THE CORRELATION OF BARK BEETLES AND WOOD BORERS TO SLASH DISPOSAL IN MICHIGAN

Thesis for the Degree of Ph. D.

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Walter Frederick Morofsky

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This is to certify that the

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The Correlation of Bark Beetles and Wood Borers to Slash Disposal in Michigan

presented by

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THE CORRELATION OF BARK BEETLES AND WOOD BORERS TO SLASH DISPOSAL IN MICHIGAN

By

WALTER FREDERICK MOROFSKY

A THESIS

Submitted to the School of Graduate Studies of Michigan
State College of Agriculture and Applied Science
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Forestry

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WALTER FREDERICK MOROFSKY ABSTRACT

Studies on the correlation of bark beetles and wood borers to slash disposal in Michigan were of primary importance in this study. Caged material and field collections in red pine (P. resinosa) and jack pine (P. banksiana) plantations showed two species of the Family Cerambycidae (wood borers) and seven species of bark beetles belonging to the Family Scolytidae.

All of these insects are of economic importance in slash disposal methods, since some species build up in the slash to epidemic proportions to attack living trees, whereas others aid in slash break-down.

Slash disposal methods at the Kellogg Forestry Tract and the Higgins Lake State Forest were studied, as both areas were infested with wood borers and bark beetles. Recommendations of slash disposal such as lopped and scattered, windrowing, piling, and lopped and left were common practices in these two areas, and from observation, these types of disposal are conducive to insect infestations. These methods were checked as to insect populations under field conditions and were found to encourage enormous numbers of insects which

sometimes built up to epidemic proportions. In addition, two of the more common methods of windrowing and piling of red and jack pine slash were studied in detail. Generally speaking, in these two methods, the "butt end" of the slash is exposed. It was found, however, that by reversing this procedure in these two methods of slash disposal--that is, putting the "butt ends" toward the center of the windrow or piles--the establishment of insect populations could be inhibited to such an extent that no significant infestations developed. It was noted, however, that the height of the windrowing and piling was also a limiting factor. Where slash exceeded 36 to 40 inches in height, populations also increased in the upper part of the slash.

Fall cutting, proper slash management, and silvicultural practices may aid in reducing insect populations.

Chemical controls, biological controls, virus controls, and predators all may or may not be present to aid in the controlling of forest insects in our plantations. The factors which are of major importance to the silviculturist and entomologist alike are those which may influence the increase or decrease in insect populations. In this study, slash disposal technique was shown to be the most important of these factors.

TABLE OF CONTENTS

	Page
INTRODUCTION	1
HISTORICAL REVIEW	6
Associations of Insects and Slash	18
EXPERIMENTAL METHODS AND TECHNIQUE	28
Discussion of Project Areas	28
Kellogg Forestry Tract (red pine)	28
Thinning and Pruning Operations	31
Higgins Lake State Forest (jack pine)	33
Pulpwood Operations	34
Insect Epidemics	36
Development of Technique	41
Cage Rearing Experiments	41
Tree Girdling	45
Soil Samples	45
Slash Studies	50
Presentation of Data	61
Tabular Results	61
Results of Caged Material	64

Page

Results of Field Counts 74

Results of the Slash-disposal Methods 84

List of Insects Collected from Red and Jack Pine Slash 90

Description of Coleoptera Collected and Reared 91

Family Cerambycidae 91

Family Scolytidae 107

Miscellaneous Insects 121

Climatic Data 125

DISCUSSION OF RESULTS 141

SUGGESTED RECOMMENDATIONS FOR INSECT CONTROL BY SLASH DISPOSAL 155

SUMMARY 156

LITERATURE CITED 158

INTRODUCTION

Slash disposal has been a controversial subject because there has not been an agreement as to the necessity for it in the control of forest insects in specific forest regions. Since the beginning of logging operations in this country, entomologists, foresters, logging companies, congresses, and others interested in this subject have discussed its merits and disadvantages.

The term "slash" as used in this manuscript refers to tops, limbs, cull logs, or other debris left on the ground after thinning, pruning, pulpwood, or other logging operations.

This study of slash disposal was begun in Michigan in 1945 as a preliminary study of the effect of forest insects in relation to red pine (*Pinus resinosa* Ait.) and jack pine (*Pinus banksiana* Lamb.) plantations.

A systematic study of slash disposal concerns many phases of forestry, as it is not only a silvicultural problem where reproduction and growth must be considered, but deals with soils, management, logging, and practically all phases of forestry (41, 55, 56).

Silviculture, according to Baker (1), may be defined as the art and science of growing and reproducing stands of timber on a basis of permanency. From this definition, silviculture may be divided into two phases: reproducing the forest, and tending the forest crop after its establishment.

The relationship of silviculture and entomology in slash disposal should be carried on simultaneously, but most of the early works considered these two problems from different viewpoints. From a silvicultural standpoint, slash disposal was primarily considered from the soil standpoint, logging technique, forest protection, and fire protection, wherein the entomological aspect was not emphasized. The several methods of slash disposal developed by early workers were based on fire hazard or for convenience. We read about slash burned by broadcast burning, windrow burning, piling and burning, light ground burning, et cetera, or we read about no slash disposal, lopping and scattering, piling, windrowing of tops, and other combination methods (14, 31, 40, 49, 50). Seldom, until the 1920's, can we find evidence of the effects of these methods from the entomological point of view.

All forest operations create environments suitable or unsuitable for insect infestations. The control by silvicultural methods is done by maintaining a biotic balance. This balance is changed during the growth of the tree because of environmental factors, any one of which may increase or decrease its susceptibility (75).

It has been said that a very high percentage of forestry is protection. This fact being true, it is of greater importance now than ever before in our plantations in preventing devastation by forest fires, insects, and diseases. Fires in the past few years have been greatly reduced in Michigan due to adequate protection. According to the Michigan Department of Conservation Field Administration reports (52) from 1928 through 1951, there have been 1,325,925.86 acres burned in Michigan. However, these statistics show that from 1941 to 1951 there has been a decrease of over 500,000 acres over the previous 10-year period.

In a report to the President, by the President's Materials Policy Commission, issued June, 1952 (74), it states:

> The present trend toward greater net growth can be accelerated. In recent years fire has destroyed an annual average of 500 million cubic feet of growing stock,

> and disease and insect epidemics perhaps a billion cubic feet more. These annual losses have included about 4.2 billion board feet of saw timber.

It further states:

> On the more positive side, timber growth itself can be increased through new plantings, careful thinning, selective cutting and other silvicultural practices . . . . Epidemics of forest insects and tree diseases make tremendous periodic inroads on the supply of commercial timber. The combined loss is hard to estimate in dollar values but is far greater than the loss from fire. Gaging the level of future losses is even more difficult because no one can tell what pest will strike next . . . . The enormous task of checking these and other insect and disease epidemics calls for cooperation among the Federal Government, the States, private organizations, and individual forest owners. In nearly every effective campaign there are three phases: research, detection, and suppression.

No region or state is without some major forest pests, and some are so widespread that complete extermination is not feasible.

One of the most destructive insect pests is the spruce bark beetle, which in the past ten years has killed enough trees to provide 4,000,000,000,000 board feet of timber, enough to construct 400,000 five-room houses. This loss represents sixteen times as much destruction as that destroyed by fire in the Rocky Mountains in the past few years. Other insects which are doing serious damage to the nation's forest resources are the spruce budworm, the tussock moth, larch sawfly, tent caterpillar, and gipsy moth. State and Federal agencies are working closely together in attempts to control these pests (78).

Forest diseases are equally as prevalent, and Federal, state, and private resources have been employed to stamp out some of the most destructive. Oak wilt (new to Michigan), white pine blister rust, brown spot, leaf diseases, pole blight, and others are being given special attention by foresters, since they attack the most valuable commercial trees in the country.

Any program today that disregards the protection of our forests from fires, insects, or diseases endangers our future timber supplies. All phases of silviculture, forest entomology, and forest pathology must be considered to prevent further destruction.

The purpose of this study is to correlate the interrelations of insects and wood-rotting organisms with rapidity of the slash breakdown. Bark beetles and wood borers build up in slash to epidemic proportions, which is not properly handled and managed. It is for this reason that the quick decomposition of slash is of major importance to prevent epidemics of insect outbreaks.

HISTORICAL REVIEW

Forest entomology as it is now known did not exist previous to 1800. Writers and workers in this field of study had their primary interests in other fields of endeavor (33). All of this work existed in Europe. Since 1800, this science has become very progressive, but nothing was written in the United States until 1856.

In France and Germany, private persons and entomologists such as Perris and Ratzeburg of Germany (62) did a grand job in familiarizing the people on the importance of forest insects, and even encouraged universities to start forestry schools.

Kaltenback, according to Packard (58), in his work entitled "Die Pflanzenfiende aus der Klasse der Insecketin," has shown many insects affecting trees and plants of central Europe; in fact, at that time he has listed 537 species of insects on oak alone, and 299 on pines, spruce, larch, and firs.

In this country, early workers such as Fitch (28), Harris (35), Packard (58), Smith (73), Riley (42), Lintner (48), Comstock (15), Felt (26, 27), Hopkins (37, 39), Forbes (30), and others in 1850 to 1900, could see the indispensable necessity for forest-insect work, as all wrote to some extent on insects of forest and shade trees.

