

The Oregon State Utility Pole Research Cooperative 41st Annual Report

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Table of Contents

COOPERATORS	5
UPRC Advisory Committee	6
Executive summary	7
OBJECTIVE I: DEVELOP SAFER CHEMICALS FOR CONTROLLING INTERNAL DECAY OF WOOD POLES	12
1.1.0 Develop Improved Fumigants for Controlling Internal Decay of Wood Poles	12
1.1.1 Performance of Dazomet With or Without Copper-based Accelerants	13
1.1.2 Effect of Potassium N-methyldithiocarbamate (KMDC) as an Internal Remedial Treatment	18
1.1.3 Performance of Dazomet in Powdered and Rod Forms in Douglas-fir Pole Sections	25
1.2.0 Performance of Water Diffusible Preservatives as Internal Treatments	32
1.2.1 Performance of Copper Amended Fused Boron Rods	32
1.2.2. Performance of fused borate rods in internal groundline treatments of Douglas-fir poles	39
1.2.3 Effect of Glycol on Movement of Boron from Fused Boron Rods	42
1.3.0 Tests Including Both Fumigants and Diffusible Remedial Treatments	52
1.3.1 Full Scale Field Trial of All Internal Remedial Treatments	53
1.3.2 Effect of Metam Sodium on Boron Rod Performance	53
1.4.0 Identification of accelerants to improve the decomposition of dazomet in dry climates	60
1.5.0 Performance of Internal Remedial Treatments in In-Service Utility Poles	60
1.5.1 Performance of Internal Remedial Treatments in Arid Climates: Rocky Mountain Power Test	60
1.6.0 References	61
OBJECTIVE II: IDENTIFY CHEMICALS FOR PROTECTING EXPOSED WOOD SURFACES IN POLES	63
2.1.0 Effect of Boron Pretreatment on the Performance of Preservative Treated Douglas-fir Poles	63
2.1.1 Boron Pre-treatment Followed by Copper Naphthenate Pressure Treatment of Douglas-fir Poles	64
2.1.2 Effect of Boron Pre-treatment on Performance of Douglas-fir Poles Treated with Pentachlorophenol, Copper Naphthenate, or Ammoniacal Copper Zinc Arsenate	75
2.1.3 Effect of Boron Pretreatment on the Performance of In-Service Utility Poles: SnoPUD System	82
2.1.4 References for Objective 2	83
OBJECTIVE III: EVALUATE PROPERTIES AND DEVELOP IMPROVED SPECIFICATIONS FOR WOOD POLES	84

3.1.0	Effect of coatings, pole caps and pole top orientation on the performance of above ground portions of utility poles.....	84
3.1.1	Effect of Conventional Capping on Pole Moisture Content:.....	85
3.1.2	Use of Polyurea Caps to Limit Moisture Intrusion on Douglas-fir Pole Tops.....	85
3.1.3	Effect of Pole Top Configuration on Moisture Uptake in Poles	85
3.1.4	Performance of Polyurea-Coated Douglas-fir Crossarm Sections Exposed in Hilo Hawaii	89
3.2.0	Developing Data on the Ability of Various Systems to Protect Poles from Wildfire	89
3.2.1	Modification of the fire testing apparatus	91
3.2.2	Initial tests using the updated fire testing apparatus on treated and untreated Douglas-fir pole sections.....	93
3.3.0	Effect of Solvents on the Performance of oil borne preservative systems.....	95
3.3.1	Effect of biodiesel-containing solvents on the performance of Copper Naphthenate and Pentachlorophenol	96
3.3.2	Effect of solvent systems on the performance 4,5-dichloro-2-n-octyl-4-isothiazolin-3-one (DCOI): E10 Soil bottle test	98
3.3.3	Effect of solvent systems on the performance 4,5-dichloro-2-n-octyl-4-isothiazolin-3-one (DCOI) in two different climates: E7 Stake test.....	99
3.4.0	Performance of 4,5-dichloro-2-n-octyl-4-isothiazolin-3-one (DCOI) as a treatment for utility poles	100
3.4.1	Performance of DCOI as a treatment for Douglas-fir utility poles in two climactic conditions	100
3.4.2	Performance of DCOI as a utility pole preservative in red pine and southern pine pole stubs at the Peavy Arboretum: 8-year assessment.....	103
3.5.0	References for Objective 3	106
OBJECTIVE IV: PERFORMANCE OF EXTERNAL GROUNDLINE PRESERVATIVE SYSTEMS.....		108
4.1.0	Effectiveness of external barriers on pole performance	108
4.1.1	Performance of Biotrans field liners in preventing moisture ingress to utility poles....	109
OBJECTIVE V: PERFORMANCE OF COPPER NAPHTHENATE TREATED WESTERN WOOD SPECIES.....		112
5.1.0	Copper naphthenate's use as a preservative treatment for western species.....	112
5.1.1	Performance of Copper Naphthenate Treated Western Redcedar Stakes in Soil Contact	112
5.1.2	Condition of Douglas-fir poles Treated with Copper Naphthenate in Diesel or Biodiesel Blends (SnoPUD/PSE Systems).....	118
5.1.3	Performance of low odor copper naphthenate against decay fungi compared to a previously existing formula.....	118

5.1.4 **References for Objective 5** **119**

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Executive summary

This year's report summarizes progress on several longstanding field studies at the Peavy Arboretum. Several older studies were assessed for a final time and removed from the field site to make room for new studies in the coming years. All site removals were accompanied with soil sampling that occurred directly beneath the pole stubs and 1 ft lateral to the pole stubs. These include several internal remedial treatment studies described in Objective 1 focusing on dazomet performance, borate rods and other borate-based treatments described in Objective 2. The fire testing apparatus was reconfigured for remote operation off two generators. Studies on the efficacy of DCOI as a utility pole preservative for western wood species continue as do efforts to characterize performance of copper naphthenate.

Objective I examines the performance of internal remedial treatments for utility poles in a variety of lab, field and in-service studies. A brief explanation of progress on studies under this objective are listed below.

Section 1.1.1: A long-term study to measure the performance of dazomet with copper-based accelerants in penta-treated Douglas-fir poles was sampled for the third year after retreatment. This is the final sampling of this project, and the study was removed this year. MITC levels were only above threshold in some samples taken 0.3 m above or below ground. MITC levels were highest for copper sulfate treatment, second for copper naphthenate and lowest for no copper-based additive. This study supports the use of copper-based accelerant along with dazomet.

Section 1.1.2: A field study comparing the performance of potassium N-methyldithiocarbamate (KMDC) to metam sodium as an internal remedial treatment was sampled three years after treatment. MITC levels tended to be lower in metham sodium-treated pole sections three years after treatment compared to KMDC treated pole sections. Both treatments yielded relatively low MITC levels in most sampling locations. For metam sodium-treated pole sections, MITC levels were at or near the effective inhibitory threshold of 20 µg/g over most of the pole sections 150 mm below groundline only and above threshold levels were rare from the groundline above. KMDC had higher average MITC levels below and at groundline. Above threshold MITC levels were rarer 150 mm and higher above groundline except in a single replicate at 150 mm that had high MITC levels. Inner pole sections tended to have higher MITC levels for both treatments.

Section 1.1.3: A field study comparing the performance of dazomet in rod and powdered forms in pole stubs at the Peavy Arboretum was sampled for the final time 21 years after installation. The study was removed this year after sampling. MITC levels were generally low in all treatments, although there were a few samples taken 0.3 m above groundline that showed inhibitory levels of MITC in the inner pole sections. While 21 years is 10+ years past a normal inspection cycle, dazomet appears to continue to produce low levels of MITC at this timepoint when added in high enough doses (at least 160 g).

Section 1.2.1: A field study monitoring the performance of copper-amended fused borate rods was sampled for a final time 20 years after installation. The study was removed after sampling. Boron levels found in poles at groundline and 150 mm below groundline were above the

effective inhibitory threshold for most treatments in this study. Some treatments also showed inhibitory levels 300 mm above groundline. Inner pole sections also tended to have higher boron levels, likely due to higher moisture contents and the placement of boron rods in the pole interior. This study shows boron rod treatment is most effective in areas of poles where moisture is highest, at and below groundline and chemical levels remain elevated enough over 20 years to inhibit the growth of decay fungi.

Section 1.2.2: A field study measuring the performance of fused borate rods as an internal groundline treatment for utility poles was sampled 28 years after installation for the final time. The study was removed from the Peavy Arboretum this year. Poles dosed with 180 or 360 g of fused borate rods were monitored for boron levels over this period. Boron levels were generally higher close to or below groundline over the entire study period. After 28 years, boron levels remained above the effective inhibitory threshold in poles receiving the 360 g dose below groundline, 7.5 and 22.5 cm above groundline. This study shows that borate rod treatments are most effective in the high moisture areas of utility poles at or around groundline. Additionally, sufficient dosing of borate rods can deliver chemical levels high enough to inhibit decay fungi 28 years after treatment.

Section 1.2.3: A field study initiated to measure the effect of glycol on the movement of boron from fused boron rods was sampled for a final time 26 years after installation. The study was removed from the Peavy Arboretum after sampling. Addition of glycol, liquid boron, or boron glycol products to fused borate rods resulted in higher boron concentration in poles within the first 5 years after treatment. After 26 years, boron levels were very low across all treatments, but many of the treatments showed boron levels that were slightly above the effective inhibitory threshold, particularly at or below groundline. While levels were quite variable among replicates, this data shows that glycol addition can improve boron mobility from fused rods initially, and boron can remain in poles near the groundline well past a normal treatment cycle. However, the impact is small.

Section 1.3.2: A field study initiated to measure the impact of metam sodium treatment on the migration of boron from fused borate rods was sampled for the third year after treatment. Boron levels were measured and boron levels continued to be generally higher in the pole interior and in the areas close to or below groundline. Metam sodium cotreatment did not appear to impact boron levels in the poles any differently than boron rods alone or boron plus water in the third year after treatment.

Objective II seeks to identify chemicals for protecting exposed wood surfaces in utility poles. Recent efforts in this area done by the UPRC focused on examining how boron migrates in poles pretreated with boron and then overtreated with an oilborne or waterborne treatment.

Section 2.1.1: A field study designed to measure the impact of boron pretreatment followed by copper naphthenate overtreatment on boron migration to the heartwood of Douglas-fir poles was sampled for the 8th year for the final time. The study was removed from the Peavy Arboretum this year. Boron levels generally remained below the effective threshold at all sampling depths greater than 50 mm below the pole surface at groundline and 1.2 m above groundline. Boron

levels remained stable greater than 50 mm below the pole surface throughout the study. Because boron levels have stabilized and the initial boron treatment was weaker than a boron pretreatment for utility poles this study was discontinued in favor of installing a replacement. Poles for a replacement study have been obtained but not installed yet.

Section 2.1.2: A field study designed to measure the impact of boron pretreatment followed by penta, copper naphthenate or Ammoniacal Copper Zinc Arsenate overtreatment on boron migration to the heartwood of Douglas-fir poles was sampled for the 5th year after treatment. Overall boron levels remained below the effective threshold for all samples 50 mm or deeper beneath the pole surface at groundline and 1.2 m above groundline. Boron levels have remained stable throughout the sampling period greater than 25 mm below the pole surface for all treatments and inward migration does not appear to be occurring.

Objective III seeks to discover improved specifications for utility poles and encompasses many research areas. Currently these include measuring the impacts of pole capping or coatings on pole and crossarm performance, developing a small-scale fire test and testing fire retardant systems for utility poles and crossarms, and testing the impact of solvent systems on utility pole preservative performance. In addition, measuring the performance of DCOI as a utility pole preservative in western wood species has been initiated under this objective.

Section 3.1.1: This section describes research into the impacts of pole capping systems on pole moisture content. Sampling of capped poles was most recently done in November of 2020 and these poles were not sampled in 2021.

Section 3.1.2: This section describes research into the impacts of polyurea caps on pole moisture content. This study was last sampled in November of 2020 and was not sampled in 2021.

Section 3.1.3: This section describes research into the impacts of pole top orientation on moisture uptake by utility poles. Pole sections were weighed in October of 2021 and very little difference in relative moisture content was measured among the different treatments. In past measurements, the greatest disparity between the different pole top orientations was measured during the winter months and this study will be sampled again during the wet months.

Section 3.2.1-3.2.2: This section describes progress on the development of a standard test method for assessing the performance of utility pole fire retardant treatments. In 2021, the fire testing apparatus was reconfigured to run off two generators which allowed remote operation. The generators added significant costs to the setup, but overall, the cost of materials still has come in under \$3,500. A small set of untreated pole stubs were burned with the new remote setup, to confirm its function.

Section 3.3.1: This section describes a stake test started in 2013 to measure the impact of biodiesel-containing solvents on the performance of copper naphthenate in Douglas-fir. This study was last evaluated in the fall of 2020 and a summary of that data is included in this draft. The study was not assessed in 2021 and will be assessed in 2022.

Section 3.3.2: This section describes an AWP A E10 soil bottle test designed to measure the impact of three different solvent systems on the performance of DCOI against decay fungi.

DCOI-treated Douglas-fir and southern pine blocks at three different retention levels were subjected to an accelerated weathering protocol prior to addition decay microcosms. The test is currently running and data being collected. The full study results will be included in the 2022 annual report.

Section 3.3.3: This section describes the setup of an AWP A E7 stake test that will be done to compare the performance of DCOI in three different solvent systems at two different field sites. Douglas-fir and southern pine stakes are being treated with DCOI in one of three solvent systems along with pentachlorophenol and copper naphthenate in a single solvent each. Stakes will be exposed at two field sites, the Peavy Arboretum and Madras, Oregon. The stakes are being treated now and will be set out in the field in 2022.

Section 3.4.1: This section describes a post test to measure the performance of DCOI against other oilborne alternatives in two different climates. In 2020, pole stubs treated with DCOI, copper naphthenate, or pentachlorophenol were set out at the Peavy Arboretum and the Madras, OR field site. Five replicates of each treatment were set out and will be sampled again in 2025. In 2021, soil samples have been taken from around DCOI treated pole stubs and these are being analyzed for DCOI content to assess preservative migration in soil. Ten more replicate pole stubs per treatment per site were obtained and these will be installed in spring/summer of 2022.

Section 3.4.2: This section describes an 8-year assessment of a long-term post test to measure the performance of DCOI as a utility pole treatment in southern pine and red pine pole sections. This test was installed at the Peavy Arboretum in 2012 using the same cohort of poles installed at two other sites in Gainesville, FL and Harrisburg, NC. Pole stubs were assessed 150 mm below groundline, at groundline and 450 mm above groundline for preservative retention and the presence of decay fungi. After 8 years in the field, retention levels for DCOI-treated southern pine remained at or above the AWP A UC4B standard currently held for that species. Red pine retention levels were below current AWP A UC4B standards, but the initial treatment was not to that level. Depletion analysis produced odd results which indicated the pole sections had appeared to increase retention of DCOI over time. This was likely due to the initial retentions being done on composite samples and the 8-year retention assays being done on individual pole stubs.

Objective IV seeks to measure the performance of external groundline preservative systems that can be utilized to protect utility poles. The only active study in this object currently is the impact of Biotrans field liners on pole moisture content and this study was sampled for a final time in 2021 and removed.

Section 4.4.1: This section describes research to measure the performance of Biotrans field liners in preventing moisture ingress to utility poles. In 2021, the poles were sampled for moisture content a final time and were removed from the Peavy Arboretum. Results continued to show that field liners appeared to retain moisture in the poles near the surface during the summer months compared to unlined poles. Moisture contents in the pole interior were more similar among treatments. Soil samples were taken beneath the poles and 1 ft lateral to pole stubs as they were removed to assess the impact of field liners on penta migration.

Objective V seeks to measure the performance of copper naphthenate as a utility pole treatment in western wood species. The 30-year evaluation of western redcedar stakes treated with copper naphthenate was completed this year.

Section 5.1.1: This section describes a 30-year fungus cellar test on copper naphthenate-treated western redcedar stakes made from fresh lumber or weathered utility poles taken out of service. Copper naphthenate provided adequate protection for the stakes over 30 years. Weathered stakes fared worse than unweathered. Chemical retention levels remaining in the stakes were much lower for sections in ground contact indicating depletion over time leading to decay and for most treatments, weathered stakes had a slightly lower retention level than weathered in the ground contact portions.

Section 5.1.3: This section describes an AWWA E10 soil bottle test that was initiated to compare the performance of a commonly used low odor copper naphthenate formula to a standard formulation of this product. The soil bottle test is underway and data is being collected. Results will be available in the 2022 report.

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

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

1.1.0 Develop Improved Fumigants for Controlling Internal Decay of Wood Poles

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

Trade Name	Active Ingredient	Concentration (%)	Manufacturer
TimberFume	trichloronitromethane	97	Osrose Utilities Services, Inc.
WoodFume	sodium n-methyldithiocarbamate	33	Osrose Utilities Services, Inc.
SMDC-Fume			Copper Care Wood Preservatives, Inc.
MITC-FUME	methyl isothiocyanate	97	Osrose 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			Osrose Utilities Services, Inc.
Impel Rods	Disodium Octaborate	100	Intec, Inc.
Bor8 Rods		97	Wood Care Systems
Cobra Rods	Disodium Octaborate, Copper Hydroxide, Boric Acid	88-91, 1.5-3, 4-8	Genics, Inc.

1.1.1 Performance of Dazomet With or Without Copper-based Accelerants

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

The original treatment holes were reopened and treated a second time for this study. Holes were probed for residual chemical and re-bored prior to the addition of chemical. Two hundred grams of dazomet were equally distributed among the three holes. One set of three poles received no additional treatment, three poles received 20 g of copper sulfate powder equally distributed among the three holes, and three received 20 g of liquid copper naphthenate (2% metallic copper) in mineral spirits, also equally distributed among the three holes. Holes were then plugged with wooden dowels. This study was sampled a final time this year (2021) and the study has been removed.

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. In addition, the final sampling included a below ground sampling after the pole stubs were removed. Because of the high volume of sampling holes from the 20-year study, sampling holes for the current round of sampling were drilled approximately 6 inches lower than the holes drilled for the first 20-year time series. The outer 25 mm of each core was discarded. The next 25 mm, and the 25 mm section closest to the pith, of each core were placed into vials containing 5 mL of ethyl acetate (Figure 1.1.1). The cores were stored at room temperature for 48 hours to extract any MITC in the wood, then the increment core was removed, oven-dried, and weighed. The oven dried weight of each core section was used to calculate chemical content on a wood weight basis ($\mu\text{g/g}$ wood). The ethyl acetate extracts were injected into a Shimadzu gas chromatograph equipped with a flame photometric detector with filters specific for sulfur (a component of MITC). MITC levels in the extracts were quantified by comparison with prepared standards and results were expressed on a μg MITC/oven dried g of wood basis (Table 1.1.2). Each core at each sampling location was analyzed for MITC to produce the heat maps (Figure 1.1.2).

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

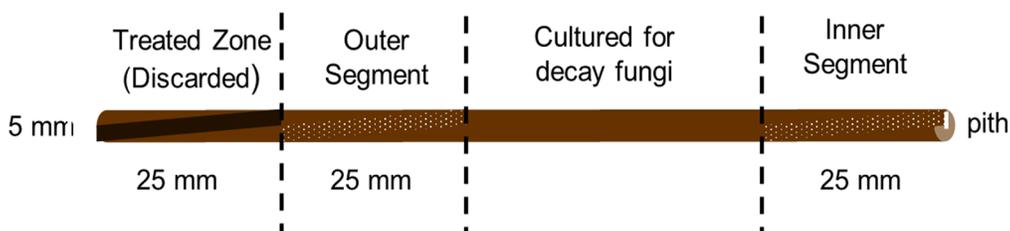


Figure 1.1.1. Schematic of core processing for fumigant analysis and fungal culturing.

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

The second year after retreatment (year 23) showed very low average MITC levels across all treatments. The only MITC levels above threshold were from dazomet + either accelerant at 0.3 m above groundline and no samples taken from dazomet alone treatments were above threshold levels. This result is unusual for the second year after treatment for dazomet and it is unclear what happened here.

In 2021, this study was sampled a final time and removed three years after retreatment and 24 years after installation. The same locations, 0.3 m, 1.3 m and 2.3 m were sampled before removal. In addition, another below ground sample was taken after the pole stubs were removed. Belowground samples were treated the same and were sectioned into inner and outer core sections. As with the previous year, above ground locations of the pole generally had lower MITC levels than expected and only the lowest sampling point, 0.3 m above groundline, showed MITC levels above the protective threshold.

The remaining core sections not extracted for MITC were cultured for decay fungi. Isolations were somewhat infrequent across all pole types and for the first two years after retreatment (Figure 1.1.3). The only sections where decay fungi were isolated from were cores taken 1.3 m above groundline from poles treated with dazomet alone or dazomet plus copper sulfate in year 1 after retreatment. In year 2 decay fungi were only found in dazomet alone treatments and 11 and 22% of cores cultured contained decay fungi 0.3 and 1.3 m from groundline. No decay fungi were isolated from any cores taken from dazomet plus copper naphthenate in year 1 or 2 after retreatment. Three years after retreatment, a total of cultures of decay fungi were isolated from poles without an accelerant whereas no decay fungi were found in poles treated with a copper-based accelerants.

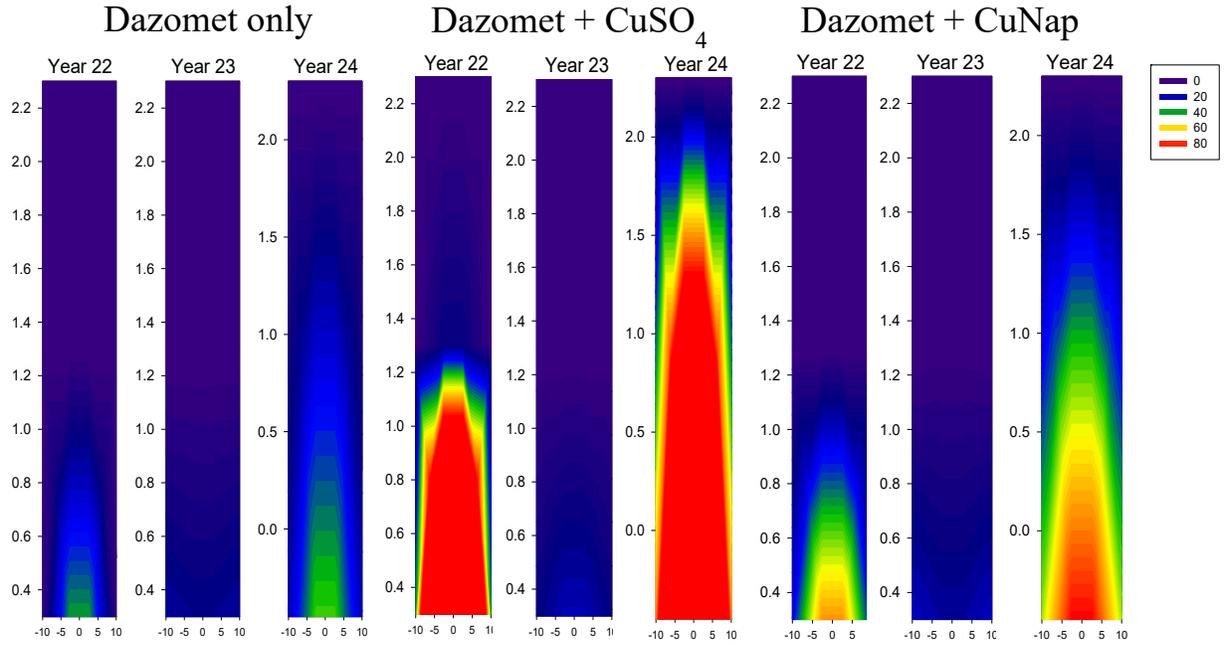


Figure 1.1.2. Residual MITC distribution in Douglas-fir pole sections following initial treatment retreatment (year 21) with 200 g of dazomet without accelerant, 200 g of dazomet plus 20 g of copper naphthenate, or 200 g of dazomet plus 20 g of copper sulfate. Purple and dark blue indicate MITC levels (ug/ below threshold, whereas other colors are above threshold.

Table 1.1.2. Residual MITC ($\mu\text{g/g}$) in Douglas-fir pole sections 1 to 20 years after treatment with dazomet with or without copper sulfate or copper naphthenate. Poles were retreated after 20 years with the same chemicals. Year 22 (1) indicates the first year after retreatment (gray). Year 23 (2) indicates 2020, and year 24 is 2021. Standard deviations are in parentheses.

Copper Treatment	Year	Residual MITC ($\mu\text{g/g}$ of wood) ^a							
		0.3 m		1.3 m		2.3 m		Below Ground	
		inner	outer	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 (13)	6 (0)	0 (0)	0 (0)	0 (0)	0 (0)		
	22	38 (31)	3 (4)	0 (0)	0 (0)	0 (0)	0 (0)		
23	14 (9)	16 (15)	0 (0)	0 (0)	0 (0)	0 (0)	43 (6)	18 -14	
24	9 (13)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)			
20 g Copper sulfate (CuSO ₄ ·5H ₂ O)	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 (26)	3 (76)	0 (0)	0 (0)	0 (0)	0 (0)		
	22	274 (288)	34 (23)	12 (22)	0 (0)	0 (0)	0 (0)		
23	19 (14)	12 (20)	0 (0)	0 (0)	0 (0)	0 (0)	223 (169)	65 (43)	
24	36 (26)	66 (76)	0 (0)	5 (9)	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 (34)	10 (15)	0 (0)	0 (0)	0 (0)	0 (0)		
	22	65 (50)	24 (17)	0 (0)	0 (0)	0 (0)	0 (0)		
23	16 (22)	20 (20)	1 (2)	0 (0)	0 (0)	0 (0)	81 (49)	48 (45)	
24	35 (34)	13 (15)	5 (9)	0 (0)	0 (0)	0 (0)			

^aValues in bold type represent chemical levels at or above the fungal threshold. Numbers in parentheses represent one standard deviation.

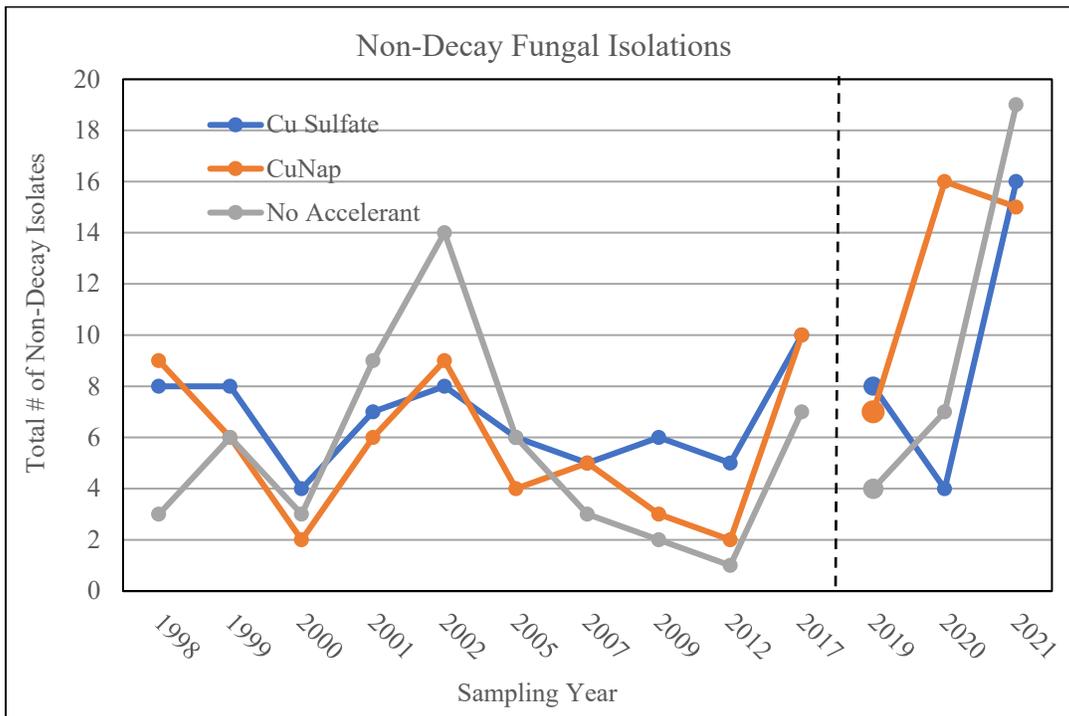
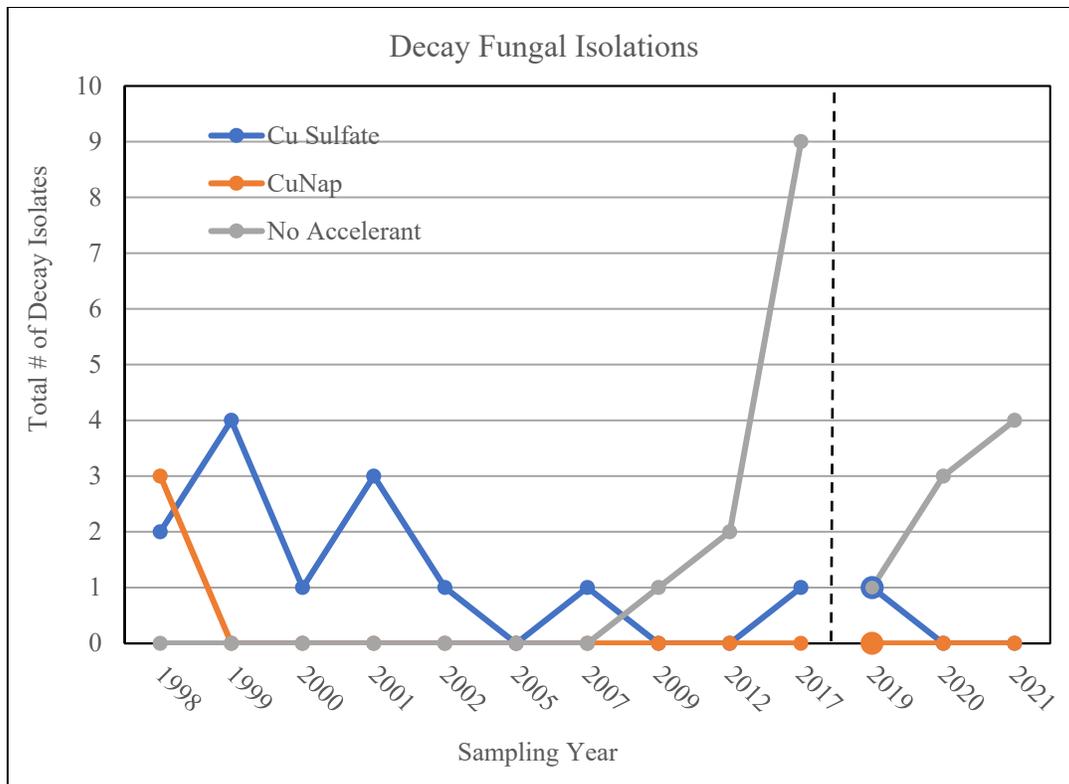


Figure 1.1.3. Decay (top) and non-decay (bottom) fungal isolations during the 20-year original treatment cycle and the first three years after retreatment. Poles were retreated in 2018 (vertical dotted line).

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

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

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

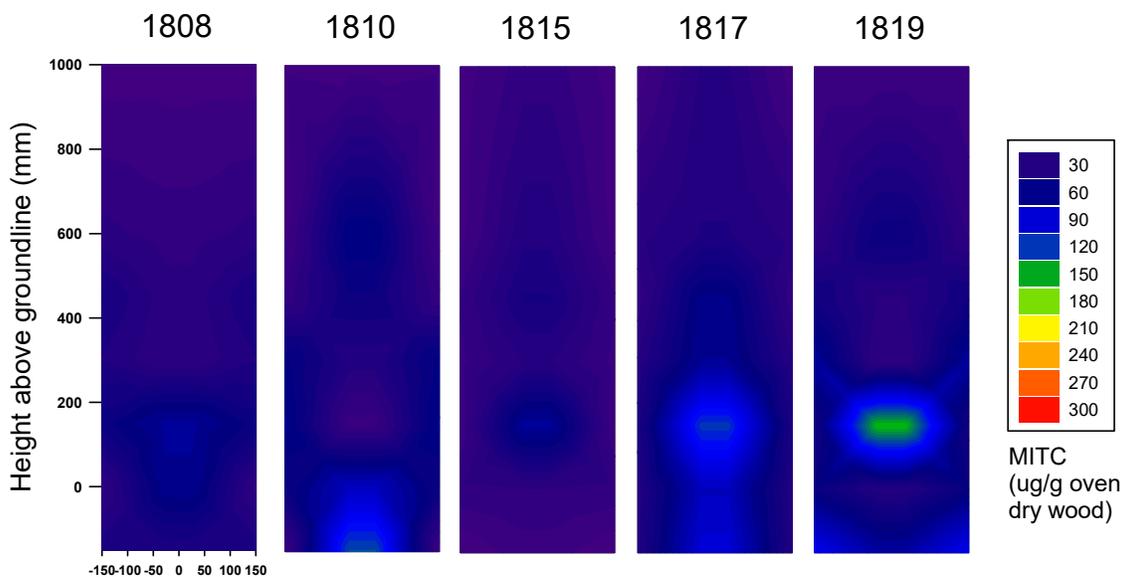
Poles are being sampled at regular intervals by removing increment cores from three equidistant points around each pole at 150 mm below groundline, groundline, and at 150 mm, 300 mm, 450 mm, 600 mm, and 1000 mm above groundline. Cores were processed by first discarding the outer treated shell and then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

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

MITC levels in year 2 for both NaMDC and KMDC-treated poles were dramatically lower than those found in year one and there were only sporadic, irregular occurrences of MITC levels

above the effective inhibitory threshold (Table 1.1.5; Figure 1.1.5). MITC levels were still somewhat higher closer to the groundline or below, but there were still many examples of core samples at or below groundline that did not have any MITC. These low MITC levels are an aberration from previous studies with NaMDC and it is unclear why the MITC levels were so much lower here. We intend to resample in year three to see if this was only an aberration or if there truly is no chemicals remaining in the poles.

Samples taken in 2021 showed MITC that were mainly below the effective inhibitory threshold at most sampling locations for both NaMDC and KMDC. There were a higher proportion of below groundline and groundline samples from the 2021 sampling that were above the effective threshold of 20 $\mu\text{g/g}$ than in the 2020 sampling, indicating that some areas at and below groundline still maintained effective fungal inhibition at this timepoint, particularly for KMDC. Above groundline, there were few sampling locations for either treatment that showed MITC levels high enough to inhibit fungi. This sampling point showed that KMDC continued to show somewhat higher levels of MITC than NaMDC.



