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Short Communication

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Efficacy of Spring and Fall Treatments of Carbaryl for Protecting Ponderosa Pine From Mortality Attributed to Mountain Pine Beetle (Coleoptera: Curculionidae)

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Abstract

High-value trees, such as those growing in residential, recreational, or administrative sites, are often susceptible to colonization by bark beetles (Coleoptera: Curculionidae: Scolytinae) as a result of increased amounts of stress associated with off-site plantings, drought, soil compaction, and/or mechanical injury. The value of these trees, cost of removing dead trees, and loss of aesthetics often justify the use of insecticides to protect trees from mortality attributed to bark beetles. Carbaryl (1-naphthyl methylcarbamate) is among the most effective, economically-viable, and ecologically-compatible insecticides available for protecting conifers from several species of bark beetles in the western United States. Treatments are usually applied in spring prior to initiation of flight of the target species. We evaluated the efficacy of spring and fall applications of carbaryl for protecting individual ponderosa pine, *Pinus ponderosa* Dougl. ex Laws. (Pinales: Pinaceae), from mortality attributed to mountain pine beetle, *Dendroctonus ponderosae* Hopkins (Coleoptera: Curculionidae), in Idaho. Both spring and fall treatments of 2.0% a.i. carbaryl (maximum label rate; Sevin SL, Bayer Environmental Science, Montvale, NJ 07645) provided one field season of protection, and thus should be applied annually if tree protection is desired for multiple years. Our research also provides some insight on the efficacy of carbaryl treatments after wildfire. We found no evidence that a mixed-severity wildfire negatively affected the efficacy of carbaryl treatments.

Key words: bole spray, insecticide, *Pinus ponderosa*, tree protection

Mountain pine beetle, *Dendroctonus ponderosae* Hopkins (Coleoptera: Curculionidae), is regarded as the most significant forest insect pest in North America, and colonizes most species of pines (Negrón and Fettig 2014). From 2000 to 2017, >10 million hectares were impacted by *D. ponderosae* in the western United States alone, which represents almost half of the total area impacted by all bark beetles during that period (Fettig et al. 2018). During such large-scale outbreaks, hundreds of thousands of trees may be treated annually with insecticides to protect them from mortality attributed to *D. ponderosae*. Treatments are usually applied with ground-based sprayers at high pressure (e.g., ≥2,241 kPa) to all bole surfaces from the root collar to a height of ~10 to 15 m until runoff. Only high-value, individual trees growing in unique environments or under unique circumstances are treated. For example, trees growing in campgrounds, residential areas, progeny tests, seed orchards, or those genetically resistant to forest diseases may be considered for preventative treatments, especially if epidemic populations of bark beetles exist in the area. The efficacy and residual activity of products used vary with concentration, active ingredient, bark beetle species, tree species, and associated climatic conditions, but generally 1 to 3 yr of protection can be expected with a single application (Fettig et al. 2013).

Carbaryl (1-naphthyl methylcarbamate) is among the most effective, economically-viable, and ecologically-compatible insecticides available for protecting conifers from mortality attributed to bark beetles (Hastings et al. 2001). Treatments are usually applied in late spring prior to emergence of *D. ponderosae*. However, during this time of year site accessibility may be difficult due to road conditions, and labor to apply treatments is often limited due to competition with agricultural markets. Furthermore, many sites where carbaryl treatments are applied (e.g., campgrounds) occur near intermittent or ephemeral streams associated with runoff from snowmelt, limiting applications in spring due to label restrictions concerning the use of no-spray buffers to protect nontarget aquatic organisms (Fettig et al. 2008). Trees within no-spray buffers are left untreated and therefore vulnerable to colonization by *D. ponderosae*. By delaying treatments to later in the year (e.g., fall), fewer no-spray buffers are necessary. Finally, delaying carbaryl treatments until fall after the majority of native pollinators have ceased flight may reduce any negative impacts associated with these treatments (Fettig et al. 2015). To address these concerns, Fettig et al. (2015) evaluated the efficacy of spring and fall treatments of 2.0% a.i. carbaryl (Sevin SL; Bayer Environmental Science, Montvale, NJ 07645) for protecting lodgepole pine, *Pinus contora* Dougl. ex Loud. (Pinales: Pinaceae), from mortality attributed to *D. ponderosae* in Wyoming, and reported both treatments provided two field seasons of protection. Similarly, the primary objective of this study was to evaluate the efficacy of spring and fall applications of 2.0% a.i. carbaryl (Sevin SL) for protecting ponderosa pine, *Pinus ponderosa* Dougl. ex Laws., from mortality attributed to *D. ponderosae*.

