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CONTROL OF THE MOUNTAIN PINE BEETLE[1] IN LODGEPOLE PINE BY THE USE OF SOLAR HEAT

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INTRODUCTION

The artificial control of bark beetles has received the consideration of foresters for the last quarter century. During this period a number of methods designed to effect control of these beetles have been advocated, but only a few of these have proved efficient in actual practice.

Entomologists directly concerned with developing this phase of forestry were not slow to avail themselves of suggestions and discoveries along this line. Early in the history of forest entomology in North America, A. D. Hopkins[2] recommended the employment of methods designed to kill the broods in the trees where they were developing. At the same time he formulated principles of artificial control which became a basis for experimentation that has resulted in the most efficient methods practiced to-day.

Since that time such progress has been made in the development of control methods that now certain of these may be confidently relied upon to reduce infestations. However, no one method has, without modifications, proved entirely satisfactory as a cure-all in combating epidemics of the various species of bark beetles or even of controlling epidemics of a given species in different host trees. For this reason it has always been necessary to modify even the

[1] *Dendroctonus monticolae* Hopk.

[2] HOPKINS, A. D. BARKBEETLES OF THE GENUS DENDROCTONUS. U. S. Dept. Agr., Bur. Ent. Bul. 83 (pt. I), 169 pp., illus. 1909.

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most reliable of known methods to fit individual conditions. This need of adaptation is emphasized in the artificial control of the mountain pine beetle, *Dendroctonus monticolae* Hopk., since this beetle attacks a number of different species of pine. For instance, two methods have been successfully used in controlling infestations of the mountain pine beetle in yellow pine and sugar pine. One method consists of felling the attacked tree and burning the bark of the infested part of the log; the other consists of removing the bark from the felled tree, thus exposing the broods of beetles, which results in their death.

Both of these methods have been practiced to some extent in the control of infestations of the mountain pine beetle in lodgepole pine. In such infestations, however, neither of them is entirely satisfactory. Owing to the denseness of the stands of lodgepole pine, there is much scorching of adjacent green trees when burning is resorted to, unless the logs are hauled, before burning, to openings in the forest. This precaution increases the cost of control, which makes this method less desirable for extensive use. The peeling method has been used only in a limited way in infestations of lodgepole pine because of the difficulty encountered in removing the bark from these trees. These difficulties were encountered in all attempts to apply the burning or peeling methods to the treatment of broods of the mountain pine beetle in lodgepole pine and led to the development of the solar-heat treatment and its application for the control of these infestations.

The purpose of this bulletin is to describe the development of the solar-heat method of control, to record the salient details of the experimental field work, and to discuss the practical application of the method on the Crater Lake Park control project.

PREVIOUS INVESTIGATIONS

The principle of the solar-heat method of bark-beetle control has been known for a number of years. F. C. Craighead published the first account of the method as a control factor.[3] His first observations were made in 1917, when the death of broods of *Cyllene caryae* Gahan in hickory logs was accounted for by the sun's heat. In 1918, in Virginia, he experimented with various species of scolytid beetles in pine and found them to be easily killed by the heat. Subsequent observations confirmed the results of these first experiments and led to further investigations into the possibility of utilizing direct sunlight as a control agency.

Craighead's first experiments in 1918 in Virginia were followed by others in the West. In the summer of 1920 detailed experiments were carried out at North Fork, Calif., by J. M. Miller, and at Ashland, Oreg., by J. E. Patterson.

The method developed by these experiments was first used as an auxiliary measure in control operations against *Dendroctonus brevicomis* Lec. in western yellow pine. At North Fork, in central California, in 1920 and 1921, and on the Antelope project in northern California, in 1921, it was used during the summer periods, when fire hazard was great, instead of the burning method usually practiced.

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[3] CRAIGHEAD, F. C. DIRECT SUNLIGHT AS A FACTOR IN FOREST INSECT CONTROL. Ent. Soc. Wash. Proc. 22: 106-108. 1920.

It was first used as a major method of control on the Crater Lake Park project in combating an epidemic infestation of the mountain pine beetle, *D. monticolae*, in lodgepole pine. In addition to being the first large-scale application of the method, this was the first time it was employed in the control of infestations in lodgepole pine.

The method has, however, been tested, with varying degrees of success, in other localities in the treatment of other pines infested with different species of bark beetles.

The method, with modifications, was tried in the Kaibab Forest, in Arizona, by F. P. Keen, who was in charge of control work on this project in 1924 and 1925. The beetle involved was *D. ponderosae* Hopk., and the tree infested was yellow pine, *Pinus ponderosa*. Altogether 602 infested trees were treated in these tests. The application of the method was varied in order to secure results on different ways of exposure. The general results were unsatisfactory, since only partial brood mortality resulted from even the best exposures obtained. It appears from this experiment that the method is not effective in the treatment of trees with thick bark.

Another test of the method was carried out in the Bitterroot Forest, Mont., during June and July, 1926 and 1927. This experiment, under the supervision of J. C. Evenden, was conducted in lodgepole pine stands infested with the mountain pine beetle, *D. monticolae*. About 200 infested trees were used in the tests, and they were felled on as many different sites and exposures as the experimental area afforded. Subcortical and air temperatures were taken daily. Tests were made on trees cut the preceding fall, as well as upon those felled during the spring months. It was found that air temperatures of 87° F. or higher were essential to obtain killing temperatures under the bark of logs exposed in direct sunlight. In these tests killing temperatures were registered only four times during the control period. Chiefly because of this failure to attain killing temperatures, the solar-heat method was not efficient for practical control purposes in this latitude. Other adverse factors were the slope of the site, which affected the incidence of the sun's rays, particularly on north exposures; and shade, due to the density of the timber stands.

Still another test of the solar-heat method was made under conditions varying greatly from those of the preceding examples. This experiment was made in the Prescott National Forest, Ariz., in May, June, and July, 1928, by John C. McNelty. The trees used were *Pinus ponderosa*, infested with mixed broods of *Ips ponderosae* Sw., *I. lecontei* Sw., and *I. integer* Eich. The trees were not infested when felled but were subsequently attacked by all three species. Temperature did not greatly affect their attack of these logs. On logs in direct sunlight the attack was made on the undersides first, though later it was extended to all surfaces. Relatively high daily air temperatures were recorded, the range being between 80° and 90° F. Bark temperatures as high as 118° were registered, the average maximum being about 112°. Mortality of the broods varied with the size of log and thickness of bark. On thin-barked logs up to 10 inches in diameter, 50 per cent of the insects were killed under a strip 4 inches wide on the tops of the logs. No mortality resulted from the exposure of thick-barked logs about 10 inches in diameter.

