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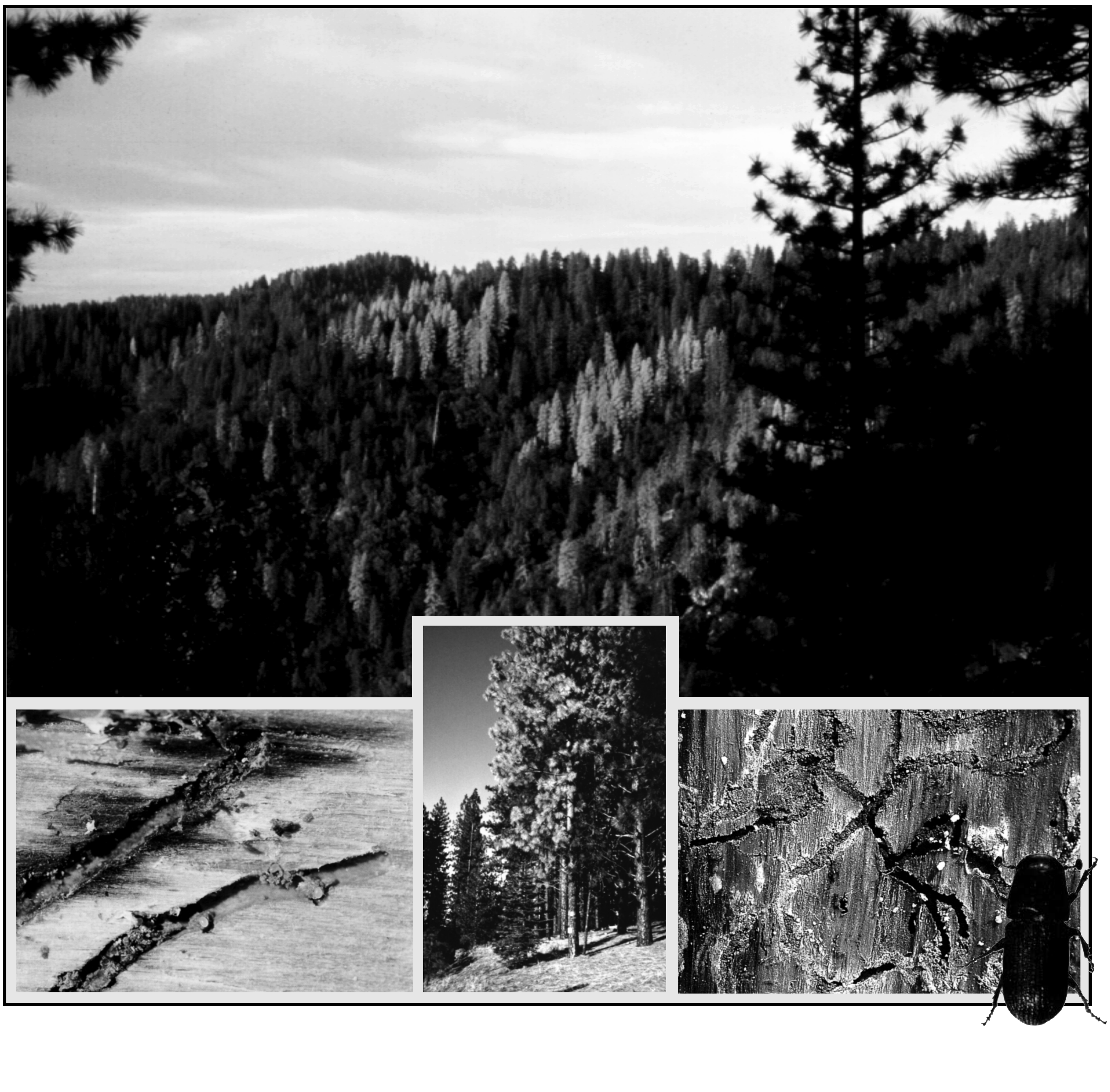
Effectiveness of Esfenvalerate, Cyfluthrin, and Carbaryl in Protecting Individual Lodgepole Pines and Ponderosa Pines from Attack by *Dendroctonus* spp.

Michael I. Haverty **Patrick J. Shea** **James T. Hoffman**
John M. Wenz **Kenneth E. Gibson**



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Abstract

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The effectiveness of registered and experimental application rates of insecticides esfenvalerate (Asana XL), cyfluthrin (Tempo WP and Tempo 2), and carbaryl (Sevimol and Sevin SL) was assessed for protection of individual high-value lodgepole pines from mountain pine beetles in Montana and ponderosa pines from western pine beetles in Idaho and California. This field test was conducted on the Deerlodge National Forest in Montana, the Boise National Forest in Idaho, and the Eldorado National Forest in California. The boles of the trees were treated with a candidate insecticide treatment to a height of about 10 m, the surface likely to be attacked by the bark beetles. To challenge the treatments, beetle attack densities were enhanced by using aggregation pheromones of the appropriate *Dendroctonus* species. One application of esfenvalerate at 0.025 percent protected lodgepole pines from mountain pine beetle for one summer, but not a second summer. Cyfluthrin applied once at 0.025 percent protected lodgepole pines for one summer and at 0.05 percent was effective for a second summer. One application of either carbaryl formulation at 1 percent protected lodgepole pines for two summers. Esfenvalerate at 0.012 percent protected ponderosa pines in Idaho for one summer; however, one application of esfenvalerate at 0.025 percent was ineffective in protecting trees for a second summer. A single application of cyfluthrin at 0.025 percent was effective for one summer, whereas a similar treatment with 0.1 percent cyfluthrin, in either the Tempo WP or Tempo 2 formulations, was effective for 16 months or two summers. One treatment with carbaryl at 2 percent was effective for the 4 summer months; only the Sevin SL formulation appeared to be effective for the second summer in Idaho. Esfenvalerate was applied once at 0.025 percent and 0.05 percent in California and protected ponderosa pines from western pine beetles for a full summer. Neither esfenvalerate treatment was effective for a second summer. Cyfluthrin was applied to ponderosa pines in California at the reduced concentrations of 0.0028 percent, 0.008 percent, and 0.025 percent. None of these treatments protected these trees from induced attack by western pine beetle for one summer.

Retrieval Terms: bark beetles, insecticides, lodgepole pine, ponderosa pine, tree protection

The Authors

Michael I. Haverty and **Patrick J. Shea** are chief research entomologist and principal research entomologist, respectively, in the Station's Chemical Ecology of Western Forest Insects research unit headquartered at 800 Buchanan Street, Albany, CA 94710 (P.O. Box 245, Berkeley, CA 94701). **James T. Hoffman** is a forest pathologist with the Intermountain Region's Forest Health Protection Staff and is stationed at the Boise Field Office, 1249 S. Vinnell Way, Boise, ID 83709. **John M. Wenz** is a forest entomologist with the Pacific Southwest Region's Forest Health Protection Staff and is stationed at the Stanislaus National Forest, 19777 Greenley Road, Sonora, CA 95370. **Kenneth E. Gibson** is a forest entomologist with the Northern Region's Forest Health Protection Staff and is stationed at the Regional Office, 200 East Broadway, Missoula, MT 59807.