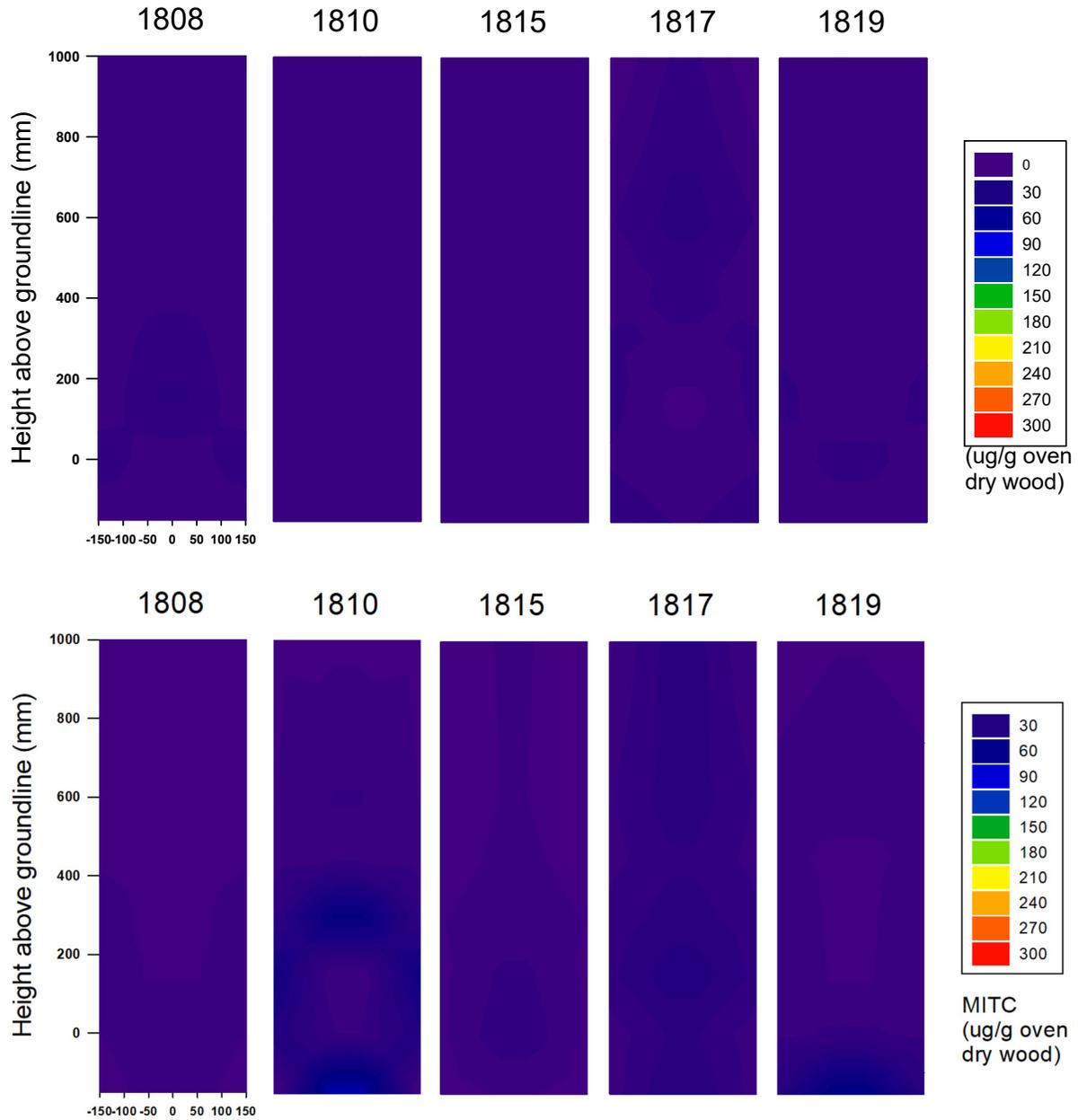
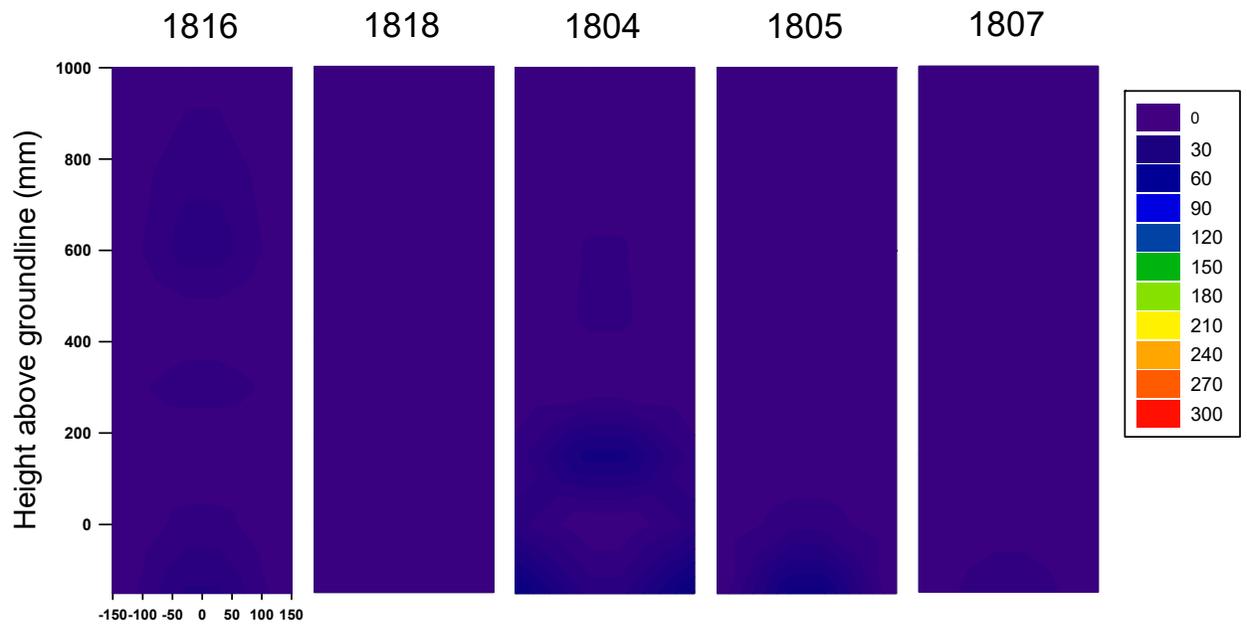
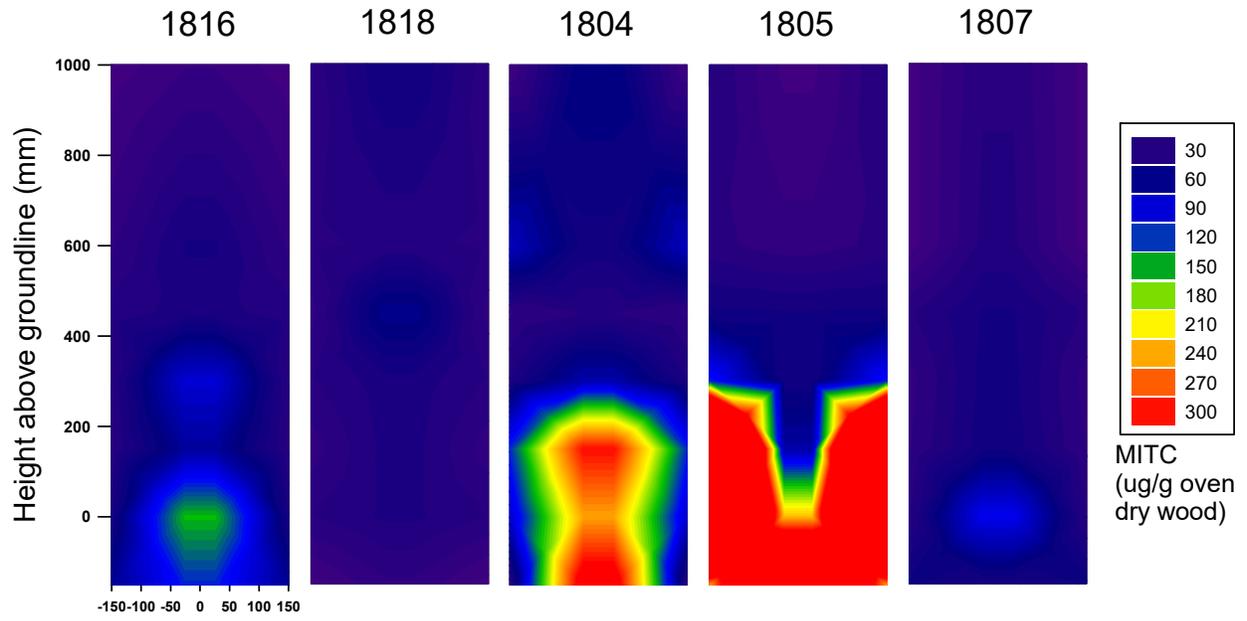


Figure 1.1.4: MITC evolution from poles treated with Metam Sodium (NaMDC) one year (top), two years (middle), and three years (bottom) after application at our Peavy Arboretum test site. Sections in purple were below the protective threshold of 20 $\mu\text{g/g}$ MITC. Numbers above each heat map indicate the specific pole identifier.



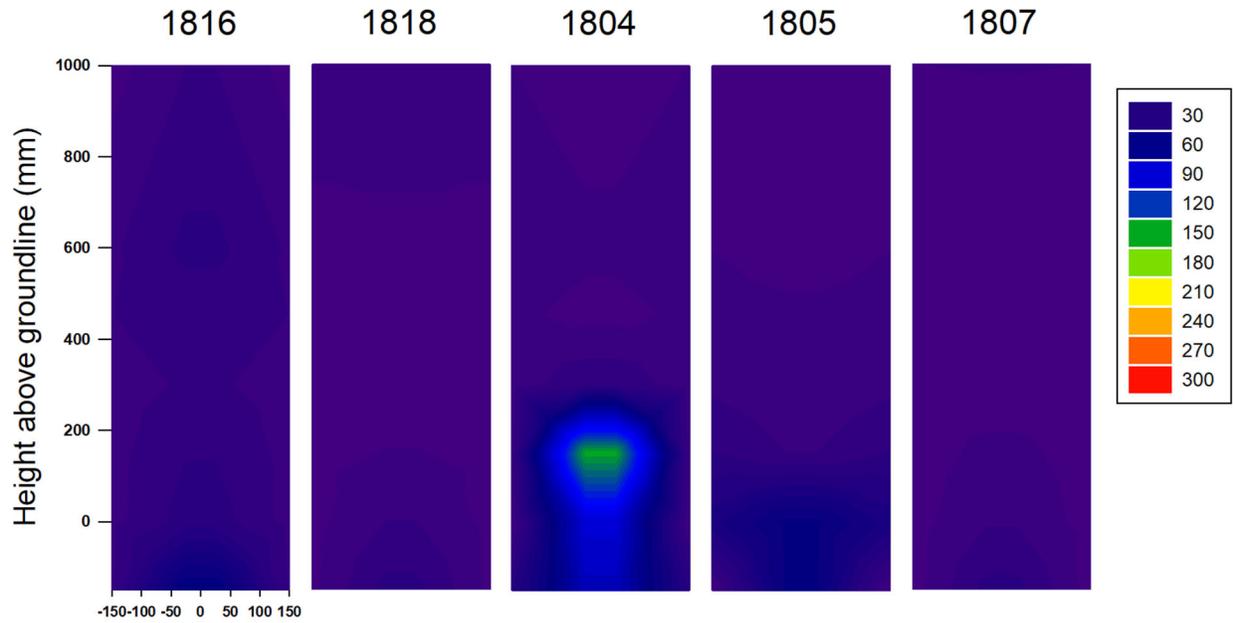


Figure 1.1.5: MITC evolution from poles treated with Metam Potassium (KMDC) one year (top) two years (middle), and three years (bottom) after application at our Peavy Arboretum test site. Sections in purple were below the protective threshold of 20 $\mu\text{g/g}$ MITC. Numbers above each heat map indicate a specific pole identifier.

Table 1.1.3. MITC concentration in poles treated with Metam Sodium (NaMDC) or Metam Potassium (KMDC) 13 months after application in Corvallis, OR. MITC levels above the protective threshold of 20 µg/g are indicated with bold green boxes.

Treatment	Pole #	150 mm Below Groundline				Groundline				150 mm Above Groundline				300 mm Above Groundline			
		inner		outer		inner		outer		inner		outer		inner		outer	
		MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.
Metam Sodium (NaMDC)	1808	30.99	(23.83)	33.54	(44.46)	58.48	(51.31)	15.92	(6.73)	61.44	(33.64)	45.25	(48.95)	18.49	(14.28)	29.56	(14.57)
	1810	132.48	(60.45)	25.25	(7.64)	91.29	(36.67)	59.39	(43.31)	26.93	(29.73)	72.63	(40.41)	44.21	(20.45)	67.54	(67.62)
	1815	8.77	(9.26)	0.72	(1.25)	17.61	(8.99)	16.02	(5.69)	62.48	(61.18)	8.14	(7.76)	24.04	(21.49)	10.04	(4.42)
	1817	86.89	(39.13)	28.29	(26.83)	76.87	(10.73)	26.00	(22.76)	116.59	(58.48)	32.74	(13.67)	60.28	(15.15)	24.76	(26.55)
	1819	60.84	(29.12)	93.11	(98.59)	20.32	(8.30)	41.87	(10.70)	149.08	(120.55)	34.17	(10.14)	11.69	(8.55)	59.37	(36.61)
	Trt. Avg.	63.99	(32.36)	36.18	(35.75)	52.92	(23.20)	31.84	(17.84)	83.31	(60.72)	38.59	(24.19)	31.74	(15.98)	38.25	(29.95)
Metam Potassium (KMDC)	1804	330.40	(396.18)	25.04	(36.06)	240.15	(85.09)	84.10	(111.21)	299.44	(299.49)	114.96	(76.87)	74.00	(2.66)	36.67	(15.26)
	1805	566.33	(911.49)	243.41	(254.54)	232.93	(189.14)	816.57	(1221.23)	86.05	(111.99)	951.78	(1351.11)	62.14	(48.10)	122.77	(66.47)
	1807	41.02	(20.83)	48.82	(26.02)	100.20	(45.16)	29.46	(36.06)	45.37	(27.78)	23.14	(13.60)	43.55	(5.73)	21.42	(6.11)
	1816	111.03	(87.49)	57.79	(65.85)	151.48	(49.76)	36.40	(27.90)	62.84	(13.87)	22.36	(16.46)	85.64	(47.63)	24.08	(22.67)
	1818	16.38	(15.04)	3.62	(0.94)	31.25	(8.89)	23.56	(13.34)	31.56	(8.89)	14.69	(14.47)	33.44	(14.56)	23.00	(5.22)
	Trt. Avg.	213.03	(286.20)	75.74	(76.68)	151.20	(75.61)	198.02	(281.95)	105.05	(92.40)	225.38	(294.50)	59.75	(23.73)	45.59	(23.15)
Treatment	Pole #	450 mm Above Groundline				600 mm Above Groundline				1000 mm Above Groundline							
		inner		outer		inner		outer		inner		outer					
		MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.				
Metam Sodium (NaMDC)	1808	20.54	(13.81)	36.56	(16.41)	15.29	(13.62)	19.87	(3.02)	2.83	(4.90)	2.57	(4.46)				
	1810	58.78	(42.07)	31.28	(32.23)	70.89	(32.65)	21.46	(12.74)	20.58	(12.06)	22.68	(20.56)				
	1815	36.63	(17.04)	12.85	(13.33)	28.00	(48.50)	3.46	(6.00)	15.14	(26.22)	2.33	(4.03)				
	1817	55.64	(25.56)	14.50	(25.11)	30.52	(20.13)	21.74	(33.41)	24.42	(37.69)	2.27	(3.94)				
	1819	16.46	(8.53)	35.94	(37.92)	40.00	(35.08)	11.30	(9.87)	0.00	0.00	0.00	0.00				
	Trt. Avg.	37.61	(21.40)	26.23	(25.00)	36.94	(30.00)	15.57	(13.01)	12.59	(16.17)	5.97	(6.60)				
Metam Potassium (KMDC)	1804	29.71	(33.27)	22.73	(18.40)	45.42	(53.88)	80.90	(108.01)	60.04	(94.31)	11.05	(19.13)				
	1805	60.61	(48.98)	61.56	(13.30)	38.54	(30.88)	44.15	(9.14)	28.34	(15.08)	48.40	(26.53)				
	1807	42.54	(16.74)	28.89	(31.66)	31.47	(13.65)	8.65	(4.13)	29.09	(7.03)	8.70	(7.60)				
	1816	32.52	(29.76)	26.29	(21.92)	36.66	(12.13)	16.95	(15.01)	11.50	(11.23)	2.23	(3.86)				
	1818	57.62	(14.83)	15.68	(5.86)	25.42	(24.73)	22.63	(9.24)	41.52	(30.98)	19.96	(10.32)				
	Trt. Avg.	44.60	(28.72)	31.03	(18.23)	35.50	(27.05)	34.66	(29.10)	34.10	(31.73)	18.06	(13.49)				

Table 1.1.4: MITC concentration in poles treated with Metam Sodium (NaMDC) or Metam Potassium (KMDC) 27 months after application in Corvallis, OR. MITC levels above the protective threshold of 20 µg/g are indicated with bold green boxes.

Treatment	Pole #	150 mm Below Groundline				Groundline				150 mm Above Groundline				300 mm Above Groundline			
		inner		outer		inner		outer		inner		outer		inner		outer	
		MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.
Metam Sodium (NaMDC)	1808	1.45	(2.52)	1.03	(1.78)	2.12	(3.66)	9.96	(11.77)	12.66	(21.92)	1.24	(2.16)	9.59	(7.16)	0.00	0.00
	1810	5.37	(4.79)	0.00	0.00	4.11	(7.12)	0.00	0.00	5.11	(7.12)	0.05	(0.09)	0.00	0.00	2.12	(3.68)
	1815	0.00	0.00	0.00	0.00	5.47	(4.84)	0.00	0.00	1.18	(2.05)	0.00	0.00	2.03	(2.43)	0.00	0.00
	1817	17.86	(6.67)	22.31	(29.17)	13.77	(1.57)	17.14	(11.72)	10.30	(7.26)	19.90	(14.88)	17.08	(3.44)	19.17	(3.20)
	1819	0.00	0.00	0.00	0.00	8.86	(15.22)	1.19	(2.05)	0.00	0.00	8.65	(12.75)	1.26	(2.18)	4.06	(7.03)
	Trt. Avg.	4.94	(2.80)	4.67	(6.19)	6.87	(6.48)	5.66	(5.11)	5.85	(7.67)	5.97	(5.98)	5.99	(3.04)	5.07	(2.78)
Metam Potassium (KMDC)	1804	15.09	(26.14)	42.68	(73.92)	0.00	0.00	13.83	(23.95)	32.66	(36.16)	8.59	(8.10)	1.10	(1.90)	0.00	0.00
	1805	37.42	(53.82)	0.00	0.00	9.44	(16.34)	0.52	(0.89)	0.00	0.00	0.00	0.00	4.13	(7.16)	0.00	0.00
	1807	11.08	(19.19)	0.00	0.00	1.92	(3.33)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1816	18.95	(13.28)	0.00	0.00	8.24	(6.11)	0.00	0.00	0.00	(0.00)	2.04	(3.53)	8.54	(1.86)	3.55	(3.09)
	1818	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Trt. Avg.	16.51	(22.49)	8.54	(14.78)	3.92	(5.16)	2.87	(4.97)	6.53	(7.23)	2.13	(2.33)	2.75	(2.18)	0.71	(0.62)
Treatment	Pole #	450 mm Above Groundline				600 mm Above Groundline				1000 mm Above Groundline							
		inner		outer		inner		outer		inner		outer					
		MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.	MITC (µg/g)	Std. Dev.				
Metam Sodium (NaMDC)	1808	1.51	(2.62)	0.00	0.00	1.91	(3.31)	0.00	0.00	0.00	(0.00)	0.00	0.00				
	1810	0.00	0.00	1.02	(1.77)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
	1815	0.00	0.00	0.00	0.00	2.03	(1.80)	0.00	0.00	2.55	(4.42)	0.00	0.00				
	1817	20.20	(3.55)	13.02	(13.16)	26.14	(10.89)	17.35	(15.05)	18.54	(11.38)	6.20	(10.74)				
	1819	1.54	(2.66)	1.96	(3.40)	1.51	(2.61)	0.00	0.00	0.00	0.00	0.00	0.00				
	Trt. Avg.	4.65	(1.77)	3.20	(3.67)	6.32	(3.72)	3.47	(3.01)	4.22	(3.16)	1.24	(2.15)				
Metam Potassium (KMDC)	1804	6.97	(5.37)	0.00	0.00	6.45	(11.18)	2.27	(3.93)	0.00	0.00	1.01	(1.75)				
	1805	4.82	(8.36)	0.00	0.00	0.00	0.00	0.00	0.00	0.57	(0.99)	0.00	0.00				
	1807	0.53	(0.92)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
	1816	1.88	(3.26)	0.00	0.00	15.17	(4.32)	0.00	0.00	3.22	(5.57)	0.00	0.00				
	1818	0.00	0.00	0.00	0.00	0.62	(1.07)	0.00	0.00	0.69	(1.19)	0.00	0.00				
	Trt. Avg.	2.84	(3.58)	0.00	0.00	4.45	(3.31)	0.45	(0.79)	0.90	(1.55)	0.20	(0.35)				

Table 1.1.5: MITC concentration in poles treated with Metam Sodium (NaMDC) or Metam Potassium (KMDC) 39 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	8.16	(4.79)	3.83	(0.65)	9.28	(8.93)	5.92	(3.44)	5.45	(1.69)	7.37	(1.66)	3.23	(0.19)	9.33	(1.93)
	1810	70.95	(84.89)	4.16	(0.71)	11.83	(7.72)	27.79	(33.68)	6.54	(2.87)	39.05	(6.56)	49.36	(6.88)	17.52	(3.45)
	1815	6.33	(2.14)	3.37	(0.15)	15.84	(8.25)	4.80	(2.32)	13.17	(5.58)	4.43	(2.71)	8.65	(4.39)	5.54	(3.26)
	1817	23.18	(8.62)	9.03	(1.18)	18.37	(2.08)	8.35	(5.68)	27.39	(3.63)	16.39	(6.56)	20.49	(8.45)	14.46	(5.41)
	1819	56.66	(63.05)	22.51	(24.05)	13.28	(11.58)	10.16	(4.04)	4.81	(2.23)	9.95	(4.28)	4.30	(1.89)	11.23	(5.59)
	Trt. Avg.	33.05	(32.70)	8.58	(5.35)	13.72	(7.71)	11.41	(9.83)	11.47	(3.20)	15.44	(4.35)	17.21	(4.36)	11.62	(3.93)
Metam Potassium (KMDC)	1804	75.43	(87.49)	22.98	(32.69)	86.48	(33.82)	5.35	(2.68)	146.41	(36.93)	9.45	(5.17)	16.76	(15.73)	7.85	(3.96)
	1805	48.57	(32.64)	4.44	(0.54)	49.20	(31.89)	33.43	(37.56)	11.93	(4.38)	18.12	(14.44)	7.81	(3.09)	10.55	(2.48)
	1807	19.89	(11.09)	3.34	(0.81)	11.08	(9.40)	3.42	(1.10)	7.15	(5.07)	3.62	(1.36)	2.78	(0.47)	3.52	(1.22)
	1816	53.47	(37.88)	11.28	(4.13)	20.74	(9.32)	9.73	(2.52)	17.63	(1.77)	9.90	(6.27)	12.58	(2.52)	9.88	(0.78)
	1818	19.71	(6.32)	4.71	(0.72)	11.94	(8.79)	4.18	(0.80)	6.13	(4.34)	4.65	(0.56)	3.89	(0.79)	4.41	(0.34)
	Trt. Avg.	43.41	(35.08)	9.35	(7.78)	35.89	(18.64)	11.22	(8.93)	37.85	(10.50)	9.15	(5.56)	8.76	(4.52)	7.24	(1.76)
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	3.98	(1.69)	4.78	(1.08)	3.62	(0.58)	3.86	(1.27)	3.25	(0.60)	3.09	(0.30)				
	1810	8.95	(4.23)	7.41	(1.40)	12.38	(4.00)	5.90	(3.49)	4.68	(0.80)	5.23	(2.53)				
	1815	7.02	(1.79)	3.56	(0.32)	6.01	(5.49)	2.91	(0.69)	6.32	(3.13)	3.33	(0.70)				
	1817	16.93	(4.23)	9.67	(9.87)	20.86	(10.61)	11.15	(10.22)	20.36	(0.59)	5.02	(2.35)				
	1819	4.03	(2.28)	7.99	(1.79)	9.26	(2.74)	7.17	(3.95)	5.63	(5.05)	3.87	(2.06)				
	Trt. Avg.	8.18	(2.85)	6.68	(2.89)	10.43	(4.68)	6.20	(3.92)	8.05	(2.04)	4.11	(1.59)				
Metam Potassium (KMDC)	1804	4.06	(0.69)	7.25	(4.12)	7.26	(3.12)	9.52	(1.67)	3.28	(0.41)	6.02	(1.82)				
	1805	7.33	(0.45)	7.96	(2.94)	3.26	(0.10)	5.85	(2.54)	3.06	(0.19)	5.22	(3.15)				
	1807	5.44	(3.52)	2.97	(0.37)	3.38	(0.47)	4.81	(2.05)	6.08	(1.31)	5.99	(3.10)				
	1816	14.56	(3.76)	11.87	(2.97)	19.52	(6.84)	10.82	(3.50)	11.88	(2.31)	3.54	(0.43)				
	1818	5.00	(2.06)	5.37	(2.67)	5.12	(1.39)	4.50	(1.00)	8.03	(4.94)	8.66	(3.82)				
	Trt. Avg.	7.28	(2.10)	7.09	(2.61)	7.71	(2.38)	7.10	(2.15)	6.47	(1.83)	5.89	(2.46)				

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

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

Since it was developed for use as an internal remedial treatment, dazomet has been formulated into first pelletized and then rod form (BASF Wolman GmbH) for easy application into bore holes. Rods have a relatively lower surface:volume than powdered forms which raised concerns of reduced efficacy due to lower contact with water and accelerants. A field test at the Peavy Arboretum field site was initiated in 2000 to test the performance of dazomet rods versus powdered forms alone or in the presence of a copper-based accelerant. MITC distribution was monitored over the course 21 years to determine how well each treatment combination would prevent fungal growth. This study progressed through and entire treatment cycle and was sampled in 2021 for a final time prior to the removal of the study. Results from the most recent sampling are summarized below along with previously collected data.

Pentachlorophenol (penta) treated Douglas-fir pole sections (206-332 mm in diameter by 3 m long) were set to a depth of 0.6 m at the Corvallis test site. Three steeply angled holes were drilled into each pole beginning at groundline and moving upward 150 mm and around 120 degrees. The holes received either 160 g of powdered dazomet, 107 g of dazomet rod plus 100 g of copper naphthenate (2% as Cu), 160 g of dazomet rod alone, 160 g of dazomet rod amended with 100 g of copper naphthenate, 160 g of dazomet rod amended with 100 g of water, or 490 g of metam sodium. Pre-measured aliquots of the amendments were placed into the treatment holes on top of the fumigants. Each treatment was replicated on five poles.

Chemical distribution was assessed 1, 2, 3, 5, 7, 8, 10, 12, 15 and 21 years after treatment by removing increment cores at three equidistant locations around each pole (0.3, 0.8 or 1.3 m above the groundline). The outer treated zone of each core was discarded, and the remaining inner and outer 25 mm of each core was placed into 5 ml of ethyl acetate. The core was extracted in ethyl acetate for 48 hours at room temperature, removed, oven dried and weighed. The ethyl acetate extract was analyzed for residual MITC by gas chromatography. The remainder of each core was placed on 1.5% malt extract agar and observed for fungal growth. Any fungal growth was examined for characteristics typical of basidiomycetes, a class of fungi containing many important wood degrading species.

In evaluating treatment effectiveness, we have traditionally used a 20 ug of MITC/oven dried g of wood fungal protection threshold. This value is based upon examination of previous culturing and chemical analysis data from our many field trials. This is the 21st and final year of assessment. While we normally recommend retreatment on a 10-year cycle, we have included two additional assessments to illustrate cycle extension.

In general, MITC levels 1.3 m above groundline were rarely above threshold for the 21-year test, although there were a few points within the first 3 years after treatment where MITC levels were above threshold. MITC was detectable after 1.3 m above groundline in at least some samples all the way out to 21 years, but generally at low levels (Table 1.1.x, Figures 1.1.x to 1.1.x). For practical purposes, further discussion will be confined to MITC levels 0.3 and 0.8 m above groundline.

MITC levels in pole sections treated with metham sodium were above threshold in the inner and outer zone 1 and 3 years after treatment 0.3 m above groundline. MITC levels were more variable 0.8 m above groundline (Figure 1.1.7). MITC levels declined sharply at the 5-year sampling and continued to decline. No MITC was detected in any pole after 10 years, indicating there is no further protective effect beyond 10 years. Metham sodium is viewed as a system that rapidly releases MITC, virtually eliminating decay fungi within one year of treatment. However, MITC levels typically decline sharply within 3 years of application. Our results closely follow that pattern. Fortunately, fungal attack does not immediately occur; it often takes 7 to 10 years to occur and this allows metham sodium to be effectively used on a 10-year cycle (Morrell and Corden, 1986).

MITC levels in poles treated with powdered dazomet alone were slightly lower than metham sodium 0.3 m above groundline one-year after treatment, and levels were much lower 0.8 m

above groundline (Figure 1.1.8). However, MITC levels rose dramatically 5 years after treatment and have remained above the protective threshold in both the inner and outer zones 0.3 m above groundline until the 21-year sampling point. After 21 years, the outer core section had MITC levels below threshold, but the inner section still had MITC levels above the inhibitory threshold. MITC levels 0.8 m above groundline were above the threshold from 2 to 10 years after treatment in the inner zone, while levels in the outer zone drifted around threshold after 5 years. Later samples were generally below threshold. These results illustrate the long-term ability of dazomet to decompose into MITC and the effectiveness of dazomet in high-moisture areas near the groundline.

MITC levels in poles receiving 160 g of dazomet in rod form (9 rods), but no other additive were above the threshold 0.3 m above the groundline 1 year after treatment and only slightly lower than those found with metham sodium (Figure 1.1.9). Levels were slightly lower 2 years after treatment but then remained above the threshold until 21 years after treatment, where MITC levels were below the effective threshold. MITC levels were also above the threshold 0.8 m above groundline in the inner zone between 2 and 12 years after treatment, but tended to be much lower in the outer zone at this height. MITC levels above this zone were much more variable and dropped below threshold after 12 years. The results indicate that dazomet in rod form follows a similar decomposition pattern as powdered dazomet with the highest moisture areas causing the greatest decomposition.

The addition of 100 g of water to pole treatment holes receiving 160 g (9 rods) of dazomet tended to follow trends similar to those found with the rod treatments without water (Figure 1.1.10). While water can accelerate dazomet decomposition, the amount applied to the holes was relatively small compared to the wood mass surrounding the hole and the water was likely sucked up into the wood rapidly. MITC levels resulting from water addition to dazomet rods were not distinguishable from dazomet rod alone treatments.

The addition of copper naphthenate to treatment holes receiving the 9-rod dosage (160 g) slightly increased MITC levels in poles 0.3 m above groundline over the first 10 years after treatment and MITC remained at effective levels until 21 years. (Figure 1.1.11). After 21 years, only the inner section of cores taken 0.3 m above groundline were above effective threshold for MITC. At this timepoint, all other heights, 0.8 and 1.3 m, had very low levels of MITC and levels. Interestingly, the 6-rod, 107 g treatment showed a similar pattern of MITC distribution throughout the experiment as the 9-rod treatment (Figure 1.1.12). Even the concentrations of MITC were similar in most equivalent sampling points and times. This suggests that the lower chemical dosage may be sufficient to

MITC levels in dazomet powder treatments were similar to those in the six and nine rod treatments that received a copper naphthenate accelerant. These results suggest placing dazomet in rod form had a slight effect on MITC levels in comparison with the powder, but the two treatments are likely not statistically distinguishable due to the high variability in MITC levels in samples taken. Using dazomet in a rod form can provide some increase in the convenience of application without a reduction in performance.

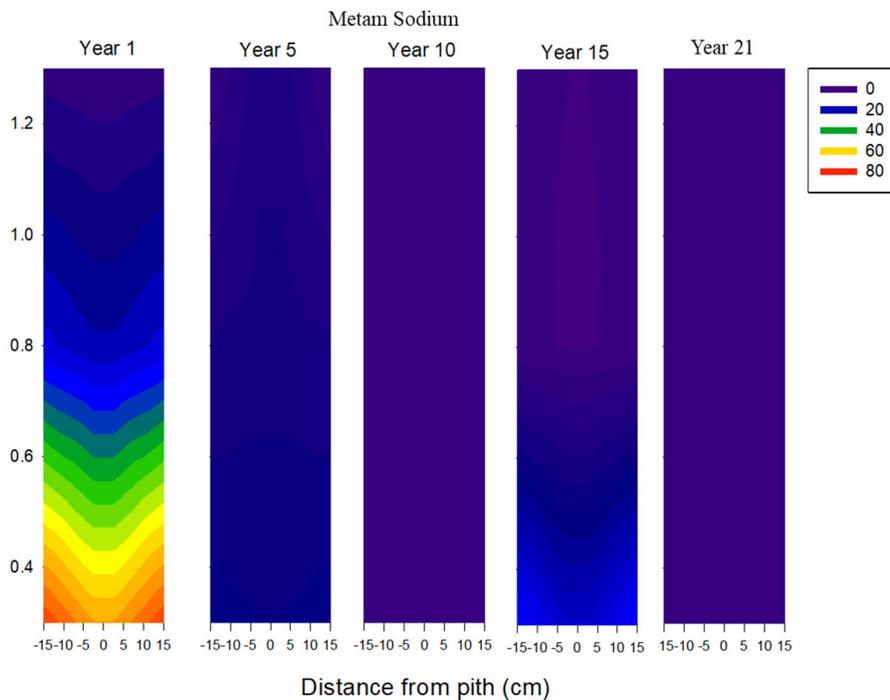


Figure 1.1.6. Map showing residual MITC levels in pentachlorophenol treated Douglas-fir poles 1 to 21 years after treatment with metham sodium where dark blue represents MITC levels below the threshold (20 $\mu\text{g/g}$) for fungal attack and increasingly green to yellow or red color represent levels above that threshold. Charts are extrapolated from individual MITC analyses at assay locations described in Table 1.1.6.

