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Evaluation of Insecticides for Protecting Southwestern Ponderosa Pines from Attack by Engraver Beetles (Coleoptera: Curculionidae: Scolytinae)

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ABSTRACT Insecticides that might protect pine trees from attack by engraver beetles (*Ips* spp.) have not been rigorously tested in the southwestern United States. We conducted two field experiments to evaluate the efficacy of several currently and potentially labeled preventative insecticides for protecting high-value ponderosa pine, *Pinus ponderosa* Dougl ex. Laws., from attack by engraver beetles. Preventative sprays (0.19% permethrin [Permethrin Plus C]; 0.03, 0.06, and 0.12% bifenthrin [Onyx]; and 1.0 and 2.0% carbaryl [Sevin SL] formulations) and systemic implants (0.875 g per capsule acephate [Acecap] and 0.650 g per capsule dinotefuran) were assessed on bolts (sections of logs) as a surrogate for live trees for a period of 13 mo posttreatment. The pine engraver, *Ips pini* (Say), was the most common bark beetle found attacking control and treated bolts, but sixspined ips, *Ips calligraphus* (Germar), and *Ips lecontei* Swain also were present. After ≈13 mo posttreatment in one experiment, the spray treatments with 2.0% carbaryl, 0.19% permethrin, and 0.06 or 0.12% bifenthrin prevented *Ips* attack on the bolts at a protection level of ≥70%. The acephate and dinotefuran systemic insecticides, and the 0.03% bifenthrin spray, provided inadequate (≤36%) protection in this experiment. For the other experiment, sprayed applications of 1.0% carbaryl, 0.19% permethrin, and 0.06% bifenthrin prevented beetle attack at protection levels of ≥90, ≥80, and ≥70%, respectively, when bolts were exposed to *Ips* beetle attack for ≈9–15 wk posttreatment. The sprays with 0.19% permethrin and 0.06% bifenthrin also provided ≥90% protection when bolts were exposed for ≈15–54 wk posttreatment. We concluded that under the conditions tested, 1.0 and 2.0% carbaryl, 0.19% permethrin, and 0.06 and 0.12% binfenthrin were acceptable preventative treatments for protecting ponderosa pine from successful engraver beetle attack for one entire flight season in the U.S. Southwest.

KEY WORDS acephate, bifenthrin, carbaryl, dinotefuran, permethrin

Engraver beetles (*Ips* spp.) are common bark beetles (Coleoptera: Curculionidae, subfamily Scolytinae) distributed throughout North America (Kegley et al. 1997, DeGomez and Young 2002). Most engraver beetles are considered as moderately aggressive species, typically attacking recently dead and weakened pine trees; however, large populations of engraver beetles can occasionally overcome healthy trees in stands with compromised defense systems (e.g., high stand density or drought) (Kennedy 1969). Engraver beetle populations often build up in green slash host material. When live trees are attacked, they are typically pole-sized trees (Kennedy 1969, Furniss and Carolin 1977, Livingston 1979, Kegley et al. 1997), but the beetles also can attack tops and larger limbs of mature trees, often in conjunction with *Dendroctonus* spp. (Wood 1982). A severe drought triggered a landscape level outbreak of *Ips* species throughout much of Arizona in 2001 through 2003, with millions of trees being killed over >809,400 ha (>2,000,000 acres) (USDA–Forest Service 2004). During this outbreak, landowners and land managers frequently requested assistance in protecting high-value ponderosa pine, *Pinus ponderosa* Dougl ex. Laws., trees, including the use of preventative insecticides.

Liquid insecticides (primarily carbaryl-based formulations) applied to the bole of healthy trees and to bolts have been shown to be effective as a preventative treatment for *Dendroctonus* bark beetles in the west-

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ern United States (Smith et al. 1977, Hall et al. 1982, McCambridge 1982, Shea et al. 1984, Gibson and Bennett 1985, Haverty et al. 1985, Shea and McGregor 1987, Hastings et al. 2001). However, several questions and uncertainties remain regarding the use of preventative sprays for bark beetles. First, differences in the efficacy of preventative treatments among geographic regions and bark beetle species (reviewed in Hastings et al. 2001) suggest that future tests should be regionally and species specific. Currently, no studies have been published on preventative treatments for many bark beetles species of the southwestern United States, particularly for *Ips* species. Second, duration of efficacy for many of these preventative sprays remains unresolved. According to Hall et al. (1982) and Hastings et al. (2001), previous studies have concluded that residual activity of many of the carbaryl-based products may last anywhere from 3 to 27 mo. Third, because there is uncertainty regarding the reregistration of carbaryl products, new insecticides need to be tested (Haverty et al. 1998).

