Protective Spray Tests on Three Species of Bark Beetles[1] in the Western United States[2]

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ABSTRACT

In an early extensive series of tests 2% oil solution or aqueous emulsion of lindane or chlorpyrifos, or 2% oil or water suspension of carbaryl prevented both attracted and forced attacks by *Dendroctonus brevicomis* LeConte, *D. ponderosae* Hopkins, and *D. adjunctus* Blandford on *Pinus ponderosa* Lawson and attacks by *D. ponderosae* on *P. contorta* Douglas. The period of effectiveness varied from 3 to more than 36 months depending on the formulation, insecticide, and type of attack: oil solution > emulsion; lindane > chlorpyrifos > carbaryl; forced attacks > attracted attacks. No marked differences could be found between beetle species in a given location. In a later series of attracted attack tests on ponderosa pine, however, 2% water emulsion of chlorpyrifos was not effective against *D. ponderosae*.

To reduce losses caused by bark beetles a forest manager may use 2 different approaches. He may seek to kill a developing brood in infested trees and thus prevent further tree mortality, or he may seek to keep threatened trees alive with protective chemical sprays. For the 1st method to be effective, a high percentage of trees containing brood must be located and treated. This is a costly and difficult process and often the suppression effort is not adequate to prevent continued tree-killing because too many brood trees are not found and treated. Also, the effort is invested in dead or dying trees and still may not protect the live trees we wish to save. The 2nd method is useful for situations where the trees are particularly valuable.

Reported here are tests designed to determine the effectiveness of 4 insecticides[6] in preventing bark beetle attacks. Of these, lindane has a long history of effectiveness in preventing attacks by bark beetles and borers (Ulmann 1972, Smith 1976). The others, chlorpyrifos, carbaryl, and mexacarbate, were determined as potentially effective in laboratory screening tests (Lyon 1971). The scope of the tests was enlarged by selecting 4 widely separated locations in California, Colorado, Idaho, and Nevada, by using 2 species of pine, i.e., ponderosa, *Pinus ponderosa* Lawson, and lodgepole, *P. contorta* Douglas, and by using 3 species of beetles, i.e., mountain pine beetle, *Dendroctonus ponderosae* Hopkins, western pine beetle, *D. brevicomis* LeConte, and roundheaded pine beetle, *D. adjunctus* Blandford.

Materials and Methods.—*Application of Insecticides.*—Insecticides were applied at the rate of 1 gal of formulated spray/40–50 ft^2 of bark surface on the basal 12–30 ft of the trunk of trees growing in forested conditions when bark was dry (Table 1). Insecticide was applied (1) with a garden-type pressure tank sprayer with a 3-, to 5-gal capacity, (2) with a bucket and stirrup pump apparatus or (3) by brush. Spray nozzles were adjusted for a medium-fine cone spray at medium to low pressure. Extension spray wands were used to apply the insecticide above the 8–10 ft height. Since the treated trees remained in the forest, the treated bark was exposed to local weather conditions from the time of insecticide application to time of beetle attack.

The basic series of tests (3, 4, 5, 6 in Table 1) was started in 1972. Results of tests number 1 and 2, already underway in 1972, and tests number 7, 8, 9, 10 started after the basic series were added to this report to increase its scope.

In an effort to increase the severity of the test conditions in Idaho, at least 2 trees were treated on only one-half their circumference with each spray preparation; the other half of the circumference was left untreated. It was hoped that the untreated portion would be attacked, thereby creating strong beetle attraction and population pressure against the treated half. Success of the treatments in protecting the treated half under these conditions would be additional proof of their effectiveness under severe beetle pressure.

The purpose of the Colorado test was to determine the ability of the spray treatment to keep the trees alive. Trees were sprayed to different heights in different years to determine the height needed to protect the tree. Both the treated and untreated portions of the trees were assessed for bark beetle activity along with the final condition of the whole tree. The success of the spray treatment was measured both by whether the tree lived or died and whether attacks were made and were successful within the treated portion.

Testing and Examination.—Procedures for determining "treatment effectiveness" were forced attacks on cut logs, which is a form of bioassay; and attracted attacks on standing trees, which is a type of operational test.

Forced Attacks on Cut Logs.—At designated periods, treated trees were felled and sectioned into logs, each 20–30 in. long. Check logs were generally taken from the untreated portion of these same trees or occasionally from designated untreated trees of

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[6] This paper reflects the result of research only. Mention of a proprietary product or pesticide does not constitute an endorsement or recommendation by the USDA. Approval by the U.S. National Environmental Protection Agency of materials tested has not been granted as of this publication date.