In Europe, Eichhoff's work on European bark-beetles gave excellent accounts of why these insects cause trouble, such as good weather and sufficient nourishment, wind, snow, frost, forest fires, and other insects, which still plays an important factor in our present-day outbreaks. Packard (58) quoted Professor Riley as saying:

> In the first place it should be borne in mind that dead stumps and decaying trees or logs left standing near groves or road side trees, are a continual menace to healthy trees, since they afford an asylum or breeding place to timber and bark borers. Such objects, large and small should be cut down or pulled up and burnt. Forests should be kept free from standing dead trees and stumps, or if left standing should have the bark removed. It is well known that lumberers remove the bark of logs to prevent injury to the lumber by "sawyers," or the grubs of timber-beetles [3].

Packard (58) also wrote about the advisability of unlumbered areas in Maine, whether or not it might pay the owners of lumber lands to send crews out to cut down sickly trees, remove the bark to prevent serious outbreaks of insects and also hasten decay. At this early date, 1890, Packard (58) stated: "Plantations and forests of limited extent can with comparative ease and slight expense be kept in neat, trim order by judicious thinning and removal of injured or infested branches, the latter being burnt."

According to Graham (34), the Swedish naturalist, Linnaeus, suggested in the eighteenth century that injury from borers could be prevented by floating the logs in water. This method is still in common use in the United States. When facilities are readily available, the simplest method of preventing insect damage is by submerging in water. Doane et al. (24) stated:

> Submerging infested logs in water is fatal to nearly all bark beetles and wood borers, provided the submersion is continued long enough. Dormancy is the first effect of submerging, from which the insects recover if the treatment is not prolonged. Six weeks of submersion has been found to be fatal to certain bark beetles, but wood-boring grubs perhaps may live even longer periods. Logs in millponds must be frequently turned; otherwise the exposed portions are apt to be attacked by ambrosia beetles.

This statement demonstrates the persistence of forest insects, making necessary all precautionary measures available in preventing damage.

It is interesting to note that up to the time of Ratzeburg's death, in 1871, most of the forest-insect work was of a biological nature, and not until Eichhoff's (58) outstanding publication "Europaischen Borkenkafer" in 1881 did there become a combination of the biological and taxonomic era. Soon after this period, experimental biology came into its own.

Eichhoff often asked the question:

> How do great numbers of bark beetles pass into regions where perhaps before they were scarcely known by name? For example, at the end of a period of fifty years, all at once Tomicus curvidens appeared in the Botanic Garden of the University of Vienna, and were very destructive to different exotic cedars, larches, and etc., afterwards attacking white firs.

Examples of extensive migrations of Ips typographus were afforded by H. Tiedemann in the province of Nishory-Novvorod. In the midst of an imperial forest of about 2,500 hectares lying in the district of Arsamass, and composed almost exclusively of hardwood trees, occur two fir growth of 50, perhaps 60, hectares in extent. In both, there were no windfalls, no burnt areas, but a good close growth in which no bark borers had appeared. Suddenly, in the year 1883, the bark borers were so numerous that two thousand fir trunks fell at once, and had to have the bark stripped off and burnt. The appearance of the bark beetles is in this case only to be explained by their flying into this area. The nearest fir growths are from 15 to 20 kilometers distant, and those of sufficient size to afford time for the infection of the fir growths in question are about 50 kilometers distant.

These were the problems confronting early investigators, and today many such problems are still unanswered. These problems brought about many ideas to be tried; for example, at this time the best methods of preventing or stopping the work of bark beetles were those of a Frenchman, M. Robert, given in the Gardner's Chronicle and quoted by Miss Ormerod:

> The best remedy appears to be that adopted with great success in France by M. Robert, after careful observation of the circumstances which stopped the operations of the female beetle when gnawing her gallery for egg-laying, or which disagreed with or destroyed the maggots, and is based in part on similar observations of the effect of flow of sap to those noticed in England by Dr. Chapman. It appeared on examination that the grubs died if they were not well protected from the drying action of the air; on the other hand, if there was a very large amount of sap in the vegetable tissues in which they were feeding, this also killed them. It was observed that when the female was boring through the bark, if a flow of sap took place she abandoned the spot and went elsewhere. It was also noticed that the attack (that is, boring of the galleries which separates much of the bark from the wood) is usually under thick bark such as that of old elm trunks rather than under the thinner bark of the branches. Working on these observations, M. Robert had strips of about two inches wide cut out of the bark from the large boughs down the trunk to the ground. It was found that where the young bark pressed forward to heal the wound and a vigorous flow of sap took place, that many of the maggots near it were killed. The bark which had not been entirely undermined was consolidated and the health of the tree was improved.

Due to these operations as stated, much work was done on scraping of trees with great success. From this came a similar process which was tried by the Botanic Society, in 1842, on trees infested by Scolytus destructor in the belt of elms encircling their garden in the Regents' Park, London. "It consists in divesting the tree of its rough outer bark, being careful at the infested parts to go deep enough to destroy the young larvae, and dressing with the usual mixture of lime and cow-dung." This operation was found very successful, and details of this account were given, as a paper, to the Society in 1848.

Early insect controls such as brushing logs, coal-tars, whitewashes, strong odors, soaps, heavy watering of trunks, insecticides (Paris green, London purple, wood ashes and lime, coal dust, Pyrethrum, Hellebore, Sulphur, Petroleum products and fumigants, etc.) were still being used until the early 1940's. These materials are being replaced now by the chlorinated hydrocarbons, phosphates, and other newer materials. Much biological work can never be ignored and must be practiced under forest conditions.

The development of forest-insect control in America was slow and began along the line of German ideas, particularly from the natural-history standpoint. Writings were scattered, and varied greatly according to sections, and not until 1890 did Packard (58) bring together much of the material. His fifth report was a masterpiece--the only work of its kind--which stood for years, and still is invaluable as a reference book.

Felt (27) also wrote, in early 1900, in regards to forest and shade-tree insects, and many others, as previously mentioned.

Hopkins (37, 39) was outstanding in his bark-beetle studies and added much to our present-day knowledge of biological and taxonomic understanding of this group of insects.

Many workers, such as Swaine (72, 73), Blackman (3), Keen (44, 45), Pearson (61), Burke (8), Chamberlain (9), and many others have aided much in the development of forest entomology in this country. Recently, two workers, Craighead (20) and Graham (34), have both published new texts, one Insect Enemies of Eastern Forests, and the latter, Forest Entomology.

Graham (34) stated that up until 1915, owners of timberland paid little attention to insect damage. As a result, the insects have in the past been studied without considering their ecological relations with the forest. Previous to this time, foresters and entomologists have generally followed European forest-insect control practices. This viewpoint has changed, and today there are many workers devoting their entire time to practical forestry. Modern forest entomologists are interested both in insects, themselves, and in forests, but their primary concern is the influence of insects upon the forest.

This modern point of view has resulted in the application of experimental biological methods to forest entomological problems. These methods have led to the recent rapid development in the fields of ecology, physiology, genetics, and biometry. Forest entomology, like other biological sciences, is now being developed on the basis of experimental work.

There are many problems today that did not exist when forests were thought to be plentiful (54, 67). It is interesting to note from the USDA Forest Service Publication 543, that of the nation's 624,000,000 acres of forest land, 196,000,000 acres are in public ownership--community, state, and Federal--and 428,000,000 acres are in private ownership. This in itself presents many problems (81).

Michigan has approximately 3,750,000 acres in state forest alone, and has a saw-timber volume of 650,000,000 board feet, according to Fontanna (29). State interest in forestry antedated Federal forestry by many years. Randall (63) stated:

> As early as 1777, North Carolina, and in 1778, South Carolina enacted laws against willful and careless woods burning. In 1867, Michigan and Wisconsin both made inquiries into conditions and needs of their forests . . . . In fact, most of the Eastern States gave early legislative attention to their forest resources, although the actions taken were far from adequate to meet the growing problem of forest depletion.

To date, practically all of the laws pertaining to forestry practices in Michigan have been concerned with fire protection only, as no indication from the insect and disease is even mentioned; for instance, Act 143 P.A. 1923--an act to provide for the preservation of the forests of this state and for the prevention and suppression of forest and prairie fires, and to create the office of chief fire warden.

The Highway Slash Law, Act 26, P.A. 1927, an act to provide better protection against the spread of forest fires, to provide for the disposal of all cuttings of forest growth, slash, and debris from strips of land along public highways and along the right of way of any railroad, that is a common carrier, any telephone, telegraph, or power line, or other public utility;

to prescribe a penalty for violation hereof; and to authorize an action for damages by the property damaged. Here again there is no mention of insect or disease, but mainly from a fire-hazard standpoint.

Only under the rules and regulations for timber sales on state lands in the Persuant to Act 178, P.A. 1935, is the slightest indication whereby this can somewhat be considered feasible. Under the general Regulations, Sec. 5, it states: "The permittee and his employee shall do all in their power to prevent and suppress forest fires; and shall dispose of brush and other refuse to meet the approval of the field representative in accordance with the terms of the permit."

The permit under the heading of, "This Permit is subject to the following conditions," Section 7, headed "Brush Disposal," says, in effect: Brush disposal shall be made as the cutting progresses, unless otherwise specified. In this timber sales permit the forester in charge writes in the method of "slash disposal" to the best of his ability, and here he may demand such handling of the slash which may effect insects and disease, rather than fires, alone.