The conclusions reached by McNelty are: "The maximum kill from sun curing by turning the logs would be 50 per cent on material under 8 inches in diameter and 20 to 30 per cent on logs up to 10 inches in diameter."

The results of this experiment are consistent with those obtained by the writer with the solar-heat method in the Crater Lake Park. Broods of Ips infesting the same trees infested with the mountain pine beetle survived the heat treatment when the latter species were killed with short exposures.

THE METHOD

HOW THE INSECTS ARE KILLED

The principle underlying the solar-heat method is extremely simple and well known, namely, that certain high temperatures are fatal to living organisms. Primarily the method consists of utilizing the sun's rays to attain such temperatures as are fatal to the broods of the beetle in or under the bark of infested logs. It has been found that bark temperatures above 110° F. are necessary to cause death. The moisture content of the inner bark seems to be important only as a factor slightly conditioning the temperatures in the bark. Beetle broods respond to this treatment only in thin-barked trees. Lodgepole pine and western white pine are examples of this type. Experiments have shown that the method is not applicable to trees that have thick bark, such as yellow pine and sugar pine, since the thickness of the bark of these trees acts as an insulator preventing the surface heat from reaching the beetle broods, which are either inside or under the bark.

TECHNIC OF APPLICATION

Since the death of the insects is contingent upon high bark temperatures, it is necessary to expose the infested logs in such a way that the desired temperatures will be attained. During the experimental application of this method in the Crater Lake Park control work, and in the tests made since, various ways of preparing and exposing the logs were tried, and a technic of handling that gave uniform and successful results was developed.

The infested trees are felled so that their trunks lie in a north-and-south direction. It is necessary to have the logs in this position in order to expose their tops and both sides to direct sunlight during the course of the day. After they have been felled, the limbs along the infested length are removed, in order to expose fully the infested bark, and the uninfested tops are cut off. After this treatment the logs are left exposed to the sun for a period of from two to five days. They are then turned over in order to expose the opposite side. In the case of the larger trees (above 20 inches in diameter) or trees felled in low brush, on uneven ground, or in situations where it is impossible to place them in a north-and-south direction, it is sometimes necessary, in order that the sun's rays may reach all the bark surface, to turn the logs twice, one-third round, or about 120°, each time. Intervals of at least two days of sunshine must elapse between turnings in order to obtain satisfactory results. It is necessary, of course, to so place the logs that unobstructed sunlight will reach them.

EXPERIMENTAL PROCEDURE

The studies reported in this bulletin were conducted in areas infested by the mountain pine beetle in the Crater Lake National Park, Oreg., during the spring and summer seasons of 1925, 1926, and 1927. They were carried out during the time that control operations against this beetle were in progress. Since several thousand infested lodgepole pines were treated by the solar-heat method during this time, the amount of material available was more than sufficient to determine the accuracy of the experimental data.

The primary objects of these studies were (1) to determine the minimum bark temperatures required to kill the broods of the beetle, and (2) to develop a practical and efficient way of handling the infested material. The following were the principal points about which the investigation centered: (1) The difference, in degrees, between effective bark temperature and the temperature of the surrounding air; (2) the length of exposure at different bark temperatures necessary to cause death; (3) the period of the day when killing temperatures occur; (4) the relation of killing temperatures to humidity; (5) the surface of the log, expressed in degrees of arc, attaining killing temperature with exposures for various periods; (6) the best position of the log relative to the angle of the sun's rays; and (7) the season of the year during which the method is effective.

Chemical thermometers were used to obtain the temperature data. This type was found most satisfactory, as the bulb was easily inserted between the bark and the wood and there was no metal to affect the temperature readings. In each test three or more thermometers were used. Two were inserted under the bark on the top or sides of the log in such positions that one registered the inner-bark temperatures in the part exposed to direct sunlight and the other gave the temperatures in the shaded part of the log. Another thermometer of the same type was hung at breast height on the north side of a near-by standing tree to register the air temperature. A thermograph was used in some of the tests made in 1927 to record the air temperatures, although most of the data are plotted from readings of the chemical thermometers.

The data on the other points investigated were obtained by exposing the logs in different positions throughout the field seasons and by variations in the length of exposures.

EXPERIMENTAL DATA

The bark temperatures and concurrent air temperatures recorded in the separate tests of the experiments are shown in Tables 1 to 6 and in Figures 1 to 6, the tables giving the data in tabulated form, and the figures presenting the same data graphically.

TABLE 1.—*Hourly temperatures recorded under the bark of a log felled and lying in a north-and-south direction, September 10, 1926*

[Elevation 6,100 feet. See fig. 1]

Hour	Air temperature in shade	Temperature under bark of log— On east side	On top	On west side	Hour	Air temperature in shade	Temperature under bark of log— On east side	On top	On west side
	°F.	°F.	°F.	°F.		°F.	°F.	°F.	°F.
8 a. m.	62	74	70	64	1 p. m.	84	104	138	90
9 a. m.	76	92	86	72	2 p. m.	85	94	136	112
10 a. m.	80	110	102	78	3 p. m.	80	90	120	128
11 a. m.	80	126	120	82	4 p. m.	78	86	96	120
12 m.	80	120	132	84	5 p. m.	72	80	92	102

TABLE 2.—*Hourly temperatures recorded under the bark of a log felled and lying in a north-and-south direction, July 10, 1927*

[Elevation 5,500 feet. See fig. 2]

Hour	Air temperature in shade	Temperature under bark on top of log— In sun	In shade	Hour	Air temperature in shade	Temperature under bark on top of log— In sun	In shade
	°F.	°F.	°F.		°F.	°F.	°F.
8 a. m.	60	72	62	1 p. m.	80	140	90
9 a. m.	78	84	76	2 p. m.	86	136	90
10 a. m.	80	100	78	3 p. m.	83	118	88
11 a. m.	81	122	82	4 p. m.	81	98	80
12 m.	83	134	84	5 p. m.	78	96	76