Table 1.—Protective spray tests on ponderosa pine (P) and lodgepole pine (L) for western pine beetle (WPB), mountain pine beetle (MPB), and roundheaded pine beetle (RPB).

Test	Year applied	Beetles	Pine[a] species	Insecticides[b]	Applied by	Testing Method	Test[c] Location
1	1965	WPB, MPB	P	Lin	Brush	Logs	a
2	1970	WPB, MPB	P	Mex	Tank sprayer	Logs	a
3	1972	WPB, MPB	PL	Lin, chlor, carb	Tank sprayer	Logs	a
4	1972	MPB	P	Lin, chlor, carb	Tank sprayer	Trees, logs	b
5	1972	MPB	L	Lin, chlor, carb	Tank sprayer	Trees, logs	c
6	1972	WPB, RPB	P	Lin, chlor, carb	Tank sprayer	Logs	d
7	1973	WPB, MPB	P	Lin	Tank sprayer	Logs	a
8	1973	MPB	P	Lin, chlor, carb	Tank sprayer	Trees	b
9	1974	MPB	P	Lin	Stirrup pump	Trees	b
10	1975	MPB	P	Lin, carb	Tank sprayer	Trees	b

[a] All trees ranged from 12–15 in. dbh except 6–8 in. for No. 6.
[b] Lin = lindane; chlor = chlorpyrifos; carb = carbaryl; mex = mexacarbate.
[c] a = Eldorado National Forest, Calif.; b = Roosevelt National Forest, Colo.; c = Targhee National Forest, Ida.; d = Toiyabe National Forest, Nev.

similar size and age as those treated. Beetles had been found to attack both types of untreated checks readily and comparably (Smith 1972).

The ends of test logs were coated with paraffin to prevent moisture loss and covered with fine mesh screening to prevent attacks from being made through the end surface of bark. Each log was placed on end on a sheet of cloth-covered polyurethane foam ¼ in. thick. A cylindrical cage of mesh wire screen was placed over each log. The cloth-covered foam sealed the bottom of the log and the bottom edge of the cage.

Mountain pine beetles were added at the rate of 10–15/ft^2 of bark surface; western pine beetle, at the rate of 25–40. However, in any given set of logs, the rate was the same for treated and untreated. Logs in all tests, except one, were maintained at 65–85°F for 2–3 weeks; the 3-month test in Nevada was conducted during a period when the temperature ranged from 30–50°F for 6 weeks. In California, the western pine beetles were reared from bark removed from naturally infested ponderosa pine; mountain pine beetles were reared from logs cut from naturally infested lodgepole pine. In Colorado and Idaho, mountain pine beetles were reared from naturally infested ponderosa and lodgepole pine, respectively. For the 1st test period in Nevada, brood bark from ponderosa pine containing roundheaded pine beetle was used; in the 2nd test, only mixed brood of western pine beetle and roundheaded pine beetle was available. This brood material from which beetles would soon emerge was placed equally in each cage. For the 3rd test, which had 26-month residual time, logs were taken from Nevada to California and included with that test with both western and mountain pine beetle.

Logs were examined by shaving the bark down to the wood and noting the incidence of attack or attack success as measured by inches of egg galleries. Attack success was then expressed as inches of egg gallery per ft^2 of bark for each treatment and untreated check or as total inches of egg gallery in treated and untreated logs of equal size. Percent effectiveness was derived by Abbott's formula.

Attracted Attacks on Standing Trees.—Trees or logs beginning to be attacked are a strong attraction for other beetles of the same species in the area. Such trees or logs were used to attract indigenous beetles to the test trees.

In Idaho, freshly attacked lodgepole pines were cut from lower elevations and moved to the higher elevation of the test area so as to have attractive sources as soon as beetles in the test area emerged. These logs, containing some unmated females, were cut into short logs, and fastened to the test trees at a height of 4–6 ft to induce the indigenous beetles to attack. In Colorado, unattacked trees were cut into logs which were exposed to regulated numbers of female beetles in individual cages. As soon as beetle attacks were producing frass, the caged logs were fastened to the test trees. The number of successful and unsuccessful attacks on the sprayed and unsprayed portion of the trees and on the unsprayed check trees was recorded and was the basis for determining effectiveness.