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Pesticide Precautionary Statement

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In Brief

Haverty, Michael I.; Shea, Patrick J.; Hoffman, James T.; Wenz, John M.; Gibson, Kenneth E. 1998. **Effectiveness of esfenvalerate, cyfluthrin, and carbaryl in protecting individual lodgepole pines and ponderosa pines from attack by *Dendroctonus* spp.** Res. Paper PSW-RP-237. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 12 p.

Bark beetles are responsible for extensive mortality among many conifers throughout North America. Two species, the mountain pine beetle (*Dendroctonus ponderosae* Hopkins) and the western pine beetle (*D. brevicomis* LeConte) cause extensive mortality in most locations where they occur. Regardless of landowner objectives, tree losses generally have a catastrophic impact. The value of a mountain home may be severely reduced by loss of shade and ornamental trees. Mortality of trees in campgrounds or other administrative sites can have long-range management effects. Land managers have few options for direct interventions to manage pine bark beetle infestations. Pine bark beetles can be prevented from successfully attacking individual trees by the application of chemical insecticides to the bole of the tree.

In 1989, only two formulations of carbaryl (Sevin SL and Sevimol), lindane, and injected metasystox-R were registered for protection of lodgepole pines from the mountain pine beetle and ponderosa pine from the western pine beetle. Lindane remains a controversial insecticide and is not likely to be used on federally managed Forest Service property. Metasystox-R has been shown to be ineffective in protecting ponderosa pine from western pine beetle. If the registration for carbaryl were suspended or canceled, or if the manufacturer decided to no longer support registration for this use, the public would be without effective, registered insecticides for tree protection. This study was performed to evaluate two synthetic pyrethroid insecticides, esfenvalerate and cyfluthrin, for protection of individual pines from attack by either the mountain pine beetle or the western pine beetle. The objective of this study was to define the effective concentrations of esfenvalerate and cyfluthrin for one or more seasons of protection of high-value pines.

Three separate evaluations of esfenvalerate and cyfluthrin were conducted, one each in Montana, Idaho, and California. In the Montana and Idaho tests, we evaluated the Sevin SL formulation of carbaryl. In the California test we adjusted the concentrations. In Montana we tested esfenvalerate at 0.006, 0.012, and 0.025 percent (Asana XL Insecticide), cyfluthrin at 0.025, 0.05, and 0.1 percent (Tempo 20WP Ornamental Insecticide), and two formulations of carbaryl at 1 percent (Sevimol and Sevin SL). In Idaho we used the same concentrations and formulations of esfenvalerate and cyfluthrin as we used in Montana. We added 0.1 percent cyfluthrin (Tempo 2), and increased the concentration of Sevimol and Sevin SL to 2 percent. In California we tested 0.025 percent and 0.05 percent esfenvalerate and 0.0028, 0.008, and 0.025 percent cyfluthrin. Insecticides were applied with a truck-mounted or trailer-mounted hydraulic sprayer, which allowed us to treat the entire bole of each tree to a height of at least 10 m.

To test the effectiveness of the insecticide treatments against mountain pine beetle, we enhanced the attack densities by attaching mountain pine beetle aggregation pheromone (*trans*-verbenol, frontalin) on the bole of each tree. To test the effectiveness of the insecticides against western pine beetle in Idaho, all test trees were baited with western pine beetle aggregation pheromone (*exo*-brevicomin, frontalin, and myrcene). Each insecticide treatment was applied to 30 to 35 randomly assigned pine trees. The only criterion used to determine the effectiveness of the insecticide treatment was whether individual trees succumbed to attack by mountain pine beetle or western pine beetle. Insecticide treatments were considered efficacious if fewer than seven treated trees died as a result of bark beetle attack.

Esfenvalerate at 0.006 percent and 0.012 percent was not judged to be effective in protecting lodgepole pine from mountain pine beetle attack in Montana. In contrast, 0.025 percent esfenvalerate was effective for protecting lodgepole pines for the season immediately after treatment, but did not provide adequate protection for the second summer. All three of the cyfluthrin and both of the carbaryl treatments were highly effective in protecting lodgepole pines from mountain pine beetle attack. All of the cyfluthrin and both of the carbaryl treatments remained effective for a second season.

All treatments appeared to be effective in protecting ponderosa pine in Idaho from western pine beetles when challenged immediately after insecticide application. When challenged 3 months after treatment, the 0.006 percent esfenvalerate treatment was ineffective. The other esfenvalerate treatments were effective for a full summer. One year after treatment, all of the esfenvalerate treatments were not effective. All three of the cyfluthrin and both of the carbaryl treatments were effective for 3 months. The lowest cyfluthrin treatment (0.025 percent) was ineffective in protecting ponderosa pine beyond the summer of application, whereas the other concentrations remained effective. The carbaryl treatments remained effective one year after application. Fifteen months after application, 0.1 percent cyfluthrin and 2 percent Sevin SL remained effective, whereas the 2 percent Sevimol treatment did not.

Because of the results from our tests in Montana and Idaho, we decided to increase the concentrations of esfenvalerate and decrease the concentrations of cyfluthrin for our test in California. Both esfenvalerate treatments (0.025 and 0.05 percent) and all of the cyfluthrin treatments (0.0028, 0.008, and 0.025 percent) proved to be effective immediately after treatment. Four months after treatment, both of the esfenvalerate treatments remained effective, whereas all of the cyfluthrin treatments were not. Fourteen months after treatment, all esfenvalerate treatments were ineffective. Clearly none of the treatments tested in California are likely to provide protection for a second season; only the two esfenvalerate treatments (0.025 and 0.05 percent) can provide adequate protection for a full summer.

Presently, the only tactic available to pest managers to protect individual trees from lethal attack by bark beetles is to spray the bole of targeted trees with insecticides to kill attacking beetles before they penetrate to the phloem and trigger a mass attack. This study extends our knowledge about the persistence and efficacy of a known insecticide (carbaryl) as a preventative treatment and establishes the efficacy of additional insecticides (cyfluthrin and esfenvalerate). Pest and land managers and private property owners should take the results of this and similar experiments and combine them with information on the pesticide labels, application and handling, safety, environmental considerations, and cost information to make informed decisions regarding protection of individual lodgepole or ponderosa pines from attack by mountain pine beetles or western pine beetles.

Retrieval Terms: bark beetles, insecticides, lodgepole pine, ponderosa pine, tree protection

Introduction

Bark beetles are responsible for extensive mortality among many conifers throughout North America. Two species, the mountain pine beetle (*Dendroctonus ponderosae* Hopkins) and the western pine beetle (*D. brevicomis* LeConte), are of particular interest because they occur in cyclical outbreaks or epidemics and cause extensive mortality in most locations where they occur.

