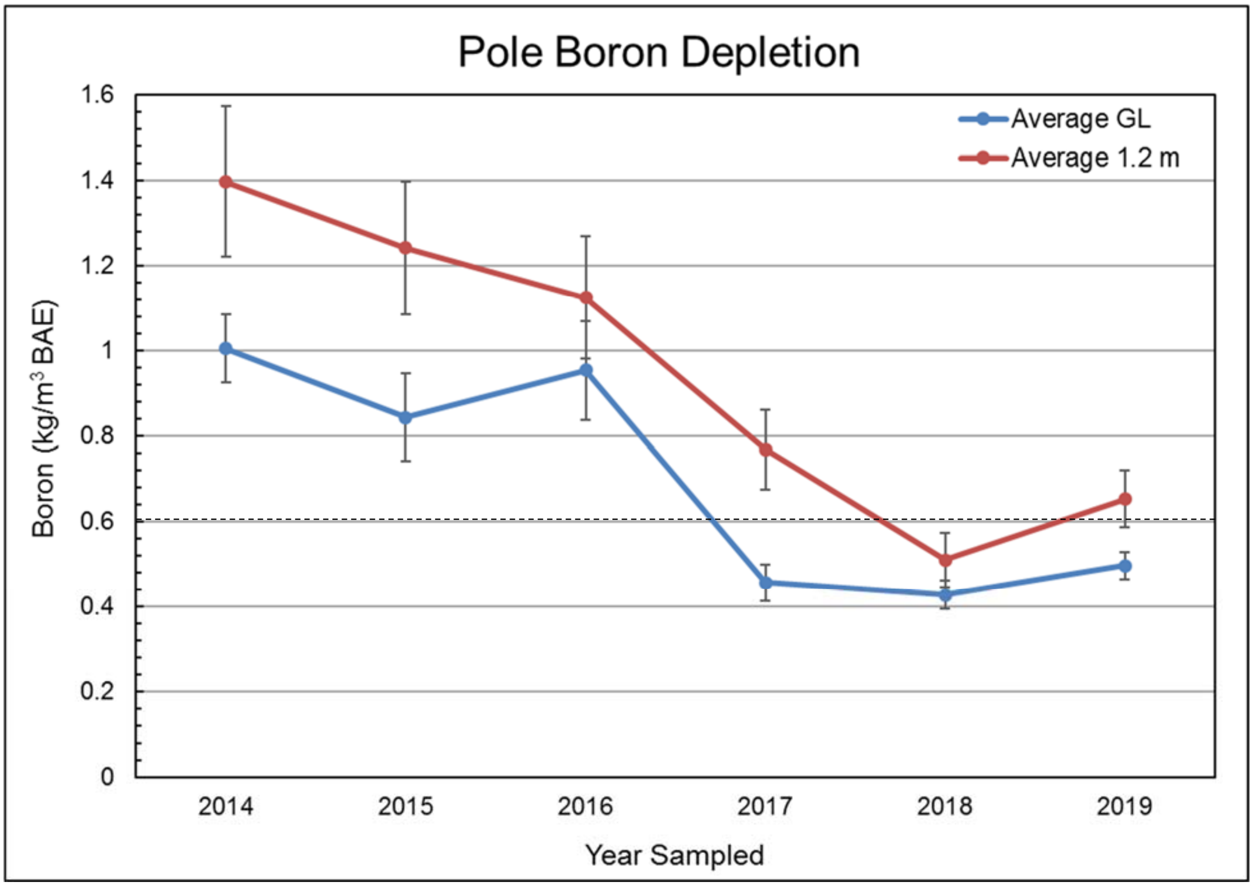


Figure II-6. Average of total pole boron content of Douglas-fir poles after pre-treatment with disodium octaborate tetrahydrate followed by kiln drying and CuNap treatment. Dotted black line indicates 0.6 kg/m^3 BAE, the threshold for decay prevention. Initial average pole boron concentrations after 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.

Table II-6. Boron content in increment cores removed from groundline or 1.2 m above groundline of Douglas-fir poles 1-6 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)

[a] Values in bold type signify boron retentions above the threshold for protection against internal fungal attack. SD= Standard

Table II-6 cont. Boron content in increment cores removed from groundline or 1.2 m above groundline of Douglas-fir poles 1-6 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)

[a] Values in bold type signify boron retentions above the threshold for protection against internal fungal attack. SD= Standard

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 UC4 retention with copper naphthenate (1.44 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 length of the poles. These cores were divided into 25 mm long segments and the 8 segments from a given depth were combined for each pole. These 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 taking additional cores. The outer 6 mm of each core was discarded, then the next 19 mm of increment core was retained. These segments were ground to pass a 20-mesh screen and analyzed by x-ray fluorescence. We experienced some interference with the ACZA samples in our XRF unit. Instead, these samples were microwave digested and analyzed by ion-coupled plasma 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 II-7). 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 second 25 mm inward from the surface among all poles. Variations in chemical distribution are to be expected in wood, but the range suggests that further work will be needed in the process to deliver more consistent treatment.

Average boron levels in copper naphthenate-treated poles were fairly low in the outer 3 zones and then were very high in two inner most sampling zones. The outer zones of several poles had very low to non-detectable boron levels, bringing down the average. The higher average levels seen in the inner sections were the result of one pole with extremely high boron concentrations. Boron levels were only above the protective threshold in 6 of 30 assays. Similarly, boron levels in penta-treated poles ranged 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 outer section, 0-25 mm and 25-50 mm, averaged above threshold, but only two of the poles at each section had levels above threshold. The average boron levels in inner sections, 75-125 mm, were increased by a single pole with very high boron levels.

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.

Table II-7. 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.

The poles were sampled in each of three years after installation by removing increment cores from three locations around each pole at groundline and 1.2 m above groundline. The 1.2 m height was selected to determine if proximity to the soil resulted in accelerated boron loss near the surface. 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.

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 II-8). Boron levels were higher in the outer 25 mm at 1.2 m in copper naphthenate-treated poles while groundline boron levels were higher in the outer 25 mm in Penta-treated poles (Figure II-8; II-9). In year 2 and 3 samplings, these differences did not exist and generally groundline and the 1.2 m samples showed similar boron levels.

Pole boron levels were above the threshold in the outer 25 mm at both groundline and 1.2 m above groundline in all treatments throughout all three years of sampling (Figure II-7; II-8; II-9). 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 farther inside the pole than 25 mm in years 2 and 3 were below threshold. There was a slight decreasing gradient with distance inward beyond the outer 50 mm, but the differences were slight and there was little evidence of substantial movement inward from the surface (Table II-8). When all samples within treatment types and sampling heights were averaged, there was a downward trend year-on-year so that overall boron levels appeared to be declining (Figure II-11).

The results would appear to differ substantially from the results immediately after treatment; however, these results must be interpreted carefully. Boron levels were generally low in the freshly treated poles except in a few poles per treatment. These outliers tended to push the averages upward so that the poles looked better-treated. 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. We will continue to monitor these poles to determine how boron redistributes in the interior of the poles.

Boron Pretreatment at Peavy Conclusions: Pressure-treatment of Douglas-fir poles with DOT prior to over-treatment with copper naphthenate, pentachlorophenol, or simultaneous treatment with ACZA resulted in high levels of boron near the surface, but limited boron redistribution further inward in two different tests. Boron levels were variable, but average boron levels easily exceeded the threshold for protection against internal fungal decay within 50 mm of the surface. Further monitoring of these tests is planned.

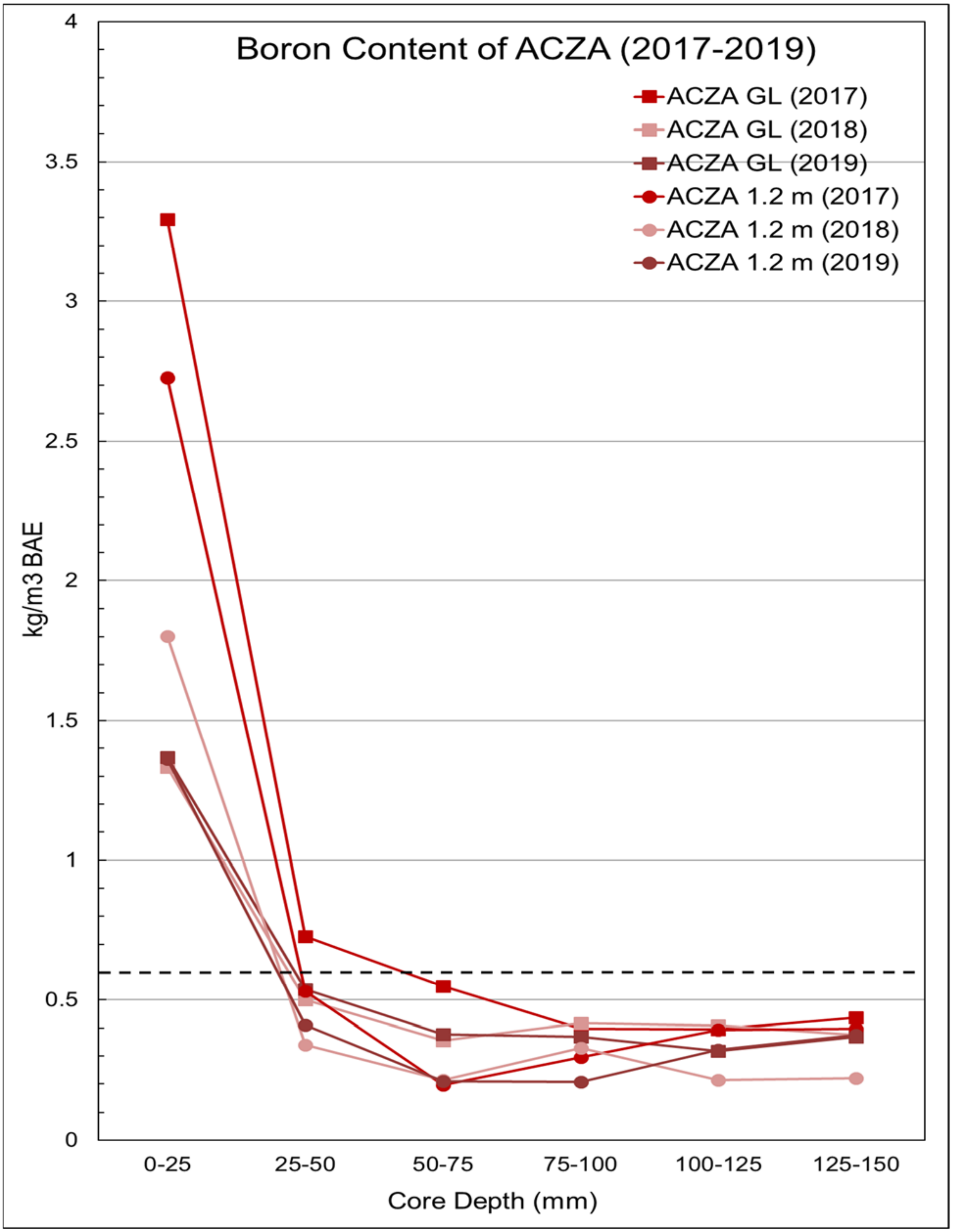


Figure II-7. Boron levels in Douglas-fir poles subjected to an ACZA/boron dual pressure treatment after 3 years. Dotted black line indicates 0.6 kg/m³ BAE, the threshold for decay prevention.

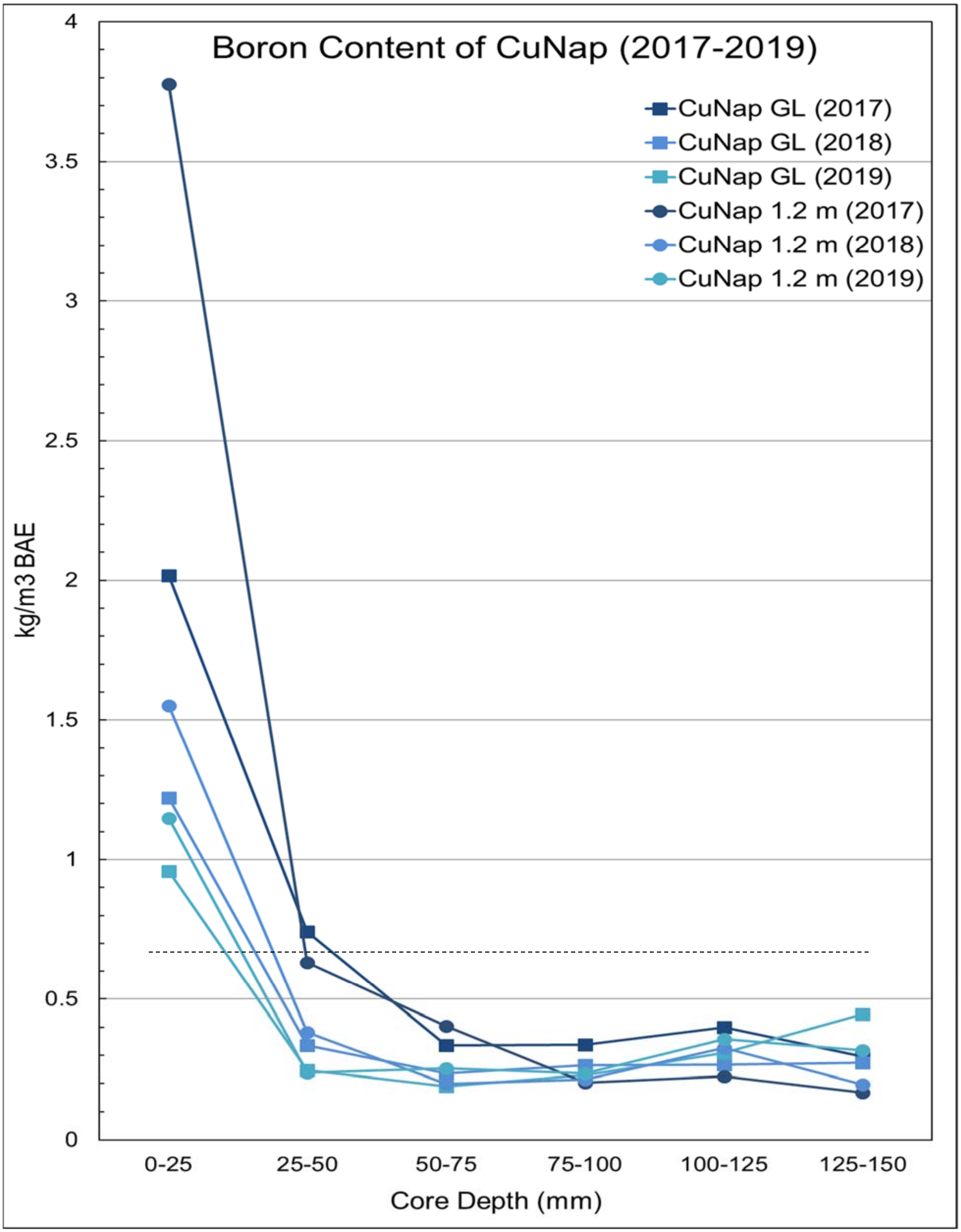


Figure II-8. Boron levels in Douglas-fir poles subjected to a boron pre-treatment followed by over-treatment with copper naphthenate after 3 years. Dotted black line indicates 0.6 kg/m^3 BAE, the threshold for decay prevention.

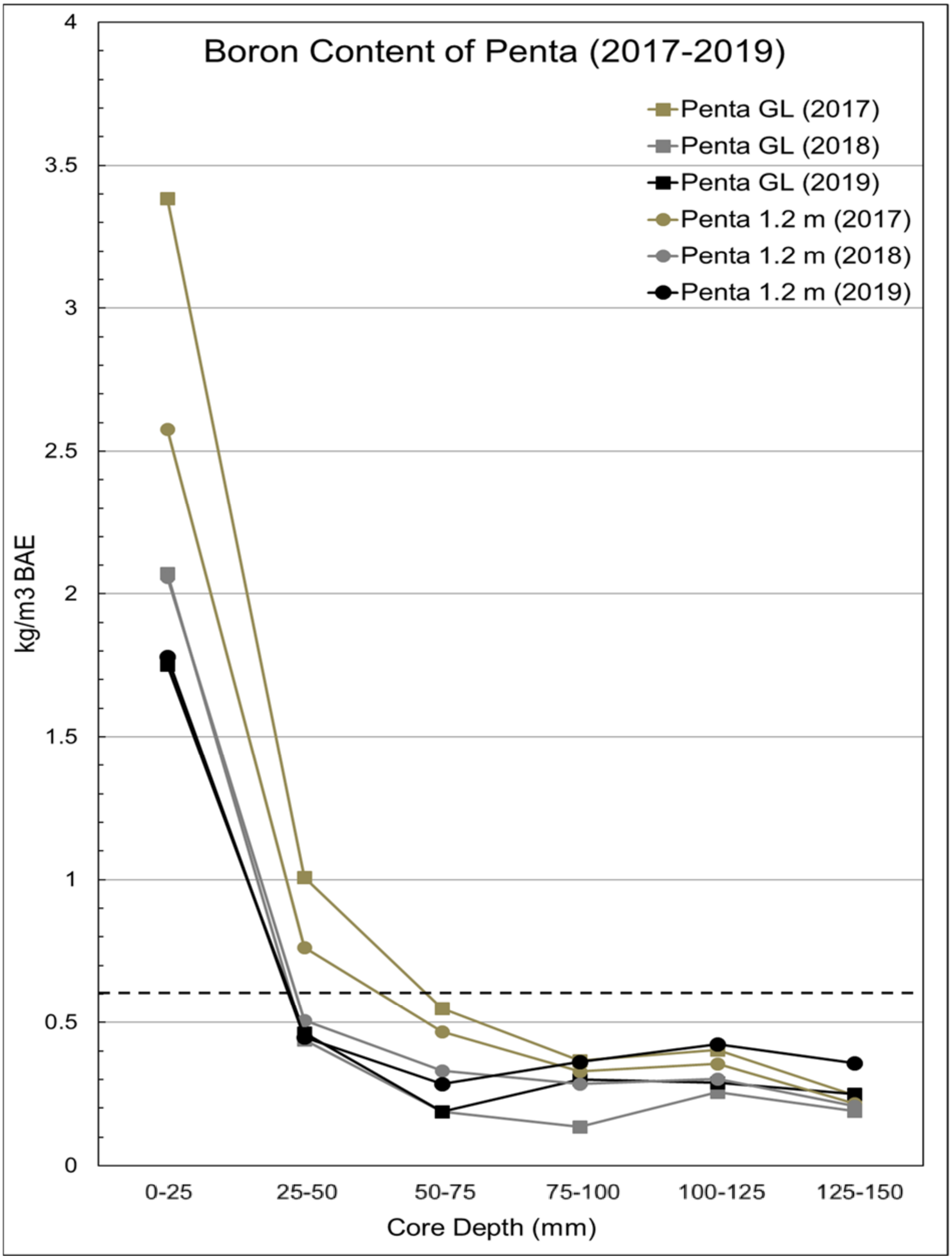


Figure II-9. Boron levels in Douglas-fir poles subjected to a boron pre-treatment followed by over-treatment with Pentachlorophenol after 3 years. Dotted black line indicates 0.6 kg/m^3 BAE, the threshold for decay prevention.

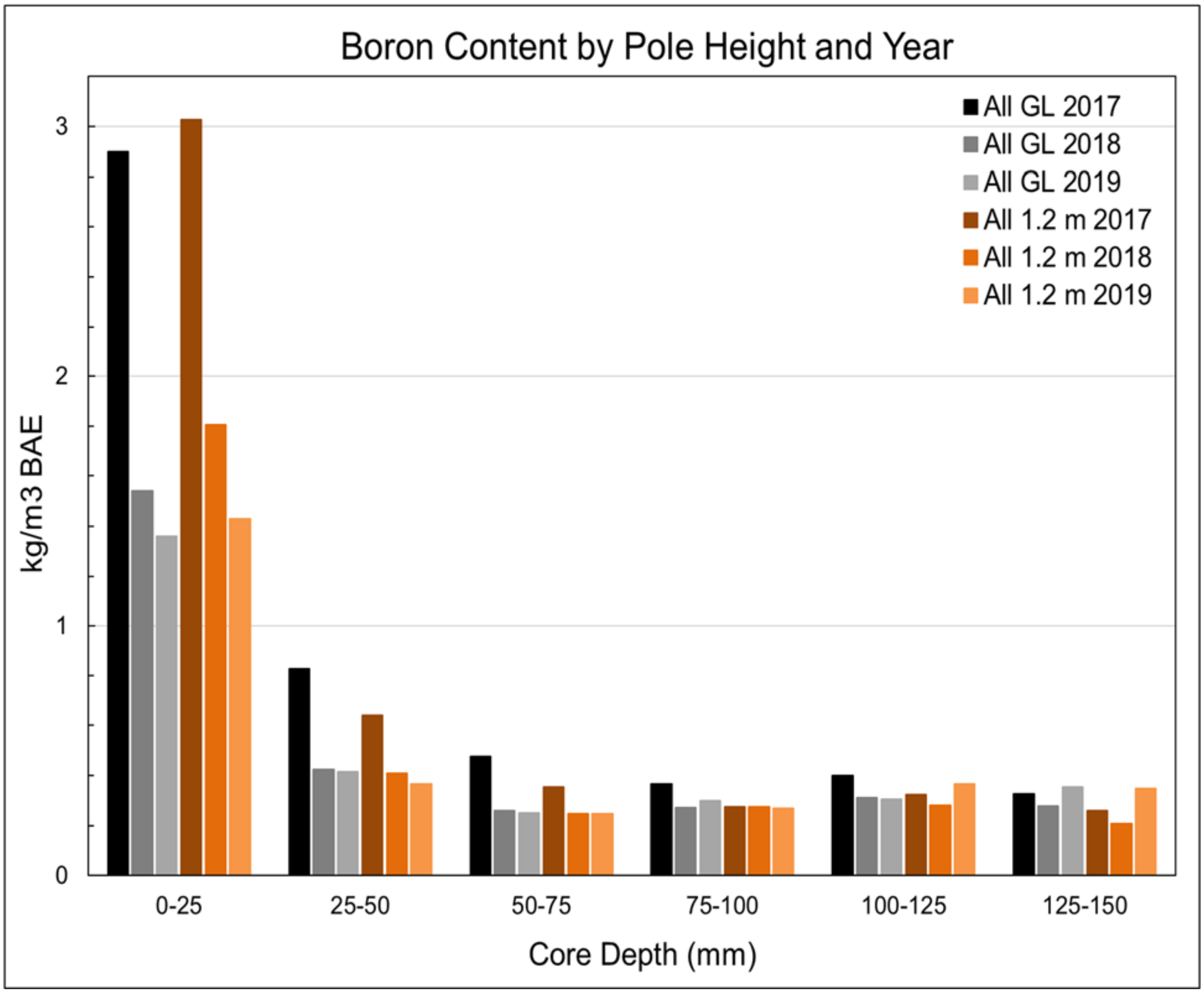


Figure II-10. Combined boron levels in Douglas-fir poles subjected to a boron pre-treatment followed by over-treatment with copper naphthenate or pentachlorophenol, or an ACZA/boron pressure treatment after 3 years. Dotted black line indicates 0.6 kg/m^3 BAE, the threshold for decay prevention.

