Effectiveness of Bifenthrin (Onyx) and Carbaryl (Sevin SL) for Protecting Individual, High-Value Conifers from Bark Beetle Attack (Coleoptera: Curculionidae: Scolytinae) in the Western United States

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ABSTRACT High-value trees, such as those located in residential, recreational, or administrative sites, are particularly susceptible to bark beetle (Coleoptera: Curculionidae: Scolytinae) attack as a result of increased amounts of stress associated with drought, soil compaction, mechanical injury, or vandalism. Tree losses in these unique environments generally have a substantial impact. The value of these individual trees, cost of removal, and loss of esthetics may justify protection until the main thrust of a bark beetle infestation subsides. This situation emphasizes the need for ensuring that effective insecticides are available for individual tree protection. In this study, we assess the efficacy of bifenthrin (Onyx) and carbaryl (Sevin SL) for protecting: ponderosa pine, *Pinus ponderosa* Dougl. ex. Laws., from western pine beetle, *Dendroctonus brevicomis* LeConte, in California; mountain pine beetle, *Dendroctonus ponderosae* Hopkins in South Dakota; and *Ips* spp. in Arizona; lodgepole pine, *Pinus contorta* Dougl. ex Loud., from *D. ponderosae* in Montana; pinyon, *Pinus edulis* Engelm. in Colorado and *Pinus monophylla* Torr. & Frem. in Nevada from pinyon ips, *Ips confusus* (LeConte); and Engelmann spruce, *Picea engelmannii* Parry ex. Engelm. from spruce beetle, *Dendroctonus rufipennis* (Kirby) in Utah. Few trees were attacked by *Ips* spp. in Arizona and that study was discontinued. Sevin SL (2.0%) was effective for protecting *P. ponderosa*, *P. contorta*, and *P. monophylla* for two field seasons. Estimates of efficacy could not be made during the second field season in *P. edulis* and *P. engelmannii* due to insufficient mortality in untreated, baited control trees. Two field seasons of efficacy was demonstrated in *P. ponderosa*/*D. brevicomis* and *P. monophylla* for 0.06% Onyx. We conclude that Onyx is an effective individual tree protection tool, but repeated annual applications may be required in some systems if multiyear control is desired.

KEY WORDS bifenthrin, carbaryl, *Pinus*, *Picea*, *Dendroctonus*

Coleoptera: Curculionidae: Scolytinae is a large and diverse group of insects consisting of ≈550 species in North America and >6,000 species worldwide (Wood 1982). Most feed on the phloem and cambium, or xylem tissue of woody plants, and a few species are recognized as the most destructive of all forest insect pests. The western pine beetle, *Dendroctonus brevicomis* LeConte, is a major cause of ponderosa pine, *Pinus ponderosa* Dougl. ex. Laws., mortality in the western United States, particularly in California (Furniss and Carolin 1977). Under certain conditions, such as extensive drought, this species may attack and kill apparently healthy trees of all ages and size classes (Miller and Keen 1960). In recent years, the amount of tree mortality attributed to *D. brevicomis* reached unprecedented levels in the mountains of San Bernardino and Riverside counties, CA, where ≈61,000 ha has been impacted (USDA–Forest Service 2002).

The mountain pine beetle, *Dendroctonus ponderosae* Hopkins, is the most destructive bark beetle in western North America. This species ranges throughout British Columbia, Alberta, most of the western United States, into northern Mexico, and colonizes several pine species, most notably, lodgepole pine, *Pinus contorta* Dougl. ex Loud.; *P. ponderosa;* sugar pine, *Pinus lambertiana* Dougl.; whitebark pine, *Pinus albicaulis* Engelm.; limber pine, *Pinus flexilis* James;

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and western white pine, *Pinus monticola* Dougl. ex D. Don. (Furniss and Carolin 1977). In 2004 and 2005, unprecedented levels of *D. ponderosae*-caused tree mortality were recorded in *P. contorta* forests throughout British Columbia where an estimated 8.5 million ha was affected (www.for.gov.bc.ca/hfp). Since 2001, >350,000 ha of *P. contorta* forest has been infested in the western United States, including vast portions of the Sawtooth National Recreation Area (Matthews et al. 2005).