Confusion also continues regarding the efficacy of systemic implants against bark beetles. The scientific literature clearly shows that systemic implants do not control bark beetles. For example, Haverty et al. (1996) reported that systemic insecticide implants of metasystox-R were not effective for prevention or remediation of western pine beetle, *Dendroctonus brevicomis* LeConte, attack of ponderosa pines. Nonetheless, Acecap (acephate) has been recommended by retailers and certified pesticide applicators for bark beetle prevention and as a remedial treatment, even though bark beetles are not listed on the label as a target insect.

We assessed the effectiveness of several preventative sprays and systemic implants over a 2-yr period to address the issues associated with these regional and species differences in insecticide efficacy, plus the uncertainty regarding the usefulness of systemics. The goals of our studies were to compare newly or potentially labeled products for preventative treatments against engraver beetles attacking ponderosa pine in Arizona with the most commonly used product (carbaryl; i.e., Sevin SL) and to evaluate the duration of the protection they offered.

Materials and Methods

Two experiments evaluating the efficacy of preventative insecticide treatments to protect ponderosa pine against bark beetles were conducted, generally following the guidelines set forth by Shea et al. (1984) and Haverty et al. (1998). Both experiments were conducted in the Northern Arizona University/Arizona State Land Department Centennial Forest, southwest of Flagstaff, AZ (35° 10.80′ N, 111° 45.70′ W), by using randomized complete block designs.

Bolts were used as a surrogate for standing live trees for several reasons. First, because there is a relatively large complex of *Ips* species that are capable of killing ponderosa pine in the vicinity of our study site, we were uncertain about what aggregation pheromone(s) to use to challenge standing trees. Aggregation pheromones for one species of *Ips* may repel other species (Light et al. 1983, Miller and Borden 1992, Ayres et al. 2001). Second, preliminary studies using *Ips* aggregation lures (tree baits) did not produce a high rate of successful attacks on standing (untreated) control trees in 2003. Third, tree baits for *Ips* species in Arizona have not been fully developed (Steed 2003). Finally, because *Ips* beetles are well known to colonize fresh pine slash (Furniss and Carolin 1977), we reasoned that using bolts would be the best method for successfully conducting a rigorous test of the preventative insecticides.

2003–2004 Experiment. This study tested the efficacy of three preventative spray formulations: 1) 0.19% permethrin with cellulose additive (Permethrin Plus C); 2) 0.03, 0.06, and 0.12% bifenthrin (Onyx); and 3) 2.0% carbaryl (Sevin SL). We also tested two systemic insecticide implants: 0.875 g per capsule Acecap (97% technical acephate) and 0.650 g per capsule dinotefuran (98% technical dinotefuran). We selected a pool of 200 test trees with diameter at breast height (dbh) (defined as 1.37 m [4.5 feet] above ground) between 23 and 30 cm and with similar heights of ≈25 m. In total, 25 trees were assigned at random to each of the seven insecticide treatments plus an untreated control. Test trees were located every 0.16 km along the established road system in the Centennial Forest. On 3 May 2003, the acephate and dinotefuran systemic implants were inserted into the sapwood of the trees by drilling 10-mm-diameter holes 3.2 cm deep into the xylem, 75 cm above the ground, every 10 cm around the bole. On 19–23 May 2003, spray formulations were applied to the bole of standing trees up to a height where the bole was 10 cm in diameter (≈20 m) to the point of runoff with a high-pressure sprayer (17,575 g/cm^2 [250 psi]) by Coconino Pest Control Co. Approximately 26 liters (≈7 gal) of formulated insecticide were used on each tree. For the formulations of carbaryl, we tested the water for pH and added vinegar to bring the water to pH 7.0.

Approximately 1 yr after the insecticides were applied, on 14–20 May 2004, we cut 25 bolts per treatment (120 cm in length with diameters of 20–28 cm) from the boles of freshly felled ponderosa pine trees that had been treated in May 2003. One bolt from each treatment and the control were laid horizontally on the ground and arranged at random within a block with 1 m between bolts; freshly cut slash was placed, as an attractant for *Ips* beetles, on the ground at the edges of each block. To ensure sufficient beetle attack pressure, treatment blocks were located every 0.16 km along established roads adjacent to a recent harvest operation that contained slash piles infested with *Ips* beetles. Bolts were checked weekly for attacks, until 60% of the control bolts had been attacked by bark beetles. Attacks were defined as discreet piles of boring dust. At this point, we cut 30-cm lengths from the center of each bolt, placed them in mesh bags made from cloth mosquito netting, and moved them to a shaded area at the Northern Arizona University greenhouse to allow brood development to continue for 6 wk. Then, we removed the bolts from the mesh bags and peeled 30.5- by 20-cm (610-cm^2) sections of bark from each of the 30-cm-long bolts to count and identify any bark beetles present.