RESULTS.—No marked differences were found among the 3 species of bark beetle where comparable conditions existed, although treatments appeared to be slightly more effective against mountain pine beetle than the western pine beetle. There are insufficient data to characterize the roundheaded pine beetle, though in the limited tests the treatments against it were equally as effective as they were against the other 2 beetles, or more so. Therefore, no effort is made in the following discussion to distinguish among the 3 species.

Attracted Attacks (Fig. 1, Table 2).—Lindane.—In the 1972 series in Colorado, both the 2% oil solution and 2% aqueous emulsion were fully effective for the 1-, to 3-month period of testing in preventing attacks in the sprayed portion of the trees, the basal 20 ft; neither was effective in preventing successful attacks (those from which brood developed and which killed the tree) above the sprayed zone.

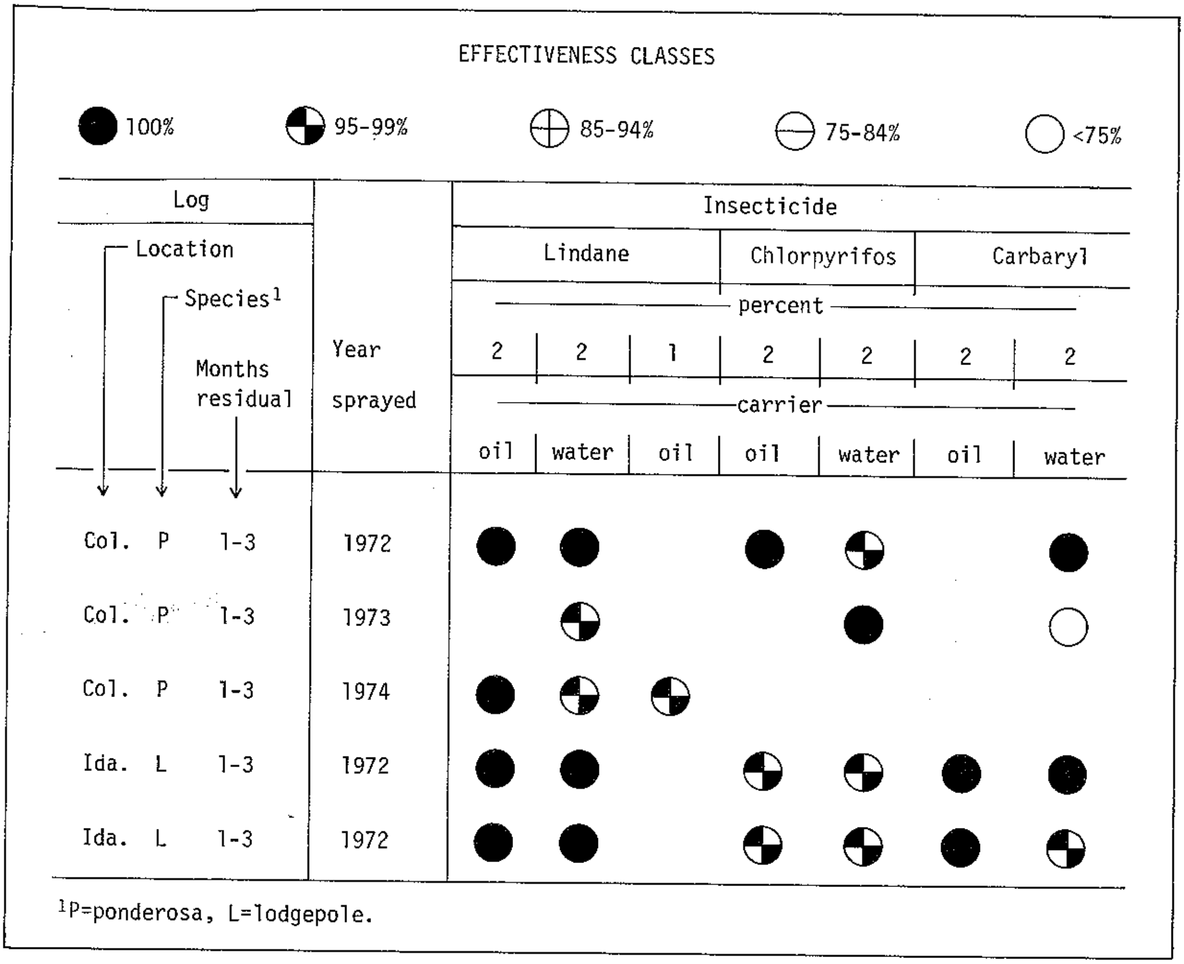

FIG. 1.—Effectiveness of 3 insecticides in reducing attracted attacks of mountain pine beetle on treated portions of 2 pine species. Effectiveness measured by reduction in number of attacks.