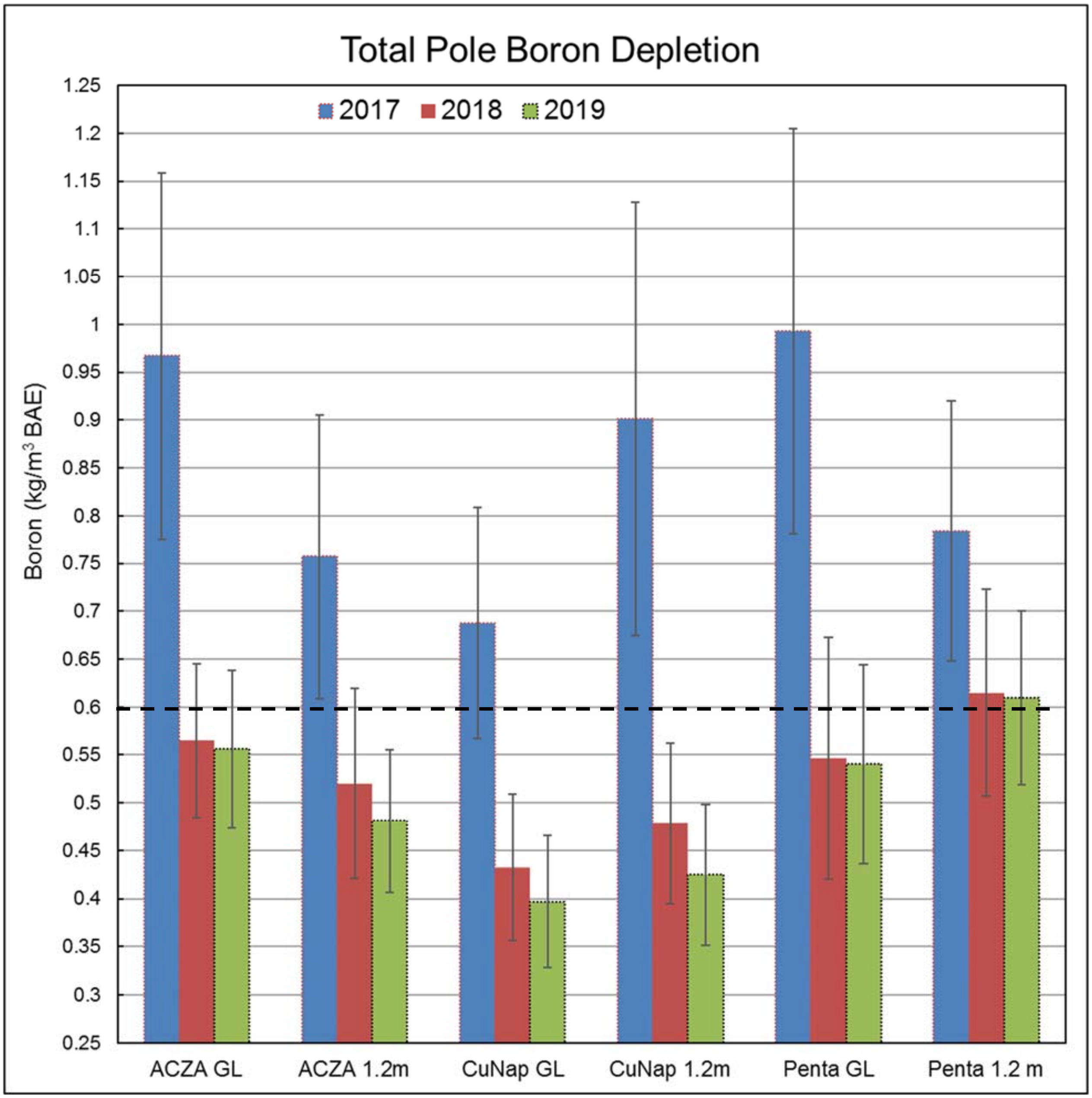


Figure II-11. Average of total pole boron content of Douglas-fir poles subjected to either a boron pre-treatment followed by over-treatment with copper naphthenate or pentachlorophenol, or an ACZA/boron pressure treatment after 3 years. Dotted black line indicates 0.6 kg/m^3 BAE, the threshold for decay prevention. Initial average pole boron concentrations after treatment are unknown. Values for 2017 represent 1-year exposed in the field. Bars represent standard error.

Table II-8. Boron levels 25 mm increments inward from the surface at groundline and 1.2 m above groundline in Douglas-fir poles one, two, and three years after dual treatment with boron plus ACZA, CuNap, or Penta.

Primary Treatment	Depth (mm)	GL		1.2 m	
		kg/m³ BAE)	Std. Dev.	(kg/m³ 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)
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)
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)

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

Pretreatment of utility poles with a diffusible preservative prior to treatment with less soluble oil-borne preservatives can be done to help prevent the colonization of heartwood by decay fungi. Water soluble treatments such as boron may diffuse toward the heartwood over time, particularly in wet climates with high decay hazard. Boron pretreatments can be combined with less mobile oil-borne treatments do improve the performance of the latter by adding a more mobile antifungal to the treated wood.

Previous and ongoing field scale studies done in Corvallis, OR have monitored the migration of boron in utility pole sections pretreated with a 7% solution of disodium octaborate tetrahydrate (DOT). Boron treatments were done prior to pressure treatment with oil-borne (CuNap or Penta) or water borne (ACZA) preservatives. In these studies, initial penetration of boron was limited and generally only the outer 25 mm of the poles contained sufficient boron levels. After 6 and 3 years of sampling for boron levels, limited to no inward diffusion of boron was detected. Boron was slowly depleted from the outer 25 mm of pole cores and this loss was most pronounced in samples taken at the groundline as opposed to 1.2 m above the groundline, as would be expected given higher moisture contents at groundline.

While this work offers valuable insight into the migration behavior of boron in Douglas-fir poles when it is used as a pretreatment, it may not fully represent real-world applications. The poles used in prior work were not whole utility poles used in service and pressure treatments used may vary slightly from those used by commercial treaters. To address these shortcomings, we sought to partner with a utility to monitor boron migration in pretreated poles used in their system. This allows us to measure boron migration in real-world conditions and also determine the efficacy of preservative loss mitigation techniques such as barrier wraps in utility poles in service. This effort would also benefit from the inclusion of other utility partners so we test the performance of boron pretreatments in a broader range of environmental conditions that are encountered by utility companies.

The work described here is a partnership with SnoPUD to monitor the migration of boron in DOT-pretreated poles that are part of their power network. A total of 48 utility poles were included in this study. 19 poles were standard copper naphthenate-treated poles commercially treated to 1.44 kg/m^3 retention. 29 poles were pressure treated with an 8% solution (BAE) of DOT prior to copper naphthenate treatment (Table II-9). Poles were installed in 2014 and 5 of the boron-pretreated poles were installed with a barrier wrap designed to prevent preservative loss.

These poles were left unsampled for five years until April 2019, when sampling for this study began. Cores were taken from all 48 poles at two locations on each pole, 150 mm below groundline and 100 mm above groundline. The cores were divided into 25 mm sections delineated by their distance from the pole surface ranging from 0-175 mm from the pole surface. Core samples from equivalent sections in poles that were treated in the same way were combined and ground to pass a 20-mesh screen prior to extraction in hot water and boron analysis according to AWPA standard A2, Method 16. Our previous work suggests that boron retention required to prevent fungal decay is 0.6 kg/m^3 and this level is used as a benchmark threshold in this study to determine effective boron levels in core sections.

The 5-year sampling showed, as expected, poles treated with only copper naphthenate had only background boron levels (Table II-10). In pretreated poles, boron was higher in the sections closest to the pole surface, in line with our prior observations. Boron levels were above the inhibitory threshold in all treatments 0-25 mm from the surface (Figure II-12). Boron levels decreased 25-50 mm from the surface but stayed above threshold levels in all treatments except the below groundline treatment with a wrap. Boron levels were generally higher in cores taken 100 mm above ground compared to 150 mm belowground, except in sections over 100 mm from the pole surface, where slightly higher boron levels were observed in the belowground samples. However, all samples taken greater than 75 mm from the pole surface were below threshold levels.

Table II-9. 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

Boron levels taken from in-service poles in this study generally had similar boron levels to those found in the 5th year of sampling our earlier study on boron pretreatment. This suggests that our previous study accurately depicts in-service conditions with regard to boron migration in wood. It also supports our prior observation that groundline boron levels are more rapidly reduced than those seen above groundline as shown by the reduced boron levels in samples taken from 150 mm below groundline. Additionally, these initial observations suggest that the barrier wraps used in this study to not have a large impact on boron migration from utility poles. There may be a slight benefit of using these wraps for above ground boron retention, but our data suggest that the belowground samples the pole surface with liners actually had lower boron content that unwrapped equivalents. This study would benefit from the inclusion of a broader sampling of boron-pretreated in-service utility poles from other service providers and we are open to initiating further sampling efforts in other areas.

Table II-10. Average boron concentrations in Doug-fir utility poles 5-years after installation. Treatments and proximity of groundline are differentiated. ***Bold*** *numbers indicate zones above 0.6 kg/m³ BAE, the threshold for fungal decay prevention.*

Core Section (mm)	Boron Concentration (kg/m³ BAE)					
	Dual Treat		Dual Treat + Liner		CuNap Only	
	Below Ground (-150 mm)	Above Ground (100 mm)	Below Ground (-150 mm)	Above Ground (100 mm)	Below Ground (-150 mm)	Above Ground (100 mm)
0-25	**0.83**	**1.67**	**0.62**	**1.93**	0.06	0.07
25-50	**0.73**	**0.64**	0.49	**0.78**	0.07	0.06
50-75	0.33	0.16	0.31	0.25	0.06	0.06
75-100	0.19	0.11	0.22	0.42	0.07	0.08
100-125	0.19	0.09	0.24	0.13	0.08	0.07
125-150	0.20	0.11	0.25	0.08	0.08	0.07
150-175	0.20	0.15	0.36	0.18	0.10	0.08

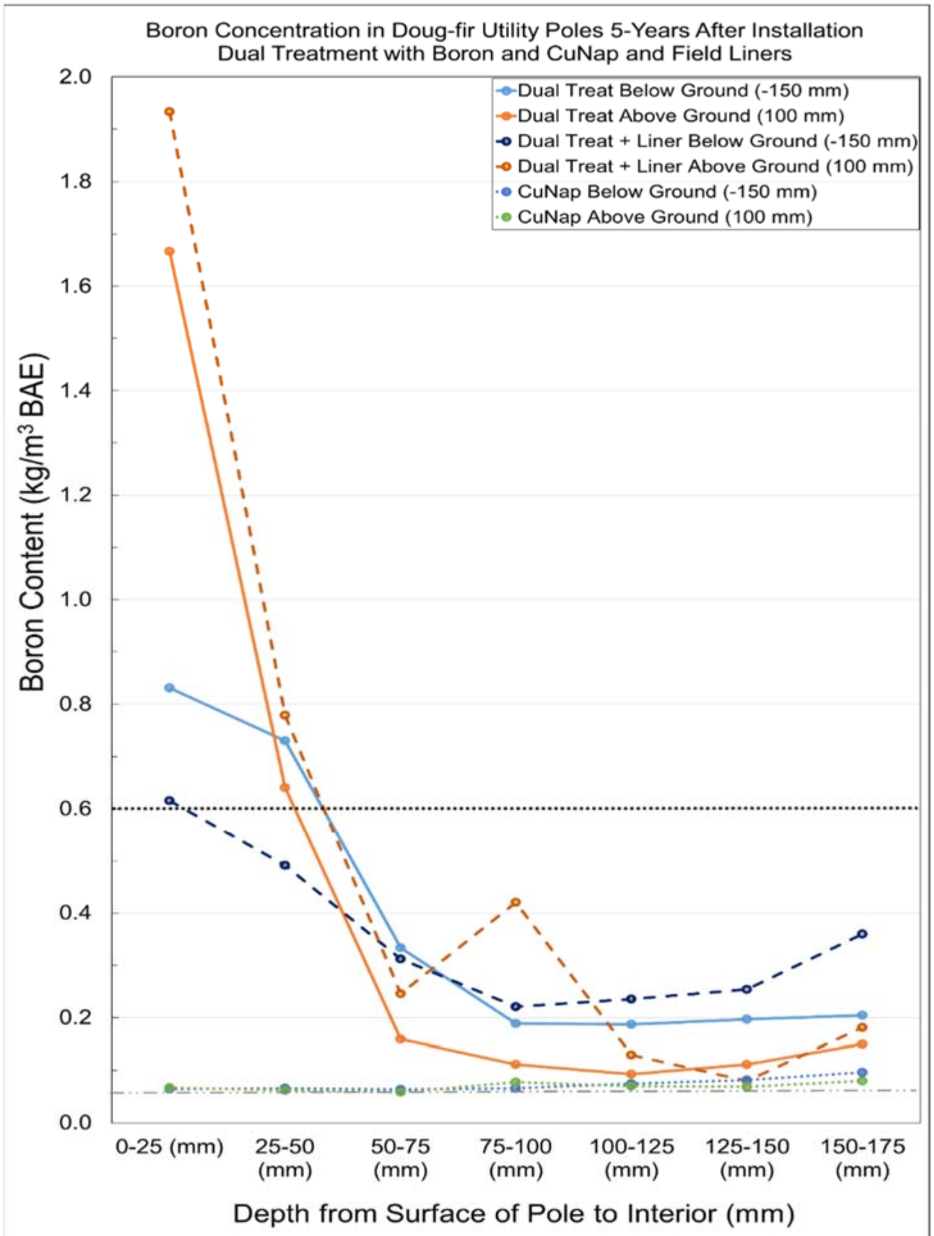


Figure II-12. Average boron concentrations in Doug-fir utility poles 5-years after installation. Treatments and proximity of groundline are differentiated. Dotted black line indicates 0.6 kg/m³ BAE, the threshold for fungal decay prevention. Dashed gray line indicates 0.07 kg/m³ BAE, the average background boron levels identified in CuNap-treated poles.

OBJECTIVE III: EVALUATE PROPERTIES AND DEVELOP IMPROVED SPECIFICATIONS FOR WOOD POLES

While most of our efforts have concentrated on developing systems for arresting in-service decay, developing methods for preventing this damage through improved initial specifications and identifying better methods for assessing in-service poles remains one of our primary goals. Objective III is 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.

A. Effect of Capping on Pole Moisture Content

Extensive application of remedial treatments at groundline have markedly improved the service life of wood poles across North America. Controlling decay at groundline, however, has little influence on fungal activity further up the pole. Although fungi invade at a much slower rate above ground, they will eventually begin to affect pole performance above groundline. One area where this becomes evident in older poles is at the top. While many utility specifications call for a water shedding cap to be applied to the top of poles, others leave pole tops without a cover.

Preservative treatment does tend to penetrate through the end of the pole for distances ranging from 150 to 450 mm depending on the species. Logic would suggest that this degree of preservative penetration should prevent fungi from entering the untreated wood beneath; however, checks and splits that develop as the pole seasons can extend beyond this preservative treatment allowing fungi and moisture to enter. The result will be decay that extends downward into the energized zone, necessitating 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.

We have 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 attacked by decay fungi.

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 142 months after installation by removing increment cores from just beneath the pole cap or at an equivalent location on the non-capped poles (Table III-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 18% over the 142 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 well below the level required for fungal growth (Table III-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%, and 13.8% the inner segments after 113, 126, and 142 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 III-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 III-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 III-1. Example of the condition of water-shedding caps at the start of exposure and after 142 months of exposure in Corvallis, OR.

Table III-1. Moisture contents in Douglas-fir poles with or without water shedding caps as determined over 142 months.

Exposure Time (Months)	Sampling Month	Moisture Content (%)			
		No Cap		Capped	
		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

2. Use of Polyurea Caps to Limit Moisture Intrusion on Douglas-fir Pole Tops:

Figure III-2. Example of a polyurea capped pole top during installation in 2011.

Polyurea barriers have proven to be durable on crossarm sections in sub-tropical exposures in Hilo, Hawaii. We wondered if these materials would also be effective for protecting the tops of newly installed utility poles. To investigate this possibility, 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 III-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 ranged from 16.0% to 31.8%. The averages for the inner and outer zones were 23.8% and 19.0%, respectively (Table III-2). The poles, installed in the spring of 2011, were sampled after 4, 12, 16, 24, 50, 73, 86, and 90 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.

The caps remain sound and free of damage 8 years after installation (Figure III-3). Moisture contents of non-coated poles were generally higher than capped poles from the 12-month sampling point 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 well below the threshold for fungal growth. Moisture levels ranged from 4.6%-21.6% 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. It is unclear if this will be a trend going forward or a result of unseasonably dry weather in the autumn of 2019. We will continue to monitor this study going forward.

Table III-2. Moisture content beneath the tops of Douglas-fir poles with and without a water-shedding polyurea coating as determined over 78 months.

Exposure Time (Months)	Sampling Month	Moisture Content (%)[a]			
		No Cap		Polyurea Coated	
		Inner	Outer	Inner	Outer
0	June	99.3	35.5	23.8	19.0
4	October	5.1	21.5	21.6	13.2
12	June	85.1	22.0	4.6	8.3
16	October	41.7	23.3	17.9	16.2
24	June	48.4	13.0	17.8	14.0
50	August	83.6	28.2	17.3	18.3
73	July	29.5	21.5	20.4	14.7
86	August	17.9	10.4	15.0	16.0
90	December	13.8	12.9	18.3	12.0

[a]Values for the non-capped control were from the Osmose test and are presented for relative comparison.

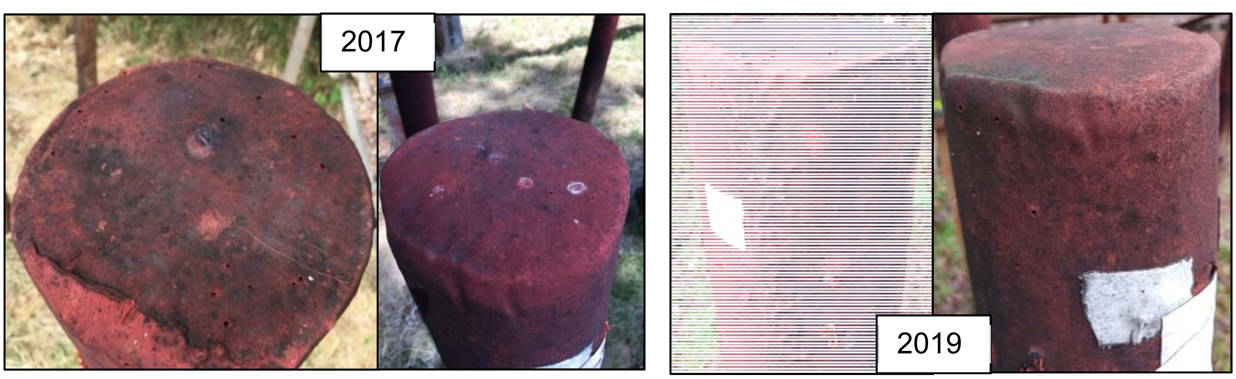


Figure III-3. Condition of polyurea coatings on the tops of Douglas-fir pole sections after 73 months (left) and 90 months (right) of exposure in Corvallis, OR.

B. 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, it has been our assertion that these sloping surfaces actually expose a greater wood surface area to wetting. This becomes especially important as poles season and check in service. Preservative treatment imparts some moisture resistance to wood, but continuous wetting will eventually lead to moisture uptake. 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 III-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 III-4. Examples of the different pole top roofing patterns assessed for their ability to resist moisture ingress.

Table III-3. Mass changes of Douglas-fir pole sections with different top configurations as determined by weighing over a 27-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)

[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 III-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 content 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. We expect that any differences in the different configurations will become more measurable as this study progresses. 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 III-5.

Figure III-5. Status and appearance of pole top configuration poles in December of 2019.

C. 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.

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

Changing climatic conditions in North America are predicted to result in hotter, drier summers with increased risk of wildfire. At the same time, decades of fire suppression, failure to otherwise manage large sections of publicly owned forests, and regional bark beetle outbreaks have created unprecedented fuel loadings in many forests. These conditions create the risk of major conflagrations, especially across the western parts of the United States and Canada. Increased fire risks have raised major concerns among electric utilities whose distribution and transmission lines run through at-risk areas, where lines are largely supported by either wood or steel poles.

At first glance, replacement of wood with steel seems like a logical approach; however, it is important to look more closely at the problem (Smith, 2014). The ability of wood to burn is well known; however, steel can melt and deform when heated under load, making it problematic in a wildfire scenario as well. Moving power lines underground is practically unfeasible due to high cost and maintenance access problems. Therefore, risk mitigation methods for above ground infrastructure are essential and must be developed. Part of this effort is the development of new treatments that provide long-term protection from fire damage.

Developing fire retardant treatments for long term exterior exposure is challenging due to some of the properties of treated wood poles. Petroleum-based solvents used in preservative treatment impart flammability to the pole and metal-based preservatives containing copper of chromium will slowly combust when ignited (Preston et al., 1993). Poles in very dry areas may develop wide, deep checks, which can act as chimneys to accelerate burning. Treatments must also last the 60-80 years in which a pole remains in service and would ideally be restricted only to the pole surface and not migrate to the interior where they serve no protective function and only serve as a reservoir to replenish lost surface deposits.

An alternative approach would be to develop fire retardant wraps or barriers that could be applied immediately after treatment. This approach is being applied in Western Australia with some success (Powell, personal communication). Given the time required to replace all poles already in service (using an estimated 60-80 year pole service life), post-treatment measures such as wraps will be important measures to protect poles already in service.

1. In-Service Pole Protection:

Protecting poles against fire is not a new concern and utilities have attempted to use various methods to limit pole fire risk over the years. Wrapping poles with thin steel sheets has been considered, but impermeable barriers tend to trap moisture which encourages decay and premature failure. Barriers can also make climbing poles more difficult, depending on how far up the pole they are placed. In addition, it is unclear whether these sheets would be completely protective for poles treated with copper-based preservatives such as CCA, ACZA, or ACQ. The metals in these systems can ignite following heating that could be transferred through metal wraps, causing smoldering beneath the protective layer.

Another long-standing alternative for fire protection is to apply a protective coating to the pole surface. These materials need to be relatively inexpensive and easy to apply in the field and must provide protection for at least a 5-10 year period. There are a second group of protectants that are sprayed on the wood surface shortly before a pole is subjected to a fire. Temporary coatings could also be applied to poles, but these would require frequent re-application.

The development of novel protective systems has increased the demand for evaluation protocols for utilities. There are existing institutions that provide fire testing services such as the Western Fire Center, but these services can be exceedingly costly which limits the number of tests that can be done. Because of this there is a need for a standardized, rapid test that can be done to screen various fire protectant treatments prior to submitting them to a certifying testing lab. Ideally this simplified protocol must: 1) use standard materials that are widely available to utilities, 2) Test small pole sections to reduce the amount of material in the test, 3) Produce reproducible and easily varied heating regimes, and 4) Have a relatively low cost to perform.

We have previously reported on our new method developed by the Utility Pole Research Cooperative to assess the performance of fire-retardant systems. The test method is relatively simple and inexpensive, but reproducible. The device uses a stainless-steel shield to contain the heat as close to the pole as desired (Figure III-6). Two infrared heating elements are placed along the stainless-steel walls. A thermocouple is placed into the pole from the pole's backside (non-heated side) to within 6 mm of the pole surface on the heat-exposed face. This thermocouple is connected to a data-logger to record temperature during exposure. In addition, an infrared scanner is used to monitor air temperature between the heating elements and wood. The system allows the pole surface to be heated incrementally with the ability to determine maximum temperatures as well as surface temperatures over the exposure period. In preliminary testing, poles were allowed to burn for 20 minutes after ignition (they could also be run to failure). In order to reduce the potential for smoke complaints, burn time was shortened to 10 minutes in subsequent tests. The degree of protection afforded by a treatment can be assessed by determining depth of char and the area burned as well as by measuring time to ignition.

Last year we described initial tests done with this fire testing system on penta-treated Douglas-fir poles without any additional fire protection to develop initial testing procedures found in the 2018 annual report (Figure III-7). Poles were assessed for fire damage via measuring char area and char depth after the burn (Figure III-8).