The mountain pine beetle is a native insect that causes extensive mortality throughout the lodgepole (*Pinus contorta* Dougl.) ecosystem of the western United States and Canada (Amman and others 1977, McGregor and Cole 1985, Safranyik and others 1974). Although lodgepole pine appears to be the preferred host of mountain pine beetle, this insect can attack at least 13 species of pine (Furniss and Carolin 1977, Wood 1963). This beetle attacks and kills proportionately more large-diameter than small-diameter trees and, in each year of an infestation, kills the largest-diameter trees of those remaining (Amman and Cole 1983, Amman and others 1985, Cole and Amman 1969). Infestations generally subside as suitable host trees become depleted (Amman 1977).

During epidemics, millions of trees are killed, accounting for the loss of billions of board feet of timber (Cole and Amman 1980) and degradation of wildlife habitat (Lyon 1976, Shea and McGregor 1987, Wellner 1978). A recent outbreak of the mountain pine beetle in the western United States covered 4.5 million acres of lodgepole pine type, and infestations severely affected such resource values as timber, watershed, wildlife, range, and recreation (Loomis and others 1985). In addition to extensive stand mortality, the mountain pine beetle can have devastating effects on other forest amenities, such as campgrounds, picnic areas, visitor centers, and permanent and summer home sites.

The western pine beetle is the most serious insect pest of ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) in the western United States (Stark and Dahlsten 1970). Severe droughts, such as those in California from 1975 to 1977 and from 1988 to 1993, are accompanied by excessive mortality of ponderosa pines in managed and unmanaged stands as a result of attacks by several bark beetle species, especially the western pine beetle. As in the case with the mountain pine beetle, mortality of high-value trees located in residential and recreational areas or administrative sites can occur as a result of stress associated with drought, overcrowding, soil compaction, or injury due to construction, logging activity, fire, or vandalism (Shea and McGregor 1987).

Regardless of landowner objectives, tree losses generally have a catastrophic impact, except in firewood production. For example, the value of a mountain home may be severely reduced by mortality of shade and ornamental trees (McGregor and Cole 1985). Mortality of trees located in campgrounds or other administrative sites can have long-range management effects. The value of these individual trees, the cost of removal, and the loss of esthetic values in campgrounds or in private residences may justify protecting individual trees until the main thrust of an infestation subsides or the conditions causing the stress abate. This situation emphasizes the need for assuring that effective insecticides are available for individual tree protection.

Past attempts to suppress epidemics of mountain pine beetle with chemical insecticides have been unsuccessful (Klein 1978). Recent research indicates that land managers have few options for direct interventions to manage mountain pine beetle infestations on large or small tracts of land. At present, the same situation exists for area-wide control of the western pine beetle. Mountain pine beetle and western pine beetle can be prevented from successfully attacking individual trees by the application of chemical insecticides to the bole of the tree.

Several formulations of carbaryl have been evaluated and found effective for protection of individual trees from attack by bark beetles. The effectiveness and residual life of 1 percent and 2 percent suspensions of carbaryl (in the Sevimol[1] formulation) for preventing successful attack of ponderosa pine by western pine beetle have been demonstrated (Hall and others 1982, Haverty and others 1985). The effectiveness and residual life of a 2 percent suspension of the same formulation of carbaryl was confirmed for protecting lodgepole pine from attack by mountain pine beetle (Gibson and Bennet 1985). These and other studies (McCambridge 1982, Smith and others 1977) led to registration of 2 percent Sevimol as a preventative spray.

Evaluation of an additional formulation of carbaryl revealed that both Sevimol and Sevin XLR formulations provided excellent protection (≥90 percent survival) of lodgepole pine from mountain pine beetle for one season at 0.5 percent, one fourth the registered rate (Shea and McGregor 1987). Furthermore, a 1 percent suspension of either formulation provided very good protection (≥80 percent survival) for two seasons, while 2 percent provided excellent protection (≥90 percent survival) for two seasons. A 2 percent carbaryl formulation (Sevimol) was empirically shown to provide excellent

[1] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

protection of lodgepole pine from attack by mountain pine beetle in high elevations (ca. 3,000 m) in the Rocky Mountains of Colorado (Page and others 1985).

In 1989, only two formulations of carbaryl, Sevin SL and Sevimol, lindane, and injected metasystox-R were registered for protection of lodgepole pines from the mountain pine beetle and ponderosa pine from the western pine beetle. Lindane remains a controversial insecticide (Koerber 1976) and is not likely to be used on federally managed Forest Service property. Metasystox-R has been shown to be ineffective in protecting ponderosa pine from western pine beetle (Haverty and others 1997). If the registration for carbaryl were suspended or canceled, or if the manufacturer decided to no longer support registration for this use, the public would be without effective, registered insecticides for tree protection.

Given the uncertain future availability of any commercial insecticide, we felt it important to develop alternative insecticides for this important use in forestry. This study was performed to evaluate two synthetic pyrethroid insecticides for protection of individual pines from attack by either the mountain pine beetle or the western pine beetle. Pyrethroid insecticides offer an excellent alternative to lindane and carbaryl. They cause few environmental disruptions, except for their high toxicity to cold-blooded vertebrates and aquatic invertebrates. Generally, pyrethroids have low toxicity to mammals and require very small quantities to control insects. We selected esfenvalerate and cyfluthrin to test for efficacy against mountain pine beetle and western pine beetle to protect individual, high-value lodgepole or ponderosa pines because the former was registered for use in forestry and the latter had potential for control of pests of ornamentals.

There are no published reports of efficacy of either of these insecticides against pine bark beetles. Esfenvalerate (Asana XL Insecticide) is the S-isomer of fenvalerate (Pydrin); fenvalerate has been shown in laboratory and field tests to be about as toxic as permethrin to another scolytid, the mountain pine cone beetle (*Conophthorus ponderosae* Hopkins) (Haverty and Wood 1981, Shea and others 1984b). In laboratory and cut-bolt bioassays, permethrin also has been shown to be more toxic than lindane to the western pine beetle and the southern pine beetle (*D. frontalis* Zimmerman) (Hastings and Jones 1976, Hastings and others 1981, Smith 1982). Three rates of permethrin were evaluated for protection of ponderosa pine from western pine beetle; 0.2 percent and 0.4 percent provided excellent protection for at least one summer (about 4 months), but would not last through the second field season (about 15 months) (Shea and others 1984a). On the basis of comparative toxicities against other Coleoptera, especially scolytids, and the greater residual life of esfenvalerate and cyfluthrin, we expected these insecticides to provide protection from mountain pine beetle and western pine beetle for the full summer season.

The objective of this study was to define the effective and ineffective concentrations of esfenvalerate and cyfluthrin for use in protection of high-value pines from attack by either mountain pine beetle or western pine beetle. Esfenvalerate (Asana XL Insecticide) is currently registered for several uses in forestry. Cyfluthrin (Tempo 20WP Insecticide) is registered for control of pests of ornamentals and structures/dwellings. If registered, these additional treatments will provide forest pest control specialists, land managers, and private citizens with cost-effective and reasonably safe alternatives to lindane or carbaryl. In addition, we evaluated the registered rate of a previously untested formulation of carbaryl, Sevin SL, and reassessed the efficacy of Sevimol. Sevimol was included as a "positive control."