TABLE 3.—*Hourly temperatures recorded under the bark of a log felled and lying in a north-and-south direction and percentage of brood killed by certain critical temperatures, June 15, 1927*

[Elevation 6,000 feet. See fig. 3]

Hour	Air temperature in shade	Temperature under bark on top of log— In sun	In shade	Brood killed	Hour	Air temperature in shade	Temperature under bark on top of log— In sun	In shade	Brood killed
	°F.	°F.	°F.	*Per cent*		°F.	°F.	°F.	*Per cent*
8 a. m.	58	60	58	0	1 p. m.	85	114	80	28
9 a. m.	63	72	61	0	2 p. m.	85	122	86	100
10 a. m.	68	79	65	0	3 p. m.	64	112	69	--------
11 a. m.	74	104	69	0	4 p. m.	61	90	66	--------
12 m.	80	110	76	6	5 p. m.	59	72	63	--------

TABLE 4.—*Hourly temperatures recorded under the bark of a log felled and lying in a north-and-south direction, intermittent clouds partially obscuring sun, June 20, 1927*

[Elevation 6,000 feet. See fig. 4]

Hour	Air temperature in shade	Temperature under bark on top of log—		Hour	Air temperature in shade	Temperature under bark on top of log—	
		In sun	In shade			In sun	In shade
	°F.	°F.	°F.		°F.	°F.	°F.
8 a. m.	60	70	60	1 p. m.	80	111	88
9 a. m.	76	82	76	2 p. m.	88	134	95
10 a. m.	79	98	78	3 p. m.	76	110	87
11 a. m.	84	118	92	4 p. m.	80	115	87
12 m.	78	113	88	5 p. m.	77	94	84

TABLE 5.—*Hourly temperatures recorded on surface of bark and under bark on top of log felled and lying in a north-and-south direction, June 21, 1927*

[Elevation 6,100 feet. See fig. 5]

Hour	Air temperature in shade	Bark temperatures in sun—		Hour	Air temperature in shade	Bark temperatures in sun—	
		On surface	Under bark			On surface	Under bark
	°F	°F	°F		°F	°F	°F
8 a. m.	60	78	70	1 p. m.	86	130	121
9 a. m.	70	84	82	2 p. m.	92	140	136
10 a. m.	80	120	96	3 p. m.	84	126	118
11 a. m.	86	128	120	4 p. m.	80	108	115
12 m.	90	134	123	5 p. m.	78	90	94

TABLE 6.—*Hourly temperatures recorded under the bark of a felled log lying north and south and of a near-by standing infested tree, June 14, 1927*

[Elevation 6,000 feet. See fig. 6]

Hour	Air temperature in shade	Temperature under bark on top of prostrate log	Temperatures under bark of standing tree on—			Hour	Air temperature in shade	Temperature under bark on top of prostrate log	Temperatures under bark of standing tree on—		
			South side of stump	South side of trunk	North side of trunk				South side of stump	South side of trunk	North side of trunk
	°F.	°F.	°F.	°F.	°F.		°F.	°F.	°F.	°F.	°F.
8 a. m.	58	60	53	62	50	1 p. m.	78	114	75	79	61
9 a. m.	63	72	55	64	52	2 p. m.	75	123	72	76	60
10 a. m.	68	79	58	67	56	3 p. m.	70	112	67	74	57
11 a. m.	69	104	68	73	60	4 p. m.	67	99	62	73	55
12 m.	76	110	74	78	60	5 p. m.	56	72	58	65	55

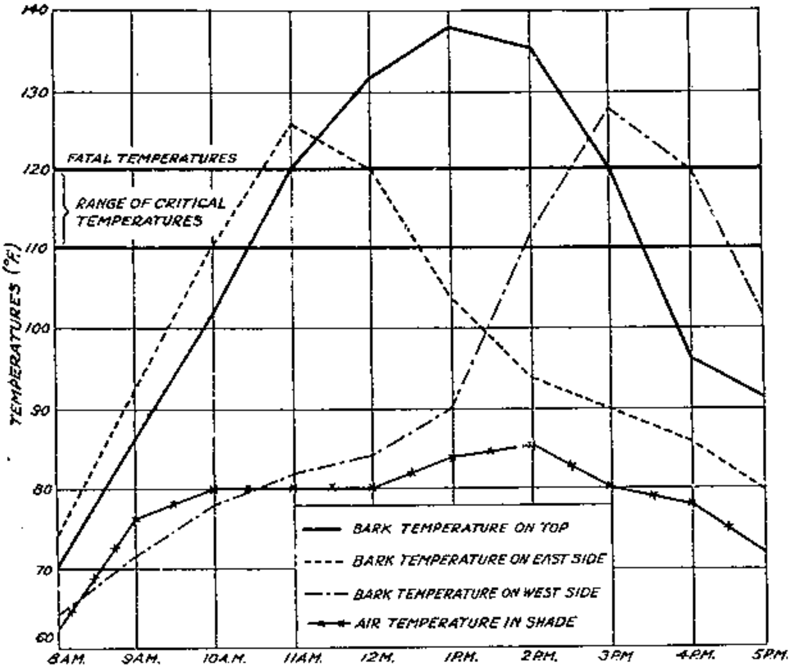

FIGURE 1.—Curves showing air temperatures in shade and concurrent temperatures recorded under the bark on the top and the east and west sides of a log felled and lying in a north-and-south direction, September 10, 1926. Elevation 6,100 feet

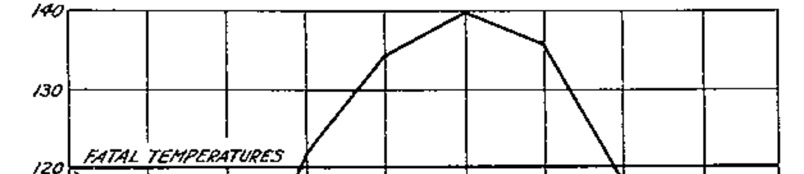

FIGURE 2.—Curves showing air temperatures in shade and concurrent temperatures recorded under bark in shade and under bark in direct sunlight on top of a log felled and lying in a north-and-south direction, July 10, 1927. Elevation 5,500 feet

