Holzforschung, Vol. 65, pp. 429–434, 2011 • Copyright © by Walter de Gruyter • Berlin • New York. DOI 10.1515/HF.2010.098

Long-term performance of fused borate rods for limiting internal decay in Douglas-fir utility poles

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Abstract

The ability of boron to diffuse from fused boron rods into surrounding wood was investigated on pentachlorophenol-treated Douglas-fir poles. Boron readily diffused into the wood surrounding the treatment holes and was present at protective levels in most poles within 1 year after application. The protected zone was generally confined to the treatment zone. Effective levels of boron were still present in this zone 15 years after treatment. Attempts to correlate the presence of decay fungi with residual boron levels indicated that these fungi were sometimes present in zones with boron at the lower threshold level of 0.5 kg m^{-3} boric acid equivalent (BAE), but most of the isolations could be explained by localized variations in distribution. Boron rods provided excellent long term protection against internal decay in Douglas-fir poles.

Keywords: basidiomycete; boron; Douglas-fir; fungal threshold; wood decay.

Introduction

As with many thin sapwood species, preservative treatment of Douglas-fir results in a well-treated sapwood shell surrounding a non-treated heartwood core. The latter can become exposed to fungal and insect attack as poles season and check in service and this can markedly shorten pole service life. Although a variety of methods have been developed for improving heartwood treatment of this species, particularly at the groundline, there is still a need for periodic inspection and supplemental treatment to arrest all internal decay (Graham 1983).

In the 1960s, fumigants were identified as a means for rapidly arresting fungal attack, and subsequent studies showed that they remained effective for 7–20 years, depending on the active ingredient involved (Graham 1983; Morrell and Corden 1986). The risks associated with application encouraged a search for alternative treatment methods.

At approximately the same time, some European utilities were exploring the use of boron as an internal remedial treatment (Becker 1976; Edlund et al. 1983; Dickinson et al. 1988; Dirol 1988; Henningsson et al. 1989). Boron is attractive because it has very low toxicity to humans and other non-target organisms and it can diffuse with moisture through the wood to affect established decay fungi or insects. Boron can move to the point where decay is active, but lacks the more toxic profile of a fumigant.

The most attractive boron formulation for remedial treatment is the fused borate rod, which is produced by heating disodium octaborate to a molten state so that it can be poured into molds. The borate hardens into an easily handled, glass-like rod as it cools. Boric acid is released from the rod in the presence of free water. A variety of laboratory and field trials have shown that boron will move through a variety of wood species provided that the moisture content is above the fiber saturation point (Smith and Williams 1967; Edlund et al. 1983; Dietz and Schmidt 1988; Dirol 1988; Morrell et al. 1990, 1992; Ruddick and Kundzewicz 1992; Schneider et al. 1993; Morrell and Schneider 1995; Freitag et al. 2000). In general, however, field trials in Douglas-fir have shown that boron appears to move much more slowly than it does in other species. The lower permeability of Douglas-fir might contribute to this more limited diffusion (Siau 1995). Over an extended time period, this limited permeability might be beneficial because it would also limit boron loss to the surrounding environment.

There are, however, few long-term studies on the performance of fused borate rods in Douglas-fir. In this report, we examine the performance of this treatment over a 15-year period in western OR and used these data to assess the validity of a laboratory determined fungitoxic threshold.

Materials and methods

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 located 20 km north of Corvallis, OR, USA. 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 150 mm upward. Each hole received either one or two 19 mm diameter by 75 mm long boron rods (180 or 360 g of rod, respectively). The holes were then plugged with tight fitting, copper naphthenate-treated wooden dowels. Each treatment was replicated on ten poles. The poles were sampled 1, 3, 4, 5, 7, 10, 12 and 15 years after treatment by removing increment cores from sites located 150 mm below groundline as well as 75, 225, 450, and 600 mm above the groundline. The cores were divided into inner and outer segments which were ground to pass a 20 mesh screen, then extracted and analyzed for boron using the Azomethine H method (AWPA 2008). Boron levels were expressed in kg m^{-3} 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 m^{-3} BAE (Freitag and Morrell 2005). This level is much lower than that reported for soil block tests (Fahlstrom 1964; Williams and Amburgey 1987), but it reflects the fact that boron leaches from the wood samples in soil block tests (Cserjesi and Swann 1969). Internally applied boron is much more protected from leaching losses than it would be when applied as either an external preservative paste or a dip treatment. We consider two levels of boron protective; a lower threshold (0.5 kg m^{-3}) which has been shown to be effective for protecting against internal decay and an upper threshold (1.1 kg m^{-3}) that is effective against more aggressive external attack.