Materials and Methods

This study was conducted on the Salmon-Challis National Forest, Idaho (first tree: 43° 25′ 25.11″ N, 115° 05′ 09.4″ W, 1563 m elevation; last tree: 45° 32′ 19.7″ N, 113° 59′ 17.0″ W, 1594 m elevation) during 2011–2016. Site selection was based on aerial and ground surveys indicating *D. ponderosae* was killing *P. ponderosa* in the area. Stands had a mean live tree (≥12.7 cm dbh, diameter at breast height, 1.37 m in height) density of 21.4 m^2/ha of basal area of which 79.6% was *P. ponderosa* with a mean dbh of 30.6 cm. The remainder was Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco (Pinales: Pinaceae). About 48.4% of adjacent *P. ponderosa* died during the first 3 yr of the study. Most mortality (72.4%) was attributed to bark beetles, primarily *D. ponderosae* but also occasionally western pine beetle, *D. brevicomis* LeConte (Coleoptera: Curculionidae), and pine engraver, *Ips pini* (Say) (Coleoptera: Curculionidae). The remainder of tree mortality was attributed to the Mustang Complex Fire, which started as a result of lighting on 30 July 2012 and burned for months through substantial areas of the Salmon-Challis National Forest and adjacent Bitterroot National Forest (USDA Forest Service 2012). The entire study area was impacted by the Mustang Complex Fire (i.e., based on evidence of consumption of surface fuels). Following the wildfire, maximum bole char heights from the root collar on the northern and southern aspect, and percent crown scorch were recorded for each experimental tree in June 2013. Bole char and crown scorch are common variables used to assess fire severity on individual trees (Sieg et al. 2006).

Thirty trees were confirmed uninfested and randomly assigned to each of seven treatments (*N* = 210): 1) 2.0% a.i. carbaryl (maximum label rate; Sevin SL, EPA Reg. No. 432–1227) in water (pH = 6.5) applied 26–27 June 2012 ('Spring' treatment), 2) 2.0% a.i. carbaryl (Sevin SL) in water (pH = 6.4) applied 7–8 September 2011 ('Initial fall treatment'), 3) 2.0% a.i. carbaryl (Sevin SL) in water (pH = 6.4) applied 24–26 September 2013 ('Second fall treatment'), and (4–7) untreated controls used to assess *D. ponderosae* 'pressure' (based on mortality of untreated, baited trees) during each year (2012–2015, Table 1). Experimental trees were separated by >100 m. There was a significant difference in *P. ponderosa* dbh among treatments ($F_{6, 203} = 4.5$, $P < 0.001$) (Table 1) that presumably exerted little influence as tree diameters in all treatments were above the threshold considered susceptible to colonization by *D. ponderosae* (Olsen et al. 1996). Insecticides were applied with a trailer-mounted hydraulic sprayer (Model 0021-F200-1511 with P15 pump; GNC Industries, Inc., Pocahontas, AR) powered by an 11-hp gasoline motor at 2,241 kPa, using a Mighty Mag Tree Spray Gun (Product No. 11-854-00; GNC Industries Inc.) with 0.319-cm diameter nozzle aperture, which allowed treatment of the entire bole until runoff to ~12 m above the ground. All insecticides were applied between 0630 and 1600 hours when wind speeds were <11 km/h.