Figure III-6. Example of the small-scale fire test apparatus showing the heating shield on a tripod and a close up of the heating elements.

In 2018 the system was subsequently used to evaluate poles receiving two external wraps (Brooks and CopperCare), along with three surface-applied systems (FireSheath, FireGuard, and SunSeeker). Results are described in detail in the 2018 Annual Report. In brief, time to ignition was 10 minutes for the non-protected control and only slightly longer for the SunSeeker (12 minutes). The remaining systems did not ignite, although they did experience surface-charring on either the barrier or the applied film. The test system was used to evaluate three more protective treatments on penta-treated poles, FireGuard, FireSheath, and Sunfire Defense 3000. Results showed that FireGuard and Fire Sheath both reduced ignition frequency, char area, and char depth relative to the untreated and penta-treated controls. SunSeeker application to poles resulted in similar metrics relative to control poles after burns, indicating it was less effective in this test.

Figure III-7. Example of the fire test apparatus being applied to a penta-treated Douglas-fir pole showing initial heating, the beginning of combustion with smoke and finally, the pole on fire.

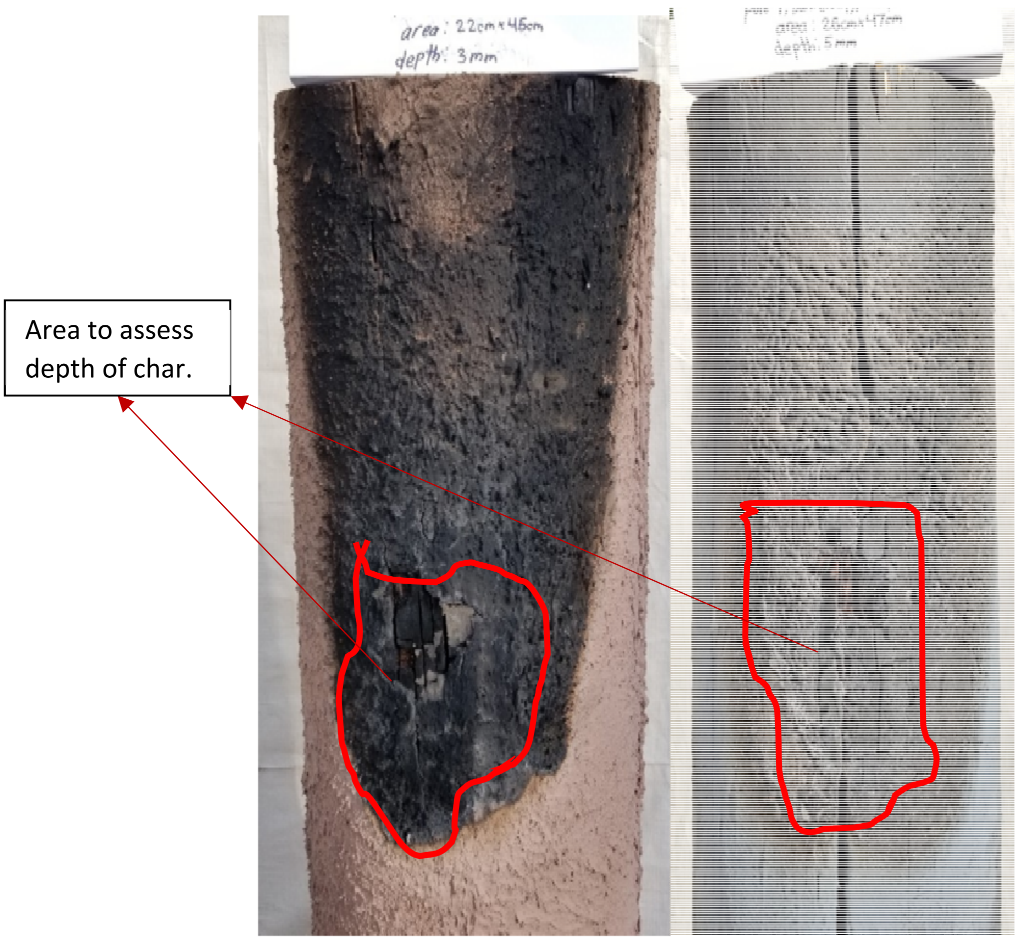


Figure III-8. Example of burned poles showing char, rough char area, and depth of char visualized by scraping surface char away.

In 2019, we performed a small test using our apparatus on protective mesh wraps provided to us by Genics. These wraps are designed to create distance between the pole surface and encroaching flames, reducing the chances of ignition. A total of four treatments plus an unprotected control were tested in this trial (Table III-4). The wraps provided differed in the arrangement of the meshing and one treatment consisted of a double layer of the standard mesh wrap. The trial was performed using the methods described above and performance was evaluated by measuring time to ignition and the maximum char depth measured in the burned area.

Three of the four mesh wraps, standard mesh wrap, X-cut, and double mesh wrap, provided improved protection compared to the control. Poles bearing these wraps did not ignite and two of them only showed superficial surface charring while the double mesh wrap did not show any. The square-cut mesh wrap performed similarly to the control under these conditions, indicating it did not offer protection from the applied heat. The square-cut mesh appears to create a chimney-like effect behind the mesh in our test, which spreads flames to a wider area on the pole surface. Because of these results we conclude that square-cut mesh wraps may have inferior performance to standard or x-cut wraps in a real-world fire scenario. Examples of the mesh wraps and the cutting patterns can be found in Figure III-9.

Table III-4. Effect of exposing Genics Fire Mesh to simulated fire testing.

Sample ID	Initial Pole Temp. (°C)	Ignition	Time to Ignition (min.)	Self-Extinguish	Max. Char Depth (mm)
Control	98	Y	6	N	4
Standard mesh wrap	87	N	-	-	surface
Mesh Wrap w/ 1.5" Square-cut	86	Y	6.5	Y	3
Mesh Wrap w/ 1.5" X-cut	86	N	-	-	surface
Double Mesh Wrap	87	N	-	-	0

While the described test method has proven useful, there was considerable discussion at the 2019 Advisory Committee meeting about modifications to the apparatus to create more uniform heating. Most of the recommendations would have substantially complicated the system, making it more similar to the fixed system that has been proposed as an ASTM Standard. In the end, the apparatus was modified to add a heating ring, but no effort was made to add fans or other devices that might create drafts to accelerate flame spread. The goal of this apparatus remains to produce an inexpensive unit that can be used to rapidly screen a wide array of protective systems to identify those which merit more extensive assessment. We are continuing to evaluate additional fire-retardant systems and will consider developing it as an ASTM Standard to supplement the larger-scale test already proposed.

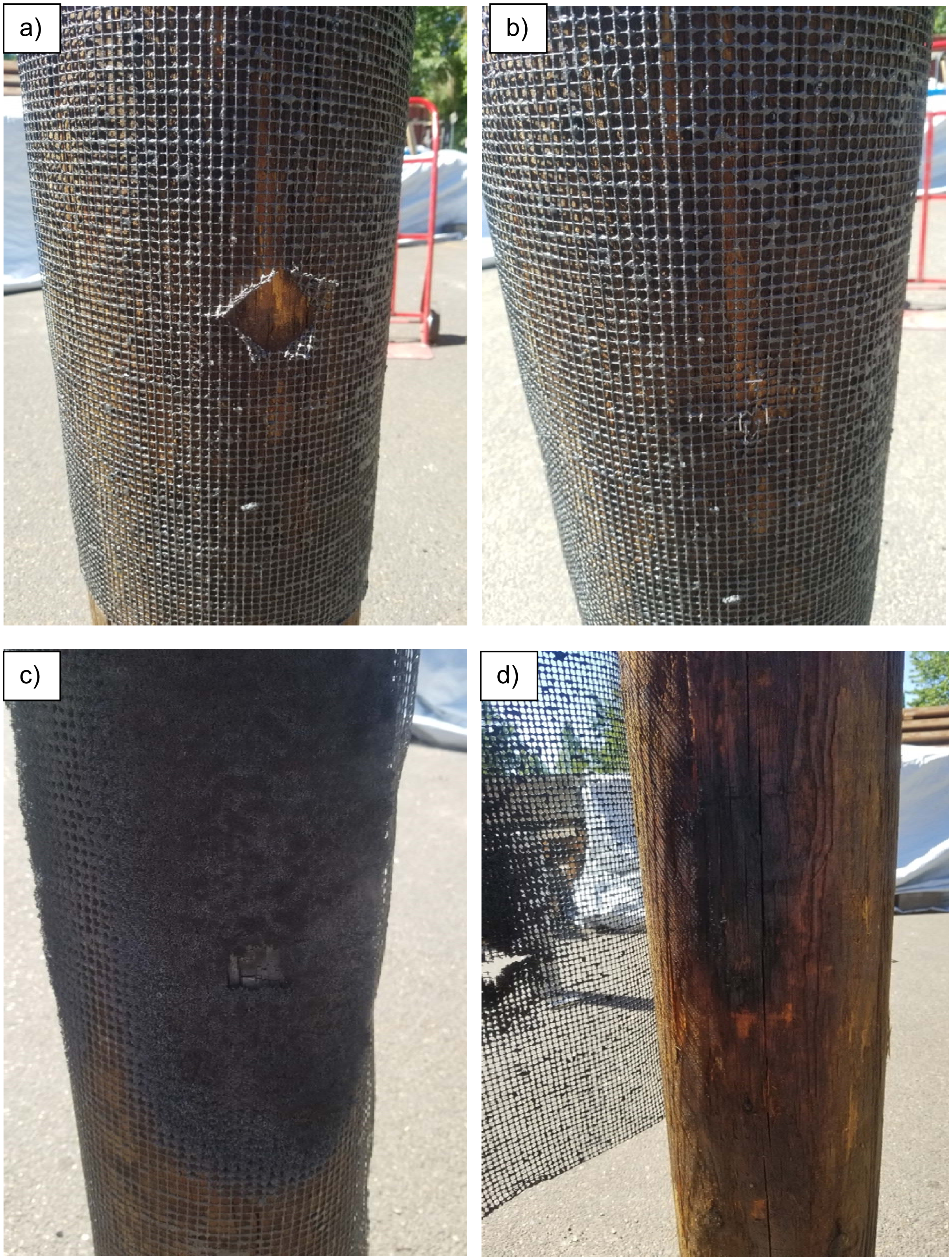


Figure III-9. Example of Genics Fire Mesh burned poles in several configurations. Photos a + b is the “x” configuration. Photo c is the square cutout configuration. Photo d is the pole surface following a burn with Genics Mesh in the “x” configuration.

E. Effect of Solvents on Performance of Copper Naphthenate and Pentachlorophenol

Many utilities prefer the use of oil-borne preservatives for protecting their poles against fungal attack. Oil-borne systems offer several advantages over water-based systems such as providing water resistance to poles and making poles easier for line personnel to climb. Perhaps the most important aspect of oil-borne systems is their impact on preservative performance. Oil-borne systems do not normally fix to the wood and instead they are immobilized in the oil within the wood. Solvent characteristics can substantially affect biological performance. For example, liquefied petroleum gas (lpg) can be substituted for heavier petroleum solvent to solubilize pentachlorophenol. This substitution allows for the rapid evaporation of lpg from wood leaving clean poles that are dry to the touch for applications where cleaner-looking poles are needed. However, the lack of residual solvent also sharply reduces the effectiveness of the preservative, leading to the development of extensive surface decay that shortens service life. 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.

Over the past 7 years, we have performed numerous trials to examine solvent effects on performance of both copper naphthenate and penta. The work originally began because of changes in the solvents commonly used to solubilize penta for Douglas-fir treatment. It was common practice for west coast treaters to take large penta blocks, place them in a treating cylinder and circulate hot oil to dissolve penta to proper solution concentrations. However, recent changes in the supply chain of petroleum-based solvents has left treaters with petroleum oils that are poorer solvents for penta. One alternative was to use a penta concentrate that was diluted with diesel oil; however, this solvent mixture had strong odors and the volatile diesel made it difficult to utilize Boulton seasoning (boiling in oil under vacuum to season prior to treatment).

One solution to the problem was the inclusion of biodiesel in the blended oil. Biodiesel can solubilize sufficient quantities of penta and has an added benefit of sharply reducing solvent 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. Biodiesel is more rapidly degraded than petroleum-based oils in soil contact without biocide, but there were no data concerning the effects of the penta/oil combination.

Extensive laboratory and field studies were undertaken to evaluate the efficacy of penta in conventional solvents, diesel with penta concentrate, and penta in a biodiesel blend. The results indicated that biodiesel performed similarly to other solvents in both the laboratory and field tests except in the case of copper naphthenate. Further investigations into the impact of biodiesel solvent on the performance of copper naphthenate concluded that biodiesel negatively impacts copper naphthenate performance. This led to treaters voluntarily stopping the use of biodiesel in copper naphthenate treatment and the initiation of field assessments of poles treated with copper naphthenate in a biodiesel solvent by two utilities. We also initiated another study on the effects of biodiesel solvents on the performance of oil-borne preservative treatments.

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 III-10). 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.

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, and 58 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 (Table III-5, III-6). Untreated control stakes in the field site remain began to show considerable signs of decay after 58 months of exposure, but were less decayed than those at the forest site. These differences likely reflect climatic conditions at the site, characterized by long, wet, but mild winters and very dry summers. Stakes in the open field site were very dry when evaluated in September while those in the forest site approximately 200 meters away were moist. Year-round moist conditions should be more conducive to 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.

Ratings of the non-treated stakes in the open field site averaged 9.90 after 22 months of exposure, while those in the forest site averaged 8.00. Stakes treated with solvent but no biocide were in slightly better condition, especially at the forest site, but differences were slight and we expect them to disappear over time. There were also slight decay spots on stakes in many treatments; however, this test is in the early stages of evaluation and we would expect treatments to differentiate with additional exposure.

Figure III-10. Stakes drying under cover after treatment with copper naphthenate (bottom) or penta (top).

Stakes at the open field site were in good condition 34 months after installation, with ratings remaining above 9.00, indicating little evidence of advanced decay while stakes in the forest site experienced more aggressive decay. The non-treated controls showed evidence of advanced decay (rating = 5.45) and average ratings for many of the samples treated with solvent alone or solvent plus the lowest preservative retentions exhibited decay (ratings 7.25-9.70).

Untreated stake ratings continued to decline after 46 months of exposure, although effects were greater at the forest site. All penta-treated stakes exposed at the field site remained in good condition after 46-months with ratings above 9.00. Copper naphthenate stakes with biodiesel began to experience measurable decay after 46 months as shown by two of the biodiesel treatments dropping below a rating of 9.00, however these differences were not statistically significant.

Stakes exposed in the forest were, on the whole, in poorer condition after 46 months and many averaged near 8, including some with pentachlorophenol. The biggest differences were found with stakes using biodiesel-solubilized copper naphthenate. Stakes treated with Cu-naphthenate solubilized in 100% biodiesel showed ratings ranging from 7.25-8.25 whereas those treated with 100% petroleum oil ranged from 8.80-9.50. Stakes treated with copper naphthenate in petroleum diesel/biodiesel blends appeared to have higher levels of decay with increased proportions of biodiesel relative to diesel copper naphthenate treatments (Figures III-11 to III-16). However, the differences among copper naphthenate treatments to date are not statistically significant from one another. The status of our biodiesel field trails in 2017 is shown in Figure III-17, while selected stakes and the trial site in 2018 are shown in Figures III-18 and III-19.

After 58 months, decay advanced further in the untreated stakes, reaching an average rating of 6.08 at the field sites and near total failure, 1.83, at the forest site. Overall, treated samples followed the same pattern and the field site stakes showed higher (6.90-9.60) average ratings compared to the forest site (4.35-8.85). At the field site, stakes treated with Copper naphthenate dissolved in bio-diesel appeared to perform worse than stakes treated with copper naphthenate dissolved in petroleum oil. The effect however was not as dramatic as was seen at the forest site, where biodiesel-copper naphthenate stakes were noticeably more degraded (average ratings 5.70-7.00) than petroleum-copper naphthenate-treated stakes (average ratings 7.40-8.60) (Figures III-11 to III-16). However, at this sampling point the differences among copper naphthenate treatments were not statistically significant. Any effect of biodiesel on penta treatments was more difficult to determine as there is no clear pattern of increasing decay with increasing biodiesel concentration.

Table III-5. Condition of Douglas-fir sapwood stakes treated with penta or copper naphthenate in various solvents and exposed for 58 months at a meadow site near Corvallis, Oregon.

Field Stake Assessment (2016-2019)

Treatment	Biodiesel %	Months	Average Stake Condition						
			Target Retentions (kg/m^3)						
Pentachlorophenol Carrier			**Water (UTC)**	**0**	**2.4**	**4.8**	**7.2**	**9.6**	**All Retentions**
Water (UTC)	-----	22	9.90 (0.3)						
		34	9.25 (1.3)						
		46	8.80 (1.7)						
		58	6.08 (3.5)						
Diesel	0*	22		9.95 (0.2)	9.98 (0.1)	10.00 (0.0)			9.98
		34		9.65 (0.5)	9.90 (0.3)	10.00 (0.0)			9.85
		46		9.35 (1.0)	9.90 (0.3)	9.95 (0.2)			9.73
		58		8.60 (0.8)	9.45 (0.8)	9.60 (0.6)			9.22
	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)	9.79
		46		9.50 (1.0)	9.70 (0.6)	9.45 (1.0)	9.40 (1.1)	9.90 (0.4)	9.59
		58		7.95 (2.5)	8.15 (1.7)	7.95 (1.5)	7.95 (1.5)	8.65 (1.1)	8.13
	50	22		9.90 (0.2)	10.00 (0.0)	9.95 (0.2)	9.95 (0.2)	9.98 (0.1)	9.96
		34		9.35 (1.2)	9.85 (0.5)	9.95 (0.2)	9.70 (0.5)	9.68 (0.7)	9.71
		46		9.15 (1.3)	9.60 (0.7)	9.95 (0.2)	9.70 (0.8)	9.68 (0.7)	9.62
		58		8.60 (1.1)	9.15 (0.8)	8.95 (1.6)	7.95 (1.3)	8.65 (0.9)	8.66
	70	22		9.70 (0.9)	9.95 (0.2)	9.95 (0.2)	10.00 (0.0)	10.00 (0.0)	9.92
		34		9.25 (1.5)	9.65 (0.8)	9.75 (0.6)	9.75 (0.0)	9.90 (0.3)	9.66
		46		9.25 (1.5)	9.35 (0.9)	9.65 (0.9)	9.75 (0.5)	9.90 (0.3)	9.58
		58		7.80 (1.9)	8.45 (1.4)	8.85 (1.2)	8.55 (1.2)	8.95 (0.8)	8.52
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 (0.2)	9.93 (0.2)	9.95
		46		10.00 (0.0)	9.80 (0.4)	9.90 (0.3)	10.00 (0.0)	9.85 (0.3)	9.91
		58		8.70 (1.0)	8.55 (1.4)	8.15 (1.4)	8.45 (1.1)	8.05 (2.2)	8.38
Naphthenic Oil	30	22		10.00 (0.0)	9.95 (0.2)	9.95 (0.2)	9.95 (0.2)	9.98 (0.1)	9.97
		34		9.35 (0.9)	9.85 (0.3)	9.95 (0.2)	9.95 (0.5)	9.90 (0.3)	9.80
		46		9.20 (0.9)	9.85 (0.3)	9.95 (0.2)	9.95 (0.2)	9.83 (0.7)	9.76
		58		6.90 (1.8)	8.50 (0.9)	8.60 (1.2)	8.75 (0.9)	8.425 (1.2)	8.24
Paraffinic Oil	30	22		9.95 (0.2)	10.00 (0.0)	10.00 (0.0)	10.00 (0.0)	10.00 (0.0)	9.99
		34		9.30 (1.5)	9.40 (1.0)	9.90 (0.3)	9.70 (0.3)	9.90 (0.3)	9.64
		46		9.20 (1.9)	9.25 (1.0)	9.90 (0.3)	9.70 (0.5)	9.90 (0.3)	9.59
		58		6.90 (2.3)	7.10 (2.7)	8.45 (0.6)	8.50 (1.0)	8.60 (0.6)	7.91
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 (0.7)	9.55 (0.6)	9.90 (0.3)	9.90 (0.6)	9.83 (0.6)	9.78
		46		9.70 (0.7)	9.35 (0.9)	9.90 (0.3)	9.80 (0.6)	9.80 (0.7)	9.71
		58		7.30 (1.6)	7.40 (1.4)	8.20 (1.5)	8.10 (1.8)	8.825 (0.9)	7.97
Ketone Bottoms	0	22		9.90 (0.2)	9.90 (0.3)	9.95 (0.2)	10.00 (0.0)	9.95 (0.2)	9.94
		34		9.45 (1.0)	9.75 (0.5)	9.90 (0.3)	9.95 (0.0)	9.80 (0.5)	9.77
		46		9.15 (1.9)	9.35 (1.2)	9.80 (0.6)	9.95 (0.2)	9.73 (0.6)	9.60
		58		7.50 (2.9)	7.55 (2.2)	8.50 (1.3)	8.15 (1.2)	8.675 (1.1)	8.08
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 (0.5)	10.00 (0.0)	9.86
		46		9.35 (1.0)	10.00 (0.0)	9.45 (0.9)	9.70 (0.8)	10.00 (0.0)	9.70
		58		8.60 (0.8)	8.60 (0.7)	8.70 (1.2)	8.98 (1.4)	9.50 (0.4)	8.88
	10	22		9.90 (0.2)	10.00 (0.0)	9.90 (0.2)	9.98 (0.1)	10.00 (0.0)	9.96
		34		9.90 (0.3)	10.00 (0.0)	9.80 (0.3)	9.85 (0.8)	10.00 (0.0)	9.91
		46		9.85 (0.5)	9.80 (0.6)	9.60 (0.7)	9.70 (0.7)	10.00 (0.0)	9.79
		58		7.40 (0.8)	8.60 (1.0)	8.70 (0.7)	8.98 (1.4)	9.40 (0.7)	8.62
	30	22		10.00 (0.0)	9.85 (0.3)	10.00 (0.0)	9.93 (0.2)	9.90 (0.3)	9.94
		34		9.75 (0.6)	9.30 (1.2)	9.85 (0.3)	9.60 (0.7)	9.95 (0.2)	9.69
		46		9.50 (1.0)	9.05 (1.3)	9.85 (0.3)	9.35 (1.1)	9.80 (0.6)	9.51
		58		7.95 (2.5)	8.55 (1.3)	8.75 (1.6)	8.75 (1.3)	9.00 (1.4)	8.60
	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 (1.2)	9.75 (0.6)	9.40 (0.7)	9.58 (0.3)	9.80 (0.5)	9.58
		46		9.15 (1.3)	9.50 (0.7)	9.35 (0.9)	9.43 (0.8)	9.80 (0.5)	9.45
		58		8.60 (1.1)	8.00 (2.3)	8.40 (1.1)	8.40 (1.7)	8.95 (0.4)	8.47
	100	22		9.95 (0.2)	9.95 (0.2)	9.60 (0.9)	9.98 (0.1)	9.95 (0.2)	9.89
		34		9.50 (1.1)	9.75 (0.8)	8.95 (1.4)	9.88 (0.0)	9.50 (1.1)	9.52
		46		8.95 (1.7)	9.70 (0.9)	8.90 (1.4)	9.78 (0.6)	9.35 (1.3)	9.34
		58		7.15 (3.0)	7.75 (1.1)	8.15 (1.7)	8.55 (1.5)	8.60 (1.6)	8.04

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), 9.30 (1.3), 8.80 (1.7), and 6.08 (3.5) after 22, 34, 46, and 58 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 III-6. Condition of Douglas-fir sapwood stakes treated with penta or copper naphthenate in various solvents and exposed for 58 months at a forest site near Corvallis, Oregon.