Only 2% emulsion was used in the 1973 series and the spray was applied to a 30 ft height by using a stirrup pump. All treated trees in areas of low and average beetle populations were unattacked on both the sprayed or unsprayed portions; several untreated check trees were attacked and killed. In an area of high beetle population, one out of the 2 treated trees was killed by attacks above the sprayed portion. The overall effectiveness for the combined areas was ca. 90%.

In the 1974 series, 1 and 2% oil solutions were 97 and 100% effective, respectively, in protecting the 40 and 80 trees treated with each one. Twenty trees were sprayed to a height of 30 ft in 1975 with 2% aqueous emulsion of lindane, and only one tree was killed.

In Idaho, both the 2% oil solution and 2% water emulsion were fully effective in preventing successful attacks on the sprayed portions of trees for 13 months. All attacks on the unsprayed portion of treated trees were unsuccessful and the trees lived. Attacks on unsprayed trees were successful and the trees died. Lack of successful attacks on the unsprayed portions of partially sprayed trees could have been caused by the dependence of beetles on the mass attack phenomenon or by beetles getting a lethal dose of the insecticide by moving about on the sprayed area before attacking the unsprayed portion.

Phytotoxic effects of oil preparations were noted in Idaho; and in Colorado, 12 of 165 trees sprayed with lindane in oil were killed by the treatment; trees averaged 12 in. dbh.

Chlorpyrifos.—In Colorado, the 2% oil solution was fully effective in preventing attacks in the sprayed zone (to 20 ft) but not in preventing successful attack above the sprayed zone in the 1972 series. The 2% emulsion was about equally effective with but one attack, apparently unsuccessful, in the sprayed zone. In the 1973 series, the 2% emulsion was effective; there were no attacks in the sprayed zone and very few attacks in the unsprayed zone above. In Idaho, both formulations prevented attacks on the sprayed portion of treated trees; and only 5% of the attacks

Table 2.—Effectiveness of 2% concentration of 3 insecticides 1–2 months after application in preventing attacks of mountain pine beetle on ponderosa pine in Colorado in 1972 and 1973.

Insecticide and Formulation	1972					1973				
		Sprayed to 20 ft height at 4 ft		at 22 ft			Sprayed to 30 ft height at 4 ft		above 30 ft	
	Trees	Trees with attacks	No. of attacks per ft²	Trees with attacks	No. of attacks per ft²	Trees	Trees with attacks	No. of attacks	Trees with attacks	No. of attacks
Lindane oil	3	0	0	1	5[a]	—	—	—	—	—
Lindane emul.	3	0	0	1	5[a]	10	1	1	1	many
Chlorpyrifos oil	3	0	0	3	18[a]	—	—	—	—	—
Chlorpyrifos emul.	2	1	1	2	10[a]	10	0	0	1	few
Carbaryl water	2	0	0	2	14[a]	10	2	many	1	some
Untreated	3	3	21	3	17	5	5	many	5	many

[a] Successful attacks above 22 ft killed the tree.

were successful on the unsprayed portion of treated trees.

However, chlorpyrifos was not effective in a series of tests just completed in 1976. In these tests water emulsions did not protect ponderosa pine from attracted attacks of mountain pine beetle in Colorado. The data for concentrations of 0.5% to 2.0% show effectiveness ranging from 6% to 26% in protecting 120 treated trees. The cause of this discrepancy with earlier results has not been determined. One could speculate on such possibilities as formulation, preparation, application, qualitative and quantitative attributes of the beetle population, or some other changes in the environmental conditions.

Carbaryl.—When used only as a 2% water suspension in Colorado, carbaryl was 100% effective in preventing attacks in the sprayed zone of the 1972 series, but successful attacks were made in the unsprayed zone. In the 1973 series, 2 trees out of 10 were heavily attacked in the sprayed zone and there were some attacks in the unsprayed zone. In 1975, a well-agitated mix protected all 10 sprayed trees where beetle pressure was very high. In Idaho, the 2% oil suspension was equally as effective as lindane in preventing attacks through treated bark and in preventing successful attacks through untreated bark on treated trees. The effectiveness of the 2% water suspension was similar to the chlorpyrifos formulations.