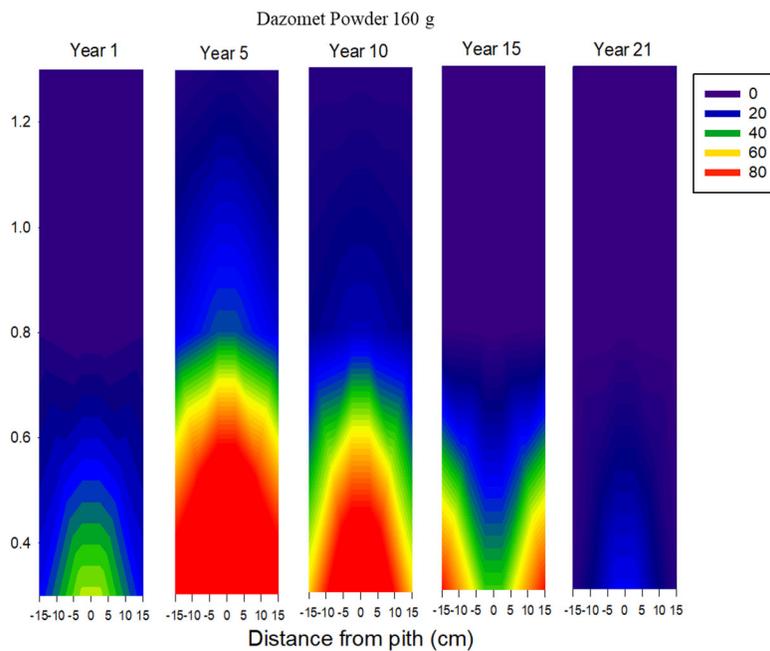


Figure 1.1.7. Map showing residual MITC levels in pentachlorophenol treated Douglas-fir poles 1 to 21 years after treatment with powdered dazomet alone (160 g) where dark blue represents MITC levels

below the threshold ($20 \mu\text{g/g}$) for fungal attack and increasingly green to yellow or red color represent levels above that threshold. Charts are extrapolated from individual MITC analyses at assay locations described in Table 1.1.6.

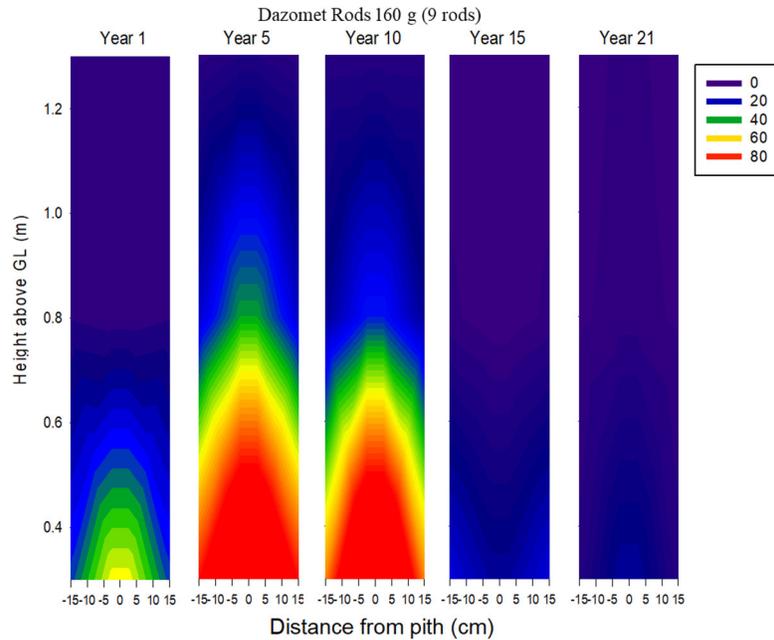


Figure 1.1.8. Map showing residual MITC levels in pentachlorophenol treated Douglas-fir poles 1 to 21 years after treatment with dazomet in rod form (9 rods, 160 g) alone where dark blue represents MITC levels below the threshold ($20 \mu\text{g/g}$) for fungal attack and increasingly green to yellow or red color represent levels above that threshold. Charts are extrapolated from individual MITC analyses at assay locations described in Table 1.1.6.

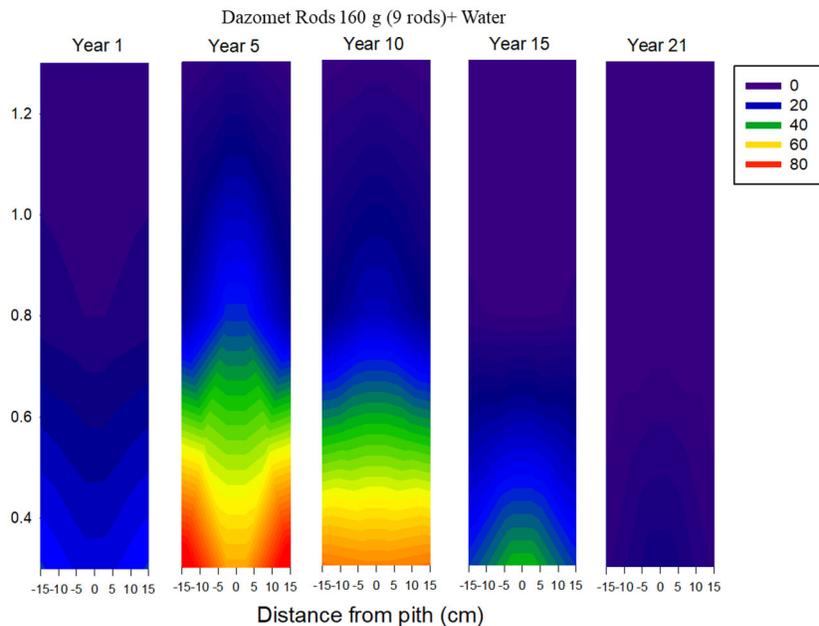


Figure 1.1.9. Map showing residual MITC levels in pentachlorophenol treated Douglas-fir poles 1 to 21 years after treatment with dazomet in rod form (9 rods, 160 g) plus 100 g of water where dark blue represents MITC levels below the threshold (20 µg/g) for fungal attack and increasingly green to yellow or red color represent levels above that threshold. Charts are extrapolated from individual MITC analyses at assay locations described in Table 1.1.6.

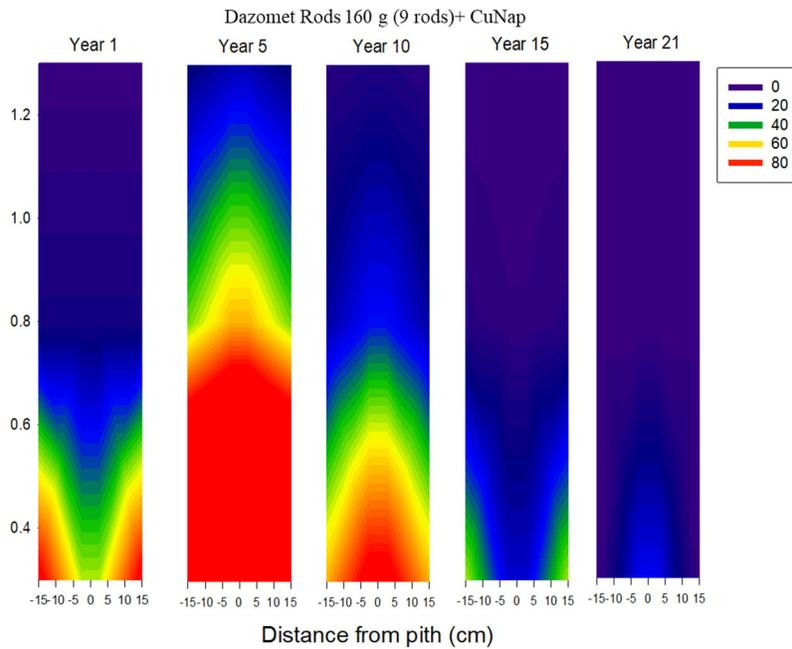


Figure 1.1.10. Map showing residual MITC levels in pentachlorophenol treated Douglas-fir poles 1 to 21 years after treatment with dazomet in rod (9 rods) form plus 100 g of copper naphthenate where dark blue represents MITC levels below the threshold (20 µg/g) for fungal attack and increasingly green to yellow or red color represent levels above that threshold. Charts are extrapolated from individual MITC analyses at assay locations described in Table 1.1.6.

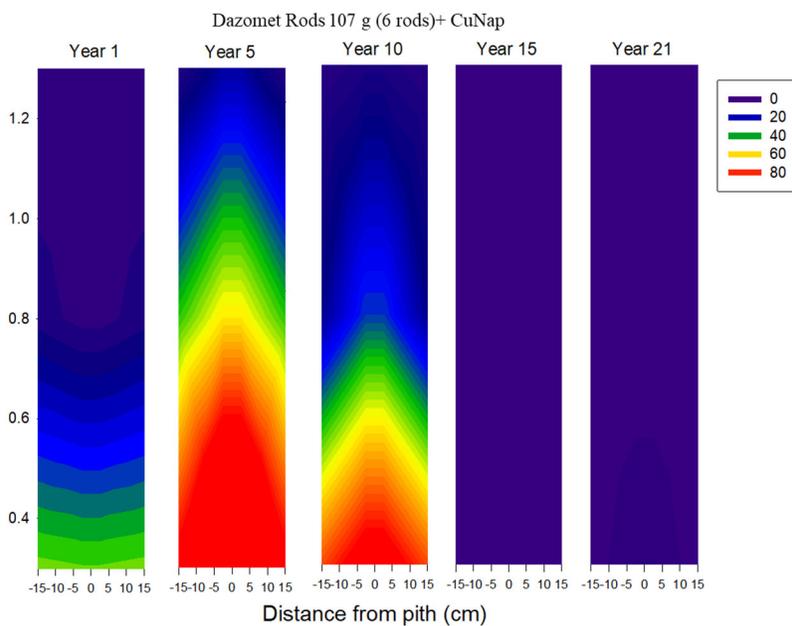


Figure 1.1.11. Map showing residual MITC levels in pentachlorophenol treated Douglas-fir poles 1 to 21 years after treatment with dazomet in rod (6 rods) form plus 100 g of copper naphthenate where dark blue represents MITC levels below the threshold (20 µg/g) for fungal attack and increasingly green to yellow or red color represent levels above that threshold. Charts are extrapolated from individual MITC analyses at assay locations described in Table 1.1.6.

Table 1.1.6. Residual MITC levels in pentachlorophenol treated Douglas-fir poles 1 to 21 years after treatment with metham sodium or dazomet in powdered or rod form in combination with water or copper naphthenate as accelerants.

Treatment	Dosage	Supplement	Year sampled	Residual MITC (ug/g wood) ^a					
				0.3 m above GL		0.8 m above GL		1.3 m above GL	
				inner	outer	inner	outer	inner	outer
Dazomet Powder	160 g	None	1	50 (35)	24 (23)	6 (17)	4 (8)	0 (0)	0 (1)
			2	52 (70)	16 (55)	42 (54)	1 (3)	25 (31)	27 (41)
			3	38 (41)	28 (44)	28 (28)	39 (65)	54 (98)	34 (51)
			5	145 (99)	97 (81)	32 (19)	22 (20)	8 (11)	4 (7)
			7	132 (45)	53 (49)	25 (23)	7 (9)	5 (6)	2 (5)
			8	132 (74)	88 (52)	42 (57)	18 (8)	12 (16)	4 (6)
			10	109 (70)	58 (44)	18 (16)	13 (10)	5 (7)	4 (7)
			12	74 (38)	28 (26)	14 (10)	7 (4)	4 (3)	2 (2)
			15	80 (73)	43 (38)	2 (4)	0 (2)	0 (0)	0 (0)
21	25 (17)	(4) (6)	(1) (3)	0 0	(2) (6)	(2) (6)			
Dazomet Rods (6)	107 g	100 g copper naphthenate	1	44 (57)	46 (44)	2 (4)	6 (8)	0 (0)	0 (0)
			2	51 (70)	0 (2)	36 (51)	1 (3)	73 (101)	14 (28)
			3	67 (81)	66 (102)	52 (98)	31 (46)	49 (67)	37 (71)
			5	118 (53)	85 (52)	56 (38)	42 (73)	16 (11)	5 (11)
			7	211 (324)	67 (58)	36 (18)	17 (11)	11 (10)	2 (4)
			8	118 (70)	115 (116)	33 (12)	20 (9)	14 (7)	6 (4)
			10	88 (54)	73 (62)	30 (21)	14 (10)	7 (6)	4 (6)
			12	63 (32)	32 (29)	20 (11)	8 (3)	6 (3)	2 (1)
			15	27 (17)	20 (33)	1 (2)	(0) (1)	0 (0)	0 (0)
21	4 (7)	1 (3)	0 0	0 0	0 0	0 0			
Dazomet Rods (9)	160 g	None	1	54 (95)	30 (30)	2 (4)	4 (7)	0 (2)	1 (3)
			2	29 (37)	3 (6)	35 (53)	1 (3)	33 (46)	6 (11)
			3	26 (36)	31 (43)	38 (51)	15 (20)	29 (34)	21 (49)
			5	113 (56)	80 (66)	38 (29)	21 (11)	6 (11)	3 (7)
			7	91 (63)	35 (28)	22 (12)	14 (13)	4 (9)	1 (3)
			8	93 (47)	119 (102)	33 (22)	22 (15)	9 (12)	4 (8)
			10	116 (97)	67 (58)	28 (34)	15 (17)	5 (10)	5 (10)
			12	60 (39)	31 (20)	21 (30)	11 (9)	7 (12)	3 (4)
			15	48 (48)	21 (22)	5 (10)	2 (4)	1 (1)	0 (1)
21	16 (28)	5 (12)	3 (7)	1 (4)	3 (11)	0 0			
Dazomet Rods (9)	160 g	100 g copper naphthenate	1	49 (63)	85 (88)	9 (16)	9 (16)	1 (2)	0 (2)
			2	80 (104)	17 (45)	49 (64)	4 (9)	62 (75)	5 (11)
			3	76 (101)	39 (53)	47 (55)	73 (115)	47 (52)	28 (48)
			5	175 (197)	159 (139)	62 (88)	46 (87)	18 (30)	11 (21)
			7	125 (70)	82 (51)	36 (45)	13 (12)	14 (19)	4 (5)
			8	114 (81)	92 (80)	33 (28)	21 (15)	13 (17)	5 (7)

			10	87 (47)	62 (50)	27 (25)	17 (14)	6 (13)	4 (7)
			12	72 (54)	34 (18)	17 (16)	9 (9)	8 (11)	3 (5)
			15	23 (18)	15 (23)	3 (4)	0 (1)	1 (2)	0 (0)
			21	25 (96)	0 0	0 0	0 0	0 0	0 0
Dazomet Rods (9)	160 g	100 g water	1	22 (21)	29 (35)	4 (6)	6 (10)	0 (0)	1 (2)
			2	33 (47)	1 (2)	32 (34)	1 (5)	41 (41)	6 (11)
			3	25 (23)	24 (28)	22 (31)	14 (26)	37 (45)	14 (27)
			5	63 (28)	87 (104)	29 (14)	15 (18)	5 (7)	1 (3)
			7	71 (37)	32 (29)	23 (16)	10 (11)	3 (5)	1 (3)
			8	70 (22)	89 (74)	25 (11)	15 (9)	7 (8)	4 (6)
			10	67 (38)	68 (58)	19 (9)	12 (14)	2 (5)	1 (2)
			12	69 (30)	41 (37)	16 (10)	8 (4)	3 (3)	2 (2)
			15	30 (19)	40 (52)	2 (4)	1 (3)	0 (0)	0 (0)
			21	9 (10)	3 (5)	0 0	0 0	0 0	
Metham Sodium	490 ml	None	1	64 (43)	75 (73)	17 (18)	22 (27)	1 (2)	2 (4)
			2	37 (49)	7 (11)	30 (27)	4 (7)	50 (78)	5 (10)
			3	22 (19)	22 (22)	17 (18)	21 (20)	18 (15)	17 (19)
			5	12 (11)	13 (10)	9 (9)	8 (10)	7 (8)	2 (5)
			7	3 (6)	3 (5)	3 (6)	1 (3)	0 (0)	0 (0)
			8	5 (8)	5 (7)	2 (4)	2 (4)	3 (6)	0 (1)
			10	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
			12	0 (1)	0 (1)	0 (1)	0 (0)	0 (0)	0 (0)
			15	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
			21	0 0	0 0	0 0	0 0	0 0	

1.2.0 Performance of Water Diffusible Preservatives as Internal Treatments

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

1.2.1 Performance of Copper Amended Fused Boron Rods

Date Established:	November 2001
Location:	Peavy Arboretum, Corvallis, OR

Pole Species, Treatment, Size	Douglas-fir penta and creosote
Circumference @ GL (avg., max., min.)	78, 102, 66 cm

Penta-treated Douglas-fir poles were treated with copper amended fused borate rods or fused borate rods beginning at groundline and moving upward 150 mm and either 90 or 120° around the pole. Poles were treated with either 4 or 8 copper/boron rods or 4 boron rods. Holes were plugged with tight fitting plastic plugs. Chemical movement was assessed 1, 2, 3, 5, 7, 9, 11, 14, 20 years after treatment by removing increment cores from locations 150 mm below groundline, at groundline, and 300 or 900 mm above-ground. The outer 25 mm treated shell was discarded, and the core was divided into inner and outer halves. Cores from a given zone on each set of poles were combined and ground to pass a 20-mesh screen. Ground wood was hot water extracted prior to being analyzed according to procedures described in American Wood Protection Standard A65, the Azomethine-H assay (AWPA, 2020). Results were expressed on a kg of boric acid equivalent (BAE)/cubic meter of wood basis. Previous studies in our lab have indicated the threshold for protection of Douglas-fir heartwood against internal decay is approximately 0.5 kg/m³ BAE (Freitag and Morrell 2005).

Boron levels in pole sections were below the protective threshold one year after treatment, but gradually increased over the threshold the next 2 years (Figures 1.2.1-1.2.3). Treatment levels appeared to drop slightly between 5-7 years after treatment, although they remained above threshold in many cases. Boron levels after 20 years were generally lower than the maximum levels recorded 5-9 years after treatment, but there were a few sampling areas where boron levels were increased after 20 years, indicating that rods were still serving as a chemical reservoir after two decades. Moisture is critical for boron movement, so it was no surprise that boron levels tended to be highest at groundline and 150 mm below-ground, reflecting the tendency for poles to be wetter in these regions. Boron levels tended to be higher in inner zones of increment cores, reflecting the positioning of rods towards the pole center. Boron levels tended to be below threshold 300 or 900 mm above groundline, reflecting the lower moisture regimes present in these zones.

Boron levels in poles sampled nine years after treatment rose sharply at a number of locations in the pole. In previous boron rod studies, we could equate these rises in boron level to an exceptionally wet year. Rainfall levels were normal for the year, but rain continued well till the end of June. Normally, rainfall would taper off sharply at the end of April and wood would begin to dry. The prolonged wet period may have enhanced boron movement, although it is difficult to see how this would make a difference so far into the test when rods have largely disintegrated.

Boron levels in poles 11 and 14 years after treatment were above threshold in the inner zone at groundline and 150 mm below. There appeared to be no consistent differences in boron levels

between the two treatments nor did application to holes spaced at 90 or 120° intervals around the pole make a noticeable difference in boron levels. This is notable because application of 8 copper amended rods did not appear to cause any major differences in boron concentration as compared to application of 4 rods. Boron levels in outer zones tended to be more variable, although they were over threshold in some instances. As with all internally applied remedial treatments, sloping application holes and the area occupied by the plug would tend to enhance chemical movement toward pole center. The presence of protective boron levels in poles 20 years after treatment indicates that these systems can deliver a sufficient amount of boron to poles in wetter climates where there is sufficient moisture for diffusion.

Boron levels in poles receiving fused borate and fused borate plus copper rods appeared to be equally effective at establishing threshold levels in application zones, suggesting that copper use had little influence on either initial boron diffusion or subsequent retention in wood.

Increasing rod dosage from 4 to 8 rods per pole did not appear to markedly enhance resulting boron levels in poles (Figure 1.2.3). Boron levels in outer zones tended to be low over the entire test period. While there was some indication that boron levels might be slightly higher in outer zones for poles receiving higher dosages, these differences were slight and probably not meaningful in terms of wood protection. As noted above, sloping holes will tend to move chemical inward, but higher dosages have the potential to place rods immediately adjacent to a poles surface and should result in higher boron levels in outer zones. It is unclear why this did not but may suggest that moisture is the primary driver behind boron spread over dosage. In addition, increased boron dosages have been expected to help maintain boron levels in poles for a longer period; however, there appeared to be no real difference in boron levels after 20 years. The 20-year sampling included a 450 mm below ground sampling as the poles were removed. Boron levels were low in all treatments at this location likely because the wood was outside of the diffusive range of the boron rods.

Copper levels in poles treated with copper amended rods were well below the protective threshold of 0.6 kg/m³ throughout the test (Figure 1.2.4-1.2.5). No copper was detected seven years after treatment, while slight amounts were detected in years 9 and 11. Similarly, this may reflect wetter conditions at the test site in those years. While copper levels increased, they were still well below those required to provide any substantive wood protection.

Culturing of the increment cores showed that fungal prevalence was generally low in the first few years except at groundline for the boron rod treatments which showed decay fungi in about 10% of cores in years 2-5. Interestingly, this trend halted at groundline in the boron-only treatments in later years (Table 1.2.1). Some decay fungi were isolated 300 or 900 mm above groundline; however, overall low levels of boron in these zones suggest that rod application had little or no consistent effect on fungal colonization at these distances above groundline. Fungal isolations near groundline tended to be more prevalent in poles receiving 4 fused borate rods

using either 90 or 120° spacing, although the isolation levels were very low (10% of cores sampled). No decay fungi were isolated at or below groundline for poles treated with either 4 or 8 fused borate/copper rods. Given the very low levels of copper associated with these treatments, it is unclear why there is any substantial difference in isolation frequency and fungal incidence differences may have precluded treatment with boron rods. After 20 years, incidence of decay fungi across all treatments generally remained low. Non-decay fungi were isolated in greater quantities and sometimes were found in up to 56 % of cores. As boron is a fungistatic substance and not a fumigant, it is expected that fungal cultures are not killed by the treatment but are prevented from moving into other areas where boron is present.

Results indicate that boron, from fused borate and fused borate/copper rods, is diffusing into Douglas-fir heartwood at rates capable of protecting against fungal attack. While there are some slight differences in chemical levels and decay fungi presence, results suggest the two treatments provide similar protection over the 20-year test.

This test was sampled for a final time in 2021, 20 years after installation. The pole stubs were removed, and this study was completed.

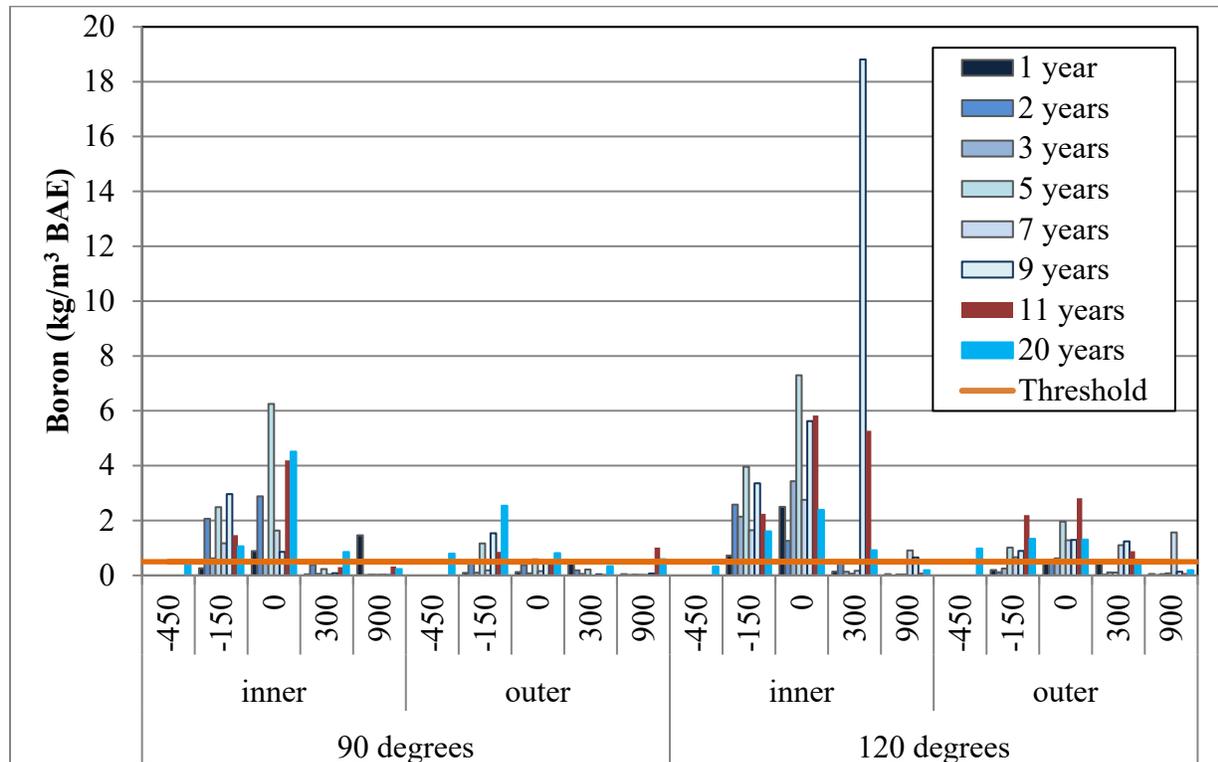


Figure 1.2.1. Boron levels at selected locations above or below groundline in Douglas-fir poles 1 to 20 years after treatment with 4 boron/copper rods.

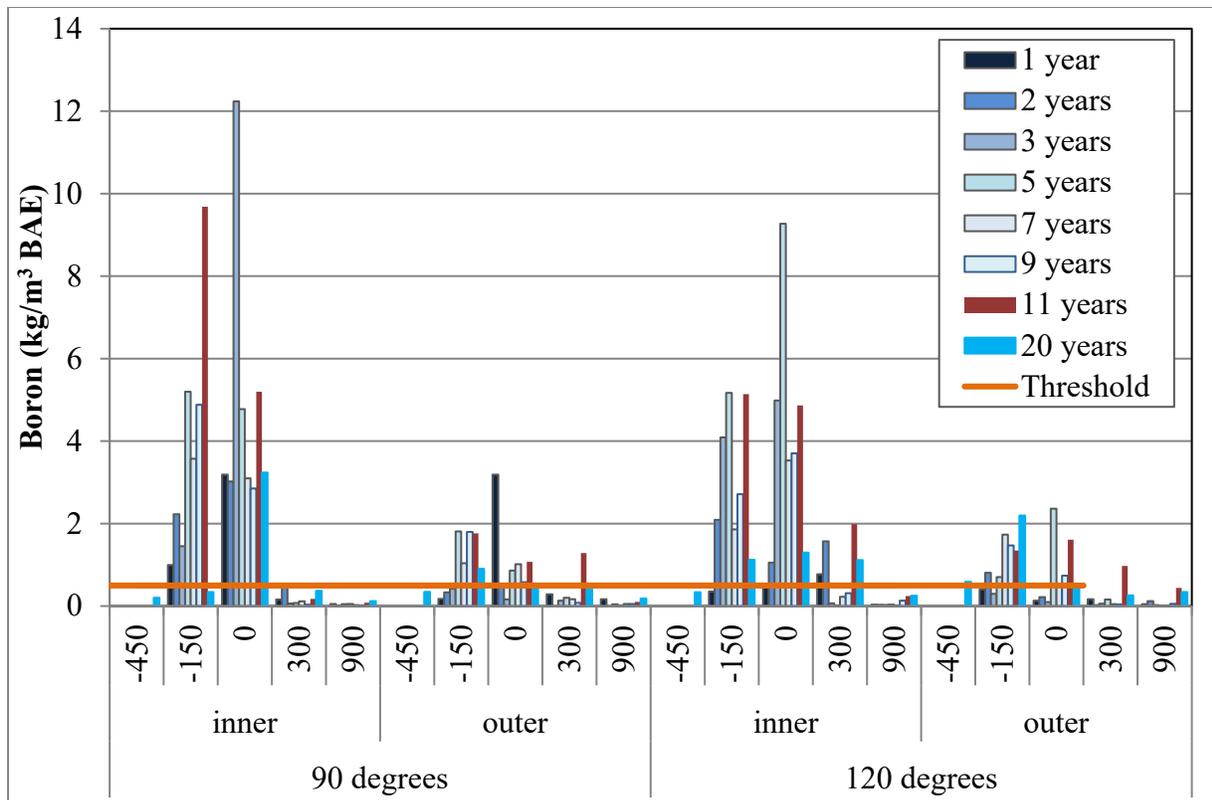


Figure 1.2.2. Boron levels at selected locations above or below groundline in Douglas-fir poles 1 to 20 years after treatment with 4 boron rods. The elevated values at 300 mm in the inner zone of poles treated using a 120-degree spacing likely reflect one very high value from a sample removed immediately adjacent to the original treatment hole.

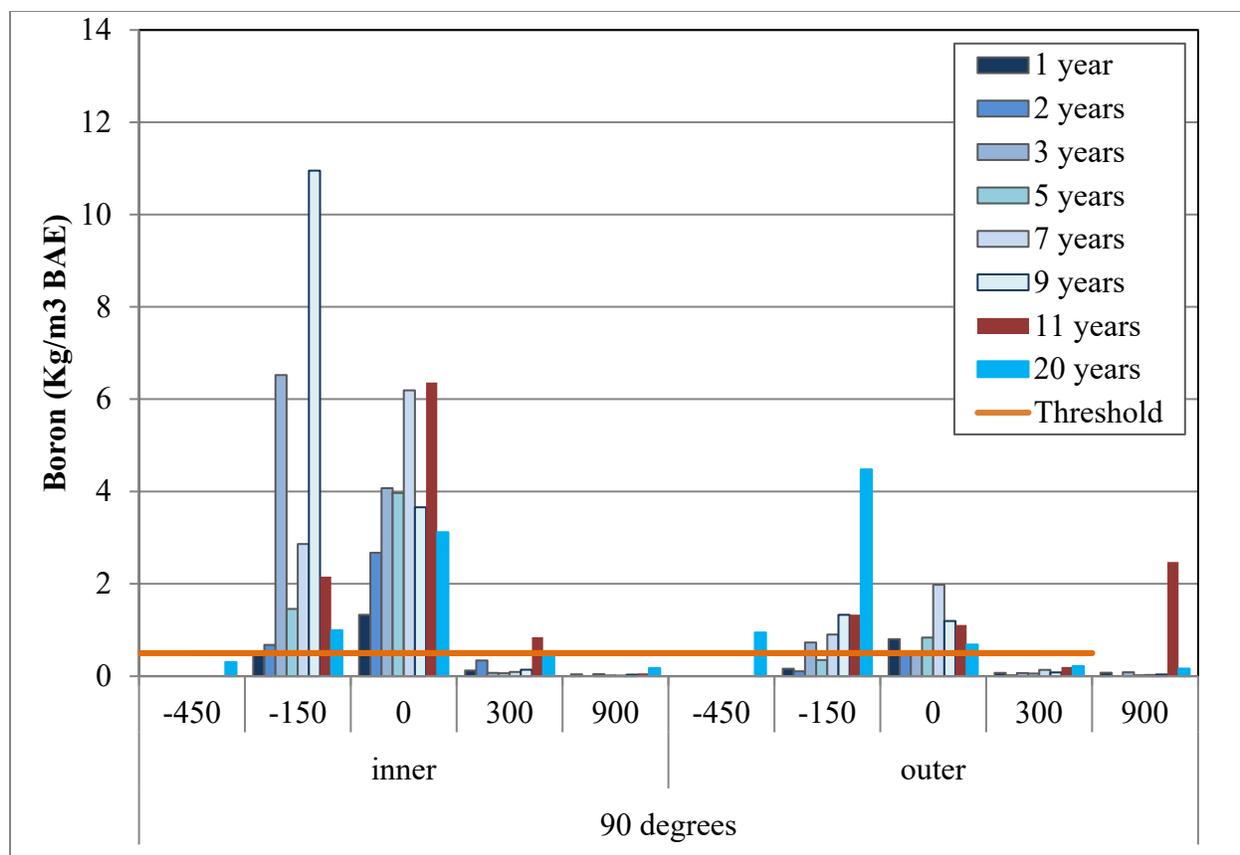


Figure 1.2.3. Boron levels at selected locations above or below groundline in Douglas-fir poles 1 to 20 years after treatment with 8 boron/copper rods.

Table 1.2.1: Frequency of decay and non-decay fungal isolations from 1-20 years after treatment.

Treatment	Rod Spacing	Year Sampled	Isolation Frequency (%) ^a									
			Below Ground ^b		-150 mm		0 mm		300 mm		900 mm	
4 copper/boron rods	90°	1	-	-	0	7	0	10	0	20	0	7
		2	-	-	0	33	0	20	0	10	7	0
		3	-	-	0	27	0	10	0	0	7	13
		5	-	-	0	33	0	30	20	0	7	13
		7	-	-	0	44	0	14	20	20	0	11
		9	-	-	0	38	0	0	0	25	0	14
		11	-	-	0	27	0	10	0	11	0	0
		14	-	-	0	22	0	25	8	33	17	22

		20	5.6	67	0	50	0	28	5.6	28	0	33
4 copper/boron rods	120°	1	-	-	0	40	0	0	0	0	0	13
		2	-	-	0	33	0	20	0	0	0	0
		3	-	-	0	47	0	30	0	0	0	7
		5	-	-	0	40	0	10	0	10	0	0
		7	-	-	0	9	0	14	0	13	29	0
		9	-	-	0	13	0	25	0	0	31	19
		11	-	-	0	6	0	0	0	0	0	0
		14	-	-	0	61	0	50	0	50	11	28
		20	0	50	0	56	0	50	5.6	33	5.6	33
4 boron rods	90°	1	-	-	0	7	0	10	0	0	0	0
		2	-	-	0	20	10	10	0	0	7	0
		3	-	-	0	40	10	50	0	0	13	7
		5	-	-	7	27	10	20	10	0	13	0
		7	-	-	10	40	0	33	0	0	0	0
		9	-	-	0	14	0	0	0	18	0	0
		11	-	-	0	0	0	8	0	8	0	0
		14	-	-	0	56	8	25	0	17	6	22
		20	0	39	11	50	0	22	0	22	0	28
4 boron rods	120°	1	-	-	0	0	0	0	0	0	0	20
		2	-	-	0	20	10	10	0	0	7	0
		3	-	-	0	40	10	50	0	0	13	7
		5	-	-	0	47	10	30	0	10	7	0
		7	-	-	0	0	0	50	0	0	0	0
		9	-	-	0	0	0	0	0	0	7	0
		11	-	-	0	0	0	0	0	0	0	0
		14	-	-	0	61	0	42	0	25	11	11
		20	5.6	44	5.6	44	0	39	0	17	5.6	33
8 copper/boron rods	90°	1	-	-	0	0	0	0	0	0	0	7
		2	-	-	0	0	0	0	0	20	0	7
		3	-	-	0	27	0	10	0	0	0	0
		5	-	-	0	33	0	0	0	0	13	33
		7	-	-	0	0	0	0	0	0	0	0
		9	-	-	0	25	0	0	0	0	0	7
		11	-	-	0	12	0	0	0	0	0	0
		14	-	-	0	44	0	17	0	17	0	22
		20	5.6	44	0	44	0	17	0	17	0	17

^aNumbers in superscript are percentages of non-decay fungi.