Forest Stake Assessment (2016-2019)

Treatment	Biodiesel %	Months	Average Stake Condition						
			Target Retentions (kg/m^3)						
Pentachlorophenol Carrier			**Water (UTC)**	**0**	**2.4**	**4.8**	**7.2**	**9.6**	**All Retentions**
Water (UTC)	-----	22	8.00 (2.0)						
		34	5.45 (2.2)						
		46	4.23 (2.5)						
		58	1.83 (1.8)						
Diesel	0*	22		8.75 (1.0)	9.83 (0.5)	9.75 (0.5)			9.44
		34		7.45 (1.4)	9.58 (0.9)	9.75 (0.5)			8.93
		46		7.30 (1.3)	9.25 (1.2)	9.65 (0.6)			8.73
		58		5.45 (2.5)	8.70 (2.4)	8.85 (2.0)			7.67
	30	22		8.70 (1.5)	9.20 (0.9)	9.65 (0.3)	9.95 (0.2)	9.88 (0.4)	9.48
		34		8.35 (2.0)	8.25 (1.8)	9.20 (0.8)	9.65 (0.6)	9.78 (0.6)	9.05
		46		7.80 (2.1)	8.05 (1.7)	8.80 (1.1)	9.25 (0.9)	9.45 (0.9)	8.67
		58		4.85 (2.8)	4.85 (3.2)	7.40 (2.6)	7.15 (2.1)	8.05 (1.8)	6.46
	50	22		9.05 (1.0)	9.50 (0.4)	9.80 (0.3)	9.95 (0.2)	9.65 (0.5)	9.59
		34		8.00 (1.1)	8.95 (0.9)	9.50 (0.5)	9.80 (0.3)	9.18 (1.2)	9.09
		46		7.60 (1.2)	8.80 (0.8)	9.30 (0.5)	9.40 (0.7)	8.58 (1.5)	8.74
		58		4.60 (2.0)	7.25 (1.5)	7.45 (1.7)	7.50 (2.7)	7.53 (1.8)	6.87
	70	22		8.95 (1.0)	9.35 (0.7)	9.45 (0.6)	9.75 (0.4)	9.73 (0.5)	9.45
		34		8.40 (1.2)	8.75 (1.3)	8.80 (1.0)	9.30 (0.7)	9.53 (0.6)	8.96
		46		8.00 (1.7)	8.60 (1.5)	8.70 (1.1)	9.10 (0.8)	9.20 (0.8)	8.72
		58		6.00 (2.6)	6.00 (1.8)	6.30 (2.3)	7.95 (2.3)	8.15 (1.7)	6.88
Aromatic Oil	0	22		9.80 (0.3)	9.85 (0.3)	9.95 (0.2)	9.85 (0.5)	9.93 (0.2)	9.88
		34		9.50 (0.7)	9.70 (0.5)	9.85 (0.3)	10.00 (0.0)	9.83 (0.4)	9.78
		46		9.50 (0.7)	9.50 (0.5)	9.60 (0.6)	9.95 (0.2)	9.48 (0.5)	9.61
		58		8.40 (1.0)	8.40 (1.1)	8.45 (1.2)	8.70 (0.7)	8.83 (0.7)	8.56
Naphthenic Oil	30	22		9.45 (0.7)	9.70 (0.5)	9.85 (0.2)	9.90 (0.3)	9.90 (0.3)	9.76
		34		7.80 (1.8)	9.30 (1.0)	9.60 (0.5)	9.75 (0.5)	9.68 (0.8)	9.23
		46		7.00 (1.4)	8.80 (1.4)	9.05 (0.7)	9.15 (1.1)	9.30 (0.8)	8.66
		58		3.75 (1.8)	5.75 (2.6)	7.20 (2.4)	7.45 (2.6)	7.45 (1.7)	6.32
Paraffinic Oil	30	22		9.35 (0.7)	9.30 (1.3)	9.95 (0.2)	9.90 (0.2)	9.70 (0.6)	9.64
		34		8.65 (1.4)	8.45 (2.2)	9.55 (0.8)	9.75 (0.4)	9.45 (0.9)	9.17
		46		8.00 (1.7)	8.10 (2.0)	9.30 (0.9)	9.35 (1.0)	9.40 (0.7)	8.83
		58		5.60 (2.8)	6.35 (2.6)	7.55 (2.4)	7.65 (1.2)	8.03 (1.8)	7.04
FPRL Oil	0	22		9.25 (0.4)	9.60 (0.5)	9.95 (0.2)	9.70 (0.7)	9.98 (0.1)	9.70
		34		8.30 (1.1)	9.05 (1.0)	8.70 (1.1)	9.30 (1.2)	9.88 (0.4)	9.05
		46		7.60 (1.1)	8.35 (1.0)	8.50 (1.0)	9.05 (1.0)	9.53 (0.8)	8.61
		58		5.70 (2.9)	5.85 (2.0)	6.90 (2.3)	7.50 (1.7)	8.13 (1.6)	6.82
Ketone Bottoms	0	22		9.25 (0.8)	9.70 (0.5)	9.90 (0.2)	9.40 (0.7)	9.95 (0.2)	9.64
		34		8.35 (1.1)	9.05 (1.0)	9.65 (0.7)	9.20 (0.9)	9.85 (0.5)	9.22
		46		7.75 (1.3)	8.70 (1.1)	9.05 (1.1)	9.15 (0.7)	9.58 (0.5)	8.85
		58		4.50 (1.4)	7.20 (1.8)	7.35 (1.7)	7.50 (1.6)	8.13 (1.3)	6.94
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)	9.61
		34		7.45 (1.4)	8.90 (1.1)	9.60 (0.7)	9.58 (0.7)	9.55 (0.8)	9.02
		46		7.30 (1.3)	8.80 (1.1)	9.50 (0.7)	9.35 (0.9)	9.40 (0.7)	8.87
		58		5.45 (2.5)	7.40 (2.2)	7.75 (2.0)	7.83 (2.1)	8.60 (1.4)	7.41
	10	22		8.85 (1.0)	9.75 (0.5)	9.65 (0.3)	9.68 (0.5)	9.85 (0.2)	9.56
		34		7.65 (1.4)	9.25 (0.9)	9.25 (0.8)	9.23 (1.0)	9.55 (0.4)	8.99
		46		7.30 (1.1)	8.85 (1.1)	9.15 (0.7)	8.93 (0.9)	9.40 (0.5)	8.73
		58		4.65 (1.5)	7.05 (1.7)	7.50 (2.0)	7.58 (1.9)	8.40 (0.8)	7.04
	30	22		8.70 (1.5)	9.55 (0.4)	9.25 (0.7)	9.63 (0.5)	9.35 (0.6)	9.30
		34		8.35 (2.0)	8.65 (1.3)	8.75 (0.7)	8.63 (1.7)	8.80 (0.5)	8.64
		46		7.80 (2.1)	8.50 (1.4)	8.65 (0.8)	8.50 (1.1)	8.50 (0.7)	8.39
		58		4.85 (2.8)	6.30 (2.0)	6.90 (2.1)	7.10 (1.9)	7.55 (1.2)	6.54
	50	22		9.05 (1.0)	8.70 (0.9)	9.40 (0.7)	9.23 (0.8)	9.55 (0.6)	9.19
		34		8.00 (1.1)	7.50 (1.5)	8.80 (1.3)	8.75 (1.0)	9.15 (1.0)	8.44
		46		7.60 (1.2)	7.15 (1.3)	8.10 (1.2)	8.55 (1.0)	8.80 (0.9)	8.04
		58		4.60 (2.0)	5.75 (2.3)	6.45 (2.0)	7.15 (1.9)	7.35 (2.3)	6.26
	100	22		8.60 (1.6)	8.60 (1.2)	8.85 (1.1)	9.35 (0.7)	8.95 (1.2)	8.87
		34		7.25 (2.4)	8.45 (1.4)	8.10 (1.9)	8.75 (1.2)	8.25 (1.5)	8.16
		46		6.55 (2.6)	7.25 (1.6)	7.60 (1.8)	8.25 (1.1)	8.25 (1.5)	7.58
		58		4.35 (3.6)	5.70 (2.1)	6.45 (2.6)	6.58 (2.2)	7.00 (2.1)	6.02

Values represent means of 10 stakes per treatment. Figures in parentheses represent one standard deviation.
Ratings for the non-treated control averaged 8.0 (2.0), 5.5 (2.2), 4.23 (2.5), and 1.83 (1.8) after 22, 34, 46, and 58 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.

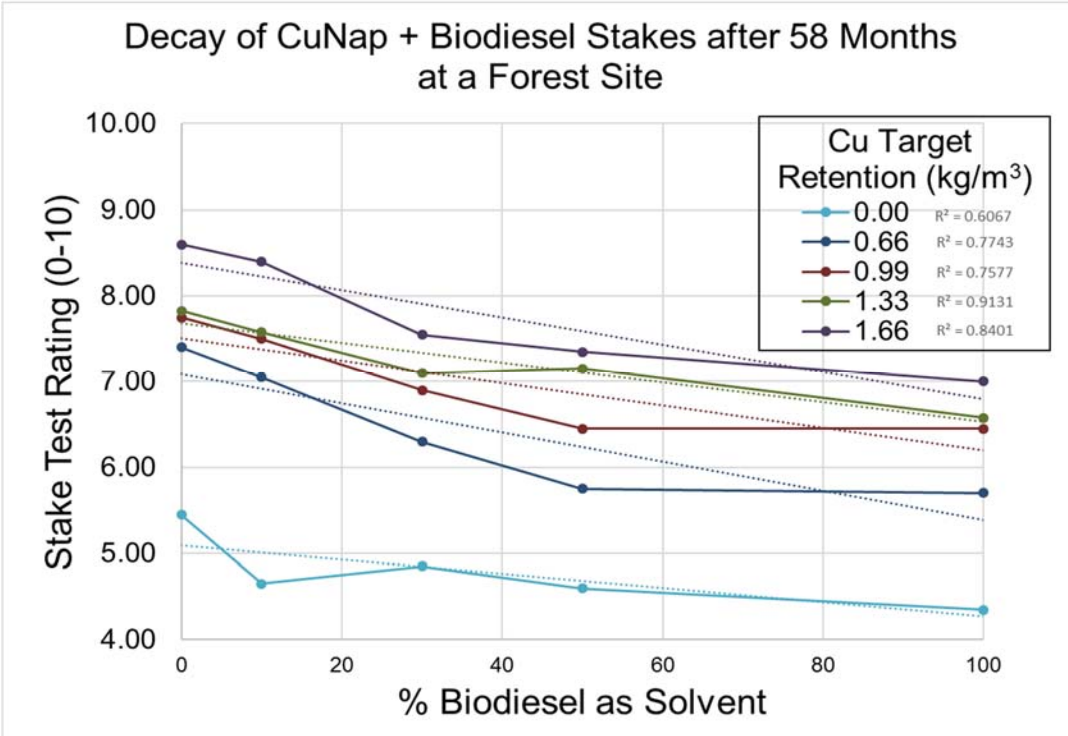


Figure III-11. Average ratings of Douglas-fir sapwood stakes at the forest site treated with copper naphthenate in mixtures of petroleum and bio-based diesel after 58 months of exposure in soil showing the relationship between increased biodiesel content and increased decay.

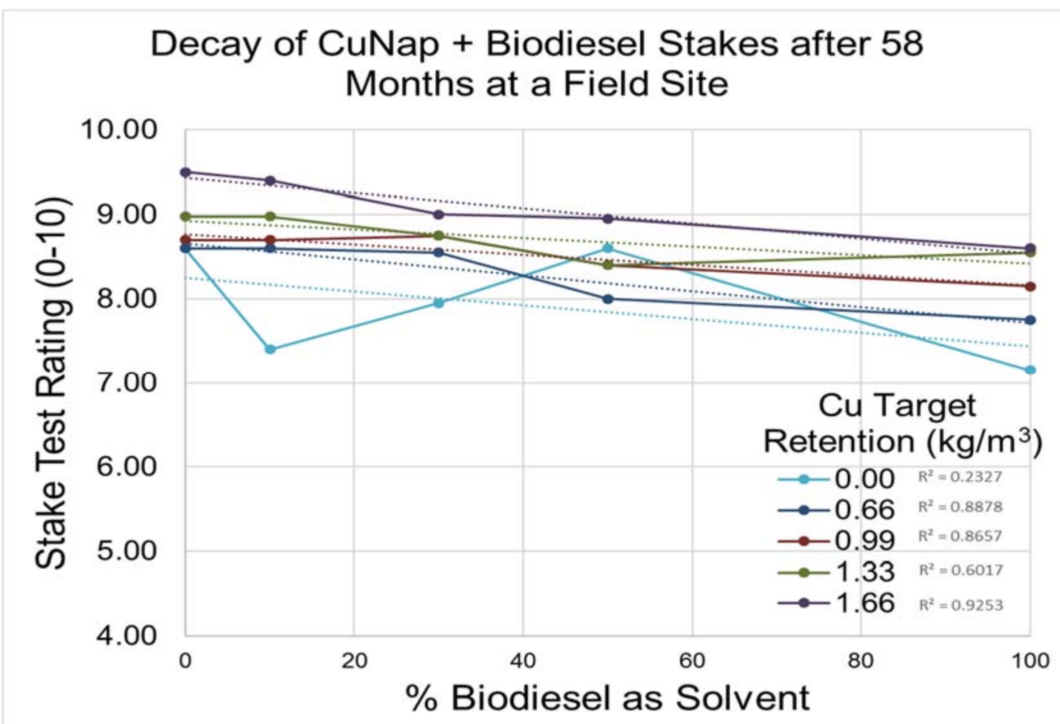


Figure III-12. Average ratings of Douglas-fir sapwood stakes at the field site treated with copper naphthenate in mixtures of petroleum and bio-based diesel after 58 months of exposure in soil.

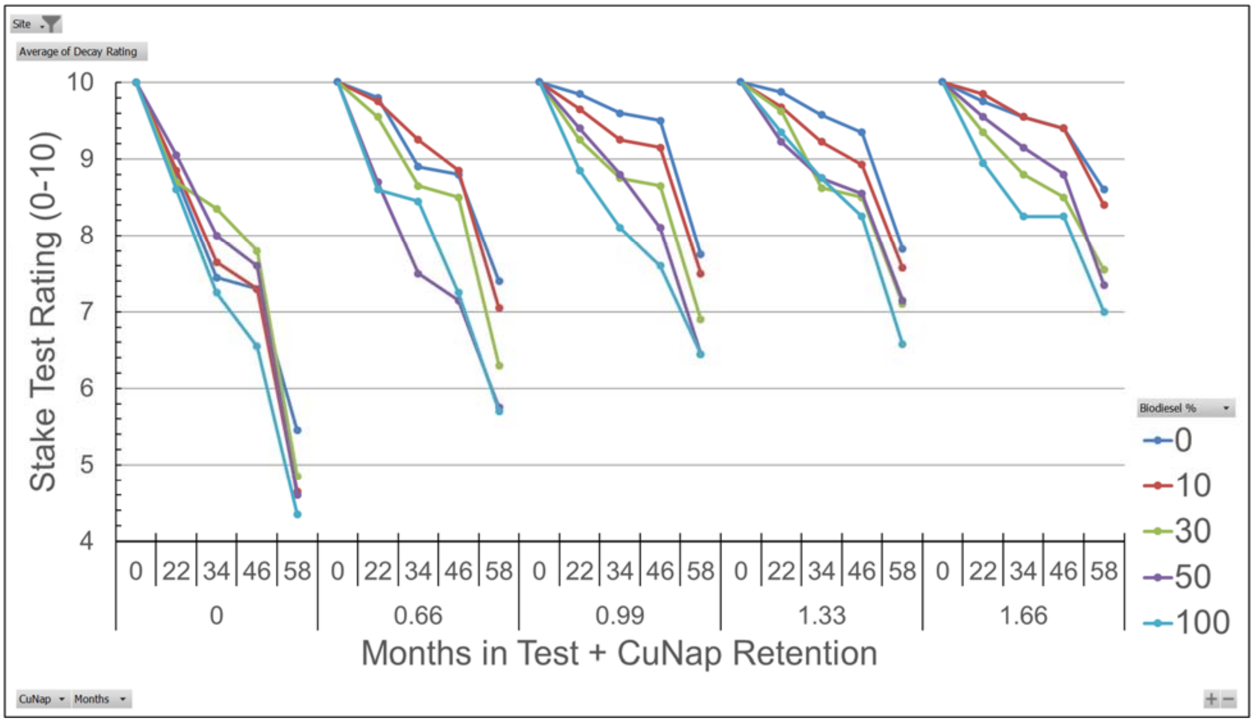


Figure III-13. Average ratings of Douglas-fir sapwood stakes at the forest site treated with copper naphthenate in mixtures of petroleum and bio-based diesel after 22, 34, 46, and 58 months of exposure in soil.

Figure III-14. Average ratings of Douglas-fir sapwood stakes at the grass site treated with copper naphthenate in mixtures of petroleum and bio-based diesel after 22, 34, 46, and 58 months of exposure in soil.

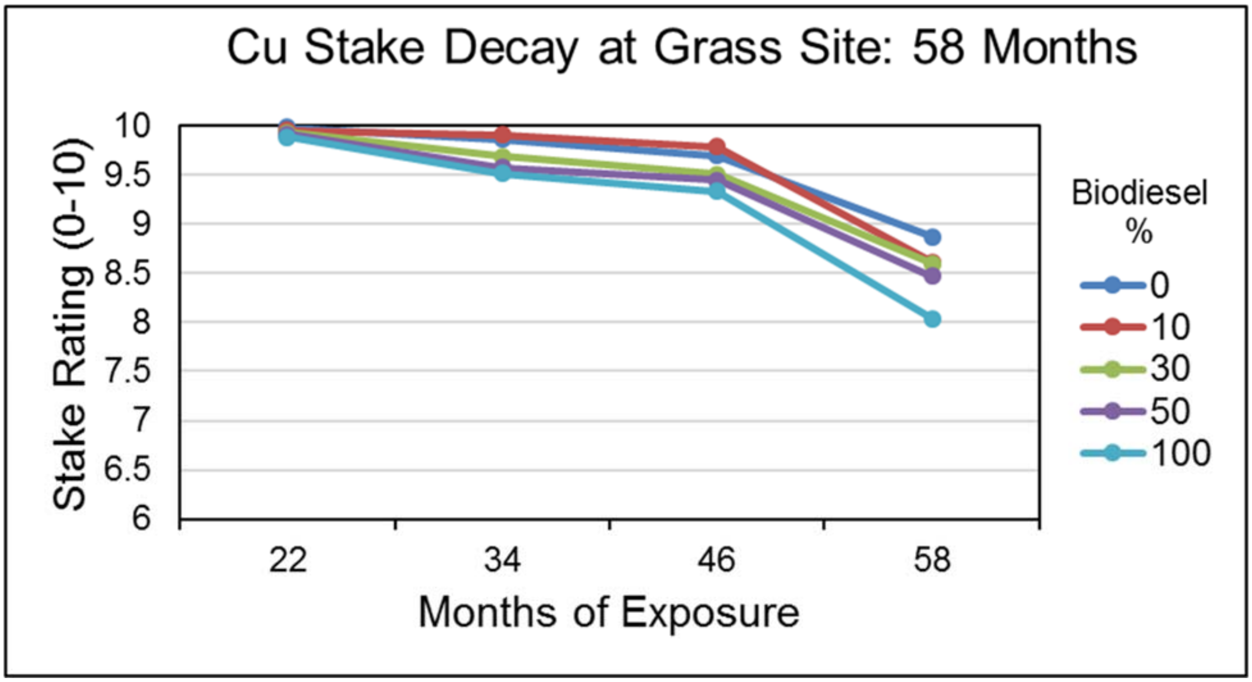


Figure III-15. Average ratings of Douglas-fir sapwood stakes at the grass site treated with copper naphthenate in mixtures of petroleum and bio-based diesel over 58 months of exposure in soil showing the relationship between increased biodiesel content and increased decay. These data combined all of the Cu retentions for each individual biodiesel level and are therefore not representative of industry treatment standards.

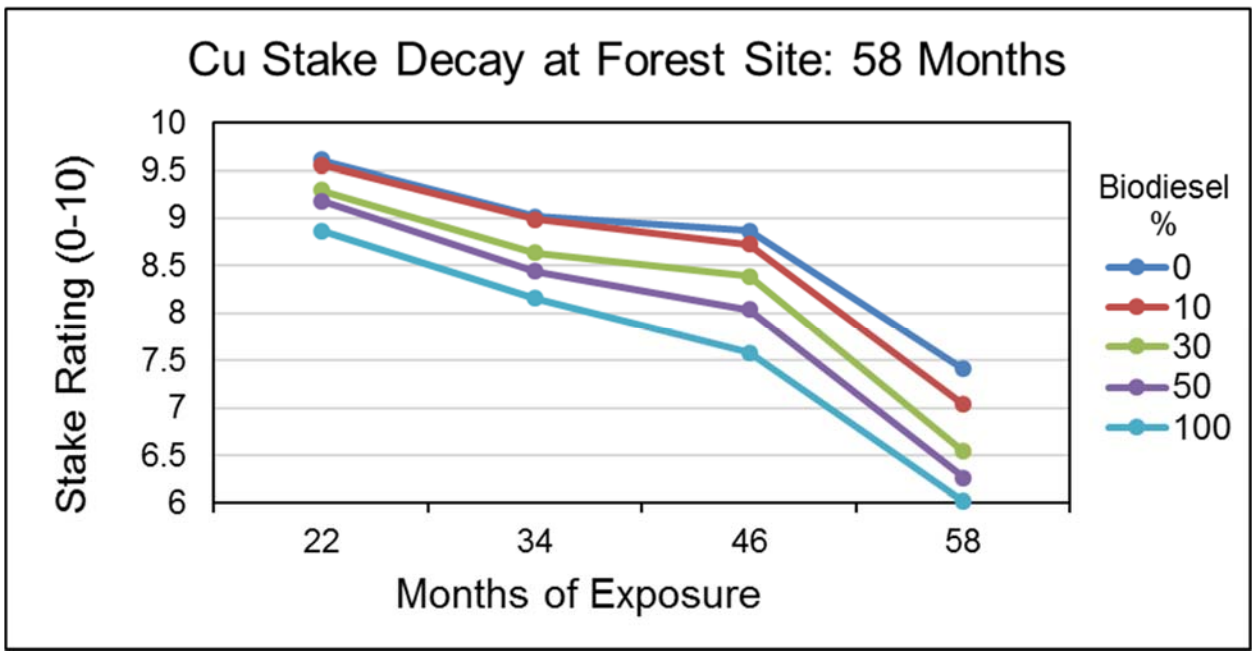


Figure III-16. Average ratings of Douglas-fir sapwood stakes at the forest site treated with copper naphthenate in mixtures of petroleum and bio-based diesel over 58 months of exposure in soil showing the relationship between increased biodiesel content and increased decay. These data combined all of the Cu retentions for each individual biodiesel level and are therefore not representative of industry treatment standards.

Figure III-17. Composite photo showing a control stake at the field site, the forest site, and the field site in early September 2017.

Figure III-18. Photos showing the same control stake from the wood site in 2016 (left) and 2018 (right).

Figure III-19. Photos from the field site in 2018 showing various levels of decay.