In June of 1947, the Forest Pest Control Act was enacted; it established a definite pest-control policy. In part, this act provided that ". . . it shall be the policy of the Government of the United States, independently and through cooperation with governments of states, territories, possessions, and private owners to prevent, retard, control, suppress, or eradicate incipient, potential, or emergency outbreaks of destructive insects and diseases, on or threatening all forest land irrespective of ownership."

Many states have their own laws to cover insects and disease regulations, but since this law was enacted, Michigan, under the Division of Forestry of the Michigan Department of Conservation, has set up a forest-pest detection program, which has been in operation for two years. This program works very closely with the Federal Forest Insect Laboratory, University of Michigan, Bureau of Entomology and Plant Quarantine, and Michigan State College. This is an outstanding contribution in the study of detection, surveys, and control of forest pests. Table I shows a detection-program reporting sheet used in Michigan.

TABLE I

MICHIGAN FOREST PEST DETECTION PROGRAM - Observation Report

PEST ______________________________ (Write in name if known)

Col. 3-4. DAY ______
Col. 5-6. MONTH ______
Col. 7-8. YEAR ______
Col. 9-10-11. SAMPLE AREA NO. ______

Col. 12-13. DISTRICT ______
Col. 14-15. TOWN ______ N S
Col. 16-17. RANGE ______ E W
Col. 18-19. SECTION ______
Col. 20-21. FORTY ______

Col. 22 OWNERSHIP
__1. Federal
__2. State
__3. Com. or Sch.
__4. Private

Col. 23. ORIGIN
__1. Seed
__2. Sprout
__3. Plantation

Col. 24. FIRE RECORD
__1. Unburned
__2. Current yr.
__3. Previous yr.
__4. Past 2-5 yrs.
__5. Older

Col. 25. CUTTING RECORD
__1. None within 5 yrs.
__2. Clearcut " "
__3. Partial cut "
__4. Thinned within 1 yr.
__5. Pruned " 5 yrs.

Col. 26. WINDFALL
__1. Normal or none
__2. Current yr.
__3. Previous yr.
__4. Past 2-5 yrs.
__5. Older

Col. 27. GRAZING RECORD
__1. None
__2. Currently
__3. Past 2-5 yrs.
__4. Older

Col. 28. SOIL GROUPS
__1. Porous
__2. Nonporous
__3. Rock outcrop
__4. Stagnant bog
__5. Stagnant marsh
__6. Seepage
__7. Flood plain

TREE SPECIES PRESENT IN ORDER OF ABUNDANCE
Col. 29-30. A ______
Col. 31-32. B ______
Col. 33-34. C ______
Col. 35-36. D ______
Col. 37-38. E ______

Col. 39. % SHADED BY VEGETATION OVER 1 FOOT
__1. 1-20
__2. 21-40
__3. 41-60
__4. 61-80
__5. 81-100

Col. 40. % DENSITY TREE CROWNS OVER 20 FEET
__1. 1-20
__2. 21-40
__3. 41-60
__4. 61-80
__5. 81-100

Col. 41. ATTACK RECORD
__1. Started this yr.
__2. Started last yr.
__3. Started earlier
__4. Old attack evident, none now
__5. None evident

HOST OR HOSTS UNDER ATTACK
Col. 42-43. A ______
Col. 44-45. B ______
Col. 46-47. C ______
Col. 48-49. D ______
Col. 50-51. E ______

Col. 52. ATTACKED TREES AVERAGE SIZE
__1. Under 2 ft.
__2. 2-6 ft.
__3. 6-15 ft.
__4. 15-30 ft.
__5. 4-6 in. diam.
__6. 6-12 in. "
__7. 12-18 in. "
__8. Over 18 in. diam.

Col. 53. % ALTERNATE HOST ATTACKED
__1. 1-10
__2. 11-20
__3. 21-40
__4. 41-60
__5. 61-80
__6. 81-100

Col. 54. HOST HEALTH CLASSES
__1. Good
__2. Medium (Dead twigs, foliage faded)
__3. Poor (Dead branches, leaves small)
__4. Dying
__5. Dead

Col. 55. % STAND COMPOSED OF HOST SPECIES
__1. 1-20
__2. 21-40
__3. 41-60
__4. 61-80
__5. 81-100

Col. 56. % SUSCEPTIBLE TREES ATTACKED
__1. 0-1
__2. 2-10
__3. 11-20
__4. 21-40
__5. 41-60
__6. 61-80
__7. 81-100

Col. 57. STAGE OF PEST
__1. Egg
__2. Larva or nymph
__3. Pupa
__4. Adult

Col. 58. DEGREE OF ATTACK

Bark Beetles
__1. One attack per sq.ft.
__2. Two attacks " " "
__3. Three " " " "
__4. Four " " " "
__5. Five or more" " "

Defoliation or Terminal Injury
__1. 1-20%
__2. 21-40%
__3. 41-60%
__4. 61-80%
__5. 81-100%

Number of Stem Cankers
__1. One
__2. Two
__3. Three
__4. Four
__5. Five or more

Col. 59. SIMILAR STANDS IN AREA
__1. Predominant
__2. Frequent
__3. Scattered
__4. Scarce

Col. 60. ABUNDANCE OF PEST IN SIMILAR STANDS
__1. None
__2. Same
__3. Lighter
__4. Heavier

OBSERVER ______________________________

(Fill out back of sheet, and make sketch map to show local distribution if this can be determined. Also indicate under remarks any information which will give a more complete picture of the situation.)

Many other surveys are being made in the state forests, such as aerial, ground reconnaisance, et cetera, in the detection of insect infestations throughout the year.

Associations of Insects and Slash

As early as 1899, Hopkins (38) reported the wasteful methods of lumbering, and also mentioned how insect breeding places were being provided by the trunks and debris left on the ground. Even at this early date, entomologists realized the importance of slash disposal and the necessity for investigative work to be done.

There are many insects which breed in slash, some being extremely dangerous to living trees, some being beneficial in aiding in the breakdown of slash; others may be classed semiharmful, and may become epidemic in habits if the proper environment presents itself. It is a known fact that where we have continuous cuttings, enough food materials may be present to prevent serious damage to standing trees from forest pests. Results of an unpublished report of experiments in Minnesota, according to the Division of Forest Insect Investigation Circular 411 (35), indicated that heavy shade is unfavorable to most potentially injurious insects. In one of the experiments, piling the small parts of the slash over the stumps very materially reduced the infestation. This experiment was on a small scale, and only about twenty stumps were used, but results were very clear cut. Pairs of stumps close together were selected; one of each pair was covered with the smaller parts of the slash, the other stump being left uncovered. The uncovered stumps were found to contain an average of forty mother tunnels of Dendroctonus valens Lec. per stump, whereas the covered stumps averaged only four each. No mention was made of insect populations in the slash itself. Other workers in Canada have observed much the same situations in spruce-logging operations.

These observations were in part used as a basis in the study of this problem in slash disposal.

The slash left from any cuttings, when fresh, is attractive to many species of wood borers and bark beetles that may be found breeding in dying standing trees. An example of this was shown by girdling of trees in an area where no apparent evidence of any bark beetles was present in the vicinity. The numbers and kinds of insect progeny depend on moisture, temperature, size, and kinds of slash. Pines seem to be more susceptible to infestation than do hardwoods. Graham (32) reported that, prior to the establishment of forest plantations in Michigan in the 1920's, insect species that normally breed in the slash of red pine and white pine in the Great Lakes region were seldom observed attacking or killing healthy trees.

Several species of Ips occasionally kill trees (13) and these, like the Dendroctonus beetles, usually breed most abundantly in the larger parts of the slash (14, 24, 37, 44, 57). The most common offenders of this group are Ips pini Say, a primary pest of red and white pines, and I. calligraphus Garman, which breeds in the white pine (24, 37, 44). The ordinary method of slash disposal, by burning, destroys only the small, entomologically innocuous parts of the slash, and leaves the parts most favorable for insect breeding. The burning of slash piled over stumps does not as a rule sufficiently char the stump to prevent subsequent insect infestations. Complete charring can be done only by keeping the fire close to the sides of the stump, and this is impractical because of the costs involved.

Craighead (18), however, stated that wood-boring species which breed in slash must be considered generally beneficial, as they he

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as they help to decompose the wood and reduce the fire hazard that accompanies a large quantity of slash. Occasionally, they may become injurious, however, and in order to reduce or avoid the menace from slash-breeding insects, a special thoroughness in slash disposal is sometimes necessary. When a logging operation is continuous, and a fresh supply of slash is furnished throughout the period of insect attack, the emerging progeny are repeatedly absorbed in the slash and in the logs removed to the mill, and no special precautions need be taken. But if a cutting operation ceases or is intermittent, as in the case of road and power-line development or forest thinnings, then some damage to adjacent trees from insects attracted into the area can be expected and should be prevented if possible.

There are many other factors which may cause infestations other than logging, pruning, or thinning operations. Among these may be mentioned climatic conditions, other insects, soils, disease, natural balance, et cetera; and the injurious insect may breed in excessive numbers to become epidemic in nature. Should this occur, and this is evident in certain of our plantations at present, drastic control measures may be necessary to curb these types of infestations.

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It is interesting to note that the first expenditure by the Bureau of Entomology was in 1902, when $5,700 was set aside for forest-insect control (82). In 1906, the first insect-control program was conducted by the United States Forest Service, when $2,700 was expended in an effort to check an epidemic of the Black Hills beetle. A total of $1,000,000 had been expended through 1931.

