Crop Protection 69 (2015) 56–59

Contents lists available at ScienceDirect

Crop Protection

journal homepage: www.elsevier.com/locate/cropro

# Alternative timing of carbaryl treatments for protecting lodgepole pine from mortality attributed to mountain pine beetle

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ARTICLE INFO

*Article history:*
Received 25 November 2014
Received in revised form
16 December 2014
Accepted 21 December 2014
Available online 26 December 2014

*Keywords:*
Bole sprays
*Dendroctonus ponderosae*
*Pinus contorta*
Tree protection

ABSTRACT

Carbaryl is regarded among the most effective, economically viable, and ecologically-compatible insecticides available for protecting conifers from bark beetle attack in the western United States. Treatments are typically applied in spring prior to initiation of bark beetle flight for that year. We evaluated the efficacy of spring and fall applications for protecting individual lodgepole pine, *Pinus contorta* Dougl. ex Loud, from mortality attributed to mountain pine beetle, *Dendroctonus ponderosae* Hopkins, the most notable forest insect pest in western North America. Both spring and fall treatments of 2.0% a.i. carbaryl (Sevin® SL) were efficacious for two field seasons, while results from a third field season were inconclusive due to insufficient beetle pressure. We discuss the implications of these and other results to the management of *D. ponderosae*.

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## 1. Introduction

Mountain pine beetle, *Dendroctonus ponderosae* Hopkins, is a major disturbance in forests of western North America where it colonizes at least 15 tree species, most notably lodgepole pine, *Pinus contorta* Dougl. ex Loud (Negrón and Fettig, 2014). The geographic distribution of *D. ponderosae* ranges from British Columbia, Canada; east to South Dakota, United States; and south to Baja California, Mexico (Wood, 1982). Populations have recently been reported in Nebraska, United States (Costello and Schaupp, 2011), and the insect is expanding its range northward in British Columbia and eastward in Alberta, Canada (De la Giroday et al., 2012). In the last decade, outbreaks of *D. ponderosae* have been severe, long-lasting, and well-documented with >27 million hectares of forest impacted (USDA Forest Service, 2012; British Columbia Ministry of Forests, Lands and Natural Resource Operations, 2013). Millions of *P. contorta* have been killed annually. While *D. ponderosae* is an important ecological component of these forests, extensive levels of tree mortality resulting from outbreaks may have undesirable social impacts; for example negatively affecting aesthetics, recreation, fire risk and severity, human safety, timber production, and real estate values. About 6.7% of forests in the United States are classified at high risk [defined as >25% of stand density represented by trees >2.54 cm dbh (diameter at breast height, 1.37 m above ground level) will die in the next 15 years] to insect and disease outbreaks, and *D. ponderosae* is ranked among the most damaging of all mortality agents considered (Krist et al., 2014).

Fettig et al. (2014a) defined two general approaches for reducing the negative impacts of *D. ponderosae* on forests. Indirect control is designed to reduce the probability and severity of future infestations within treated areas by manipulating stand, forest and/or landscape conditions. Direct control involves short-term tactics designed to address current infestations by manipulating beetle populations, and includes, among other strategies, applications of liquid formulations of contact insecticides to the bole of individual trees using ground-based sprayers at high pressure (e.g., ≥2241 kPa). Only high-value, individual trees growing in unique environments (e.g., in residential, recreational or administrative sites) or under unique circumstances are treated. Tree mortality in these environments generally results in undesirable impacts such as reduced shade, screening, aesthetics, property values and visitor use. Dead trees also pose potential risks to public safety, requiring routine inspection and eventual removal. Trees growing in progeny tests, seed orchards, or those genetically resistant to certain forest diseases may also be considered for treatment, especially if

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http://dx.doi.org/10.1016/j.cropro.2014.12.011
0261-2194/Published by Elsevier Ltd.

outbreak populations of *D. ponderosae* are present. During large-scale outbreaks, hundreds of thousands of trees may be treated annually in the western United States (Fettig et al., 2013), however once an outbreak subsides preventive treatments are often no longer necessary. In recent years, systemic insecticides injected directly into the tree bole have also been demonstrated effective (Fettig et al., 2014b), and registered for use as a preventive treatment. Insecticides are no longer used for direct or remedial control of *D. ponderosae* (i.e., subsequent treatment of infested trees or logs to kill developing and/or emerging brood).

Insecticides are typically applied to all bole surfaces to a height of ~10.6–15.2 m until runoff during spring prior to initiation of *D. ponderosae* flight that year. Carbaryl is regarded among the most effective, economically viable, and ecologically-compatible insecticides available for protecting individual trees from bark beetle attack in the western United States (Fettig et al., 2006a,b, 2013), but other active ingredients (a.i.) (e.g., bifenthrin and permethrin, among others) are available and effective. Application efficiency, the percentage of carbaryl applied that is retained on trees, ranges from ~80 to 90% (Fettig et al., 2008). Carbaryl is an acetylcholinesterase inhibitor that prevents cholinesterase enzymes from breaking down acetylcholine, increasing both the level and duration of action of the neurotransmitter acetylcholine, which leads to rapid twitching, paralysis and ultimately death (Hastings et al., 2001). Carbaryl is considered essentially nontoxic to birds, moderately toxic to mammals, fish and amphibians, and highly toxic to honey bees, *Apis mellifera* L., and several aquatic insects (Jones et al., 2003). An application of 2.0% a.i. carbaryl in spring is commonly used to protect individual *P. contorta* and typically reapplied every other year during outbreaks. The objective of this study was to determine the efficacy of spring and fall applications of 2.0% a.i. carbaryl for protecting individual *P. contorta* from mortality attributed to *D. ponderosae*. It would be highly desirable if fall treatments (i.e., applied ~9 months prior to beetle flight) yielded similar efficacy to spring treatments (i.e., applied several weeks prior to beetle flight) thereby expanding the treatment window while potentially reducing several negative environmental impacts.