^bYears with a "-" were not sampled in the Below Ground (pole butt) position.

1.2.2. Performance of fused borate rods in internal groundline treatments of Douglas-fir poles

Date Established:	May-93
Location:	Peavy Arboretum, Corvallis, OR
Pole Species, Treatment, Size	Douglas-fir, penta
Circumference @ GL (avg., max., min.)	101, 114, 89 cm

Thirty pentachlorophenol treated Douglas-fir poles (283-364 mm in diameter by 2 m long) were set to a depth of 0.6 m at the Peavy Arboretum test site. Three 19 mm diameter by 200 mm long holes were drilled perpendicular to the grain beginning at groundline and moving around the pole 120 degrees and upward 15 cm. Each hole received either 1 or 2 boron rods (180 or 360 g of rod, respectively). The holes were then plugged with tight fitting wooden dowels. Each treatment was replicated on 10 poles. The poles were sampled 1, 3, 4, 5, 7, 10, 12, 15, 20 and 28 years after treatment by removing increment cores from sites located 15 cm below groundline as well as 7.5, 22.5, 45, and 60 cm above the groundline. The cores were divided into inner and outer segments which were combined according to treatment and height, then ground to pass a 20-mesh screen, extracted and analyzed for boron using the Azomethine H method. Boron levels were expressed on a kg/m³ of boron as boric acid equivalent (BAE). Previous studies in our laboratory indicate that the threshold for protection of Douglas-fir heartwood against internal decay is approximately 0.5 kg/m³ BAE.

Non-treated control poles naturally contained low levels of background boron ranging from 0.01 to 0.35 kg/m³ and were mostly outside of the detection limit of the assay (Table 1.2.2). These levels are well below the threshold for protection. Boron levels in the inner zones of poles treated with 180 g of boron rod were at or above the threshold 150 mm below ground as well as 75 and 225 mm above the groundline until 28 years where they started to dip below the effective threshold (Figure 1.2.6). Boron levels in the outer zones were generally lower at these same locations which could be partly due to the preservative treated shell impeding boron migration and the more frequent drying that occurs near the pole surface. However, there were several outer zones that did contain boron levels above the effective threshold up to year 20. Boron levels 450 and 600 mm above groundline were much lower and generally below the protective threshold over the course of the test. These sampling sites were well above the original treatment zone and it is likely that boron diffusion was not able to reach 450 mm or higher.

Boron levels in poles treated with 360 g of boron rod followed similar trends to those for the 180 g treatment, although the levels of boron detected were sometimes much greater, particularly in the inner zone 75 mm above groundline (Figure 1.2.7). This area corresponded to the center of the treated zone. We often observe the absence of a dosage effect with boron rods and have attributed this lack of effect to inadequate moisture in the wood; however, there did appear to be some difference in boron levels between the two dosages early in the test. This effect disappeared after five years but appeared again 15, 20 and 28-year sampling points. Boron levels above the effective threshold were detected 28 years after application up to 450 mm above

groundline. This indicates that with the higher doses of boron, there may still be a reservoir of boron for diffusion throughout wood 28 years after treatment.

Fungal isolations were only performed in the later years of this test (16, 20 and 28) and the results varied widely among the poles and with distance from the groundline (Table 1.2.2). Decay fungi were isolated predominantly not isolated from below, at or slightly above groundline out to the 28-year timepoint. In area farther up the pole, 450-600 mm above groundline, much higher rates of decay fungi isolation persisted which reflects the lower boron concentration at these levels.

The results indicate that boron continues to remain in the treated zone of the poles at levels capable of conferring protection against fungal attack 28 years after treatment. Although the protected zone is likely too limited to provide protection to the entire pole, treatment appeared to effectively inhibit the proliferation of decay fungi in areas where moisture levels were high enough to enable boron diffusion.

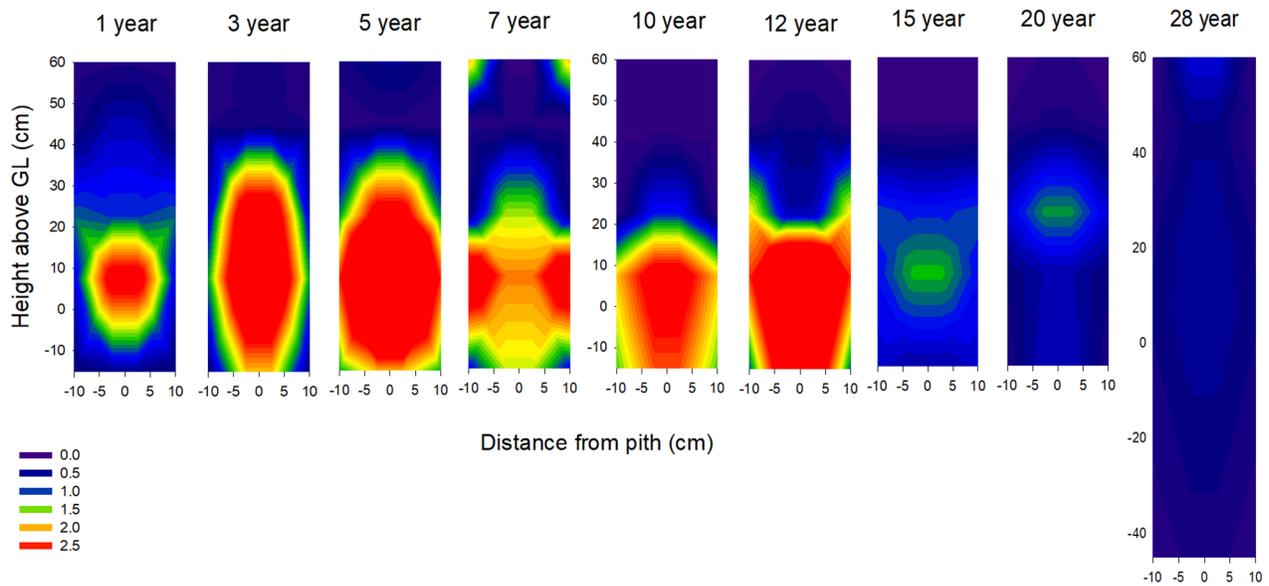


Figure 1.2.6: Heatmaps showing boron levels in Douglas-fir poles treated with 180 g of fused borate rods over a 28-year period.

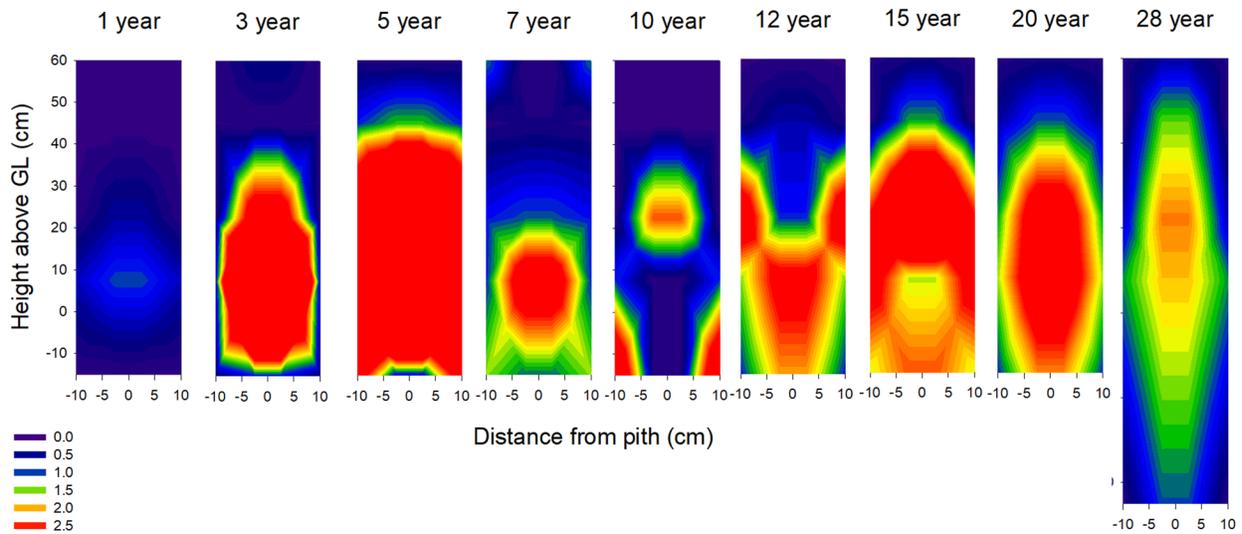


Figure 1.2.7: Heatmaps showing boron levels in Douglas-fir poles treated with 360 g of fused borate rods over a 28-year period.

Table 1.2.2: Boron levels in pole segments 1-28 years after treatment with fused boron rods

Dosage (g)	Sampling Ht. (cm)	Core Section	Boron (kg/m ³ BAE) ¹										
			Year 1	Year 3	Year 4	Year 5	Year 7	Year 10	Year 12	Year 15	Year 20	Year 28	
180		inner											0.23
		outer											0.11
	-15	inner	0.38	1.81	2.39	1.85	1.54	2.16	3.33	0.50	0.59		
	-15	outer	0.24	0.25	0.49	1.14	0.70	1.32	0.94	0.62	0.23		
	7.5	inner	2.82	3.75	6.02	6.40	2.05	2.83	4.65	1.25	0.52	0.49	
	7.5	outer	0.65	1.10	1.16	2.32	3.38	1.84	2.28	0.82	0.31	0.32	
180	22.5	inner	0.89	3.16	2.09	2.82	1.47	0.81	0.52	0.86	1.15	0.48	
	22.5	outer	0.98	0.58	0.35	1.10	0.31	0.14	1.70	0.96	0.67	0.28	
	45	inner	0.54	0.22	0.21	0.17	0.15	0.00	0.28	0.05	0.22	0.37	
	45	outer	0.22	0.20	0.11	0.09	0.12	0.00	0.12	0.07	0.10	0.10	
	60	inner	0.18	0.24	0.19	0.41	0.08	0.00	0.11	0.02	0.11	0.69	
	60	outer	0.14	0.09	0.06	0.25	1.80	0.00	0.04	0.00	0.03	0.08	
360		inner											0.97
		outer											0.13
	-15	inner	0.09	0.76	0.62	0.60	1.00	0.09	1.94	2.29	2.09		
	-15	outer	0.07	0.23	0.27	3.00	1.42	3.94	0.82	1.62	0.88		
	7.5	inner	0.96	10.8	7.27	12.0	3.28	0.11	2.77	1.56	3.43	1.89	
	7.5	outer	0.59	0.61	1.33	3.93	0.85	0.89	1.39	3.01	1.51	1.14	
360	22.5	inner	0.48	3.21	1.35	7.30	0.95	2.27	0.81	5.23	3.28	2.13	
	22.5	outer	0.13	0.14	0.42	4.34	0.77	0.07	3.30	2.57	1.17	0.55	

	45	inner	0.04	0.11	0.08	1.24	0.21	0.00	0.50	1.20	0.99	1.40
		outer	0.02	0.09	0.07	0.83	0.17	0.00	0.21	0.12	0.48	0.13
	60	inner	0.05	0.39	0.21	0.16	0.10	0.00	0.13	0.27	0.25	0.48
		outer	0.02	0.09	0.09	0.16	1.02	0.00	0.06	0.13	0.13	0.14
Contr ol		inner										0.35
		outer										0.03
	-15	inner	0.02	0.09	0.02	0.05	0.06	0.00	0.01	0.00	0.00	
		outer	0.02	0.09	0.02	0.07	0.06	0.00	0.00	0.00	0.05	
	7.5	inner	0.02	0.06	0.06	0.03	0.05	0.00	0.02	0.00	0.03	0.17
		outer	0.02	0.07	0.02	0.02	0.05	0.00	0.02	0.00	0.04	0.07
22.5	inner	0.01	0.08	0.02	0.05	0.05	0.00	0.05	0.00	0.16	0.09	
	outer	0.01	0.07	0.02	0.03	0.04	0.00	0.01	0.00	0.07	0.05	
45	inner	0.03	0.06	0.02	0.03	0.03	0.00	0.04	0.00	0.04	0.35	
	outer	0.02	0.10	0.02	0.02	0.03	0.00	0.06	0.00	0.03	0.06	
60	inner	0.02	0.08	0.02	0.27	0.08	0.00	0.06	0.01	0.07	0.29	
	outer	0.01	0.09	0.03	0.11	0.04	0.00	0.02	0.02	0.01	0.09	

Table 1.2.3. Decay fungi isolated from Douglas-fir poles treated with fused boron rods at two dosage levels, 180 or 360 g. The values presented are Percentage of all cores containing decay fungi.

Dosage (g)	Years after treatment	Cores with decay fungi (%)				
		Height above groundline (cm)				
		-15	7.5	22.5	45	60
180	16	0	0	0	7	21
	20	3	0	0	11	19
	28	0	0	10	3	n/a
360	16	3	0	3	15	19
	20	3	0	4	7	19
	28	0	0	0	7	n/a

1.2.3 Effect of Glycol on Movement of Boron from Fused Boron Rods

Date Established:	Mar-95
Location:	Peavy Arboretum, Corvallis, OR
Pole Species, Treatment, Size	Douglas-fir, penta
Circumference @ GL (avg., max., min.)	84, 104, 65 cm

While boron has been found to move with moisture through most pole species (Dickinson et al., 1988; Dietz and Schmidt, 1988; Dirol, 1988; Edlund et al., 1983; Ruddick and Kundzewicz,

1992), our initial field tests showed slower movement in the first year after application. One remedy to the slow movement that has been used in Europe has been the addition of glycol. Glycol is believed to stimulate movement through dry wood that would normally not support diffusion (Bech-Anderson, 1987; Edlund et al., 1983).

Penta-treated Douglas-fir pole sections (259 to 315 mm in diameter by 2.1 m long) were set to a depth of 0.6 m in the ground at the Peavy Arboretum test site. The pole test site receives an average yearly precipitation of 1050 mm with 81% falling between October and March. Four 19 mm diameter holes were drilled at a 45° downward sloping angle in each pole, beginning 75 mm above the groundline, then moving 90 degrees around and up to 230, 300, and 450 mm above the groundline. An equal amount of boron (227 g BAE) was added to each pole, but was delivered in different combinations of boron, water, or glycol (Table 1.2.4). The borate rods were 100 mm long by 12.7 mm in diameter and weighed 24.4 g each. An equal weight of boron composed of one whole rod and a portion of another, were placed in each hole followed by the appropriate liquid supplement or were left dry. The holes were then plugged with tight fitting wooden dowels. Each treatment was replicated on five poles.

Table 1.2.4 Combinations of boron rods and various boron additives used to treat Douglas-fir poles. All treatments delivered 227 g BAE per pole.

Boron rod (g)	Supplement	Amount of supplement (g)	Total glycol (g)	Total water (g)	Supplement source	Supplement formulation
156	None	0	0	0		
137	BoraCare 1:1 in water	118	28	65	Nisus Corp. Rockford, TN	Disodium octaborate tetrahydrate plus poly and monoethylene glycol
137	Boracol 20	122	77	20	Viance LLC Charlotte, NC	Disodium octaborate tetrahydrate plus poly-ethylene glycol (20%)
104	Boracol 40	164	95	0	Viance LLC Charlotte, NC	Disodium octaborate tetrahydrate plus poly-ethylene glycol (40%)
156	Poly ethylene glycol	100	100	0	VanWaters and Rogers, Seattle, WA	
146	Timbor 10% in water	118	0	106	U.S. Borax Inc.	Disodium octaborate tetrahydrate

The pole sections were sampled 1, 2, 3, 5, 7, 10, 12, 15, 20 and 26 years after treatment by removing two increment cores 180 degrees apart from 30 cm below the groundline, and cores from three equidistant locations around the pole 150 and 300 mm the groundline. The treated portion of the cores were discarded, then the remainder of each core was divided into zones corresponding to 0-50 (O), 51-100 (M), and 101-150 (I) mm from the edge of the treated zone. The zones from the same depth and height from a given treatment were combined and ground to pass a 20-mesh screen. The resulting sawdust was then extracted and analyzed using the azomethine-H method.

Boron levels in poles receiving only rods were above threshold at or below groundline one year after treatment, but below that level above groundline (Table 1.2.5; Figure 1.2.8). Levels at groundline remained above the threshold for the next 25 years after treatment in most of the sampling locations. After 26 years, the only location where boron levels were consistently below threshold levels was in the 18-inch below ground sample taken at the end of the study. This point may have been too far away from the treatment hole to allow for migration.

The addition of Boracare or Boracol 20 to the rods resulted in much higher overall boron levels at or above groundline one year after treatment, but had little to no effect on boron levels belowground (Figures 1.2.9-1.2.10). Boron levels remained above the threshold for the next 11 years and average boron levels (when outer, middle and inner zones were combined). After 26 years, Boracare treatments showed relatively high boron levels at and 150 mm above groundline. Most other sampling points were above threshold except below groundline. Boracol 20 treatments had somewhat lower boron concentrations after 26 years, and most samples were below threshold except the inner sections take at and above groundline.

Addition of Boracol 40 to the boron rods produced much higher boron levels in wood at the groundline level years 1, 3, and 5 years after treatment (Figure 1.2.11). The comparison of the two Boracol treatments as informative because it appeared that the higher glycol treatment (Boracol 40) delivered a higher impulse of boron early on in the study. However, this was diminished in later sampling points and by year 26, poles treated with Boracol 40 showed boron levels only just at (0.5 kg/m^3) or below threshold levels in nearly all samples.

The addition of glycol alone to the boron rods also resulted in an increase in boron levels over the course of the test, particularly at groundline and 150 mm above the level (Figure 1.2.12). This pattern was somewhat similar to Boracol 40 at least in the early years of the test. Enhanced boron migration was still evident 20 years after treatment. After 26 years, virtually all sampling locations showed boron levels at or slightly above threshold levels.

Similarly, boron levels in poles receiving rods with liquid Timbor were elevated compared to those just receiving rods (Figure 1.2.13). It is unclear whether the enhanced boron levels in these treatments was due to the application of liquid or to the addition of solubilized boron, but levels did appear to increase nonetheless. After 26 years any initial benefit had subsided and while most sampling locations were above threshold, they were not distinguishable from boron rods alone.

The overall trends in this test can be difficult to interpret because of the multiple sampling sites and inspection times. It is relatively simple to look at average boron content at groundline where

treatment would be most critical, over time. Boron continued to be detectable in virtually all pole sections at groundline through the life of the study. Boron levels at groundline were highest in poles receiving boron rods plus Boracol 40; however, these levels also declined to low levels by the end of the test. Several treatments produced initial increases in boron levels, but the overall levels were similar for most treatments over the course of the test, particularly at sampling points after 5 years. Boron levels after 10 years after treatment tended to be uniformly low (although levels were somewhat higher in the boron glycol treatment), but still over the threshold for protection against fungal attack. This work shows that boron rods with or without the addition of a glycol-based additive can diffuse enough boron into poles to inhibit fungal growth even decades after application.

The results with various combinations of boron rods and Boracare, Boracol, Timbor, or glycol suggest that some supplemental liquid enhanced boron movement, particularly within the first 5 years after treatment whether or not the additive contained boron or glycol. As a result, supplemental applications in conjunction with boron rods should especially be considered where these formulations are being applied to actively decaying wood where considerable additional damage might occur while the boron diffuses from the rods into the surrounding wood.

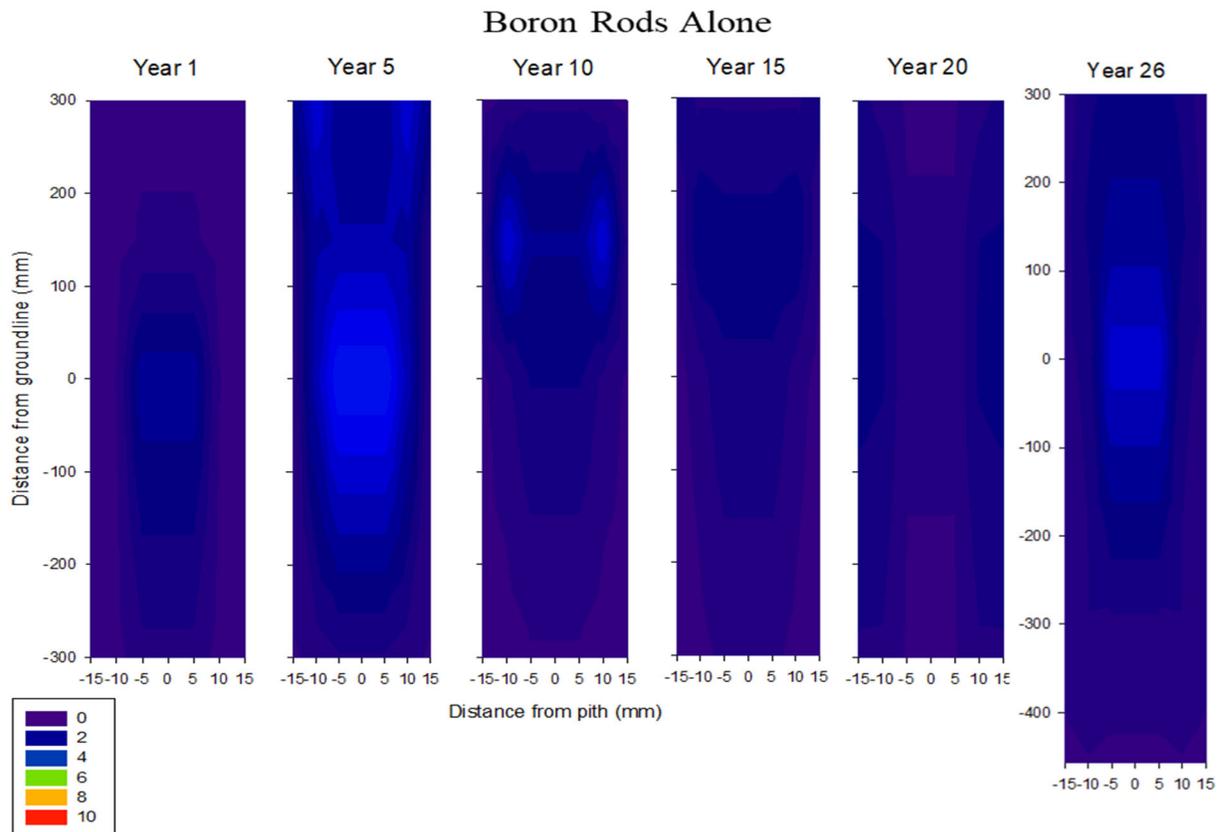


Figure 1.2.8: Boron distribution in Douglas-fir poles 1 to 26 years after treatment with fused boron rods. Purple represents levels below the threshold for protection against fungal attack,

while lighter blue, green and orange colors represent increasing boron concentrations in the wood. Charts are extrapolated from individual boron analyses at assay locations described in

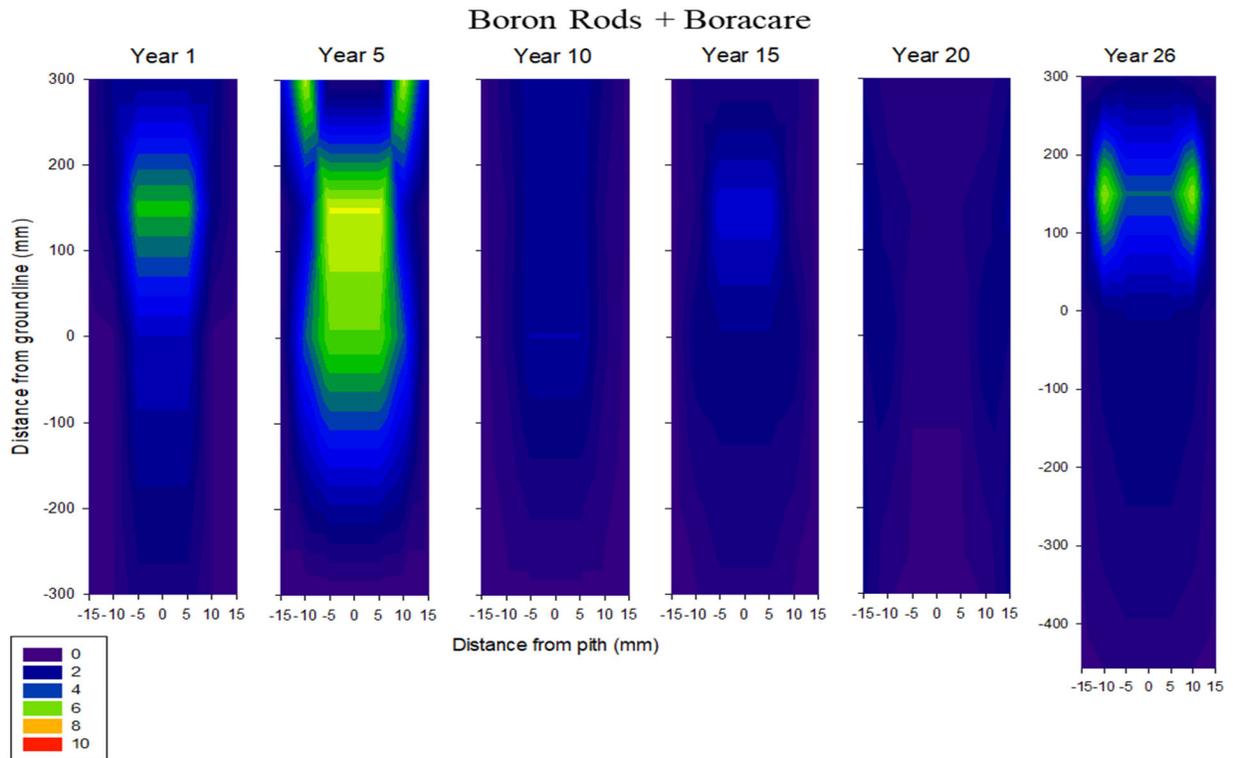


Figure 1.2.9: Boron distribution in Douglas-fir poles 1 to 26 years after treatment with fused boron rods plus Boracare. Purple represents levels below the threshold for protection against fungal attack, while lighter blue, green and orange colors represent increasing boron concentrations in the wood. Charts are extrapolated from individual boron analyses at assay locations described in Table 1.2.5.

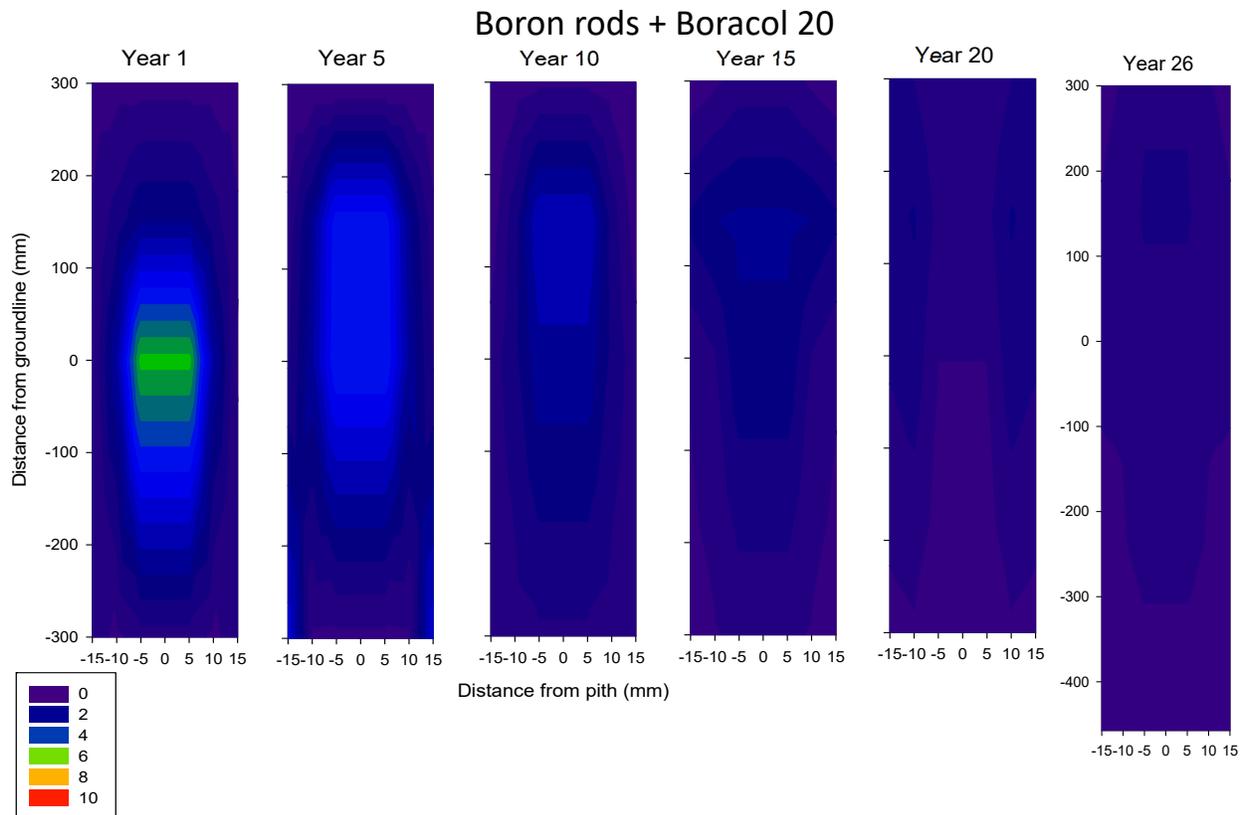


Figure 1.2.10 Boron distribution in Douglas-fir poles 1 to 26 years after treatment with fused boron rods plus Boracol 20. Purple represents levels below the threshold for protection against fungal attack, while lighter blue, green and orange colors represent increasing boron concentrations in the wood. Charts are extrapolated from individual boron analyses at assay locations described in Table 1.2.5.

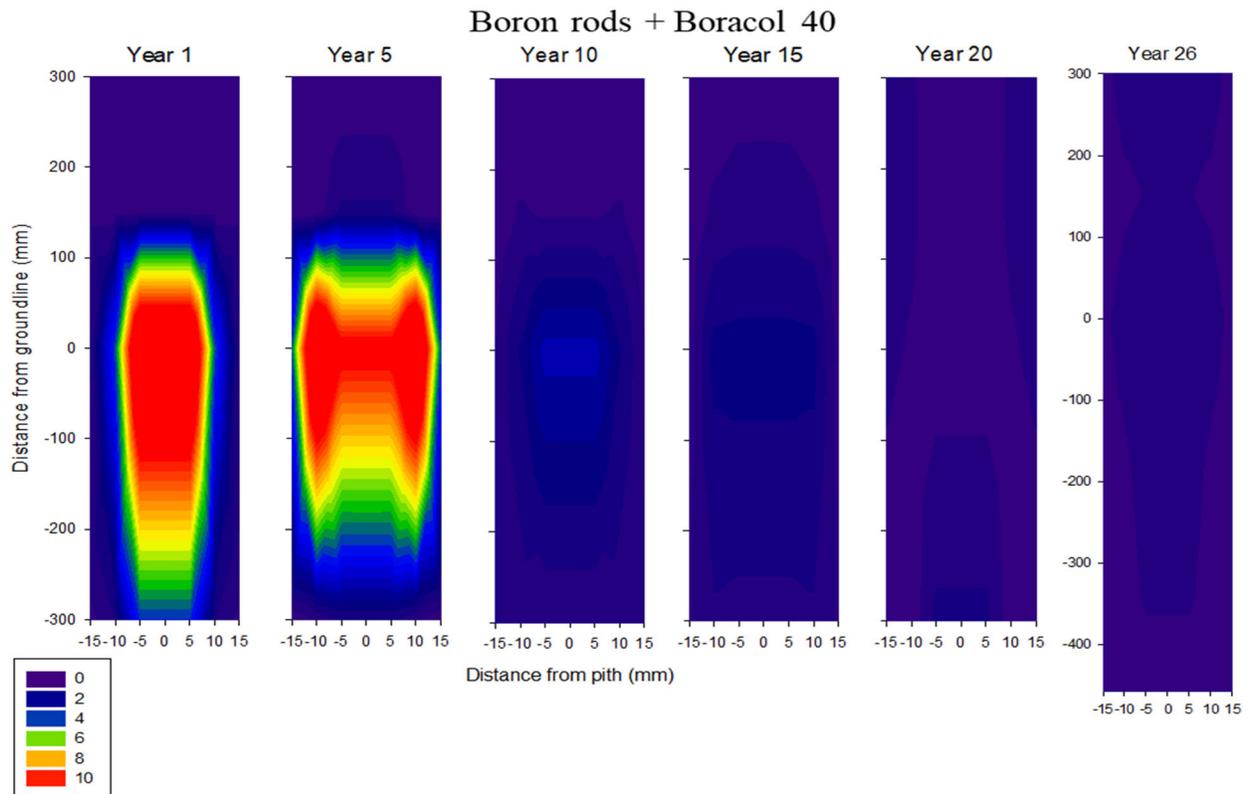


Figure 1.2.11 Boron distribution in Douglas-fir poles 1 to 26 years after treatment with fused boron rods plus Boracol 40. Purple represents levels below the threshold for protection against fungal attack, while lighter blue, green and orange colors represent increasing boron concentrations in the wood. Charts are extrapolated from individual boron analyses at assay locations described in Table 1.2.5.