Mexacarbate.—In Colorado, a 2% oil solution was effective in preventing attacks in the treated portion but attacks above this portion killed the tree. There was strong phytotoxic response by the tree, and testing was discontinued. Mexacarbate has been omitted from the figure and table because it was not tested comprehensively, showed strong phytotoxicity, and was ineffective as an emulsion in another test in California.

Forced Attacks (Fig. 2, 3).—A range of 5–10 attacks and 25–75 in. of egg galleries/ft² of bark surface was found in untreated logs; generally, the smaller values were for mountain pine beetle and the larger ones for western and roundheaded pine beetles.

Lindane.—In California, the 2 and the 0.5% oil solution sprays were 100% effective on ponderosa pine for the maximum period of testing, 26 and 16 months, respectively, against both beetles. The 2% oil solution had been found previously to be 100% effective for 36 months against both beetles on ponderosa pine (Smith 1972). The 2% oil solution, carefully applied by brush, was 91 and 96% effective, respectively, against western and mountain pine beetle for 6 years; at 7 years, its effectiveness declined to 74 and 82%. The 2% emulsion was 100% effective for the maximum testing period of 16 months on ponderosa pine in one series; in another series on ponderosa pine, it was 100% effective for 10 months, but dropped to 60–88% effectiveness at 26 months. The 1% emulsion was 100% effective for 16 months, though it appears to begin losing this full effectiveness at about this time; beetles were just reaching the cambial area but could not make galleries before

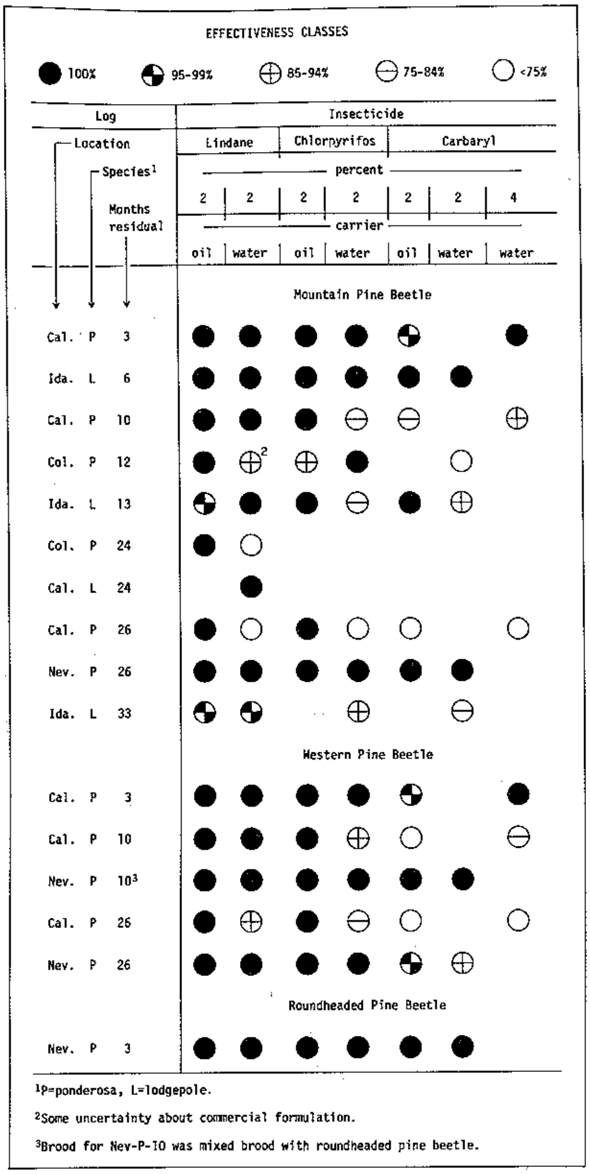

FIG. 2.—Effectiveness of 3 insecticides in preventing forced attacks of bark beetles on pine logs cut from trees at periods after spraying bark. Effectiveness measured by reduction in length of egg gallery per square foot of bark.

53% for the 24-month test; however, after the material had been applied, the emulsion concentrate used for the work was found to have partially broken down.