Pinyon ips, *Ips confusus* (LeConte), is a major cause of mortality in pinyon pine, *Pinus edulis* Engelm. and *P. monophylla* Torr. & Frem., throughout the Southwest and Intermountain regions of the United States (Furniss and Carolin 1977). Large infestations were associated with extended periods of drought in Arizona, New Mexico, Nevada, Utah, and southwestern Colorado during 2001–2004. In 2003, the USDA–Forest Service estimated 15–30% of pinyons were killed on >1.6 million hectares (USDA–Forest Service 2004).

Engraver beetles, *Ips* spp., typically attack stressed, weakened, dead or dying trees (Kegley et al. 1997). The pine engraver, *Ips pini* (Say), has a transcontinental distribution and is one of the most common bark beetle species in North America (Furniss and Carolin 1977). Outbreaks are often short-lived, but they may increase when suitable host material is plentiful and populations increase sufficiently to colonize apparently healthy trees. In 2001, a severe drought triggered a landscape level *Ips* outbreak throughout much of Arizona, resulting in millions of trees killed on >810,000 ha (USDA–Forest Service 2004).

The spruce beetle, *Dendroctonus rufipennis* (Kirby), is the most significant mortality agent of mature spruce, *Picea* spp., in the United States (Holsten et al. 1999). At the peak of the outbreak in Alaska, >500,000 ha of spruce stands was infested (Wittwer 2000). From 1990 to 2005, large amounts of Engelmann spruce, *Picea engelmannii* Parry ex. Engelm, mortality were attributed to *D. rufipennis* in the Rocky Mountains (Matthews et al. 2005).

Bark beetle outbreaks and associated tree mortality not only affect watershed, timber and wildlife resources but also esthetic, cultural, and recreational values. Tree losses due to bark beetle infestation in residential, recreational, or administrative sites generally result in undesirable impacts such as reduced shade, screening, and esthetics thus compromising visitor experiences (Helm and Johnson 1995). Dead trees pose potential hazards to public safety requiring routine inspection and maintenance (Johnson 1981). Costs associated with hazard tree removal are high with even greater amounts paid in tort claims each year (Johnson 1981). Trees located in residential, recreational, 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). Regardless of landowner objectives, tree losses in these unique environments generally have a catastrophic impact. For example, the value of a mountain home may be severely reduced by mortality of adjacent shade and ornamental trees (McGregor and Cole 1985). The value of these trees, cost of removal, and loss of esthetics may justify protecting individual trees until the main thrust of a bark beetle infestation subsides. Trees growing in progeny tests, seed orchards, or those genetically resistant to forest diseases are also of increased value. These situations emphasize the need for ensuring that effective insecticides are available for individual tree protection.