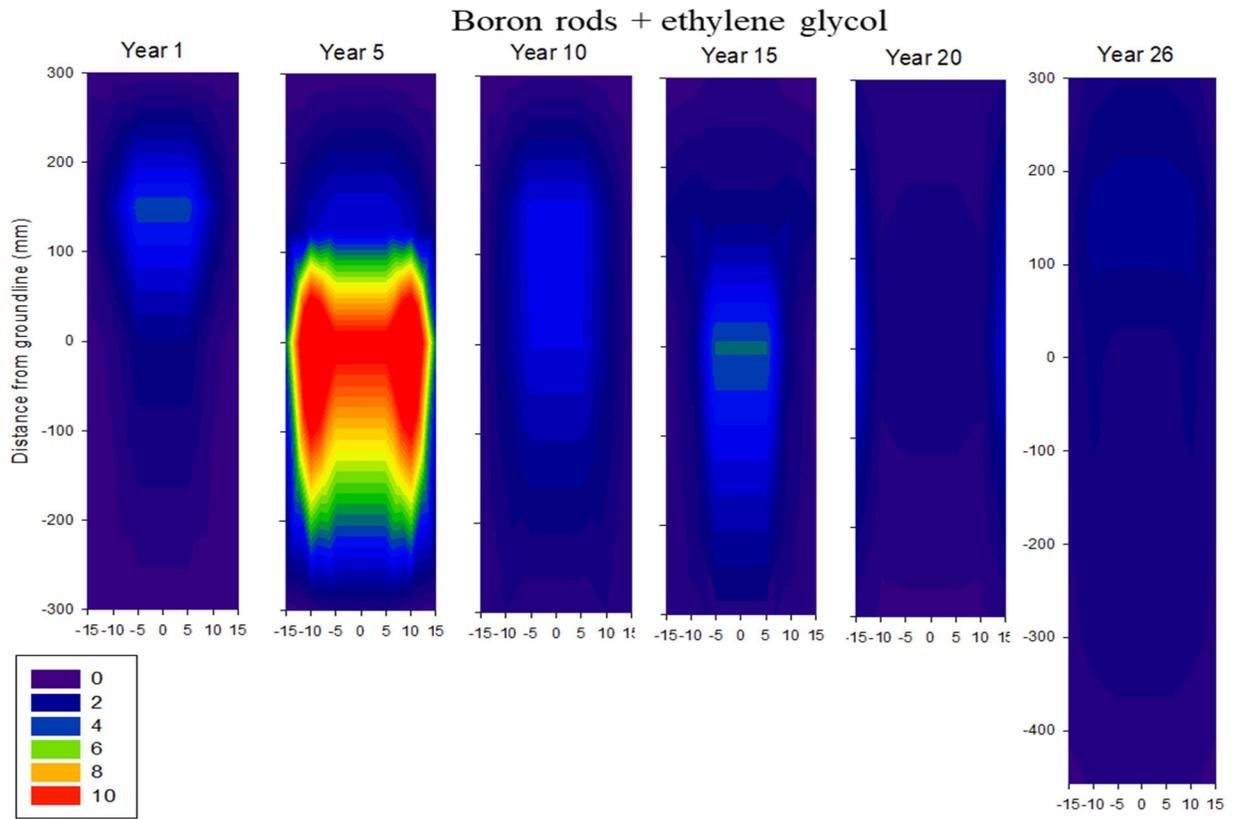


Figure 1.2.12: Boron distribution in Douglas-fir poles 1 to 26 years after treatment with fused boron rods plus Ethylene Glycol. Purple represents levels below the threshold for protection against fungal attack, while lighter blue, green and orange colors represent increasing boron concentrations in the wood. Charts are extrapolated from individual boron analyses at assay locations described in Table 1.2.5.

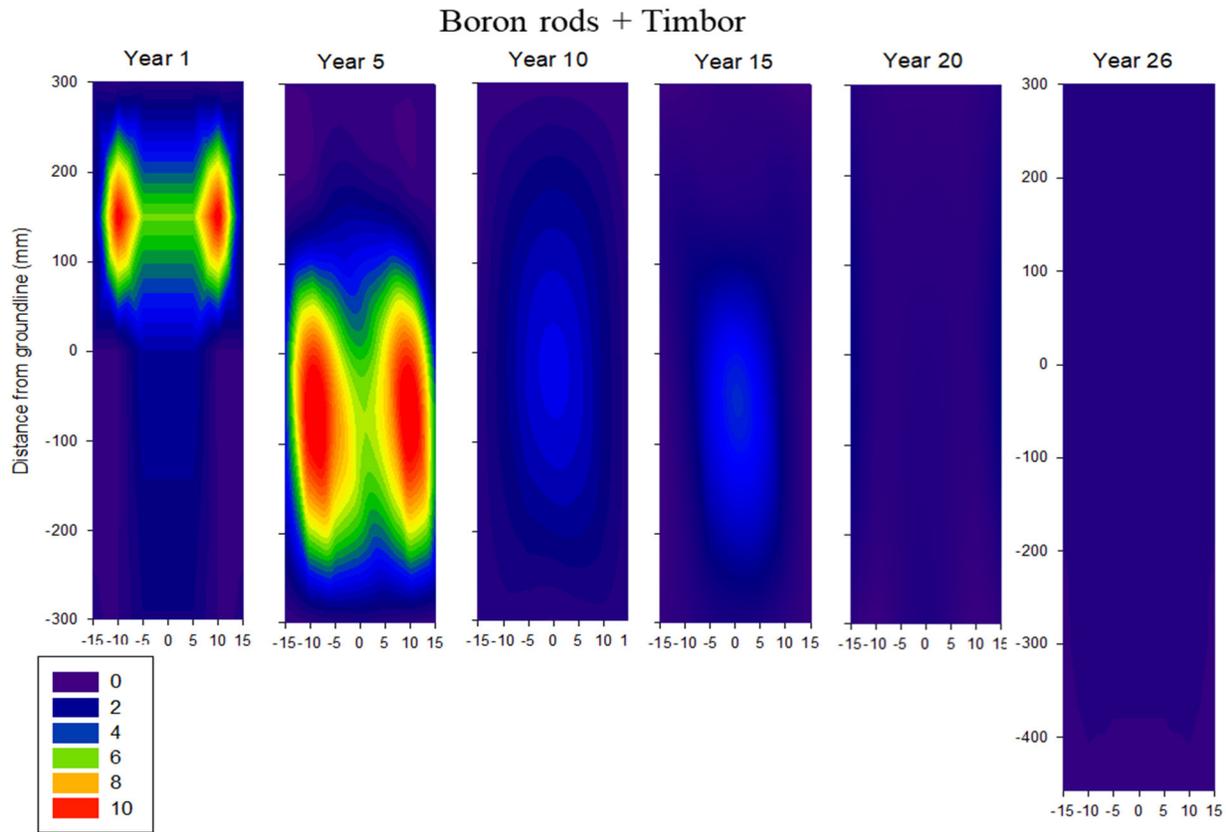


Figure 1.2.13 Boron distribution in Douglas-fir poles 1 to 26 years after treatment with fused boron rods plus Timbor solution. Purple represents levels below the threshold for protection against fungal attack, while lighter blue, green and orange colors represent increasing boron concentrations in the wood. Charts are extrapolated from individual boron analyses at assay locations described in Table 1.2.5.

Table 1.2.5: Boron levels in Douglas-fir poles 1 to 20 years after treatment with various combinations of fused boron rod and various water or glycol based additives. Numbers in bold represent boron levels above the toxic threshold of 0.5 kg/m³ BAE. Figures in parentheses represent one standard deviation

Treatment	Height (mm)	Depth	Boron (Kg/m ³ BAE) ^a										
			Year 1	Year 2	Year 3	Year 5	Year 7	Year 10	Year 12	Year 15	Year 20	Year 26	
Rods alone	-457	I											0.3 (0.10)
		M											0.4 (0.29)
		O											
	-300	I	0.52 (0.45)	1.40 (1.23)	0.87 (0.82)	0.53 (0.92)	0.46 (0.64)	0.35 (0.17)	0.23 (0.40)	0.49 (0.06)	0.34 (0.14)	0.7 (0.79)	
		M	0.81 (1.34)	0.83 (0.91)	0.37 (0.30)	0.37 (0.69)	0.37 (0.56)	0.21 (0.35)	0.22 (0.39)	0.29 (0.11)	0.74 (0.19)	0.8 (0.67)	
		O	0.30 (0.10)	0.43 (0.56)	0.24 (0.23)	0.50 (0.59)	0.10 (0.08)	0.28 (0.35)	0.11 (0.20)	0.07 (0.02)	0.74 (0.37)	0.6 (0.47)	
0	I	1.31 (1.91)	2.16 (0.97)	2.15 (1.97)	2.88 (1.98)	1.10 (0.87)	1.23 (0.38)	0.81 (0.44)	1.12 (0.90)	0.45 (0.18)	2.6 NA		
	M	0.34 (0.24)	1.05 (0.85)	2.43 (2.66)	1.86 (0.82)	1.07 (0.92)	0.69 (0.14)	0.63 (0.65)	0.64 (0.16)	1.24 (0.92)	0.9 (0.61)		

Rods plus Boracare	150	O	0.24 (0.13)	0.23 (0.29)	1.67 (2.09)	0.42 (0.46)	0.69 (0.78)	0.32 (0.14)	0.25 (0.35)	0.20 (0.07)	1.35 (1.27)	0.7 (0.53)	
		I	0.45 (0.29)	1.65 (2.24)	2.12 (1.62)	1.87 (1.72)	2.54 (1.82)	1.64 (0.72)	0.57 (0.46)	1.41 (1.39)	0.46 (0.23)	1.7 (2.17)	
		M	0.22 (0.07)	1.39 (2.47)	2.88 (3.32)	1.47 (1.43)	1.83 (1.66)	2.74 (2.89)	0.87 (0.59)	1.61 (1.84)	1.19 (1.13)	1.3 (1.17)	
	300	O	0.29 (0.18)	0.43 (0.86)	0.54 (0.86)	0.41 (0.49)	0.27 (0.28)	0.54 (0.34)	0.55 (0.50)	0.41 (0.26)	1.26 (0.94)	0.6 (0.32)	
		I	0.23 (0.13)	0.30 (0.54)	0.49 (0.59)	1.14 (2.03)	14.16 (29.02)	0.73 (0.74)	0.01 (0.02)	0.74 (0.37)	0.33 (0.20)	1.4 (0.85)	
		M	0.20 (0.06)	0.17 (0.16)	0.33 (0.34)	1.79 (3.13)	0.81 (0.90)	0.48 (0.52)	0.02 (0.03)	0.74 (0.68)	0.68 (0.61)	1.1 (0.79)	
	Rods plus Boracol 20	-457	O										0.6 (0.50)
			M										0.4 (0.26)
			O										
		-300	I	1.57 (1.80)	0.36 (0.25)	0.51 (0.32)	0.20 (0.16)	0.15 (0.14)	0.30 (0.24)	0.41 (0.62)	0.71 (0.55)	0.27 (0.30)	1.1 (0.90)
			M	0.36 (0.20)	0.43 (0.37)	0.56 (0.28)	0.07 (0.10)	0.12 (0.10)	0.28 (0.17)	0.18 (0.18)	0.34 (0.19)	0.43 (0.39)	0.9 (0.77)
			O	0.23 (0.05)	0.16 (0.03)	0.58 (0.59)	0.04 (0.06)	0.10 (0.04)	0.22 (0.14)	0.03 (0.05)	0.10 (0.01)	1.28 (1.11)	0.4 (0.25)
0		I	2.80 (1.86)	7.59 (6.38)	2.40 (1.51)	5.68 (6.61)	10.39 (9.85)	2.00 (1.52)	1.85 (1.45)	1.55 (1.41)	0.47 (0.52)	1.6 (0.63)	
		M	0.32 (0.18)	4.77 (4.78)	1.34 (0.92)	5.03 (4.71)	0.78 (0.90)	0.87 (0.67)	1.00 (0.72)	1.46 (1.27)	1.50 (0.81)	1.4 (1.12)	
		O	0.22 (0.05)	0.40 (0.39)	0.87 (0.93)	0.83 (0.91)	0.53 (0.67)	0.18 (0.11)	0.20 (0.18)	0.20 (0.10)	1.17 (1.47)	0.6 (0.43)	
150		I	4.35 (3.61)	3.55 (1.22)	4.13 (4.66)	5.17 (3.72)	3.14 (2.65)	1.84 (1.88)	1.11 (1.42)	2.67 (2.62)	0.78 (0.49)	4 (2.45)	
		M	1.06 (1.10)	1.32 (1.67)	4.10 (4.50)	1.86 (0.97)	1.69 (1.72)	0.80 (1.01)	1.04 (0.88)	0.80 (0.62)	1.01 (0.78)	6 (8.56)	
		O	0.50 (0.34)	0.49 (0.90)	0.40 (0.30)	1.08 (1.85)	0.21 (0.23)	0.28 (0.20)	0.35 (0.41)	0.23 (0.13)	1.71 (1.49)	0.6 (0.37)	
300	I	1.79 (1.16)	1.22 (1.09)	0.81 (1.05)	2.27 (3.19)	1.83 (1.29)	1.92 (1.64)	1.31 (1.12)	0.88 (1.17)	0.42 (0.24)	1.2 (0.33)		
	M	1.16 (1.91)	0.33 (0.29)	0.89 (1.36)	4.23 (8.09)	0.89 (0.68)	1.09 (0.90)	0.53 (0.72)	0.93 (0.75)	0.56 (0.30)	0.8 (0.81)		
	O	0.33 (0.19)	0.15 (0.18)	1.00 (1.77)	1.62 (2.88)	0.12 (0.06)	0.20 (0.14)	0.12 (0.18)	0.25 (0.26)	1.15 (0.82)	0.5 (0.18)		
Rods plus Boracol 40	-457	I										0.2 (0.06)	
		M										0.2 (0.06)	
		O										0.1 (0.04)	
	-300	I	0.87 (0.71)	0.69 (0.75)	0.50 (0.53)	0.26 (0.19)	1.61 (1.06)	0.73 (0.33)	0.92 (0.72)	0.50 (0.44)	0.13 (0.32)	0.4 (0.16)	
		M	0.49 (0.48)	0.29 (0.26)	0.26 (0.24)	0.22 (0.23)	0.99 (0.90)	0.63 (0.21)	0.79 (0.57)	0.36 (0.09)	0.34 (0.32)	0.3 (0.14)	
		O	0.47 (0.49)	0.20 (0.21)	0.22 (0.15)	1.62 (3.36)	0.13 (0.19)	0.49 (0.22)	0.21 (0.26)	0.22 (0.11)	0.25 (0.21)	0.3 (0.10)	
	0	I	4.51 (5.32)	2.41 (0.73)	3.93 (2.95)	3.33 (1.95)	2.22 (2.74)	1.87 (1.56)	3.82 (4.14)	1.48 (1.04)	0.40 (0.19)	0.7 (0.29)	
		M	1.44 (2.09)	0.79 (0.53)	2.38 (2.32)	1.99 (1.25)	0.89 (0.58)	1.07 (1.08)	0.89 (0.70)	0.76 (0.48)	1.04 (0.51)	0.4 (0.12)	
		O	0.32 (0.12)	1.11 (2.11)	2.96 (2.91)	0.55 (0.63)	0.11 (0.11)	0.57 (0.35)	0.46 (0.36)	0.46 (0.55)	0.86 (0.38)	0.5 (0.19)	
	150	I	1.84 (0.95)	3.64 (4.00)	1.65 (1.79)	3.69 (1.56)	2.06 (1.47)	2.39 (1.49)	3.49 (1.98)	1.69 (0.56)	0.66 (0.64)	0.8 (0.03)	
		M	0.73 (0.70)	1.00 (0.65)	3.39 (5.04)	1.85 (1.16)	3.86 (1.89)	1.02 (0.97)	1.25 (0.40)	1.58 (0.91)	1.23 (0.76)	0.6 (0.40)	
		O	0.36 (0.23)	0.93 (1.45)	0.30 (0.27)	0.44 (0.41)	0.27 (0.20)	0.15 (0.09)	0.46 (0.29)	1.28 (1.34)	1.05 (0.88)	0.4 (0.13)	
300	I	2.87 (4.37)	0.70 (0.72)	0.93 (1.12)	0.36 (0.70)	0.91 (1.22)	0.31 (0.24)	0.89 (0.92)	0.59 (0.65)	0.51 (0.28)	0.8 (0.14)		
	M	0.67 (0.62)	1.09 (1.16)	0.58 (0.82)	0.27 (0.56)	1.04 (1.66)	0.18 (0.15)	0.59 (0.51)	0.31 (0.33)	0.79 (0.51)	0.4 (0.32)		
	O	0.24 (0.07)	1.37 (2.44)	0.20 (0.24)	0.40 (0.72)	0.20 (0.36)	0.06 (0.03)	0.06 (0.05)	0.07 (0.05)	0.94 (0.83)	0.3 (0.17)		

Table 1.2.5 continued.

Treatment	Height (mm)	Depth	Boron (Kg/m ³ BAE) ^a										
			Year 1	Year 2	Year 3	Year 5	Year 7	Year 10	Year 12	Year 15	Year 20	Year 26	
Rods plus Boracol 40	-457	I											0.3 (0.18)
		M											0.2 (0.02)
		O											0.2 (0.02)
	-300	I	2.49 (2.38)	0.92 (0.63)	0.71 (0.62)	0.62 (0.73)	1.32 (1.17)	0.46 (0.30)	0.51 (0.49)	0.69 (0.26)	0.89 (1.19)	0.5 (0.30)	
		M	0.55 (0.41)	0.71 (1.09)	1.53 (2.57)	0.37 (0.36)	0.41 (0.34)	0.55 (0.49)	0.20 (0.31)	0.74 (0.43)	0.12 (0.07)	0.3 (0.04)	
		O	0.21 (0.08)	0.74 (0.99)	1.36 (2.66)	0.07 (0.07)	0.14 (0.28)	0.40 (0.22)	0.22 (0.39)	0.33 (0.40)	0.23 (0.29)	0.2 (0.08)	
	0	I	11.15 (6.98)	10.41 (9.50)	5.82 (3.21)	10.82 (9.22)	5.86 (4.24)	2.16 (0.06)	1.31 (0.35)	1.38 (1.06)	0.17 (0.20)	0.5 (0.16)	
		M	3.38 (2.69)	5.16 (3.23)	9.54 (10.73)	13.82 (10.66)	7.49 (3.73)	1.23 (0.46)	1.17 (0.23)	1.33 (0.54)	0.36 (0.24)	0.5 (0.01)	
		O	0.45 (0.31)	1.26 (1.47)	2.65 (2.21)	2.53 (1.85)	0.53 (0.34)	0.42 (0.10)	0.34 (0.36)	0.27 (0.04)	0.47 (0.17)	0.3 (0.09)	

	150	I	0.37 (0.24)	0.33 (0.30)	0.35 (0.30)	0.63 (0.86)	1.39 (1.58)	0.36 (0.49)	0.46 (0.37)	0.60 (0.32)	0.20 (0.10)	0.4 (0.16)
		M	0.22 (0.03)	0.44 (0.43)	0.41 (0.31)	0.33 (0.53)	0.47 (0.40)	0.44 (0.57)	0.40 (0.19)	0.48 (0.19)	0.46 (0.29)	0.4 (0.09)
		O	0.18 (0.11)	0.33 (0.28)	0.26 (0.08)	0.14 (0.27)	0.06 (0.04)	0.12 (0.14)	0.03 (0.03)	0.12 (0.07)	0.49 (0.24)	0.2 (0.07)
	300	I	0.18 (0.12)	0.10 (0.09)	0.08 (0.07)	0.03 (0.04)	0.37 (0.67)	0.04 (0.06)	0.03 (0.05)	0.22 (0.14)	0.24 (0.24)	0.5 (0.10)
		M	0.15 (0.10)	0.08 (0.05)	0.09 (0.08)	0.04 (0.05)	0.18 (0.17)	0.03 (0.01)	0.02 (0.03)	0.13 (0.06)	0.44 (0.22)	0.5 (0.23)
		O	0.15 (0.11)	0.07 (0.04)	0.08 (0.07)	0.02 (0.02)	0.04 (0.02)	0.27 (0.37)	0.00 (0.00)	0.05 (0.02)	0.67 (0.34)	0.3 (0.14)
Rods plus ethylene glycol	-457	I										0.5 (0.28)
		M										0.5 (0.43)
		O										0.3 (0.32)
	-300	I	0.32 (0.29)	0.33 (0.20)	0.16 (0.13)	0.14 (0.21)	0.30 (0.24)	0.52 (0.38)	0.96 (0.93)	1.04 (0.70)	0.32 (0.28)	1 (1.01)
		M	0.19 (0.06)	0.18 (0.11)	0.07 (0.13)	0.04 (0.09)	0.10 (0.07)	0.79 (0.48)	0.80 (0.98)	0.43 (0.19)	0.30 (0.21)	0.9 (0.88)
		O	0.16 (0.10)	0.10 (0.11)	0.10 (0.13)	0.03 (0.05)	0.19 (0.31)	0.44 (0.36)	0.35 (0.52)	0.11 (0.02)	0.66 (0.69)	0.7 (0.79)
	0	I	5.30 (8.91)	3.71 (2.92)	3.88 (3.84)	2.84 (1.97)	4.86 (3.37)	2.83 (2.02)	3.07 (3.21)	4.09 (4.30)	1.11 (1.65)	1 (0.85)
		M	0.97 (1.20)	0.61 (0.39)	0.67 (0.46)	2.81 (2.00)	5.17 (7.26)	1.70 (0.80)	2.45 (2.07)	1.11 (0.78)	0.97 (0.64)	1.3 (1.63)
		O	0.21 (0.16)	0.17 (0.17)	0.68 (1.20)	1.61 (1.90)	0.49 (0.46)	0.54 (0.38)	0.24 (0.32)	0.25 (0.13)	2.75 (3.95)	0.8 (0.87)
	150	I	2.98 (3.50)	5.02 (4.32)	5.31 (1.72)	2.77 (2.53)	2.89 (1.34)	3.00 (3.04)	1.99 (2.08)	1.33 (0.86)	0.86 (1.23)	1.9 (2.33)
		M	1.34 (1.53)	1.09 (1.36)	2.34 (2.63)	6.53 (10.12)	3.08 (2.69)	1.74 (1.46)	2.78 (3.78)	1.59 (1.74)	0.76 (0.50)	1.8 (2.46)
		O	0.29 (0.22)	0.10 (0.08)	1.45 (2.03)	4.29 (7.08)	0.27 (0.18)	0.33 (0.11)	1.04 (1.51)	1.25 (1.82)	2.11 (2.40)	1 (1.17)
300	I	0.17 (0.11)	0.24 (0.16)	1.50 (1.83)	1.57 (2.79)	0.63 (1.10)	0.33 (0.08)	0.65 (0.76)	0.50 (0.24)	0.59 (0.78)	1.2 (1.01)	
	M	0.19 (0.05)	0.18 (0.22)	0.56 (0.69)	3.44 (6.66)	1.16 (1.73)	0.19 (0.08)	0.11 (0.10)	0.19 (0.09)	0.50 (0.30)	1 (1.03)	
	O	0.20 (0.04)	0.61 (0.97)	0.91 (1.72)	2.33 (4.85)	0.43 (0.48)	0.09 (0.02)	0.29 (0.47)	0.05 (0.02)	0.84 (0.57)	0.4 (0.16)	
Rods plus Timbor	-457	I										0.3 (0.06)
		M										0.3 (0.01)
		O										0.2 (0.07)
	-300	I	0.83 (0.43)	0.67 (0.37)	0.30 (0.22)	0.32 (0.39)	1.12 (1.58)	0.35 (0.24)	0.69 (0.50)	1.23 (0.93)	0.42 (0.47)	0.5 (0.13)
		M	0.30 (0.07)	0.26 (0.11)	0.54 (0.37)	0.13 (0.22)	0.32 (0.33)	0.40 (0.36)	0.53 (0.52)	1.16 (0.83)	0.82 (0.79)	0.6 (0.08)
		O	0.33 (0.18)	0.14 (0.06)	0.51 (0.60)	0.03 (0.04)	0.04 (0.06)	0.26 (0.25)	0.24 (0.29)	0.40 (0.46)	0.72 (0.57)	0.3 (0.03)
	0	I	2.75 (2.36)	2.68 (2.36)	5.67 (4.81)	7.58 (11.41)	2.59 (2.46)	1.58 (0.37)	2.35 (0.45)	1.44 (0.42)	0.70 (0.50)	0.6 (0.33)
		M	0.32 (0.17)	1.84 (1.99)	1.46 (1.35)	1.54 (0.78)	0.85 (0.53)	1.24 (0.65)	1.60 (1.07)	0.92 (0.20)	1.09 (1.16)	0.6 (0.26)
		O	0.34 (0.23)	0.20 (0.17)	0.54 (0.55)	0.47 (0.49)	0.55 (1.10)	0.56 (0.52)	0.69 (0.87)	0.34 (0.06)	0.84 (0.50)	0.6 (0.11)
	150	I	3.53 (3.44)	2.89 (2.22)	2.83 (2.85)	2.22 (1.10)	14.00 (21.75)	3.47 (0.32)	2.96 (0.60)	1.57 (1.07)	0.63 (0.27)	0.8 (0.29)
		M	6.60 (12.26)	1.42 (1.89)	1.74 (1.98)	6.15 (7.51)	2.51 (2.13)	2.86 (0.60)	2.04 (0.44)	1.31 (0.70)	1.16 (0.70)	0.7 (0.44)
		O	0.72 (0.79)	0.35 (0.30)	0.94 (0.74)	1.13 (0.83)	0.54 (0.43)	0.88 (0.65)	0.74 (0.54)	0.44 (0.15)	0.90 (0.43)	0.7 (0.34)
300	I	2.94 (5.56)	1.74 (2.22)	1.57 (1.91)	3.38 (5.19)	1.33 (1.30)	2.03 (1.55)	1.61 (1.22)	0.71 (0.37)	0.37 (0.27)	0.6 (0.18)	
	M	0.38 (0.23)	0.40 (0.35)	1.84 (2.42)	0.68 (0.66)	1.00 (0.54)	0.91 (0.30)	0.78 (0.12)	0.45 (0.08)	0.70 (0.38)	0.7 (0.32)	
	O	0.45 (0.32)	0.15 (0.07)	3.14 (2.42)	0.34 (0.48)	0.22 (0.25)	0.31 (0.19)	0.28 (0.35)	0.12 (0.03)	0.84 (0.36)	0.4 (0.22)	

1.3.0 Tests Including Both Fumigants and Diffusible Remedial Treatments

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

1.3.1 Full Scale Field Trial of All Internal Remedial Treatments

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

This study was last sampled in 2020 and was not sampled this year.

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

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

1.3.2 Effect of Metam Sodium on Boron Rod Performance

One of the combination treatments considered for the internal remedial treatment of utility poles is the combination of boron rods with metam sodium (NaMDC). The combination of the two has potential to function as a dual action remedial treatment with fumigant properties and also the longer-lasting water-soluble treatment. This combination has the potential to reduce the number

of treatment holes that need to be drilled in each pole. Additionally, metam sodium is thought to act as an accelerant and stimulate faster boron diffusion into poles. The UPRC initiated a field trial at the Peavy Arboretum site in 2019 to test the combination of these two chemicals as a remedial treatment. This study was sampled in 2020 and will be sampled annually hereafter.

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

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

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

After one year of sampling, boron concentrations were highest in the below groundline samples, reaching the 0.5 kg/m³ inhibitory threshold level 150 mm below groundline when inner and outer pole core sections were averaged (Table 1.3.5). Average boron generally declined as the distance above groundline increased. Boron levels tended to be higher in the inner core sections, congruent with the downward sloping treatment holes and outer core sections were below threshold for boron in all sampling locations. Outer core sections had boron levels below threshold levels at all sampling locations across all treatments. Boron levels among the different treatments were similar at equivalent sampling locations and no effect of metam sodium or water was obvious.

Year two sampling showed similar patterns, with the inner core sections showing higher boron concentrations and boron levels generally decreasing with increasing height above groundline (Table 1.3.2). Boron levels in most core sections at or below groundline were above the effective threshold. In the second year, many samples taken from 150 mm above groundline showed boron levels above threshold, indicating boron migration was progressing. Boron levels were generally

higher in year 2 than year one, especially boron rods treated with a metam sodium solution. Boron levels in the pole interior reached well above the effective threshold up to the 450 mm above groundline sampling point. This is an early indication that the boron-metam sodium cotreatment have a positive impact on boron diffusion, however we will continue to monitor this study to determine if the increased boron diffusion is a durable phenomenon. Boron levels continued to increase in year 3, primarily driven by increases in boron concentration in the inner pole sections. Boron levels were highest at groundline, 150 mm above and 150 mm below groundline. This is likely due to higher moisture contents, which are required to facilitate boron migration. Boron+ metam sodium appeared to generate similar boron levels as boron rods alone and a difference could not be distinguished with confidence.

No fungi were isolated from metam sodium-treated poles in year 1, but there were sporadic isolations of decay fungi from poles treated with boron rods alone with or without water addition (Table 1.3.7). Most of the isolations occurred in cores below groundline. In year two, boron only poles contained decay and non-decay fungi in both aboveground and belowground samples (Table 1.3.8). Some of the poles in this group contained more widespread instances of decay fungi, while at least one pole (1802, did not contain any. Poles treated with boron plus metam sodium contained similar amounts of decay fungi overall, although they tended to be more prevalent in the at or below groundline samples (Table 1.3.9). There were three instances of decay fungi originating from above groundline samples and these were limited to two of the replicate poles. These isolations do not necessarily indicate the immanent loss in structural integrity in poles treated with boron rods. Boron is fungistatic and can prevent the growth of decay fungi found in poles with boron rods, provided boron levels remain above the effective threshold. These early results are somewhat promising for the efficacy of the dual treatment, however further sampling points will tell whether the treatment remains so for an extended period. After three years, fungal isolations were generally lower than in year two. Boron only treated poles contained sporadic decay fungi. There were no decay fungi isolated from poles treated with metam sodium in 2021. This is probably due to the fumigant moving through the wood and killing fungal cells, as is know to occur after metam sodium treatment.

Table 1.3.2: Boron concentration from 2019 – 2021 in poles combining both assay zones, and with the inner and outer assay zones separated. Boron levels above the protective threshold of 0.5 kg/m³ BAE are indicated with bold green boxes.

Treatment	Pole Zone	Sampling Year	150 mm Belowground		Groundline		150 mm Aboveground		300 mm Aboveground		450 mm Aboveground	
			[Boron] kg/m ³ BAE	Std. Dev.								
B Rods		2019	0.623	(0.61)	0.467	(0.57)	0.492	(0.61)	0.175	(0.17)	0.143	(0.17)

	Whole Pole	2020	2.574	(4.85)	1.537	(2.26)	1.907	(2.20)	0.294	(0.37)	0.021	(0.03)
		2021	4.993	(8.09)	4.730	(6.37)	4.658	(5.52)	0.633	(1.13)	0.126	(0.08)
	Interior	2019	0.946	(0.67)	0.407	(0.52)	0.693	(0.75)	0.213	(0.18)	0.165	(0.22)
		2020	5.004	(5.93)	2.846	(2.58)	2.671	(2.02)	0.425	(0.44)	0.013	(0.01)
		2021	9.237	(9.66)	8.658	(7.06)	9.047	(4.73)	1.044	(1.49)	0.163	(0.09)
	Exterior	2019	0.300	(0.37)	0.527	(0.67)	0.290	(0.43)	0.137	(0.17)	0.121	(0.13)
		2020	0.145	(0.25)	0.229	(0.35)	1.143	(2.11)	0.162	(0.24)	0.030	(0.04)
		2021	0.749	(1.19)	0.801	(0.55)	0.269	(0.15)	0.221	(0.07)	0.089	(0.04)
	B Rods + H ₂ O	Whole Pole	2019	0.583	(0.56)	0.672	(0.72)	0.414	(0.48)	0.120	(0.14)	0.053
2020			2.161	(2.43)	0.829	(1.35)	1.020	(1.63)	0.287	(0.56)	0.054	(0.04)
2021			2.833	(3.78)	1.737	(2.52)	0.916	(1.48)	0.655	(0.85)	0.088	(0.05)
Interior		2019	0.807	(0.54)	1.115	(0.74)	0.549	(0.46)	0.190	(0.18)	0.068	(0.04)
		2020	3.829	(2.36)	1.588	(1.59)	1.967	(1.87)	0.498	(0.73)	0.068	(0.03)
		2021	4.635	(4.32)	3.691	(2.73)	1.703	(1.77)	1.223	(0.90)	0.107	(0.06)
Exterior		2019	0.359	(0.53)	0.229	(0.36)	0.279	(0.51)	0.051	(0.02)	0.037	(0.02)
		2020	0.493	(0.81)	0.071	(0.06)	0.072	(0.09)	0.077	(0.08)	0.040	(0.04)
		2021	1.031	(1.85)	0.174	(0.05)	0.130	(0.07)	0.087	(0.03)	0.069	(0.02)
B Rods + NaMD C	Whole Pole	2019	0.608	(0.83)	0.455	(0.54)	0.370	(0.53)	0.125	(0.11)	0.202	(0.41)
		2020	1.243	(2.27)	3.231	(2.90)	2.452	(2.72)	0.580	(1.29)	0.525	(1.36)
		2021	3.434	(3.54)	1.911	(1.72)	3.670	(5.57)	0.742	(0.93)	0.084	(0.07)
	Interior	2019	0.704	(1.09)	0.667	(0.70)	0.561	(0.71)	0.175	(0.12)	0.336	(0.57)
		2020	2.349	(2.79)	4.778	(2.42)	4.431	(2.56)	1.010	(1.71)	0.962	(1.81)
		2021	6.277	(2.95)	3.360	(1.16)	7.132	(6.18)	1.265	(1.08)	0.090	(0.09)
	Exterior	2019	0.512	(0.58)	0.244	(0.24)	0.179	(0.19)	0.075	(0.08)	0.069	(0.04)
		2020	0.136	(0.13)	1.683	(2.48)	0.473	(0.62)	0.149	(0.16)	0.088	(0.12)
		2021	0.591	(0.43)	0.461	(0.58)	0.209	(0.14)	0.219	(0.08)	0.078	(0.03)

Table 1.3.4: Results of culturing for decay and non-decay fungi after 13 months. Metam sodium poles were completely devoid of fungi and only poles that contained at least one fungal culture are listed in this table.

Sample (pole) Number	Treatment Name	Height (mm)	Pole Side	Non-Decay	Decay
1801	B Rods + H ₂ O	0	C	1	0
1802	B Rods	-150	C	1	0
1806	B Rods + H ₂ O	0	C	1	0
1809	B Rods + H ₂ O	-150	C	0	1
1809	B Rods + H ₂ O	150	C	1	1
1809	B Rods + H ₂ O	0	B	1	0
1811	B Rods + H ₂ O	450	C	1	0
1811	B Rods + H ₂ O	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

Table 1.3.5: Results of culturing from poles treated with boron rods 27 months after treatment. Decay and non-decay fungi were totaled.

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

1820	B Rods	0	C	1	1	3
1820	B Rods	150	A	1	0	
1820	B Rods	150	B	1	0	
1820	B Rods	150	C	1	0	
1820	B Rods	300	A	1	0	
1820	B Rods	300	B	1	1	3
1820	B Rods	300	C	1	0	

Table 1.3.6: Results of culturing boron + water or boron + metam sodium poles 27 months after installation. Decay and non-decay fungi were counted.

