N O T E

Efficacy of Fipronil for Protecting Individual Pines from Mortality Attributed to Attack by Western Pine Beetle and Mountain Pine Beetle (Coleoptera: Curculionidae, Scolytinae)[1]

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Bark beetles (Coleoptera: Curculionidae, Scolytinae) are commonly recognized as important tree mortality agents in coniferous forests of the western U.S. Most species feed on the phloem and cambium, or xylem tissue of woody plants; and a few are recognized as the most destructive of all forest insect pests. The last decade has seen elevated levels of bark beetle caused tree mortality in spruce, *Picea* spp., forests of south-central Alaska and the Rocky Mountains; lodgepole pine, *Pinus contorta* Dougl. ex Loud., forests of the Rocky Mountains; pinyon-juniper, *Pinus-Juniperus* spp., woodlands of the Southwest; and ponderosa pine, *P. ponderosa* Dougl. ex Laws., forests of Arizona, California, Colorado and South Dakota (Cain and Hayes 2009, U.S. Dept. of Agric. For. Serv. Gen. Tech. Rep. PNW-GTR-784). Today, about 8% of forests in the U.S. are classified at high risk (defined as >25% of stand density will die in the next 15 years) to insect and disease outbreaks (Krist et al. 2007, U.S. Dept. of Agric. For. Serv. FHTET Report 2007 - 06). Mountain pine beetle, *Dendroctonus ponderosae* Hopkins, is ranked most damaging of all mortality agents considered and colonizes several pine species, most notably *P. contorta*, *P. ponderosa*, sugar pine, *P. lambertiana* Dougl., whitebark pine, *P. albicaulis* Engelm., limber pine, *P. flexilis* James, and western white pine, *P. monticola* Dougl. ex D. Don. (Furniss and Carolin 1977, U.S. Dept. of Agric. For. Serv. Misc. Publ. 1339). The western pine beetle, *D. brevicomis* LeConte, is also a major cause of *P. ponderosa* mortality in much of the western U.S., specifically in California (Furniss and Carolin 1977). Together, these 2 bark beetle species are

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predicted to cause significant (>82,000,000 m^2 of basal area, cross-sectional area of tree boles at 1.37 m above ground level) levels of tree mortality in the next 15 yrs (Krist et al. 2007).

Trees located in residential, recreational (e.g., campgrounds) or administrative sites are particularly susceptible to bark beetle attack as a result of increased amounts of stress associated with drought, soil compaction, mechanical injury or vandalism (Haverty et al. 1998, U.S. Dept. of Agric. For. Serv. Res. Pap. PSW-RP-237). Tree losses in these unique environments generally result in undesirable impacts such as reduced shade, screening, aesthetics and visitor use. Dead trees pose potential hazards to public safety, requiring routine inspection (Johnson 1981, U.S. Dept. of Agric. For. Serv. Tech. Rept. R2 - 1) and increased costs associated with removal. Furthermore, property values may be significantly impacted (McGregor and Cole 1985, U.S. Dept. of Agric. For. Serv. Gen. Tech. Rept. INT-GTR-174). Each situation emphasizes the need for assuring that effective insecticide treatments are available for this use.

Protection of individual trees from bark beetle attack has historically involved applications of liquid formulations of contact insecticides applied directly to the tree bole using hydraulic sprayers. Fettig et al. (2006a, J. Econ. Entomol. 99: 1691 - 1698) reported that carbaryl is still one of the most effective, economically viable, and ecologically-compatible insecticides available for protecting individual trees from bark beetle attack in the western U.S., and generally provides 2 field seasons of protection with a single application. However, the long-term future of carbaryl as a tool for protecting conifers from bark beetle attack is uncertain as many uses have been voluntarily cancelled (U.S. Env. Prot. Agency 2007, Publ. EPA-738R07 - 018). Pyrethroids, such as permethrin and bifenthrin, are registered and effective for protecting conifers from bark beetle attack in the western U.S. (Fettig et al. 2006a; Fettig et al. 2006b, Arbor. Urban For. 32: 247 - 252), but generally only provide a single field season of protection per treatment. Spray applications require transporting hydraulic sprayers and other large equipment into remote areas, which can be problematic. This is an important concern when treating *P. contorta* at high elevations (>2400 m) in the Intermountain West where snow loads in May-June may limit access, preventing treatment prior to the initiation of flight activity and, thus, host colonization by *D. ponderosae* that year. Furthermore, concerns regarding the potential for spray drift to be deposited onto adjacent bodies of water and impact nontarget aquatic organisms are common, although recent evidence suggests drift poses little threat if appropriate no-spray buffers are used (Fettig et al. 2008, J. Env. Qual. 37: 1170 - 1179; Fettig et al. 2009, Univ. of Arizona Bull. AZ1493).