2004 Experiment. This study tested the efficacy of 0.19% permethrin with cellulose additive (Permethrin Plus C), 0.03 and 0.06% bifenthrin (Onyx), and 1.0% carbaryl (Sevin SL) spray formulations in preventing *Ips* attacks in ponderosa pine bolts over three successive exposure periods. Although the recommended label rate for Sevin SL is a 2.0% formulation, Shea and McGregor (1987) found that rates of 1.0% carbaryl were effective in protecting trees from attack by mountain pine beetles, *D. ponderosae* Hopkins, for two seasons. Thus, we used a 1.0% formulation to determine its effectiveness against *Ips* species because this lower rate would reduce cost and environmental impacts when used operationally to protect trees in high-use areas.

We selected a pool of 125 test trees with dbhs between 23 and 30 cm and with similar heights of ≈25 m. In total, 25 trees were assigned at random to each of the four insecticide treatments plus an untreated control. Liquid pesticides were applied to the bole of standing trees by Coconino Pest Control Co. on 4–6 May 2004, by using the same methods previously described for the 2003–2004 experiment. All treated and control trees were felled on 24–27 May 2004. Trees were delimbed, and three contiguous 120-cm bolts were cut from the bole starting at approximately breast height or 28-cm diameter, whichever was smaller. The three bolts were laid horizontally on the ground and arranged in arrays with 1 m between bolts, with one bolt exposed to bark beetle attack and the remaining two bolts placed in mesh bags to prevent beetle attack. Freshly cut slash was placed, as an attractant for *Ips* beetles, on the ground at the edges of each array. At the end of the first 6-wk exposure period, one of the two remaining bolts was removed from the mesh bag to become the next cohort exposed to beetles. Thus, bolts were exposed to beetle attacks in three successive exposure periods, the first two lasting 6 wk (cohort 1, exposed from 27 May to 8 July 2004; cohort 2, exposed from 9 July to 17 August 2004) and with the exposure of cohort 3 lasting 9 mo, from 18 August 2004 to 19 May 2005. Cohort 3 was left in the field through the fall and winter. Fresh cut slash was placed on the ground surrounding the bolts as a bark beetle attractant.

Bark beetle attacks were recorded weekly during the 6-wk exposures of cohorts 1 and 2. At the end of an exposure period, we cut 30-cm lengths from the center of the exposed bolts and then placed them in mesh bags and moved them to a shaded area adjacent to the Northern Arizona University greenhouse to allow brood development to continue for 6 wk. We subsequently peeled 30.5- by 20-cm (610-cm^2) sections of bark from each of the 30-cm-long bolts and any bark beetles present were counted and identified.

In May 2005, we cut 30-cm-long bolts from the center of the cohort 3 bolts, 9 mo after the mesh bags were removed and 12 mo posttreatment. We peeled the bark from 610-cm^2 sections of each bolt and inspected it for evidence of bark beetle larval galleries and exit holes to determine whether successful brood production had occurred. Some of the mesh bags covering the cohort 3 bolts were extensively damaged while they were in the field for ≈15 wk before their prescribed exposure period, and thus the bolts were attacked by bark beetles before the scheduled time. Consequently, from two to nine of the replications per treatment were lost for this cohort due to experimental error.

Determination of Efficacy. We assumed that the ponderosa pine bolts treated with insecticides had sufficient attack pressure by *Ips* beetles if at least 60% of the untreated control bolts were attacked. This is the criterion established by Shea et al. (1984) and Haverty et al. (1998). However, because we used bolts instead of standing live trees, our measure of failure or success was based on the presence or absence of *Ips* attacks rather than the tree being dead or alive at the end of the experiment. If <60% of the control bolts were attacked, our criterion of sufficient beetle attack was not met, and we did not analyze the data.

In both experiments, we categorized individual bolts as successfully protected if no *Ips* attacks were observed on the bolt. It was possible that beetles could successfully attack the bolts, but then die before gallery establishment. Our definition of one or more beetle attacks being equivalent to failure of the treatment and death of the tree constituted a very rigorous test of the insecticide treatments. We felt this was necessary because there were no constitutive or induced resin defenses in the tree bolts. We did not record observations of *Ips* attacks on bolts in the field for cohort 3 of the 2004 study. Instead, we used the presence of beetle exit holes to define treatment failure, with one or more exit holes in a bolt determining treatment failure.