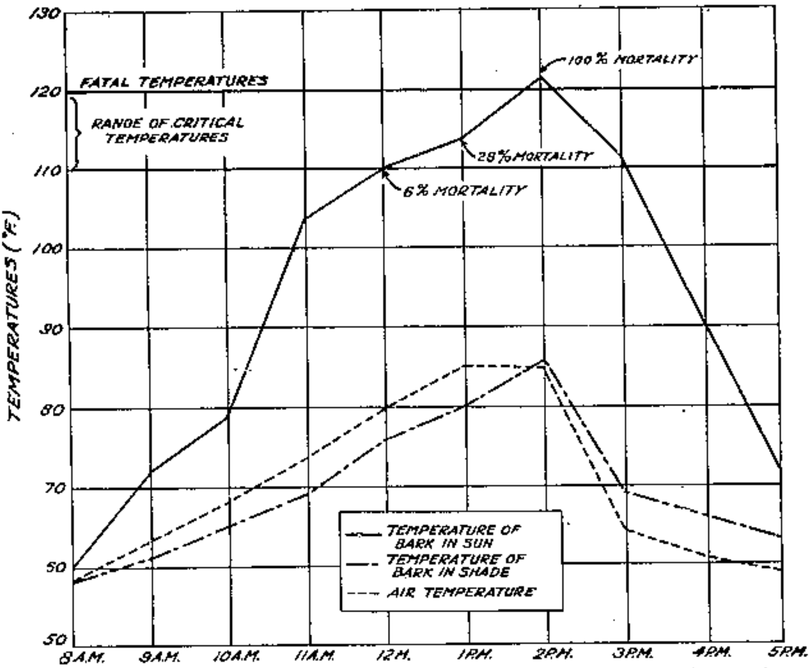

FIGURE 3.—Curves showing air temperatures in shade and concurrent temperatures recorded under bark on top of a log, both in shade and in direct sunlight, and percentage of brood of the mountain pine beetle killed in the portion exposed to the sun by certain critical temperatures, June 15, 1927. Elevation 6,000 feet

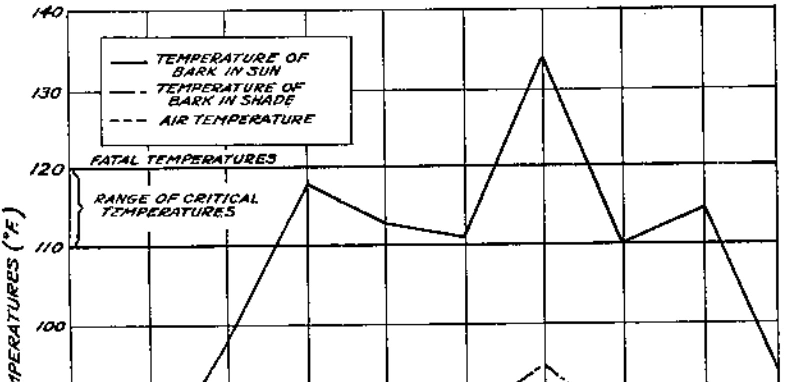

FIGURE 4.—Curves showing air temperatures in shade and concurrent temperatures recorded under bark on top of a log, both in shade and in intermittent sunlight, June 20, 1927. Elevation 6,000 feet

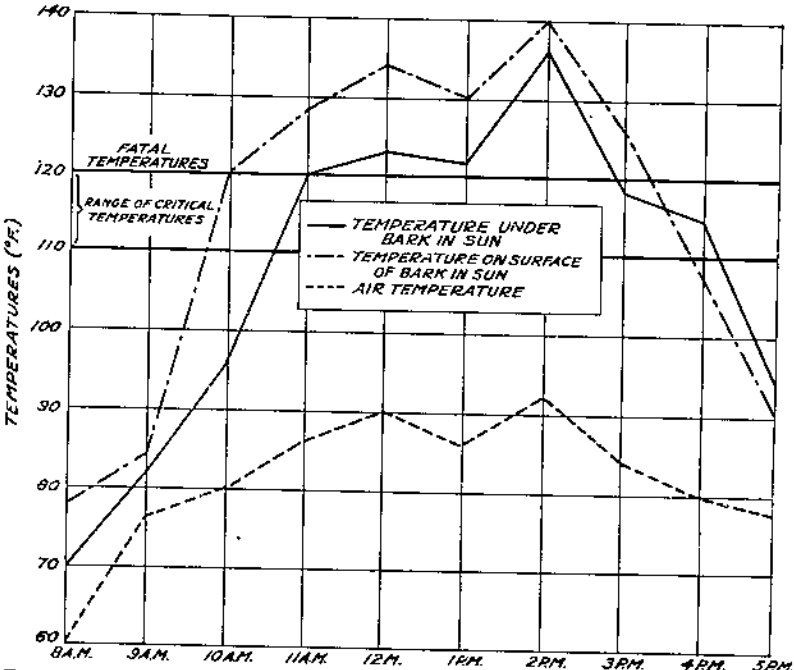

FIGURE 5.—Curves showing air temperatures in shade and concurrent temperatures recorded on the surface of bark and under the bark on the top of a log felled and lying in a north-and-south direction in direct sunlight, June 21, 1927. Elevation 6,100 feet

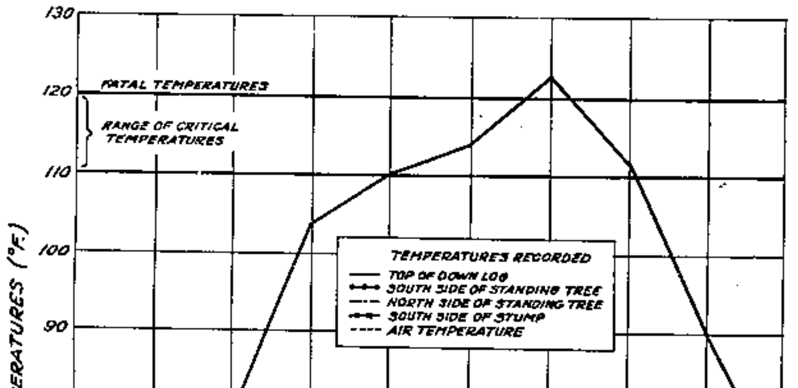

FIGURE 6.—Curves showing air temperatures in shade and concurrent temperatures under the bark on the top of a felled log lying north and south, on the south and on the north sides of an infested standing tree, and on the south side of an infested stump, June 14, 1927. Elevation 6,000 feet