Methods

Three separate evaluations of esfenvalerate and cyfluthrin were conducted, in succession, in Montana (1989), Idaho (1989), and California (1990). In the Montana and Idaho tests, we evaluated the Sevin SL formulation of carbaryl. In the California test we adjusted the concentrations used previously and the number of treatments.

In Montana, the test was conducted on the Jefferson Ranger District of the Deerlodge National Forest located in western Montana. In Idaho, the test was conducted on the Boise Basin Experimental Forest of the Boise National Forest and adjacent property managed by the Idaho Department of Lands, and by Boise Cascade Corporation. In California, the test was conducted on the western slope of the Sierra Nevada between 750 and 1,700 m elevation on the Placerville and Amador Ranger Districts of the Eldorado National Forest in central California.

Insecticide Treatments

In the Montana test there were 10 treatments: esfenvalerate at 0.006, 0.012, and 0.025 percent (Asana XL Insecticide, E.I. du Pont du Nemours & Co.); cyfluthrin at 0.025, 0.05, and 0.1 percent (Tempo 20WP Ornamental Insecticide, Mobay Corp.); carbaryl at 1 percent (for both the Sevimol and Sevin SL formulations, Union Carbide Corp.); and two separate unsprayed controls, one to assess beetle pressure immediately after treatment and one to assess beetle pressure one year later (*table 1*).

In the Idaho test there were 13 treatments. We used the same concentrations and formulations of esfenvalerate (0.006, 0.012, and 0.025 percent Asana XL) and cyfluthrin (0.025, 0.05, and 0.1 percent Tempo 20WP) as we used in Montana. We added one concentration of the emulsifiable concentrate formulation of cyfluthrin (0.1 percent Tempo 2), and increased the concentration of Sevimol and Sevin SL to 2 percent. We established a separate unsprayed control for two baitings in each of 2 years (*table 1*).

In the California test there were eight treatments. We eliminated the two lower concentrations and added one higher concentration of esfenvalerate; the two concentrations that we used were 0.025 percent and 0.05 percent (Asana XL). We eliminated the two higher concentrations of cyfluthrin and added two lower concentrations; the concentrations tested in California were 0.0028, 0.008, and 0.025 percent (Tempo 20WP). No carbaryl or "positive control" was included in the California test (*table 1*). There was a separate unsprayed control for two pheromone baitings in 1990 and one baiting in 1991.

All insecticides were formulated in water buffered to pH 5. In Montana, sprays were applied to lodgepole pines during the second week of June 1989, about 2 to 3 weeks before flight of the mountain pine beetle. In Idaho, treatments were applied June 19 to 26, 1989, and in California from May 8 to 15, 1990, about 2 to 3 weeks before the second flight of the western pine beetle. Insecticides were applied with a truck-mounted or trailer-mounted FMC Bean hydraulic sprayer (≈300 psi), which allowed us to treat the entire bole of each tree until runoff to a height of at least 10 m. This application technique has been shown to result in at least 80 percent of the insecticide being applied to the bole of the tree (Haverty and others 1983). About 8 to 15 liters of formulated material were required per tree. All treatments were applied between 0600 and ca. 1100 when winds were minimal.

Experimental Design and Treatment Evaluation

In Montana, test trees were located in an area with heavy mountain pine beetle activity and isolated from other sample trees by at least 100 m. This was done to ensure that there would be a sufficient beetle population in the vicinity of each tree to rigorously test the effectiveness of treatments. Trees selected were 20 to 50 cm dbh (diameter breast height), 80 to 110 years old, and within 75 m of an access road to facilitate treatment.

In Idaho and California, sample trees were ponderosa pine, 28 to 52 cm dbh. Trees were also selected so that they were within 75 m of an access road to facilitate treatment. The spacing between

Table 1*—Insecticide treatments evaluated for protection of lodgepole pine from attack by the mountain pine beetle in Montana and protection of ponderosa pine from attack by the western pine beetle in Idaho and California.*

Treatment	Montana	Idaho	California
Esfenvalerate (Asana XL)			
0.006 pct	X	X	
0.012 pct	X	X	
0.025 pct	X	X	X
0.05 pct			X
Cyfluthrin (Tempo 20WP)			
0.0028 pct			X
0.008 pct			X
0.025 pct	X	X	X
0.05 pct	X	X	
0.1 pct	X	X	
Cyfluthrin (Tempo 2)			
0.1 pct		X	
Carbaryl (Sevimol)			
1 pct	X		
2 pct		X	
Carbaryl (Sevin SL)			
1 pct	X		
2 pct		X	
Untreated controls[1]	2	4	3

[1]The number of groups of 30 to 35 trees that served as the untreated treatment for each baiting period.

trees, no less than 400 m, was selected to ensure that a sufficient number of western pine beetles would be in the vicinity of each tree to rigorously test the efficacy of the treatments (Hall and others 1982, Haverty and others 1985, Shea and others 1984a).

To test the effectiveness of the insecticide treatments against mountain pine beetle, we enhanced the attack densities by attaching mountain pine beetle aggregation pheromone (*trans*-verbenol, frontalin; MPB Tree Bait; PHEROTECH, Inc.) on the bole of each tree, 2 m above the ground. Baits were left on the trees for the entire summer and were removed at the time of the first treatment evaluation. To test the effectiveness of the insecticides against western pine beetle in Idaho, all test trees were baited with western pine beetle aggregation pheromone (*exo*-brevicomin, frontalin, and myrcene; WPB Tree Bait; PHEROTECH, Inc.) for 2 weeks in July and for 4 weeks in September 1989, and the surviving treated trees and check trees were baited again, for the same length of time, in July and September 1990. In California, trees were baited with WPB Tree Bait in May and September 1990; the surviving treated trees and untreated check trees were baited again in July 1991. Baits remained on the trees for 4 weeks in May and for only one week in September. Untreated check trees were monitored every week. If ≥60 percent of these trees showed signs of successful attack, i.e. boring dust in bark crevices, the pheromone baits were removed from all trees.

Each insecticide treatment was applied to 30 to 35 randomly assigned pine trees; a similar number of trees was used in each of the untreated checks. During the course of the experiment, several trees were lost because of road building, wood cutting, logging, fire, or top-killing by *Ips* (Hall and others 1982, Haverty and others 1985, Shea and McGregor 1987, Shea and others 1984a). These trees were deleted from the analysis; our goal was to have at least 30 trees/treatment at the end of the experiment. Thus, sample sizes were not always equal among all treatments.

The only criterion used to determine the effectiveness of the insecticide treatment was whether individual trees succumbed to attack by mountain pine beetle or western pine beetle (Hall and others 1982, Haverty and others 1985, Shea and McGregor 1987, Shea and others 1984a). Tree mortality was assessed in August 1989 (ID), September 1989 (MT), October 1989 (ID), August 1990 (MT & ID), September 1990 (CA), October 1990 (ID), January 1991 (CA), and November 1991 (CA). The presence of mountain pine beetle galleries and pitch tubes was verified in each lodgepole pine tree for it to be considered successfully attacked. The period between pheromone removal and mortality assessment was sufficient for ponderosa pines to "fade," an irreversible symptom of pending mortality. Presence of western pine beetle galleries was verified in each tree counted as dead or dying.