We used one-sample proportion (i.e., binomial) tests (Analytical Software 2000) to determine whether each of the insecticide treatments (and the untreated control) provided a protection rate of ≥90% (i.e., H_0: p [proportion successes] ≥ 0.90, H_A: $P < 0.90$, $\alpha = 0.05$). The data used for the tests were the number of independent trials (i.e., the number of ponderosa pine bolts tested for each treatment), the number of bolts that were successes (i.e., there were no *Ips* beetle attacks), and the probability of success per trial (between 0 and 1). If we failed to accept the null hypothesis, H_0, that the protection rate was ≥90% (i.e., the *P* value for the binomial test was <0.05), then we conducted another test to decide whether the treatment provided a protection rate ≥80%. If the *P* value for the ≥80% protection rate test was also <0.05, we conducted one more test to see whether the protection rate was ≥70%. The program also computed the 95% confidence interval (CI) associated with the actual proportion of successes observed for each treatment. We plotted the 95% CI for the observed protection rates for each experiment to visually assess the patterns of differences among the treatments.

Table 1. Efficacy of preventative spray formulations and systemic implants in protecting ponderosa pine bolts from *Ips* bark beetle attack

Treatment			No. pine bolts			% protection	P value for rejecting[a] binomial test H_0 that proportion successes was ≥ to		
Insecticide	Formulation[b]	Spray or systemic	Tested	Failures[c]	Successes		0.90	0.80	0.70
Control			25	20	5	20.0	<0.001	<0.001	<0.001
Acephate	0.875 g	Systemic	25	18	7	28.0	<0.001	<0.001	<0.001
Bifenthrin	0.03%	Spray	25	18	7	28.0	<0.001	<0.001	<0.001
Bifenthrin	0.06%	Spray	25	11	14	56.0	<0.001	0.003	0.095
Bifenthrin	0.12%	Spray	25	9	16	64.0	<0.001	0.040	0.331
Dinotefuran	0.650 g	Systemic	25	16	9	36.0	<0.001	<0.001	<0.001
Permethrin	0.19%	Spray	25	9	16	64.0	<0.001	0.040	0.331
Carbaryl	2.0%	Spray	23[d]	9	14	60.9	<0.001	0.021	0.233

[a] Rejection is more accurately described as "failing to accept the null hypothesis, H_0."
[b] Grams per capsule; percentage of active ingredient.
[c] Treatment failure defined as one or more *Ips* beetle attack per bolt.
[d] Two of the 25 treatment bolts were most likely removed from the study site by vandals.

To give more information on the *Ips* attack pressure that occurred per pine bolt, we show data on the number of beetle attacks per bolt (expressed as number of attacks per 1,000 cm^2 of bark surface area) for the 2003–2004 experiment, and for cohorts 1 and 2 of the 2004 experiment. For cohort 3 of the 2004 experiment, we show these data in terms of the number of beetle exit holes per bolt (expressed as number of exit holes per 1,000 cm^2 of bark surface area).

Results

2003–2004 Experiment. This study exceeded the 60% criterion for test rigor proposed by Shea et al. (1984) and Haverty et al. (1998); 20 of the 25 control bolts (80%) were attacked by *Ips* beetles ≈13 mo posttreatment (Table 1). None of the treatments provided ≥90% protection ($P < 0.001$), or even ≥80% protection ($P \leq 0.040$), ≈1 yr after the insecticides were applied (Table 1). However, the 0.06 and 0.12% bifenthrin, 0.19% permethrin, and 2.0% carbaryl spray treatments had ≥70% protection rates ($P \geq 0.095$). Thus, these four spray treatments seemed to offer protection compared with the untreated control, based on the binomial test results and the 95% CIs for the observed protection rates (Fig. 1). However, the 0.03% bifenthrin spray, and the acephate and dinotefuran systemics, had protection rates ≤36%, which were not noticeably different from the control. The number of *Ips* attacks per bolt also indicated that the

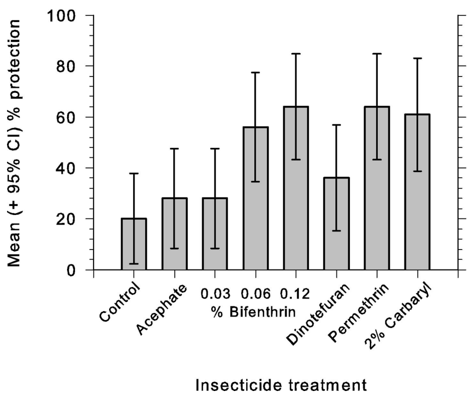

Fig. 1. Mean ± 95% CI percentage protection of ponderosa pine bolts from *Ips* bark beetle attack for five spray formulation (0.03, 0.06, and 0.12% bifenthrin; 0.19% permethrin; and 2% carbaryl) and two systemic implant (0.875 g of acephate and 0.650 g of dinotefuran) insecticide treatments, plus an untreated control. See Table 1 for binomial test results and other details.