At year 15, an additional set of samples was removed from the poles so that both the residual boron could be quantified and the presence of decay or non-decay fungi could be determined. The outer and inner 2.5 mm zones from a single core do not yield enough sawdust for boron analysis. To obtain a sufficient quantity of wood for analysis, the inner or outer zones of three cores removed from the same height were combined for a given treatment. The remaining wood from each core was briefly flamed to reduce the presence of contaminating surface microfungi, then placed on 1.5% malt extract agar in a plastic Petri dish. The core was observed over a 28-day period for evidence of fungal growth. All fungal growth was examined under a microscope for characteristics typical of Basidiomycotina. Although not all fungi in this taxonomic group cause wood decay, it contains many important wood decay fungi. Fungi with these characteristics were categorized as decay fungi whereas those without were classified as non-decay fungi. We recognize that this is an arbitrary classification that ignores the potential for the non-basidiomycetous fungi to cause soft rot attack of wood. However, because soft rot attack tends to predominate on sapwood and the wood in question was heartwood, it was most important to examine susceptibility to white or brown rot. The occurrence of decay fungi in the cores was then compared with the aggregate boron level from the inner and outer zones of three cores. This approach has some drawbacks because the combined assay results mask low values and there is often a steep gradient of boron across the diameter of a pole, but it provided a reasonable method for comparing chemical levels with protective effect.

Results and discussion

Non-treated control poles naturally contained low levels of background boron ranging from 0.01 to 0.11 kg m^{-3} (Table 1).

Table 1 Boron levels in pentachlorophenol-treated Douglas-fir pole sections 1–15 years after treatment with 180 or 360 g of fused borate rod.

Dosage (g)	Sampling Ht. (cm)	Core Section	Boron content (kg m^{-3} boric acid equivalent)[a]							
			Year 1	Year 3	Year 4	Year 5	Year 7	Year 10	Year 12	Year 15
180	-15	Inner	0.38	**1.81**	**2.39**	**1.85**	**1.54**	**2.16**	**3.33**	**0.50**
		Outer	0.24	0.25	0.49	**1.14**	**0.70**	**1.32**	**0.94**	**0.62**
	7.5	Inner	**2.82**	**3.75**	**6.02**	**6.40**	**2.05**	**2.83**	**4.65**	**1.25**
		Outer	**0.65**	**1.10**	**1.16**	**2.32**	**3.38**	**1.84**	**2.28**	**0.82**
	22.5	Inner	**0.89**	**3.16**	**2.09**	**2.82**	**1.47**	**0.81**	**0.52**	**0.86**
		Outer	**0.98**	**0.58**	0.35	**1.10**	0.31	0.14	**1.70**	**0.96**
	45	Inner	**0.54**	0.22	0.21	0.17	0.15	0.00	0.28	0.05
		Outer	0.22	0.20	0.11	0.09	0.12	0.00	0.12	0.07
	60	Inner	0.18	0.24	0.19	0.41	0.08	0.00	0.11	0.02
		Outer	0.14	0.09	0.06	0.25	**1.80**	0.00	0.04	0.00
360	-15	Inner	0.09	**0.76**	**0.62**	**0.60**	**1.00**	0.09	**1.94**	**2.29**
		Outer	0.07	0.23	0.27	**3.00**	**1.42**	**3.94**	**0.82**	**1.62**
	7.5	Inner	**0.96**	**10.88**	**7.27**	**12.01**	**3.28**	0.11	**2.77**	**1.56**
		Outer	**0.59**	**0.61**	**1.33**	**3.93**	**0.85**	**0.89**	**1.39**	**3.01**
	22.5	Inner	0.48	**3.21**	**1.35**	**7.30**	**0.95**	**2.27**	**0.81**	**5.23**
		Outer	0.13	0.14	0.42	**4.34**	**0.77**	0.07	**3.30**	**2.57**
	45	Inner	0.04	0.11	0.08	**1.24**	0.21	0.00	0.50	**1.20**
		Outer	0.02	0.09	0.07	**0.83**	0.17	0.00	0.21	0.12
	60	Inner	0.05	0.39	0.21	0.16	0.10	0.00	0.13	0.27
		Outer	0.02	0.09	0.09	0.16	**1.02**	0.00	0.06	0.13
Control	-15	Inner	0.02	0.09	0.02	0.05	0.06	0.00	0.01	0.00
		Outer	0.02	0.09	0.02	0.07	0.06	0.00	0.00	0.00
	7.5	Inner	0.02	0.06	0.06	0.03	0.05	0.00	0.02	0.00
		Outer	0.02	0.07	0.02	0.02	0.05	0.00	0.02	0.00
	22.5	Inner	0.01	0.08	0.02	0.05	0.05	0.00	0.05	0.00
		Outer	0.01	0.07	0.02	0.03	0.04	0.00	0.01	0.00
	45	Inner	0.03	0.06	0.02	0.03	0.03	0.00	0.04	0.00
		Outer	0.02	0.10	0.02	0.02	0.03	0.00	0.06	0.00
	60	Inner	0.02	0.08	0.02	0.27	0.08	0.00	0.06	0.01
		Outer	0.01	0.09	0.03	0.11	0.04	0.00	0.02	0.02

