Effectiveness of Carbaryl and Chlorpyriphos for Protecting Ponderosa Pine Trees from Attack by the Western Pine Beetle (Coleoptera: Scolytidae)[1]

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ABSTRACT

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A large-scale field experiment was conducted to examine the efficacy of 1, 2, and 4% chlorpyriphos and 1, 2, and 4% carbaryl for protecting high-value ponderosa pine trees from attack by *Dendroctonus brevicomis* LeConte. Each of the 510 trees utilized in the experiment was separated by at least 0.4 km. At 1 month, 3 months, and 1 year after insecticide application, *D. brevicomis* pheromone was attached to the boles of treated and untreated check trees. All six treatments were regarded as effective 1 month after application. At 3 months after application, 1 and 2% chlorpyriphos were regarded as ineffective. One year after application, low mortality of untreated check trees hindered the determination of efficacy of the remaining four treatments. At 3 months and 1 year after application, significantly more *Temnochila chlorodia* (Mannerheim) were found in catchment traps beneath treated than beneath untreated trees. The best explanation for this is insecticide-induced mortality of *T. chlorodia.* There were no significant differences in numbers of *D. brevicomis* or *Enocleris lecontei* (Wolcott) in the catchment traps.

The western pine beetle, *Dendroctonus brevicomis* LeConte, is a major pest of ponderosa pine, *Pinus ponderosa* Laws., in the western United States (Stark and Dahlsten 1970). During 1977 and 1978, when many trees were stressed by drought, high mortality of high-value trees (i.e., in residential and recreational areas and administrative sites) emphasized the need for a method of protecting living trees from attack by *D. brevicomis.* Considerable effort has been expended to test the effectiveness of insecticides for use in protecting trees from *D. brevicomis* (Smith 1967, 1970, Smith et al. 1977, Swain[5]). As a result of these tests, lindane and carbaryl were registered for this purpose.

Lindane may be unavailable for future use against *D. brevicomis* because considerable controversy surrounds its use in forestry (Koerber 1976), and its use is currently under review by the Environmental Protection Agency through the Rebuttable Presumption Against Re-registration. Preliminary field tests of carbaryl for protecting trees from *D. brevicomis* suggested that it was not effective; other field tests of carbaryl had mixed results (Smith et al. 1977). Thus, further testing of carbaryl was desirable as this chemical was registered for tree protection in several western states. Objectives of the present study were to evaluate insecticides as alternatives to lindane for use in protection of high-value ponderosa pine from attack by *D. brevicomis.*

The compounds evaluated in this study were carbaryl and chlorpyriphos. Carbaryl is currently registered for use in California. Chlorpyriphos appeared to be effective in preventing attack of *D. brevicomis* in preliminary field tests (unpublished data).

Materials and Methods

Tree Selection

Selection of sample trees was completed on 6 June 1979; all were living ponderosa pine, 28 to 57 cm diameter at breast height (dbh), located on the western slope of the Sierra Nevada between 750 and 1,700 m elevation in the Lassen, Plumas, Tahoe, and Eldorado National Forests. Each sample tree was located at least 0.4 km from other sample trees and, whenever possible, at least 5 m from neighboring ponderosa pines. The 0.4-km separation was utilized to assure that there was no significant interference between pheromone sources and to assure that sufficient beetles were in the vicinity of each tree to give the insecticide treatments a rigorous test of efficacy.

A total of 510 trees was used in the experiment. Seventy trees were assigned to each of six insecticide treatments, whereas 90 trees served as untreated controls (30 trees for each of three baiting periods). All sample trees were randomly assigned to the treatments before insecticide application.

Three treated trees were cut down in late 1979 or early 1980. Thus, they were removed from the experiment. None of the three trees was killed as of October 1979. One tree each was treated with 1, 2, and 4% carbaryl. Thus, only 69 trees were included in the analysis of efficacy for these treatments.