Carbaryl is one of the most effective and environmentally safe insecticides used to prevent bark beetle attacks (Hastings et al. 2001). Several formulations have been evaluated for protection of individual trees from attack by western bark beetles, primarily *D. brevicomis* and *D. ponderosae* (Haverty et al. 1998). The effectiveness of 1.0 and 2.0% carbaryl (Sevimol) for preventing successful attack of *P. ponderosa* by *D. brevicomis* has been demonstrated (Hall et al. 1982, Haverty et al. 1985). The effectiveness of 2.0% carbaryl also was confirmed for protecting *P. contorta* from *D. ponderosae* attack (Gibson and Bennett 1985, Page et al. 1985, Shea and McGregor 1987). These and other studies (Smith et al. 1977, McCambridge 1982) led to the registration of 2.0% Sevimol as a preventive spray. A 1.0% suspension of carbaryl (Sevimol and Sevin SL) was effective for protecting *P. contorta* from *D. ponderosae* attack in Montana for at least 1 yr. A 2.0% suspension was effective in protecting *P. ponderosa* from *D. brevicomis* attack in southern Idaho for 1 yr (Haverty et al. 1998). Shea and McGregor (1987) evaluated the efficacy of 0.5, 1.0, and 2.0% carbaryl (Sevimol and Sevin XLR) and found all concentrations and formulations were effective for protecting *P. contorta* from *D. ponderosae* attack for 1 yr. The 1.0 and 2.0% rates were efficacious for 2 yr. In south central Alaska, Werner et al. (1986) reported that carbaryl protected white spruce, *Picea glauca* (Moench) Voss, and Lutz spruce, *Picea glauca* × *lutzii* Little, from attack by *D. rufipennis* for three field seasons. Johnson (1996) indicated that 1.0 and 2.0% carbaryl (Sevimol) were effective for protecting *P. engelmanii* from *D. rufipennis* attack for 2 yr. Berisford et al. (1981) reported that 2.0% carbaryl was ineffective for preventing attack by southern pine beetle, *Dendroctonus frontalis* Zimmerman, which later was linked to tolerance in that beetle associated with an efficient conversion of carbaryl into metabolites, and a rapid rate of excretion (Zhong et al. 1995a).

Pyrethroids offer a potential alternative to carbaryl for individual tree protection. Synthesized from petroleum-based chemicals and related to the potent insecticidal properties of flowering plants in the genus *Chrysanthemum,* in general this class of insecticides is of high toxicity to invertebrates and relatively low toxicity to mammals (Pajares and Lanier 1989). Shea at al. (1984) examined the effectiveness of permethrin (Pounce) at three rates, 0.1, 0.2, and 0.4%, for protecting *P. ponderosa* from *D. brevicomis* attack, and reported that 0.2 and 0.4% provided control for 4 mo. Haverty et al. (1998) examined several rates of esfenvalerate and cyfluthrin for protecting *P. ponderosa* and *P. contorta* from *D. brevicomis* and *D. ponderosae,* respectively. In the Sierra Nevada, esfenvalerate (Asana XL) applied at 0.025 and 0.05% provided protection of *P. ponderosa* for a full summer. Neither esfenvalerate treatment was effective for a second field season (Haverty et al. 1998). In Montana, 0.006 and 0.012% esfenvalerate were ineffective for protecting *P. contorta* from *D. ponderosae* attack. However, the 0.025% rate was effective for a single field season. Cyfluthrin (Tempo 20 WP) applied at 0.025% provided protection of *P. ponderosa* for one field season in Idaho, but not California (Haverty et al. 1998). All three cyfluthrin treatments, 0.025, 0.05, and 0.1%, were effective for protecting *P. contorta* for two field seasons (Haverty et al. 1998). DeGomez et al. (2006) reported that 0.19% permethrin plus-C (Masterline) and 0.06% bifenthrin (Onyx) were effective for protecting *P. ponderosa* bolts from *Ips* spp. attacks. The registered rate (0.2%) of permethrin plus-C protected *P. contorta* from *D. ponderosae* attack for one field season in Montana (Fettig et al. 2006). In Utah, 0.025% cyfluthrin and 0.025% and 0.05% esfenvalerate were efficacious for 1 yr for protecting *P. engelmanii* from *D. rufipennis* attack (Johnson 1996). Hall (1984) examined the efficacy of carbaryl, chlorpyriphos, fenitrothion, and permethrin for preventing red turpentine beetle, *Dendroctonus valens* LeConte, attack and reported that only 2.0 and 4.0% carbaryl and 4.0% fenitrothion were effective.

The objective of this study was to assess the efficacy of 2.0% carbaryl (Sevin SL) and 0.03, 0.06, and 0.12% bifenthrin (Onyx) for protecting *P. ponderosa* from *D. brevicomis* (California), *D. ponderosae* (South Dakota), and *Ips* spp. attack (Arizona); *P. contorta* from *D. ponderosae* attack (Montana); *P. edulis* (Colorado) and *P. monophylla* (Nevada) from *I. confusus* attack; and *P. engelmannii* from *D. rufipennis* attack (Utah).