## 2. Materials and methods

This study was conducted on the Bridger-Teton National Forest, Wyoming (43° 08′ 37.8″ N, 110° 52′ 47.4″ W; 1903 m elevation) during 2010–2014. Site selection was based on aerial and ground surveys indicating that *D. ponderosae* was colonizing and killing trees in the area. Surrounding stands had a mean live tree (≥12.9 cm dbh) density of 20.7 $m^2$ of basal area/ha of which 98.4% was *P. contorta* with a mean dbh of 26.0 cm. The remainder was represented by Engelmann spruce, *Picea engelmannii* Parry ex Engelm., and subalpine fir, *Abies lasiocarpa* (Hooker) Nuttall. About 12.2% of *P. contorta* and 16.3% of *P. contorta* basal area had been killed by *D. ponderosae* during the previous two years within the study area, which represent conditions that warrant the use of insecticides to protect high-value trees. For example, several campgrounds in the area were treated with carbaryl to reduce tree losses attributed to *D. ponderosae* (Blackford, 2013).

Thirty (30) trees were confirmed uninfested and randomly assigned to each of five treatments ($N = 150$): (1) 2.0% a.i. carbaryl (Sevin® SL; Bayer Environmental Science, Montvale, NJ 07645; EPA Reg. No. 432-1227) in water (pH = 6.5) applied 21–22 June 2011 (“Spring” treatment), (2) 2.0% a.i. carbaryl (Sevin® SL) in water (pH = 6.4) applied 15–16 September 2010 (“Fall” treatment), and (3–5) untreated controls used to assess *D. ponderosae* “pressure” (based on mortality of untreated, baited trees) during 2011–2013. Experimental trees were separated by >100 m. There was a significant difference in *P. contorta* dbh among treatments ($F_{4, 145} = 3.4$, $P = 0.01$), but presumably exerted little influence as experimental trees in all treatments averaged >23 cm dbh (Table 1), the preferred size class for *D. ponderosae* colonization (Björklund and Lindgren, 1999). 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 2241 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 a height of ~12 m. All insecticides were applied between 0630 and 1600 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. contorta* at ~2 m in height on the northern aspect prior to the initiation of *D. ponderosae* flight each year. The manufacturer estimates the life expectancy of these baits is 100–150 days depending on weather conditions, covering most of the flight activity period (~15 June to 1 October). All baits were removed after *D. ponderosae* flight ceased. Tree mortality was estimated initially based on external characteristics of the condition, distribution and density of *D. ponderosae* attacks on tree boles (none, unsuccessful attack, strip attack, and mass attack based on pitch tubes and boring dust) in the fall of each year. However, mortality was based on presence (dead) or absence (live) of crown fade, an irreversible symptom of tree mortality, in June the following year (e.g., in 2012 for trees colonized in 2011). 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 effectiveness 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 were killed as a result of *D. ponderosae* attack. Insecticide treatments were considered efficacious when <7 trees die as a result of *D. ponderosae* attack (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%). These parameters provide a conservative binomial test ($\alpha = 0.05$) to reject Ho when more than six trees die. The power of this test, that is the probability of having made the correct decision in rejecting Ho, is 0.84 (Hall et al., 1982; Shea et al., 1984). This experimental design is accepted as the standard for evaluating insecticides for tree protection in the western United States, and provides a very conservative test of efficacy (Fettig et al., 2013).

**Table 1**
Efficacy of an alternative timing of ground-based applications of carbaryl to protect individual *Pinus contorta* from mortality attributed to *Dendroctonus ponderosae*, Bridger-Teton National Forest, Wyoming (43° 08′ 37.8″ N, 110° 52′ 47.4″ W; 1903 m elevation), 2010–2014.

| Treatment | Mean dbh ± SEM[a] | 2011 Mortality[b]/n | 2012 Mortality[b]/n | 2013 Mortality[b]/n |
|---|---|---|---|---|
| Spring | 31.2 ± 1.2 ab | 0/30 | 0/29[c] | 1/29[c] |
| Fall | 31.8 ± 1.1 ab | 0/30 | 0/30 | 4/30 |
| Untreated control 2011 | 32.0 ± 0.8 a | 27/30 | – | – |
| Untreated control 2012 | 31.8 ± 1.1 ab | – | 26/30 | – |
| Untreated control 2013 | 27.3 ± 1.0 b | – | – | 16/30 |

[a] Means ± SEM followed by the same letter are not significantly different ($P > 0.05$). Dbh, diameter at breast height, 1.37 m above ground level.
[b] Based on the presence (dead) or absence (live) of crown fade the following June.
[c] One tree was windthrown and therefore excluded from the experiment.