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

1808	B Rods + Metam Sodium	450	C	1	0	
1808	B Rods + Metam Sodium	600	A	1	0	
1815	B Rods + Metam Sodium	450	A	1	0	
1819	B Rods + Metam Sodium	300	A	1	0	
1819	B Rods + Metam Sodium	450	C	1	0	

Table 1.3.7: Results of culturing boron, water or boron, metam sodium, or Kpam poles after 3 years of incubation. Decay and non-decay fungi were counted and only poles that harbored live cultures were listed.

Sample (pole) Number	Treatment Name	Height (mm)	Non-Decay	Decay	Decay Morphogroup
1802	B Rods	-150	1	0	
1803	B Rods	-150	1	0	
1803	B Rods	0	1	0	
1803	B Rods	150	1	0	
1803	B Rods	450	0	1	Kpam_2021_MG1
1812	B Rods	300	1	0	
1814	B Rods	-150	1	0	
1814	B Rods	0	0	1	Kpam_2021_MG2
1814	B Rods	150	0	1	Kpam_2021_MG4
1820	B Rods	-150	1	0	
1820	B Rods	0	1	0	
1801	B Rods + H2O	-150	1	0	
1801	B Rods + H2O	0	1	0	
1801	B Rods + H2O	150	0	1	Kpam_2021_MG2
1801	B Rods + H2O	300	1	0	
1801	B Rods + H2O	450	0	1	Kpam_2021_MG4
1806	B Rods + H2O	0	1	0	
1806	B Rods + H2O	450	1	0	
1809	B Rods + H2O	-150	1	0	
1809	B Rods + H2O	0	1	0	
1809	B Rods + H2O	300	1	0	
1809	B Rods + H2O	150	0	1	Kpam_2021_MG3
1809	B Rods + H2O	450	0	1	Kpam_2021_MG1
1811	B Rods + H2O	-150	1	0	
1811	B Rods + H2O	0	1	0	
1811	B Rods + H2O	150	1	0	
1811	B Rods + H2O	450	0	1	Kpam_2021_MG4
1813	B Rods + H2O	-150	1	0	
1813	B Rods + H2O	0	1	0	
1813	B Rods + H2O	150	1	0	
1813	B Rods + H2O	300	0	1	Kpam_2021_MG1
1813	B Rods + H2O	450	0	1	Kpam_2021_MG2
1808	B Rods + Metam Sodium	-150	1	0	
1815	B Rods + Metam Sodium	-150	1	0	

1817	B Rods + Metam Sodium	-150	1	0	
1807	B Rods + Kpam	-150	1	0	

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

Extensive field and laboratory testing has shown that dazomet decomposition into the active gaseous fumigant methylisothiocyanate is highly dependent on water. This creates some issues for its effective use in dry climates. Metal-based accelerants added to dazomet can improve its decomposition in dry conditions. This section summaries research toward the improvement of dazomet accelerants for dry climates so the advantages of this fumigant can be fully realized in a wider variety of climates.

There were no new experiments done in this section in 2021. The data presented in this section last year was presented at the 2021 American Wood Protection Association meeting in Nashville, TN and submitted as a proceedings paper which can be found in the 2021 proceedings

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

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

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

Date Established:	August 2010
Location:	Utah
Pole Species, Treatment, Size	Pine, cedar, Douglas-fir, penta, creosote, cellon
Circumference @ GL (avg., max., min.)	87, 107, 71 cm

This test was not sampled in 2021. During the annual meeting of the UPRC advisory board, it was suggested that this project waws complete and there is no need to resample. We will no

longer sample this test. Further research sites to monitor fumigant performance in dry climates will be sought in Eastern Oregon.

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

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

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

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

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

Water soluble preservatives have properties that make them an attractive potential treatment for preserving heartwood. Water soluble preservatives such as borates or fluorides tend to migrate in wood once they are pressure treated. This makes them less well-suited for exposure to the elements as they tend to migrate out of treated wood. However, mobility also means they have the potential to migrate throughout the wood ultrastructure and may be able to migrate into the heartwood, impacting decay resistance deep within a pole. An initial pressure treatment with

borates followed by an overtreatment with an oil-borne preservative typically used to treat poles may enable the migration of preservative to the heartwood while preventing borate loss from the pole.

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

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

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

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

Freshly peeled Douglas-fir pole sections (2.4 m long by 250-300 mm in diameter) were pressure treated with a 7% solution (BAE) of DOT, then six increment cores were removed from two sides near the middle of each pole to determine initial borate retention. Cores were divided into 25 mm segments from surface to pith and combined by depth for each pole. Combined cores were ground to pass a 20-mesh screen before extraction in hot water and boron analysis according to AWPA Standard A2, Method 16. There is no AWPA borate retention specified for utility pole pre-treatment, however the standard for pre-treatment of ties specifies 2.7 kg/m³ of boron (as B₂O₃, equal to 4.9 kg/m³ BAE). Previous studies have shown that the boron threshold for protecting Douglas-fir from internal decay is much lower than this and can be as little as 0.4-0.44 kg/m³ (Freitag and Morrell 2005). For these studies a value of 0.6 kg/m³ was used as an effective inhibitory threshold to indicate fungistatic potential.

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

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

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

Boron retentions (as kg/m³ BAE) were highest in the outer 25 mm of each pole, ranging from 4.56 to 15.17 kg/m³ immediately after treatment but before drying (Table 2.1.1). With the exception of one pole, retentions were extremely low in the next 25 mm inward and remained low toward the pole center. These results are typical of any short-term pressure treatment of Douglas-fir poles. If all boron in pole sections immediately after treatment was considered, poles would contain an average of 2.36 kg/m³ BAE, or about half the level required for boron pretreatment of railroad ties, albeit not evenly distributed throughout the pole. These values are

skewed by one pole that had high boron levels in 4/6 assay zones. The remaining poles had much lower boron levels and, in all poles, boron was largely confined to the outer 25 mm.

After kiln drying, boron levels remained elevated in the outer 25 mm of pole sections (Table 2.1.2), but were lower than directly after treatment, sometimes substantially (Table 2.1.3). If total boron levels were averaged across each pole section, it would equate to 1.02 kg/m³ BAE, far below the specified level, but still above the effective inhibitory threshold. Some of these reductions may be attributed to differences in sampling locations at different time points as well as to movement of boron into the next 25 mm from the surface, but the levels of loss also suggest some of the boron was lost from the wood during drying. The results suggest that drying will have to be optimized for this application as it is a major point of boron loss.

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

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

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

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

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

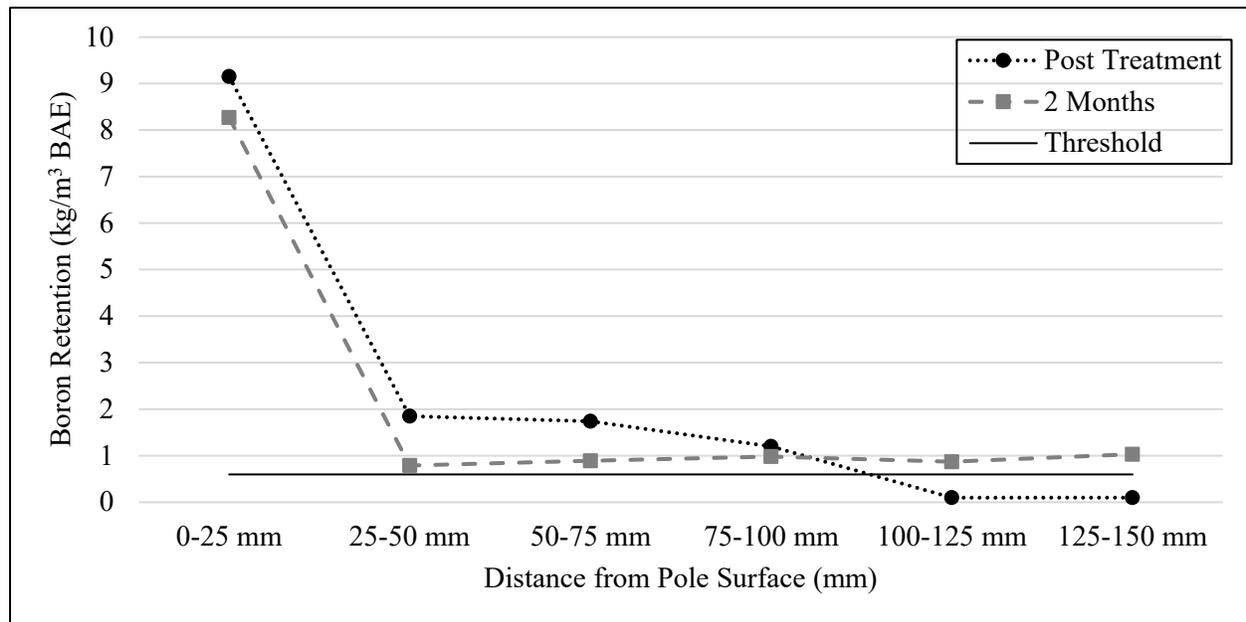


Figure 2.1.1. Boron retentions in 25 mm increments inward from the surface in Douglas-fir poles immediately after pressure treatment with disodium octaborate tetrahydrate and again 2 months later. These poles were not treated with an over treatment.

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

Boron levels in the outer 25 mm of poles that had undergone either seasoning type one year after treatment had declined (Figure 2.1.2; 2.1.3 and Tables 2.1.4; 2.1.5). The field site receives ~1200 mm of rainfall per year and tends to be extremely wet during the winter which may have resulted in boron leaching from the outermost layer. Previous tests revealed that interior pole moisture

content at groundline tends to be above 30% most of the year, but only reaches that level above groundline near the end of winter. The higher moisture content at groundline would be expected to cause greater boron loss to the surrounding soil in that zone and indeed average boron levels across both treatment types are higher than at groundline (Figure 2.1.2). However, boron levels in the above ground sampling zone also had reduced boron levels compared to their pre-installation levels (Figure 2.1.3), which indicates rainwater leaching is responsible for some loss. Boron levels were similar or slightly lower in the inner 25 to 150 mm at both heights, suggesting there had been relatively little inward movement after installation. In addition, outside of the first 50 mm below the pole surface, few samples had boron concentrations above the 0.6 kg/m³ inhibitory threshold level.

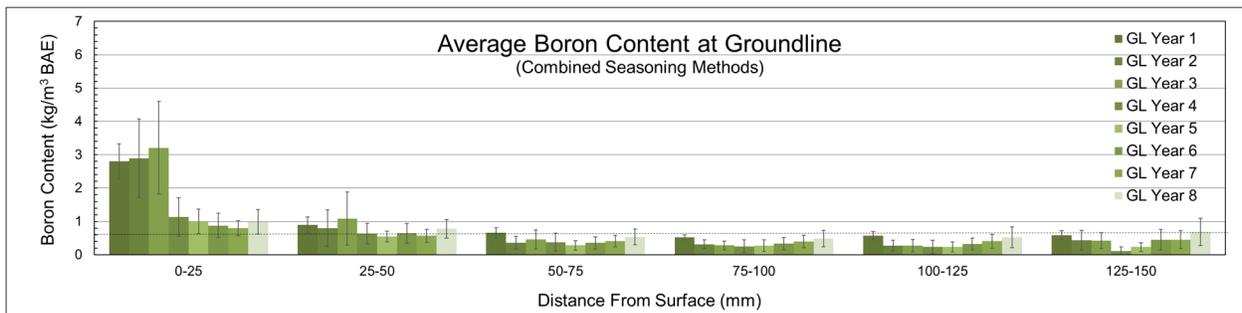


Figure 2.1.2. Boron content at groundline (GL) in 25 mm increments from Douglas-fir pole surface 1-8 years after pre-treatment with disodium octaborate tetrahydrate followed by either kiln drying or Boulton seasoning and CuNap treatment. Both kiln and Boulton seasoning are combined for each year. Dotted line indicates 0.6 kg/m³ BAE, the threshold for decay prevention.

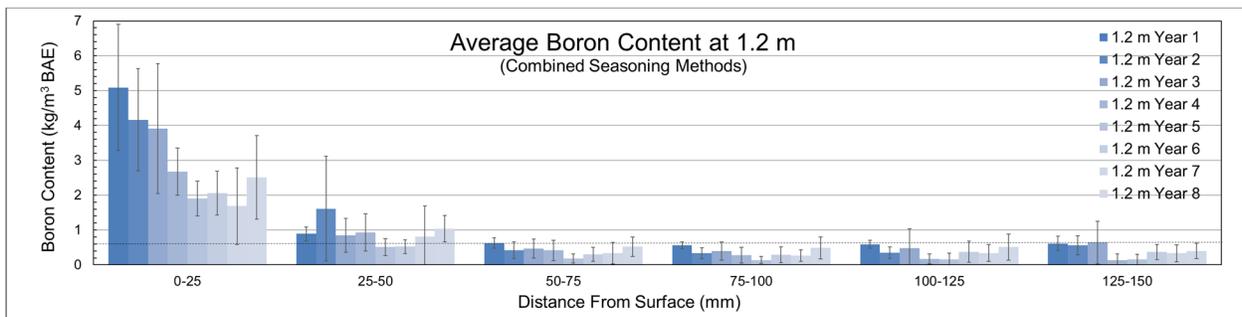


Figure 2.1.3. Boron content 1.2 m above groundline in 25 mm increments from Douglas-fir pole surface 1-8 years after pre-treatment with disodium octaborate tetrahydrate followed by either kiln drying or Boulton seasoning and CuNap treatment. Both kiln and Boulton seasoning are combined for each year. Dotted line indicates 0.6 kg/m³ BAE, the threshold for decay prevention.

The initial assays done here indicate that boron levels should be higher to be effective. Initial boron application levels could be increased by using a stronger treatment solution. Pole sections were treated with a process typically used on lumber for the Hawaiian market and solution concentrations might have been somewhat lower than needed. Other treaters have made us aware that solutions of DOT used in commercial pretreatment of poles are typically 20% for pressure treatment and 30% for dip treatment prior to copper naphthenate overtreatment. This is a

significant difference in solution strength compared to the 7% solution (BAE) as DOT used in this study and may explain why inward boron migration was limited here. A future study using poles pretreated to boron (as DOT) retentions of at least 0.25 pcf (4.0 kg/m³) prior to overtreatment would be useful to measure boron migration in poles treated using common standards.

In the seven subsequent sampling years 2-8, the overall trends seen after the first year's sampling continued. Boron levels were generally highest in the first 25 mm from the surface, rapidly tapering off deeper in the pole (Figure 2.1.2 and 2.1.3). Total boron levels in the outermost section showed a steady decrease year to year. This combined with the fact that internal boron levels remained fairly constant indicate that the majority of boron loss is a result of loss to the soil rather than migration to the pole interior. Boron levels also remained somewhat higher in the outermost core samples taken from 1.2 m above ground throughout the 8-year sampling. Boron levels in sections taken from 25 mm or deeper below the surface were more similar between the two heights which suggests that groundline preservative loss does not impact boron levels in the heartwood very much if at all. Samples greater than 50 mm below the surface tended to have boron levels below the effective threshold at all sampling points except for year 1.

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

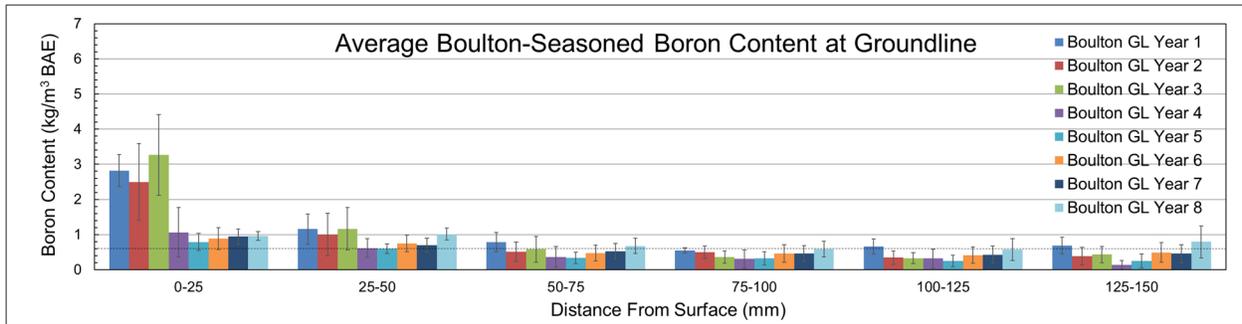
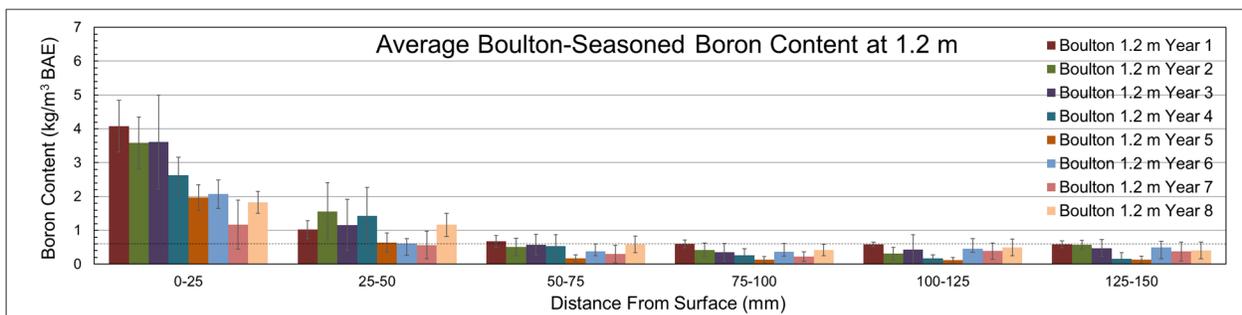


Figure 2.1.4. Boron content in 25 mm increments from Douglas-fir pole surface taken at groundline 1-8 years after pre-treatment with disodium octaborate tetrahydrate followed by Boulton seasoning and CuNap treatment. Dotted black line indicates 0.6 kg/m³ BAE, the



threshold for decay prevention.
Figure 2.1.5. Boron content in 25 mm increments from Douglas-fir pole surface taken 1.2 m above groundline 1-8 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.

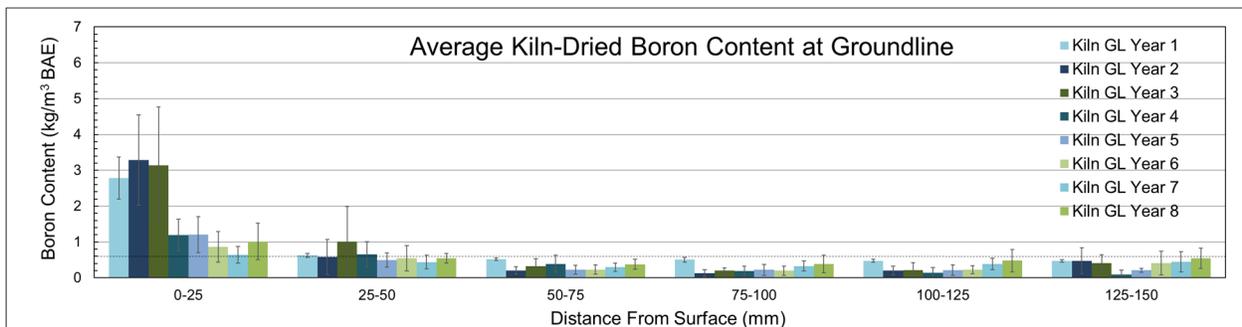


Figure 2.1.6. Boron content in 25 mm increments from Douglas-fir pole surface taken at groundline 1-8 years after pre-treatment with disodium octaborate tetrahydrate followed by kiln drying and CuNap treatment. Dotted black line indicates 0.6 kg/m³ BAE, the threshold for decay prevention.

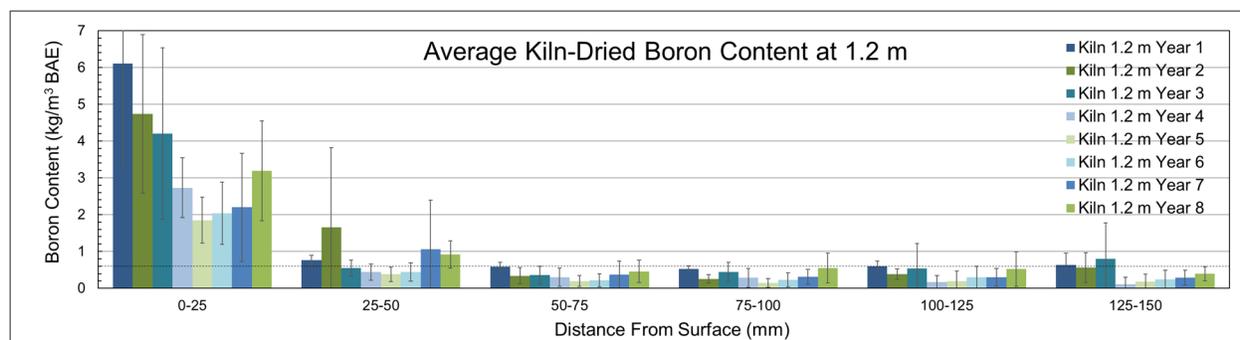


Figure 2.1.7. Boron content in 25 mm increments from Douglas-fir pole surface taken 1.2 m above groundline 1-8 years after pre-treatment with disodium octaborate tetrahydrate followed by kiln drying and CuNap treatment. Dotted black line indicates 0.6 kg/m³ BAE, the threshold for decay prevention.

Deeper than 50 mm below the pole surface boron content was generally below the inhibitory threshold on average in nearly all poles of both treatment types. However, in years 6-8 there appeared to be an uptick in boron concentration in the inner sections of a few Boultonized poles which pushed boron content above the inhibitory threshold. In addition, one kiln dried pole in year 7 also saw several sections greater than 50 mm under the pole surface rise above the threshold levels and remain there in year 8 (Table 2.1.4; 2.1.5). It is unclear if this is due to inward migration or spatial differences in boron distribution within the pole, however it is encouraging that in the Boulton seasoned poles, some of the increases were maintained for two years straight. Overall, these increases were sporadic and given the highly variable nature of the data pole-to-pole, it is not expected that these later year increases are statistically significant.

Total average boron concentrations calculated from all samples taken each year are shown to illustrate total boron depletion over time (Figure 2.1.8). Boron losses were higher from the groundline, but were also quite large from the above groundline as shown by the large difference between initial boron retentions and the year 1 sampling point. Average boron levels decreased each year until year 6 where they increased and remained stable in year 7 and may have shown a slight increase in year 8. This increase may be due to uneven boron distribution at different sampling locations which may have driven up concentrations in the more recent sampling points. These results suggest that the pool of boron available for inward diffusion may have stabilized.

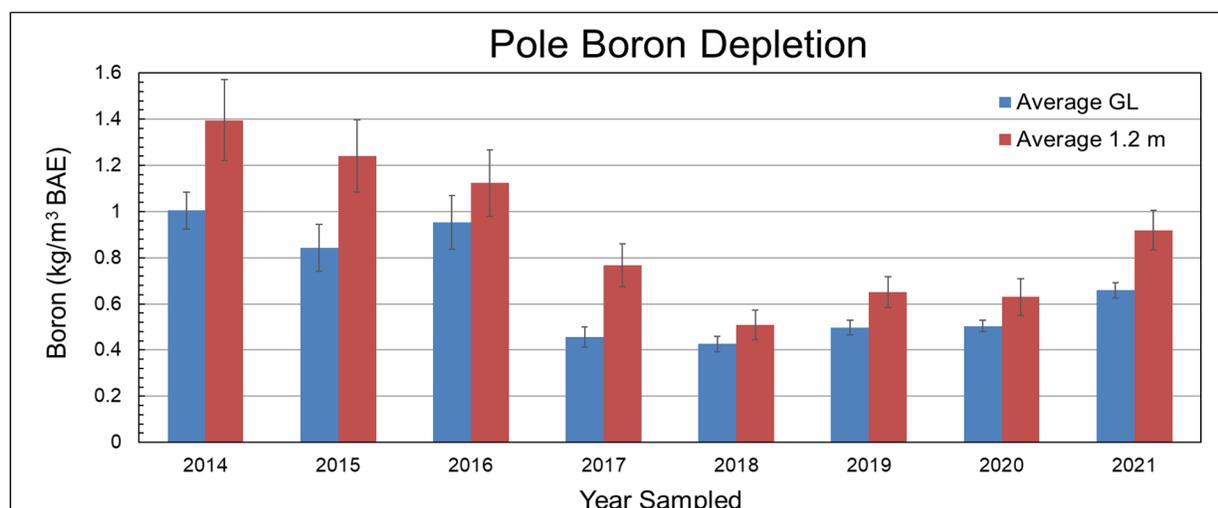


Figure 2.1.8. Average of total pole boron content of Douglas-fir poles after pre-treatment with disodium octaborate tetrahydrate followed by kiln drying and CuNap treatment. Dotted black line indicates 0.6 kg/m³ BAE, the threshold for decay prevention. Initial average pole boron concentrations after treatment were 9.44 kg/m³ BAE (pre-drying) and 5.40 kg/m³ BAE (post-drying). Values for 2014 represent 1-year exposed in the field and highlight the faster loss of total pole boron at groundline than 1.2 m above ground. Bars represent standard error.

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

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

The 2021 sampling of this study was the final sampling, and it was removed. A replacement test will be installed in 2022 using Douglas-fir poles that were pressure treated with boron prior to a copper naphthenate overtreatment. These poles are being sent to OSU in early 2022 for installation in the spring/summer of 2022.

Table 2.1.4. Boron content in increment cores removed from groundline or 1.2 m above groundline of Douglas-fir poles 1-8 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 (SD)		2.82 (0.45)	4.08 (0.77)	1.16 (0.43)	1.02 (0.27)	0.79 (0.28)	0.67 (0.17)	0.55 (0.08)	0.60 (0.11)	0.66 (0.21)	0.59 (0.07)	0.69 (0.24)	0.59 (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 (SD)		2.50 (1.09)	3.58 (0.77)	1.00 (0.61)	1.56 (0.85)	0.51 (0.27)	0.51 (0.26)	0.50 (0.17)	0.42 (0.20)	0.34 (0.19)	0.31 (0.18)	0.38 (0.25)	0.57 (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 (SD)		3.27 (1.15)	3.61 (1.39)	1.16 (0.60)	1.16 (0.76)	0.58 (0.37)	0.57 (0.30)	0.36 (0.18)	0.35 (0.26)	0.33 (0.16)	0.43 (0.44)	0.43 (0.23)	0.48 (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 (SD)		1.06 (0.70)	2.63 (0.54)	0.62 (0.27)	1.43 (0.84)	0.36 (0.29)	0.53 (0.34)	0.31 (0.25)	0.27 (0.19)	0.32 (0.27)	0.17 (0.10)	0.14 (0.13)	0.16 (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 (SD)		0.79 (0.24)	1.97 (0.38)	0.60 (0.14)	0.64 (0.28)	0.34 (0.17)	0.17 (0.11)	0.33 (0.18)	0.13 (0.09)	0.25 (0.16)	0.12 (0.08)	0.25 (0.20)	0.13 (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 (SD)		0.89 (0.31)	2.07 (0.41)	0.75 (0.24)	0.61 (0.14)	0.48 (0.23)	0.38 (0.22)	0.46 (0.25)	0.36 (0.26)	0.42 (0.23)	0.46 (0.30)	0.49 (0.28)	0.49 (0.19)
759	Boulton Year 7	0.73	2.28	0.68	0.83	0.52	0.31	0.56	0.22	0.64	0.26	0.65	0.22
760		1.03	1.78	0.78	1.21	0.70	0.79	0.68	0.39	0.55	0.43	0.77	0.44
762		0.66	0.38	0.46	0.29	0.26	0.16	0.19	0.15	0.16	0.77	0.17	0.19
763		1.03	0.73	0.54	0.07	0.31	0.02	0.18	0.00	0.11	0.03	0.14	0.13
764		1.26	0.70	1.03	0.42	0.83	0.26	0.68	0.36	0.69	0.44	0.57	0.89
Mean (SD)		0.94 (0.22)	1.17 (0.72)	0.70 (0.20)	0.57 (0.41)	0.52 (0.22)	0.31 (0.26)	0.46 (0.23)	0.22 (0.14)	0.43 (0.25)	0.39 (0.24)	0.46 (0.26)	0.37 (0.28)
759	Boulton Year 8	0.72	1.90	1.07	1.76	0.68	0.63	0.66	0.49	0.71	0.87	1.04	0.32
760		1.03	1.36	1.09	1.28	0.89	1.04	0.85	0.70	0.67	0.67	0.98	0.74
762		1.00	1.97	0.74	0.88	0.40	0.37	0.32	0.20	0.19	0.32	0.27	0.32
763		0.97	2.31	1.24	0.81	0.47	0.40	0.34	0.34	0.26	0.17	0.26	0.15
764		1.08	1.62	0.94	1.09	0.96	0.49	0.77	0.37	1.03	0.48	1.42	0.54
Mean (SD)		0.96 (0.13)	1.83 (0.32)	1.02 (0.17)	1.16 (0.34)	0.68 (0.22)	0.58 (0.24)	0.59 (0.22)	0.42 (0.17)	0.57 (0.31)	0.50 (0.25)	0.79 (0.46)	0.42 (0.21)

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

Table 2.1.5. Boron content in increment cores removed from groundline or 1.2 m above groundline of Douglas-fir poles 1-8 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	0.49	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	0.49	0.49	0.49	0.54
Mean (SD)		2.79 (0.59)	6.10 (2.86)	0.63 (0.06)	0.76 (0.13)	0.52 (0.04)	0.58 (0.13)	0.50 (0.07)	0.53 (0.08)	0.47 (0.05)	0.59 (0.15)	0.47 (0.04)	0.64 (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 (SD)		3.28 (1.26)	4.74 (2.16)	0.58 (0.49)	1.66 (2.16)	0.21 (0.11)	0.34 (0.22)	0.13 (0.10)	0.26 (0.11)	0.20 (0.12)	0.39 (0.14)	0.48 (0.36)	0.56 (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 (SD)		3.14 (1.63)	4.20 (2.33)	1.00 (0.99)	0.55 (0.22)	0.33 (0.20)	0.35 (0.24)	0.20 (0.08)	0.44 (0.26)	0.21 (0.20)	0.53 (0.68)	0.41 (0.24)	0.80 (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 (SD)		1.20 (0.44)	2.73 (0.82)	0.65 (0.35)	0.44 (0.23)	0.39 (0.24)	0.30 (0.25)	0.19 (0.13)	0.29 (0.26)	0.14 (0.14)	0.17 (0.18)	0.09 (0.12)	0.11 (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 (SD)		1.21 (0.50)	1.85 (0.62)	0.50 (0.20)	0.38 (0.19)	0.22 (0.12)	0.20 (0.15)	0.22 (0.16)	0.14 (0.12)	0.21 (0.14)	0.20 (0.27)	0.21 (0.05)	0.18 (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 (SD)		0.86 (0.43)	2.03 (0.85)	0.54 (0.35)	0.44 (0.25)	0.23 (0.13)	0.22 (0.18)	0.20 (0.13)	0.23 (0.20)	0.23 (0.11)	0.29 (0.30)	0.41 (0.33)	0.24 (0.24)
766	Kiln Year 7	0.21	0.53	0.17	0.10	0.14	0.07	0.11	0.07	0.14	0.11	0.00	0.16
767		0.75	1.55	0.39	0.27	0.27	0.13	0.27	0.15	0.36	0.17	0.51	0.13
770		0.90	0.84	0.71	4.82	0.50	3.70	0.54	1.08	0.56	0.63	0.84	0.70
788		0.73	2.64	0.57	0.56	0.32	0.33	0.38	0.41	0.56	0.42	0.57	0.41
789		0.63	1.44	0.36	0.68	0.24	0.23	0.33	0.30	0.29	0.07	0.30	0.10
Mean (SD)		0.64 (0.23)	1.40 (0.73)	0.44 (0.18)	1.29 (1.78)	0.29 (0.12)	0.89 (1.41)	0.33 (0.14)	0.40 (0.36)	0.38 (0.16)	0.28 (0.21)	0.44 (0.28)	0.30 (0.23)
766	Kiln Year 8	0.63	2.01	0.38	0.56	0.23	0.12	0.11	0.37	0.23	0.10	0.29	0.17
767		0.87	2.06	0.51	0.40	0.25	0.25	0.30	0.21	0.13	0.35	0.35	0.29
770		1.98	2.19	0.49	1.36	0.50	0.74	0.79	0.79	0.93	0.76	0.95	0.65
788		0.99	4.77	0.79	1.12	0.57	0.89	0.53	1.22	0.75	1.32	0.66	0.73
789		0.60	4.92	0.53	1.16	0.34	0.31	0.20	0.16	0.34	0.18	0.27	0.45
Mean (SD)		1.01 (0.51)	3.19 (1.35)	0.54 (0.13)	0.92 (0.37)	0.38 (0.14)	0.46 (0.30)	0.39 (0.24)	0.55 (0.40)	0.48 (0.31)	0.54 (0.45)	0.50 (0.27)	0.46 (0.21)

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

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

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

Class 3, 40-foot long Douglas-fir poles were cut into twenty-four, 2.4 m long sections and allocated to one of three treatments. Twelve poles were tagged and sent to be commercially treated with a 10% solution of disodium octaborate tetrahydrate (DOT) as part of a lumber charge. After treatment, the poles were commercially treated to the AWP A UC4C retention with copper naphthenate (2.4 kg/m^3) or pentachlorophenol (9.6 kg/m^3). The remaining six pole sections were impregnated with a DOT/ammoniacal copper zinc arsenate solution. Following treatment, increment cores were taken at 300 mm increments along the 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 inductively coupled plasma optical emission spectroscopy for copper, zinc, arsenic, and boron for the initial retention analysis.

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

process parameters may need to be changed to accommodate Douglas-fir pole sections to deliver more consistent treatment.

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

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

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

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

The poles were sampled in each of four years after installation by removing increment cores from three locations around each pole at groundline and 1.2 m above groundline. Each core was divided into 25 mm long segments. Core segments from a given location on each pole were combined and ground to pass a 20-mesh screen. The resulting ground wood was hot water-extracted and analyzed for boron via the Azomethine H method. Results were expressed on a

kg/m³ boric acid equivalent (BAE) where the threshold for fungal protection is considered to be equal to, or greater than 0.6 kg/m³ BAE.

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

Average boron levels were above the threshold in the outer 25 mm at both groundline and 1.2 m in all treatments throughout all four years of sampling (Figure 2.1.9-11). This is in contrast to the patterns observed in the initial sampling before installation where boron content in the outermost sections were lower on average than those observed deeper beneath the pole surface (Table 2.1.6). Average boron levels declined sharply to the inside of the outermost 25 mm section, but stayed above threshold levels in the 25-50 mm section in most of the year 1 samples. All boron levels 25 mm or farther inside the pole in year 2 onward were below threshold. Differences between all samples taken from all treatments greater than 50 mm below the pole surface were slight and have remained so through the 5th year sampling.