Materials and Methods

This study was conducted at seven locations: 1) Lassen County, CA (40.4° N, 120.8° W; 1,585-m elevation); 2) Black Hills Experimental Forest, South Dakota (44.2° N, 103.6° W; 1,621-m elevation); 3) Coconino County, AZ (35.2° N, 111.5° W; 2,104-m elevation); 4) Beaverhead-Deerlodge National Forest, Montana (45.9° N, 121.4° W; 1,966-m elevation); 5) Southern Ute Reservation, Colorado (37.1° N, 107.8° W; 2,010-m elevation); 6) Pine Nut Range, Nevada (39.1° N, 119.6° W; 1,798-m elevation); and 7) Dixie National Forest, Utah (38.2° N, 111.5° W; 3,048-m elevation). At each site, 25 (Colorado, Nevada, South Dakota, and Utah), 28 (Arizona), 30 (Montana, 2004), or 35 (California and Montana, 2003) randomly selected trees were assigned to each of six treatments: 2.0% carbaryl (Sevin SL, Bayer Environmental Science, Montvale, NJ; EPA reg. no. 432-1227); 0.03, 0.06, and 0.12% bifenthrin (Onyx, FMC Corporation, Agricultural Products Group, Philadelphia, PA; EPA reg. no. 279-3177), and two separate untreated controls. One control group was used to assess bark beetle pressure (based on mortality of untreated, baited trees) during each of two field seasons (2003–2004). In Montana, we reevaluated 0.06% Onyx and Sevin SL at a nearby site (46.0° N, 121.3° W; 1,970-m elevation) in 2004–2005. Treatment and evaluation dates are reported in Tables 1–6.

Insecticides were applied with a hydraulic sprayer, which allowed treatment of the entire bole (*Dendroctonus* spp.), or bole and all branches >5 cm in diameter (*Ips* spp.), of each tree, until runoff, to a height of 12 m. This application technique has been shown to result in >80% of the insecticide being applied to the tree bole (Haverty et al. 1983). The amount of insecticide (and water) used per tree varied with diameter and tree species; the latter primarily as a result of differences in bark and crown architecture. All treatments were applied between 0630 and 1400 hours, when wind speeds were <11 km/h.

At each site, sample trees were confirmed uninfested and located in areas with recent bark beetle activity. To rigorously test the efficacy of these treatments, the spacing between adjacent trees was >100 m to enhance the likelihood that sufficient numbers of beetles would be in the vicinity of each tree. All treated trees and the first set of untreated control trees were baited with appropriate species-specific lures (Phero Tech Inc., Delta, British Columbia, Canada; Tables 1–6) for 6–14 wk, depending on beetle pressure in the area. Surviving treated trees in each treatment (if less than seven were killed), and the second set of untreated controls were rebaited in 2004.

Treatments were considered to have sufficient beetle pressure if ≥60% of the untreated control trees died from bark beetle attack. Insecticide treatments were considered efficacious when less than seven trees died as a result of bark beetle attack (Shea et al. 1984). These criteria were established based on a sample size of 22–35 trees/treatment and the 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 such evaluations and provides a very conservative test of efficacy (Shea et al. 1984, Haverty et al. 1985, 1998; Fettig et al. 2006).

Results

California: *P. ponderosa* and *D. brevicomis*. In 2003 and 2004, beetle pressure was sufficient to adequately challenge these treatments as 63 and 74% of untreated controls died from *D. brevicomis* attack, respectively. Onyx applied at 0.06% and 0.12 and 2.0% Sevin SL were efficacious for two field seasons with a single application (Table 1). The low rate of Onyx (0.03%) was ineffective for protecting *P. ponderosa* from *D. brevicomis* attack. Only one Sevin SL and 0.12% Onyx-treated tree died from *D. brevicomis* attack (Table 1).