F. Flexural Properties of Douglas-fir Crossarms (M.S. Thesis for Hunter Anderson, a Wood Science/Civil Engineering Student Supported by the UPRC)

NOTE: A link to the full thesis of Mr. Hunter Anderson is provided. If you would like further information or to refer to the specific citations in this section, please download the thesis from Oregon State University. Link: https://ir.library.oregonstate.edu/concern/graduate_thesis_or_dissertations/zc77sw48x

Although we typically think about the utility pole as a support for transmission wires, it is important to note that most wires are supported on poles using wooden crossarms. Wood is economical and reliable and provides excellent service life. The primary species used to produce crossarms is Douglas-fir, which has excellent strength properties and dimensional stability.

The rigorous loading and environmental conditions to which crossarms are exposed require careful selection of materials for this application. These specifications appear in the West Coast Lumber Inspection Bureau standards and place substantial limitations on wood characteristics, such as the slope of grain and growth rate, but the most critical parameters are the presence and location of knots.

These limitations have produced exceptional reliability, but they also sharply limit the supply of wood that can meet these specifications. While wood crossarms have been used for over a century to support overhead lines, there are surprisingly few data examining the effects of various defects on properties. These data could provide a more rational system for selecting arms to ensure they meet the required performance attributes, but also ensure specifications do not inadvertently eliminate acceptable materials.

The purpose of this work is to compare the flexural properties of Douglas-fir distribution arms that are currently acceptable with those that have been rejected due to various defects (primarily knots).

Test Method: Two hundred fifty Douglas-fir crossarms (87.5 mm by 112.5 mm by 2.4 m long) were provided by Brooks Manufacturing for the study. All arms had been predrilled and incised, but not treated. Fifty arms met the current ANSI 05.3 specification for wooden cross arms, while the remainder had been rejected for various reasons, including knot size and location.

Knot Mapping: Each specimen was numbered and arbitrarily labeled on each long side as A-D. Knot diameters were measured to the nearest 1.5 mm on all four faces. The knots were delimited into zones (Figure III-20) and total knot area was calculated for each zone.

Flexural Testing: The difficulty in assessing knot effects on crossarm performance is designing a test apparatus that actually stresses the area containing the knot. Conventional third or fourth point loading tests do not completely assess knot effects because they only load a small area at the center and the knot may lie outside that area.

Preliminary calculations were performed to determine a reasonable angle to use in order to simulate an ice load on an arm in the field. This angle was determined to be 17.5 degrees and assumed a 25 mm thick ice layer on the line. The test apparatus attached an arm to a steel beam mounted to the floor. Load was applied at an angle from the bottom of each arm to simulate the reaction that develops from the line hanging from the opposite end. The orientation of the arm was determined by ensuring the worst defects on the arm were placed in a tension zone wherever possible. The arm was pinned in the center to the steel beam. Spacers were used to ensure the beam could deflect between the pins without resting on steel, therefore changing boundary conditions. An actuator was fixed through the pre-drilled hole intended for mounting the transmission lines. This actuator utilized a custom bracket that allowed the load to be applied at the same 17.5 degree angle previously described (Figure III-21).

The actuator had a potentiometer that provided deflection data along the line of load application. The actuator was controlled by the potentiometer and load was applied at 1 inch of deflection per minute. Load and deflection were continuously monitored. Arms tended to fail within 5 to 7 minutes. A total of 250 arms were tested using these procedures.

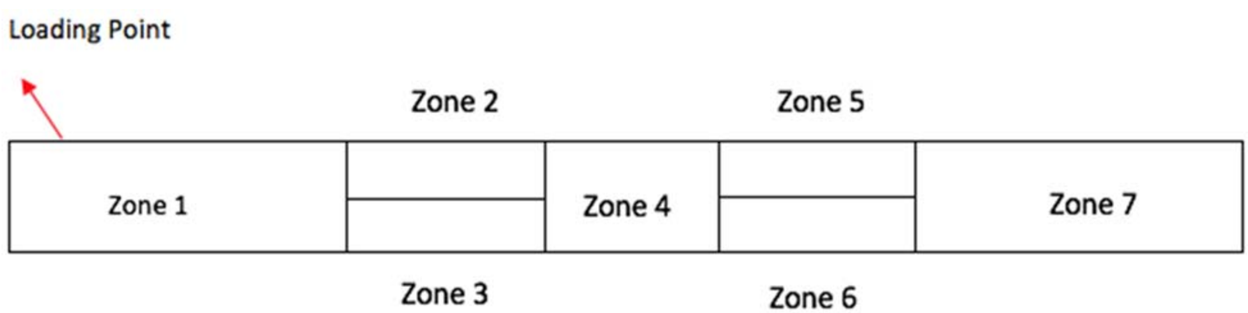


Figure III-20. Zone delimitation for crossarms used to separate defects.

The resulting data were used to calculate Modulus of Rupture (MOR) and Modulus of Elasticity (MOE) and were compared with arm characteristics that included knot diameter and location. Data analysis focused on comparisons of knot area in different zones with MOR. The zone of failure was determined by post-test visual assessment and the total defect area in that zone was compared to the total area observed in failure zones of the other arms. Knot areas of tension zones were compared in a similar fashion, as was the total defect area in the bottom half of the arm. Relationships between knot area in a zone and strength of the arm were examined. Arms that failed in zones with no obvious defect were highlighted in order to establish a threshold where knot area in zones outside of critical tension zones did not affect arm failure.

The arms failed in a variety of modes (Figure III-22a/b), but the majority failed in tension along a defect. The ANSI 05.3 standard specifies a minimum MOR of 7800 psi for Douglas-fir arms. MOR values were above this minimum for 49 of the 50 acceptable arms and the value for the one arm below this minimum was nearly 7000 psi. Results indicated 98% of the currently acceptable arms met the minimum value and the majority of arms had MOR values between 10000 and 13000 psi. One positive attribute of wood variability is the fact that we establish minimum values well below those for a majority of a population. This means that systems have a substantial amount of excess capacity that helps them perform well under extreme loading conditions.

MOR values for the 50 acceptable arms averaged 76.07 MPa, well above the 53.78 MPa minimum assumed for arms by ANSI 05.3; however, MOR values for the rejected arms averaged 65.41 MPa, again, well over the minimum ANSI value (Table III-7). It is important to note that average MOR values for the rejected arms were only 86% of those for the acceptable arms, but the standard deviations were somewhat higher. Similar trends were noted for MOE with both populations.

Table III-7. Average MOR and MOE values for rejected and acceptable Douglas-fir crossarms tested to failure in bending.

Arm Category	# of Specimens	Modulus of Rupture in MPa (Std. Dev)	Modulus of Elasticity in MPa (Std. Dev)
Rejected	200	65.41 (16.81)	6715.70 (1344.40)
Accepted	50	76.07 (10.63)	7537.30 (928.00)

While averages and standard deviations are useful for characterizing populations, they are less useful when a structure must perform as a stand-alone unit. In this case, the number of samples above or below a minimum design value becomes more critical. One of the fifty acceptable arms had an MOR value below the minimum ANSI value, while 38 of the 200 arms that were rejected had values below the minimum (Figure III-23). While the number of weak arms in the rejected population was high, it is important to remember that 81% of the rejected arms had MOR values above the minimum and two had the highest MOR values for all arms. It is also important to note that the rejected arms were always tested with the most critical defect in tension while the acceptable arms were tested in the orientation dictated by the grader. The grader intentionally orients the arm to minimize the effects of any defect, thereby minimizing the effects of defects.

Figure III-21. Photos of the test set up used to assess crossarm properties showing: A) an arm bolted to the steel bracket, B) an arm showing deflection under load as it is tested, and C) the hydraulic rod used to pull the arm.

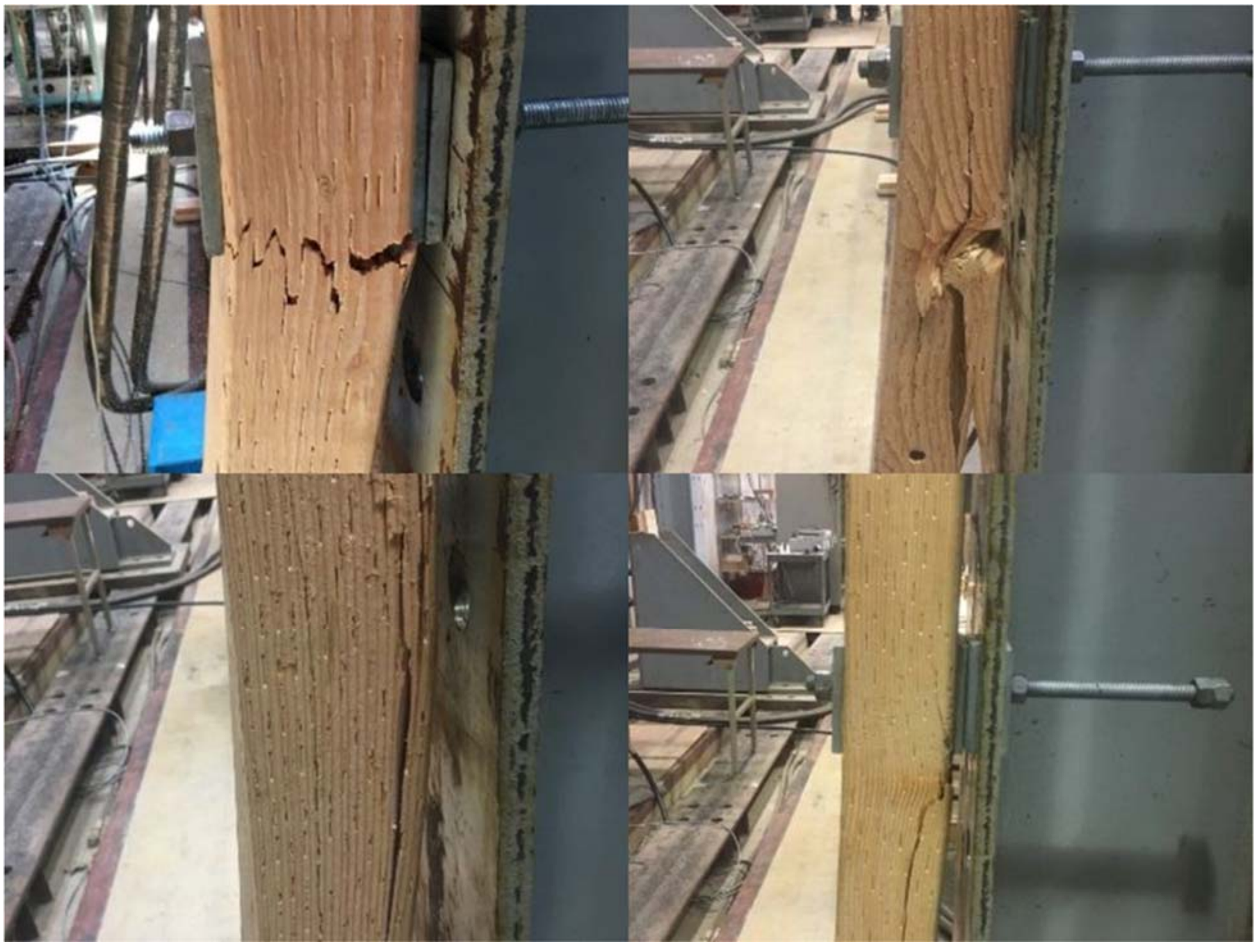


Figure III-22a. Examples of various failures of Douglas-fir crossarms tested to failure in bending.

Failure location can also be useful for assessing the impacts of defects. In general, the highest stresses should occur towards the center of the arm where it attaches to the pole and the grading rules are most restrictive in this zone. Failures occurred most frequently in Zone 4, which represented the center of the arm (Figure III-24). The preponderance of failures in this zone reflects the fact that the loading configuration loaded the arm from the tip with the center pinned to a steel column thereby inducing the highest stresses in this zone. Over 50% of the failures occurred in this zone; however, the frequencies were similar for both acceptable and rejected arms. Almost 20% of the acceptable arms failed in Zone 1, while a little more than 10% of the rejected arms failed in this zone. Rejected arms tended to fail more frequently in Zone 3, which might reflect the presence of defects close to the critical Zone 4. The results suggested that failure locations were somewhat similar for the acceptable and reject arms.

Figure III-22b. Examples of crossarm failures (red arrows) following full-scale flexural testing.

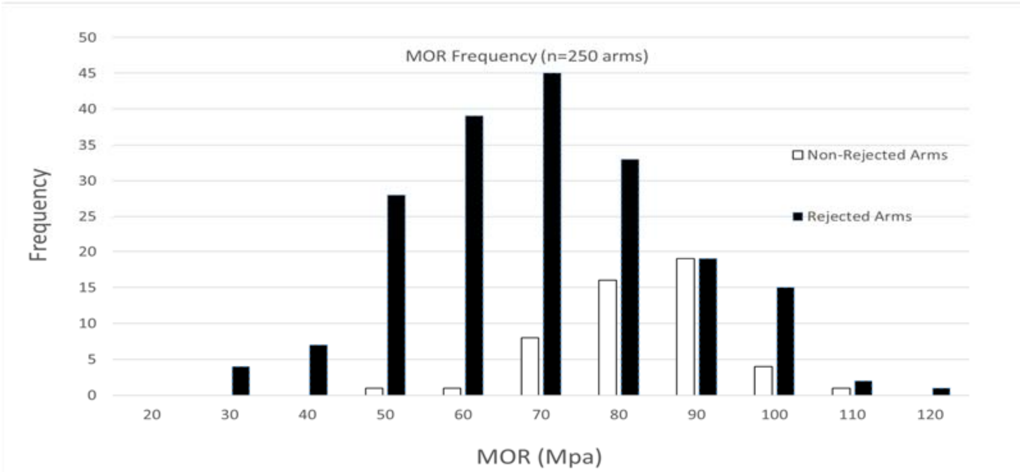


Figure III-23. Distribution of MOR values for acceptable and rejected Douglas-fir crossarms tested to failure where the assumed minimum ANSI value for MOR is 53.78 MPa.

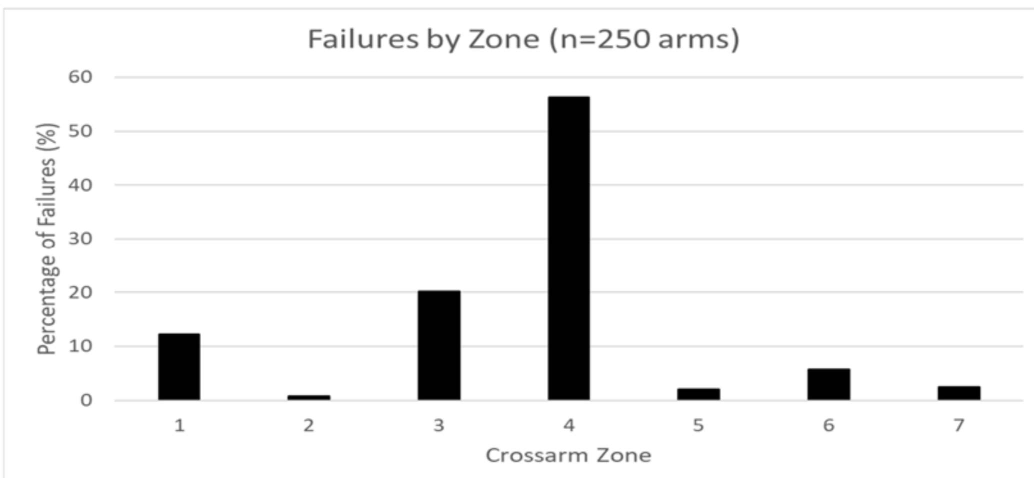


Figure III-24. Frequency of failure in the seven zones of the crossarms as shown in Figure III-20.

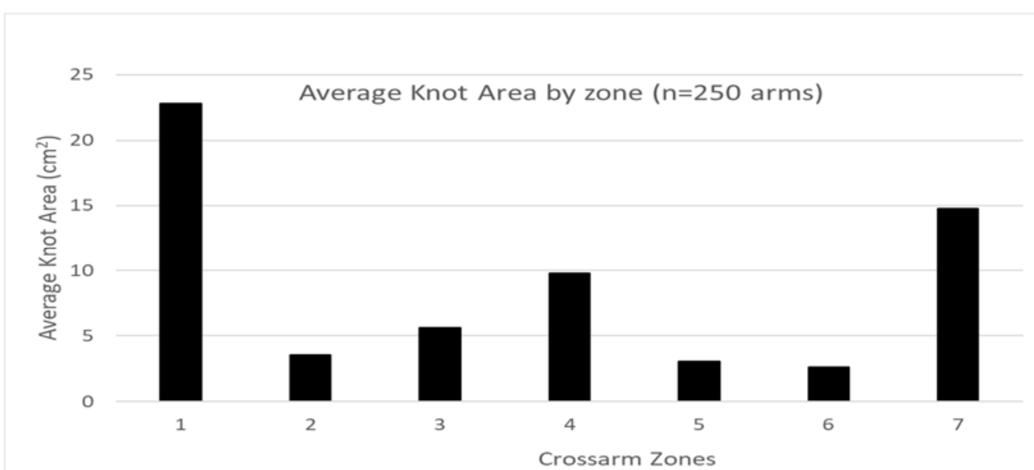


Figure III-25. Average knot area in zones of Douglas-fir cross arms that were accepted or rejected based upon ANSI 05.3 criteria.

The currently grading rules rely heavily on knot sizes and locations, although they do incorporate other defects such as slope of grain. Grain angle can also influence timber properties, but it can be very difficult to measure. Reliance on knots is consistent with the relative ease by which they can be visually assessed. However, knots can have a range of characteristics that could affect how they influence timber properties. For example, knots on the tension face are far more likely to affect properties than those on either the compression face or in the neutral axis. Knot diameter has obvious effects on the amount of clear wood in the cross-section, but can also have more subtle effects on grain orientation as the tree grows around the branch.

Knot maps were used to categorize knot diameters by location on the arm and these values were then compared with MOR or MOE values by simple linear regression. Average knot areas tended to be higher towards the outer edges of the arms where the requirements for knots are less stringent (Zones 1 and 7) (Figure III-25). These zones are also areas where failures were more common, although most failures occurred in Zone 4, where the stresses also tended to be highest during testing. Interestingly, knot area in Zone 1 for rejected arms was considerably higher than area for acceptable arms, but the incidence of failures in this zone was lower for the rejected arms. The variations suggest that other factors influenced failure.

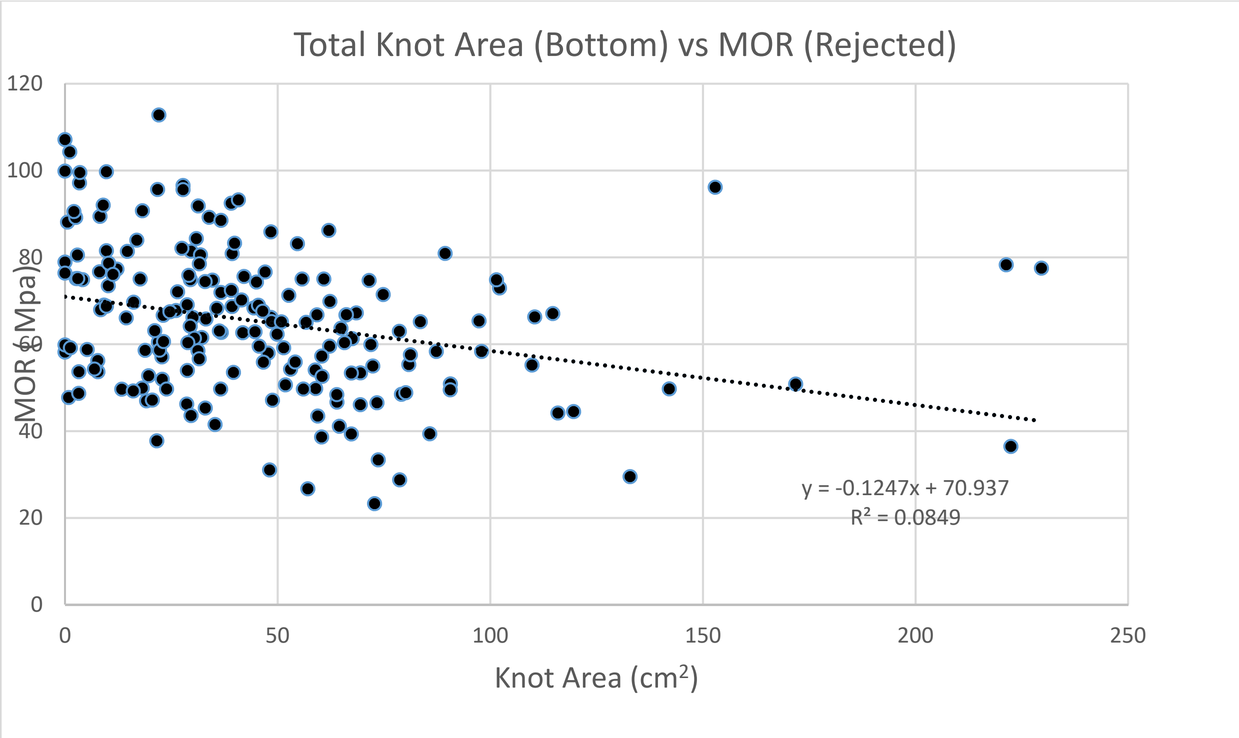
Correlations between knot area or number and MOR or MOE were generally poor (r^2 <0.2), for both acceptable and rejected arms (Figures III-26, III-27). The poor correlations likely reflect the concentration of values near the Y-axis which is a function of the very limited numbers and sizes of knots allowed in the specification. However, a number of arms with larger knot areas or sizes also had values that were similar to those with fewer smaller knots. These results indicate that knot characteristics are a poor predictor of overall timber properties. A series of further analyses where arms with decreasing knot areas or knot numbers were considered also failed to identify a point where knots could serve as a useful predictor or flexural properties. The poor correlations highlight the difficulty in using knots to determine whether a given piece of timber is fit for purpose.

The Analysis of Variance comparing MOR or MOE vs total knot area, total knot area in each zone, % of knots in a given zone, number of knots in a given zone or % of all knots in a given zone suggested that some factors were significant (Tables III-7, III-8). Total knot area, total knots in the failure zone, largest knot area, and knot area in Zone 4 all significantly affected MOR ($p>0.05$). Similarly, total knot area in zones 1, 4, and 5 were also significant, while the relationship between % of knot area and MOR was significant in any zone. Number of knots in Zones 1, 3, 4, and 7 were also significant. Relationships between MOE and these same factors varied considerably from those found with MOR. The relatively weaker relationship between knots and MOE likely reflects the comparative influence of solid wood and knots on flexure. Knots, unless on an extreme edge in tension, are less likely to affect initial deflection and thus the slope of the stress/strain curve used to calculate MOE.

While the ANOVA results indicate that there were significant differences between knot sizes and locations, none of the knot-related factors examined were well correlated with either MOR or MOE. The results suggest that other wood quality related factors may play a stronger role in determining these properties and suggests the need for a re-examination of current grading practices to determine if there are better systems for selecting materials for this application. One more practical approach would be to use a combination of visual and machine stress rating to classify timbers. MSR is already widely used for sorting timbers for production of laminated beams and is routinely used in other countries for lumber grading. This would require considerably more evaluation but might be a more reliable method for selecting materials for critical applications such as crossarms that does not unnecessarily reject large quantities of materials that would perform well.

Conclusions

While over 80% of crossarms that had been rejected for use on the basis of current grading rules had acceptable MOR values, no reliable method could be identified to select arms based upon visual characteristics such as the presence or size of the knots. The results suggest the need for a re-examination of current crossarm grading practices and perhaps consideration of machine stress grading to more accurately categorize timber properties.