One commercially-available two-component tree bait (*trans*-verbenol [~1.2 mg/d] and *exo*-brevicomin [~0.3 mg/d]; Contech Inc., Delta, BC) was stapled to the bole of each *P. ponderosa* at ~2 m above the ground on the northern aspect prior to the initiation of *D. ponderosae* flight each year. Tree mortality was based on the presence (dead) or absence (live) of crown fade the following year (e.g., in June 2013 for trees colonized in 2012). All surviving trees in each treatment (if <7 were killed), and the appropriate control was baited the following year. The only criterion used to determine the efficacy of each treatment was whether individual trees died due to colonization by *D. ponderosae*. Treatments were considered to have sufficient beetle pressure if ≥60% of the untreated control trees died due to colonization by *D. ponderosae*. Insecticide treatments were considered efficacious when <7 trees die (Hall et al. 1982, Shea et al. 1984). These criteria were established based on a sample size of 22–35 trees and test of the null hypothesis, Ho: S (survival ≥ 90%). This experimental design is accepted as the standard for evaluating insecticides for tree protection in the western United States (Fettig

Table 1. Efficacy of carbaryl for protecting *Pinus ponderosa* from mortality attributed to *Dendroctonus ponderosae*, Salmon-Challis National Forest, Idaho

Treatment	Dbh (cm)[a]	2012 Mortality/*n*	2013 Mortality/*n*	2014 Mortality/*n*	2015 Mortality/*n*
Spring (June 2012)	35.2 ± 1.1a	1/29[b]	8/28	-	-
Initial fall (Sept. 2011)	32.1 ± 1.1ab	8/30	-	-	-
Second fall (Sept. 2013)	30.9 ± 1.3ab	-	-	3/30	16/27
Untreated control 2012	28.1 ± 1.1b	29/30	-	-	-
Untreated control 2013	34.5 ± 1.2ab	-	25/30	-	-
Untreated control 2014	34.2 ± 1.5a	-	-	26/30	-
Untreated control 2015	30.3 ± 0.8ab	-	-	-	30/30

All trees were baited with *trans*-verbenol (~1.2 mg/d) and *exo*-brevicomin (~0.3 mg/d) at ~2 m above the ground on the northern aspect prior to *D. ponderosae* flight each year. All surviving trees in each insecticide treatment were baited each consecutive year until cumulative mortality exceeded seven trees. Each untreated control was baited for a single year. Insecticide treatments are considered efficacious when <7 trees die, and mortality is ≥60% in the corresponding untreated control.

[a]Dbh, diameter at breast height, 1.37 m above ground level. Means ± SEM followed by the same letter within column are not significantly different ($P > 0.05$).

[b]One tree was lost to woodcutting.

Table 2. Measures of burn severity on live and dead *Pinus ponderosa*, and on 20 trees that were treated with carbaryl in spring 2012 and impacted by wildfire that year but survived baiting for *D. ponderosae* in 2013, Salmon-Challis National Forest, Idaho

Condition	Mean bole char height (N aspect, m)	Mean bole char height (S aspect, m)	Crown scorch (%)
Dead trees	1.19 ± 0.15a	0.61 ± 0.12a	7.4 ± 1.4a
Live trees	1.25 ± 0.24a	0.76 ± 0.21a	10.0 ± 3.1a
Spring	2.07 ± 0.49	1.34 ± 0.52	20.7 ± 5.8

Means ± SEM followed by the same letter within columns (for dead and live trees only) are not significantly different ($P > 0.05$).

et al. 2013). A one-way analysis of variance (ANOVA) was used to test for differences between measures of fire severity and tree survival, but transformed data did not meet assumptions of normality and homoscedasticity. As such, the non-parametric Kruskal–Wallis test on ranks was used.

Results

D. ponderosae pressure was sufficient to adequately challenge treatments as >83% of untreated controls died each year (Table 1). The spring treatment provided one field season of efficacy, while the initial fall treatment was ineffective (8 of 30 trees died). The second fall treatment provided one field season of efficacy (Table 1). About 71% of experimental trees experienced some level of bole char, and 37.1% experienced some crown scorch. No significant differences in mean bole char heights on the northern and southern aspects ($H = 1.5$, df = 1, $P = 0.22$; $H = 0.4$, df = 1, $P = 0.51$, respectively), and percent crown scorch ($H = 2.2$, df = 1, $P = 0.14$) were observed between live and dead trees (Table 2).