South Dakota: *P. ponderosa* and *D. ponderosae*. In 2003, beetle pressure was insufficient to adequately challenge the treatments, but in 2004 68% of the un-

Table 1. Effectiveness of bifenthrin (Onyx) and carbaryl (Sevin SL) for protecting *P. ponderosa* (mean dbh = 42.7 cm) from *D. brevicomis* attack, Lassen Co., CA (40.4° N, 120.8° W), 2003–2004

Treatment[a]	Mortality/n		
	2003[b]	2004[c]	Cumulative
0.03% Onyx	12/34	—	12/34
0.06% Onyx	0/31	4/31	4/31
0.12% Onyx	0/29	1/28[d]	1/28
2.0% Sevin SL	1/34	0/33	1/34
Untreated control	22/35	26/35	48/70

[a] Applied 19–22 May 2003.
[b] Assessed 23–24 June 2004. Trees actively baited with racemic frontalin (1–3 mg/24), racemic *exo*-brevicomin (1–3 mg/24 h), and myrcene (15–20 mg/24 h) for 42 d.
[c] Assessed 21–22 October 2004. Trees actively baited for 48 d. Dash indicates assessments were discontinued in 2004 after treatment was found to be ineffective in 2003.
[d] Tree removed from sample due to lightning strike.

treated controls died from *D. ponderosae* attack. During the initial field season, 12 and 0% of trees treated with the mid- and high rate of Onyx died from bark beetle attack, whereas 48.0% mortality was observed in the untreated controls (Table 2). If three additional control trees had died, bark beetle pressure would have been sufficient to make definitive estimates of efficacy (Shea et al. 1984), and we would have concluded that both 0.06 and 0.12% Onyx were effective during the first field season. None of the Onyx treatments were efficacious for two field seasons (Table 2). Sevin SL was efficacious during both field seasons with 0 and 24% mortality observed in 2003 and 2004, respectively.

Arizona: *P. ponderosa* and *Ips* spp. To our knowledge, this study was the first attempt to evaluate the effectiveness of insecticides for protecting individual *P. ponderosa* from *Ips* spp. attack. Accordingly, standing live trees were baited in 2003 with 97% (−)-ipsdienol (0.2 mg/24 h) and lanierone (0.009 mg/24 h) for 92 d. Unfortunately, very few trees were attacked, and only one tree died from *Ips* attacks. Based on activity levels in nearby slash, there was a relatively large complex of *Ips* species in the vicinity of our study site. However, commercial tree baits are not available, and aggregation pheromones for one species may repel others (Light et al. 1983, Miller and Borden 1992, Ayers et al. 2001). This study was discontinued in 2003 because we were unable to initiate sufficient numbers of *Ips* attacks on standing trees (DeGomez et al. 2006).

Table 2. Effectiveness of bifenthrin (Onyx) and carbaryl (Sevin SL) for protecting *P. ponderosa* (mean dbh = 35.7 cm) from *D. ponderosae* attack, Black Hills Experimental Forest, South Dakota (44.2° N, 103.6° W), 2003–2004

Treatment[a]	Mortality/n		
	2003[b]	2004[c]	Cumulative
0.03% Onyx	8/25	—	8/25
0.06% Onyx	3/25	13/22	16/25
0.12% Onyx	0/25	9/25	9/25
2.0% Sevin SL	0/25	6/25	6/25
Untreated control	12/25	17/25	29/50

[a] Applied 30 June 2003.
[b] Assessed 6 October 2003. Trees actively baited with 75% (−)-*trans*-verbenol (1–2 mg/24 h) and racemic frontalin (1–3 mg/24 h) for 94 d.
[c] Assessed 4 October 2004. Trees actively baited for 92 d. Dash indicates assessments were discontinued in 2004 after treatment was found to be ineffective in 2003.