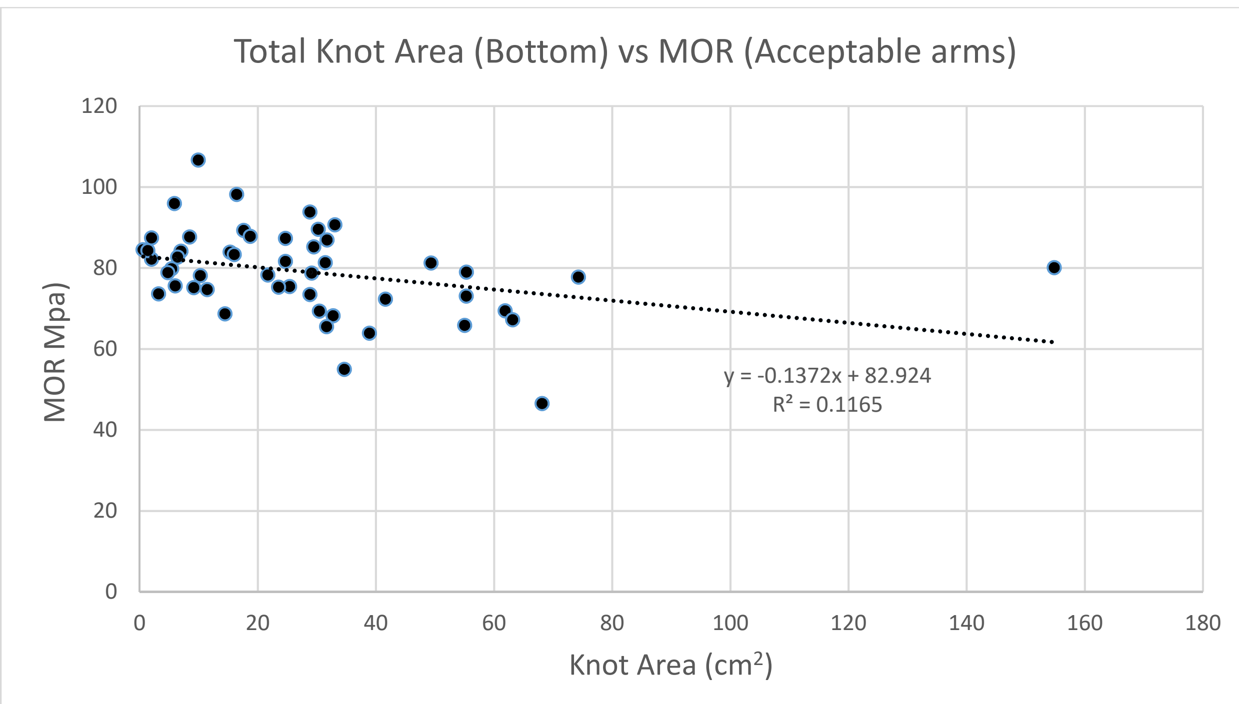
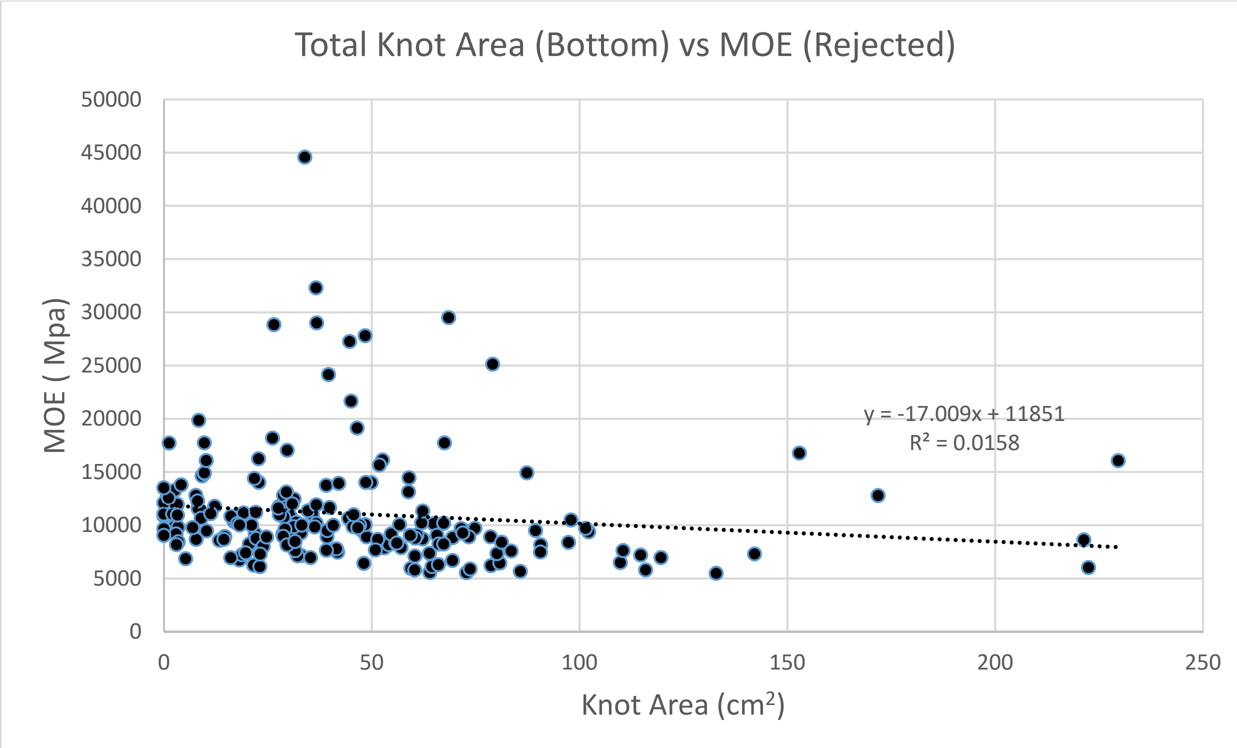


Figure III-26. Relationship between total knot area on the bottom (tension) face and MOR for accepted and rejected Douglas-fir crossarms.



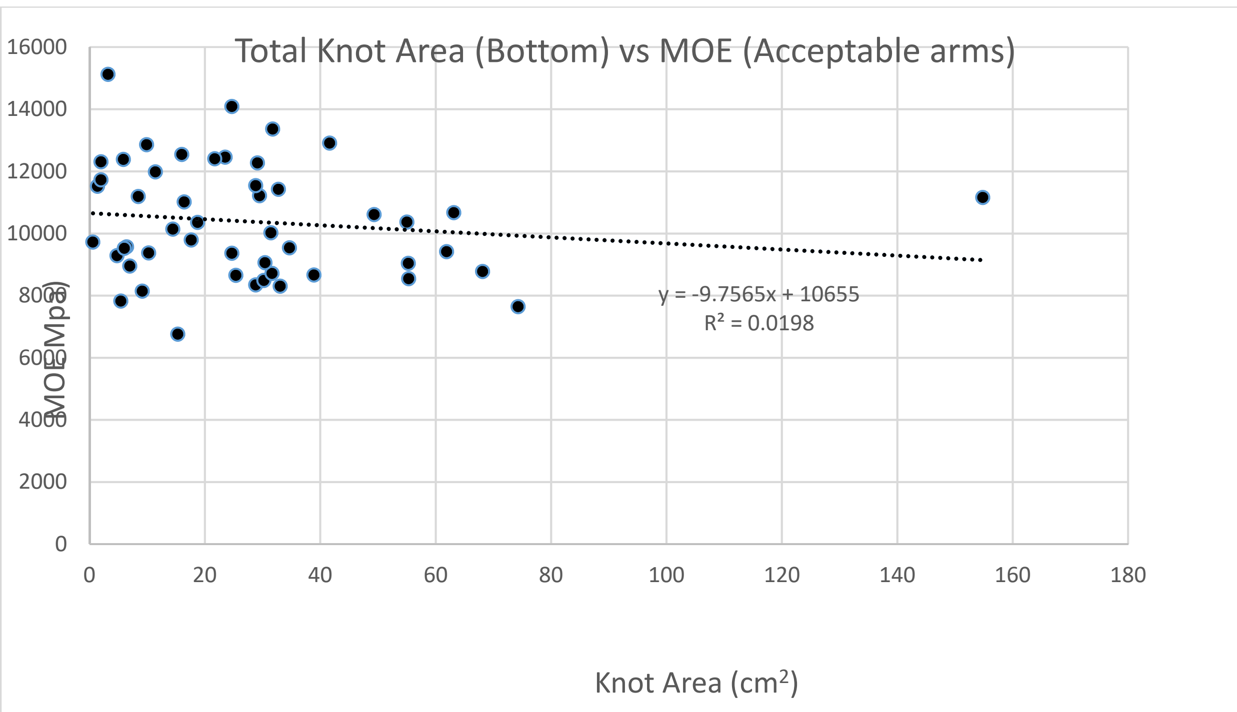


Figure III-27. Relationship between total knot area and MOE for accepted and rejected Douglas-fir crossarms.

Table III-7. ANOVA results for comparisons between various knot parameters and Modulus of Rupture (MOR).

	Df	Sum Sq	Mean Sq	F Value	Pr>(>F)
Total Knot Area	1	180794408	180794408	35.377	0.0000*
Failure Zone	1	1283795	1283795	0.2191	0.6401
Failure Zone Area	1	118272129	118272129	22.099	0.0000*
Total Knot Area Bottom	1	160972804	160972804	30.996	0.0000*
Area in the Critical Zone	1	149023575	149023575	28.421	0.0000*
Largest Knot Area	1	65538789	65538789	11.719	0.0007*
Total Knot Area Zone 1	1	64342388	64342388	11.417	0.0008*
Total Knot Area Zone 2	1	13106512	13106512	2.2408	0.1357
Total Knot Area Zone 3	1	9721672	9721672	1.6581	0.1991
Total Knot Area Zone 4	1	207949081	207949081	41.282	0.0000*
Total Knot Area Zone 5	1	50291021	50291021	8.832	0.0033*
Total Knot Area Zone 6	1	4149174	4149174	0.7049	0.4020
Total Knot Area Zone 7	1	57960585	57960585	10.236	0.0016
Percentage Total Knot Area Zone 1	225	1275069643	5666976	0.6787	0.8942
Percentage Total Knot Area Zone 2	133	814798732	6126306	1.1089	0.2887
Percentage Total Knot Area Zone 3	109	679085255	6230140	1.1229	0.261
Percentage Total Knot Area Zone 4	165	1018819192	6174662	1.194	0.1914
Percentage Total Knot Area Zone 5	105	623576417	5938823	1.0254	0.4424
Percentage Total Knot Area Zone 6	106	591416551	5579401	0.9191	0.674
Percentage Total Knot Area Zone 7	189	1178436434	6235113	1.3852	0.08201
Number of Knots Zone 1	1	121620954	121620954	22.535	0.0000*
Number of Knots Zone 2	1	8000090	8000090	1.3628	0.2442
Number of Knots Zone 3	1	28773960	28773960	4.9749	0.0266*
Number of Knots Zone 4	1	146005141	146005141	27.572	0.0000*
Number of Knots Zone 5	1	15071843	15071843	2.5804	0.1095
Number of Knots Zone 6	1	9838519	9838519	1.6781	0.1964
Number of Knots Zone 7	1	70258649	70258649	12.522	0.0005*
Percentage Number of Knots Zone 1	83	602433802	7258239	1.4168	0.0311*
Percentage Number of Knots Zone 2	44	321886283	7315597	1.3227	0.1024
Percentage Number of Knots Zone 3	45	336910921	7486909	1.3655	0.0775
Percentage Number of Knots Zone 4	58	503822690	8686598	1.7503	0.0027*
Percentage Number of Knots Zone 5	39	334540795	8577969	1.6087	0.0190*
Percentage Number of Knots Zone 6	44	297977061	6772206	1.1983	0.2033
Percentage Number of Knots Zone 7	74	560521867	7574620	1.4858	0.0190*

Table III-8. ANOVA Results for comparisons between various knot parameters and Modulus of Elasticity (MOE).

	Df	Sum Sq	Mean Sq	F Value	Pr>(>F)
Total Knot Area	1	1.7539e+12	1.7539e+12	3.6507	0.0572
Failure Zone	1	7.8207e+11	7.8207e+11	1.6280	0.2032
Failure Zone Area	1	2.2405e+12	2.2405e+12	4.6847	0.0314*
Total Knot Area Bottom	1	1.4407e+12	1.4407e+12	2.9908	0.0850*
Area in the Critical Zone	1	3.8550e+12	3.8550e+12	8.1738	0.0046*
Largest Knot Area	1	2.1664e+11	2.1664e+11	0.4450	0.5054
Total Knot Area Zone 1	1	2.0709e+11	2.0709e+11	0.4271	0.5140
Total Knot Area Zone 2	1	5.8659e+10	5.8659e+10	0.1208	0.7284
Total Knot Area Zone 3	1	7.5890e+09	7.5890e+09	0.0156	0.9006
Total Knot Area Zone 4	1	6.1599e+12	6.1599e+12	13.389	0.0003*
Total Knot Area Zone 5	1	5.7803e+09	5.7803e+09	0.0119	0.9132
Total Knot Area Zone 6	1	6.0312e+11	6.0312e+11	1.2482	0.2650
Total Knot Area Zone 7	1	9.2413e+11	9.2413e+11	1.9178	0.1674
Percentage Total Knot Area Zone 1	225	4.8290e+11	4.8290e+11	1.0356	0.5019
Percentage Total Knot Area Zone 2	133	3.4847e+13	2.6201e+11	0.3494	1
Percentage Total Knot Area Zone 3	109	4.4054e+11	4.4054e+11	0.8546	0.8021
Percentage Total Knot Area Zone 4	165	9.4772e+13	5.7438e+11	2.0282	0.0003*
Percentage Total Knot Area Zone 5	105	4.7497e+13	4.5235e+11	0.8971	0.7194
Percentage Total Knot Area Zone 6	106	6.3211e+13	5.9633e+11	1.5197	0.0108*
Percentage Total Knot Area Zone 7	189	1.0346e+14	5.4741e+11	2.2115	0.0005*
Number of Knots Zone 1	1	7.7787e+11	7.7787e+11	1.6122	0.2054
Number of Knots Zone 2	1	4.6017e+07	4.6017e+07	1e-04	0.9922
Number of Knots Zone 3	1	1.4569e+08	1.4569e+08	3e-04	0.9862
Number of Knots Zone 4	1	2.8556e+12	2.8556e+12	6.0266	0.0148*
Number of Knots Zone 5	1	1.4859e+11	1.4859e+11	0.3063	0.5805
Number of Knots Zone 6	1	4.4529e+10	4.4529e+10	0.0917	0.7623
Number of Knots Zone 7	1	5.9131e+11	5.9131e+11	1.2236	0.2698
Percentage Number of Knots Zone 1	83	4.2045e+13	5.0657e+11	1.0806	0.3351
Percentage Number of Knots Zone 2	44	2.1744e+13	4.9419e+11	1.0318	0.4274
Percentage Number of Knots Zone 3	45	2.5054e+13	5.5676e+11	1.1984	0.2016
Percentage Number of Knots Zone 4	58	3.1809e+13	5.4844e+11	1.1904	0.1933
Percentage Number of Knots Zone 5	39	1.7020e+13	4.3640e+11	0.8898	0.6586
Percentage Number of Knots Zone 6	44	2.4218e+13	5.5041e+11	1.1799	0.2229
Percentage Number of Knots Zone 7	74	3.7218e+13	5.0295e+11	1.0647	0.3655

OBJECTIVE IV:
PERFORMANCE OF EXTERNAL GROUNDLINE PRESERVATIVE SYSTEMS

While preservative treatments provide excellent long-term protection against fungal attack, they lose efficacy over time and become susceptible to soft rot attack on wood surfaces. This can lead to considerable losses in pole circumference over time which reduces strength and decreases time before replacement is needed. In cases where surface soft rot is a risk, pole service life can be extended by belowground application of external preservative pastes that eliminate fungi near the wood surface and provide a protective barrier against fungal re-invasion from surrounding soil.

Pastes incorporate diverse chemical mixture including pentachlorophenol, potassium dichromate, creosote, fluoride, and an array of insecticides. In the 1980s, the U.S. Environmental Protection Agency re-examined pesticide registrations and designated many compounds as restricted use, leading utilities and their chemical suppliers to develop alternative formulations. These newer formulations contained proven wood preservatives, but were not yet widely tested as pastes for external application, which led us to establish this objective aimed at studying the performance of groundline preservative applications.

A. Previous External Groundline Treatment Tests

Over the past 20 years, we established a number of field trials for external groundline preservative pastes on pole stubs at our Peavy Arboretum field site or poles in active utility lines. Most of these trials have been completed. A trial summary can be found in Table IV-1 along with references to the Annual Report in which results are presented.

B. Effect of External Barriers on Pole Performance

Preservative treatment is a remarkably effective barrier against biological attack, but these chemicals can migrate into surrounding soil. A number of studies documenting chemical migration have shown movement occurring for short distances around treated structures, although not at levels high enough to cause environmental degradation. Some utilities have explored external barriers for the purpose of containing migrating preservative within wood to extend their effective lifespan and limiting moisture ingress.

In 2018 we sampled the soil around pentachlorophenol poles with and without barriers to examine chemical migration into surrounding soil. These data are summarized in the 2018 Annual Report (Objective IV; Section B; page 126; Table IV-2).

Table IV-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.	

Additionally, in 2019, a small number of poles were included in the new boron pretreatment study in the SnoPUD system. Please refer to (Objective II; Section B; page 70; Table II-10, Figure II-12) in this report to see how barrier wraps affected boron retention/loss.

The potential for barriers to limit moisture uptake in poles was assessed in a trial where pole sections with two different barriers were installed in either soil or water. The poles were maintained indoors and were not subjected to overhead watering. The results showed that considerable moisture wicked up poles in this exposure and moisture contents at groundline were suitable for decay development, even with the barriers. As might be expected, poles immersed in water wetted more quickly than those in wet soil; however, all poles were generally wet enough for decay to occur within 2 years of installation. These poles have subsequently been moved to our field test site and set such that the tops of the barriers extend 150 mm above the soil level. These pole sections were then sampled for wood moisture content (MC) at groundline, 150 mm above the groundline and 300 mm above groundline immediately after installation and 2 years after installation.

In 2007, an additional 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 IV-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 poles were sampled 6, 12, 18, 42, 45, 77, 95, and 116 months after installation by removing three increment cores from a single location 150 mm below groundline. The cores were cut into zones corresponding to 0-13, 13-25, 25-50, and 50-75 mm from the wood surface. Each segment was placed into an individual tared vial, capped tightly and returned to the lab. The cores were weighed, oven-dried, and then weighed again. The difference between initial and oven-dry weight was used to determine MC. The sampling holes were plugged and any damage to the external coating was repaired to limit the potential for moisture to move into the wood through the sample holes.

Initial MC of the poles was approximately 30%, which is near the fiber saturation point for Douglas-fir (Table IV-2). These conditions are barely suitable for fungal attack. Moisture contents 6 months after installation had increased for all three treatments especially in the outer 25 mm of the pole. These samples were removed at the end of our wet season. The test site receives approximately 1.1 m of rainfall per year, but most of this rain falls between November and May. The soil at the field site becomes extremely wet and the water table approaches the surface in some areas. This should create conditions for extreme wetting of non-protected poles whereas Biotrans liners should limit wetting at groundline. The results suggest that water running down the poles was entering the wood to increase the wood MC.

Moisture contents in samples taken from non-wrapped poles at the end of the dry season were less than 30% and levels were lowest near the surface. Average moisture levels in poles with the liners approached 45% near the wood surface at this time-point.

Figure IV-1. Example of a Biotrans liner at the OSU Peavy Arboretum test site.

Moisture contents 18 months after installation followed patterns similar to those found at 6 months. Poles without barriers had moisture contents over 45% at the surface, while poles with liners had even higher moisture contents (60% for the liner that extended 300 mm above groundline), suggesting that the liners tended to retain moisture.

Moisture patterns at 42 and 45 months followed similar trends with higher moisture levels at the end of the rainy season in poles with no barriers. Relatively little difference was seen in MC in poles with barriers 300 mm above groundline between the wet and dry seasons. Moisture levels in poles with barriers extending 150 mm above groundline tended to have a greater difference in moisture levels between the wet and dry seasons, similar to the unwrapped poles.

Moisture contents at 77 months followed trends similar to previous assessments, although moisture contents in poles with no barrier tended to be lower at groundline than poles with barriers (Figure IV-2). Moisture contents in pole centers tended to be more stable for the first 42 months of the test; interior moisture contents were higher at 45 months and slightly lower at 77 months.

Moisture contents after 95 month dry season sampling point showed similar trends with unwrapped poles showing lower moisture contents at groundline than those with barriers. At this time-point, there were +10% differences in moisture content between wrapped and unwrapped poles at multiple sampling depths. At the 116-month sampling the difference in moisture content was much less between wrapped and unwrapped poles and was not statistically significant in the outermost pole section. Lower moisture in unwrapped poles at these sampling points held throughout all sampling depths except for 25-50 mm to the pole interior at 116 months.

While there was an initial tendency for the barrier to hold moisture within the pole, there was also evidence that moisture contents cycled with season in poles with barriers and were not building up to extremely high levels. The moisture levels present in poles with barriers have tended to be slightly higher than those without, but the differences have been small in all sampling times outside of the 95-month sampling point (dry season).

The relatively lower moisture contents in poles with barriers set 150 mm above groundline at most sampling points versus those set 300 mm above that zone were also surprising. Both barriers should restrict the potential for moisture to move into the zone below the groundline, thereby limiting moisture ingress to water running down the poles and entering the below ground area through checks. It is unclear why placing the barrier slightly higher up the pole would reduce that potential. But it does suggest that there is some advantage to placing the barriers above the groundline.

Table IV-2. Moisture contents at groundline at selected depths from the surface of poles with and without a barrier wrap [a].