[a] Values represent means of three analyses per location as boric acid equivalent. Values in bold are the lower threshold for protection against internal fungal attack.

These levels are well below the threshold for protection against internal fungal attack (0.5 kg m^{-3}) (Freitag and Morrell 2005).

Boron levels in the inner zones of poles treated with either 180 or 360 g of rod tended to be higher and less variable than those in the outer zone over the entire test (Table 1). The higher levels in the inner zone most probably reflect the placement of the rods as well as the volume of wood in the inner versus outer zone. The rods were placed as far in towards the center of the pole as possible, thereby directing the treatment towards the heartwood. In addition, the volume of wood in the center of the pole is lower than that in the outer zone where the diameter is larger. As a result, all boron that diffused from the rod would be distributed over a wider

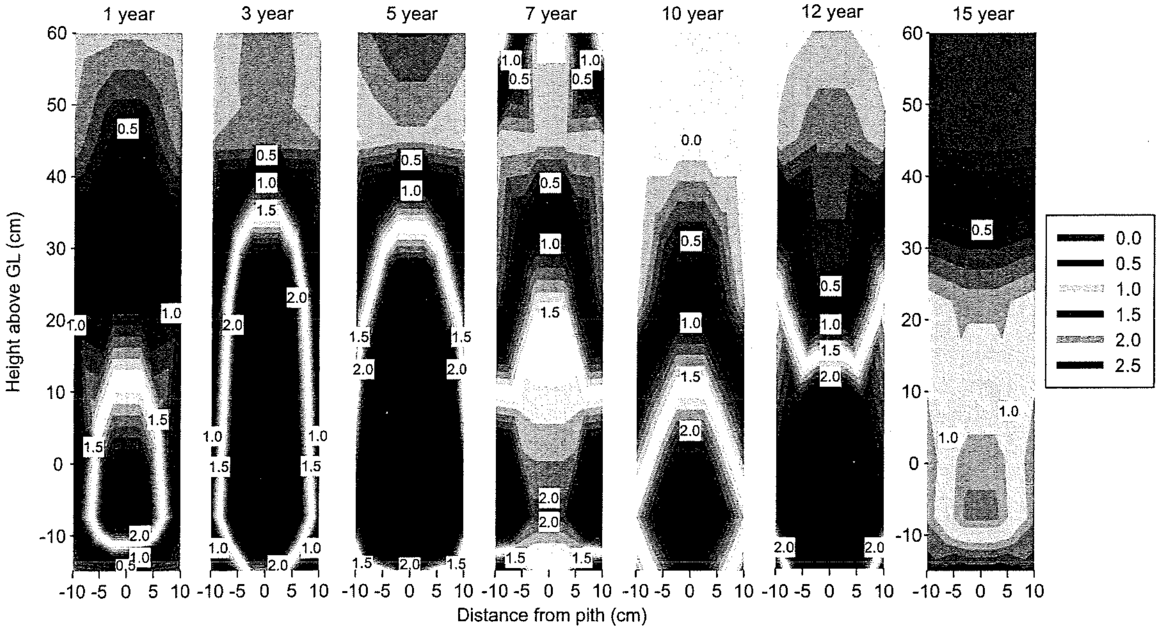

Figure 1 Boron levels in pentachlorophenol-treated Douglas-fir pole sections 1–15 years after treatment with 180 g of fused boron rod. Darker shades indicate boron levels at or above the threshold for fungal attack. Lighter shading indicates boron levels below the fungal threshold.