Treatments were considered to have sufficient beetle pressure if at least 60 percent of the untreated control trees died after attack by beetles. Insecticide treatments were considered efficacious if fewer

***Table 2**—Effectiveness of two pyrethroid insecticides, esfenvalerate and cyfluthrin, and two formulations of carbaryl for preventing lodgepole pine mortality resulting from attack by mountain pine beetle in Montana immediately after treatment.[1]*

		No attack[2]		Pitch out and strip attack[3,4]		Dead[5]	
Treatment[6]	N[7]	n	pct	n	pct	n	pct
Esfenvalerate							
0.006 pct	35	6	17.1	7	20.0	22	62.9
0.012 pct	35	15	42.9	9	25.7	11	31.4
0.025 pct	35	28	80.0	5	14.3	2	5.7
Cyfluthrin							
0.025 pct	30	30	100.0	0	0.0	0	0.0
0.05 pct	35	35	100.0	0	0.0	0	0.0
0.1 pct	31	31	100.0	0	0.0	0	0.0
Carbaryl							
1.0 pct Sevimol	35	34	97.1	1	2.9	0	0.0
1.0 pct Sevin SL	35	34	97.1	1	2.9	0	0.0
Untreated	35	4	11.4	8	22.8	23	65.7

[1] Trees were treated during the period of June 12 to 14, 1989. The baits were on the trees from June 14, 1989, through the beetle flight period (early September 1989). Mortality was assessed on August or September 5 to 7, 1989.
[2] Trees with no evidence of attack by mountain pine beetle.
[3] Trees with evidence of attack by mountain pine beetle, but no beetles were successful. All invading adults were pitched out.
[4] A portion of the tree was inadequately treated, and there was sccessful attack along a strip of bark that was apparently not protected by the insecticide.
[5] Trees that were successfully attacked and showed evidence of infestation by mountain pine beetle parent adults.
[6] Esfenvalerate in Asana XL and cyfluthrin in Tempo 20WP formulations.
[7] Number of trees in the sample.

than seven treated trees died as a result of bark beetle attack. These criteria were established on the basis of a sample size of 30 to 35 trees/treatment and the test of the null hypothesis, H_0:S (survival ≥90 percent). These parameters provide a conservative binomial test ($\alpha = 0.05$) to reject H_0 when more than six trees die. The power of this test, that is, the probability of having made the correct decision in rejecting H_0, is 0.84 when the true protection rate is 70 percent. On the basis of consideration of the above error rate, we will fail to reject the null hypothesis (90 percent survival) for any treatment in which no more than six out of 30 trees die as a result of bark beetle attack (Shea and others 1984a).

Results and Discussion

Montana: Mountain Pine Beetle vs. Lodgepole Pine

Treated trees were evaluated over a 2-year period. Treatments were challenged during each of the two mountain pine beetle flight periods after treatment. Beetle pressure was sufficient to adequately challenge the treatments both years; 65.7 percent of the untreated trees succumbed to attack by the beetles responding to the aggregation pheromone during the first season (*table 2*), and 70.6 percent were successfully attacked during the second season (*table 3*).

The two lower concentrations of esfenvalerate (0.006 percent and 0.012 percent) were not judged to be effective in protecting lodgepole pine from mountain pine beetle attack. After the first baiting, 22 and 11 trees, respectively, were successfully attacked, exceeding the threshold of six dead trees for a successful treatment. In contrast, only two of the trees treated with the 0.025 percent treatment were successfully attacked by mountain pine beetles (*table 2*). This treatment is considered effective for protecting lodgepole pines for the season immediately after treatment.

All three of the cyfluthrin and both of the carbaryl treatments were highly effective in protecting lodgepole pines from mountain pine beetle attack. None of the trees in these treatments was successfully attacked when challenged shortly after treatment (*table 2*).

The one remaining esfenvalerate treatment (0.025 percent) did not provide adequate protection for the second summer. Eighteen of the remaining 30 trees were successfully attacked when baited 12 months after insecticide application (*table 3*). This significantly exceeds the allowable threshold of six dead trees to meet the criterion of 90 percent protection.

All of the cyfluthrin and both of the carbaryl treatments remained effective for a second season. No more than three trees in these treatments succumbed to mountain pine beetle attack (*table 3*). There was,

Table 3—Effectiveness of two pyrethroid insecticides, esfenvalerate and cyfluthrin, and two formulations of carbaryl for preventing mortality of lodgepole pine resulting from attack by mountain pine beetle in Montana one year after treatment.[1]

		No attack[2]		Pitch out and strip attack[3,4]		Dead[5]	
Treatment[6]	N[7]	n	pct	n	pct	n	pct
Esfenvalerate							
0.025 pct	30	1	3.3	11	36.6	18	60.0
Cyfluthrin							
0.025 pct	25	10	40.0	12	48.0	3	12.0
0.05 pct	30	19	63.3	11	36.7	0	0.0
0.1 pct	27	27	100.0	0	0.0	0	0.0
Carbaryl							
1 pct Sevimol	31	31	100.0	0	0.0	0	0.0
1 pct Sevin SL	30	17	56.7	11	36.7	2	6.7
Untreated	34	1	2.9	9	26.5	24	70.6

[1] Trees were treated during the period of June 12 to 14, 1989. The baits were on the trees in early June and were not removed until mortality was assessed in early September 1990.
[2] Trees with no evidence of attack by mountain pine beetle.
[3] Trees with evidence of attack by mountain pine beetle, but no beetles were successful. All invading adults were pitched out.
[4] A portion of the tree was inadequately treated, and there was successful attack along a strip of bark that was apparently not protected by the insecticide.
[5] Trees that were successfully attacked and showed evidence of infestation by mountain pine beetle parent adults.
[6] Esfenvalerate in Asana XL and cyfluthrin in Tempo 20WP formulations.
[7] Number of trees in the sample, excluding trees that were successfully attacked in 1989, missing (cut), or not found in 1990.

however, a tendency to display more "pitch outs" and "strip attacks" for the two lower concentrations of cyfluthrin and the Sevin SL formulation of carbaryl during the second season after treatment (*table 3*). This suggests that these treatments are on the verge of failure and would likely prove ineffective for a third season. This was not tested and is only speculation at this point.

All of the treatments received a significant challenge by mountain pine beetle over two summers, because mortality in the untreated controls exceeded the predetermined threshold of 60 percent mortality. The two lowest concentrations of esfenvalerate (0.006 percent and 0.012 percent) provided no protection; the highest concentration (0.25 percent) protected trees for the season immediately after treatment, but not for the second summer. Probably one or two higher concentrations (i.e., 0.05 percent and/or 0.1 percent) should be tested in the future to determine whether one treatment of this insecticide can provide two (or more) seasons of protection of lodgepole pine from mountain pine beetle attack.