In Idaho, the 2% oil solution was fully effective in preventing gallery construction at 3 months; at 13 months it dropped to 99% effectiveness, but this level still remained at 33 months. The 2% emulsion was fully effective for 13 months and 99% at 33 months. Many attacks were made through the phloem but dying. The 0.5% emulsion was 100% effective for 6 months but not for 16 months. In a separate small test, 2% emulsion on lodgepole pine was 100% effective for 24 months against mountain pine beetle; however, beetles were just able to reach the wood before dying, suggesting that the spray was beginning to lose its full effectiveness.

In Colorado, the 2% oil solution was fully effective in preventing egg gallery construction for both the 12-, and 24-month period of testing. The 2% emulsion was 89% effective for the 12-month test and only

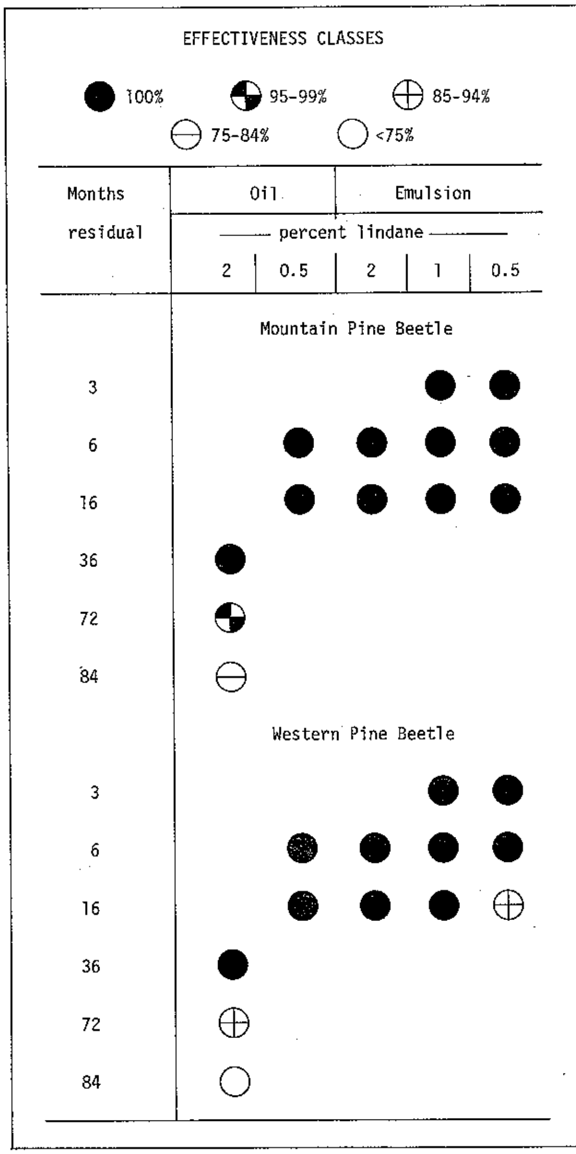

FIG. 3.—Effectiveness of lindane formulations in preventing forced attacks of 2 bark beetles on ponderosa pine logs cut from trees at periods after spraying the bark in California. Effectiveness measured by reduction in length of egg gallery per square foot of bark.

there was no gallery construction. Streaks of resinosis could be found infrequently in the xylem of trees treated with the oil solution, suggesting some phytotoxic response; the emulsion caused no such reaction.

In Nevada, the 2% oil solution and the 2% aqueous emulsion were fully effective in preventing egg gallery construction for 26 months, the maximum time tested. After 3 months, the insecticides were effective against the roundheaded pine beetle, after 10 months against a mixture of western and roundheaded pine beetle, and after 26 months against both western and mountain pine beetle. The logs from Nevada were moved to California for the 26 month test period.

Chlorpyrifos.—In California, the 2% oil solution was 100% effective for the maximum testing period, 26 months; the 2% emulsion was 98 to 100% effective for 3 months but its effectiveness dropped off considerably at 10 and 26 months. In Colorado, the 2% emulsion was 100% effective at 12 months; 2% oil was 94% effective. In Idaho, the 2% oil solution was fully effective at 3 and 13 months but dropped to 85% at 33 months. The 2% emulsion was fully effective at 3 months but dropped to 88% at 13 months; no test was made at 33 months. In Nevada, the 2% oil solution and 2% aqueous emulsion were as effective as lindane.