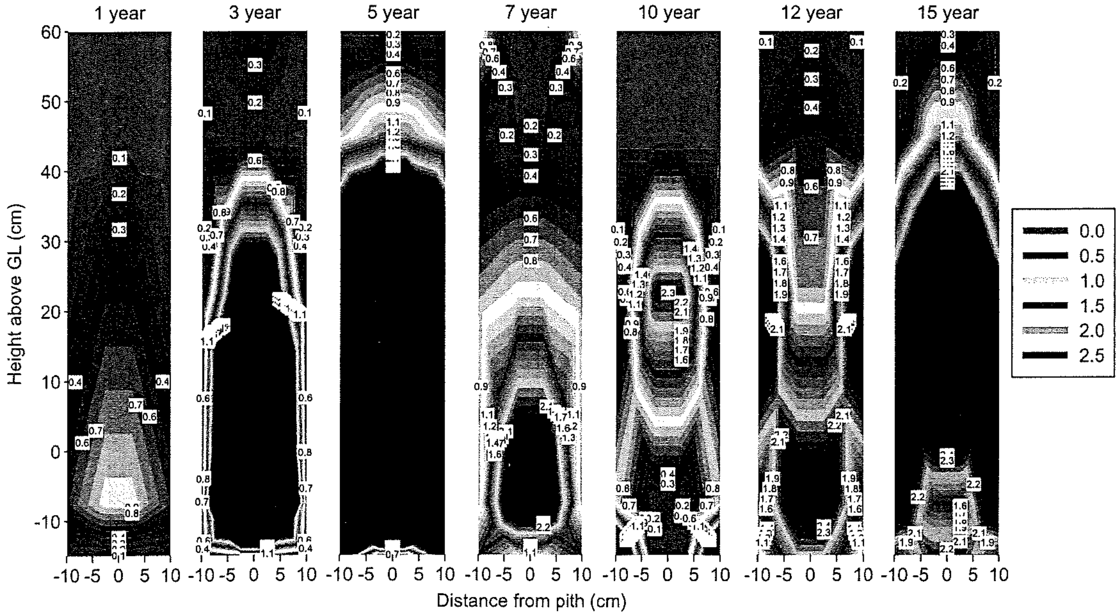

Figure 2 Boron levels in pentachlorophenol-treated Douglas-fir pole sections 1–15 years after treatment with 360 g of fused boron rod. Darker shading indicates boron levels at or above the threshold for fungal attack. Lighter shading indicates boron levels below the fungal threshold.

Table 2 Relation between boron levels in the inner and outer zones of increment cores removed from selected distances above or below groundline in Douglas-fir poles 15 years after application of fused boron rods and the frequency of fungal isolation from the center of the same cores[a].