All concentrations of cyfluthrin proved effective in protecting lodgepole pine from mountain pine beetle for two summers or two full flight seasons. After the second year, there were indications of weakening by the two lowest concentrations during the second summer. We still lack information on the concentration that does not protect lodgepole pine for either one or two seasons. Perhaps future evaluations should include the same concentrations as were tested for esfenvalerate to clearly delimit the break between effective and ineffective treatments.

The evaluation of 1 percent carbaryl corroborates the earlier findings (Page and others 1985, Shea and McGregor 1987) that this treatment provides protection of lodgepole pine from mountain pine beetle attack for two full seasons. The previously untested formulation of carbaryl, Sevin SL, provided protection similar to that of the Sevimol formulation.

Idaho: Western Pine Beetle vs. Ponderosa Pine

Treated trees were evaluated over a 2-year period. Trees were challenged with western pine beetle aggregation pheromones twice during the first year (immediately after treatment and 3 months after treatment) and twice during the second year (12 months after treatment and 15 months after treatment). Beetle pressure was sufficient to adequately challenge treatments each time. Mortality of the untreated control trees ranged from 69.4 percent to 80.6 percent (*tables 4-7*), well above our threshold requirement of 60 percent.

All treatments appeared to be effective in protecting ponderosa pine from western pine beetles when challenged immediately after insecticide application. Only two trees treated with 0.006 percent esfenvalerate died; no trees in the other treatments succumbed right after treatment (*table 4*). When challenged at the end of the first summer, 3 months after treatment, additional trees in the 0.006 percent esfenvalerate treatment were killed by western pine beetle (*table 5*). Tree mortality exceeded the threshold of 6, and thus the 0.006 percent esfenvalerate treatment should be considered ineffective for protecting ponderosa pine from western pine beetle for a full summer. The other esfenvalerate treatments appeared to be effective for a full summer.

All four of the cyfluthrin and both of the carbaryl treatments appeared to be effective in protecting ponderosa pine from western pine beetles for 3 months. Five trees in the 0.025 percent cyfluthrin treatment and four trees in the 2 percent Sevimol treatment died (*table 5*). Both of these treatments were below the threshold of six dead trees and appeared to remain effective 3 months after treatment. The other cyfluthrin treatments and the other carbaryl treatment suffered minimal or no mortality (*table 5*).

One year after treatment, all of the esfenvalerate treatments experienced mortality in excess of the threshold. Sixteen trees in the 0.006 percent treatment, seven in the 0.012 percent treatment, and 10 in the 0.025 percent treatment died when challenged one year after insecticide application (*table 6*). Thus, we would not expect any of the levels of esfenvalerate that we tested to last over a winter and protect ponderosa pines from western pine beetle attack.

The cyfluthrin treatments also showed signs of failure one year after application. Ten trees in the 0.025 percent cyfluthrin treatment, five trees in the 0.05 percent treatment, and two each in the 0.1 percent cyfluthrin treatments died when challenged one year after insecticide application (*table 6*). Thus we consider the lowest cyfluthrin concentration ineffective in protecting ponderosa pine beyond the summer of application. The other concentrations remained effective.

Mortality in the carbaryl treatments remained below the efficacy threshold. Only four trees in the 2 percent Sevimol treatment and two trees in the 2 percent Sevin SL treatment died when challenged one year after treatment (*table 6*). These carbaryl treatments appeared to remain effective one year after application.

Table 4*—Effectiveness of two pyrethroid insecticides, esfenvalerate and cyfluthrin, and two formulations of carbaryl for preventing ponderosa pine mortality resulting from attack by western pine beetle in Idaho immediately after treatment.*[1]

Treatment[4]	N[5]	No attack[2]		Dead[3]	
		n	pct	n	pct
Esfenvalerate					
0.006 pct	31	29	93.5	2	6.5
0.012 pct	28	28	100.0	0	0.0
0.025 pct	31	31	100.0	0	0.0
Cyfluthrin					
0.025 pct	30	30	100.0	0	0.0
0.05 pct	30	30	100.0	0	0.0
0.1 pct	30	30	100.0	0	0.0
0.1 pct (EC)	28	28	100.0	0	0.0
Carbaryl					
2 pct Sevimol	32	32	100.0	0	0.0
2 pct Sevin SL	29	29	100.0	0	0.0
Untreated	31	6	19.4	25	80.6

[1] Trees were treated during the period of June 19 to 26, 1989. The baits were on the trees from June 28, 1989, to July 12, 1989. Mortality was assessed from October 3 to 5, 1989.
[2] Trees with no evidence of attack by western pine beetle.
[3] Trees that were successfully attacked and showed evidence of infestation by western pine beetle parent adults.
[4] Esfenvalerate in Asana XL and cyfluthrin in Tempo 20WP with one level of Tempo 2, the emulsifiable concentrate (EC) formulation.
[5] Number of trees in the sample.

Table 5*—Effectiveness of two pyrethroid insecticides, esfenvalerate and cyfluthrin, and two formulations of carbaryl for preventing ponderosa pine mortality resulting from attack by western pine beetle in Idaho 4 months after treatment.*[1]

Treatment[4]	N[5]	No attack[2]		Dead[3]	
		n	pct	n	pct
Esfenvalerate					
0.006 pct	31	24	77.4	7	22.6
0.012 pct	28	26	92.9	2	7.1
0.025 pct	31	29	93.5	2	6.5
Cyfluthrin					
0.025 pct	30	25	83.3	5	16.7
0.05 pct	30	29	96.7	1	3.3
0.1 pct	30	30	100.0	0	0.0
0.1 pct (EC)	28	28	100.0	0	0.0
Carbaryl					
2 pct Sevimol	32	28	87.5	4	12.5
2 pct Sevin SL	29	29	100.0	0	0.0
Untreated	32	8	25.0	24	75.0

[1] Trees were treated during the period of June 19 to 26, 1989. The baits were on the trees from September 5, 1989, to October 3, 1989. Mortality was assessed from July 9 to 11, 1990.
[2] Trees with no evidence of attack by western pine beetle.
[3] Cumulative number of trees that were successfully attacked and showed evidence of infestation by western pine beetle parent adults.
[4] Esfenvalerate in Asana XL and cyfluthrin in Tempo 20WP with one level of Tempo 2, the emulsifiable concentrate (EC) formulation.
[5] Number of trees in sample.