There are many possible silvicultural methods applicable to growing stands to bring about conditions unfavorable for the development of insect outbreaks. Dates and time of planting, and size of stock play an important role in silviculture practices. Many factors have been studied, such as tree vigor, overmature timber, forest composition, thinning, choice of site, planting, slash disposal, reproduction, density, ground cover, and perhaps many others. Among these was the so-called "sun-curing method" inaugurated in Crater Lake district on the mountain pine beetle in 1925-1926 (33) and still being used.

In the lodge-pole pine infestation of Yellowstone National Park (83), a method was devised for burning the bark from the trees while standing. This proved very effective when fuel oil was available, and is still being used to a certain extent.

Chemical controls have come a long way since the first use of Paris green in 1868. There has been a feeling among foresters that chemical controls were too expensive, and too, that methods of applications under forest conditions have hampered their development. However, with our newer insecticides which have been developed since 1940, forest-insect control has been revolutionized.

Today, with the development of many new methods of application by air, advances in ground equipment and planting methods, and lowered costs of application, this no longer presents a problem.

The first application of insecticides from the air was in 1921, and since that time thousands of acres, especially since 1943, have been sprayed or dusted from the air.

With these new insecticides, many problems have arisen for the forester, entomologist, and others concerned with the manufacture and use of these materials. The appraisal of new insecticides involves many phases of research before they can safely and satisfactorily be used for the control of insects. The following appraisals must be considered:

1. Toxicity to insects.

   a. Injurious insects.

      (1) Species controlled.

      (2) Determination of the time in the life history of the insect when control is best obtained.

      (3) Problems of good coverage.

   b. Beneficial insects.

      (1) Danger of poisoning pollinating insects, such as the honey bee.

      (2) The problem of poisoning predacious and parasitic insects.

2. Toxicity to man and animals.

   a. Toxicity may be to the nerves or organs, or both.

   b. Extent of toxicity: mild, moderate, acute, or cumulative.

   c. Will the poison be carried through animals to man?

3. Toxicity to plants.

   a. Burning, or other manifestations, as stunting or undesirable stimulation.

   b. Will the poison be carried by plants to man and animals?

4. Residues in the soil.

   a. Effects of the insecticides in the soil upon plant growth and productivity.

      (1) Toxic.

      (2) Nontoxic.

      (3) Toxicity to soil organisms.

5. Residues on plants.

   a. Residues should not be permitted on food plants at harvest time.

   b. The serious problem of lasting residues.

   c. Residues of taste and smell.

6. Dependability or repeatability of the control value of the insecticide from season to season.

   a. Repeated usage (experimentally and commercially) is necessary to establish knowledge of dependability.

   b. One year's testing gives only superficial evidence of what any new material will do.

   c. It took 5 years to establish the fact that DDT remains at least 5 years in the soil.

7. Manufacturing considerations.

   a. Proper formulations.

b. Economy of use.

c. Compatibility with fungicides and other insecticides.

d. Physical properties.

(1) Dust flowability; mixability with water or other liquids.

(2) Transportation.

(3) Storage and keeping qualities.

In the short period of 40 years or so, as a result of the methods of silvicultural and biological control, the coming of newer insecticides, and modern methods of application, many new fields of endeavor have developed. Craighead and Miller (18) stated that mechanical devices and versatile power units are taking the hand labor out of bark-beetle control, and marvelous insecticides are spread quickly over thousands of acres by airplane at costs that are a mere fraction of the value at stake. Certainly, for today the possibilities in chemical and mechanical methods of control look far brighter than the possibilities for silvicultural methods of prevention. In the meantime, it seems that more and more reliance must be placed on these different measures of control, and more effort must go into their improvement. At the same time, our detection surveys must be greatly strengthened and our research into biological and silvicultural methods of preventing damage must be pursued diligently for a more propitious future.

EXPERIMENTAL METHODS AND TECHNIQUE

Discussion of Project Areas

Two project areas were selected for study because of the character of infestations, and also because of the species of trees where bark beetles and wood borers were causing similar damage.

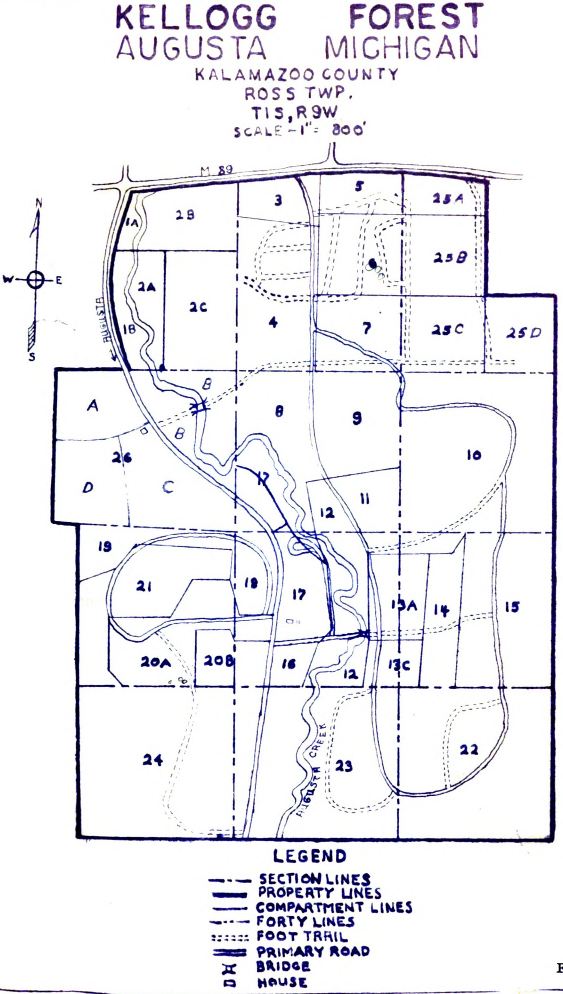
Kellogg Forestry Tract (red pine)

The Kellogg Forestry Tract is located near Battle Creek, Michigan, in Kalamazoo County, Ross Township (T1S, R9W), which was given to Michigan State College in 1932. It consisted of 280 acres at that time, and now consists of 485 acres.

This tract of land (all except 40 acres) had been cleared and farmed previous to 1929. After this date, production and income had decreased to a point where farming was no longer profitable, except on a limited area along the Augusta Creek river bottom. The Kellogg tract is of sloping character, and considerable erosion had taken place prior to planting. Soil specialists have indicated that as much as 5 feet of soil had washed off the steeper slopes, leaving little topsoil; leaving behind semisterile, nonproductive sands and gravel without heavier subsoil to hold moisture.

Mr. W. K. Kellogg, in donating this parcel to Michigan State College, indicated his desire to see if lands of this type could be rehabilitated. This project was assigned to the Department of Forestry, and they have endeavored to initiate a multiple land-use program which would produce sawlogs, firewood, pulpwood, Christmas trees, and other plants as game food, shelter, and other uses, and at the same time eliminate further erosion.

The Kellogg Forestry Tract was divided into compartments as indicated in the map of this area. This problem on slash disposal was conducted in Compartments 6A, 6B, and 20A (Fig. 1) because of thinning and pruning operations therein. Compartment 6A, consisting of 10 acres, is of a Rodman gravelly, sandy loam, much of it a steep, rocky slope facing west, whereas the other half of this compartment, 6B, consists of some of the steepest land in the forest, the gradient varying from 5 to 30 percent, with several small ravines. This 6B compartment (10 acres) is of a Coloma loamy soil, and has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PROPERTY LINES
COMPARTMENT LINES
FORTY LINES
FOOT TRAIL
PRIMARY ROAD
BRIDGE
HOUSE

Figure 1

24 Linch

been badly eroded. Compartment 6A was planted in the fall of 1931, with 3-year-old red pine (Pinus resinosa) seedlings, 6 to 10 inches, and Compartment 6B was planted in the spring of 1932, with 3-year-old red pine seedlings, 6 to 10 inches in height. These two compartments were planted by different methods in order that a study of the effect of frost could be observed. Compartment 6A was furrowed with a plow at intervals of 8 feet, running north and south and planted with a planting bar. In Compartment 6B, a small hole was dug and trees were planted by putting soil around the roots by hand. Parts of these areas were 8 x 8 spacings, and part were 6 x 6 spacings, but mostly 8 x 8 spacings in study areas.

Thinning and Pruning Operations

In 1945 and 1946, thinning and pruning operations began in both compartments. All thinning of merchantable size up to 3-inch tops were utilized for lumber, posts, and other uses, and the slash was scattered throughout the area or left where felled (Fig. 2). In the thinning processes, the slash was lopped or scattered. In 1946, 1947, and 1948, abnormal reactions were noted in certain trees, particularly in Compartment 6B, on

Figure 2. Type of slash disposal: "Left where Felled."

steeper slopes. Many of these trees were dead or dying, and heavily infested with both bark beetles and wood borers. Upon examination, all of the 1- and 2-year-old slash contained many of the same insects. Similar outbreaks had been observed in the Higgins Lake State Forest after pulpwood operations, thinning, and pruning.

