

CONTROL WORK AGAINST BARK BEETLES IN WESTERN FORESTS AND AN APPRAISAL OF ITS RESULTS

By F. C. CRAIGHEAD,¹ J. M. MILLER,² J. C. EVENDEN,³ AND F. P. KEEN⁴

United States Bureau of Entomology

Has control work against bark beetles paid? Approximately one million dollars have been expended on a number of control projects. This article is a discussion of the economics of control work and is a candid appraisal of what the money has bought in the way of values saved and of experience gained for guiding future control efforts. With bark beetles still important factors, the recommendations for control policies here offered are particularly timely.

INTRODUCTION

EVER SINCE forest protection entered into the program of federal and private owners of our western forest areas, the control of those insects that kill timber by mining the cambium of living trees has been a problem of increasing importance. In the efforts to combat this destructive agency direct measures of artificial control developed by entomologists have, during the past few decades, been applied on a fairly large scale against the more important *Dendroctonus* beetles, and to a very small extent against species of bark engravers (*Ips* spp.) and flat-headed borers (Buprestidae).

Such methods were untried to begin with, and their effectiveness could be determined only by actual test in the field. The owner of threatened timber was obliged to make his decision between these two courses of action: either to let nature take its course and await developments, hoping that natural factors would check the insects; or to spend money on expensive

direct measures of control, without positive assurance that the results would be profitable or lasting. In spite of the uncertainty as to what might be accomplished by employing the methods and plans recommended by entomologists, control campaigns of a fairly comprehensive nature have been undertaken on both federal and private timberlands.

The first control project of which there is a record was initiated on the Black Hills National Forest in South Dakota in 1906, when \$2,700 was expended in an effort to check an epidemic of the Black Hills beetle. Since then many projects have been carried out, some of them covering areas of more than 100,000 acres. Up to the present time (1930) approximately \$1,000,000 has been expended in the control of bark-beetle infestations, mainly in reserves of timber which are being held until conditions warrant logging and marketing of the lumber.

With this great amount of work as a background, and with the experience that has been acquired, it seems desir-

¹Principal Entomologist, Washington, D. C.; ²Senior Entomologist, Berkeley, Calif.; ³Entomologist, Coeur d'Alene, Ida.; ⁴Entomologist, Portland, Ore., Division of Forest Insect Investigations, Bureau of Entomology, U. S. Department of Agriculture.

able to take stock of the results obtained and to decide just how this phase of forest protection has paid off on the investment. Without regard to preliminary theories and expectations as to results, what projects have accomplished an actual saving of timber? Under what conditions has control work succeeded and under what conditions has it failed? Continuation of this activity on the scale now being advocated in national forests, parks, and other holdings should at least be guided by the answers to these questions, based upon an unbiased analysis of results of past work.

Unfortunately, because of limited space, it is impossible to present the facts pertaining to each one of these control projects. Consequently these will be reserved for a later and more comprehensive paper, to be published probably by the U. S. Department of Agriculture. In the present article it will be possible to give only a short abstract of the projects, grouped by bark-beetle species and by tree species or region as the case may be.

Control methods necessarily must be based upon information regarding the seasonal history and habits of the insects, and also, until thoroughly tried out in practice, upon certain conceptions and theories. In the employment of proposed methods it was at first taken for granted that the killing of beetles saved trees. This theory depended largely on the early assumption that when a newly-developed brood of beetles emerge from an infested tree, they attack and kill another tree in the vicinity, so that each succeeding generation kills a fairly regu-

lar quota of trees. Therefore, destroying the broods in one infested tree before they emerge saves at least one living tree from attack by the next generation. This conception, if it were the whole truth, would greatly simplify the problem of estimating costs and appraising benefits derived from control work. Obviously on this basis the volume of timber saved would be in direct proportion to the amount of timber treated. However, it was soon realized that so simple an idea of the problem failed to take into account the complex biotic factors which control the abundance of insect populations and govern the rise and fall of bark-beetle epidemics. These even now, after many years' experience in control and investigation, are very little understood.

Other difficulties become obvious when an analysis of the long series of control projects undertaken during the last thirty years is attempted. The following appear to be the most outstanding of these:

1. Lack of accurate data obtained after the completion of the work from the area treated. Some projects have been closely studied by the Bureau of Entomology, but on many others no attempt was made to measure the actual volume of reinfestation that developed after control work was completed.

2. Lack of suitable check areas by which a treated area could be compared with an untreated one. To a great extent this lack of checks is due to natural conditions which can not be remedied. No two areas are ever identical, and seldom even similar in

all their aspects, and it is therefore difficult to reach a conclusion on the results of control work by comparison with check areas.

3. Obscurity of the natural factors influencing the course of the infestation before, during, and after the period of control work. These factors, such as the effects of climatic influences and predators and the distances which beetles fly in reinfesting a control area, may completely outweigh and make it difficult to evaluate the influence of artificial control.