Insecticide Application

Chlorpyriphos and carbaryl were applied to sample trees at rates of 1, 2, and 4% from 13 June to 11 July 1979. Four percent chlorpyriphos was applied to 69 trees. The remaining five treatments were each applied to a different group of 70 trees. Thus, 419 trees were treated with insecticide.

Insecticides were applied from the ground to the

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[5] K. M. Swain. 1968. Protecting ponderosa pine from bark beetle attack by use of a lindane-water emulsion spray. Unpublished report. USDA For. Serv. Div. Timber Manage. 13 pp.

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bark surface of the trees. Insecticides were delivered from a Hudson stirrup pump through 6.4-mm (ID) Tygon tubing to a nozzle located atop a telescoping fiberglass pole. Tank pressure was ≤ 2.8 kg/cm^2. Insecticides were applied over the entire bole of the trees to a height of ca. 10.5 m. Application was made to the point of runoff, ca. 0.8 liter of formulated spray material per m^2 or ca. 8.0 liter of formulated spray material per tree.

Pheromone Baiting

To test the effectiveness of the insecticides on *D. brevicomis*, all living treated trees and 30 untreated trees were baited with *D. brevicomis* pheromone based on methods developed by J. O. Rodin and P. E. Tilden (unpublished data). Thirty different untreated trees were used each time the treated trees were baited. Trees were baited in July 1979, September 1979, and June to July 1980. Each time trees were baited, pheromone remained on the trees for 2 weeks. To bait a tree, the components of the pheromone, *exo*-brevicomin, frontalin, and myrcene, were placed in glass tubes which had one end sealed. Three tubes, one containing each compound, were placed in foil-covered salt shakers and suspended on the bole of the sample tree ca. 3 m above the ground. Weight losses for these compounds under field conditions averaged ca. 2 mg/day (Browne 1978). *Exo*-brevicomin and frontalin were obtained from Chemical Samples Co., Columbus, Ohio, and myrcene from Aldrich Chemical Co., Milwaukee, Wisc. Any *exo*-brevicomin or frontalin which remained in the glass tubes following baiting was recovered and reused in subsequent baitings, but myrcene was not.

Determination of Insecticide Efficacy

Efficacy of insecticide treatments was determined by observing the proportion of trees which were killed by *D. brevicomis* after pheromone baiting. Residual effectiveness was assessed by observing cumulative tree mortality resulting from successive pheromone baitings. To assume that treated trees had sufficient attacks by *D. brevicomis* to rigorously test the effectiveness of the treatments, at least 22 of 30 (73%) of the baited, untreated trees must have been killed by *D. brevicomis*. If less than 22 untreated trees were killed after a certain baiting period, our criterion of sufficient beetle attack was not met, and any inferences concerning efficacy of insecticide treatments must account for less than maximum beetle attack pressure for that baiting period. Given sufficient mortality of untreated trees, an insecticide was considered effective if 56 of 70 (80%) of the trees treated with it were not killed by *D. brevicomis*. A given treatment was considered ineffective if more than 20% (24) of the trees treated with it were killed by *D. brevicomis*, regardless of the level of mortality in the baited untreated trees. The levels of mortality utilized in the determination of efficacy were set to approximate a worst-case situation.

All baited trees were periodically examined for evidence of *D. brevicomis* activity, i.e., pitch tubes, successful attacks, or fading. Pitch tubes are a host response to beetles which successfully bore through the bark of the trees. Successful attacks were indicated by pitch tubes which contained reddish-colored frass of *D. brevicomis*, or by the presence of boring dust, with or without pitch tubes. The foliage fades or changes color from green to yellowish or reddish on trees killed by *D. brevicomis*. Since trees could fade for a number of reasons, *D. brevicomis* activity was confirmed in each faded tree by removing a portion of the bark and examining it for *D. brevicomis* galleries.