DISCUSSION OF THE DATA

The results obtained in these experiments show that a bark temperature of 120° F. is fatal to broods of the mountain pine beetle with a minimum exposure of 20 minutes. (Figs. 7 and 8.) Longer

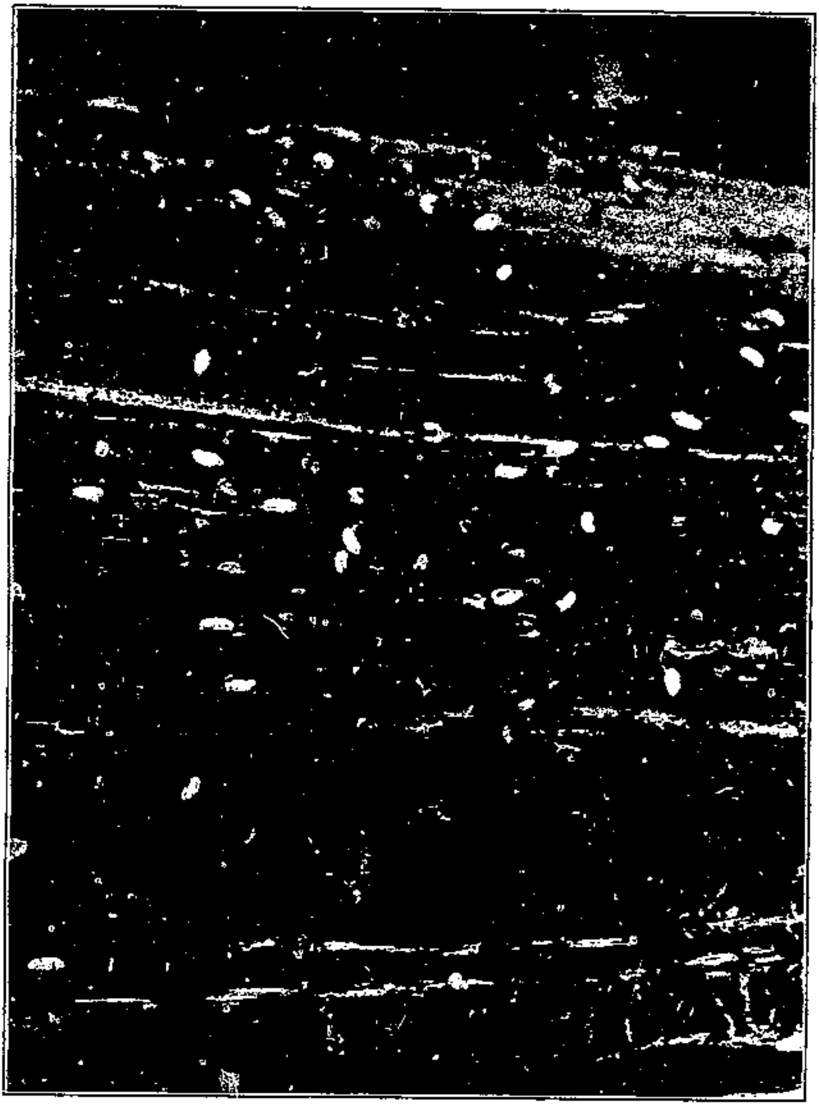

FIGURE 7.—Brood of the mountain pine beetle which had been protected from the sun's rays by a covering of brush placed over the log at this point; the larvae and pupae in this part were uninjured

exposure at lower temperatures will also cause death, though the broods of the beetle will safely endure bark temperatures of less than 100°. The range of critical temperatures is between 110° and 120°. Bark temperatures at any point in this range resulted in death after an exposure of sufficient length. Approximately 5 to 6 per cent of the brood was killed at 110° with short exposures, and mortality increased as the temperature rose above this point, reaching the maximum at 120°, which was found to be 100 per cent fatal. (Fig. 3.)

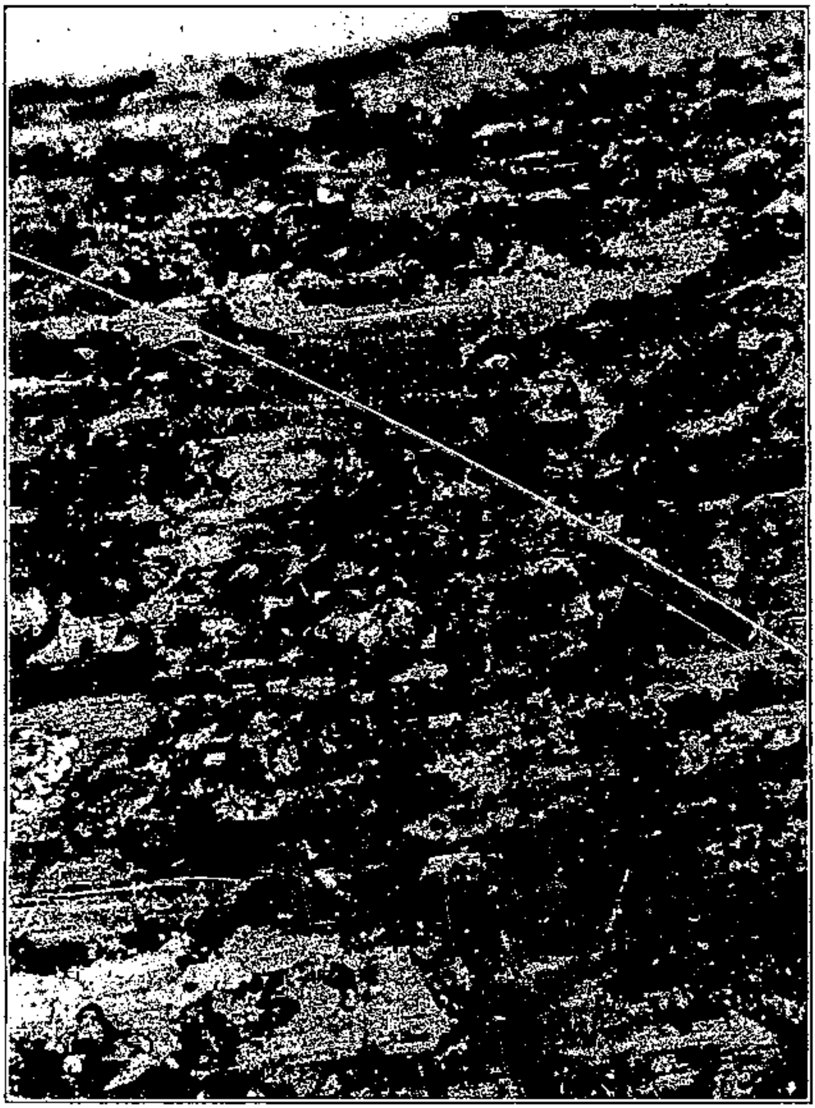

FIGURE 3.—Brood of the mountain pine beetle under a section of the bark which had been exposed to the direct rays of the sun for one day. The maximum temperature registered under the bark of this section was 126° F. The larvae and pupae show as shrunken bodies in the pupal cells