Compartment 20A was planted in 1937, with mixed conifers and a few hardwoods, for production of wood products. This area is planted to several species of conifers, and was used as a check plot against 6B, due to the fact that this soil is of the better type, mostly a Hillsdale loam, which is composed of a pale yellowish-gray fine sandy loam surface and yellowish-brown sandy clay loam subsoil. No signs of any insects could be detected in this area; also, it is three-quarters of a mile from infestation in Compartment 6B. Trees were girdled in this area to study time, migration, and kinds of insects, and their effect upon healthy trees.

Higgins Lake State Forest (jack pine)

Two areas in the Higgins Lake State Forest near Roscommon, Michigan, were selected for study on jack pine, as both areas showed similar signs of insect infestations. The first of the plantations studied was located in Roscommon County (SE 1/4 of SW 1/4, Sec. 27, T25N, R4W), and was established in the fall of 1916 and the spring of 1917, and was 29 years old at the time cutting began. Planting was with alternate white pine (_Pinus strobus_ Linn.) and jack pine, spaced 4 feet in furrows 6 feet apart, totaling approximately 1,800 trees per acre. The soil type is light, dry sand (Grayling sand); topography, gently rolling. The original stand here was white and red pine.

Pulpwood Operations

The condition of the stand before cutting showed a 50-percent survival of jack pine as against 30 percent survival of white pine. The average height of the jack pine was 30 feet; white pine, 5 feet. The stand is, in general, overcrowded, with a few scattered small openings in it. In spite of the crowded condition, the jack pine is thrifty, but there was little self-pruning of the lower dead branches (Fig. 3).

The area was cut on a marked-tree basis, with particular emphasis placed on release of white pine and improvement of remaining jack pine through removal of deformed and defective

Figure 3. Type of slash disposal: "Lopped and Scattered."

trees. Slash disposal, in this operation, consisted of lopping and scattering the brush to a depth not exceeding 24 inches.

The second area selected at Higgins Lake State Forest was very similar in age and species of trees. It was located in Crawford County (NW 1/4 of NE 1/4, Sec. 28, T25N, R4W), and was planted in the fall of 1916 on a Grayling sand type of soil. However, no cutting, thinning, or pruning had been practiced in this area, although twenty-five trees were girdled particularly for this study.

Insect Epidemics

The two locations in the Higgins Lake area were selected also because, for the past 6 years, several other serious insect epidemics had caused considerable losses. Some of these insects are still present, and may have a bearing on the present problem. For instance, up until 1950, certain areas near plots to be studied in this forest were almost completely defoliated with the redheaded pine sawfly (*Neodiprion lecontei* Fitch), which in turn has resulted in the infestation by enormous numbers of wood borers and bark beetles. The redheaded pine sawfly is considered of major importance to foresters and entomologists, alike, because of its defoliating habits on young pines in the eastern half of the United States and in Canada. In Michigan, the preferred hosts seem to be jack pine and red pine, but according to Benjamin (1950), the larvae of this sawfly confine their attack to pines belonging to the hard-pine group. Occasionally, under conditions of food scarcity, the larvae may migrate to adjacent white pine, tamarack (*Larix laricina* [DuRoc] Koch), or deoder cedar (*Cedrus deodara* [Roxb.] Lond.) to complete their development.

During observations at the Higgins Lake area it was noted that 1 year after defoliation, many species of *Ips pini* and other bark beetles were present in these defoliated areas, causing considerable concern as to their effect on adjacent stands.

Perhaps the most important economic insect in the Higgins Lake area at the present time is the jack pine budworm, *Choristoneura* sp. Since 1947, this insect has increased in this area to epidemic proportions. The jack pine budworm, according to Graham (1935), is morphologically similar to the spruce budworm, *Choristoneura fumiferana* (Clem.), but considered a biological race attacking jack pine. In the Higgins Lake area, this insect has caused considerable damage to Scotch, white, and red pine in addition to jack pine. The constant defoliation by this insect since 1947 has so weakened the trees as to make them susceptible to wood borer and bark beetle attack (Fig. 4).

The ravages of this insect in the Higgins Lake area plantations no doubt have caused the increase in wood borers and bark beetles in the girdling plots, as previously described, due to its extensive defoliation.

Another insect belonging to the Family Scarabeidae, either Anomola or Pachystethus oblivia (Horn), has caused considerable concern in this area, as in 1939, and again in 1950, large areas of jack pine were partially defoliated by this insect. Injury from this insect is worse in more open stands, and attacks the new growth. Injury is caused by the adults feeding on new growth down to the bundle sheath, giving the tree a burned appearance during the latter part of June and July. Many of the trees survive this attack, but the larval stages are spent in the ground feeding on the rootlets. The combination of the adults and the larvae no doubt play an important part in weakening of jack pine, and in certain areas of heavy infestations, bark beetles have been found entering the more susceptible

Figure 4. Trees killed by bark beetles after repeated defoliation by the spruce budworm. Higgins Lake State Forest.

trees, causing considerable damage, especially to the younger plantations.

The white pine weevil, Pissodes strobi (Peck) is ever-present in both the Kellogg and Higgins area, and attacks are common on white, red, Scotch, and jack pine, and spruces.

This weevil has become an important pest of jack pine, as well as white pine. Normally, the injury caused by the larvae of this insect consists of the girdling of the terminal shoot and often 2 to 4 years' growth may be killed. Upon examination after dieback, bark beetles of the Family Scolytidae may be found in the damaged part of the tree. This insect not only makes favorable conditions for bark beetle infestations, but also causes forked and crooked trees, resulting in great stumpage loss over a period of years.

For the past few years, heavy to epidemic outbreaks of the Saratoga spittlebug, Aphrophora saratogensis (Fitch), have developed in red and jack pine in the Higgins Lake area. The immature stages of this insect feed on sweet fern and other plants. Sweet fern is very prevalent in many of the plantations. The adult spittlebugs, while feeding on the pines, extract large quantities of sap, causing scar tissue to form. Flagging is prevalent in these infested areas. These insects are not considered killers of trees, but may cause sufficient weakening so that they invite other insect attacks.

Other forest insects are present in the Higgins Lake area, but the ones previously mentioned are the more important ones which may have influenced the insect counts, although all must be considered in any silvicultural or management plan to reduce their numbers to a less-hazardous situation than now exists in this area.

Development of Technique

Cage Rearing Experiments

Two types of cages were used in this study for the purpose of collecting the insects present in the material to be studied.

One type of cage (Fig. 5) was constructed to handle some of the larger material such as trunks, large thinnings, or the larger parts of the slash. These cages were 2 x 2 x 4 feet or 2 x 2 x 3 feet in size. The ends were wood, and the sides were of ordinary window screen. It was found that this screen was too coarse to capture certain species of bark beetles, but

Figure 5. Large emergence cages.

worked satisfactorily for most of the larger species found in the slash.

The other type of breeding cage used, as shown in Figure 6, is known as a codling-moth cage. These were 14 x 20 x 20 inches in size, and are enclosed with a fine 28-mesh screen. This cage was used in rearing bark beetles and other smaller insects.

These cages were filled with infested materials to be studied, and placed out of doors under natural conditions in both the Kellogg and Higgins Lake areas.

Individual records were kept of the emergence from these cages. Each species of insect emerging from the wood in the various cages was given its proper number and date of emergence. Each part of the tree, such as slash and smaller branches, was recorded separately to determine the numbers and kinds of insects in different sections of the tree.

Collection of materials for this study was begun in 1946, and proceeded through 1951, using only red and jack pine.

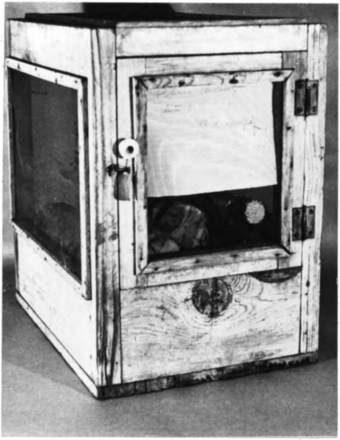

Figure 6. Small emergence cage (codling-moth cage).

Tree Girdling

In addition to the insects found in slash and weakened trees, girdling experiments in 1946 were established in both areas to study their effects on attraction of insects. Two trees were completely girdled; two, one-half; and two, one-quarter. This procedure was repeated in the fall of 1949 with additional trees, to secure a more accurate count of the infestation.

Counts were made on these trees at Kellogg and Higgins Lake forests, as indicated in Figure 7. A one-linear-foot sample was taken at the diameter breast height and at 10 feet above diameter breast height (or 14-1/2 feet from the ground). The third was made 6 feet from the top of the tree. This gave a cross section of the numbers and kinds of insects to be found in the two species of trees studied. The smaller branches were caged separately. In addition to this, several weakened trees already infested were cut and studied as a comparison.

Soil Samples

It was noted that at the Kellogg tract (Fig. 8), a heavy concentration of bark beetles and wood borers appeared in a part of Compartment 6B soon after thinning and pruning operations

FIGURE 7

DIAGRAM OF A TREE SHOWING AREAS WHERE

BARK BEETLE AND WOOD BORER COUNTS WERE TAKEN

Figure 8. Infested area at Kellogg Forestry Tract after thinning.

had been started. Six soil samples were taken in this compartment in three different areas, at two depths, as shown in Table II. Samples one and two were taken at the top of the hill, which had a 3 to 4 percent slope, with no apparent injury from insects. Samples three and four were taken on the hillside, having a 25 to 30 percent slope and a serious infestation. This infestation was actually killing the living trees. Two more samples were taken at the bottom of the hill, where a 3 to 4 percent slope existed, with no evident infestation.