Table 3. Effectiveness of bifenthrin (Onyx) and carbaryl (Sevin SL) for protecting *Pinus contorta* (mean dbh = 27.7 cm) from *D. ponderosae* attack, Beaverhead-Deerlodge National Forest, Montana (45.9° N, 121.4° W and 46.0° N, 121.3° W), 2003–2005

Treatment[a]	Mortality/n		
	2003[b,d]	2004[c,d]	Cumulative
0.03% Onyx	22/32	—	22/32
0.06% Onyx	11/34	—	11/34
0.12% Onyx	1/32	24/31	25/32
2.0% Sevin SL	0/35	3/33	3/33
Untreated control	30/35	25/34	55/69
	2004[e]	2005[f]	Cumulative
0.06% Onyx[g]	1/29	20/28	21/28[h]
2.0% Sevin SL	0/30	1/30	1/30
Untreated control	30/30	22/30	52/60

[a] Applied 18–20 June 2003.
[b] Assessed 16–17 August 2003. Trees actively baited with 75% (–)-*trans*-verbenol (1–2 mg/24 h) and racemic frontalin (2–3 mg/24 h) for 42 d.
[c] Assessed 16–17 September 2004. Trees actively baited for 42 d. Dashes indicate assessments were discontinued in 2004 after treatments were found to be ineffective in 2003.
[d] Some trees lost to fuels reduction project.
[e] Assessed 16–17 September 2004. Trees actively baited with 75% (–)-*trans*-verbenol (1–2 mg/24 h) and racemic frontalin (1–3 mg/24) for 42 d.
[f] Assessed 27–28 September 2005. Trees actively baited for 42 d.
[g] Applied 15–17 June 2004.
[h] One tree lost to woodcutting.

Montana: *P. contorta* and *D. ponderosae*. Bark beetle pressure was extremely heavy during this evaluation, as indicated by mortality levels reported for the untreated controls, and was more than adequate to challenge the insecticide treatments (Table 3). Neither the low nor mid-rate of Onyx protected *P. contorta* for a single field season. The high rate of Onyx (0.12%) provided one field season of efficacy (3.1% mortality), but in 2004 a significant number of Onyx-treated trees died from *D. ponderosae* attacks (77.5% mortality) (Table 3). The Sevin SL treatment was efficacious during both field seasons with 0 and 9.1% mortality observed in 2003 and 2004, respectively.

In 2004 and 2005, beetle pressure was sufficient to adequately challenge these treatments. During this second evaluation, 0.06% Onyx provided adequate control during the first field season, but a significant number of trees were killed in 2005 (Table 3). Again, Sevin SL was efficacious during both field seasons with 0 and 3.3% mortality observed in 2004 and 2005, respectively (Table 3).

Colorado: *P. edulis* and *I. confusus*. In 2003, beetle pressure was sufficient to adequately challenge these treatments. The high rate of Onyx (0.12%) was efficacious, but both 0.03 and 0.06% Onyx were ineffective (Table 4). Sevin SL was efficacious during the initial field season. Bark beetle pressure was insufficient in

Table 4. Effectiveness of bifenthrin (Onyx) and carbaryl (Sevin SL) for protecting *P. edulis* (mean basal diameter = 13.8 cm) from *I. confusus* attack, Southern Ute Reservation, Colorado (37.1° N, 107.8° W), 2003–2004

Treatment[a]	Mortality/n		
	2003[b]	2004[c]	Cumulative
0.03% Onyx	7/25	—	7/25
0.06% Onyx	7/25	—	7/25
0.12% Onyx	3/25	0/22	3/25
2.0% Sevin SL	5/25	1/20	6/25
Untreated control	17/25	0/21[d]	17/46

[a] Applied 4 May 2003.
[b] Assessed 11 August 2003. Trees actively baited with racemic ipsenol (0.1–0.3 mg/24 h), racemic ipsdienol (0.1–0.3 mg/24 h), and *cis*-verbenol (1–2 mg/24 h) for 50 d.
[c] Assessed 31 August 2004. Trees actively baited for 50 d. Dashes indicate assessments were discontinued in 2004 after treatments were found to be ineffective in 2003.
[d] One control tree missing at time of assessment.