Researchers looking for more portable, and potentially safer, alternatives have examined the effectiveness of injecting small quantities of systemic insecticides directly into western conifers. Previous efforts indicated acephate (Shea et al. 1991, W. J. Appl. For. 6: 4 - 7; DeGomez et al. 2006, J. Econ. Entomol. 99: 393 - 400), azadirachtin (neem) (Duthie-Holt and Borden 1999, J. Entomol. Soc. Brit. Col. 96: 21 - 24.), carbofuran and dimethoate (Shea et al. 1991), dinotefuran (DeGomez et al. 2006) and oxydemeton methyl (Haverty et al. 1996, U.S. Dept. of Agric. For. Serv. Res. Note PSW-RN-420) are ineffective for protecting individual trees from attack by several bark beetle species indigenous to the western U.S. More recently, Grosman et al. (2010, W. J. Appl. For., in press) evaluated the effectiveness of experimental formulations of emamectin benzoate and fipronil for preventing tree mortality caused by *D. brevicomis* in *P. ponderosa*; *D. ponderosae* in *P. contorta*; and spruce beetle, *D. rufipennis* (Kirby), in Engelmann spruce, *Picea engelmannii* Parry ex Engelm. Emamectin benzoate was effective for protecting *P. ponderosa* from *D. brevicomis* attack during the third year following a single injection. Fipronil was ineffective for protecting *P. ponderosa* during the third year, but efficacy could not be determined during the first and second years of their study due to insufficient mortality of untreated, baited control trees (<60%). Estimates of efficacy could not be made in *P. contorta* due to insufficient mortality of untreated, baited control trees. Finally, both emamectin benzoate and fipronil were ineffective for protecting *Pi. engelmannii* from mortality attributed to *D. rufipennis* attack (Grosman et al. 2010).

The objectives of our study were to evaluate the efficacy of 2 new formulations of fipronil, each at 2 application rates, for protecting *P. ponderosa* from *D. brevicomis* attack and *P. contorta* from *D. ponderosae* attack; and to gain some insight into the influence of time of injection (May versus August) on efficacy in *P. contorta*. These formulations have characteristics that make them suitable for injection into pines (H. Quicke, BASF Corp., pers. commun.), but have not been evaluated for this application.