4. Wide variation in objectives, in the control operations that have been undertaken, and in the values, aesthetic or commercial, to be protected. On recreational areas like those in southern California, control work can be considered successful if only a few trees are saved at high cost. In the commercial timber stands of the Northwest, on the other hand, it is frequently the case that a control operation, to be successful, must cause the permanent saving for the sawmill of a quantity of potential lumber worth more than the amount of money spent in killing the beetles. Therefore considerations not purely entomological often enter into the appraisal of results on certain projects.

Another phase of the results from control which has received very little consideration up to the present time has to do with the indirect benefits of the forest. These are seldom tangible and are very difficult to estimate. Perhaps the most important is the reduction of fire hazard within the control area through the removal of trees which would otherwise stand as snags

to start lightning fires and to spread burning embers when fires occur. Forests which have been swept by bark-beetle outbreaks, and in which thousands of dead trees have been left among the surviving live ones, become tremendous fire risks and remain so for years. Control methods which require the felling of infested trees serve to remove many of these dangerous snags from the stand. Projects, therefore, which do not show an actual profit from the viewpoint of the amount of timber saved from beetle attack may in the long run pay through reduction of the fire hazard.

Some forest-protective organizations have maintained yearlong employment for their summer fire-protection force by carrying on insect-control work during the winter period, and consider this good practice, even though the reduction of infestation is not outstanding.

From the considerations just enumerated it is obvious that the entire problem involved in the formulation of a control policy is very complicated and can not be settled by merely laying down a few hard-and-fast rules as to when and where and under what conditions control work is to be recommended. Local conditions and values, and quite often other considerations that are not entomological, must largely determine the plans and strategy for each specific project; and these factors should be taken into account in determining the success or failure of each undertaking.

With all these considerations in mind, it is obvious that any broad conclusions as to the results of past

projects are subject to many reservations. However, at least one outstanding conclusion applies to the entire matter, and may be stated as follows: Each species of bark beetle presents its own special problem and must be dealt with differently from other species as to control methods and strategy, and even the same species may present problems which differ in different regions. The management of control operations must therefore vary according to local conditions within the area to be protected. The treatment of the subject in this paper is therefore by species and region.

THE WESTERN PINE BEETLE (*Dendroctonus brevicomis* Lec.)

The western pine beetle is by far the most destructive enemy of western yellow pine over a great part of its range through British Columbia, Montana, Idaho, Washington, Oregon, and California. Everywhere throughout the western yellow pine forests of this area it kills a few trees each year. It is in California and southern Oregon, however, that its depredations are the most serious, and the losses here frequently run into hundreds of millions of board feet annually. Western yellow pine is the only host tree attacked except in the southern limit of its range, where Coulter pine, a tree of small commercial importance, is also affected.

Under endemic conditions this bark beetle shows a decided preference for the slower-growing trees, and confines its attacks to single trees and small groups of seldom more than 4 or 5

trees in the overmature stands on the poorer sites. But when outbreaks become epidemic it shows less discrimination. The groups increase until they may include from 50 to 100 trees each, and extend into the better sites and include faster growing stock. Under any condition the infested trees and groups are distributed more or less evenly over large areas.

Observations on the same area over a period of years indicate that in some cases losses are rather closely correlated with climatic conditions. Periods of drought with a deficiency of soil moisture result in a building up of epidemics. With a return to conditions of normal moisture, tree growth is accelerated and the losses decrease. Sometimes low winter temperatures cause a high mortality in the broods and bring about sudden declines in the losses.

THE WESTERN PINE BEETLE IN THE PACIFIC COAST STATES

Infestation Types

The conditions under which control has been attempted may be roughly grouped in three types. These represent differences not only in natural factors, such as climate, site, and composition, but also in the character of the infestations which develop and in the objectives to be accomplished by control work. These types are therefore considered separately in the analysis of results.

West Slope of the Sierra Nevada and of the Cascade Mountains.— This type is limited to the western

slopes of the Cascade Mountains and the Sierra Nevada and to the Coast Range, where conditions of site are varied and the topography is very rough. Pure stands seldom occur, western yellow pine being found in mixture with white fir, Douglas fir, sugar pine, and incense cedar. Conditions of site and growth as a rule are much more favorable than those of the east-slope, the unfavorable sites occurring locally along the lower fringe of the timber belt. All stands are more or less uneven aged and contain a high percentage of young and thrifty mature trees. Although much of the west-side timber is of good quality, stumpage prices are relatively lower than in the east-side type, because of higher logging costs.

Annual losses due to beetles in this type seldom exceed 1 per cent of the stand, and under maximum epidemic conditions do not exceed more than 2 or 3 per cent annually, except in very local outbreaks. Records indicate that an increasing infestation does not maintain its momentum for more than two or at most three seasons, when at least a temporary decline of losses can be expected. Control work here has been taken up mainly for the protection of stumpage values on small areas, although purely recreational areas have been included on a few projects.