Population Monitoring

Two different trap designs were used to monitor arthropod populations on or near study trees. A 250-cm^2 piece of hardware cloth coated with Stikem Special was suspended from the bole of each baited tree ca. 0.3 m above the pheromone bait. These traps were designed to monitor arrival of *D. brevicomis* and selected associates, i.e., *Enocleris lecontei* (Wolcott) and *Temnochila chlorodia* (Mannerheim). Arrival traps also were placed on untreated, unbaited trees during each baiting period. The number of unbaited trees with traps was 9, 14, and 14 for the first, second, and third baitings, respectively.

Catchment traps were placed at or near the base of selected, baited trees to capture arthropods falling from the bark surface. Catchment traps consisted of a disposable plastic paint tray liner, coated inside with Stikem Special. During the first baiting, a single trap was placed beneath the tree ca. 30 cm from the base of the tree. In the second and third baitings, two traps were placed beneath each tree; each trap had one edge in contact with the base of the tree. The number of trees with catchment traps were 69, 79, and 70 for the first, second, and third baitings, respectively.

Trap data were analyzed based on a modification by Games and Howell (1976) of Tukey's multiple comparison test. This technique was utilized because variances among treatments were heterogeneous (Keselman and Rogan 1978).

Results and Discussion

Results of the First Baiting

Ultimately, 26 of 30 (87%) of the untreated trees baited during the first baiting period were killed as a result of *D. brevicomis* attack. Of the four unfaded, untreated trees, one overcame an apparent heavy attack by *D. brevicomis;* the remaining three were not heavily attacked. Based on the experimental design, it is possible to assume that the effectiveness of the treatments was rigorously tested during the first baiting.

Table 1 gives the number of treated trees which faded as a result of *D. brevicomis* attacks initiated during pheromone baiting. Since fewer than 20% of

Table 1.—Mortality of ponderosa pine trees baited with *D. brevicomis* pheromone[a]

Treatment	Ratio, alive:dead			Cumulative mortality (%)[b]
	July 1979	Sept. 1979	July 1980	
1% Chlorpyriphos	60:10	45:25	40:30	43
2% Chlorpyriphos	65:2	53:17	51:19	27
4% Chlorpyriphos	67:2	58:11	55:14	20
1% Carbaryl	63:6	62:7	60:9	13
2% Carbaryl	65:4	63:6	59:10	14
4% Carbaryl	63:6	63:6	62:7	10
Untreated	4:26	17:13	25:5	–

[a] Mortality of treated trees is presented cumulatively, whereas mortality of untreated trees is presented under baiting periods.

[b] Based on the criteria set forth at the beginning of the experiment, a treatment was to be considered ineffective if the cumulative mortality exceeded 20%.

the trees treated with each treatment were killed, all treatments were regarded as effective before the second baiting.

Only 76 of the 420 insecticide treated trees had no pitch tubes or other evidence of *D. brevicomis* attack, and only one tree had no *D. brevicomis* on the arrival trap. Thus, all but one of the baited trees were visited by *D. brevicomis*, and most had evidence of boring through the bark despite the insecticide. In most of these cases, attacking beetles were apparently overcome. Thus, an interaction between the insecticide and host response to beetle attack appeared to prevent mortality of many of the treated trees.

Results of the Second Baiting

During the second baiting, 98% of the arrival traps on treated trees and 100% of the traps on untreated trees contained *D. brevicomis*. Also, 98% of the untreated trees had pitch tubes and 80% had some evidence of successful attack by *D. brevicomis*. However, only 13 of 30 (43%) untreated trees were killed by *D. brevicomis* during the second baiting (Table 1). Thus, mortality of treated trees fell short of the 73% needed to assume sufficient beetle attack pressure on the treated trees. One explanation for the insufficient untreated tree mortality is a decrease in the number of *D. brevicomis* arriving at the trees during the second baiting as compared to the first baiting (see later section).

Two treatments were determined to be ineffective after the second baiting. Cumulative mortality in trees treated with 1% chlorpyriphos was 36%, and 24% for trees treated with 2% chlorpyriphos. Cumulative mortality in trees treated with 4% chlorpyriphos and with all three rates of carbaryl was not sufficient to reject those treatments as ineffective.