This study was conducted at 3 locations: (1) Yuba Co., CA (39.42°N, 121.30°W; ~700 m elevation), (2) Salmon-Challis National Forest, Custer Co., ID (44. 39°N, 115.18°W; ~2,000 m elevation), and (3) Uinta-Wasatch-Cache National Forest, Summit Co., UT (40.84°N, 110.85°W; ~2700 m elevation). Locations were selected based on ground surveys indicating bark beetle infestations were active in these areas. At each site, 12 [Idaho, a preliminary study limited in sample size due to the quantity of insecticide (R&D formulation) available] and 28 (California and Utah) randomly-selected trees were assigned to each of 5 treatments: (1) trunk injections of an experimental formulation (BAS 350 PWI) of fipronil [5% active ingredient (a.i.), BASF Corp., Agricultural Products Group, Research Triangle Park, NC] applied at 0.2 g a.i. per 2.54 cm diam at breast height (dbh, 1.37 m above ground level) mixed 1:1 with distilled water; (2) trunk injections of BAS 350 PWI applied at 0.4 g a.i. per 2.54 cm dbh, (3) trunk injections of an experimental formulation (BAS 350 UKI) of fipronil (5% a.i.) applied at 0.2 g a.i. per 2.54 cm dbh mixed 1:1 with distilled water, (4) trunk injections of BAS 350 UKI applied at 0.4 g a.i. per 2.54 cm dbh, and (5) an untreated control. Each formulation of fipronil was directly injected into the tree bole at 4 cardinal points ~0.3 m above the ground using the Arborjet Tree IV™ microinfusion system (Arborjet Inc., Woburn, MA) during 1 - 9 May 2007 (Idaho), 29 - 31 May 2007 (California) and 20 - 23 August 2007 (Utah). Fipronil-treated trees were allowed 7 wks (California), ~11 wks (Idaho) or ~41 wks (Utah) to translocate the insecticide prior to being challenged by application of commercially-available baits for each respective bark beetle species (Table 1; Contech Inc., Delta, BC). In all cases, baits were stapled to the bole of each tree at ~2 m in height, and were not removed until treatment evaluations were conducted (Table 1). The manufacturer estimates the life expectancy of these baits is 100 - 150 d depending on weather conditions (www.pherotech.com/page194.htm), which covers the major flight activity period of each bark beetle species (Fettig et al. 2004, Pan-Pacific Entomol. 80: 4 - 17, Fettig et al. 2005, Pan-Pacific Entomol. 81: 6 - 19 for *D. brevicomis* in California; Bentz 2006, Can. J. For. Res. 36: 351 - 360 for *D. ponderosae* in Idaho).

The only criterion used to determine the effectiveness of fipronil injections was whether individual trees succumbed to attack by *D. brevicomis* or *D. ponderosae*. Trees were considered dead when foliage began to "fade", an irreversible symptom of tree mortality. Treatments were considered to have sufficient beetle pressure if ≥60% of the untreated, baited control trees died of bark beetle attack. Insecticide treatments

Table 1. Effectiveness of bole injections of fipronil for protecting *Pinus ponderosa* in California (mean dbh = 40.4 cm dbh) and *Pinus contorta* in Idaho and Utah (mean dbh = 25.0 and 21.2 cm, respectively) from bark beetle attack, 2007 - 2009.

Treatment	Rate (/2.54 cm dbh)	2007	2008
D. brevicomis/P. ponderosa (California)		Mortality/n*	Mortality/n+
BAS 350 PWI	0.2 g	1/28	1/26++
BAS 350 PWI	0.4 g	5/28	2/22++
BAS 350 UKI	0.2 g	4/28	1/23++
BAS 350 UKI	0.4 g	1/27**	3/23†
Untreated control	-	10/28	11/18
D. ponderosa/P. contorta (Idaho)		Mortality/n††	Mortality/n
BAS 350 PWI	0.2 g	7/12	-
BAS 350 PWI	0.4 g	7/12	-
BAS 350 UKI	0.2 g	6/12	-
BAS 350 UKI	0.4 g	9/11‡	-
Untreated control	-	6/12	-
D. ponderosa/P. contorta (Utah)		Mortality/n	Mortality/n‡‡
BAS 350 PWI	0.2 g	-	18/28
BAS 350 PWI	0.4 g	-	16/28
BAS 350 UKI	0.2 g	-	22/28
BAS 350 UKI	0.4 g	-	17/28
Untreated control	-	-	24/28

dbh = diameter at breast height (1.37 m in height).
* Injected 29 - 31 May 2007. Trees baited with frontalin (3 mg/d), *exo*-brevicomin (3 mg/d), and myrcene (18 mg/d) on 19 July 2007. Mortality assessed 18 - 19 July 2008, based on presence of crown fade.
** One tree could not be found.
+ Trees baited with frontalin (3 mg/d), *exo*-brevicomin (3 mg/d), and myrcene (18 mg/d) on 19 - 20 July 2008. Mortality assessed 6 - 7 August 2009.
++ One tree lost to wildfire.
† Three trees lost to wildfire.
†† Injected 1 - 9 May 2007. Trees baited with *trans*-verbenol (1.2 mg/d) and *exo*-brevicomin (0.3 mg/d) on 20 July 2007. Mortality assessed 19 - 20 August 2008.
‡ One tree lost to attack by *D. ponderosae* prior to baiting.
‡‡ Injected 20 - 23 August 2007. Trees baited with *trans*-verbenol (1.2 mg/d) and *exo*-brevicomin (0.3 mg/d) on 10 June 2008. Mortality assessed 23 July 2009.