East Slope of the Sierra Nevada and of the Cascade Mountains.—

This type includes practically pure stands of western yellow pine growing mainly on volcanic soils east of the Cascade Mountains and the Sierra

Nevada. Some mixture of incense cedar, white fir, and sugar pine may occur to a very limited extent. The type forms an almost continuous belt, extending from the Columbia River in Oregon, or even a little farther north in Washington, to the Tahoe National Forest in California. The timber is slow-growing, largely mature and over-mature, but of fine merchantable quality and high stumpage value. Conditions are favorable for serious beetle epidemics, especially when long periods of drought result in a slowing-down of tree growth. The more severe epidemics have resulted in an annual loss of as high as 15 per cent of the total stand, and in the killing of 50 per cent or more of the timber within a five-year period, as in the Glass Mountain Unit, Modoc National Forest. On this unit the number of trees killed in a single year may run as high as 1,200 per timbered section, but ordinarily the maximum is from 400 to 800. The losses in volume of timber are subject to wide annual fluctuations, an increase for two or three years being followed by a decline from natural causes. The longest period of increase for which there is a record started in 1923 in southern Oregon and northern California, when the annual volume of infested timber increased for four successive seasons, from 1924 to 1928, inclusive, and then declined 80 per cent from natural causes.

Control work in this region is mainly for the protection of stumpage, which ranges in value from \$2.00 to \$7.00 per thousand.

Southern California Recreational Areas.—Conditions here involve small, more or less isolated areas, located at the higher elevations above the brush belt, where western yellow pine occurs in mixture with white fir, sugar pine, Jeffrey pine, Coulter pine, and incense cedar. The site is generally poor. Annual losses to about the same extent occur in western yellow pine and Coulter pine and are of about the same character and duration as those in the West Side type described above. As protection is primarily for the maintenance of cover on recreational areas and summer home sites, values can be rated much higher than in commercial forests.

History of Control Work

The first projects to deal with the control of the western pine beetle were undertaken in the winter and spring of 1912 in the Klamath National Forest. Following this initial attempt, numerous other projects involving a total expenditure of approximately \$275,000 have been carried out under a great variety of conditions, such as those of increasing and decreasing infestation, and in practically all the types of yellow pine stands. These projects have been conducted in the fall, spring, or summer, and continued from one to four years in the same area; and practically all the known methods of controlling outbreaks, such as felling the trees and burning the bark, the use of trap trees, the solar-heat method, and control through logging, have been tested. The acreage covered, the number of trees and the

volume of timber treated, and the costs are given in Table 1.

Conclusions and Recommendations for Control Policy

Admittedly the success of all these projects for western pine beetle control has not been spectacular or outstanding. In many cases the work has shown tangible results, but often these results were not substantial enough to show a profit. Some projects were apparently failures. The data to prove positively either success or failure of certain projects is often inadequate. Indirect benefits of control work, such as the reduction of fire hazard, are usually too intangible to be appraised. With the data at hand any broad conclusions, therefore, must be based upon convictions of entomologists and owners who have had long experience in this work, rather than upon any overwhelming weight of evidence. The predilection of the western pine beetle for slow-growing trees and its apparently quick response to climatic influences must also be taken into consideration. With these limitations in mind it is believed that the following conclusions are considered reasonable by all who have followed and closely analyzed these projects:

1. One season of thorough control work results in a reduction of western pine beetle losses on the treated areas as compared with similar untreated areas.

2. (a). The benefits have been greatest when the natural tendency of the infestation was upward;

- (b). Under a declining infestation

there was only a small difference in favor of the treated over the untreated areas.

3. The benefits from control work have been temporary, lasting only one or two seasons, and a return to conditions similar to those on untreated areas can be expected unless work is continued on the same area year after year.

In the face of these results, under what conditions is direct control work to be recommended? Considering both economic and entomological factors, control of the western pine beetle is believed practicable under the following conditions:

1. In parks and on recreational areas with high values, where dying trees are objectionable and should be removed for aesthetic considerations or for those of forest sanitation. Under these conditions control work need not necessarily pay its way on the basis of stumpage values saved from further beetle attack.

2. (a). On small, well-isolated areas, where the timber is of high value and where the entire infestation can be treated in one season;

(b). On large areas, preferably with partial isolation, where the entire infested area can be treated and where

it is to be logged within three or four years.

3. In commercial stands, whether isolated or not, where control work can be supplemented by logging and salvaged at a low cost or a small profit. Such work may be combined with selective logging to remove susceptible trees and produce better growth conditions, in order to give permanent protection for long periods.

THE WESTERN PINE BEETLE IN THE NORTHERN ROCKY MOUNTAIN REGION

Although the western pine beetle is not nearly so destructive in the northern Rocky Mountain region as in California and Oregon it is of considerable economic importance in Idaho and Montana and northeastern Washington as an enemy of western yellow pine. Light endemic infestations are always present in these yellow pine forests and there have been a few outbreaks which have resulted in the destruction of rather large volumes of timber. There seems to be a much sharper line of demarcation between endemic and epidemic infestations in this region than farther west. Nevertheless the western pine beetle is decidedly secondary in importance as compared with the mountain pine

TABLE 1
RECORD OF CONTROL WORK ON THE WESTERN PINE BEETLE

Type	Number of projects	Period covered	Total ¹ acreage	Number of trees treated	Total Volume M.B.M.	Total Cost
West Slope Yellow Pine	15	1911-1924	750,180	15,103	14,437	\$ 59,310.71
East Slope Yellow Pine	7	1912-1929	743,929	46,825	50,990	211,738.95
S. Cal. Areas	2	1922-1928	43,500	509	363	2,666.88
Total	24		1,537,609	62,437	65,790	\$273,716.54

¹Acres covered on same areas during successive years are totaled, as are the annual costs of maintenance work on the same areas.

beetle. Very frequently such outbreaks are in combination with attacks of the mountain pine beetle, the mountain pine beetle taking the smaller trees and the western pine beetle the older and larger ones. Slow-growing trees and over-mature stands are in abundance, so the fact that the losses are usually light must be due largely to unfavorable climatic conditions for beetle propagation rather than to any lack of suitable host material.