Pole #	Height (mm)	Boron content (kg m^{-3}) Inner	Outer	% Isolations	Pole #	Height (mm)	Boron content (kg m^{-3}) Inner	Outer	% Isolations
277	-150	0.00	0.06	33	284	-150	**0.72**	0.22	0
	75	0.07	0.09	0		75	**1.11**	**0.70**	0
	225	0.15	0.07	0		225	**0.53**	**0.68**	0
	450	0.05	0.10	67		450	**1.97**	**1.75**	0
	600	0.08	0.10	33		600	0.34	0.14	0
278	-150	**0.78**	**1.43**	0	285	-150	**2.46**	**0.94**	0
	75	**2.69**	**1.73**	0		75	**3.37**	**1.27**	0
	225	**2.07**	**3.91**	0		225	**1.58**	**0.71**	0
	450	**1.15**	**0.61**	0		450	0.28	0.20	0
	600	**1.01**	0.36	0		600	0.15	0.14	0
279	-150	**0.83**	**0.71**	0	286	-150	**1.05**	0.41	0
	75	**1.24**	**2.28**	0		75	**0.81**	0.35	0
	225	**2.86**	**2.47**	0		225	**1.34**	**0.55**	0
	450	**0.58**	0.28	33		450	0.42	0.24	0
	600	0.11	0.25	67		600	0.25	0.10	0
280	-150	**1.21**	0.43	0	287	-150	**1.01**	0.12	0
	75	**2.39**	**1.39**	0		75	**2.49**	**1.41**	0
	225	**3.69**	**1.74**	0		225	**0.79**	0.00	0
	450	0.19	0.13	100		450	0.00	0.01	33
	600	0.12	0.14	0		600	0.17	0.00	67
281	-150	**1.03**	**0.53**	33	288	-150	0.08	0.16	0
	75	**1.08**	**0.52**	0		75	0.25	0.30	0
	225	**0.95**	**0.56**	0		225	0.18	0.25	100
	450	**0.73**	0.18	0		450	0.31	0.14	–
	600	0.37	0.15	33		600	0.21	0.03	0
282	-150	**0.51**	0.05	0	289	-150	**6.72**	**4.09**	0
	75	0.14	0.18	0		75	**4.24**	**3.49**	0
	225	0.29	0.30	0		225	**2.07**	**2.31**	0
	450	0.20	0.19	0		450	**0.83**	0.20	0
	600	0.15	0.11	0		600	0.18	0.02	0
283	-150	0.24	0.13	0	290	-150	**4.52**	**0.57**	0
	75	0.28	**0.53**	0		75	**5.43**	**12.97**	0
	225	0.20	0.47	0		225	**19.30**	**1.57**	0
	450	0.16	0.24	0		450	**1.38**	0.05	33
	600	0.13	0.22	0		600	0.09	0.02	33
291	-150	**1.99**	0.48	0	295	-150	**1.47**	0.47	0
	75	**10.98**	**1.14**	0		75	**6.42**	**1.36**	0
	225	**15.63**	0.49	0		225	**6.46**	**0.82**	0
	450	**1.87**	0.13	0		450	**0.93**	0.44	0
	600	0.25	0.10	33		600	0.00	0.08	33
292	-150	**0.58**	0.33	33	296	-150	**1.35**	0.43	0
	75	**0.87**	0.32	0		75	**4.61**	**2.16**	0
	225	**5.57**	0.12	0		225	**11.63**	**4.00**	0
	450	0.29	0.44	0		450	**2.10**	**0.76**	0
	600	0.21	0.09	33		600	**1.00**	0.15	0
293	-150	**3.01**	**0.66**	0	297	-150	**1.51**	0.38	0
	75	**6.12**	**1.64**	0		75	**7.30**	**3.02**	0
	225	**20.62**	**0.84**	0		225	**8.34**	**6.58**	0
	450	**5.72**	0.24	0		450	**3.80**	**0.67**	33
	600	**1.75**	0.07	33		600	**0.99**	0.15	0
294	-150	**1.23**	0.20	0	–	–	–	–	–
	75	**8.07**	**4.16**	0		–	–	–	–
	225	**13.31**	**3.32**	0		–	–	–	–
	450	**6.01**	**0.55**	0		–	–	–	–
	600	**4.51**	**0.81**	0		–	–	–	–

[a] Values represent means of three cores per position per pole. Figures in bold represent are at or above the lower threshold (0.5 kg m^{-3}), whereas those that are underlined represent levels at or above the upper threshold value (1.1 kg m^{-3}).

area in the outer zone and should, therefore, be present at lower concentrations.

Boron was detected at threshold levels in poles treated with 180 g of rod 75 and 225 mm above groundline within 1 year after treatment. Boron levels were above the threshold 75 mm above groundline in poles receiving 360 g of rod, but only approached the threshold in the inner zone at 225 mm. Interestingly, boron levels were not above the threshold 150 mm below groundline 1 year after treatment. Moisture levels at the test site are extremely high during the wet winter months and should have facilitated boron movement.

In subsequent years, boron levels were above the threshold level 75 mm above groundline in poles receiving either rod dosage with one exception at the higher dosage 7 years after treatment. The inner zones 225 mm above groundline had protective levels of boron 3–15 years after treatment with both dosages.

Dosage had little effect on the number of samples with protective boron levels, although poles treated with 360 g of boron rod often had much greater levels of residual boron than those treated with 180 g. This was particularly true in the inner zone 75 mm above groundline which was at the center of the treated zone (Figure 1). This effect disappeared after 5 years, but appeared again 15 years after treatment when boron levels were much higher in poles receiving the 360 g dosage (Figure 2).

Boron levels were rarely at or above the threshold at sampling locations above the treated zone. There were four instances where threshold levels were present in the 450 mm sampling zone, and two in the 650 mm sampling site; however, these detections were scattered. The original rods were applied up to 300 mm above the groundline. The limited presence of boron 450 mm above the groundline indicates that the primary direction of boron movement from the rods is downward. It also reflects the lower moisture contents present in wood above the groundline. The pattern of rod insertion was based upon fumigant application patterns. Insertion of a great proportion of rods below the groundline might have resulted in a more rapid and even boron distribution.