Bark temperatures of logs exposed to sunlight were from 30° to 50° higher than the surrounding air temperatures, the main difference being about 40°. Bark temperatures as high as 140° F. were registered when the air temperature was 89°, a difference of 51°. With an air temperature of 80° the concurrent temperature in the inner bark on prostrate logs in direct sunlight was often 120° or higher. Temperatures of the inner bark in shaded positions did not vary greatly from the air temperatures and were not fatal to the broods.

There is a greater correlation between the angle of incidence of the sun's rays and bark temperatures than between air temperatures and bark temperatures. Thus it will be seen that the data in Table 1 and Figure 1 show a higher relative bark temperature on the east side of an exposed log than on its top or west side during the hours from 8 a. m. to 11 a. m., and, conversely, higher bark temperatures are recorded on the top and west side of a log during the hours from 11 a. m. to 2 p. m., and from 2 p. m. to 5 p. m., respectively; while at any given time during the daily period of exposure the concurrent air temperature is the same near all surfaces of the log. Air temperature, however, is perhaps a better criterion for presupposing lethal bark temperatures, since it can be ascertained by simple tests, and it is therefore more convenient in practical application. Air temperatures of 80° to 85° F. and above insure lethal temperatures in bark exposed to the sun's rays.

The length of exposure necessary to kill the broods in the upper ranges of bark temperatures is surprisingly short. The minimum duration of exposure required to effect mortality at 120° or higher was from 20 to 30 minutes. Longer exposure was necessary at lower temperatures, two to three hours being required with a bark temperature of 110°. Anesthesia set in at 110° and this condition resulted in death when prolonged.

The bark of the trees on which the tests were made varied in thickness with the size of the trunk. At the base the thickness ranged from one-fourth to three-fourths of an inch, with an average of one-half inch. Thirty feet from the ground the range was from one-eighth to three-fourths, with an average of three-eighths inch. At the top, where the top was reduced to about 4 inches in diameter, the bark averaged one-sixteenth of an inch thick.

Broods of *D. monticolae* under white pine bark up to 1¼ inches thick die with an exposure of six hours at the critical temperature.

The susceptibility of the various developmental stages of the insect was practically the same. The old adults and new adults succumbed first, followed in order by the pupae and larvae. Individuals in all stages, however, became inactive at about 110° F., the slight difference in rate of mortality being correlated with duration of exposure rather than with difference in temperature. Incubation of the eggs was not prevented, though the newly hatched larvae were very susceptible to high temperatures.

The experiments showed that killing temperatures were registered in the inner bark from 10 a. m. to 4 p. m. (Fig. 1.) The duration of this period varied slightly, however, with the season, and is relative to the angle of the sun's rays. The maximum duration of this period occurs in June and July in the latitude in which these experiments were made. (Fig. 9.)

The moisture content or humidity of the inner bark does not play an important rôle in the death of the insects. Broods in logs having a very moist inner bark died at the same temperatures as other broods in logs on which the bark was very dry. Humidity does, however, have a direct bearing on bark temperatures, since it facilitates the penetration of heat, and therefore the killing point is reached sooner in moist bark. Equally high temperatures are registered in dry bark, though a slightly longer exposure is required. Death of the broods results when killing temperatures are reached regardless of humidity in the bark.

A study of the moisture content of the beetles themselves was not attempted, although the fact that some beetles resisted critical temperatures for a period, but eventually succumbed, indicates that it is a factor of importance.

The arc of the circumference of the log on which killing temperatures are registered during each exposure is dependent upon the position of the log relative to the axis of the earth. A greater arc is subjected to direct sunlight, and resultant lethal temperatures, when

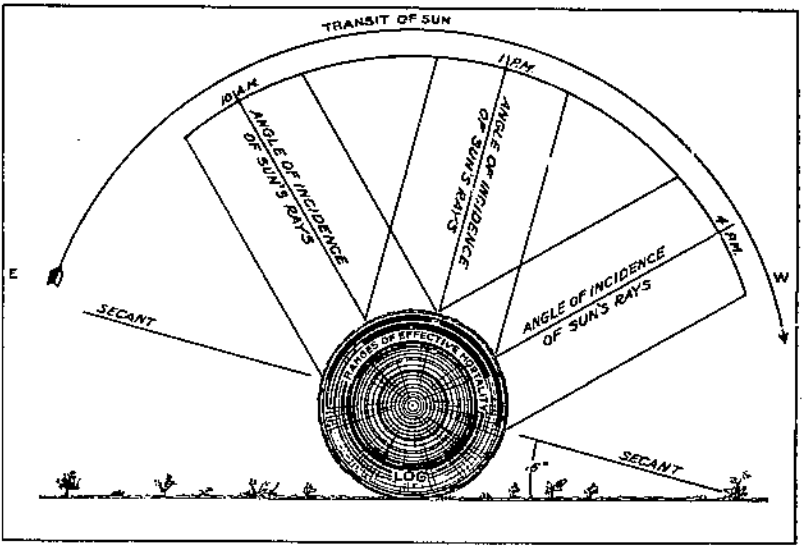

FIGURE 9.—Diagram illustrating ranges of mortality from solar heat under the bark of the upper half of a log during the transit of the sun through the daily arc (June and July) when the log is lying in a north-and-south direction. When the logs are rolled for the second exposure the part that was not thus exposed takes exactly the position occupied here by the exposed portion

the log is approximately parallel with the earth's axis and at right angles to the apparent daily transit of the sun. (Fig. 9.) When the log is in this position almost the entire upper half of the circumference is exposed to the direct rays of the sun during the daily period when killing temperatures are registered. Under these conditions the range of mortality covers an arc of one-half the circumference of the log. This range is not limited to the portion of the circumference on which the sun's rays fall perpendicularly during the period of killing temperatures, but extends down the sides of the log beyond this arc, as shown in Figure 9, to where the sunlight strikes at an angle several degrees from the perpendicular. The heat reflected from the ground serves to carry this killing range somewhat farther around the log, and its effect is an overlapping of the ranges of mortality during the second exposure. Though the secant of the mortality arc on the log is not parallel with the ground surface (fig. 9), this can be disregarded when the log is turned for the second exposure, since the log is turned one-half over, which brings the unexposed surface into the position formerly occupied by the exposed part.