Discussion

Several rates and formulations of carbaryl have been evaluated for protecting conifers from mortality attributed to bark beetles in the western United States. Efficacy was first demonstrated for protecting *P. ponderosa* from *D. brevicomis* and *P. contorta* from *D. ponderosae* (e.g., Hall et al. 1982, Gibson and Bennett 1985, Haverty et al. 1985, Page et al. 1985). Shea and McGregor (1987) evaluated the efficacy of 0.5, 1.0, and 2.0% a.i. carbaryl (Sevimol and Sevin XLR) and found all concentrations and formulations were effective for protecting *P. contorta* from mortality attributed to *D. ponderosae* for 1 yr. The 1.0 and 2.0% rates were efficacious for 2 yr. Fettig et al. (2006) reported 2.0% a.i. carbaryl (Sevin SL) protected *P. ponderosa* from *D. brevicomis* in California, *P. ponderosa* from *D. ponderosae* in South Dakota, and *P. contorta* from *D. ponderosae* in Montana for two field seasons. Alternatively, 2.0% a.i. carbaryl (Sevimol) was effective for protecting *P. ponderosa* from *D. brevicomis* in Idaho for only 1 yr (Haverty et al. 1998). Fettig et al. (2015) reported both spring and fall treatments of 2.0% a.i. carbaryl (Sevin SL) protected *P. contorta* from *D. ponderosae* for two field seasons in Wyoming, while results from a third field season were inconclusive. In south-central Alaska, 1.0% and 2.0% a.i. carbaryl (Sevin SL) protected white spruce, *Picea glauca* (Moench) Voss (Pinales: Pinaceae), and Lutz spruce, *P. glauca* X *lutzii* Little (Pinales: Pinaceae), from mortality attributed to spruce beetle, *D. rufipennis* Kirby, for three field seasons (Werner et al. 1986).

We are unable to explain the failure in efficacy observed for the initial fall treatment (Table 1). Such failures are most commonly associated with inadequate coverage, improper mixing resulting in solutions of reduced concentration, or improper storage of insecticide products (Fettig et al. 2013). The residual activity of carbaryl on pine bark is largely influenced by weather conditions, which affects hydrolysis and microbial activity and thus degradation of carbaryl. Shorter residual activity is expected in wetter and warmer environments (Zhong et al. 1995). As such, it is possible that in some years (e.g., during wet, warm falls and winters) fall treatments may not yield sufficient efficacy, at least in terms of meeting the criteria of our experimental design which provides for a very conservative experiment (Fettig et al. 2013). To that end, in October 2011 (i.e., the month following our initial fall treatment) precipitation (3.71 cm) was much higher than in October 2013 (1.45 cm) the month following our second fall treatment (Salmon KSRA, ID; Western Regional Climate Center, wrcc@dri.edu). This could have contributed to the lack of efficacy observed in the initial fall treatment.

Our study provides some insight into the influence of wildfire on protection of trees that were previously treated with carbaryl, a frequent question of resource managers in the western United States that has not been addressed due to the cost and complexities of executing such an experiment. We thought that wildfire would negatively impact treatment efficacy through heating of the environment (i.e., affecting all trees), and burning of carbaryl residues on trees that came in direct contact with fire (*see* Peterson and Costello 2013 for concentrations of carbaryl in smoke recovered from treated bark burned under laboratory conditions). However, we found no evidence to support this. For example, 20 (of 29) trees that were treated with carbaryl in spring 2012 that were impacted by wildfire that year survived baiting for *D. ponderosae* in 2013 (Table 2). Furthermore, we observed no significant differences in measures of fire severity between live and dead trees (Table 2). We conclude that spring and fall treatments of 2.0% a.i. carbaryl (Sevin SL) are efficacious for protecting *P. ponderosa* from mortality attributed to *D. ponderosae* for only one field season. Treatments should be applied annually if tree protection is desired for multiple years.

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