Fifteen months after application, all esfenvalerate treatments were clearly ineffective; mortality levels in the two lowest concentrations, 61.3 percent and 64.3 percent for the 0.006 percent and 0.012 percent concentrations, respectively, approached the mortality, 69.4 percent, of the untreated control (*table 7*). The 0.1 percent cyfluthrin treatments remained effective with only four and five trees dying in each of them, whereas 12 trees in the 0.025 percent treatment and seven trees in the 0.05 percent treatment succumbed (*table 7*), exceeding the threshold level of efficacy. One of the

Table 6—Effectiveness of two pyrethroid insecticides, esfenvalerate and cyfluthrin, and two formulations of carbaryl for preventing ponderosa pine mortality resulting from attack by western pine beetle in Idaho one year after treatment.[1]

		No attack[2]		Dead[3]	
Treatment[4]	N[5]	n	pct	n	pct
Esfenvalerate					
0.006 pct	31	15	48.4	16	51.6
0.012 pct	28	21	75.0	7	25.0
0.025 pct	31	21	67.7	10	32.3
Cyfluthrin					
0.025 pct	30	20	66.7	10	33.3
0.05 pct	30	25	83.3	5	16.7
0.1 pct	30	28	93.3	2	6.7
0.1 pct (EC)	28	26	92.9	2	7.1
Carbaryl					
2 pct Sevimol	32	28	87.5	4	12.5
2 pct Sevin SL	29	27	93.1	2	6.9
Untreated	31	9	29.0	22	71.0

[1] Trees were treated during the period of June 19 to 26, 1989. The baits were on the trees from June 25, 1990, to July 9, 1990. Mortality was assessed from October 2 to 4, 1990.
[2] Trees with no evidence of attack by western pine beetle.
[3] Cumulative number of trees that were successfully attacked and showed evidence of infestation by western pine beetle parent adults.
[4] Esfenvalerate in Asana XL and cyfluthrin in Tempo 20WP with one level of Tempo 2, the emulsifiable concentrate (EC) formulation.
[5] Number of trees in the sample.

Table 7—Effectiveness of two pyrethroid insecticides, esfenvalerate and cyfluthrin, and two formulations of carbaryl for preventing ponderosa pine mortality resulting from attack by western pine beetle in Idaho 15 months after treatment.[1]

		No attack[2]		Dead[3]	
Treatment[4]	N[5]	n	pct	n	pct
Esfenvalerate					
0.006 pct	31	12	38.7	19	61.3
0.012 pct	28	10	35.7	18	64.3
0.025 pct	31	18	58.1	13	41.9
Cyfluthrin					
0.025 pct	30	18	60.0	12	40.0
0.05 pct	30	23	76.7	7	23.3
0.1 pct	30	26	86.7	4	13.3
0.1 pct (EC)	28	23	82.1	5	17.9
Carbaryl					
2 pct Sevimol	32	25	78.1	7	21.9
2 pct Sevin SL	29	25	86.2	4	13.8
Untreated	36	11	30.6	25	69.4

[1] Trees were treated during the period of June 19 to 26, 1989. The baits were on the trees from September 4 to 6, 1990. Mortality was assessed from July 8 to 10, 1991.
[2] Trees with no evidence of attack by western pine beetle.
[3] Cumulative number of trees that were successfully attacked and showed evidence of infestation by western pine beetle parent adults.
[4] Esfenvalerate in Asana XL and cyfluthrin in Tempo 20WP with one level of Tempo 2, the emulsifiable concentrate (EC) formulation.
[5] Number of trees in the sample.

carbaryl treatments, 2 percent Sevimol exceeded the threshold with seven trees dying (table 7). The 2 percent Sevin SL treatment, however, appeared to remain effective; only four trees in this treatment died (*table 7*).

All of the treatments received a significant challenge by western pine beetle over the two summers, because mortality in the untreated controls exceeded the predetermined threshold of 60 percent mortality. Only the lowest concentration of esfenvalerate, 0.006 percent, failed to provide sufficient protection for the first summer. None of the esfenvalerate treatments could be expected to provide protection for two full summers; they did not protect lodgepole pine from mountain pine beetle in Montana for two summers either (t*ables 3* and *7*). One or two higher concentrations of esfenvalerate (i.e., 0.05 percent and/or 0.1 percent) should be tested in the future to determine whether one treatment of this insecticide can provide protection of ponderosa pine from western pine beetle attack for two seasons.

All concentrations of cyfluthrin proved effective in protecting ponderosa pine from western pine beetle throughout the first summer. However, the lower concentrations did not prove efficacious for the second summer in contrast to their performance with lodgepole pine and mountain pine beetles in Montana (*tables 3* and *7*).

Both carbaryl treatments were effective in protecting ponderosa pines during the first summer after treatment and even for the first 12 months. However, only the 2 percent Sevin SL treatment provided what appeared to be adequate protection for the full second summer. In an earlier test of the longevity of carbaryl on ponderosa pine, neither a 2 percent Sevimol nor a 2 percent Sevin XLR treatment provided adequate protection for 9 or 12 months, respectively (Haverty and others 1985).

California: Western Pine Beetle vs. Ponderosa Pine

Because of the results from our tests in Montana and Idaho, we decided to increase the concentrations of esfenvalerate and decrease the concentrations of cyfluthrin for our test in California. We did this for two reasons. First, when we field-test an insecticide we think it is important to elucidate a range of concentrations, dosages, or application rates that are effective and ineffective. This allows us to determine the level at which the treatment is no longer effective or allows us to recommend a repeated application when a low rate is effective for only a short period of time. In the Montana and Idaho tests, all of the esfenvalerate treatments were judged ineffective after one year, and none of the cyfluthrin treatments was ineffective after the first summer. Second, in California, the beetle flight season or summer in ponderosa pine sites (ranging from ca. 200 to 3,000 m elevation) in the central Sierra Nevada of California is longer than it is in either Idaho or Montana, and insecticides are more likely to degrade faster in California. For this reason, we also thought it was necessary to increase the concentrations of esfenvalerate.

Treated trees were evaluated over a 14-month period. Immediately after the treatments were applied, 76.7 percent of the untreated trees were either dead or showed symptoms of impending death (*table 8*). After the fall baiting, 4 months after treatment application, only 30.0 percent of the untreated trees were mortally attacked (*table 9*). Fourteen months after treatment, 63.6 percent of the untreated trees succumbed to western pine beetle attack (*table 10*). Our experience with western pine beetle in California is that the number of western pine beetles in flight is higher during the summer than during the fall (P.J. Shea, unpublished data).[2] Nonetheless, beetle pressure was very high and provided a worse-case test for the treatments during the first and third baiting period. After the second baiting period, 12 of the 21 trees that were alive had suffered successful beetle attacks, but there was no apparent change in color of the foliage.

Both esfenvalerate treatments appeared to be effective immediately after treatment; one tree in each treatment succumbed during the first baiting (*table 8*). All of the cyfluthrin treatments proved to be effective. Three trees in the lowest concentration sustained mortal wounds when challenged immediately after treatment application, and 7 of the 27 live trees sustained successful western pine beetle attacks (*table 8*). The middle concentration of cyfluthrin was also effective, suffering two dead trees immediately after treatment. The highest rate of cyfluthrin was unaffected by western pine beetles when challenged promptly after treatment.

Four months after treatment, both of the esfenvalerate treatments appeared to remain effective with only four trees each dying from western pine beetle attack (table 9). In contrast, all of the cyfluthrin treatments suffered mortality in excess of the threshold of six trees per treatment, even though the beetle pressure was not as great as it was immediately after treatment (*table 9*).

Fourteen months after treatment, all esfenvalerate and cyfluthrin treatments appeared to be ineffective. Tree mortality in the esfenvalerate treatments was 43.3 percent and 24.1 percent, whereas mortality for the cyfluthrin treatments ranged from 33.3 percent to 63.3 percent. Clearly, none of the treatments tested in California is likely to provide protection for a second season; only the two esfenvalerate treatments can provide adequate protection for a full summer.