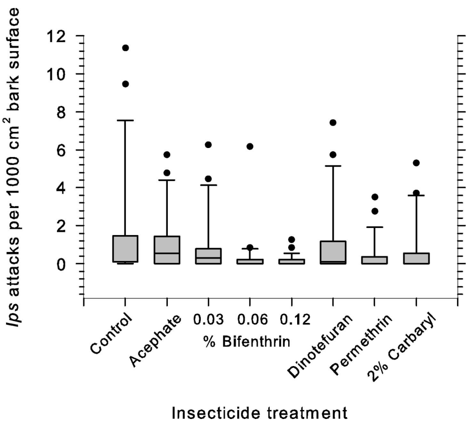

Fig. 2. Box plot comparing variation in *Ips* beetle attack pressure per pine bolt among the seven insecticide treatments described in Fig. 1, plus an untreated control. The lower boundary of the box indicates the 25th percentile for each treatment, the line within the box marks the median value, and the upper boundary indicates the 75th percentile. The error bars above and below the boxes indicate the 90th and 10th percentiles, and the dots show outlying points. The median line is equivalent to the 25th percentile for the following treatments: control, 0.06 and 0.12% bifenthrin, 0.19% permethrin, and 2% carbaryl. See Table 1 for details.

Table 2. Efficacy of preventative spray formulations in protecting ponderosa pine bolts from *Ips* bark beetle attack for cohorts 1, 2, and 3

Treatment		No. pine bolts			% protection	P value for rejecting[a] binomial test H_0 that proportion successes was $\geq$ to		
Insecticide	% active ingredient	Tested	Failures[b]	Successes		0.90	0.80	0.70
A. Cohort 1 (bolts exposed to *Ips* beetle attack for ≈6 wk, from 27 May to 8 July 2004, ≈3–9 wk postspray)								
Control		25	14	11	44.0[c]			
Bifenthrin	0.03	25	3	22	88.0			
Bifenthrin	0.06	25	2	23	92.0			
Permethrin	0.19	24	0	24	100.0			
Carbaryl	1.0	25	0	25	100.0			
B. Cohort 2 (bolts exposed to *Ips* beetle attack for ≈6 wk, from 9 July to 17 Aug. 2004, ≈9–15 wk postspray)								
Control		24	19	5	20.8	<0.001	<0.001	<0.001
Bifenthrin	0.03	24	13	11	45.8	<0.001	<0.001	0.009
Bifenthrin	0.06	25	9	16	64.0	<0.001	0.040	0.331
Permethrin	0.19	24	8	16	66.7	<0.001	0.084	
Carbaryl	1.0	25	3	22	88.0	0.500		
C. Cohort 3 (bolts exposed to *Ips* beetle attack for ≈9 mo, from 18 Aug. 2004 to 19 May 2005, ≈15–54 wk postspray)								
Control		16	10	6	37.5	<0.001	<0.001	0.005
Bifenthrin	0.03	22	7	15	68.2	0.001	0.132	
Bifenthrin	0.06	19	1	18	94.7	0.620		
Permethrin	0.19	19	0	19	100.0	0.858		
Carbaryl	1.0	23	7	16	69.6	0.002	0.161	

[a] Rejection is more accurately described as "failing to accept the null hypothesis, H_0."

[b] Treatment failure defined as one or more *Ips* beetle attack per bolt for cohorts 1 and 2 and as one or more *Ips* beetle exit hole per bolt for cohort 3.

[c] The cohort 1 control treatment did not experience the *Ips* beetle attack pressure required to produce a rigorous test of the treatments, so the data were not analyzed.

0.06 and 0.12% bifenthrin, 0.19% permethrin, and 2.0% carbaryl spray treatments had lower attack rates compared with the control, the two systemics, or the 0.03% bifenthrin spray (Fig. 2).