During the second baiting, significantly fewer trees treated with each treatment were killed than untreated trees. Thus, even though an insignificant portion (as defined before the experiment) of untreated trees were killed, it appears that each insecticide treatment protected the trees better than no treatment at all. However, this comparison should be interpreted cautiously. Treated and untreated trees may not be comparable because of cumulative effects of the first baiting on treated trees (untreated trees were not baited before the second baiting).

Two effects could influence the validity of comparisons between previously baited and previously unbaited trees. Cumulative effects of baiting could weaken the treated trees and make them more susceptible to *D. brevicomis* induced mortality. Such a condition would lead to conservative conclusions about the effectiveness of insecticide treatments and, thus, should not seriously affect conclusions regarding efficacy of treatments based upon baitings where a greater proportion of the untreated trees were killed than were the treated trees (e.g., the second baiting). Another possible effect concerns the differential susceptibility of all trees in the population to mortality caused by *D. brevicomis*. For example, if a certain proportion of trees utilized in the experiment is extremely susceptible to attack and subsequent mortality, such trees have a higher probability of being killed after one pheromone baiting than other trees in the population. Thus, trees that survive one baiting may be less susceptible to mortality than the general population, i.e., previously unbaited trees. If such a phenomenon exists, one would expect a higher proportion of the previously unbaited trees to be killed by *D. brevicomis*. Comparisons would overestimate untreated tree mortality, thereby overestimating the effectiveness of the insecticide treatments.

The only comparison which appears to overcome problems with effects of previous baitings on the trees is a comparison of cumulative mortality of treated trees (i.e., trees killed as a result of the first and second baitings) with mortality of untreated trees within the second baiting. This comparison is conservative because treated trees received more attack pressure than did untreated trees. Four treatments, 4% chlorpyriphos and 1, 2, and 4% carbaryl, had significantly less mortality as a result of the first and second baitings than did untreated trees in the second baiting, based on χ^2 contingency tables ($\alpha = 0.05$). The two treatments, 1 and 2% chlorpyriphos, which were not significantly better than no treatment, were the same treatments determined to be ineffective, based on criteria set forth at the beginning of the experiment.

Table 2.—Arrival trap catches of *D. brevicomis* for all pheromone baitings

Treatment[a]	Mean no. of *D. brevicomis*/trap (SE)[b] July 1979	Sept. 1979	July 1980
1% Chlorpyriphos	65.2 (6.9)a	59.4 (6.3)a	64.1 (5.3)a
2% Chlorpyriphos	75.2 (6.2)ab	62.0 (6.8)a	59.2 (5.9)a
4% Chlorpyriphos	95.8 (8.2)ab	66.3 (7.2)a	73.8 (5.1)a
1% Carbaryl	103.2 (8.0)b	64.2 (7.2)a	62.8 (4.7)a
2% Carbaryl	84.0 (7.0)ab	57.4 (8.4)a	61.9 (3.8)a
4% Carbaryl	105.3 (7.9)b	44.0 (6.5)a	62.3 (4.7)a
Untreated	40.3 (7.1)a	65.7 (8.6)a	51.6 (5.1)a
Unbaited	0.3 (0.2)c	0 (0)b	0.4 (0.2)b

[a] The first seven treatments contained trees baited with *D. brevicomis* pheromone.

[b] Means followed by the same letter are not significantly different at the 5% level by the Games and Howell (1976) modification of the Tukey multiple comparison test.

Results of the Third Baiting

During the third baiting, 338 of 341 (99%) treated trees and 100% of the untreated trees had *D. brevicomis* on their arrival traps. Also, 289 of 341 treated trees (85%) and 28 of 30 (93%) untreated trees had some evidence of attack by *D. brevicomis* within the third baiting period.