There is no doubt that any effective method of slash disposal is close utilization. European countries, in their close utilization, have practically eliminated any dangerous insect infestations. Stebbings (70) stated that experience has shown that in countries where large tracts are covered with a single species of conifer, such as is the case in America and, to a lesser extent, in India, uncontrolled fellings have resulted in the most disastrous infestations of bark-boring beetle pests.

The parts of the slash suitable for the breeding of potentially injurious insects are normally limited to those parts which do not dry out quickly. Such ecological conditions as exceedingly high or low temperatures, or those which induce

TABLE II

ANALYSIS OF SOILS TAKEN AT KELLOGG FORESTRY TRACT, 1948

Site	Depth of Sample (inches)	Ph[1]	$CaCO_3$ Equiv. of Replaceable H_2[2]	Chemosoluble Phosphorus[3]	Replaceable Potassium[4]
Top of hill, 3-4% slope	0 - 6	5.4	7,000	22	88
	6 - 14	5.7	6,000	13	150
Slope of hill, 25-30% slope	0 - 6	5.1	8,000	89	98
	6 - 14	5.4	7,000	114	136
Bottom of hill, 3-4% slope	0 - 6	5.7	6,000	46	76
	6 - 14	5.9	3,000	63	64

[1] Data based on 1:1 soil-water suspension.

[2] Expressed as pounds per acre plow slice, or on 2,000,000 pounds of soil as determined by the procedure of Bray and DeTurk (5).

[3] Expressed as pounds per acre as determined by the procedure of Bray (6).

[4] Replaceable potassium per acre plow slice, or 2,000,000 pounds, as determined by the procedure of Bray (7).

fermentation or fungus formations, are not conducive to insect infestations. Such is the case commonly found in the larger branches, tops, and slash when not shaded. Poor burning methods may invite insect populations (Patterson, 60).

Slash Studies

For the purpose of this study on the relation of insects to slash-disposal methods, five recognized sample plots of slash-disposal methods were established. At the Higgins Lake area, five plots were established under pulpwood and thinning operational conditions. At the Kellogg area, three methods of slash disposal were established under thinning, pruning, and release-cutting conditions.

The methods of slash disposal used are as follows:

1. Lopped and Scattered (Fig. 9): Lopping, which has had rather wide usage at one time or another, is based upon the belief that bringing the limbs and waste close to the ground will hasten decay. It has been estimated that the lopped tops would cease to be a fire hazard in seven years, while unlopped tops would persist much longer.

Figure 9. Type of slash disposal: "Lopped and Scattered."

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Spaulding (68, 69), in his report on decay of white pine slash, said that on soils that are moist the year around, slash lying directly on the ground became waterlogged and prevented the breakdown from fungus action. Lopping, in this case, did not cause slash breakdown. On the light sandy soil, drying inhibited the slash decomposition, causing slash to remain a hazard for long periods of time.

This method of slash disposal is of economic importance from an insect standpoint, also, because of its attractiveness to beetles.

2. Windrowing (Figs. 10 and 11): Two methods of windrowing were used in this study. Normal windrowing is in common practice in Michigan at the present time, and is recommended in many pulpwood operations. The common practice of windrowing consists of placing the tops toward the center with the butts out, and the height of the windrows are regulated by the forester in charge.

The other method of windrowing made in this study was of similar height regulation. Instead of placing the tops toward the center and the butts out, the trunks are reversed, placing the butts in (toward the center), with the tops out. In all cases,

Figure 10. Type of slash disposal: "Windrowing, Butts Out" (regular).

Figure

Figure 11. Type of slash disposal: "Windrowing, Butts In."

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insect infestations were decreased significantly by this type of windrowing.

3. Piling (Figs. 12, 13, and 14): Normal piling is done with more or less round piles, varying the depth and size of the piles. A considerable amount of work has been done on this type of disposal in Michigan by Zon and Cunningham (80) and others (11, 21, 76), with respect to slash breakdown and burning methods, with no mention of insect control.

Two methods of piling were again practiced in this study, from the insect-control standpoint. These included piling with butts out (normal piling) and piling with butts in (toward the center), with height and size of brush being considered. The results from piling with butts in gave similar results as windrowing with butts in.

4. Undisposed (Fig. 15): This type of slash disposal was left where it fell, no effort being made to dispose of it. This method is a common practice used in Michigan in the pulpwood, pruning, and thinning operations, and is exceedingly conducive to heavy insect infestations.

5. Lopped and Left (Fig. 16): In this operation, tops were lopped where they lay in order to bring the slash close

Figure

Figure 12. Type of slash disposal: "Piling, Butts Out" (regular). Photo by USFS.

Figure 13. Type of slash disposal: "Piling, Butts In."

Figure 14. Prunings piled, Butts In (toward center).

Figure 15. Type of slash disposal: "Undisposed."

Figu

Figure 16. Type of slash disposal: "Lopped and Left."

to the ground. This method is seldom used in Michigan except in hardwood operations, although this method is practiced in thinning operations in certain areas.

In addition to the prescribed slash-disposal methods, time of cutting was observed, as each group of species has its own food requirements. Any change in food composition, it was noted, increased the numbers and kinds of insects present.

Presentation of Data

Tabular Results

Five of the larger cages were filled with small logs cut from the tops of red pine in the thinning area in the Kellogg tract during April, 1948. These logs were cut during the period from June 12 to 20, 1947. All slash laid on the ground in an undisposed method from the time it was cut until it was placed in the cages. The total volume of the logs was 8.64 cubic feet. The average diameter was 3.6 inches. Table III shows the results of wood borers and others taken from these cages.

This experiment was repeated in May of 1949, with logs containing 6.31 cubic feet of wood, and the results are recorded in Table IV.

TABLE III

THE TOTAL NUMBER OF INSECTS EMERGING FROM CAGED RED PINE; KELLOGG FORESTRY TRACT, 1948

Date	*M. titillator*	*A. guttata*	*I. mesocentrus*	Others
June				
19	10	0	0	
26	50	5	1	several moths
July				
3	27	7	0	
12	89	40	2	1 grass-hopper
21	52	10	0	
26	1	6	2	
Aug.				
1	0	0	0	
11	8	0	2	
Total	237	68	7	

TABLE IV

THE TOTAL NUMBER OF INSECTS EMERGING FROM CAGED RED PINE; KELLOGG FORESTRY TRACT, 1949

Date	*M. titillator*	*A. guttata*	*I. mesocentrus*	Others
May				
14	2	0	0	
22	10	0	0	
June				
7	13	1	0	2 Curculionidae
18	11	0	0	
25	45	2	0	2 Curculionidae 2 Scolytidae
July				
5	30	2	0	5 Curculionidae
14	3	2	0	
Aug.				
12	2	0	0	
Total	116	7	0	

Five cages were also prepared at the Higgins Lake area with comparable volume content of jack pine, but only a few wood borers of Monochamus scutellator were recovered in 1948, due to the misfortune of mice entering the cages before counts were made, eliminating total counts of wood borers and others present, although enough material was saved for determination of species present.

Results of Caged Material

The results by individual cages of the material at the Kellogg and Higgins Lake areas are shown as follows:

Cage 1 was caged with nearly completely dead red pine, containing 1.22 cubic feet, which was cut at the same time.

Cage 2 was caged August 10, 1948, from tops cut in May, 1947. It contained 0.98 cubic foot of wood.

Cage 3 was caged August 10, 1948, with tops of trees removed for pulpwood cut in May, 1947. This cage contained 1.98 cubic feet of wood.

Cage 4 was caged May 4, 1949, with red pine which was cut November, 1948, for boughs. This cage contained 2.13 cubic feet of wood.

CAGE 1

Date	*M. titillator*	*A. guttata*	Curculionidae
June 18	3		2
June 25	24		1
July 5	18		4
July 14	2		0
Aug. 12	2		0

CAGE 2

Date	*M. titillator*	*A. guttata*	Curculionidae
July 18	2		1
June 25		1	1
July 5		1	1

CAGE 3

Date	*M. titillator*	Scolytidae
June 18	1	
July 5		2
July 14	1	

CAGE 4

Date	*M. titillator*	*A. guttata*	*M. scutellatus*	Vespidae	Braconidae
May 14	2				
May 23	10				
June 7	6	1	7		
June 18	4				
June 25	20	2	1	1	1
July 5	12	1			
July 14		2			1

Cages 2 and 3, containing red pine cut in the spring of 1947, produced very few insects. This may indicate that red pine which has been cut for 12 months or more is no longer a suitable breeding place for the pine sawyers. Cage 5 gave no results, due to the fact that material was 17 months old at the time of filling.

Cages were again established in 1949 and 1950, at the Higgins Lake State Forest, comparable to the Kellogg area, and all but two cages were destroyed by visitors overcurious as to what was inside, but the two unharmed cages showed the following results in jack pine:

Cage 3 was caged May 12, 1949, with jack-pine slash cut in the summer of 1948. This cage contained 1.96 cubic feet of wood.

Cage 5 was caged May 12, 1949, with pulpwood logs cut in 1948. This cage contained 2.23 cubic feet of wood.

In September of 1949, some of the smaller prunings of red pine were examined, ranging from 1.125 to 2.25 inches at the base, and varying from 4 feet 7 inches to 7 feet in length, on the Kellogg area. Total numbers of Cerambycid larvae are recorded in Table V.