Ips calligraphus (Germar), *Ips lecontei* Swain, and *Ips pini* (Say) were found successfully reproducing in the experimental bolts. *I. pini* brood production was observed in the control, and each of the insecticide treatments. We noted that five of 198 bolts (≈2.5%) had both *I. pini* and *I. lecontei* brood production together in a single bolt, and one bolt had all three *Ips* species reproducing together in a single bolt.

2004 Experiment. In the 2004 study, only 56% of the control bolts in cohort 1 were attacked by *Ips* beetles (Table 2A). Therefore, cohort 1 treatments did not experience the ≥60% attack pressure required to produce a rigorous test of the treatments, so the data were not analyzed with binomial tests. However, we did compute 95% CIs for the observed protection rates (Fig. 3A); the patterns indicated all four of the spray formulations provided better protection than the control. Data on the number of attacks per bolt reflected this same pattern (Fig. 4A).

A rigorous test of the treatments did occur in cohort 2; 79.2% of the control bolts were recorded as treatment failures (Table 2B). Only the 1.0% carbaryl treatment provided ≥90% protection ($P = 0.500$), whereas the 0.19% permethrin treatment had ≥80% protection ($P = 0.084$), and the 0.06% bifenthrin spray had ≥70% protection ($P = 0.331$). The 0.03% bifenthrin treatment had an observed protection rate of only 45.8%, which did not seem to be any better than the control (Table 2B). However, the other three spray treatments did seem to provide more protection than the control. Alternatively, the data in Fig. 4B indicate that all four treatments had lower attack rates compared with the control. One of the control bolts and one of the 0.03% bifenthrin bolts were most likely removed from the study site by vandals.

In the third cohort, 10 of the 16 control bolts (62.5%) were attacked by *Ips* beetles, thus meeting the criteria for a rigorous test (Table 2C). Both the 0.06% bifenthrin and the 0.19% permethrin sprays provided ≥90% protection ($P \geq 0.620$), which was clearly superior to the control (Fig. 3C). Although the 0.03% bifenthrin and 1.0% carbaryl treatments had ≥80% protection ($P \geq 0.132$), this did not seem to be higher than the control based on the 95% CIs. This result is at least partly because the confidence interval for the control in cohort 3 was quite large due to the small sample size of only 16 bolts. Data on the number of exit holes per bolt showed a similar pattern (Fig. 4C).

I. calligraphus and *I. pini* had successful reproduction in both cohorts 1 and 2. In addition, *I. lecontei* brood were produced in cohort 1. We found extensive damage to the phloem from woodborer larvae (Coleoptera: Cerambycidae) in the control bolts for cohort 2, including damage to the bark beetle galleries; less severe woodborer damage also occurred in all of the spray treatment bolts for cohort 2. The *Ips* beetles in cohort 3 could not be identified to species level because adults had already emerged by the time we destructively sampled the bolts.

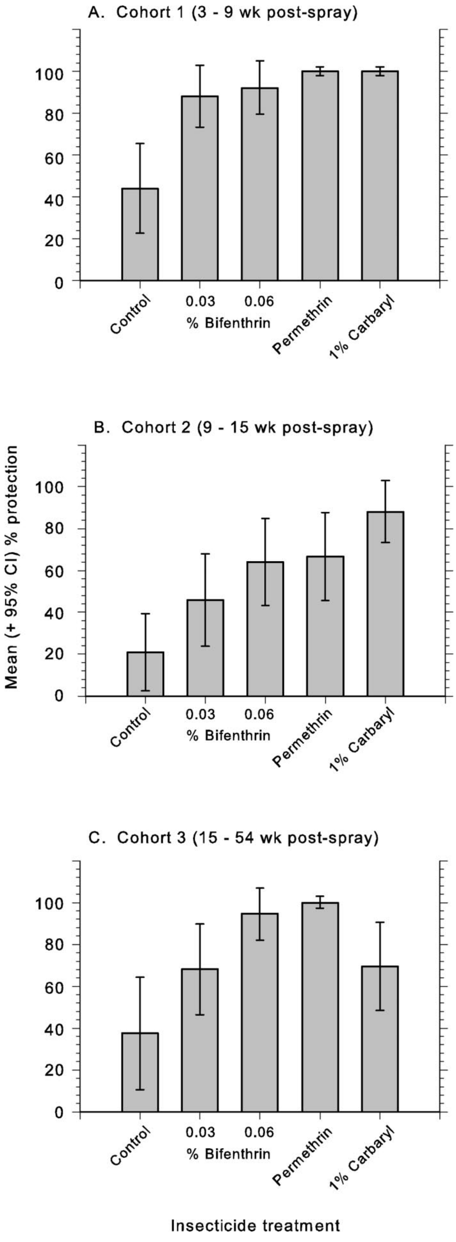

Fig. 3. Mean ± 95% CI percentage protection of ponderosa pine bolts from *Ips* bark beetle attack for spray formulations of four insecticide treatments (0.03 and 0.06% bifenthrin, 0.19% permethrin, and 1% carbaryl), plus an untreated control. Results are shown for three cohorts of pine bolts exposed to *Ips* beetle attack for periods of time from 3 to 9 wk (A), 9 to 15 wk (B), or 15 to 54 wk (C) after the insecticide sprays were applied. See Table 2 for binomial test results and other details.