After this baiting, only 5 of 30 (17%) untreated trees were killed by *D. brevicomis* (Table 1). This extremely low rate of tree mortality was probably due to relatively low arrival of *D. brevicomis* (see below) and increased vigor of the trees during this baiting period. Increased vigor could be attributed partly to an extremely wet winter during 1979 and 1980 and to unseasonably heavy rains which occurred on 2 July 1980 near the end of the baiting period.

Mortality of treated trees also was low within the third baiting. Significantly fewer trees treated with 2% chlorpyriphos and 1 and 4% carbaryl were killed than untreated trees, based on χ^2 contingency tables ($\alpha = 0.05$). However, caution should be exercised in interpreting the biological significance of such results (see previous section). The low rate of untreated tree mortality obscures any differences that may exist when comparing cumulative mortality of treated trees with the mortality of untreated trees in the third baiting.

Cumulative Mortality

When tree mortality is examined over all three baitings, only trees treated with 1 and 2% chlorpyriphos had sufficient mortality to be judged as not protected from attack by *D. brevicomis*. Fourteen trees (20%) treated with 4% chlorpyriphos were killed by *D. brevicomis*. Thus, that treatment was on the borderline between effective and ineffective. Although it was not possible to reject 4% chlorpyriphos, or 1, 2, and 4% carbaryl, it is not possible to state that those treatments were extremely effective over the entire experiment because of the relatively low levels of mortality in the untreated trees during the second and third baitings.

During the first baiting, sufficient untreated trees were killed and less than 20% of the trees in each treatment were killed by *D. brevicomis*. Thus, based on our criteria, all treatments were effective after the first baiting. Since all living treated trees were baited during the second pheromone baiting, it was not possible to determine what portion of the 1 and 2% chlorpyriphos trees were killed as a result of the second baiting and what proportion of the trees would have died in the absence of the second baiting. Since a significant portion of the 1 and 2% chlorpyriphos trees were dead after the second baiting, it is valid to question the effectiveness of those treatments for short-term tree protection.

Population Monitoring

Table 2 gives arrival trap catches for *D. brevicomis*. The only consistent significant differences among arrival trap catches were between baited and unbaited trees. Since significantly more beetles were captured on the baited trees, the pheromone apparently was attracting *D. brevicomis*.

Arrival trap catches from 326 treated trees which were baited three times were compared with a two-factor analysis of variance. One factor was the individual trees and the other factor was the baiting period. Mean number of *D. brevicomis* captured (SE in parentheses) were: 84.46 (3.48), 56.99 (3.18), and 63.21 (2.04), for the first, second, and third baitings, respectively. The F value for baiting period (with 2 and 650 df) was 38.2 ($P < 0.01$). The mean for the first baiting significantly differed from the means for the second and third baitings based on the modification (Games and Howell 1976) of the Tukey multiple comparison test ($\alpha = 0.05$). Thus, arrival at baited trees was significantly lower in the second and third baiting periods than in the first. This decrease may have been due to a decrease in *D. brevicomis* activity, or to a decrease in the effectiveness of the pheromone baits. Whatever the reason, the decrease in arrival may partially explain the relatively low rates of untreated tree mortality in the second and third baitings.

Arrival of *E. lecontei* was significantly greater on baited trees than on unbaited trees for all three baitings. Although the differences were not always statistically significant, there were more *E. lecontei*

Table 3.–Number of *T. chlorodia* captured in catchment traps beneath ponderosa pine trees baited with *D. brevicomis* pheromone

Treatment	Mean no. of *T. chlorodia*/trap[a]		
	July 1979	Sept. 1979	July 1980
1% Chlorpyriphos	6.1	21.2a	13.5a
2% Chlorpyriphos	4.2	9.5ab	10.8a
4% Chlorpyriphos	1.8	8.6ab	13.3a
1% Carbaryl	2.5	7.0b	11.6a
2% Carbaryl	4.1	9.6ab	15.3a
4% Carbaryl	3.2	6.0b	14.3a
Untreated	0.7	0.6c	2.0b

[a] Means followed by the same letter are not significantly different at the 5% level, by the Games and Howell (1976) modification of the Tukey multiple comparison text. Means not followed by letters were not significantly different.

captured on baited, untreated trees than on baited, treated trees. This was probably due to a higher density of attacks by *D. brevicomis* on the untreated trees. *E. lecontei* is generally not attracted to the pheromone triplet alone (Wood 1972); however, it is attracted to trees under attack by *D. brevicomis* (Berryman 1970).