CAGE 3

Date	*M. scutellatus*	Curculionidae	Tachinidae	Formicidae
June 22	19	4	9	7
July 20	26	1	2	0
Aug. 14	4	0	1	2

CAGE 5

Date	*M. scutellatus*	Curculionidae	Vespidae	Tachinidae
June 11	7	1	5	1
June 21	36	5	9	7
July 20	11	1	2	2
Aug. 17	2	2	0	0

TABLE V

NUMBER OF CERAMBYCID LARVAE TAKEN FROM PRUNINGS OF RED PINE; KELLOGG FORESTRY TRACT, SEPTEMBER, 1949

Diameter at Base (in inches)	Total Length	Number of Wood-borer Larvae
1.125	4 ft. 7 in.	10
1.25	4 ft. 8 in.	11
1.5	5 ft. 0 in.	16
1.083	5 ft. 9 in.	15
1.5	6 ft. 0 in.	19
1.75	6 ft. 2 in.	11
1.75	6 ft. 6 in.	21
1.75	6 ft. 0 in.	22
2.0	6 ft. 5 in.	23
2.0	6 ft. 4 in.	27
2.125	6 ft. 5 in.	24
2.125	6 ft. 6 in.	24
2.125	6 ft. 9 in.	27
2.125	7 ft. 0 in.	13
2.25	6 ft. 8 in.	25

The same counts were made at the Higgins Lake area, but were taken from jack pine of comparable sizes and lengths, and results are recorded in Table VI.

It is interesting to note that in all cases the Cerambycid larvae were more prevalent in the red pine than in the jack pine; also, a different species of Monochamus prevailed. According to Parmelee (59), both species were commonly found in both red and jack pine, but this was not the case in this study, as Monochamus titillator predominated in the red pine and M. scutellatus predominated in the jack pine in the two areas studied.

In the two areas, the codling-moth cages were established under natural conditions in order to determine total numbers and kinds of bark beetles and others which one might find in red and jack pine slash. In both areas, in 1949 and 1950, the cages were filled with larger thinnings, averaging 4 and 5 inches in diameter, and composed of 5 linear feet in each cage. The results are recorded in Tables VII and VIII.

Other codling moth cages were filled with smaller parts of the slash, as indicated in Tables IX and X, with total numbers and kinds recorded. Here, the reverse is noticed, that

TABLE VI

NUMBER OF CERAMBYCID LARVAE TAKEN FROM PRUNINGS OF JACK PINE; HIGGINS LAKE FOREST, SEPTEMBER, 1949

Diameter at Base (in inches)	Total Length	Number of Wood-borer Larvae
2.5	4 ft. 8 in.	10
3.125	6 ft. 2 in.	3
4.0	4 ft. 4 in.	4
4.25	7 ft. 2 in.	2
3.0	6 ft. 5 in.	1
2.75	4 ft. 3 in.	9
2.50	4 ft. 9 in.	7
1.25	6 ft. 2 in.	11
1.25	7 ft. 0 in.	4
1.25	6 ft. 0 in.	7
2.125	7 ft. 1 in.	1
1.125	4 ft. 7 in.	6
2.0	5 ft. 8 in.	8
2.125	6 ft. 6 in.	2
4.0	9 ft. 2 in.	14

TABLE VII

NUMBER OF BARK BEETLES EMERGING FROM FIVE ONE-LINEAR-FOOT PIECES OF RED PINE; KELLOGG FORESTRY TRACT

Date Caged	Average Diameter (in inches)	Cage 1	Cage 2	Total
1947	5	410	95	505
1950	4	356	245	601

TABLE VIII

NUMBER OF BARK BEETLES EMERGING FROM FIVE ONE-LINEAR-FOOT PIECES OF JACK PINE; HIGGINS LAKE STATE FOREST

Date Caged	Average Diameter (in inches)	Cage 1	Cage 2	Total
1947	5	145	521	766
1950	4	235	736	971

TABLE IX

NUMBER OF BARK BEETLES EMERGING FROM RED PINE SLASH; KELLOGG FORESTRY TRACT

Date Caged	Average Diameter (in inches)	Average Length (in inches)	Cage 1	Cage 2	Total
1947	1.25	55	38	23	61
1950	2.50	80	40	29	69

TABLE X

NUMBER OF BARK BEETLES EMERGING FROM JACK PINE SLASH; HIGGINS LAKE STATE FOREST

Date Caged	Average Diameter (in inches)	Average Length (in inches)	Cage 1	Cage 2	Total
1947	2.2	61	177	287	464
1950	1.75	54	99	163	262

more bark beetles prevail in jack pine than in red pine, and this, perhaps, is accounted for by heavy damage and defoliation caused by other insects in the Higgins Lake area.

Results of Field Counts

Field counts and collections were made on all of the original trees that were girdled in 1946, and also on those that were completely or partly killed by other causes within the areas. It was observed that of the six trees originally girdled in the Kellogg area, the two trees completely girdled did not show signs of infestation by bark beetles or wood borers until the spring of 1948. Those one-half and one-quarter girdled red pine completely revived, and are still free from insect attack.

In the Higgins Lake area, however, the completely girdled jack pine were infested heavily with bark beetles in 1947, and half girdled were not killed until 1948. The one-quarter girdled died in 1950.

In 1949, several trees were girdled, but these trees were not located in the area where any cutting, pruning, or thinning operations were in progress. These areas were chosen where no evident infestation was present, in what were supposedly good sites, and the objects here were to see how far the bark beetles would travel, how much time must elapse before an infestation might build up, and also to check numbers and kinds of insects which might prevail under man-made conditions, as compared to common silvicultural practices such as thinning, pruning, or pulpwood operations.

The significance of this process showed the same results as the original girdling experiment, and also the same kinds of insects were present in each case; and the total numbers of wood borers and bark beetles in 3 linear feet of each tree of a definite diameter breast height is recorded in Tables XI and XII for each area. These counts were taken as indicated in Figure 7.

From this later study it was noted that certain of these insects could be found in definite parts of the tree. A diagrammatic sketch was constructed (Fig. 17), showing parts of the tree most susceptible to different insects, both harmful and beneficial.

Figure 18 to 21 show the numbers of wood borers and bark beetles which were found to be present at the diameter

TABLE XI

NUMBER OF BARK BEETLES AND WOOD BORERS IN ONE-FOOT LENGTHS OF RED PINE TAKEN AT THREE HEIGHTS; KELLOGG FORESTRY TRACT, SEPTEMBER, 1951

Tree No.	D.B.H.[1]	Total Height	At D.B.H.		At 14-1/2 Feet		At 6 Feet From Top	
			B.B.[2]	W.B.[3]	B.B.	W.B.	B.B.	W.B.
1	4.3	23 ft. 2 in.	67	13	22	11	10	dead
2	4.3	24 ft. 5 in.	49	7	19	5	15	2
3	4.4	28 ft. 0 in.	35	0	10	3	4	5
4	4.6	32 ft. 0 in.	71	10	31	7	top dead	
5	4.7	23 ft. 0 in.	69	17	27	10	0	2
6	4.9	25 ft. 0 in.	76	8	11	2	23	0
7	5.0	30 ft. 4 in.	51	10	31	0	21	0
8	5.1	32 ft. 0 in.	82	19	49	13	19	3
9	5.2	31 ft. 0 in.	85	7	60	17	8	6
10	5.2	32 ft. 0 in.	60	11	52	10	7	7
11	5.2	33 ft. 3 in.	55	13	71	8	32	9
12	5.4	31 ft. 1 in.	97	2	41	11	17	5
13	5.5	38 ft. 0 in.	89	11	37	14	29	10
14	5.6	33 ft. 9 in.	107	4	21	9	38	17
15	5.8	35 ft. 0 in.	92	5	90	2	40	3

[1] Diameter breast height.

[2] Bark beetles, including the Families Tenebrionidae and Histeridae.

[3] Wood borers, Buprestidae and Cerambycidae.

TABLE XII

NUMBER OF BARK BEETLES AND WOOD BORERS IN ONE-FOOT LENGTHS OF JACK PINE TAKEN AT THREE HEIGHTS; HIGGINS LAKE STATE FOREST, SEPTEMBER, 1951

Tree No.	D.B.H.[1]	Total Height	At D.B.H.		At 14-1/2 Feet		At 6 Feet From Top	
			B.B.[2]	W.B.[3]	B.B.	W.B.	B.B.	W.B.
1	3.0	30 ft. 0 in.	35	9	23	0	26	7
2	3.5	31 ft. 0 in.	29	2	43	0	121	5
3	4.0	29 ft. 3 in.	30	7	41	0	98	6
4	4.0	29 ft. 6 in.	59	1	51	0	102	0
5	4.1	32 ft. 0 in.	47	16	65	1	163	21
6	4.2	30 ft. 5 in.	42	5	77	7	198	3
7	4.4	33 ft. 0 in.	31	11	32	0	210	19
8	4.8	33 ft. 5 in.	52	3	119	0	99	0
9	5.0	35 ft. 0 in.	No insects--tree not entirely dead					
10	5.5	35 ft. 3 in.	44	8	88	0	188	7
11	6.0	32 ft. 5 in.	34	7	117	0	290	10
12	6.3	31 ft. 0 in.	39	10	123	1	77	19
13	6.3	33 ft. 2 in.	42	3	98	2	129	1
14	6.3	34 ft. 9 in.	80	8	77	0	287	8
15	6.4	33 ft. 2 in.	47	6	73	0	225	6
16	6.5	35 ft. 0 in.	30	18	121	0	211	26
17	7.0	33 ft. 7 in.	53	9	154	7	177	3
18	7.1	32 ft. 1 in.	56	12	126	1	312	9
19	7.3	33 ft. 3 in.	60	15	147	0	291	11
20	7.4	34 ft. 0 in.	30	17	180	0	126	21
21	7.5	32 ft. 6 in.	72	14	112	1	181	16
22	8.1	34 ft. 2 in.	77	18	78	3	217	29
23	8.9	33 ft. 3 in.	110	8	114	0	210	3
24	12.3	33 ft. 5 in.	52	32	98	0	117	19
25	14.9	32 ft. 8 in.	65	20	182	2	321	32

[1] Diameter breast height.