Treatment	Months After Installation	Distance From Pole Surface (mm)			
		0-13	13-25	25-50	50-75
Biotrans 150 mm	0 (installation)	39.5 (10)	35.1 (7)	34.0 (12)	33.5 (11)
	6 (wet season)	57.8 (19)	48.1 (11)	37.6 (3)	37.7 (6)
	12 (dry season)	48.7 (14)	35.6 (10)	35.7 (15)	34.6 (16)
	18 (wet season)	48.8 (12)	40.6 (11)	34.7 (5)	31.6 (5)
	42 (wet season)	53.1 (31)	42.7 (16)	47.6 (26)	46.2 (27)
	45 (dry season)	32.2 (11)	28.7 (4)	32.3 (10)	34.4 (7)
	77 (wet season)	45.6 (25)	41.3 (29)	66.3 (66)	53.4 (33)
	95 (dry season)	31.6 (15)	43.8 (27)	45.2 (32)	51.8 (42)
	116 (dry season)	45.4 (17)	43.4 (15)	47.6 (18)	46.4 (13)
Biotrans 300 mm	0 (installation)	38.5 (8)	32.2 (4)	32.2 (8)	40.3 (24)
	6 (wet season)	67.1 (18)	49.5 (6)	38.8 (3)	35.5 (3)
	12 (dry season)	45.1 (21)	34.6 (10)	33.3 (7)	33.1 (7)
	18 (wet season)	60.0 (15)	40.1 (6)	37.4 (5)	36.5 (6)
	42 (wet season)	63.3 (23)	47.4 (31)	45.8 (26)	53.5 (35)
	45 (dry season)	55.4 (19)	36.7 (9)	37.0 (6)	37.2 (6)
	77 (wet season)	49.2 (20)	36.8 (10)	35.9 (19)	41.1 (18)
	95 (dry season)	29.8 (16)	36.8 (13)	42.5 (20)	74.4 (90)
	116 (dry season)	43.8 (15)	49.1 (12)	39.7 (18)	49.1 (14)
Unlined Control	0 (installation)	34.4 (3)	28.9 (3)	27.2 (3)	29.1 (3)
	6 (wet season)	54.3 (15)	47.1 (7)	42.1 (8)	43.7 (11)
	12 (dry season)	20.2 (5)	28.7 (16)	28.8 (8)	29.5 (4)
	18 (wet season)	47.3 (15)	34.7 (6)	31.5 (4)	31.7 (5)
	42 (wet season)	49.7 (23)	45.4 (26)	62.6 (56)	61.1 (59)
	45 (dry season)	17.9 (9)	24.7 (9)	39.9 (20)	63.5 (19)
	77 (wet season)	33.1 (12)	29.3 (17)	38.0 (20)	32.6 (20)
	95 (dry season)	18.1 (4)	25.6 (4)	30.2 (9)	40.3 (24)
	116 (dry season)	41.3 (13)	40.9 (10)	41.8 (14)	42.0 (15)

[a] *Values represent means of 6 measurements per location. Figures in bold are above 30% moisture content (approximate fiber saturation point for wood).*

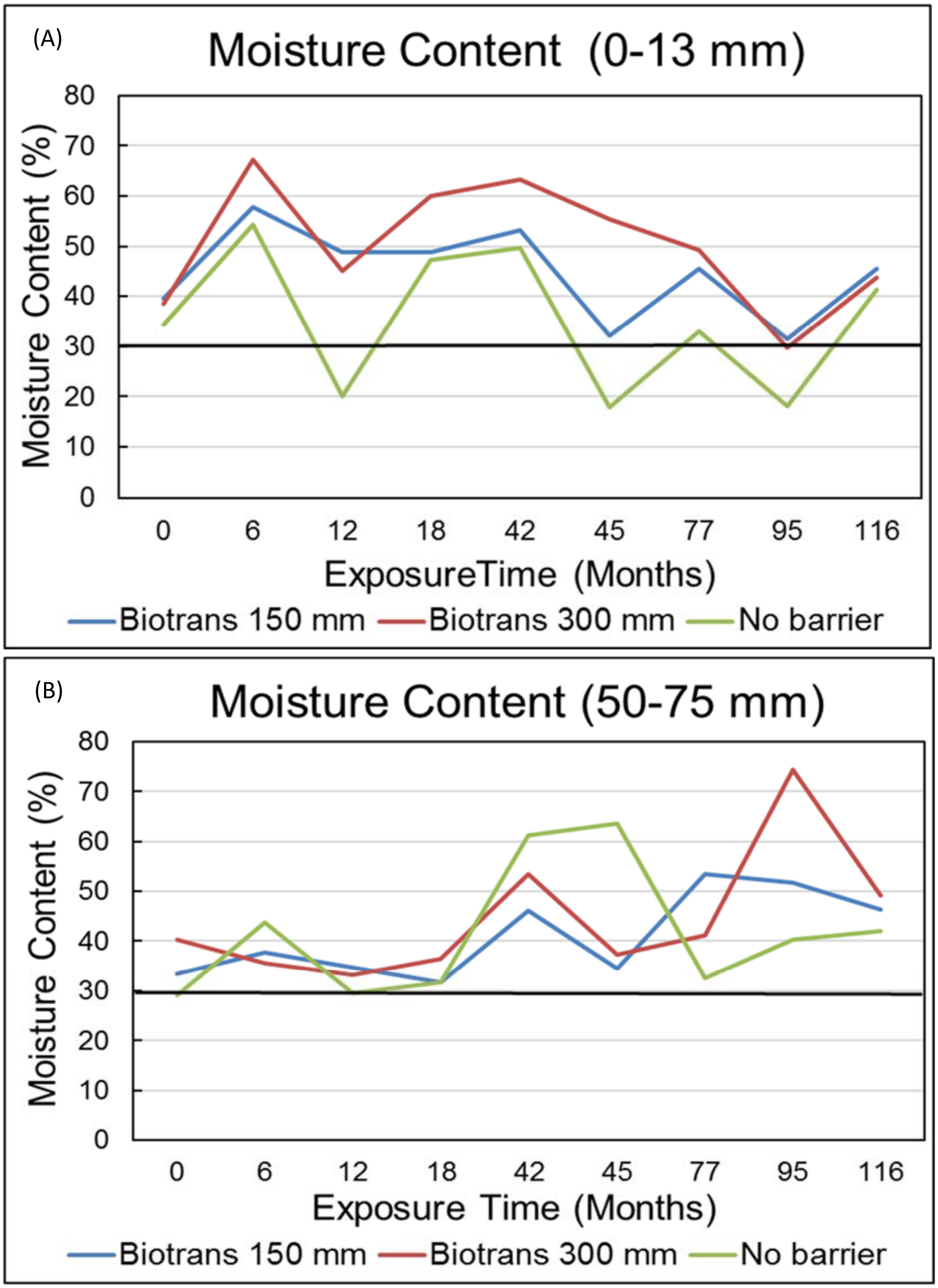


Figure IV-2. Moisture contents in the outer 0-13 mm (A) *and inner 50-75 mm* (B) *zones of pentachlorophenol treated Douglas-fir poles with or without a Biotrans liner set so the liner top was 150 or 300 mm above groundline. The line at 30% represents the approximate fiber saturation point of wood.*

OBJECTIVE V: PERFORMANCE OF COPPER NAPHTHENATE TREATED WESTERN WOOD 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 that is now used as a stand-alone treatment. Copper naphthenate is currently listed as a non-restricted use pesticide, meaning applicators do not require special licensing to apply this chemical. Some users have sought to replace more heavily-restricted chemicals with CuNap in an effort to cultivate a more environmentally-friendly image. CuNap is included as an alternative treatment by many utilities.

We performed a number of tests to ensure the suitability of this system for use on western wood species. Initial tests examined copper naphthenate performance on western redcedar, but concerns about the effects of solvent substitutions on biocide performance encouraged us to set up field evaluations of copper naphthenate poles in service. Our first work examined the condition of Douglas-fir poles treated with copper naphthenate using diesel as the primary solvent and we found no evidence of early decay in poles exposed in Oregon or California. More recently, data suggesting the addition of biodiesel as a co-solvent to reduce diesel odors had a negative effect on performance led us to evaluate poles in the Puget Sound area. We will continue to evaluate copper naphthenate performance to ensure that utilities are aware of the effects of process changes on performance.

A. Performance of Copper Naphthenate Treated Western Redcedar Stakes in Soil Contact

Copper naphthenate provides effective protection in a variety of field stake tests and is incorporated in a variety of American Wood Protection Association Standards for use in ground contact (Use Category, UC 4). However, few long-term studies have been done to assess the efficacy of copper naphthenate when used to treat western wood species. The test described below was initiated nearly 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 and 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 V-1, V-2). Non-treated stakes failed within 180 months while stakes treated with diesel have average ratings of approximately 0.9 after 348 months of exposure. This was expected as diesel is known to provide no protection against fungal decay. At 348 months, all freshly sawn stakes treated with copper naphthenate to retentions of 4.0 kg/m^3 continue to provide excellent protection after 348 months with average ratings of 7.1. 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 ratings near 4, indicating the presence of substantial decay. The average decay rating for the intermediate retention (2.4 kg/m^3) was just 5.5, while the second highest retention (3.2 kg/m^3) averaged about 6.3. 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 V-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 348 months, the three lowest retentions (0.8, 1.6, and 2.4 kg/m^3) had average ratings below 2.0, indicating the presence of substantial external decay (Figure V-3). Stakes treated to 3.2 or 4.0 kg/m^3 had average ratings of 3 and 4, respectively. 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. The effects of these differences on overall performance may be minimal. 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.

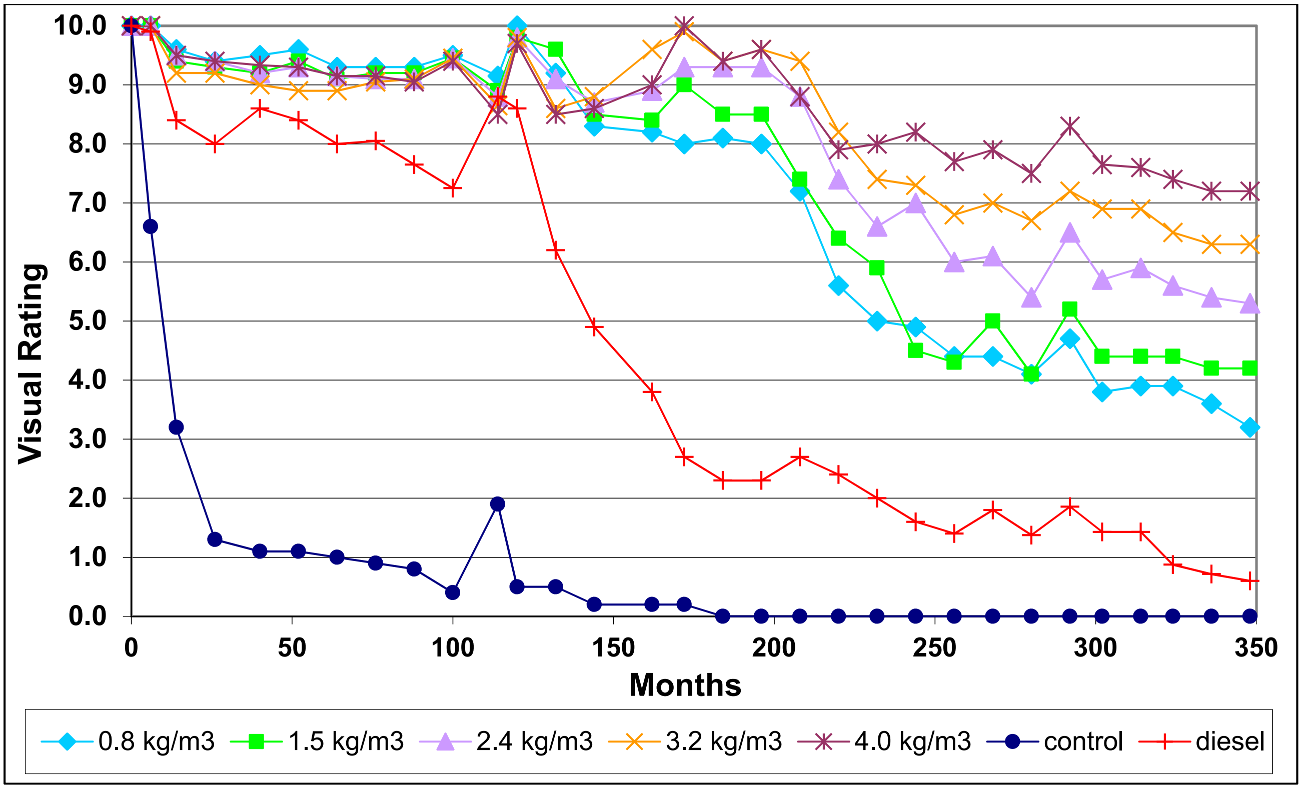


Figure V-1. Condition of freshly sawn western redcedar sapwood stakes treated with selected retentions of copper naphthenate in diesel oil and exposed in a soil bed for 348 months.

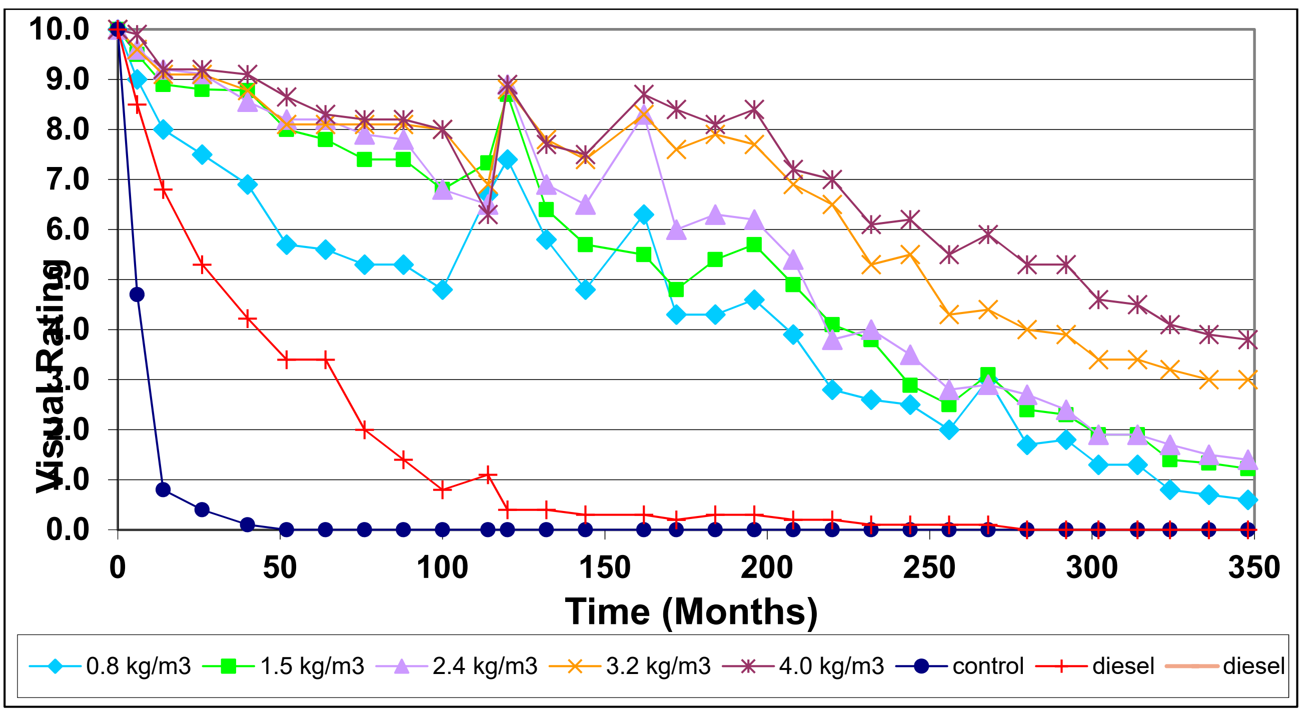


Figure V-2. Condition of weathered western redcedar sapwood stakes treated with selected retentions of copper naphthenate in diesel oil and exposed in a soil bed for 348 months.

Figure V-3. Examples of western redcedar stakes cut from weathered poles and freshly sawn lumber that have failed in test showing a tendency for wood to decay towards the lower end of the samples.

B. 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 using petroleum diesel or biodiesel as a carrier solvent. These poles were last sampled in 2015 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. In 2019 these poles were sampled again and the same analyses were done that were described in the 2016 and 2017 Annual Reports (Section V-B). Here we describe new findings from the 2019 sampling which are then compared to previous data from 2015.

Copper naphthenate has for many years provided excellent performance when dissolved in diesel as a solvent. More recently, biodiesel has been substituted for petroleum diesel in varying proportions to reduce odor and there have been concerns about the performance of this system. 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). 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). The poles were inspected just below groundline by probing the wood surface for the presence of softened wood, then removing increment cores from 3 locations around each pole 150 mm below and 100 mm above groundline. The outer 6 mm of each core was removed for assessing the presence of soft rot, then the zone from 6 to 25 mm from the surface was removed and core zones from a given location on each pole were combined before being ground to pass a 20 mesh screen. The resulting sawdust was analyzed for copper retention by x-ray fluorescence spectroscopy. The remainder of each core was plated on malt extract agar and observed for the growth of soft rot and basidiomycete decay fungi as previously described. The outer segments were digested into individual wood fibers and these fibers were examined for evidence of soft rot fungal attack as either cell wall thinning or diamond shaped cavities. The results of these analyses on the 65 poles are described in the 2016 and 2017 annual reports.

In 2019, the previously sampled poles were sampled again according to the above described procedure. This set of poles consisted of 37 poles treated with a biodiesel carrier and 21 poles treated with a petrodiesel carrier. The same analyses that were competed in 2016/2017 were done again on the new samples. Results were then compared to the earlier sampling point to monitor the retention of preservative, the progression of decay, and any increases in the presence of decay fungi in the poles. To recap, the poles sampled were a mixture of ages and poles treated with biodiesel as a carrier were on average installed more recently than those with petroleum diesel as a carrier (Table V-1). Interestingly, copper naphthenate retentions increased in the 2019 sampling from where they were in 2015 in both petroleum and biodiesel-based treatments (Figure V-4)(Table V-2). This may be attributed to cores being taken in areas where retention was higher. As was seen in the 2015 sampling, poles treated with a petrodiesel carrier showed slightly higher copper retentions (average 2.29 kg/m^3) than biodiesel (average 1.83 kg/m^3). There were also more poles treated with a biodiesel carrier that were below the threshold level of 1.5 kg/m^3 than there were poles treated with a petrodiesel carrier below this level. Copper penetration was similar for both petroleum diesel and biodiesel treatments, whereas at the 2015 sampling point petrodiesel penetration was slightly higher.

Tracheid macerations made from the outer 2 mm of cores taken from below ground were examined microscopically for evidence of soft rot decay. These included diamond-shaped cavities and cell wall thinning typical of soft rot decay. In 2012, the majority of all poles surveyed did not show evidence of soft rot decay in the examined tracheids, including 37 poles treated with a biodiesel carrier and 27 poles treated with a petrodiesel carrier (Table V-2). Low levels of soft rot were observed in 8 biodiesel and 6 petrodiesel poles. Three poles of each type contained medium levels of soft rot decay while 2 biodiesel poles and 1 petrodiesel pole contained high levels of soft rot in the outer 2 mm.

Cores from copper naphthenate-treated poles were cultured for the presence of soft rot and other decay fungi as a proxy for level of decay hazard. Soft rot fungal isolations were generally low across all poles and wood-degrading basidiomycetes were only found in below ground samples from four poles, all of which were treated with a biodiesel carrier (Table V-2). Poles treated with a biodiesel carrier had lower rates of soft rot fungal isolation than poles treated with a petrodiesel carrier. However, the species makeup coming out of these isolations differed among treatments and fungal identity may end up having a greater impact on pole longevity than just the overall rate of soft rot isolation.

Table V-1. Initial frequency of soft rot damage in wood tracheids in the outer 1-2 mm of the pole surface at groundline in Douglas-fir poles treated with copper naphthenate in petroleum or bio-based diesel. These data are from 2012, when the initial pole population was identified.

Solvent	Year Installed	Number Sampled	Poles with Differing Levels of Soft Rot[a]			
			None Observed	Low	Medium	High
Biodiesel	2008	25	17	6	1	1
	2009	12	7	2	2	1
Petroleum diesel	2003	6	4	1	1	0
	2005	9	5	2	1	1
	2009	12	8	3	1	0

[a]Where soft rot ratings of low, medium, and high signify finding 1, 1-5, and >5 tracheids with soft rot cavities per ~100 tracheids examined, respectively.

The 2019 sampling showed increases in the degree of soft rot that was present in treatments with both biodiesel and petrodiesel carriers (Figure V-5; Table V-2). In poles treated with a biodiesel carrier, form 2015 to 2019 soft rot intensity increased in both above ground and below ground sampling locations. In poles treated with a petrodiesel carrier, from 2015 to 2019 soft rot intensity increased only in the below ground location, and slightly decreased in the aboveground cores. Belowground soft rot was more advanced in poles with a petrodiesel carrier as was the case in the 2015 sampling, but in 2019 the aboveground samples for these poles showed less soft rot decay than their biodiesel-treated equivalents. An example of healthy Douglas-fir cells and those with significant soft-rot damage can be found in Figure V-6.

We plan to delve deeper into soft-rot capabilities of the isolated fungi using laboratory tests in the coming years. Some are of interest concerning their abilities to degrade wood in the literature. A summary of those species of interest is provided in Table V-3. The isolated basidiomycetes from both 2015 and 2019 are provided in Table V-4.

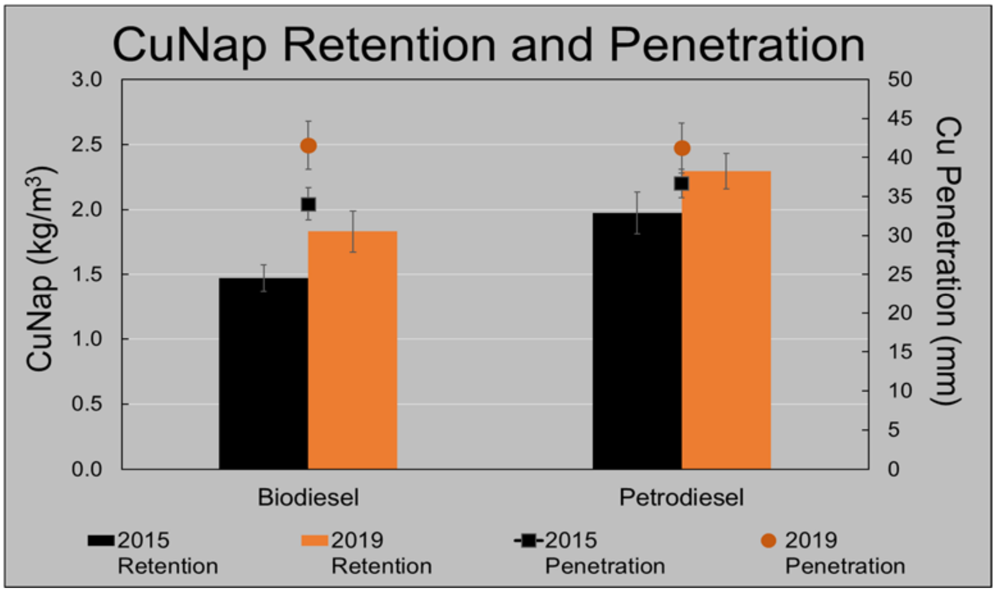


Figure V-4: Copper retention levels and copper penetration levels measured in cores from 65 copper naphthenate-treated utility poles using biodiesel or petrodiesel as a carrier. Data presented are from the 2015 and 2019 sampling. Error bars represent standard error.

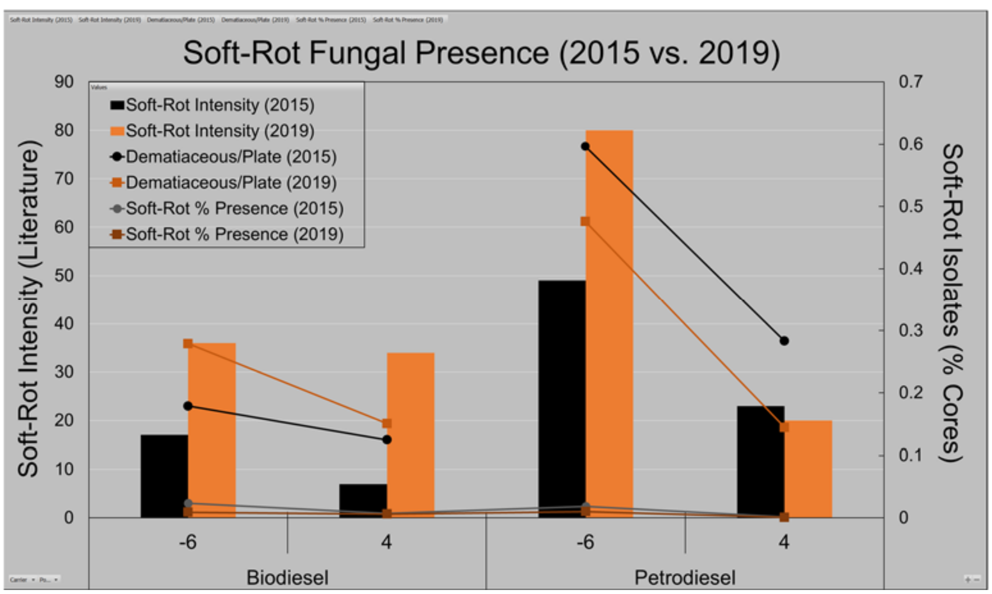


Figure V-5: Soft rot intensity and frequency of soft rot fungal isolations coming from the outer 2 mm of core taken from above and below ground areas of copper naphthenate treated utility poles using either a biodiesel of petrodiesel carrier. Data from the 2015 and 2019 samplings are presented.