Conclusions and Recommendations for Control Policy

Although the few attempts which have been made to control the western pine beetle in this region seem to have been successful, it is not felt that sufficient experience is available to warrant any definite conclusions. The more broken distribution of the yellow pine type should lend itself rather well to artificial control of this insect.

THE SOUTHWESTERN PINE BEETLE (*Dendroctonus barberi* Hopk.) IN ARIZONA AND NEW MEXICO

In appearance, habits, and character of attack there is very little to distinguish the southwestern pine beetle from its near relative, the western pine beetle. The chief host tree is western yellow pine. This beetle shows a decided preference for old, over-mature trees, and these are attacked singly or in small groups in very scattered distribution. Several species of *Ips* are often associated with this bark beetle in trees attacked by the overwintering generation.

Broods of the Colorado pine beetle (*Dendroctonus approximatus* Dietz) and of the Arizona pine beetle (*D. arizonicus* Hopk.), two species which are largely secondary, may be found in the same trees with the southwestern pine beetle. An outbreak which caused considerable concern occurred on the Prescott National Forest from 1927 to 1928. This infestation, which at its height averaged about 200 trees per section, developed in trees of older age classes which were in competition with a second story of young western yellow pine. Control methods are entirely similar to those employed against the western pine beetle.

History of Control Work

Only one project has been undertaken. An area of 16,000 acres on the Prescott National Forest was covered during the winter and spring seasons of 1928 and 1929. A total of 3,185 trees, with a volume of 413,230 board feet, were treated. Results of the first year's work showed a reduction in losses of 70 per cent, as compared with an increase of 300 per cent on near-by untreated areas. There was a general decline of infestation in the region following the control in 1929, and no further maintenance work has been attempted.

Conclusions and Recommendations for Control Policy

Because of the similarity of this insect to the western pine beetle, both in its habits and in the results which have been obtained on this one pro-

ject, the same recommendations are suggested for the present.

THE MOUNTAIN PINE BEETLE (*Dendroctonus monticolae* Hopk.)

The mountain pine beetle, perhaps the most destructive of all *Dendroctonus* beetles, is of economic importance throughout the states of Washington, Oregon, California, western Nevada, Idaho, western Montana, northwestern Wyoming, and southwestern Canada. This insect attacks and kills western yellow pine, white pine, lodgepole pine, limber pine, white-bark pine, sugar pine, and sometimes Engelmann spruce when it is in association with infested pine. However, it is in the lodgepole pine and white pine stands of the Northern Rocky Mountain region, eastern Oregon, and eastern Washington, and in the sugar pine of California that the destructive activities of this insect are most important.

THE MOUNTAIN PINE BEETLE IN LODGE- POLE PINE IN THE NORTHERN ROCKY MOUNTAIN REGION AND EAST OF THE CASCADES

Normal or endemic infestations of the mountain pine beetle can be found in practically all mature lodgepole pine forests. The loss of timber resulting from such infestations is of no economic importance and the trees attacked are usually those which have been weakened by fire, lightning, or other causes. From such apparently harmless endemic infestations, however, destructive epidemics may develop with surprising rapidity. These epi-

demics may be reasonably short-lived, or they may continue, as is more often the case, for a number of years, destroying tremendous volumes of timber and gradually spreading over enormous areas. A striking example of the destructiveness of such epidemics exists at this time in Idaho and Montana. When we consider the tremendous volume of timber destroyed, the dangerous fire hazards created, and the cost and often the physical impossibility of applying control, the urgent need for the early prevention of outbreaks of the mountain pine beetle in the lodgepole pine stands of eastern Oregon and Washington, Idaho, Wyoming, and Montana is plainly apparent. In contrast to the trees selected under endemic conditions, it is the larger, thick-barked trees that are first attacked during epidemics. From these the infestation rapidly spreads until from 60 to 80 per cent of the total number of trees over large acreages are often destroyed.

From 6 to 8 years are required for an epidemic to pass through a given area and leave behind it a devastated forest. As these dead trees fall the resulting mass of tangled logs and tops is frequently swept by fire, causing the complete destruction of all the forest cover. No accurate data are available for the volume of lodgepole pine which has been destroyed during the past 20 years from the attacks of the mountain pine beetle. However, we do know that at the present time millions of trees are being destroyed each year, and strenuous efforts are being made to check these outbreaks

where the stumpage or esthetic values warrant the expenditures for control.