2004 to make definitive estimates of efficacy as 0% of untreated controls died from *I. confusus* attacks. A rapid decline in *I. confusus* populations and associated levels of tree mortality were observed throughout much of Colorado in 2004 (USDA–Forest Service 2005).

Nevada: *P. monophylla* and *I. confusus*. In 2003 and 2004, beetle pressure was sufficient to adequately challenge these treatments. During this experiment, all insecticides and rates examined provided two field seasons of protection (Table 5). No Sevin SL-treated trees died during the experiment.

Utah: *P. engelmannii* and *D. rufipennis*. In 2004, beetle pressure was sufficient to adequately challenge these treatments as 84% of untreated controls died from *D. rufipennis* attack. All insecticides and rates were effective, because no tree mortality was observed in these treatments (Table 6). In 2005, beetle pressure was insufficient (56%) to make definitive estimates of efficacy. If one additional control tree had died, bark beetle pressure would have been sufficient to make estimates of efficacy (Shea et al. 1984), and we would have concluded that all insecticides and rates were effective for providing two field seasons of protection.

Table 5. Effectiveness of bifenthrin (Onyx) and carbaryl (Sevin SL) for protecting *P. monophylla* from *I. confusus* attack, Pine Nut Range, Nevada (39.1° N, 119.6° W), 2003–2004

Treatment[a]	Mortality/n		
	2003[b]	2004[c]	Cumulative
0.03% Onyx	0/25	3/24[d]	3/24
0.06% Onyx	1/25	2/24	3/25
0.12% Onyx	1/25	1/24	2/25
2.0% Sevin SL	0/25	0/25	0/25
Untreated control	20/25	16/25	36/50

[a] Applied 29 September–2 October 2003.
[b] Assessed 9–10 June 2004. Trees actively baited with racemic ipsenol (0.1–0.3 mg/24 h), racemic ipsdienol (0.1–0.3 mg/24 h), and *cis*-verbenol (1–2 mg/24 h) for 50 d.
[c] Assessed 21–22 September 2004. Trees actively baited for 50 d.
[d] Tree lost to woodcutting.

Table 6. Effectiveness of bifenthrin (Onyx) and carbaryl (Sevin SL) for protecting *P. engelmannii* from *D. rufipennis* attack, Dixie National Forest, Utah (38.2° N, 111.5° W), 2004–2005

Treatment[a]	Mortality/n		
	2004[b]	2005[c]	Cumulative
0.03% Onyx	0/25	0/25	0/25
0.06% Onyx	0/25	0/25	0/25
0.12% Onyx	0/25	0/25	0/25
2.0% Sevin SL	0/25	0/25	0/25
Untreated control	21/25	14/25	35/50

[a] Applied 25–29 August 2003.
[b] Assessed 16–17 August 2004. Trees actively baited with racemic frontalin (2–3 mg/24 h) and α-pinene (75–150 mg/24 h) for 100 d.
[c] Assessed 16–17 September 2005. Trees actively baited for 100 d.