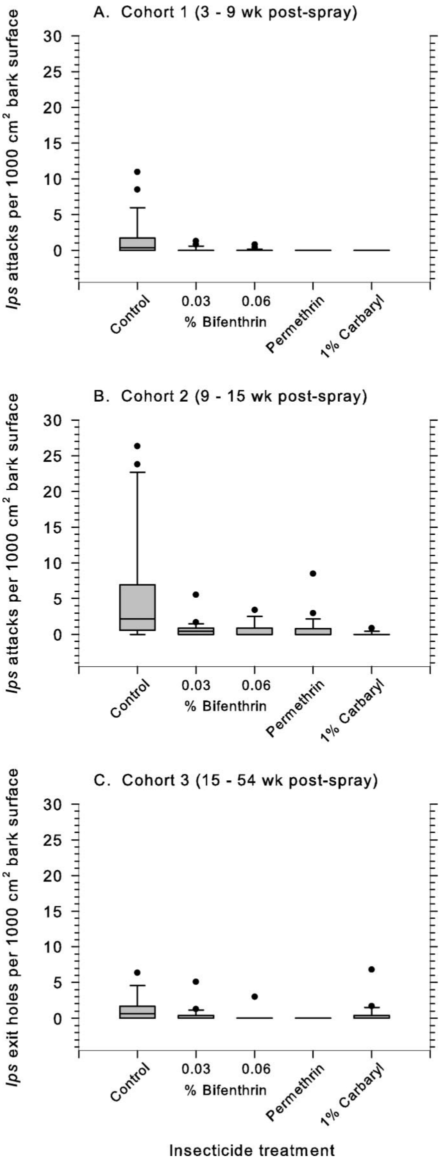

Fig. 4. Box plots comparing variation in *Ips* beetle attack pressure per pine bolt among the four insecticide treatments described in Fig. 3, plus an untreated control. See Fig. 2 for interpretation of the box plot format. The median line is equivalent to the 25th percentile for the following treatments: 0.03% bifenthrin (A and C), 0.06% bifenthrin (A–C), 0.19% permethrin (B), and 1% carbaryl (B and C). There were no attacks on the 0.19% permethrin (A and C) or 1% carbaryl (A) bolts. See Table 2 for details.

Discussion

We think our insecticide tests were very rigorous because tree defenses were absent in the treatment bolts, and *Ips* beetles have a strong preference for infesting fresh pine slash. Nonetheless, questions remain regarding what level of attack on control bolts is sufficient to create a rigorous test of the insecticide treatments, and what level of *Ips* beetle attack and colonization should constitute failure of a treatment bolt, thus representing tree mortality. A more powerful test of these treatments might have been achieved by increasing the attack pressure criterion to ≥90% of the control bolts being attacked and increasing sample sizes.

Management recommendations already exist for using insecticides to protect high-value trees in recreation sites or in ornamental settings from various species of *Dendroctonus* bark beetles (Smith et al. 1977; Hall et al. 1982; McCambridge 1982; Shea et al. 1984; Shea and McGregor 1987; Haverty et al. 1996, 1998; Hastings et al. 2001). Our results suggest that the proper use of insecticides also will help prevent attack from *Ips* spp. bark beetles on ponderosa pines in the southwestern United States. Formulations of 1.0 or 2.0% carbaryl, 0.06 or 0.12% bifenthrin, and 0.19% permethrin should protect trees from a variety of *Ips* spp. for the current season, if the sprays are applied in the spring just before bark beetle flight. Furthermore, formulations of 2.0% carbaryl, 0.12% bifenthrin, and 0.19% permethrin will offer some residual protection to trees from *Ips* spp. for up to 13 mo after they are applied. We note that FMC Corporation, the manufacturer of bifenthrin (i.e., Onyx) has not labeled Onyx for use at the 0.12% level for bark beetle control.