History of Control Work

The first effort to control an outbreak of the mountain pine beetle in lodgepole pine was made in 1910 and 1911 on the Whitman National Forest in northeastern Oregon. A great many projects have followed the initial attempt. Some have been carried out against small isolated infestations within a single creek drainage while others have been large-scale undertakings aimed to test the possibility of heading off the advancing infestation where no natural barriers existed. In recent years projects involving an expenditure of over \$100,000 in a single season have been attempted. The total expenditures on some 15 to 20 projects between 1910 and 1930 have amounted to \$300,000 involving the treatment of over 300,000 trees on approximately 600,000 acres.

Conclusions and Recommendations for Control Policy

The control projects that have been directed against infestations of the mountain pine beetle in lodgepole pine have covered a variety of conditions. Some of the outbreaks that have been combated have been large and others small, some have been increasing and others decreasing, in some cases 100 per cent cleanups have been attempted and in others control by partial cleanups involving a certain percentage of the infested trees. It is nevertheless fully realized that the available information concerning these projects is

often incomplete, in the sense that results have not been followed up and the status of the infestation in the regions adjacent to the areas covered by control has not been determined. Generalizations taking into consideration all projects are therefore impossible. From the information available on more recent projects it would seem that the only conclusion that can be drawn is that the results of treatment are in rather direct proportion to the thoroughness with which the control work has been carried out.

In plans for the control of the mountain pine beetle the ability of this species to fly rather long distances should always be kept in mind, although experience with many infestations leads to the belief that long flights of this beetle probably occur only from the heavier centers of infestation such as exist in severe epidemics in lodgepole pine.

Observations over the past 30 years indicate that lodgepole pine forests throughout this region are inevitably destroyed when they reach a certain stage of maturity. In a way this is nature's method of harvesting and preparing for a new stand and would indicate that this tree species should be handled on a rotation short enough to avoid beetle epidemics.

The adoption of any control policy for the mountain pine beetle in lodgepole pine must be on the premise that an ounce of prevention is worth a pound of cure. To prevent epidemics adequate attention must be given to increasing infestations. A few grouped, insect-infested, but otherwise normal

trees should be regarded as much a potential danger as a smouldering fire. It is true that the adoption of such a policy of control will result in a much higher cost per tree for treatment than if control work is delayed until epidemic conditions exist. Nevertheless, if proper weight be given to considerations such as the present and expectation values of timber saved through the prevention of epidemics, the potential threat from active epidemics to stands of continuous type even 100 miles distant, the prevention of fires which result in even greater timber losses, and the complete alteration of forest types, which often revert to less valuable mixtures, it will be found that the prompt treatment of developing infestations is the most economical policy to follow.

On the basis of prevention of outbreaks, the following policy for control is recommended:

1. The making of annual surveys for red-top trees in all lodgepole pine forests, in order to locate all incipient outbreaks. Such surveys should be thorough, and a recognized duty of each forest officer responsible for the protection of the timbered areas under his charge.

2. The prompt and thorough control of the infestation by proper treatment or utilization of all infested trees. By thorough control is meant the treatment of as nearly 100 per cent of the infestation as is feasible within physical limits.

3. Should epidemics occur, the treatment of all infested trees over the entire area within one season is essen-

tial, and such treatment should be followed by annual maintenance control for as long as is necessary.

4. No projects should be undertaken without fairly accurate knowledge of conditions in all the surrounding watersheds.

5. If it is obvious that an outbreak is rapidly declining, no control measures should be undertaken.

6. Lumbering operations in forest types susceptible to insect attack, and the utilization of infested trees through salvage operations, should be encouraged. During such operations logs should be left in the woods for a period of three or four weeks during the flight of the beetles in order that they may act as traps for the insects by drawing their new attacks.

THE MOUNTAIN PINE BEETLE IN THE WHITE PINE TYPE IN THE NORTHERN ROCKY MOUNTAIN REGION

The mountain pine beetle can be found in all mature white pine stands, but it is in Idaho and Montana that the insect causes the greatest economic loss to this species. Endemic infestations are always present in the northern Rockies. In these the attacked trees are scattered throughout the forest and the resulting annual losses are less than 1 per cent of the total volume of the stand. Trees weakened and decadent from over-maturity, fire scorching, lightning, etc., are apparently preferred. The economic importance of such infestations lies not only in the actual destruction of merchantable timber, offsetting in many areas the annual increment of the stand and

eventually resulting in a complete elimination of this valuable species from the forest type, but in the leaving throughout the forest of thousands of inflammable snags that become a serious fire menace.

From time to time endemic infestations change rapidly into epidemics, which kill more than 1 per cent, though rarely over 3 per cent, of the stand annually, destroy enormous quantities of valuable timber in a few years, and then subside for a longer or shorter period of relative quiescence. During epidemics no selection seems to be shown by these insects for trees of any definite characteristics. The attacked trees may be scattered or may be in groups of different sizes, and during severe outbreaks groups of 75 to 100 attacked trees are not uncommon. The destructiveness of this insect can be more fully appreciated from the fact that in 1911, 1912, and 1913 a widespread outbreak occurred in the white pine stands of northern Idaho which destroyed at least 1,400,000,000 board feet of merchantable timber. During the past few years, beginning with 1927, there has again been a marked increase in the activity of this insect and at this time severe losses are occurring in all of the white pine forests of this region.