[2] Unpublished data on file, Pacific Southwest Research Station, Davis, CA.

Table 8—Effectiveness of two pyrethroid insecticides, esfenvalerate and cyfluthrin, for preventing ponderosa pine mortality resulting from attack by western pine beetle in California immediately after treatment.[1]

		Alive [2]		Dead[3]	
Treatment[4]	N[5]	n	pct	n	pct
Esfenvalerate					
0.025 pct	30	29	96.7	1	3.3
0.05 pct	30	29	96.7	1 [6]	3.3
Cyfluthrin					
0.0028 pct	30	27	90.0	3	10.0
0.008 pct	30	28	93.3	2	6.7
0.025 pct	30	30	100.0	0	0.0
Untreated #1	30	7	23.3	23	76.7

[1] Trees were treated during the period of May 8 to 15, 1990. The baits were on the trees from May 11, 1990, to June 12, 1990. Mortality was assessed on September 4 to 6, 1990.
[2] Trees with no evidence of significant attack by western pine beetle. Less than 10 "white" pitch tubes, no boring dust, and foliage was still green. Also trees under attack by western pine beetle with numerous pitch tubes ($\geq$10) with boring dust present in bark crevices, but no fading of foliage evident. These latter trees will likely survive.
[3] Trees with numerous pitch tubes ($\geq$50) and abundant boring dust in the bark crevices; foliage beginning to fade from green to yellow. Also trees that were successfully attacked with numerous pitch tubes, with abundant boring dust, and foliage had faded over the entire crown, to yellow or straw color.
[4] Esfenvalerate in the Asana XL and cyfluthrin in the Tempo 20WP formulations.
[5] Number of trees in the sample.
[6] This tree was in the middle of a large group kill. We suspect that this tree was either not treated or was treated after it had been under attack.

Table 9—Effectiveness of two pyrethroid insecticides, esfenvalerate and cyfluthrin, for preventing ponderosa pine mortality resulting from attack by western pine beetle in California 4 months after treatment.[1]

		Alive [2]		Dead[3]	
Treatment[4]	N[5]	n	pct	n	pct
Esfenvalerate					
0.025 pct	30	26	86.7	4	13.3
0.05 pct	30	26	86.7	4	13.3
Cyfluthrin					
0.0028 pct	30	20	66.7	10	33.3
0.008 pct	30	23	76.7	7	23.3
0.025 pct	30	23	76.7	7	23.3
Untreated # 2	30	21	70.0	9	30.0

[1] Trees were treated during the period of May 8 to 15, 1990. The baits were on the trees from September 4 to 11, 1990. Mortality was assessed on January 10, 1991.
[2] Trees with no evidence of significant attack by western pine beetle. Less than 10 "white" pitch tubes, no boring dust, and foliage was still green. Also trees under attack by western pine beetle with numerous pitch tubes ($\geq$10) with boring dust present in bark crevices, but no fading of foliage evident. These latter trees will likely survive.
[3] Trees with numerous pitch tubes ($\geq$50) and abundant boring dust in the bark crevices; foliage beginning to fade from green to yellow. Also trees that were successfully attacked with numerous pitch tubes, with abundant boring dust, and foliage had faded over the entire crown, to yellow or straw color.
[4] Esfenvalerate in the Asana XL and cyfluthrin in the Tempo 20WP formulations.
[5] Number of trees in the sample.

Conclusion

Periodically, severe outbreaks of various species of *Dendroctonus* occur throughout the western United States, including Alaska (Hofacker and others 1991). These outbreaks can be very localized or widespread. Area-wide droughts are often given as the stimulus for extensive outbreaks, whereas other triggering events causing localized problems include winter blow-down, logging, fire-scorch, and construction activity in forest environments. A long-term management strategy for bark beetles includes thinning of overstocked stands to reduce susceptibility of the remaining trees to bark beetle attacks. Obviously, large areas of overstocked forests cannot be thinned in response to the beginning of

Table 10—Effectiveness of two pyrethroid insecticides, esfenvalerate and cyfluthrin, for preventing ponderosa pine mortality resulting from attack by western pine beetle in California 14 months after treatment.[1]

Treatment[4]	N[5]	Alive[2] n	Alive[2] pct	Dead[3] n	Dead[3] pct
Esfenvalerate					
0.025 pct	30	17	56.7	13	43.3
0.05 pct	29	22	75.9	7	24.1
Cyfluthrin					
0.0028 pct	30	12	40.0	18	60.0
0.008 pct	30	11	36.7	19	63.3
0.025 pct	30	20	66.7	10	33.3
Untreated #3	22	8	36.4	14	63.6

[1] Trees were treated during the period of May 8 to 15, 1990.The baits were on the trees from late June to early July, 1991. Mortality was assessed on November 12 to 19, 1991.

[2] Trees with no evidence of significant attack by western pine beetle. Less than 10 "white" pitch tubes, no boring dust, and foliage was still green. Also trees under attack by western pine beetle with numerous pitch tubes (≥10) with boring dust present in bark crevices, but no fading of foliage evident. These latter trees will likely survive.

[3] Trees with numerous pitch tubes (≥50) and abundant boring dust in the bark crevices; foliage beginning to fade from green to yellow. Also trees that were successfully attacked with numerous pitch tubes, with abundant boring dust, and foliage had faded over the entire crown, to yellow or straw color.

[4] Esfenvalerate in the Asana XL and cyfluthrin in the Tempo 20WP formulations.

[5] Number of trees in the sample.

a drought. Also, thinning is not always feasible or desirable depending upon management objectives, i.e. watershed zones, wildlife areas, and lack of access. Another response to excessive bark beetle-caused mortality is salvage harvesting of dead trees. Salvage harvesting and thinning do not, however, solve the problem of how to protect high-value trees from beetle attack. Such trees, those in parks, campgrounds, visitor centers, rest and picnic areas, adjacent to private dwellings, and other administrative sites, require short-term management tactics or strategies to prevent unwanted and unnecessary mortality.

Presently, the only tactic available to pest managers to protect individual trees from lethal attack by bark beetles is to spray the bole of targeted trees with insecticides to kill attacking beetles before they penetrate to the phloem and trigger a mass attack. This study extends our knowledge about the persistence and efficacy of a known insecticide (carbaryl) as a preventative treatment and establishes the efficacy of additional insecticides (cyfluthrin and esfenvalerate). Lastly, pest and land managers and private property owners should take the results of this and similar experiments (Gibson and Bennett 1985, Hall and others 1982, Haverty and others 1985, McCambridge 1982, Shea and McGregor 1987, Shea and others 1984a, Smith and others 1977) and combine them with information on application and handling (Haverty and others 1983), safety (Haverty and others 1983), environmental considerations (Hoy and Shea 1981, Hastings and others 1998), and cost information (Gibson and Bennett 1985, Shea and McGregor 1987) to make informed decisions regarding protection of individual lodgepole or ponderosa pines from attack by mountain pine beetles or western pine beetles.

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