Previous reports of residual boron in poles treated with fused rods have shown protective levels for 6 years in creosote-treated Scots pine (*Pinus sylvestris*) poles (Dickinson et al. 1988), and 10 years in Scots pine millwork (Edlund et al. 1983). Boron is traditionally viewed as extremely water soluble and able to rapidly diffuse from treated wood in soil contact; however, it is probable that the oil-treated shell limited the ability of boron to diffuse outward contributing to treatment longevity as suggested by Dickinson et al. (1988). These results contrast with those from poles treated with waterborne chromate copper arsenate, where boron leaching was apparent after 5 years (Henningsson et al. 1989), but are consistent with long-term protection of railroad ties dip-treated in boron before creosote treatment (Amburgey et al. 2002).

Fungal isolations varied among the poles and with distance from the groundline (Table 2). Non-decay fungi were common in all of the poles, although their role in boron performance is unknown. Previous studies of fumigant treated poles reported that some of these non-decay fungi were potentially antagonistic to decay fungi and further studies would be useful to determine if boron fosters a similar protective flora (Giron and Morrell 1989a,b).

Although no decay fungi were isolated from most samples with boron levels above the thresholds for protection against either internal or external decay, there were a few exceptions. Decay fungi were isolated from 18 of 67 cores where the boron level was below the fungal threshold, compared with three of 36 cores where the boron level was below the upper threshold (Figure 3). Only one decay fungus was isolated from the 52 cores where the boron level was above the upper protective threshold. The results indicate that the risk of fungal decay is much lower where the boron levels are above either threshold, but they are particularly low when the level exceeds the upper threshold. The boron assays were done on

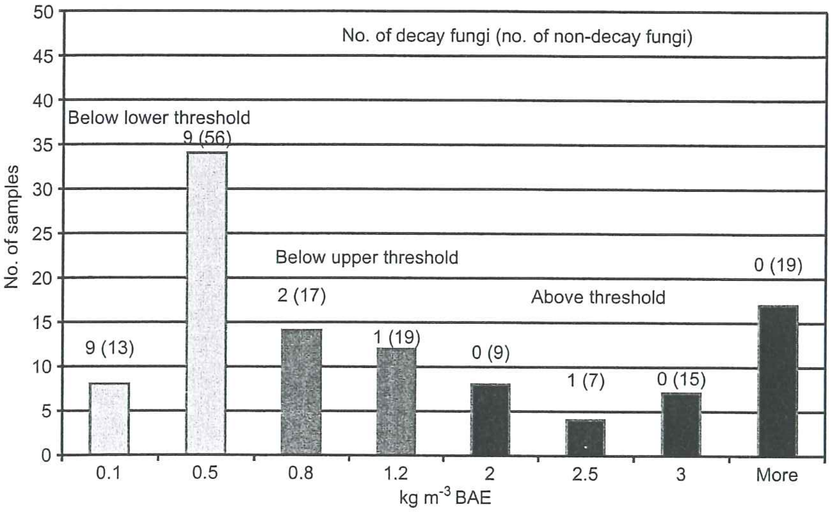

Figure 3 Comparison between fungal isolation frequency and boron levels (expressed as boron acid equivalent, BAE) in cores removed from Douglas-fir poles 15 years after application of fused borate rods.

a pooled sample of three cores and then the values for the inner and outer samples were averaged to obtain a single number. As a result, the exact boron levels associated with the location of each fungal isolation cannot be determined. The gradient of boron from the inner assay zone to the outer was very steep for three of the four samples from which decay fungi were isolated although the average boron level was over the threshold. The outer assay zones had background levels of boron in these two cases.

It is important to view these comparisons with some caution. Fungi are highly unlikely to immediately reinvade an area of wood as soon as the boron level declines below the threshold. Instead, reinvasion is a slower process and is a function of proximity to exterior checks or other avenues of entry. In addition, decay fungi must compete for resources with other non-wood decay fungi. The results do confirm that protective levels of boron are present in most poles 15 years after treatment, particularly in the areas closer to the groundline where moisture levels are likely to be higher.

Conclusions

Boron from fused borate rods readily diffused into Douglas-fir heartwood and remained at effective levels for up to 15 years after treatment. The protective zone remained confined and there was little evidence of substantial upward diffusion. Chemical analysis appeared to be a good indicator of residual protection against reinvasion by decay fungi. Caution should be exercised in projecting these results to poles treated with waterborne preservatives.

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Received February 4, 2010. Accepted May 6, 2010.
Previously published online January 6, 2011.