The factors contributing toward the development or decline of epidemics are little understood. The presence of an abnormal quantity of favorable host material resulting from windfalls, etc., undoubtedly is of importance, and varying climatic conditions may be of prime consideration though no definite

correlation between such factors and bark-beetle outbreaks has been established.

An important characteristic in the activity of this beetle in the white pine type is that the adult flight is less marked than in the lodgepole pine type. This is because the white pine occurs more or less isolated in drainages usually separated from the next stand by a distinct change of type.

History of Control Work

Some fifteen distinct projects have been conducted against the mountain pine beetle in the white pine type from 1911 to 1930. Work has been done under a great diversity of conditions and includes the largest bark-beetle control project ever attempted, involving the expenditure of approximately \$135,000 in one season on the Coeur d'Alene National Forest. Altogether nearly \$200,000 has been spent in this work, requiring the treatment of over 40,000 trees, equivalent to some 20,000,000 board feet on 115,000 acres.

Conclusions and Recommendations for Control Policy

Until results are obtainable from several large projects now under way on the Coeur d'Alene and Kootenai national forests it is felt that final conclusions on the effectiveness of artificial control against the mountain pine beetle in the white pine type must be postponed. It appears, however, that much the same results have been obtained here as with lodgepole pine—results that are directly proportional

to the percentage of the infestation treated.

The policy to be recommended, therefore, is substantially that suggested for the lodgepole type. Less emphasis, however, need be put on certain features. Associated with the broken distribution of the host and the less active type of infestation there appears to be a relatively less marked tendency for long flight by the adult beetles, indicating that suppression measures of a more local character can be justified.

Because of the smaller percentage of the stand which is destroyed during epidemics it is possible, in considering the advisability of control, to give more consideration to the present stumpage values and the probable time of marketing the stand on any particular area.

The timber values at stake and the probable time of harvesting the stand can also be taken into consideration in deciding on the advisability of applying control to infestations killing less than 1 per cent of the stand annually. It does not seem advisable at the present time to recommend treatment of all endemic infestations.

THE MOUNTAIN PINE BEETLE IN SUGAR PINE IN CALIFORNIA AND OREGON

The habits of the mountain pine beetle in attacking sugar pine are quite different from those of the same insect in attacking lodgepole pine and western white pine. Whereas the outbreaks of this beetle in lodgepole pine and white pine in the northwestern region are characterized by centers of infesta-

tion made up of large groups of trees, infested sugar pines always occur singly or in small groups. The distribution of its attack is therefore quite comparable to that of the western pine beetle in the same region. To a certain extent this may be due to the fact that sugar pine always occurs in type mixture with yellow pine, white fir, and other species. Much of the endemic infestation in sugar pine develops first in the tops of large trees, and the attack is continued on down the trunk for two or three successive seasons before the tree is finally killed. Under epidemic conditions, on the other hand, large trees may be killed outright in one season, sometimes in groups of 5 or 6. The losses that result often represent high values, because trees from 6 to 8 feet in diameter, with a large percentage of clear lumber, are killed.

History of Control Work

Minor infestations of this beetle have occurred on nearly all western pine beetle projects in the West Slope type. These have usually been treated, although only incidentally to the control of the western pine beetle, and the results as relating to the mountain pine beetle can not be isolated to show what benefits, if any, were secured.

On four projects control of the mountain pine beetle in sugar pine was the primary object. These involved the expenditure of \$14,000 for the treatment of 1,228 trees representing nearly 5,000,000 board feet on 64,000 acres.

Conclusions and Recommendations for Control Policy

Sufficient control work for this beetle in sugar pine has not yet been carried on to warrant final conclusions. The work that has been done up to the present time, however, indicates that this beetle is much more readily controlled than the western pine beetle, and that satisfactory results can be expected from one year's operations.

Control work is recommended, therefore, against increasing infestations in stands carrying a high percentage of sugar pine.

THE MOUNTAIN PINE BEETLE IN THE YELLOW PINE TYPE IN THE NORTHERN ROCKY MOUNTAIN REGION

Mountain pine beetle outbreaks in yellow pine are less aggressive but somewhat similar to those in white pine. A difference exists, however, in that practically no infestation is found in the yellow pine forests except during epidemics of the mountain pine beetle in lodgepole pine, when a certain percentage of the yellow pine adjacent to and associated with the lodgepole is always destroyed. It would appear that the yellow pine of Idaho and Montana is not a preferred host of this species. Furthermore, it seems that independent outbreaks of the mountain pine beetle in yellow pine will seldom occur unless as a result of some abnormal condition such as windthrows or fires.

There is one record of an outbreak of this insect in the yellow pine stands of the Snowy Mountains, Jefferson Na-

tional Forest. In 1909 some 1,150 trees were treated at a cost of \$358. This project was reported as being successful, and in 1910 only 8 trees were infested. The source of this infestation is unknown and little information as to the actual results obtained is available. It is reasonable to assume, however, that when outbreaks do develop in yellow pine prompt treatment of a large percentage of the infested trees with the adjacent lodgepole pines will be effective in checking them, and this tentative conclusion should be adopted at least until more experience has been gained.