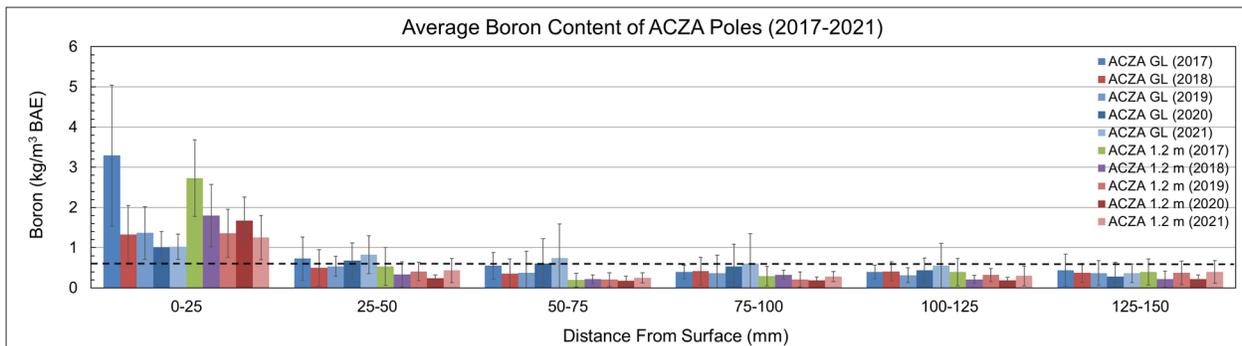


Figure 2.1.9. Boron levels in Douglas-fir poles subjected to an ACZA/boron dual pressure treatment for the first 4 years of sampling. Dotted black line indicates 0.6 kg/m³ BAE, the threshold for decay prevention.

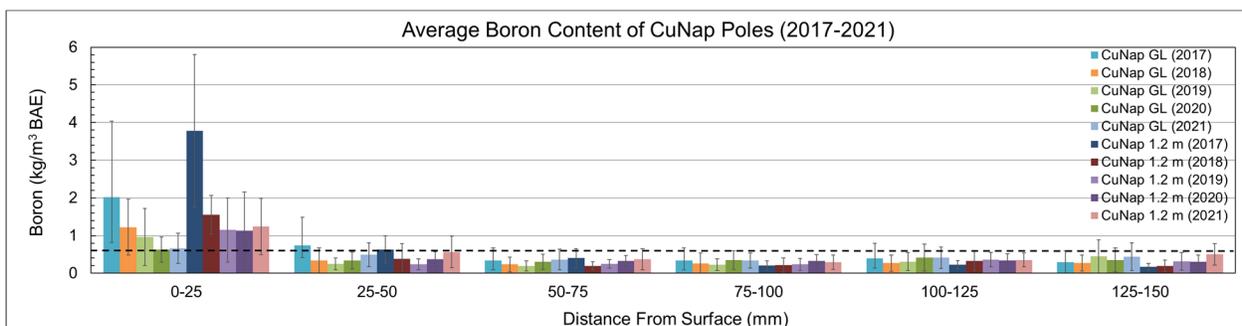


Figure 2.1.10. Boron levels in Douglas-fir poles subjected to a boron pre-treatment followed by over-treatment with copper naphthenate for the first 4 years of sampling. Dotted black line indicates $0.6 \text{ kg/m}^3 \text{ BAE}$, the threshold for decay prevention.

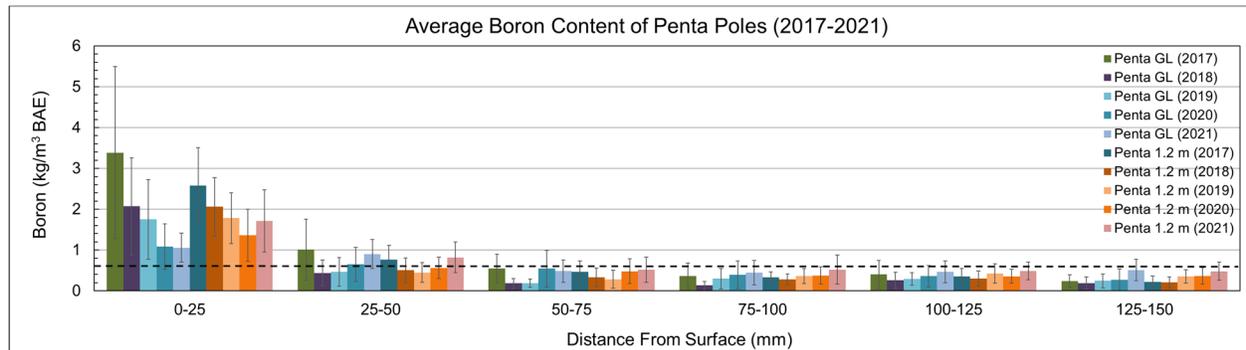


Figure 2.1.11. Boron levels in Douglas-fir poles subjected to a boron pre-treatment followed by over-treatment with Pentachlorophenol the first four years of sampling. Dotted black line indicates $0.6 \text{ kg/m}^3 \text{ BAE}$, the threshold for decay prevention.

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

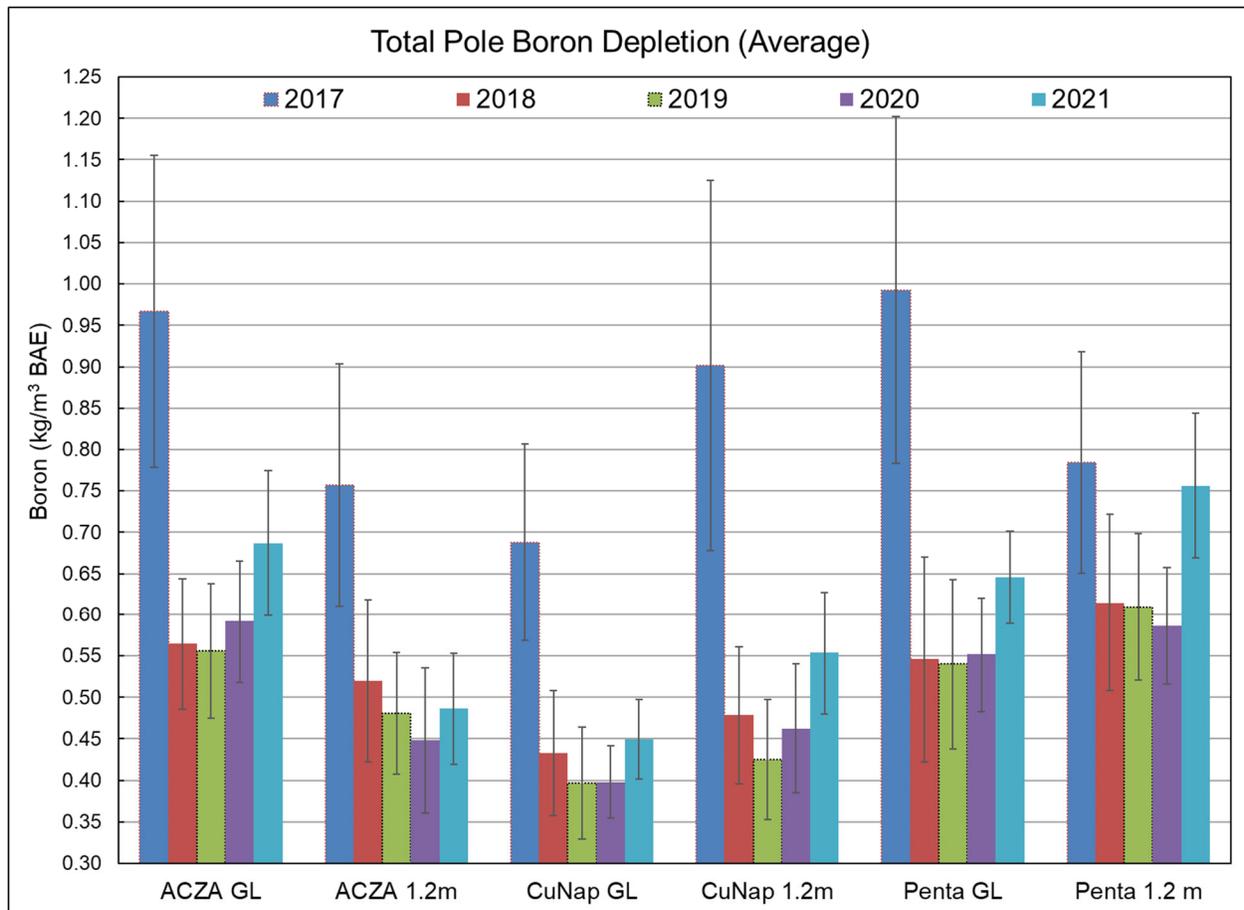


Figure 2.1.12. Average of total pole boron content of Douglas-fir poles subjected to either a boron pre-treatment followed by over-treatment with copper naphthenate, pentachlorophenol, or an ACZA/boron pressure treatment after 4 years. Dotted black line indicates 0.6 kg/m³ BAE, the threshold for decay prevention. Initial average pole boron concentrations after treatment are unknown. Values for 2017 represent 1-year exposed in the field. Bars represent standard error.

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

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

Primary Treatment	Depth (mm)	GL		1.2 m	
		(kg/m ³ BAE)	Std. Dev.	(kg/m ³ BAE)	Std. Dev.
ACZA (2017)	0-25	3.29	(1.92)	2.73	(1.04)
	25-50	0.73	(0.59)	0.53	(0.51)
	50-75	0.55	(0.36)	0.20	(0.19)
	75-100	0.40	(0.19)	0.30	(0.26)
	100-125	0.39	(0.18)	0.39	(0.38)
	125-150	0.44	(0.43)	0.40	(0.36)
ACZA (2018)	0-25	1.33	(0.78)	1.80	(0.85)
	25-50	0.50	(0.50)	0.34	(0.34)
	50-75	0.36	(0.41)	0.21	(0.12)
	75-100	0.42	(0.38)	0.33	(0.12)
	100-125	0.41	(0.26)	0.21	(0.11)
	125-150	0.37	(0.26)	0.22	(0.21)
ACZA (2019)	0-25	1.37	(0.71)	1.36	(0.65)
	25-50	0.54	(0.27)	0.41	(0.25)
	50-75	0.38	(0.58)	0.21	(0.19)
	75-100	0.37	(0.49)	0.21	(0.21)
	100-125	0.32	(0.20)	0.32	(0.18)
	125-150	0.37	(0.34)	0.38	(0.32)
ACZA (2020)	0-25	1.01	(0.39)	1.67	(0.59)
	25-50	0.68	(0.44)	0.24	(0.09)
	50-75	0.60	(0.62)	0.18	(0.11)
	75-100	0.53	(0.56)	0.19	(0.08)
	100-125	0.44	(0.30)	0.19	(0.08)
	125-150	0.28	(0.35)	0.22	(0.10)
ACZA (2021)	0-25	1.02	0.31	1.25	0.55
	25-50	0.83	0.47	0.44	0.30
	50-75	0.74	0.85	0.25	0.12
	75-100	0.61	0.74	0.28	0.13
	100-125	0.55	0.56	0.30	0.25
	125-150	0.37	0.23	0.40	0.28

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

Primary Treatment	Depth (mm)	GL		1.2 m	
		(kg/m ³ BAE)	Std. Dev.	(kg/m ³ BAE)	Std. Dev.
CuNaph (2017)	0-25	2.02	(1.32)	3.78	(2.22)
	25-50	0.74	(0.35)	0.63	(0.40)
	50-75	0.34	(0.27)	0.40	(0.28)
	75-100	0.34	(0.27)	0.20	(0.13)
	100-125	0.40	(0.29)	0.22	(0.12)
	125-150	0.30	(0.32)	0.17	(0.10)
CuNaph (2018)	0-25	1.22	(0.81)	1.55	(0.56)
	25-50	0.34	(0.37)	0.38	(0.44)
	50-75	0.24	(0.21)	0.20	(0.12)
	75-100	0.26	(0.30)	0.22	(0.20)
	100-125	0.27	(0.24)	0.33	(0.28)
	125-150	0.27	(0.23)	0.20	(0.17)
CuNaph (2019)	0-25	0.96	(0.83)	1.15	(0.93)
	25-50	0.25	(0.17)	0.24	(0.16)
	50-75	0.19	(0.15)	0.25	(0.12)
	75-100	0.23	(0.17)	0.24	(0.18)
	100-125	0.31	(0.26)	0.36	(0.21)
	125-150	0.45	(0.48)	0.32	(0.26)
CuNaph (2020)	0-25	0.62	(0.33)	1.13	(1.03)
	25-50	0.34	(0.22)	0.37	(0.21)
	50-75	0.31	(0.20)	0.33	(0.14)
	75-100	0.35	(0.24)	0.32	(0.17)
	100-125	0.42	(0.36)	0.33	(0.18)
	125-150	0.35	(0.32)	0.30	(0.19)
CuNaph (2021)	0-25	0.66	0.40	1.24	0.74
	25-50	0.49	0.32	0.56	0.42
	50-75	0.36	0.27	0.38	0.28
	75-100	0.34	0.20	0.30	0.19
	100-125	0.41	0.29	0.35	0.18
	125-150	0.44	0.37	0.50	0.28

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

Primary Treatment	Depth (mm)	GL		1.2 m	
		(kg/m ³ BAE)	Std. Dev.	(kg/m ³ BAE)	Std. Dev.
Penta (2017)	0-25	3.39	(2.31)	2.58	(1.02)
	25-50	1.01	(0.82)	0.76	(0.39)
	50-75	0.55	(0.39)	0.47	(0.30)
	75-100	0.37	(0.34)	0.33	(0.15)
	100-125	0.40	(0.38)	0.36	(0.21)
	125-150	0.24	(0.17)	0.22	(0.17)
Penta (2018)	0-25	2.07	(1.30)	2.06	(0.78)
	25-50	0.44	(0.34)	0.51	(0.33)
	50-75	0.19	(0.13)	0.33	(0.25)
	75-100	0.13	(0.10)	0.28	(0.15)
	100-125	0.26	(0.22)	0.30	(0.20)
	125-150	0.19	(0.16)	0.21	(0.15)
Penta (2019)	0-25	1.75	(1.07)	1.78	(0.69)
	25-50	0.46	(0.38)	0.45	(0.26)
	50-75	0.19	(0.11)	0.28	(0.24)
	75-100	0.30	(0.27)	0.36	(0.21)
	100-125	0.29	(0.17)	0.42	(0.26)
	125-150	0.25	(0.19)	0.36	(0.18)
Penta (2020)	0-25	1.09	(0.56)	1.37	(0.64)
	25-50	0.65	(0.42)	0.56	(0.27)
	50-75	0.55	(0.45)	0.48	(0.31)
	75-100	0.39	(0.34)	0.38	(0.21)
	100-125	0.36	(0.26)	0.36	(0.17)
	125-150	0.27	(0.27)	0.37	(0.20)
Penta (2021)	0-25	1.06	0.35	1.71	0.76
	25-50	0.90	0.36	0.82	0.38
	50-75	0.48	0.27	0.52	0.31
	75-100	0.45	0.30	0.52	0.35
	100-125	0.47	0.27	0.49	0.22
	125-150	0.51	0.26	0.48	0.22

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

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

Poles monitored in this study were installed in 2014 and were first sampled 2019 and the results of this sampling are described in the 2019 report. There was no sampling done in 2021. We will return to this study after it has had some time to mature in the field.

Table 2.1.8. Total number of poles sampled for each treatment.	
Treatment	Poles (#)
CuNap Only	19
Dual Treatment	24
Dual Treatment + Field Liner	5
Total Poles in Study	48

2.1.4 References for Objective 2

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

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

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

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

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

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

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

3.1.1 Effect of Conventional Capping on Pole Moisture Content:

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

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

This study was not sampled in 2021 and will be sampled again at a later date.

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

Polyurea barriers have proven to be durable on crossarm sections in sub-tropical exposures in Hilo, Hawaii. Given good performance in high decay hazard environments, these coatings are likely to perform well as moisture barriers in other applications as well. The UPRC initiated a study to investigate polyurea coatings as a pole capping system. Six penta-treated Douglas-fir pole sections (3.0 m long) were coated with polyurea from the tip to approximately 0.9 m below that zone (Figure 3.1.2). The poles were set to a depth of 0.6 m at a test site on the OSU campus. Increment cores were removed from the non-coated section of the pole and divided into inner and outer 25 mm sections as described above. Each core section was weighed immediately after removal from the pole, oven-dried, and re-weighed. The difference was used to determine MC. The sampling hole was covered with a patch of seal-fast tape (Mule-Hide Products, Beloit, WI). Moisture contents at the time of installation 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).

This study was not sampled in 2021 and will be sampled again at a later date.

3.1.3 Effect of Pole Top Configuration on Moisture Uptake in Poles

In previous tests, we have explored the benefits of capping poles at the time of installation to retard moisture uptake and limit the potential for pole top decay. These tests have shown dramatic differences in moisture content between poles with and without caps. One other aspect of a pole specification is variation in the shape of the pole top. Some utilities specify a flat top, while others require sloping or roofed tops. The presumption is that the slope encourages water to run off the wood more quickly, thereby reducing the risk of water uptake that creates conditions conducive to fungal attack. However, sloping surfaces expose a greater wood surface

area to wetting, thereby potentially increasing the risk of moisture uptake. This becomes especially important as poles season and check in service. Preservative treatment imparts some moisture resistance to wood, but continuous wetting and drying can lead to checking and greater moisture uptake over time. This increased moisture content swells the wood. Stresses develop as the wood dries which lead to the development of micro-checks on the upper surface that act as conduits for moisture to penetrate into the wood, potentially beyond the original depth of preservative treatment. There are, however, no data examining differences in moisture uptake on pole tops with differing roofing patterns. In 2017, we established a study to test the effect of pole top orientation on moisture content.

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

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

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



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

Table 3.1.3. Mass changes of Douglas-fir pole sections with different top configurations as determined by weighing over a 27-month exposure period in western Oregon.

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

12/11/2020	0.8	(3.1)	3.0	(2.1)	2.5	(1.8)	8.3	(14.4)
7/11/2020	-4.1	(4.6)	0.3	(0.7)	-2.6	(0.3)	-2.4	(1.6)
10/11/2021	-2.1	(1.4)	-0.8	(1.1)	-2.0	(1.4)	-3.0	(0.3)
<i>^aValues represent means of 4 or 5 replicates per roof style. Figures in parentheses represent one standard deviation.</i>								

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

The second year of sampling (2018-2019) showed only small differences in the relative moisture contents among the different treatment types on the order of only a few percentage points at maximum. The double-pitched pole tops tended to run slightly drier after the summer months than the flat uncapped configuration, but these differences were mostly statistically indistinguishable. The flat capped configuration tended to remain slightly drier than the others during the wetter months. One interesting sampling point was a 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. Summer and Autumn samplings in 2020 and 2021 again show increased drying in orientations with greater surface area. We expect that differences in the 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 3.1.5.



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

3.1.4 Performance of Polyurea-Coated Douglas-fir Crossarm Sections Exposed in Hilo Hawaii

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

This study was sampled in 2020 and the results were summarized in the 2020 report. It was not sampled in 2021 but will be sampled again at a later date.

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

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

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

With the development of new fire retardant products and barriers comes the need for testing to verify the efficacy of treatments for individual utilities. Some utilities and chemical manufacturers have responded with their own independent, unstandardized testing methods, but these are inherently incomparable to one another due to the variety of methodologies and conditions utilized. Standardized testing at designated testing facilities is very expensive and time consuming and can only be done at designated facilities (Herdman, 2019). Testing centers

are not a viable solution for research and development and standard methodologies for fire retardant treatment testing of utility poles that can be employed cheaply are needed.

The OSU UPRC has made strides to develop a standard method for pole fire retardant testing that is inexpensive and can be constructed and carried out with readily available materials. Several small-scale test methods have been developed in the UPRC and elsewhere and these vary in the fuel source for ignition and mode of flame or heat exposure (Carey, 2018; Morrell, 1999, 2014; Yang & Archer, 2018). Previous tests have used straw bales to generate open flames at the pole surface, which simulate low level, lower intensity brush fires (Morrell, 1999). Other methods use gas or propane torches to apply a flame directly to the pole surface which simulates a much more intense heat exposure and is by its nature more reproducible than biomass combustion (Morrell, 2014). Finally, some tests employ electric heat panels to generate enough heat at the pole surface to cause combustion (Konkler & Morrell, 2015). Each test method has strengths and weaknesses, but none of these have been standardized. Now the pole cooperative intends to continue to develop our testing capabilities with the end goal of standardizing a testing method to be included in the American Wood Protection Association (AWPA) Book of Standards.

The use of straw fuel and an open flame to test fire retardant treatments suffered from several deficiencies that made these types of tests difficult to reproduce. While it was generally considered beneficial that the pole sections would be exposed to an open flame, the fire intensity was not reproducible year to year due to variations in the ambient conditions. Heterogeneity in the fuel source is another issue for this method and variations in the moisture content and quality of the straw fuel led to variation in the testing conditions year-to-year.

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

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

The heat panel testing apparatus has been used to test several spray-on or paint-on fire retardant treatments in addition to several protective barriers and mesh wraps. The results of these tests

can be found in previous reports (Morrell, 2018; Morrell et al., 2015; Presley et al., 2019). The original design of the fire testing apparatus had some significant drawbacks. It only allowed a small portion of the pole surface to be burned, and therefore limited to the testing area to a small portion of the total surface area. This caused a deficiency in measuring damage because total circumference loss as a measure of fire damage was not useful in this test. Instead depth of char and total surface area burned was used as a measure of fire damage. Circumference loss can be used to calculate estimated strength loss so as a practical matter it is a more useful for determining the impact on pole performance. The small area bracketed by the heat shield in the original design also allowed excessive heat loss to the surrounding and greater protection of the heat source of the apparatus was needed to expose the poles to a more rigorous evaluation.

3.2.1 Modification of the fire testing apparatus

In this year's report we describe modifications to the fire testing apparatus allowed us to operate the tests remotely away from any building power sources. The design presented in 2020 was rewired to run off of two 12,000 W maximum generators (Figure 3.2.1-3.2.2).

The fire testing apparatus was constructed by affixing three ceramic heating panels (Tempco, 240V, 1000W) on piece of sheet metal formed into a U-shape with 5 flat surfaces. A hot wire igniter was affixed above the heat panels shielded by a small piece of sheet metal to ensure ignition once adequate temperatures were reached. The entire setup was mounted on small dollies so it can be easily wheeled up to pole sections for a test (Figure 1). Two dollies each with three heating panels were constructed and were used together for testing. The test is powered by two 12,000 peak Watt portable gas generators, one for each testing apparatus. This design allowed for the heat to be directed to a pole surface while shielding the panels from environmental influences.



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



Figure 3.2.2: Remote operation of the electric fire test using two generators as a power source

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

Table 3.2.1: Cost estimates for fires test components.

Item	Specs	Supplier	Quantity	Cost	Total
Hastelloy Thermocouple	18-inch, plain, Type-K	Chemglass	1	104.45	104.45
Thermocouple extentsion cord	Type-K	Chemglass	1	61.29	61.29
Thermocouple reader/data logger		Chemglass	1	242.05	242.05
Robert Shaw hot surface igniter	LP/NG, 120V AC, 4 1/2 in L., Silicon Carbide	zoro	2	15.16	30.32
Tempco IR heaters	240V, 1000W	zoro	6	21.64	129.84
plugs + cord	220 V, 20 amp, 35'	zoro	2	81.51	163.02
Extension cord	50'	zoro	2	45	90
Hand Truck		zoro	2	62.42	124.84
Sheet metal		TBD		TBD	N/A

Generator	Pulsar G12KBN-SG Heavy Duty Portable Dual Fuel Generator - 9500 Rated Watts & 12000 Peak Watts - Gas & LPG	TBD	2	950	1900
Total Costs					3345.81

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

The testing apparatus was tested on a set of untreated Douglas-fir pole sections to confirm its functionality. Tests were performed by wheeling both units up to the pole surface so that the heating elements are as close as possible to the pole surface and are enclosed on all sides by sheet metal. A type K Hastelloy thermocouple was loosely affixed to the pole surface with each tests using a staple. The thermocouple was connected to a data logger that allowed continuous monitoring of surface temperatures during the test. When ready, generators were started and the elements are plugged in to begin heating. For the initial testing, a standard heating period of 20 minutes was done and heating continued throughout the combustion period. After the 20-minute burn, the fire testing apparatuses are wheeled away from the pole surface. The pole sections were then allowed to smolder for 2 hours after the initial burn prior to quenching with water (Figure 3.2.3). The pole sections are allowed to cool overnight before measurements are made.

After quenching damage is assessed and several parameters were used to measure the extent of damage. Loss in circumference was measured by scraping away the char layer around the entire pole circumference and measuring circumference. The difference between the original circumference and post burn circumference is used as a measure of the damage done to the pole. Maximum char depth is measured at the point of greatest damage. Some pole sections had checks in them and for these check widening was another parameter used to measure the extent of damage. Checks tended to act like a chimney and maintain active smoldering during the smoldering period. Surface temperature monitoring also indicated time to ignition and maximum surface temperature which will be an important parameter to measure once fire-retardant treatments are tested with this apparatus.



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

Nine untreated Douglas-fir pole stubs were tested in initial tests to prove the system functioned. Poles tested in this initial trial were about 5 ft long and 10 inches in diameter. The test can accommodate larger or shorter pole sections so long as they are not shorter than 4 ft. Only a small portion of the pole sections, about 12-20 inches off the ground, are directly exposed to heat so longer pole sections do not necessarily benefit the test.

The testing apparatus successfully burned untreated poles and functioned consistently. Time to ignition for untreated poles was about 6 minutes with this apparatus. Damage to the poles varied with loss in circumference ranging from 1.5 to 6.6% and maximum char depth ranged from 4-10 mm (Table 1). Surface temperatures all reached above 665°C which was indicative of combustion. The surface temperature parameter will be useful for measuring the success of fire-retardant treatments in preventing combustion at the pole surface. Check widening was only measurable on some pole sections as they did not all have checks (Figure 3). Check widening also varied widely ranging from 3-92 mm where larger checks exhibited more vigorous smoldering after the heat application.

Table 3.2.2: Data collected from burning untreated Douglas-fir sections from 6 poles burned in 2021.

Pole #	Max surface Temp (°C)	Circumference loss %	Max char depth (mm)	Check widening (mm)
1	711.3	4.8	8	N/A
2	704.6	3.2	9	N/A
3	666.9	6.0	10	N/A
4	741.2	1.5	5	10
5	671.5	5.6	7	52

6	676.3	3.9	4	76
7	718.2	3.9	6	3
8	761.7	3.8	10	86
9	665.1	6.6	9	92

This test exposes pole sections to intense direct heat and represents a level of intensity that may not be encountered by poles in wildfires. However, it allows relatively consistent application of heat across different treatments which is not the case for some other fuels sources such as straw bales. Greater consistency allows for this testing apparatus to be utilized in a wider variety of conditions at different times of year where biomass fuel sources require dry, still conditions to perform tests. Testing will continue with treated pole sections to generate baseline performance data for the different preservative treatments with this testing apparatus prior to incorporating fire retardant treatments.

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

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

The UPRC has performed extensive testing on the performance both copper naphthenate and penta. The work originally began because of changes in the solvents commonly used to solubilize penta for Douglas-fir treatment. Changes in the availability of petroleum-based solvents has left treaters with petroleum oils that are poorer solvents for penta. This caused treaters to consider diesel oil for Douglas-fir treatment which comes with strong odors and is difficult to utilize for Boulton seasoning. Some of these negative characteristics can be mitigated by including biodiesel in a blend with diesel oil. Biodiesel is a better solvent for penta than diesel oil and greatly reduces odors. The mixture could still meet the AWWA Solvent Standard P9 Type A; however, there was concern among some treaters about the efficacy of biodiesel as a solvent for penta compared to conventional petroleum-based oil. However, there were still concerns about the impacts of the inclusion of biodiesel on the performance of penta-treated Douglas-fir poles.

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

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

Douglas-fir lumber was collected from a local mill shortly after sawing. The lumber was primarily sapwood free of knots, splits and other defects and was cut into standard stakes prior to treatment. The samples were weighed and allocated to treatment groups so that each group contained stakes and blocks with approximately similar density distributions. The samples were then treated with combinations of copper naphthenate or penta in mixtures of diesel alone or amended with 30, 50, 70, or 100% biodiesel using an empty cell process. The same commercially available soy-based biodiesel (FP9-HTS) was used to treat both penta and copper naphthenate treatments. In addition, each biocide was tested in an aromatic oil, a paraffinic oil, FPRL oil, and penta concentrate concurrently with biodiesel treatments. Penta target retentions were 2.4, 4.8, 6.4, and 9.6 kg/m³, copper naphthenate retentions were 0.66, 0.99, 1.33, and 1.66 kg/m³ as Cu.

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



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

We included two test sites in this study. One was an open field and one was a mature forest, adjacent to each other at our Peavy test site. Each site offers a unique microclimate for fungal decay, with the forest naturally harboring more wood-decay fungi. Stake condition was rated on a scale from 10 to 0 as described in AWP Standard E7 where:

<u>Grade No.</u>	<u>Description of Condition</u>
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

This study was not sampled in 2021 and will be sampled in 2022.

3.3.2 Effect of solvent systems on the performance 4,5-dichloro-2-n-octyl-4-isothiazolin-3-one (DCOI): E10 Soil bottle test

DCOI has been standardized as an oilborne treatment in a variety of solvents previously as described in a data packaged submitted to the P3 committee in 2005 (AWPA 2005). However, many new solvent systems are currently available for DCOI that have not been tested with this system. Solvent systems play a critical role in the efficacy of oilborne preservative systems both in chemical delivery and long-term retention (Arsenault et al. 1984). Therefore, as the use of DCOI becomes more widespread, long-term performance data of this chemical in combination with available solvent systems will aid pole manufacturers in producing longer-lasting DCOI-treated poles.

Two studies of DCOI performance in currently available solvent systems are currently being conducted. The first test is an AWPA E10 soil bottle test. Douglas-fir and Southern pine 19 mm blocks treated with DCOI using one of three solvent systems, HBB-30 oil, RHT-70 oil, or #2 diesel (AWPA 2020). Biodiesel has previously been shown to have no significant impact on the performance of DCOI in AWPA E10 tests, so it will not be tested here (Hua-Kang et al. 2013). Blocks have been/are being treated to one of three retentions listed in Table 3.3.3. Retentions were selected based on the UC4B AWPA standard retention for either species and 0.5 kg/m³ based on the effective threshold determined for DCOI against decay fungi (Greenley and Hegarty 1984). A third retention level 50% of the effective threshold was selected as well to representing severe undertreatment.

Blocks were weighed directly after treatment and a retention value for each treatment was measured using solution uptake. In addition, a subset of blocks was reserved directly after treatment for retention analysis by X-ray fluorescence according to AWPA A9. After treatment blocks were subjected to an AWPA E11 leaching protocol (AWPA 2020). During the leaching tests, blocks were exposed to 9 water exchanges. The first water exchange from the highest DCOI retention level for each wood species was reserved for analysis as well. Blocks from each treatment cohort were reserved for retention analysis by X-ray fluorescence to measure preservative loss due to leaching.

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

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

After leaching, blocks were sterilized by gamma irradiation and exposed to one of two brown rot fungi, (*Gloeophyllum trabeum*, *Postia placenta*) or one white rot fungus (*Trametes versicolor*)

for 12 weeks (brown rot) or 16 weeks (white rot). Mass losses were assessed and used as an indicator of resistance to fungal decay relative to control.

Decay tests are still running for this study. Currently most brown rot decay tests have been completed and a few are due to come out of the test in late December 2021/ January 2022. Data will be collected and included in the 2022 annual report.

3.3.3 Effect of solvent systems on the performance 4,5-dichloro-2-n-octyl-isothiazolin-3-one (DCOI) in two different climates: E7 Stake test

The performance of DCOI in several solvent systems is also being tested in an AWP A E7 stake test concurrently at two field sites operated by the UPRC. In addition to a comparison of solvent systems, DCOI performance will be compared to two other oilborne preservative systems commonly used to treat utility poles used by western species, low odor copper naphthenate and pentachlorophenol. Stakes will be set out at two sites in Oregon, the Peavy Arboretum field site (~41 inches annual rainfall) and the Madras dry site (~10 inches annual rainfall). Stakes are currently being treated and will be set out in the field in the spring/summer of 2022.

Douglas-fir and Southern pine stakes will be treated to target retention levels shown in Table 3.3.4. using the same solvent systems used in the soil bottle test described above DCOI plus biodiesel-containing mixtures of the #2 diesel treatment. The stake tests will be done at two field sites concurrently, at the Peavy Arboretum (~41" annual rainfall) and our field site at Madras, Oregon (~11" annual rainfall). Douglas-fir and southern pine stakes will be treated with DCOI to three different retentions (Table 3.3.4) using one of five different solvent systems (Table 3.3.5). Stakes will also be treated with a low odor (refined) copper naphthenate in #2 diesel or pentachlorophenol in HBB-30 oil at three different retentions as controls. Depletion will be assessed with the highest retention for copper naphthenate and penta and all retentions for DCOI for 5 timepoints during the study.

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

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

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

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

Penta	HBB-30
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Each unique treatment will contain 10 replicate stakes for annual assessment in addition to three stakes used for depletion analysis (5 at each of 5 timepoints). Assessments will be done according to the grading criteria described in the AWPAs E7 standard (AWPA 2020). The study will be assessed until solvent system performance can be resolved statistically, likely at least 8 years at the Peavy Arboretum and longer at the Madras field site.

3.4.0 Performance of 4,5-dichloro-2-n-octyl-4-isothiazolin-3-one (DCOI) as a treatment for utility poles

Recent developments have led to the sole manufacturer of pentachlorophenol (penta) in North America to plan to discontinue its production by the end of 2021 (Tullo 2020). Penta is the most commonly used wood preservative for utility poles and as much as 60% of poles in the United States are treated with penta (Gulliford, 2008). The loss of this preservative means a combination of other oil borne treatments will have to fill the void. DCOI and copper naphthenate are positioned to play a much larger role as utility pole treatments in western utilities once penta is no longer available. Copper naphthenate has a long history of successful use as a treatment for utility poles. DCOI was standardized for utility poles relatively recently and most of the performance data supporting its efficacy utilizes southern pine. DCOI's performance in western species such as Douglas-fir have primarily been tested in few smaller-scale trials and western utilities have requested more information about its performance in Douglas-fir in environments relevant to their utility networks

DCOI is not a new chemical and has been a proven effective wood preservative since the 1980s (Nicholas et al. 1984; Greenley and Hegarty 1988). However, more information on the long-term performance of this chemical as a utility pole treatment in a variety of environments, particularly in western species, would help utilities make informed decisions about which chemicals would be best suited for specific environments within their network. More information on the performance of DCOI in Douglas-fir would also be valuable for western utilities as most of the performance data submitted to the AWPAs for standardization of DCOI was in southern pine.