To obtain the killing temperatures in the inner bark on the maximum log surface for each exposure it is necessary to place the log in a position which will permit direct sunlight to reach the greatest area of bark surface between 10 a. m. and 4 p. m. It has been found by experimentation and in actual practice that the best position of the felled logs is approximately north and south. In this position the east side of the log is exposed to the direct rays of the sun during the period before midday, the top during midday, and the west side during the post-midday. The sun's rays also fall more nearly perpendicular to the surface of the log when it is so placed. It is a well-known fact that air temperatures are much higher very near the ground than a foot or more above the ground surface. Because the same conditions affect bark temperatures, the logs should be dropped directly on the ground rather than left bedded on prostrate logs or other débris, since more heat radiation from the earth reaches the logs when they lie on the ground.

A modification of the above procedure would perhaps be necessary in the treatment of trees on steep north slopes where the angle of incidence of the sun's rays would be more oblique, owing to the inclined position of the log. In these situations the placing of the logs in an east-and-west direction would be better, though this would entail turning them twice in order to secure complete exposure to the direct rays of the sun. As there were no north exposures on the experimental control area, this detail could not be studied.

Temperature tests made on infested standing trees gave some interesting results. (Fig. 6.) The temperatures of the inner bark on the south side and the north side of the trunk, and the south side of the base or stump, of these trees were recorded. The bark temperatures on the top of a neighboring felled log, and the air temperatures were recorded at the same time. The bark temperatures on the south side of the standing trees varied only a few degrees from the air temperatures. The bark temperature on the north side was considerably lower, the difference being 17° at the peak of the curve. The highest bark temperature of the stump was 4° lower than that of the trunk (south side) at breastheight. While these temperatures remained below 80° F., bark temperatures on the felled log reached a peak of 123°. These tests show the difference between bark temperatures of standing and of felled trees, and they explain why mortality does not occur in broods developing in standing trees.

It has been determined, at least for the climate in which this work was done, that an air temperature of 80° F. indicates lethal temperatures in the inner bark of portions of felled logs exposed to direct sunlight. Since this relation is fairly constant, air temperature becomes an indicator of the efficacy of the solar-heat method of control at any given time. It can be safely assumed that the method will be effective during any part of the year when air temperatures are 80° or higher. It was employed with entire success during May, June, July, September, and early October of 1925, 1926, and 1927, on the Crater Lake Park control project. No control work was done in August, as the beetles are flying at that time.

PRACTICAL APPLICATION IN THE CRATER LAKE PARK PROJECT

The crucial test of any method of insect control comes with its practical application in the field where natural conditions prevail. The solar-heat method was given a thorough trial on the Crater Lake Park project during the years 1925, 1926, and 1927. Its effectiveness was demonstrated in the successful treatment of over 9,000 lodgepole pines infested with broods of the mountain pine beetle.

PHYSICAL CONDITIONS ON THE PROJECT AREA

The Crater Lake National Park is situated on the crest of the Cascade Mountains in southern Oregon, in latitude 43° north. The control area is located in the southern half of the park in elevations ranging from 5,500 to 6,300 feet. The topography of this area ranges from rugged canyon walls to flat plateaus or benches. The slopes are mainly southern, with east and west exposures. The infested areas occurred almost entirely in the pure lodgepole pine type of stand.

The meteorological conditions are typical of the high mountainous section of the North Pacific States. Daily temperatures during the period of control operations ranged from 32° F. at night to a maximum of 90° at midday. Electrical storms, followed by rain, were frequent throughout the seasons. These storm periods, however, did not seriously interfere with the solar-heat treatment of the infested logs, since the percentage of clear days was comparatively high. In general, the conditions on this project were favorable for the effective employment of the solar-heat method, and accordingly the method should be equally successful on all other areas where the meteorological conditions are similar.

APPLICATION OF THE METHOD

The use of the solar-heat method on the Crater Lake Park project did not involve any material changes in artificial-control technic prior to the actual treatment of the logs. The infested areas were surveyed in the usual way, and the trees to be treated were marked by established methods. However, from this point on to the last detail of the actual treatment of the logs an entirely new procedure was followed.

The trees were felled so as to lie north and south, in order to expose the greatest arc of their circumference to direct sunlight. Care was exercised in felling the logs to get them in such position that they were shaded as little as possible by adjacent standing trees. Whenever feasible, the bole was placed in contact with the ground to obtain for it the highest temperatures. The limbs along the infested length of the log were then removed and the top cut off. (Fig.10.) The limbs and tops were either piled or scattered; the former method was used on camp sites, along roads, and in other places where a thorough clean-up was desired, and the latter procedure was followed in more remote situations. After the logs had been prepared in this way, they were left to the action of direct sunlight from two to five days. They were then turned half over to expose the other side. (Fig. 11.) This completed the treatment.