THE MOUNTAIN PINE BEETLE IN LODGEPOLE PINE IN THE SIERRA NEVADA REGION

The lodgepole pine type in the central and southern Sierra Nevada differs from that in the northern Rocky Mountains, the Cascades, and northern California. Lodgepole pine in its southern range grows only at the higher elevations, and is usually quite common above the yellow pine-sugar pine-fir belts to the upper timber line. It prefers moist sites, and grows best along streams and around mountain meadows. Its distribution is much broken up, and no extensive areas of pure, even-aged stands exist such as occur in its northern range. The trees reach very great age and size, some of the veterans exceeding 4 and 5 feet in diameter d.b.h.

Under these conditions infestations of the mountain pine beetle rarely build up into epidemics in which large mass centers of infested trees are in-

volved. Under the endemic status, weakened or injured trees are attacked, usually singly, and seldom in groups of more than 2 or 3. The epidemic is characterized by indiscriminate attacks in groups of from 10 to 100 trees or more; but usually these groups are localized, and may continue for long periods in the same vicinity with about the same annual rate of killing. Only in Yosemite National Park, where some areas are found on which fairly even-aged stands of lodgepole cover several thousand acres, have such groups coalesced so as to form large masses of infested trees.

The epidemic just referred to, which developed within the Tuolumne River watershed of the Yosemite National Park, is, from the standpoint of damage, the most outstanding example of a mountain pine beetle outbreak in this region. The situation can not, however, be regarded as a normal one, for the mountain pine beetle outbreak was preceded by the work of a defoliating caterpillar, the lodgepole pine needle-miner (*Recurvaria milleri* Busck), which greatly weakened the trees and completely checked the growth of a high percentage of the stand. This defoliator, which started its attack some years previous to 1900, spread slowly through the tributary watersheds of the Tuolumne, and up to 1920 had covered about 30,000 acres. The bark beetle followed the needle-miner through the defoliated area, and between 1910 and 1924 killed approximately 500,000 trees. This epidemic subsided from natural agencies, however, after it had worked out of the defoliated areas.

History of Control Work

Projects for control in this type have been limited to national park areas, as no commercial value is attached to lodgepole pine. Five projects have been attempted, costing \$3,275 for the treatment of 3,456 trees on 3,510 acres.

Conclusions and Recommendations for Control Policy

Since lodgepole pine in this region has little commercial value, control work need be considered only in parks and recreational areas.

1. Endemic conditions, as represented by attacks on weakened, injured trees, or by scattered attacks on healthy trees occurring singly, can be disregarded except where the removal of such trees is desirable for æsthetic reasons or for fire prevention on intensively-used areas.

2. Control work is feasible and should be considered where epidemic conditions, as represented by small or large groups of infested trees, exist. Such work is inadvisable, however, unless the control area is isolated, or unless all epidemic infestations within a fairly large area (several thousand acres) can be treated.

THE MOUNTAIN PINE BEETLE IN THE WESTERN YELLOW PINE TYPE IN CALIFORNIA

The mountain pine beetle is of secondary importance in both the East Slope and West Slope types. It occurs only in very suppressed trees or in association with the western pine beetle

in trees which have been killed by the latter. It is usually found with other secondary insects in the trees, such as *Ips emarginatus* Lec. The only epidemic of note which has occurred in this region was in the North Warner Mountains of Modoc County (1918-1921), where heavy competition existed between white fir and western yellow pine in the restocking of a 75-year-old burn. Here the mountain pine beetle killed practically all the pines, leaving only white fir on the area.

No control projects which primarily involved this insect and host have been undertaken in the region.

THE JEFFREY PINE BEETLE (*Dendroctonus jeffreyi* Hopk.) IN JEFFREY PINE IN CALIFORNIA

This species attacks only one host tree, Jeffrey pine, and is therefore restricted in distribution and economic importance.

In mature stands the Jeffrey pine beetle usually attacks trees singly in very scattered distribution. In some heavy stands of pole size and larger in northern California, however, it has been found in groups of 10 to 20 trees killed in one season. The tendency to build up large mass centers of infested trees, as with the mountain pine beetle in lodgepole pine, has not been observed in this species. The heaviest losses recorded occurred in the Inyo National Forest in a stand of Jeffrey pine, where, in 1927, an infestation of 200 mature trees per section developed. This, however, was attributed to the influence of a heavy windfall within the area.

The only project on record concerned with the control of this beetle was carried out in Yosemite National Park in 1918. A total of 31 trees, with a volume of 60,820 board feet, was treated at a cost of \$130.50. This work was followed by a reduction in infestation of 80 per cent the first year and a further reduction of 27 per cent the second year.

There is insufficient basis for control recommendations for this species, and it is felt that the formulation of any policy should await the results of further experimental work.