Carbaryl.—In California, the 4% water suspension was 100% effective for 3 months but there was an increasing loss of effectiveness at 10 and 26 months; the 2% oil suspension was 93 and 95% effective against the 2 beetle species at 3 months but the loss of effectiveness at 10 and 26 months was somewhat greater than for the 4% water suspension. In Colorado, only a 2% aqueous suspension was used and it was 70% effective at the end of 12 months. In Idaho, the 2% oil suspension was fully effective for 13 months; the 2% water suspension was fully effective after 3 months, dropped to 93% after 13 months, and 76% after 33 months. The top of one of the trees sprayed with 2% oil suspension was broken off in 1972–73 which should have made it susceptible to *Ips* and secondary borers. However, 2 years later there were no *Ips* attacks in the broken-off tree and only limited borer attacks. In Nevada, the 2% oil suspension was 100% effective against the roundheaded pine beetle for 3 months, against a mixture of western and roundheaded for 10 months, and against the mountain pine beetle for 26 months; it was 95% effective for 26 months against the western pine beetle. The 2% water suspension was slightly less effective under the same test conditions.

In all tests in Nevada, the insecticides were far more effective than in comparable tests in California except those treatments that were fully effective for 26 months.

Mexacarbate.—In California, a solution of 2% in diesel oil was 100% effective for 12 months on ponderosa pine against both beetles. However, there was a very strong phytotoxic response by the tree as evidenced by pitch eruptions on the bark surface and by numerous necrotic patches in the phloem-cambial zone. The 2% aqueous emulsion was less than 50% effective for 3 months and completely ineffective at 12 months and testing was discontinued. Mexacarbate has been omitted from Fig. 2 for the reasons stated under the discussion of attracted attacks.

Discussion.—Lindane, chlorpyrifos, and to a lesser degree carbaryl, were effective for varying periods of time in preventing attacks by western pine, mountain pine, and roundheaded pine beetles on ponderosa pine and by mountain pine beetle on lodgepole pine. Treatments were slightly less effective when beetles were attracted to treated trees than when they were forced to attack logs cut from treated trees. This difference could be caused by the greater number of attacking beetles and the prolonged attack period for attracted attacks or by some behavioral difference—as yet unknown—between attacks on living trees and cut logs. There was no appreciable difference between species of beetle.

The period of effectiveness varied both with the insecticide: lindane > chlorpyrifos > carbaryl—and with the formulation: oil solution > water emulsion. However, there were phytotoxic effects of oil preparations on thin-barked trees of both species; and there were inconsistencies in results with chlorpyrifos in later tests with mountain pine beetle on ponderosa pine. Research should be done on both problems.

The longer period of effectiveness in Nevada and Idaho than in California and Colorado might be caused by the generally lower temperatures and lower precipitation in the form of rain in Nevada and Idaho or by slower growth rate of the trees.

The extended period of effectiveness of lindane under the test conditions is surprising since in the longest test the trees grew more than 1 inch in diam and 15 to 20% in bark area with considerable sloughing of bark. Such persistence could be explained by penetration of the insecticide into the bark or by some kind of bonding of the insecticide with organic molecules in the bark. The bark could be visualized as an organic sponge which soaks up and then slowly releases the insecticide. Sloughing of bark and erosion are other ways for the release of the insecticides. Pine bark has been suggested as a material for picking up oil spills in water and on land (Ironsides 1973). The extended period of effectiveness of chlorpyrifos could be explained in the same way as lindane; but the persistence of carbaryl, which forms only a suspension in water or oil, cannot be explained in this way.

The insecticide and formulation selected for use would depend on the situation; but particular consideration must be given to possible phytotoxic effects of oil preparations on trees with thin bark.

Under operational conditions for mountain pine beetle, it appears that the basal 30 ft of ponderosa pine less than 18 in. in diam should be sprayed; further field testing is needed to determine the height for larger trees. Height of protective sprays has not been determined for western pine beetle or for mountain pine beetle in lodgepole.

All materials used in the field tests ranked high in toxicity to bark beetles in topical application bioassay (Lyon 1971). However, field tests must be conducted to determine how these insecticides perform under actual field conditions. The laboratory bioassay ranking of mexacarbate > chlorpyrifos > lindane was reversed by the field tests with emulsions to lindane > chlorpyrifos > mexacarbate.

The degree of effectiveness needed to protect the tree has not been fully resolved because we do not know the number of attacks on either a weakened or vigorous tree needed to: initiate the processes leading to death of the tree; establish a strong attractive center for larger numbers of beetles; and effectively establish fungi which can weaken or kill the tree.

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