Our results are similar to those of previous workers who tested insecticides for the protection of ponderosa pines against bark beetles. Smith et al. (1977) tested 2.0% carbaryl on bolts where they forced attacks by mountain and roundheaded (*Dendroctonus adjunctus* Blandford) pine beetles. After 3 mo, the treatment was 100% effective and after 13 mo it was 93% effective. In California, Hall et al. (1982) found that formulations of 1.0 and 2.0% carbaryl were effective for 3 mo against attacks by western pine beetle. Haverty et al. (1985) also reported that a formulation of 2.0% carbaryl as Sevin XLR applied to ponderosa pines provided effective protection against western pine beetles. Shea and McGregor (1987) determined that 1 and 2% formulations of carbaryl as Sevimol and Sevin XLR protected ponderosa pines from mountain pine beetle attack for two flight seasons and that 0.5% formulations were effective for one season. Shea et al. (1984) established that a 2.0% solution of permethrin (without added cellulose) provided excellent protection against western pine beetle attack on ponderosa pine in California for one summer. This body of work, along with our study, supports the effectiveness of carbaryl and permethrin as preventative treatments against both *Ips* and *Dendroctonus* bark beetles when applied properly.

Our results may have economic implications for choosing which insecticide to use, given that the base cost of using these insecticides is highly variable. In our study, we sprayed ≈26 liters of mixed insecticide on individual trees with an average dbh of ≈26.5 cm and height of 25 m. The cost per tree of the insecticide varied from $3.60 for the 0.19% permethrin (with cellulose additive) to $10.80 for the 0.06% bifenthrin and $14.00 for the 2.0% carbaryl. The permethrin was one-third the cost of the 0.06% bifenthrin and one-quarter the cost of the 2.0% carbaryl. We assume that permethrin products without the cellulose additive, which are labeled for bark beetle control, would have an effectiveness similar to the Permethrin Plus C that we tested, for virtually the same cost per tree. Because there are many products available that contain carbaryl or permethrin, we caution against using products that are not specifically formulated and labeled for protection against bark beetles, because they will be ineffective and economically disappointing.

The failure of both the acephate and dinotefuran systemic formulations in protecting treatment bolts 1 yr posttreatment is further evidence that these products are not useful against phloem feeding insects. These insecticides are placed in the xylem, which may account for their ineffectiveness against bark beetles that feed in the phloem. The claimed successful use of Acecap by certified applicators and others might suggest that the trees treated were not actually under mass attack from bark beetles.

The ability to use insecticides to protect high-value trees is an important management tool in urban, recreational, and ornamental forestry settings; however, it is not appropriate for wide-scale use within natural forests. We recommend that appropriate silvicultural treatments be used to increase individual tree resistance to attack by bark beetles. Practices such as reducing basal area within stands have been shown to increase resin production, which can lead to improved bark beetle resistance in trees (Kolb et al. 1998). These types of silvicultural treatments are much more practical on a forest wide level for the prevention of bark beetle attacks than using insecticides.

Last, we discuss some of the challenges we faced applying the methods developed by others for *Dendroctonus* spp. to *Ips* spp. Shea et al. (1984) and Haverty et al. (1998) prescribed spraying live healthy trees and then applying pheromones to attract *Dendroctonus* spp. bark beetles to the trees and thus ensure the sprayed trees are challenged. However, the *I. pini* attractant pheromones used in our 2003 preliminary study (ispdienol +0.03/−0.97 and lanierone) were ineffective at challenging the control trees. Therefore, we decided to test the efficacy of preventative spray and systemic implant treatments on fresh ponderosa pine bolts, which *Ips* species are known to infest without the aid of aggregation pheromones. Thus, we felled our 2003 trees, cut them into bolts, and then moved the bolts to set up the randomized block design. Unfortunately, we lost some of the bark while transporting the bolts. This loss of bark, with the insecticides that were sprayed on it, may have contributed to the high attack rates we observed in the 2003–2004 experiment spray treatments.

The cloth bags we used to prevent beetle attack on the cohort 2 and 3 bolts in the 2004 experiment presented another problem. From 9 July to 17 August 2004, while the cohort 2 bolts were being attacked by cerambycids, 20.8% of the 125 bags that were intended to protect cohort 3 from bark beetle attack experienced enough damage that we removed the bolts from the study. Many of the bolts with torn bags were infested with cerambycids; this may have attracted birds to those bolts to feed upon the woodborer larvae, and in the process the birds tore the bags open. Nine of the 26 bags destroyed were on control bolts, implying that the insecticide treated bolts may have prevented more extensive cerambycid attack. This problem could be avoided in the future by constructing the protective bags out of metal screening instead of the cloth mosquito netting we used.

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