THE DOUGLAS FIR BEETLE (*Dendroctonus pseudotsugae* Hopk.) IN THE NORTHERN ROCKY MOUNTAIN REGION

This beetle is generally distributed throughout the range of its host tree, Douglas fir. In the commercial fir region of Washington and Oregon it plays a very secondary rôle and is seldom if ever of any economic importance. In the region east of the Cascades and in the Rocky Mountain Region of Idaho and Montana, however, it is responsible for the sporadic destruction of large volumes of Douglas fir. The infestation usually occurs as spot killings that continue over a period of years, though in the past few years rather extensive losses have occurred in northern Idaho and northwestern Montana from a rather general infestation. Throughout this region Douglas fir is of rather low commercial value, and the greatest concern is felt in the case of those infestations within the scenic forests of our recreational areas.

Since between 1909 and 1930 only four small control projects have been attempted, very little regarding the results which may be expected can be said until more experience in the control of this species has been gained.

THE BLACK HILLS BEETLE (*Dendroctonus ponderosae* Hopk.) IN THE CENTRAL ROCKY MOUNTAIN REGION AND THE COLORADO PLATEAU

The Black Hills beetle, potentially one of the most destructive of all the species of *Dendroctonus*, is generally distributed and of economic importance in the Black Hills of South Dakota and adjacent forested areas, in the Rocky Mountain region south of the Green River Basin, and on the Colorado Plateau south to the northern portion of Arizona and New Mexico. It attacks western yellow pine (*Pinus ponderosa*), lodgepole pine, limber pine, Mexican white pine, pinyon pine, white spruce, and Engelmann spruce. For the purposes of the present discussion this region will be considered as a unit and the insect treated only from the standpoint of western yellow pine.

The past history of this insect indicates that it is found endemic throughout the region in lightning-struck and dying trees or logs and is normally of but little importance. However, from time to time epidemics build up very rapidly and in a few years spread and destroy enormous quantities of timber. At such times the beetle shows no choice of trees of poor vigor or slow growth but on the contrary apparently prefers thrifty timber, taking practi-

cally all the trees above the smaller diameter classes (6 inches). Evidences of its destructive power are well exemplified by the Black Hills outbreak between the years 1895 and 1905 and the Kaibab epidemic between 1918 and 1925. In the earlier epidemic approximately a billion feet of timber were destroyed and in the latter approximately 12 per cent of the stand, amounting to 300,000,000 board feet. Little is positively known of the factors responsible for the rapid building up of these outbreaks or for their equally rapid and phenomenal decline. There is some indication that windfalls serve as a nucleus for building up the beetle population locally. Climatic influences are no doubt of considerable importance but from the evidence at hand the interpretation of these forces is not conclusive. Dr. M. W. Blackman's observations indicate that the sudden checking of the Kaibab epidemic was due to two very dry seasons which caused high mortality of the broods beneath the bark.

Past studies have also indicated that these insects readily attack felled logs and that continuous logging operations have a very beneficial effect in keeping down infestations. It is worth while in this connection to call attention to the fact that few outbreaks have developed since 1910 except in areas, such as the Kaibab and Colorado National Forests, where little lumbering was going on when the infestation built up. Several group killings indicating potential outbreaks have occurred in the Black Hills and Harney National Forests but were quickly suppressed through prompt utilization of the infested timber.

History of Control Work

The first attempt to control a bark-beetle outbreak was carried on against this species in the Black Hills National Forest in 1906, 1907, and 1908. Since then, up to and including 1930, at least 15 distinct projects have been attempted, requiring the expenditure of over \$107,000 and the treatment of nearly 100,000 trees, amounting to 22,000,000 board feet, on an area of 372,000 acres.

Conclusions and Recommendations for Control Policy

The work attempted in the control of this species was frequently initiated without a very sound knowledge of the status of the outbreak. Furthermore, the work on two of the larger projects, and probably on some of the others, coincided with the natural decline of the outbreak. It is, therefore, obviously dangerous to draw very definite conclusions. However, if the extreme aggressiveness of this species, its potentialities for rapid increase under favorable conditions, and the fact that when epidemic it attacks the most vigorous stands, are considered in connection with the results of several properly timed and well executed control projects, it seems only logical to draw the tentative conclusion that prompt, thorough, and persistent control will effectively check outbreaks.

It is therefore recommended that,

until further experience gives evidence to the contrary, the following policy be adopted.

1. Thorough annual reconnaissance of all yellow pine forests within this region in order to pick up incipient outbreaks.

2. Prompt and thorough control of the infestation by proper treatment or utilization of all infested trees, when the infestation begins grouping in clumps of 3 or more trees. By thorough control is meant the treatment of 100 per cent of the infestation within the limits physically possible.

3. When large epidemics develop, the treatment of all the infestation over the entire area in a single season is indicated, if physically possible, and this should be followed by maintenance control as long as is necessary. Surveys preliminary to control should include all the surrounding watersheds, as well as the area in which the outbreak is first recognized.

4. No control work should be done in case the infestation is rapidly declining.

5. The encouragement of local lumbering operations in the yellow pine type is desirable and these operations should, in areas of moderate infestation, be regulated to permit the green logs to be left lying on the ground during the flight period of the beetles. It is believed that this practice prevents the development of epidemics through trapping of the endemic infestation.