Arrival traps on baited trees caught significantly more *T. chlorodia* than on unbaited trees. The significantly higher trap catches on the baited trees are not surprising because *T. chlorodia* has been shown to be attracted by *exo*-brevicomin, a component of the pheromone bait (Birch et al. 1974).

There were no statistically significant differences in numbers of *D. brevicomis* or *E. lecontei* captured in catchment traps beneath baited trees. The lack of significance can be attributed to extreme variability among trap catches.

In the second and third baitings, significantly more *T. chlorodia* were captured in catchment traps beneath the treated trees (Table 3). In the first baiting, this trend is consistent but not statistically significant. The lack of statistical significance in the first baiting was due to large variances in the data. Variance was reduced in subsequent baitings by doubling the sample size and repositioning the traps. It appears that *T. chlorodia* were falling from the treated trees in greater numbers than from untreated trees. Adverse effects of the treatments (i.e., insecticide-induced mortality) is the best explanation for this phenomenon.

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REFERENCES CITED

Berryman, A. A. 1970. Evaluation of insect predators of the western pine beetle, pp. 102–112. *In* R. W. Stark and D. L. Dahlsten [eds.], Studies on the population dynamics of the western pine beetle, *Dendroctonus brevicomis* LeConte (Coleoptera: Scolytidae). Univ. Calif. Div. Agric. Sci. Berkeley. 179 pp.

Birch, M., K. Trammel, H. H. Shorey, L. K. Gaston, D. D. Hardee, E. A. Cameron, C. J. Sanders, W. D. Bedard, D. L. Wood, W. E. Burkholder, and D. Muller-Schwartze. 1974. Programs utilizing pheromones in survey or control, pp. 410–461. *In* M. C. Birch [ed.], Pheromones. American Elsevier Publishing Co., Inc., New York. 495 pp.

Browne, L. E. 1978. A trapping system for the western pine beetle using attractive pheromones. J. Chem. Ecol. 4: 261–275.

Games, P. A., and J. F. Howell. 1976. Pairwise multiple comparison procedures with unequal N's and/or variances: a Monte Carlo study. J. Educ. Stat. 1: 113–125.

Keselman, H. J., and J. C. Rogan. 1978. A comparison of the modified-Tukey and Scheffe methods of multiple comparisons for pairwise contrasts. J. Am. Stat. Assoc. 73: 47–52.

Koerber, T. W. (compiler). 1976. Lindane in forestry...a continuing controversy. U.S. Dep. Agric. For. Serv. Gen. Tech. Rep. PSW-14. 30 pp.

Smith, R. H. 1967. Lindane in diesel oil prevents western pine beetle attacks for at least one year. J. Econ. Entomol. 60: 1746–1747.

1970. Length of effectiveness of lindane against attacks by *Dendroctonus brevicomis* and *D. ponderosae* in California. Ibid. 63: 1180–1181.

Smith, R. H., G. C. Trostle, and W. F. McCambridge. 1977. Protective spray tests on three species of bark beetles in the western United States. Ibid. 70: 119–125.

Stark, R. W., and D. L. Dahlsten [eds.], 1970. Studies on the population dynamics of the western pine beetle *Dendroctonus brevicomis* LeConte. Univ. Calif. Div. Agric. Sci. Berkeley. 179 pp.

Wood, D. L. 1972. Selection and colonization of ponderosa pine bark beetles, pp. 101–117. *In* H. F. Van Emden [ed.], Insect/plant relationships. Symp. R. Entomol. Soc. (London) No. 6. 213 pp.