An effort to study the efficacy of DCOI as a utility pole treatment was started in a series of studies at different scales. Two studies on the impacts of solvent systems on the efficacy of DCOI as a preservative system were started (section 3.3.2 and 3.3.3). In addition, a long-term durability test comparing DCOI, CuNap and penta-treated pole stubs has been initiated at the Peavy Arboretum and the Madras, Oregon field site (section 3.4.1). Finally, we are continuing to assess a now 9-year old study of DCOI-treated southern and red pine pole stubs at the Peavy Arboretum and this report contains the 8-year assessment of those poles (section 3.4.2).

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

Site(s)	Peavy Arboretum	Madras, Oregon
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Installation date Species Treatments Number of Poles	Oct-20 Douglas-fir			Feb-21 Douglas-fir		
	DCOI	Qnap	Penta	DCOI	Qnap	Penta
Groundline circumference (cm)	109.1	109.9	90.0	101.7	113.3	90.4
Average Retentions (kg/m ³)	2.4	1.5	9.5	3.5	1.6	12.6
Pole length (5ft)	5	5	5	5	5	5

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

The first study installed at the Madras, Oregon dry site is a long-term post test which includes a side-by-side comparison of three common oilborne treatments used for Douglas-fir utility poles. Douglas-fir pole sections, 5-foot or 8-foot x 12-14" diameter were obtained from treating facilities in the Oregon/Washington region. Ten, 5-foot poles of each of three treatments, DCOI, Qnap, and penta, were initially obtained for this study. Each pole was cored at three equidistant locations at the center and these cores were pooled and assayed for retention using X-ray fluorescence according to AWP A9 (AWPA, 2020). In addition, the remainder of the pole cores taken for retention analysis were cultured for decay fungi. The first batch of poles were installed at the Peavy Arboretum site in October 2020 (Figure 3.4.1) and were installed in Madras, Oregon in February, 2021. Summaries of the retention analysis and fungal culturing data for this first set of 15 pole stubs at each site are included in Table 3.4.1 (Peavy) and 3.4.1 (Madras).

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

Table 3.4.1: Size, Retention analysis and fungal culturing data for the 15 poles installed at the Peavy Arboretum in October 2020.

Primary Treatment	Replicate	Barcode #	Pole Circumference (cm) ¹		Diameter (cm)	Preservative Retention (kg/m ³)	Culturing Results Prior to Pole Installation
			Groundline	Pole Top	Pole Top		
DCOI	1	OSU2777	106.0	104.6	33.3	2.75	No Fungi
DCOI	2	OSU2778	104.0	99.5	31.7	1.92	No Fungi
DCOI	3	OSU2779	111.6	114.3	36.4	2.35	No Fungi
DCOI	4	OSU2780	110.6	110.3	35.1	2.49	No Fungi
DCOI	5	OSU2781	113.0	111.1	35.4	2.32	No Fungi
Penta	1	OSU2772	98.7	95.3	30.3	11.91	3/6 Cores, 5 Non-Decay Species
Penta	2	OSU2773	83.5	79.1	25.2	7.50	No Fungi

Penta	3	OSU2774	86.4	81.4	25.9	7.91	No Fungi
Penta	4	OSU2775	92.1	85.9	27.4	9.38	2/6 Cores, 2 Non-Decay Species
Penta	5	OSU2776	89.2	92.7	29.5	10.77	3/6 Cores, 1 Non-Decay Species
CuNap	1	OSU2767	114.0	116.2	37.0	1.66	1/6 Cores, 1 Non-Decay Species
CuNap	2	OSU2768	107.3	102.9	32.8	1.17	No Fungi
CuNap	3	OSU2769	116.8	114.8	36.6	1.68	No Fungi
CuNap	4	OSU2770	111.6	114.0	36.3	1.63	No Fungi
CuNap	5	OSU2771	99.7	102.2	32.6	1.33	No Fungi

Table 3.4.2: Size, Retention analysis and fungal culturing data for the 15 poles installed at the Peavy Arboretum in February, 2021.

Primary Treatment	Replicate	Barcode #	Pole Circumference (cm) ¹		Diameter (cm)	Preservative Retention (kg/m ³)	Culturing Results Prior to Pole Installation
			Groundline	Pole Top	Pole Top		
DCOI	1	1355	103.0	105.0	33.6	2.16	No Fungi
DCOI	2	1356	93.0	95.8	31.4	5.20	No Fungi
DCOI	3	1357	100.8	97.5	31.2	2.49	No Fungi
DCOI	4	1358	114.3	110.5	35.5	4.45	No Fungi
DCOI	5	1359	97.4	101.2	31.1	3.21	No Fungi
Penta	1	1360	95.0	90.0	29.2	12.80	3/6 Cores, 2 Non-Decay Species
Penta	2	1361	86.0	76.3	25.0	14.95	No Fungi
Penta	3	1362	85.5	70.6	22.8	9.15	1/6 Cores, 1 Non-Decay Species
Penta	4	1363	99.4	86.0	26.9	14.47	2/6 Cores, 1 Non-Decay Species
Penta	5	1364	86.0	82.0	26.6	11.67	2/6 Cores, 1 Non-Decay Species
CuNap	1	1350	119.7	120.0	37.7	1.20	No Fungi
CuNap	2	1351	111.8	118.0	38.0	1.48	1/6 Cores, 1 Non-Decay Species
CuNap	3	1352	114.3	112.0	36.5	2.33	1/6 Cores, 1 Non-Decay Species
CuNap	4	1353	101.6	94.5	29.8	1.41	1/6 Cores, 1 Non-Decay Species
CuNap	5	1354	119.4	112.0	36.8	1.52	No Fungi



Figure 3.4.1 Peavy Arboretum site for the DCOI post test.

In 2022, another 10 poles stubs for each treatment, eight feet in length, will be installed at the sites. The pole stubs have been acquired and will be installed when the weather is more favorable. This will bring the total number of replicate stubs at each site to 15 per treatment at each site.

This study will not be sampled until 5 years after installation. In the interim, soil samples are being taken annual from around the base of each pole treatment to monitor migration over the lifespan of the study. An assessment of soil migration will be included in later reports.

3.4.2 Performance of DCOI as a utility pole preservative in red pine and southern pine pole stubs at the Peavy Arboretum: 8-year assessment

As part of its standardization as a utility pole treatment through the AWPA, a large data package on DCOI performance and treatability with several wood species was submitted. Part of this package was a multi-site AWPA E8 post test that was initiated in 2012 in conjunction with the Forest Products Laboratory in Madison, WI (Archer and Zahora, 2018). Red pine and southern pine pole stubs, 5-feet long by 8-11 inches in diameter, were treated in Madison Wisconsin whereafter they were sent to one of three field sites, Harrisburg, NC, Gainesville, FL and the Peavy Arboretum in Corvallis, OR. Red pine and southern pine pole stubs were treated using an average 1.33 % DCOI solution in #2 diesel oil. In addition, another set of southern pine poles were treated with an average 2.25 % solution of DCOI in #2 diesel oil. This set of poles was cored and sampled for penetration and retention as part of the data collection process for standardization (Archer and Zahora, 2018). Retentions were assayed by X-ray fluorescence on a pool of cores taken from each charge where the pole stubs were treated. In addition, estimates of retention were made by monitoring solution uptake during the treatment process. In 2013, a set of 20 penta treated southern pine pole stubs were installed at the site as well, although the initial assay retentions from these poles are unknown.

After 5-years (2017) the pole stubs were assessed at each site and the presence or absence of decay fungi was measured. At the Peavy Arboretum site, none of the DCOI or penta-treated

samples showed signs of decay or decay fungi. The study was then left to carry out until late 2020, 8 years after installation, where it was sampled again at the Peavy Arboretum site for chemical retention and presence/absence of decay fungi.

DCOI and penta pole stubs were sampled at three locations, 150 mm below groundline, at groundline and 450 mm above groundline. Three equidistant cores were taken at sampling zones and the three cores for each height were pooled for retention and culturing. The appropriate assay zones were isolated for red pine (3-41 mm) and southern pine poles (13-51 mm) and the outer zone was discarded. The remainder of the cores were plated on malt agar and malt-benlate agar for the isolation of non-decay/dematiaeous and decay fungi, respectively. The assay zones were analyzed for DCOI or penta retention using an X-ray fluorescence analyzer according to AWWA A9 (AWWA, 2020). Retention levels were averaged for each sampling location/treatment combination and the results are summarized in Figure 3.4.2 and Table 3.4.2.

After 8 years, DCOI retention levels remained near AWWA standard retention levels for poles treated to UC4B retention levels Table 3.4.3. Red pine poles were below the UC4B level of 2.7 kg/m³ and had a retention of 2.01 across all sampling locations. Southern pine poles treated with a 1.3% or a 2.25% DCOI solution had retention levels generally above the 2.1 kg/m³ standard for UC4B. Penta-treated southern pine poles were also well above the UC4B standard of 6.08 kg/m³. The sampling location did not appear to result in a large difference in retention levels within the different treatments. Chemical retention data indicate that the poles in this study should continue to successfully protect poles from decay.

Chemical depletion was estimated in DCOI poles based on a composite retention assay that was done shortly after treatment in 2012. Comparison of the initial retentions with 2020 data showed that the red pine and 1.3 % DCOI solution southern pine poles appeared to gain DCOI retention over time. This may be due to slight differences in sampling location that yielded different DCOI retention levels that made the appearance of chemical gain. Southern pine poles treated with a 2.25% DCOI solution only lost about 7% of the original chemical over an 8-year time period. Together these data indicate that very little depletion likely occurred during the 8-year period between installation and the 2020 sampling.

The remainder of the cores sampled for retention analysis were reserved for fungal culturing. Fungal cultures isolated from cores were classified as decay, non-decay or dematiaceous fungi and the data was summarized as a % of all cores for each pole type that contained decay. No decay fungi were found in any DCOI or penta-treated samples. Red pine DCOI-treated poles had the highest proportions of non-decay and dematiaceous fungi, 27% and 13%, respectively. Southern pine poles treated with DCOI had similar rates of dematiaceous fungi isolation as compared to penta-treated poles. Untreated control poles had much higher levels of fungi and also had visible signs of decay after 2017.

Overall these results indicate that DCOI treatment continues to provide similar levels of protection compared to penta after 8 years of field exposure.

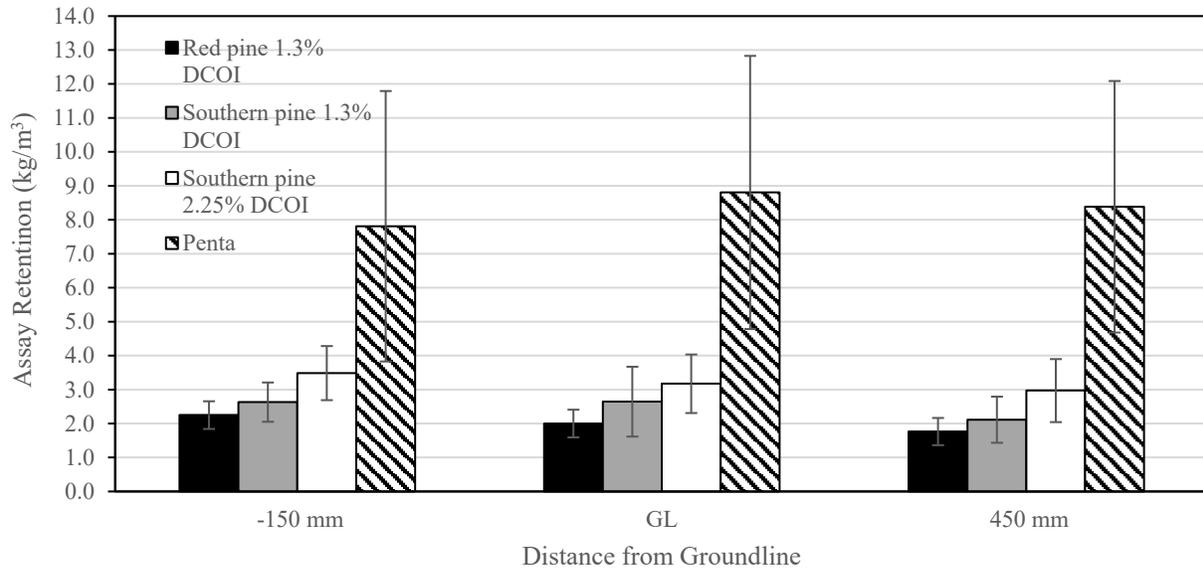


Figure 3.4.2: Assay retention levels found in DCOI and penta-treated pole sections from the 2020 sampling

Table 3.4.2: Assay Retention levels found in DCOI and penta-treated pole sections from the 2020 sampling.

Species	n	Initial Trt. Soln. Strength (%)	height	Assay retention 2020 (kg/m ³)	Std. Dev.	Assay retention 2020 (lbs/ft ³)	Std. Dev.
Red Pine	15	1.33	-150 mm	2.25	0.41	0.14	0.03
Red Pine	15	1.33	GL	2.00	0.41	0.12	0.03
Red Pine	15	1.33	450 mm	1.76	0.40	0.11	0.02
Southern Pine	15	1.33	-150 mm	2.63	0.58	0.16	0.04
Southern Pine	15	1.33	GL	2.65	1.03	0.17	0.06
Southern Pine	15	1.33	450 mm	2.11	0.68	0.13	0.04
Southern Pine	14	2.25	-150 mm	3.49	0.80	0.22	0.05
Southern Pine	14	2.25	GL	3.17	0.86	0.20	0.05
Southern Pine	14	2.25	450 mm	2.97	0.93	0.19	0.06
Southern Pine	20	N/A	-150 mm	7.81	3.98	0.49	0.25

Southern Pine	20	N/A	GL	8.81	4.02	0.55	0.25
Southern Pine	20	N/A	450 mm	8.38	3.70	0.52	0.23

Table 3.4.3: Estimated depletion from DCOI-treated southern pine and red pine based on combined assay retention done when pole stubs were treated in 2012.

	% DCOI treating solution	Avg initial gauge retention	Avg initial assay retention kg/m ³	Avg 2020 assay retention kg/m ³	% DCOI loss vs initial assay
Red Pine	1.33	1.74	1.35	2.01	-49.0
SYP	1.33	2.22	1.68	2.46	-46.8
SYP	2.25	3.43	3.46	3.21	7.23

Table 3.4.4: Fungal isolation frequency from cores taken from DCOI or penta-treated pole stubs after 8 years. Fungi are classed as decay, dematiaceous or non-decay fungi.

Pole Species	Treatment	Treating solution strength (%)	Decay (%)	Dematiaceous (%)	Non-Decay (%)
Red Pine	None	-	0.0	33.3	66.7
	DCOI	1.3	0.0	13.3	26.7
Southern Pine	None	-	0.0	44.4	100.0
	DCOI	1.3	0.0	2.2	6.7
	DCOI	2.25	0.0	2.2	11.1
	Penta	N/A	0.0	3.3	5.0

3.5.0 References for Objective 3

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OBJECTIVE IV: PERFORMANCE OF EXTERNAL GROUNDLINE PRESERVATIVE SYSTEMS

4.1.0 Effectiveness of external barriers on pole performance

Over time, utility pole treatments can lose efficacy, resulting in an increased prevalence of external decay or shell rot caused by soft rot fungi. If left uncontrolled, external decay can result in the loss of effective shell and pole strength causing the need for early pole replacement. Surface decay can be prevented by the addition of preservative pastes and wraps that impart supplemental biocides to the pole surfaces at and below groundline. This helps slow or stop the growth of soft rot fungi at the pole surface and prevent the invasion of soft rot fungi in these areas. Wraps can also be used as a water impermeable barrier to prevent the ingress of moisture into poles at and below groundline where the risk of decay is highest and prevent the migration of preservative from poles into the environment.

External supplementary preservative treatments typically contain known preservative chemicals including borate, copper, or fluoride. Over the past 20 years, the UPRC has established a number of field trials for external groundline preservative pastes and barrier wraps on pole stubs at our Peavy Arboretum field site or poles in active utility lines. Most of these trials have been

completed and a summary of past studies can be found objective IV of the 2019 annual report (page 111).

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

In 2007, a set of penta-treated Douglas-fir pole stubs were encased in the newest generation of Biotrans liner and set into the ground at our Peavy Arboretum research site (Figure 4.1.1). The poles were each sampled prior to installation to determine chemical penetration and retention and baseline MC. Five poles received a Biotrans liner that extended 150 mm above groundline; five received a Biotrans liner that extended 300 mm above groundline and eleven poles were left without liners. In 2021, these poles were sampled a final time and were removed. Poles were sampled for moisture content and soil samples were taken beneath the poles and from soils 1-foot lateral to the base of the pole stubs to measure the impact of the liners on chemical migration into the soils.



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

The poles were sampled 6, 12, 18, 42, 45, 77, 95, 116 and 140 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 4.1.1). These conditions are suitable for fungal attack, but could easily decrease to a point at which fungi cannot decay the wood. Moisture contents 6 months after installation had increased for all three treatments especially in the outer 25 mm of the pole, likely because the samples were taken in the wet season. Most of the site's annual rainfall falls between November and May and the wet season was defined as sampling falling within that time. The field liners were expected to limit water ingress at the groundline, however early data from this study suggests that water running down the pole in the wet season allows lined-poles to experience wetting similarly to unlined poles.

Dry season sampling 12 months after installation showed that unlined poles were dryer at the pole surface than lined poles. Unlined poles were below the fiber saturation point at all depths, while poles with liners were above the fiber saturation point. The difference was notable at the pole surface, 0-13 mm deep, where lined poles averaged moisture contents of 45-49% and unlined poles averaged 20% moisture content (Table 4.1.1).

The 18, 42, and 77-month wet season samplings showed that all poles at all depths averaged above 30% moisture content except for one location in unlined poles 13-25 mm beneath the pole surface. As seen before, the outermost depth had the highest moisture contents in most of the sampling points except for unlined and 150 mm barriers at the 77 month timepoint where the highest average moisture content was seen 25-50 mm from the pole surface. Poles without barriers had moisture contents 33-49% at the surface, while poles with liners had equivalent or higher moisture contents. At the 18 and 42-month timepoints, the 300 mm barriers had average moisture contents of 60-63% in the outer pole sections, suggesting that the liners helped retain moisture.

Dry season samplings 45, 95, 116 and 140-months from installation mostly showed a similar pattern of moisture contents. First, the outermost pole sections had equal or lower moisture contents than sections taken from deeper in the pole. Sometimes the difference was quite large due to some samples taken from the pole interior having very high (83-92%) moisture contents. In most of the dry season sampling points, the core sections closest to the pole surface tended to have lower moisture contents in the unlined poles, which suggests the liners inhibited drying in the summer heat. This was not always the case, however, and the 116-month dry season sampling point showed similar moisture contents in the lined and unlined pole sections.

The largest differences seen in moisture contents between the unlined and the lined pole sections were seen at the section taken 0-13 mm from the pole surface. Core sections taken from deeper within the poles were more similar between lined and unlined pole sections. Another important fact about this data is the high variability. While there did appear to be notable differences, especially in the dry season outermost pole sections, higher average moisture contents in the lined poles encompassed some replicate samples that were well below the fiber saturation point. This suggests there may be other factors at play combining with the positioning of field liners that led to higher moisture retention in the summer months in lined poles.

Table 4.1.1: Moisture contents of cores at selected depths from the pole surface for poles with Biotrans field liners at two heights and unlined control poles.

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)
140 (dry season)	32.2 (8)	59.4 (16)	59.3 (23)	82.8 (44)	
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)
140 (dry season)	31.3 (8)	47.5 (20)	53.8 (20)	91.6 (53)	
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)	

	140 (dry season)	20.5 (3)	43.9 (24)	66.8 (43)	80.3 (47)
^a Values represent means of 6 measurements per location. Figures in bold are above 30% moisture content (approximate fiber saturation point for wood).					

OBJECTIVE V: PERFORMANCE OF COPPER NAPHTHENATE TREATED WESTERN WOOD SPECIES

5.1.0 Copper naphthenate's use as a preservative treatment for western species

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

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

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

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

Stakes were conditioned to stable weight at 23°C and 65% relative humidity (12% moisture content and weighed. Freshly cut and weathered stakes were pressure treated with copper

naphthenate diluted in diesel oil to produce target retentions of 0.8, 1.6, 2.4, 3.2, and 4.0 kg/m³, with 10 replicates for each stake type. Sets of 10 stakes of 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 an 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 continued to out-perform weathered stakes at all retention levels (Figures 5.1.1 and 5.2.2). Non-treated stakes failed within 180 months while stakes treated with diesel alone have virtually all failed after 360 months. At 360 months, all freshly sawn stakes treated with copper naphthenate to retentions of 4.0 kg/m³ continue to provide excellent protection with average ratings of 7.1 (Figure 5.1.1). While some decay is present, it remains relatively minor and the wood is still serviceable. The conditions of stakes treated at the two lowest retentions (0.8 and 1.6 kg/m³) continued to decline over the past 3-years and both treatments have average ratings of 2.5 and 3.7, indicating the presence of substantial decay and some failures. The average decay rating for the intermediate retention (2.4 kg/m³) was just 4.7, while the second highest retention (3.2 kg/m³) averaged about 6.2. The exposure conditions used in this test are designed to encourage soft rot and decay of this type was evident on several of the stakes as shown by an hourglass taper at the tip of decayed stakes (Figure 5.1.3). This suggests conditions were more suitable for decay deeper in the soil. Stake tests similar to this one are typically run for much shorter periods, but these results support copper naphthenate as an effective treatment to prevent soft rot in western redcedar over multiple decades.

Weathered stakes have consistently exhibited greater degrees of damage at a given treatment level than stakes made from freshly cut wood. The condition of these stakes continues to decline and all treatment levels would be non-serviceable in their current condition. The non-treated and diesel-treated controls were destroyed after 200 months. At 360 months, the three lowest retentions (0.8, 1.6, and 2.4 kg/m³) had average ratings below 1.0, indicating the presence of substantial external decay and several failures (Figure 5.1.2). Stakes treated to 3.2 or 4.0 kg/m³ had average ratings of 2.6 and 3.8, respectively after 360 months. While weathering clearly reduced the service life of treated stakes, treatment with copper naphthenate to higher retentions shows potential for extending the life of weathered wood. The performance of weathered wood treated to 3.2 or 4.0 kg/m³ showed similar resistance to decay as fresh cut wood treated to the lowest retention, 0.8 kg/m³.

Copper retention levels were assessed after the remaining stakes were destructively sampled after 360 months in the fungus cellar. Copper retentions were measured using X-ray fluorescence spectroscopy according to standard protocols described in AWWA A9 (AWWA, 2021). Stakes were separated into aboveground and belowground sections and the wood was ground and homogenized prior to analysis. Measurements are summarized in table 5.1.1. As expected, no copper was detected in the remaining untreated and oil-treated controls. Belowground sections of the stakes had much lower levels of copper, ranging from 4.7-6.5 times below the aboveground sections of stakes from the same treatment group. This is to be expected as metal diffusion out of the wood should be almost entirely limited to the below ground portion due to the absence of precipitation in this test. In the below ground sections, unweathered stakes appeared to retain a higher level of copper than their weathered counterparts after 30 years. Belowground sections of unweathered had 1.1-1.6 times the copper as their weathered counterparts in the same treatment group. Only the 1.5 kg/m³ treatment showed the opposite pattern where weathered stakes retained more copper after 30 years.

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

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

As of 2021, this study is completed and will not be assessed or reported on in subsequent reports.

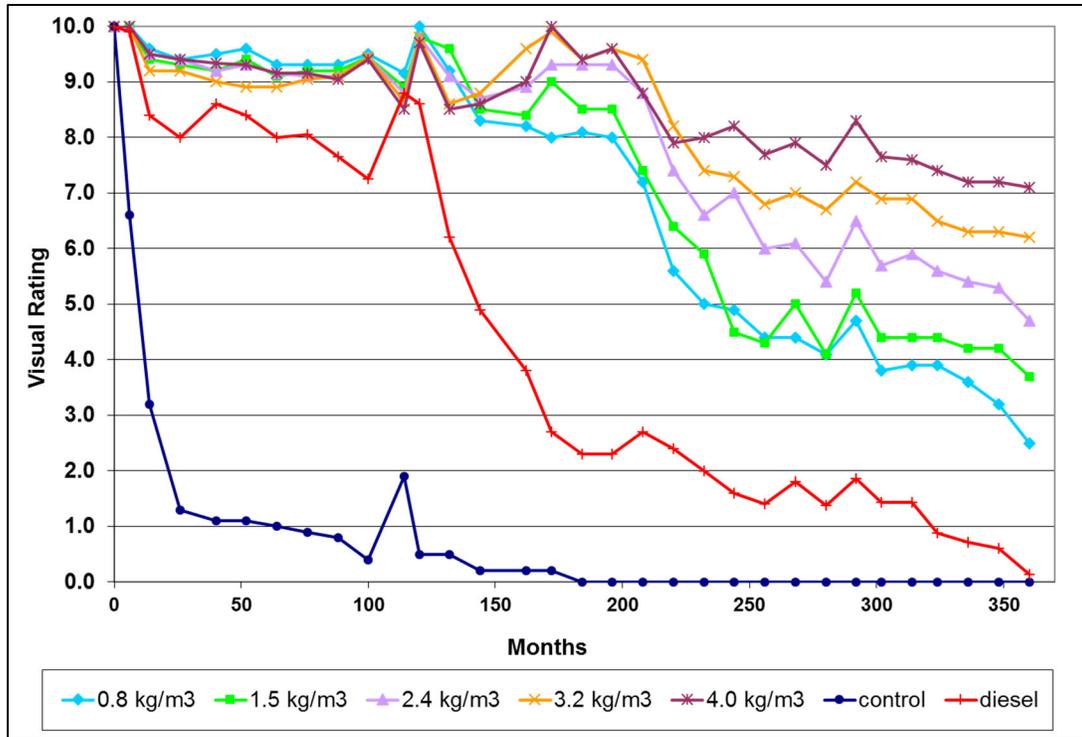


Figure 5.1.1: Condition of freshly sawn western redcedar sapwood stakes treated with selected retentions of copper naphthenate in diesel oil and exposed in a soil bed for 360 months.

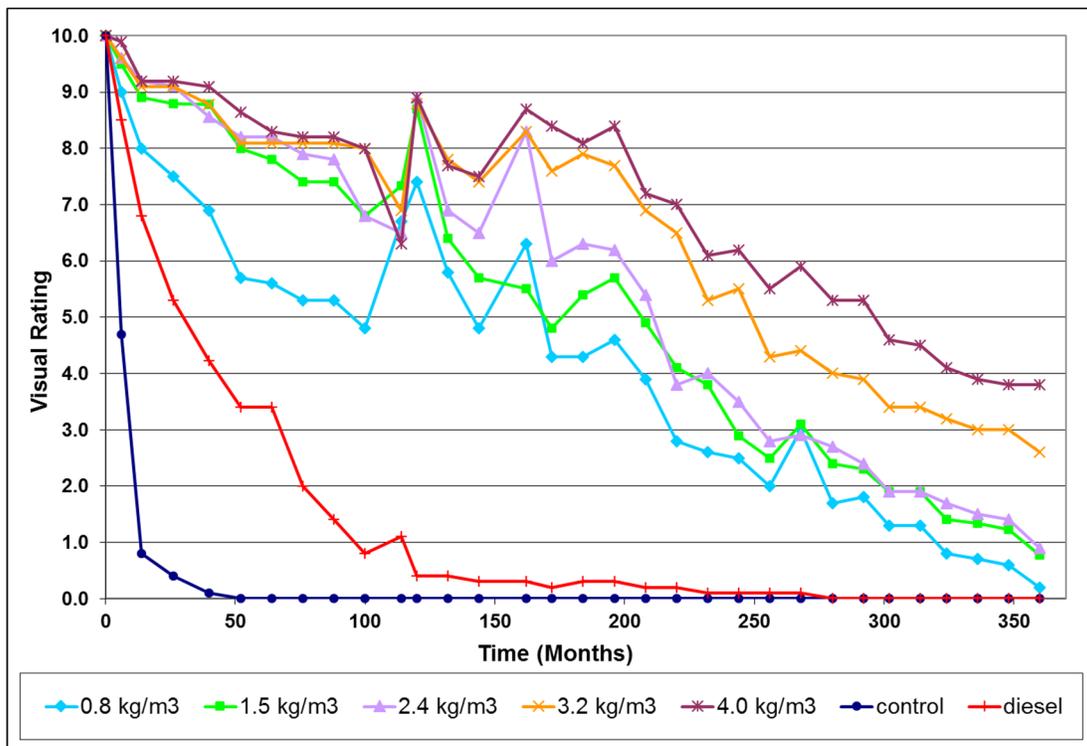


Figure 5.1.2: Condition of weathered western redcedar sapwood stakes treated with selected retentions of copper naphthenate in diesel oil and exposed in a soil bed for 360 months.

Table 5.1.1: Copper retention levels in above ground and below ground portions of weathered and unweathered western redcedar stakes after 30 years in a fungus cellar test.

Treatment	Stake Weathering	Above Ground CuNap (kg/m ³)	Std.Dev.	Below Ground CuNap (kg/m ³)	Std.Dev.	Decay Rating at 30 Years (0-10)
Untreated	fresh	0.000	0.00	0.000	0.00	0.00
	weathered	0.000	0.00	0.000	0.00	0.00
	combined	0.000	0.00	0.000	0.00	0.00
Diesel	fresh	0.000	0.00	0.000	0.00	0.14
	weathered	0.000	0.00	0.000	0.00	0.00
	combined	0.000	0.00	0.000	0.00	0.07
0.8 kg/m ³ CuNap	fresh	0.419	(0.08)	0.093	(0.04)	2.50
	weathered	0.514	(0.06)	0.085	(0.03)	0.20
	combined	0.458	(0.09)	0.090	(0.03)	1.35
1.5 kg/m ³ CuNap	fresh	0.631	(0.20)	0.143	(0.05)	3.70
	weathered	1.004	(0.15)	0.165	(0.04)	0.78
	combined	0.785	(0.26)	0.152	(0.05)	2.32
2.4 kg/m ³ CuNap	fresh	0.968	(0.16)	0.244	(0.10)	4.70
	weathered	1.035	(0.19)	0.178	(0.04)	0.90
	combined	0.999	(0.18)	0.213	(0.08)	2.80
3.2 kg/m ³ CuNap	fresh	1.620	(0.33)	0.319	(0.09)	6.20
	weathered	1.765	(0.27)	0.202	(0.07)	2.60
	combined	1.693	(0.31)	0.260	(0.10)	4.40
4.0 kg/m ³ CuNap	fresh	2.058	(0.50)	0.427	(0.11)	7.10
	weathered	1.922	(0.25)	0.291	(0.11)	3.80
	combined	1.990	(0.40)	0.359	(0.13)	5.45



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

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

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

These poles were not sampled in 2021 and they will be returned to in a later sampling point to be determined.

5.1.3 Performance of low odor copper naphthenate against decay fungi compared to a previously existing formula.

Copper naphthenate is one of several oilborne preservative systems that can be used to protect utility poles made from western wood species. As pentachlorophenol becomes unavailable as a utility pole treatment in North America, alternative systems will have to fill the need western utilities have for effective oilborne preservative systems. The utility pole research cooperative has extensively studied the performance of copper naphthenate in western wood species using lab-scale experiments and in-service assessments. This work shows that copper naphthenate can perform just as well as other oilborne alternatives provided a compatible solvent system is used. However, all smaller-scale stake and soil block tests done by the cooperative to date have been done using copper naphthenate formulas that were available before 2010.

Like many other preservative systems, the formulations of copper naphthenate available in the marketplace have changed over time due to efforts to improve properties of the preservative system. One example of this is the low odor, “refined formula” copper naphthenate which is a newer configuration of the chemical treating solution designed to reduce the odors associated with treating with copper naphthenate. The process incorporates extra distillation steps into the production process to eliminate unnecessary odorous compounds. The low odor formulation is now being widely used by western treaters, but some concerns exist as to whether the extra distillation steps reduce the efficacy of copper naphthenate as a utility pole preservative.

A test was initiated to compare the efficacy of a standard copper naphthenate formula to the low odor formula. An AWPA E10 soil bottle test was setup to compare the performance of the two formulas of copper naphthenate against two brown fungi (*Rhodonina placenta* and *Gloeophyllum*

trabeum) and one white rot fungus (*Trametes versicolor*). Douglas-fir or southern pine 19 mm blocks were treated to four retentions with low odor or traditional copper naphthenate using #2 diesel as a carrier solvent (Table 5.1.1). Once treated, a subsample of blocks were assayed for copper retention using X-ray fluorescence spectroscopy (XRF) according to AWWA A9 (AWWA, 2021). Treated Blocks were then subjected to an AWWA E11 leaching protocol prior to addition to the soil bottle microcosms. Leached blocks were then sterilized using gamma irradiation prior to addition to inoculated soil bottles. Controls used were untreated blocks as well as oil-only treatments. The test was run alongside a larger E10 test that included DCOI in three solvent systems which were all subjected to the same leaching protocol for comparison (See section 3.3.2).

Table 5.1.1: Copper naphthenate treatments and target retentions for blocks used in this study along with the fungi the treatments were exposed to.

Treatment	Wood Species	Solvent	Target Retention		Fungi tested
			kg/m ³	PCF	
Standard Cunap	Douglas-fir	none	0.000	0.000	<i>Rhodonina placenta</i> , <i>Gloeophyllum</i> <i>trabeum</i> , <i>Trametes</i> <i>versicolor</i>
Standard Cunap	Douglas-fir	#2 Diesel	0.000	0.000	
Standard Cunap	Douglas-fir	#2 Diesel	1.520	0.095	
Standard Cunap	Douglas-fir	#2 Diesel	0.760	0.047	
Standard Cunap	Douglas-fir	#2 Diesel	0.380	0.024	
Standard Cunap	Douglas-fir	#2 Diesel	0.190	0.012	
Low odor Cunap	southern pine	none	0.000	0.000	
Low odor Cunap	southern pine	#2 Diesel	0.000	0.000	
Low odor Cunap	southern pine	#2 Diesel	1.280	0.080	
Low odor Cunap	southern pine	#2 Diesel	0.640	0.040	
Low odor Cunap	southern pine	#2 Diesel	0.320	0.020	
Low odor Cunap	southern pine	#2 Diesel	0.160	0.010	

Test will be run for 12 weeks for brown rot fungi and 16 weeks for white rot fungi and the efficacy will be assessed by how well each treatment prevents mass loss by decay fungi. To date, all treatments have been treated, leached and added to soil bottle tests. The final data for this test will be available in the 2022 final report.

5.1.4 References for Objective 5

AWWA, 2021. American Wood Protection Association 2021 Book of Standards. Birmingham, AL.