Discussion

In this study, a single application of 2.0% carbaryl (Sevin SL) was effective during two field seasons for protecting *P. ponderosa* from *D. brevicomis* and *D. ponderosae* attack; *P. contorta* from *D. ponderosae* attack (two studies); *P. monophylla* from *I. confusus* attack; and probably *P. engelmannii* from *D. rufipennis* attack (Tables 1–6). A previous study indicated that another formulation of 2.0% carbaryl was effective for protecting *P. engelmannii* for 2 yr (Johnson 1996). In Colorado, Sevin SL protected *P. edulis* during the first field season, but beetle pressure was insufficient during the second field season to make estimates of efficacy (Table 4). However, six of 25 Sevin SL-treated trees died from *I. confusus*, whereas 0% mortality was observed in the untreated control in 2004. The data suggest that Sevin SL is not effective for protecting *P. edulis* from *I. confusus* for two field seasons. The differences in efficacy observed between *I. confusus* in *P. monophylla* (Nevada) and *P. edulis* (Colorado) is interesting. The abiotic and edaphic factors are very similar between the two study locations, and the hosts are closely related and hybridize (Ronco 1990). In addition, the same baits and release rates were used to initiate attacks on treated trees. In Colorado, insecticide treatments were applied by a commercial contractor, whereas the applications in Nevada were made by our research team. The care and meticulousness with which applications are made can influence efficacy (Pedigo 2002). Many commercial tree care specialists in this area are now making two insecticide applications per year (March and July or August) on each tree.

Data contained here regarding Onyx are the first published report on its effectiveness for preventing bark beetle attack on individual standing trees; however, bifenthrin has been evaluated for its effect on maturation feeding by pine shoot beetle, *Tomicus piniperda* (L.) (Coleoptera: Curculionidae: Scolytinae) (McCullough and Smitley 1995). Our results suggest at minimum one field season of efficacy can be expected (Tables 2–4), and two field seasons of efficacy were observed in *P. ponderosa*/*D. brevicomis*, *P. monophylla*/*I. confusus*, and probably *P. engelmannii*/*D. rufipennis*. These results are similar to those described for other pyrethroids, including permethrin

(Shea et al. 1984), cyfluthrin and esfenvalerate (Haverty et al. 1998), and permethrin plus-C (Fettig et al. 2006). However, cyfluthrin and esfenvalerate only protected *P. engelmannii* from *D. rufipennis* attack for one field season in Utah (Johnson 1996). Since the initiation of this study, Onyx has been registered at the 0.06% rate. We conclude that Onyx is an effective individual tree protection tool, but repeated annual applications may be necessary in some systems if multiyear control is desired.

Presently, the only effective insecticide technique available for protecting individual, high-value trees from bark beetle attack in the western United States is to treat the bole of target trees before beetle colonization (Grosman and Upton 2006). This study expands our knowledge of the persistence and efficacy of carbaryl (Sevin SL) to bark beetle–host complexes that have not been evaluated previously. It also establishes the efficacy of bifenthrin (Onyx) for this important use. We hope that forest health professionals and other resource managers use these data and other published reports to make informed, judicious decisions concerning the application of these tools on the basis of efficacy and persistence (Hall et al. 1982; McCambridge 1982; Shea et al. 1984; Gibson and Bennett 1985; Haverty et al. 1985, 1997, 1998; Page et al. 1985; Werner et al. 1986; Shea and McGregor 1987; Zhong et al. 1995b; Hastings et al. 2001; DeGomez et al. 2006; Fettig et al. 2006), toxicity (Ware 1994, Hastings et al. 2001), safety (Haverty et al. 1983), environmental concerns (Hoy and Shea 1981; Hastings et al. 1998, 2001; Dwyer et al. 2005), and cost.

In this study, we demonstrated an increase in residual activity with carbaryl (Sevin SL) compared with bifenthrin (Onyx) in some systems. The mammalian toxicity of bifenthrin is slightly higher than carbaryl (Ware 1994). Carbaryl was one of the least toxic chemicals evaluated on six freshwater mussels (Glochidia) and of lower toxicity than permethrin (Milam et al. 2005). DeGomez et al. (2006) sprayed ≈26 liters of formulated product (insecticide + water) on individual trees with an average diameter at breast height (dbh) (diameter at 1.37 m) of 26.5 cm and height of 25 m. They reported an insecticide cost (exclusive of labor) per tree of $10.80 for the 0.06% Onyx and $14.00 for the 2.0% Sevin SL. In many respects, carbaryl is still one of the most effective, economically viable, and ecologically compatible insecticides available for protecting individual trees from bark beetle attack.

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