were considered efficacious when <7 trees died as a result of bark beetle attack. This experimental design serves as a standard for such evaluations in the western U.S. (Strom and Roton 2009, J. Entomol. Sci. 44: 297 - 307) and provides a very conservative test of efficacy (see Hall et al. 1982, J. Econ. Entomol. 75: 504 - 508; Shea et al. 1984, J. Georgia Entomol. Soc. 19: 427 - 433 for a complete description).

During this study, we observed no external symptoms of phytotoxicity associated with either formulation of fipronil. Average uptake time (i.e., the amount of time required for trunk injected solutions to completely enter the tree) was 8 min for *P. ponderosa* in California, 12 min for *P. contorta* in Idaho, and 20 min for *P. contorta* in Utah. In California, beetle pressure was insufficient to validate the effectiveness of treatments as only 35.7% (10 of 28 trees) of untreated, baited controls died of *D. brevicomis* attack. During this time, mortality rates among fipronil treatments ranged from 3.6% (BAS 350 PWI, 0.2 g a.i.) to 17.9% (BAS 350 PWI, 0.4 g a.i.) (Table 1). Although this study was designed for a single field season, all surviving trees were rebaited in 2008 due to the low rate of tree mortality observed. In 2008, 61.1% (11 of 18 trees) of the remaining untreated, baited controls died of *D. brevicomis* attack whereas mortality rates among fipronil treatments ranged from 3.9% (BAS 350 PWI, 0.2 g a.i.) to 13% (BAS 350 UKI, 0.4 g a.i.) (Table 1). In Idaho, only 50% (6 of 12 trees) of untreated, baited controls died of *D. ponderosae* attack. During this time, mortality rates among fipronil treatments ranged from 50% (BAS 350 UKI, 0.2 g a.i.) to 81.8% (BAS 350 UKI, 0.4 g a.i.) (Table 1). In Utah, 85.7% (24 of 28 trees) of untreated, baited controls died of *D. ponderosae* attack whereas mortality rates among fipronil treatments ranged from 57.1% (BAS 350 PWI, 0.4 g a.i.) to 78.6% (BAS 350 UKI, 0.2 g a.i.) (Table 1).

Techniques for managing bark beetle infestations are limited to tree removals (thinning) that reduce stand density and presumably host susceptibility (Fettig et al. 2007, For. Ecol. Manage. 238: 24 - 53); the use of insecticides and semiochemicals for specific bark beetle-host species complexes (Goyer et al. 1998, J. For. 98: 29 - 33); and a combination of these and other treatments for suppressing localized infestations (Bentz and Munson 2000, West. J. Appl. For. 15: 122 - 128). Our results indicate bole injections of fipronil are not effective for protecting individual *P. contorta* from mortality attributed to *D. ponderosae* attack. Our preliminary evaluations conducted in Idaho (Table 1), in combination with results reported by Grosman et al. (2010), suggest time of injection (i.e., May versus August) may have little influence on the efficacy of fipronil injections in *P. contorta* as has been previously suggested. Because of the limited levels of mortality observed in the untreated, baited controls in California, we are precluded from making conclusions regarding the efficacy of fipronil injections for protecting *P. ponderosa* from mortality attributed to *D. brevicomis* attack. However, a careful review of the data (Table 1) suggests that some level of protection occurred (i.e., cumulative levels of tree mortality were 75% in the untreated, baited control, but ranged from 7.4% to 25.9% among fipronil treatments). Furthermore, bark samples were removed from several *P. contorta* and *P. ponderosa* injected with fipronil that showed evidence of reduced levels of brood production and limited beetle emergence compared with the untreated, baited controls.

Our results, combined with those of Grosman et al. (2010), suggest that the use of fipronil for protection of individual pines from mortality attributed to *D. brevicomis* and *D. ponderosa* attack is not currently advisable. Finally, the use of all bark beetle management tools should be considered in an integrated approach.

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