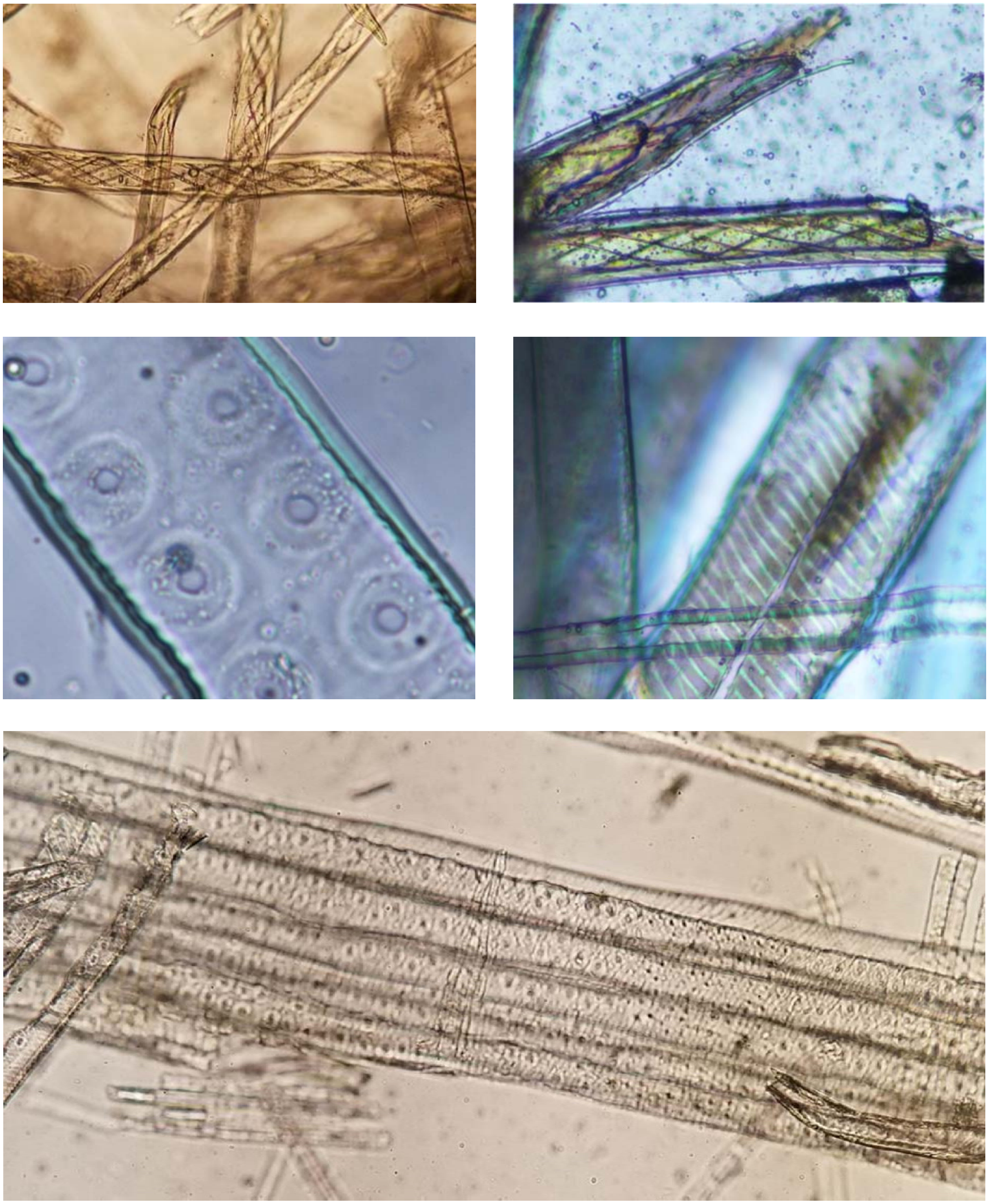


Figure V-6. Examples of Douglas-fir tracheids removed from the outer surfaces of poles showing bordered pits and the spiral thickenings typical of this species (bottom) and diamond-shaped soft-rot cavities (top row).

Table V-2. Averages of all data collected in 2015 and 2019, separated by height, year, and carrier.

Carrier	Year In-Service	Pole Height (mm)	Preservative Penetration 2015 (mm)	Additive Soft Rot 2015	Dem Fungi/ Plate 2015	Soft-rot % 2015	CuNap Retention 2015 (kg/m^3)	Total Fungal Isolations 2015	Average Fungal Isolations/ Plate 2015	Preservative Penetration 2019 (mm)	Additive Soft Rot 2019	Dem Fungi/ Plate 2019	Soft-rot % 2019	CuNap Retention 2019 (kg/m^3)	Total Fungal Isolations 2019	Average Fungal Isolations/ Plate 2019
Biodiesel	2008	-150	39.04	6	0.08	1.77%	1.60	14	0.19	54.48	24	0.28	0.17%	2.01	43	0.57
		100	28.61	0	0.03	0.25%		6	0.08	32.85	21	0.11	0.15%		20	0.27
	2009	-150	38.50	11	0.28	2.97%	1.21	19	0.53	41.69	12	0.28	1.64%	1.45	21	0.58
		100	30.56	7	0.22	1.17%		21	0.58	32.89	13	0.19	1.08%		16	0.44
Petrodiesel	2003	-150	38.11	18	0.89	1.39%	2.24	19	1.06	37.89	22	0.44	1.94%	2.17	19	1.06
		100	29.22	18	0.67	0.00%		15	0.83	29.33	3	0.11	0.00%		14	0.78
	2005	-150	40.47	12	0.40	2.77%	1.84	16	0.53	60.53	39	0.57	0.10%	2.67	25	0.83
		100	38.40	3	0.10	0.17%		9	0.30	40.40	13	0.27	0.07%		22	0.73
	2009	-150	39.61	19	0.50	1.44%	1.95	38	1.06	42.33	19	0.42	0.97%	2.04	41	1.14
		100	32.08	2	0.08	0.33%		20	0.56	32.39	4	0.06	0.14%		24	0.67

*Additive Soft Rot = The cumulative potential for the isolated soft-rot fungal species to cause wood deterioration based on a literature review of species ecologies (higher = worse).
*Dem Fungi/Plate = Dematiaceous fungi are darkly pigmented and based on growth form, are more likely to be ecologically capable of soft rot (higher = worse).
*Soft rot % = The percent of random fields of view on a compound microscope that had wood cells showing evidence of soft-rot decay.

Table V-3. Isolated soft-rot fungi of interest for future laboratory experiments. Once decay capabilities are known, poles with the most aggressive fungi will be more closely monitored in an attempt to link fungal species presence with decay progression.

Soft Rot Fungi	Impact (From Literature)	Soft-Rot Type
Cadophora melinii	Aggressive Soft Rotter	Type I, Type II
Aureobasidium melanogenum	Aggressive Soft Rotter	Type II
Phialophora fastigiata	Strong Soft Rotter	Type I, Type II
Amorphotheca resinae	Soft Rotter	Type II
Epicoccum nigrum	Soft Rotter	Type II
Pseudeurotium sp.	Soft Rotter	Type II

Table V-4. Basidiomycete (decay) fungi isolated in 2015 and 2019. The only decay fungi isolated came from biodiesel poles. These poles will be closely monitored in the future as these two species are capable of significant brown-rot decay in utility poles.

OSU Pole ID	Carrier	Year	Zone	Species ID
PSE 1	Biodiesel	2015	Belowground	Postia placenta
SnoPud 1	Biodiesel	2019	Belowground	Amyloporia carbonica
PSE 19	Biodiesel	2019	Belowground	Amyloporia carbonica
PSE 25	Biodiesel	2019	Belowground	Postia placenta

C. Condition of Doug-fir Poles Treated with CuNap in Biodiesel or Petrodiesel (ClarkPUD System)

We are continuing efforts to compare the performance of poles treated with copper naphthenate using either biodiesel or petrodiesel as a carrier in in-service utility poles. This work was initiated in 2012 when we began sampling poles treated with a biodiesel and petrodiesel carrier with two utilities in the Puget Sound area. Initially 65 poles were sampled in the PSE/SnoPUD systems. The number of poles sampled so far has given us a large dataset to examine the difference in performance of copper naphthenate in a biodiesel versus a petrodiesel carrier. However, these poles are located generally in the same region and the comparison would benefit from including poles from other utility networks located in different geographical regions.

To address this we have identified an additional 72 copper naphthenate-treated poles within the ClarkPUD system located in Clark County, WA (Figure V-7). Half of the poles (36) were treated using biodiesel as a carrier and the other half were treated with petrodiesel as a carrier. Twelve biodiesel poles were installed in each of three years 2010, 2011, and 2012 while 12 petrodiesel poles were installed in each of three years 2013, 2014, and 2015. These poles will be monitored over the next decade to observe the progression of decay in poles of each treatment type and determine whether use of biodiesel as a carrier for copper naphthenate has any effect on pole performance.

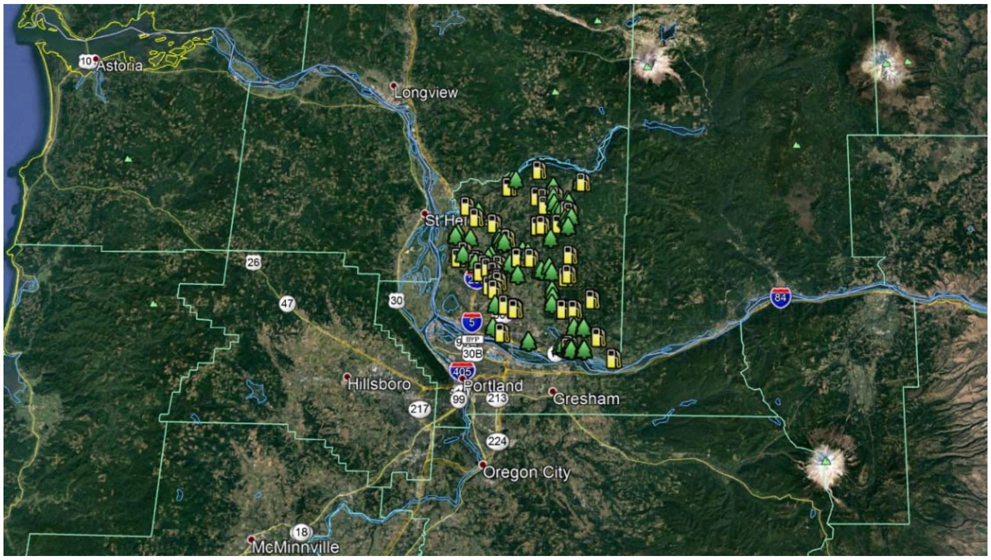


Figure V-7: Location of the 72 utility poles in Clark County, WA sampled in this study.

This set of 72 poles was first sampled in 2019. Six increment cores were taken from each pole, three at 150 mm below groundline and three from 100 mm above groundline. The three cores taken at each height were taken 120° apart around the circumference of the pole. The depth of copper naphthenate penetration for each core was recorded. The outer 6 mm of each core was removed to assess the presence of soft rot, then the zone from 6 to 25 mm from the surface was removed and core zones from a given location on each pole were combined before being ground to pass a 20 mesh screen. The resulting sawdust was analyzed for copper by x-ray fluorescence spectroscopy to measure copper naphthenate retention. The remainder of each core was plated on malt extract agar and observed for the growth of soft rot and basidiomycete decay fungi as previously described. The outer 2 mm segments were digested into individual wood fibers and these fibers were examined for evidence of soft rot fungal attack as either cell wall thinning or diamond shaped cavities. Where possible, pure fungal cultures underwent sequencing to identify each species and relate it to their decay capabilities.

Copper naphthenate retention was higher on average for poles treated with a petrodiesel carrier (Figure V-8). This was consistent with our observations in previous work comparing the two different carrier types. Average copper penetration depth was very similar for both treatment types and were well beyond the minimum 19 mm depth required (Figure V-9). There was considerable variability in copper retention among poles installed in different years. This was the case for poles treated with a biodiesel carrier installed in 2012, which on average had retention levels below the minimum required 1.5 kg/m^3 level. Poles treated with a petrodiesel carrier that were installed in 2014 had much higher copper retention levels, which brought up the average for the whole treatment group.

In general, poles treated with a biodiesel carrier showed higher levels of soft rot damage than petrodiesel-treated poles (Figure V-10). Soft rot intensity in above ground cores taken from poles treated with a biodiesel carrier was slightly higher than equivalent segments of petrodiesel poles. The difference was more pronounced in below ground cores. Culturing efforts showed that biodiesel poles also contained more culturable soft rot fungi than petrodiesel poles. Decay fungi were found in 5 biodiesel poles in below ground cores and one petrodiesel pole in an above ground core. These preliminary results show that poles treated with a biodiesel carrier may be more susceptible to decay than poles treated with a petrodiesel carrier. This may be due to the fact that biodiesel poles installed in 2012 were not sufficiently treated, which could allow more prolific growth of decay fungi in these early stages.

Moving forward, we plan to perform in-house decay tests with the most commonly isolated fungi to determine their ability to damage utility poles (Table V-5). We also plan to compare data from the SnoPUD/PSE and ClarkPUD poles in future annual reports.

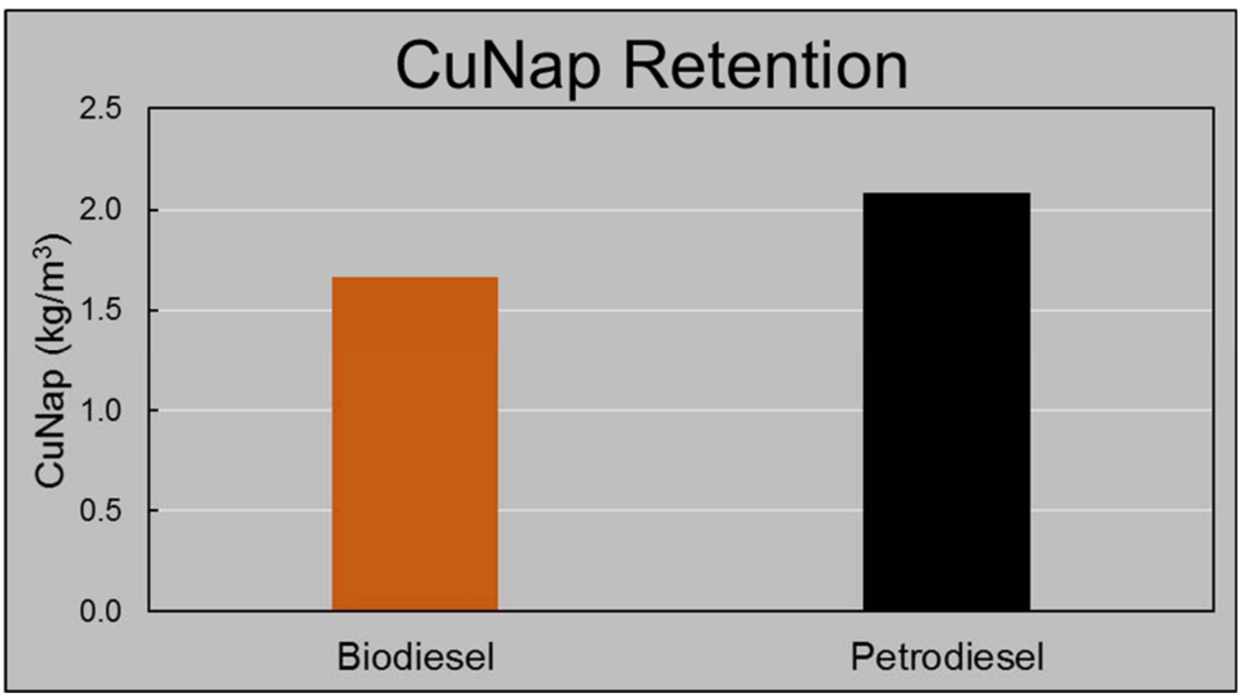


Figure V-8. Average retention levels of copper naphthenate in the outermost 6-25 mm of the poles. Retentions for all poles from each treatment type were averaged.

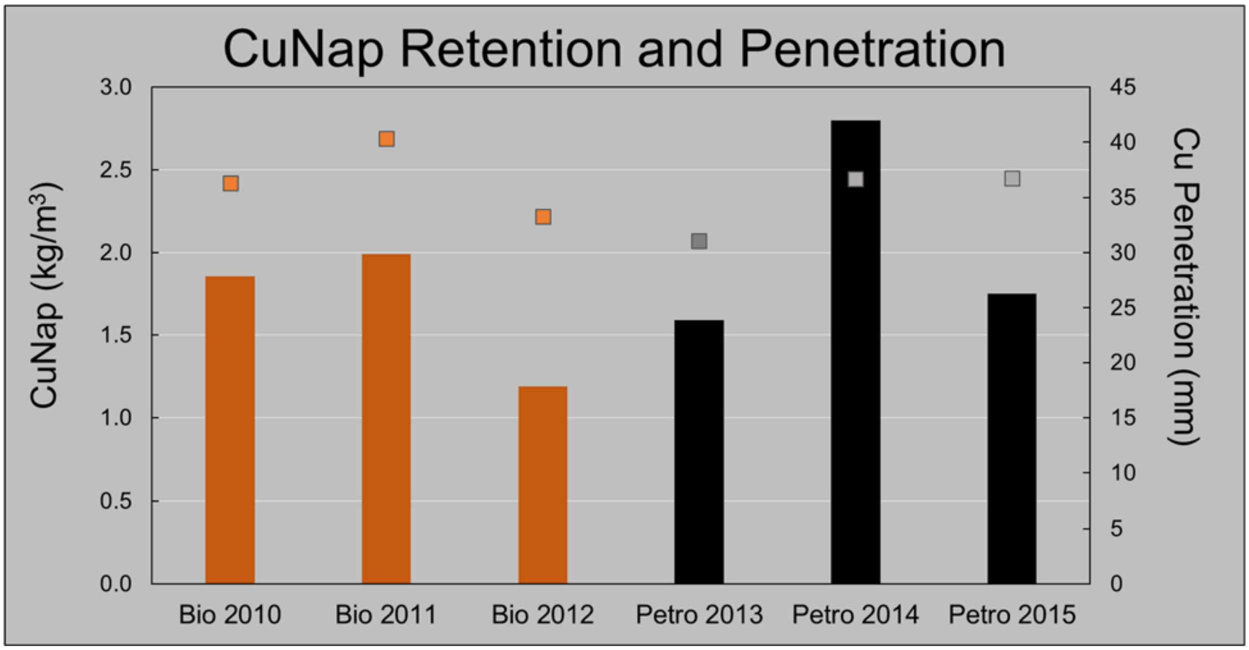


Figure V-9. Average retention levels and penetration depth of copper naphthenate in biodiesel and petrodiesel carrier-treated poles separated by the year they were installed.

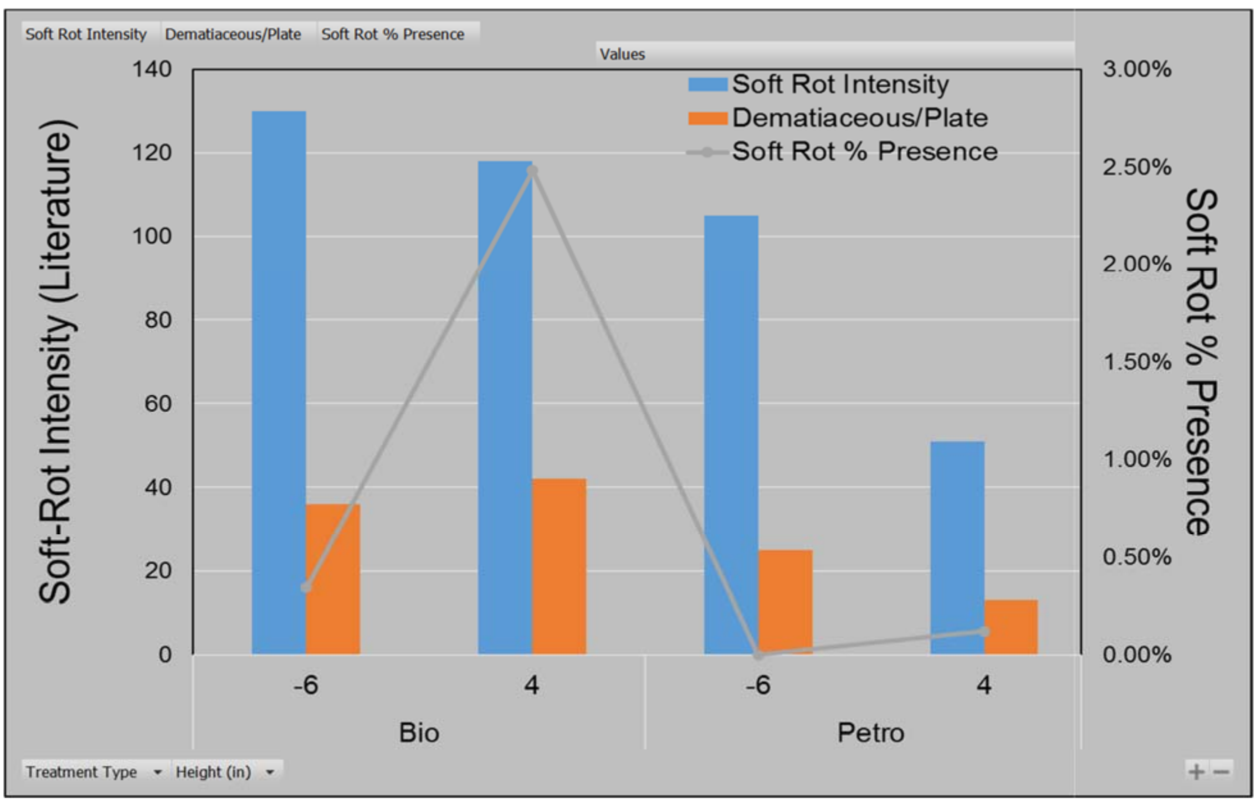


Figure V-10. Soft rot intensity and rates of isolation of soft-rot fungi from the outer 2 mm of increment cores taken 6 mm above ground and 4 mm below ground from poles treated with a biodiesel or petrodiesel carrier.

*Table V-5. Important soft rot fungi isolated in the ClarkPUD system in 2019. The three fungi in **bold** were also commonly isolated in the SnoPUD and PSE systems. Based on peer-reviewed literature, an "impact" rating was assigned to each fungus indicating the extent of damage it is capable of causing.*

Soft Rot Fungi	Impact (From Literature)	Soft-Rot Type
Cadophora melinii	Aggressive Soft Rotter	Type I, Type II
Aureobasidium melanogenum	Aggressive Soft Rotter	Type II
Pachnocybe ferruginea	Aggressive Soft Rotter (more?)	Type II?
Scytalidium album	Strong Soft Rotter	Type II?
Trichoderma hamatum	Strong Soft Rotter	Type II
Amorphotheca resinae	Soft Rotter	Type II
Cephaloascus albidus	Soft Rotter	Type I

LITERATURE CITED

Please refer to the Literature Cited section of our website for documentation related to the Annual Report. We will constantly be updating this section in the future as new relevant research is published.

SUPPLEMENTAL MATERIAL

A separate document will be posted on the UPRC website under the Members Only section (“2019 UPRC Annual Report Supplemental Material”). This document will contain all peer-reviewed publications from the laboratory during 2019. This will ensure all members have access to the research from our biodeterioration lab, even if you do not have journal access.