FIGURE 10.—Method of preparing lodgepole pines infested with the mountain pine beetle for treatment by solar heat. The trees are felled to lie in a north-and-south direction in order to secure the maximum exposure on the surface of the bark during the daily period of killing temperatures. The logs are then limbed and topped, and the brush is piled, or scattered, well away from the logs to allow direct sunlight to reach them

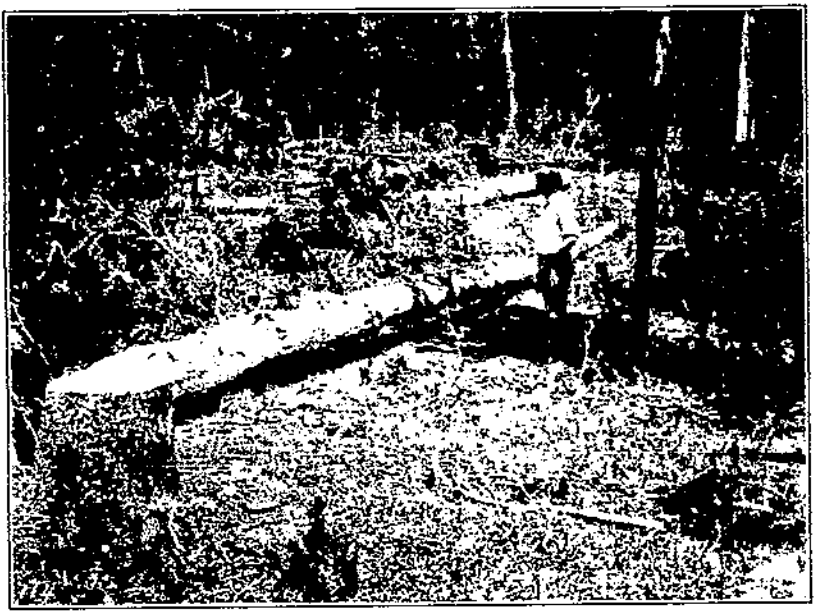

FIGURE 11.—A group of logs that have been treated by the solar-heat method. The logs are shown in the final position after they have been rolled half over and exposed for the second time. The photograph gives a general view of a treated area, showing the average spacing of infested trees and surrounding conditions

Each treating crew consisted of three men. Two men felled and topped the trees, while the third man cut off the limbs, and piled them when necessary. Each crew felled and prepared an average of 40 trees per day. The same crew returned and rolled in one day all the logs prepared in one week. Each log was cut so that the prepared section contained the entire brood of the insect; consequently the logs ranged in length from 20 to 60 feet, and in some cases included the entire bole of the tree. Cant hooks and peaveys were used in turning the logs. Three men experienced no difficulty in turning all but the very largest and longest logs. When such were encountered, they were cut into two or more sections. After each log was turned for the final exposure, a distinguishing ax mark was made against the kerf on the butt end to denote that the log had been turned. One man of each turning crew checked off from the treating record the serial number of each tree as it was turned, and thus all missed logs were identified and located for subsequent turning.

COMPARISON OF THE SOLAR-HEAT TREATMENT WITH THE BURNING METHOD

In the first control work on this project, early in 1925, the burning method of treatment was employed. It was soon apparent that this method was not at all suitable for use in this type of infested timber because the stands were fairly dense and therefore much scorching of green trees resulted. Enough trees were burned, however, to establish a basis for comparing the effectiveness and cost of this method with the solar-heat treatment which was subsequently employed. These data, secured on a project where both methods were used, are of great value in comparing results and costs. In addition to this basic information, similar data on the burning method are available from other projects in lodgepole pine infested by the same beetle.

These data show that the two methods were equally effective in killing the beetle broods. The average cost of the burning treatment was $2 per tree, and of the solar-heat treatment, $1.22 per tree, a difference of 78 cents per tree in favor of the solar-heat treatment. An analysis of these costs, however, reveals factors peculiar to each method which account for this difference. For instance, it is almost always necessary to buck the logs in piles to obtain thorough treatment by burning. Also, when working in crowded stands, it is necessary to haul the logs to openings for burning in order to avoid scorching the adjacent green trees. This additional work results in increased unit cost when the burning method is used. On the other hand, the cost of the solar-heat treatment is increased and approximates that of the burning method when it is necessary completely to dispose of the slash.

The advantages and disadvantages of the solar-heat method, as compared with the burning method, may be summarized in the following way:

When slash is scattered or piled, the cost is lower, the same supervision is required, and the effectiveness is equal.

When logs are decked after curing and slash is burned, the cost is higher, closer supervision is required, and the effectiveness is equal.

Other things being equal, the absence of scorching of green stock leaves the forest in better condition.

When the weather is cloudy or the air temperatures are less than 80° F., the solar-heat treatment is not effective.

SUMMARY

The solar-heat method of bark-beetle control consists primarily in utilizing direct sunlight to kill broods of beetles in the inner bark of thin-bark trees, thus eliminating the necessity for peeling them.

It is particularly effective in treating broods of the mountain pine beetle, *Dendroctonus monticolae*, in lodgepole pine logs. It has also been used, with modifications, in treating other pines infested with other species of bark beetles.

Temperature is the major factor. Bark temperatures under 110° F. are not effective. Bark temperatures of 120° or higher will kill the insects with a minimum exposure of 20 minutes. The temperatures between 110° and 120° are critical, and any temperature within this range will kill the broods if maintained two or three hours. Anesthesia occurs at about 110°.

Bark temperatures as high as 140° were registered when the air temperature was 89°. The mean difference between air temperatures and the concurrent bark temperatures is 40°.

Killing temperatures are registered in the bark of logs exposed to direct sunlight and lying north and south, during the hours from 10 a. m. to 4 p. m., when the air temperature is 80° F. or higher.

The effectiveness of the method has been demonstrated by the successful treatment of over 9,000 lodgepole pines infested with broods of the mountain pine beetle in Crater Lake National Park, Oreg. The meteorological data given apply specifically to elevations ranging between 5,500 and 6,300 feet, at 43° north latitude.

The essential points in the application of the method are as follows: Logs should lie north and south and in contact with the ground. They must be limbed and topped and the brush piled or scattered away from the logs. The logs must be fully exposed to the direct rays of the sun during midday for a period of from two to five days. After the first exposure they must be turned one-half over in order to expose the other side. On north slopes it may be necessary to place the logs east and west and turn them twice, 120° each time.

As compared with the burning treatment, the solar-heat method is cheaper, unless the slash is thoroughly cleaned up, when the cost is the same or slightly higher. When the limbs only are burned the two methods are on par as to cost.

The main advantages of the solar-heat treatment are that no standing trees are scorched and no conditions attractive to insects are set up by the work, as is the case when the logs are burned. Its principal disadvantage is that ordinarily more slash is left in the forest, unless it is burned later at additional expense. Both methods are effective in killing the beetle broods.

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