[2] Bark beetles, including the Families Tenebrionidae and Histeridae.

[3] Wood borers, Buprestidae and Cerambycidae.

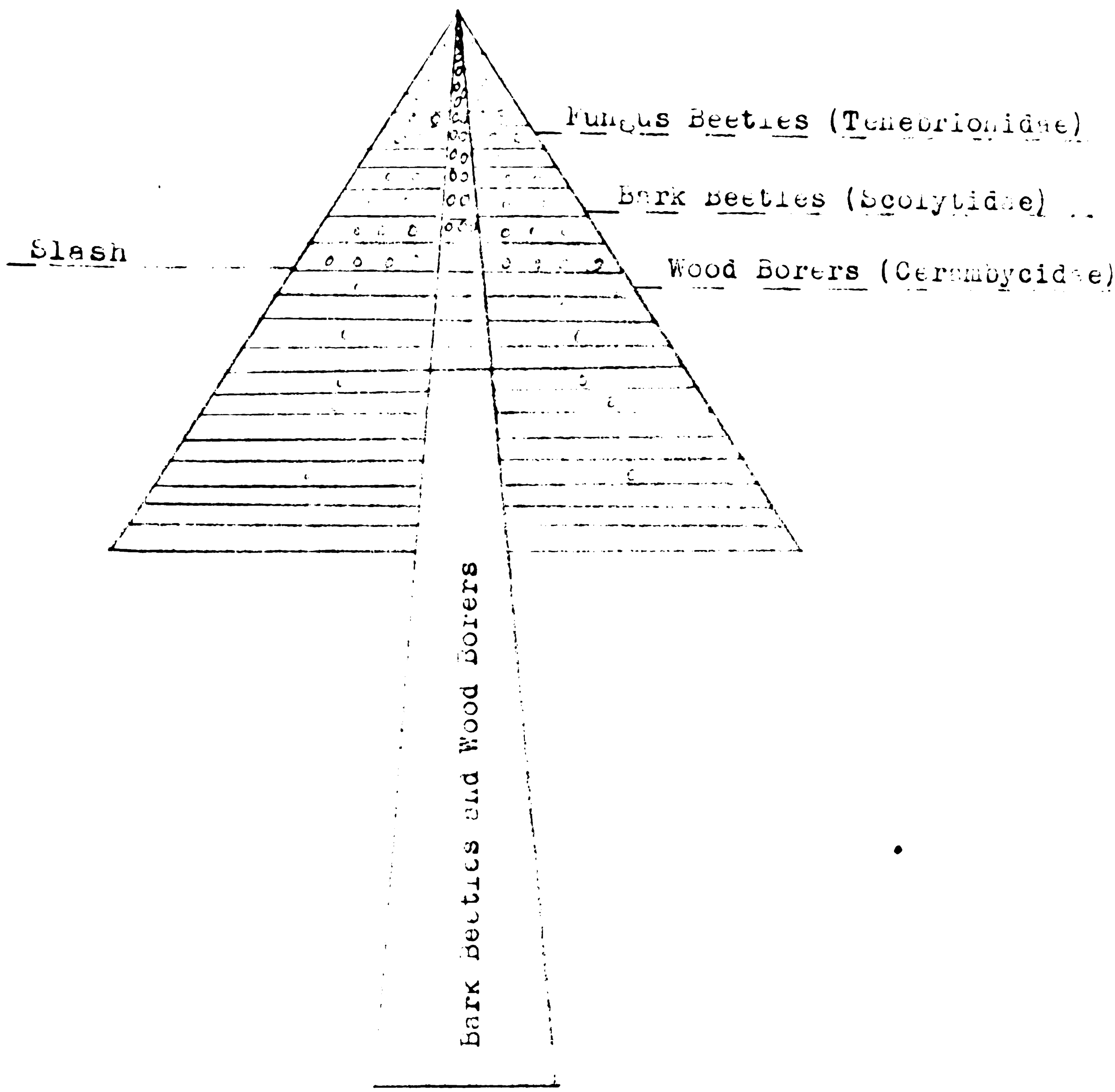


FIGURE 17

DIAGRAM SHOWING SECTION OF THE TREE MOST SUSCEPTIBLE TO BARK BEETLE, WOOD BORER AND FUNGUS BEETLE DAMAGE

FIGURE 18

THE TOTAL NUMBER OF BARK BEETLES IN THREE LINEAR FEET OF RED PINE, KELLOGG FOREST TRACT

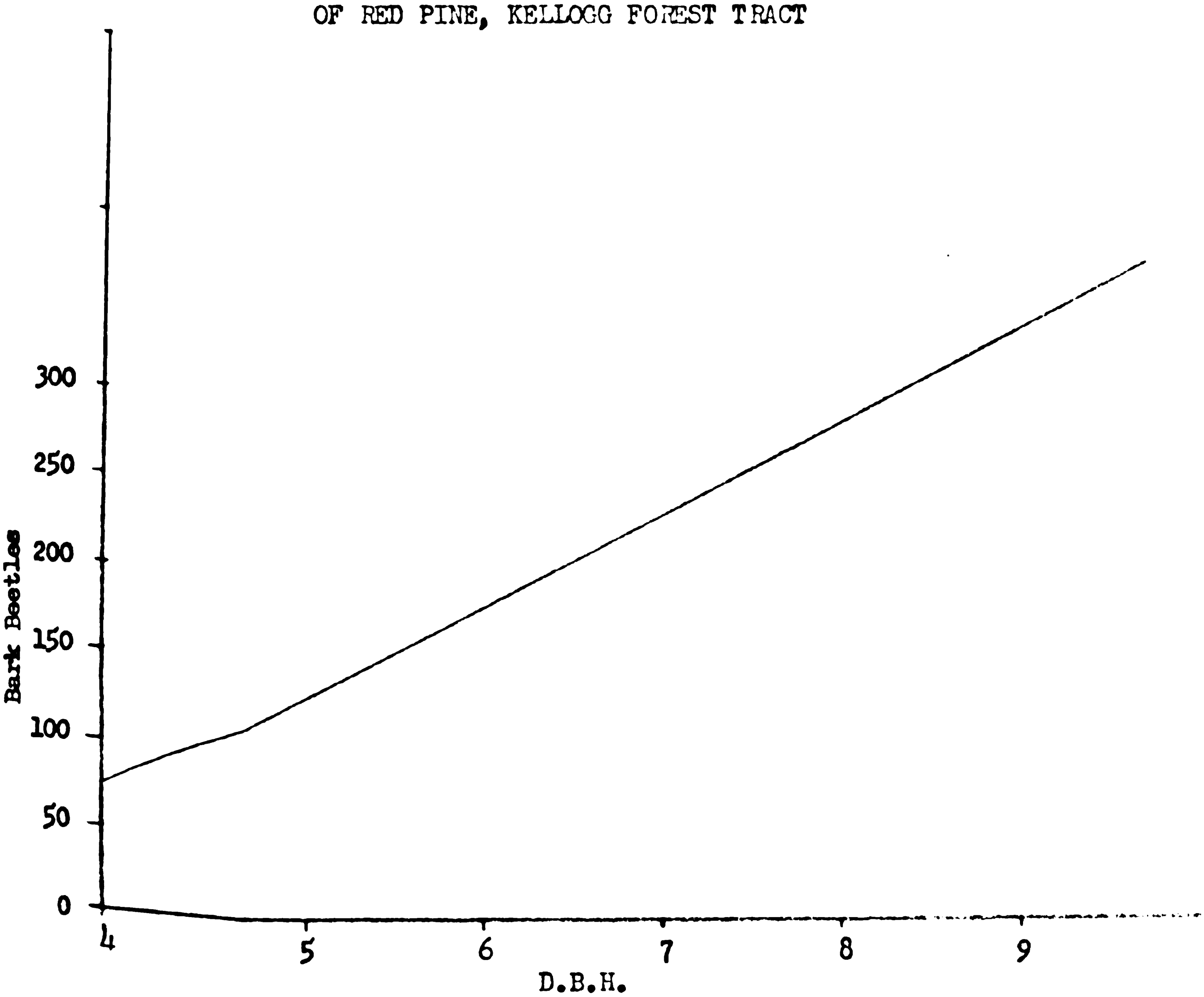


FIGURE 19

THE TOTAL NUMBER OF WOOD BORERS IN THREE LINEAR FEET
OF RED PINE, KELLOGG FOREST TRACT

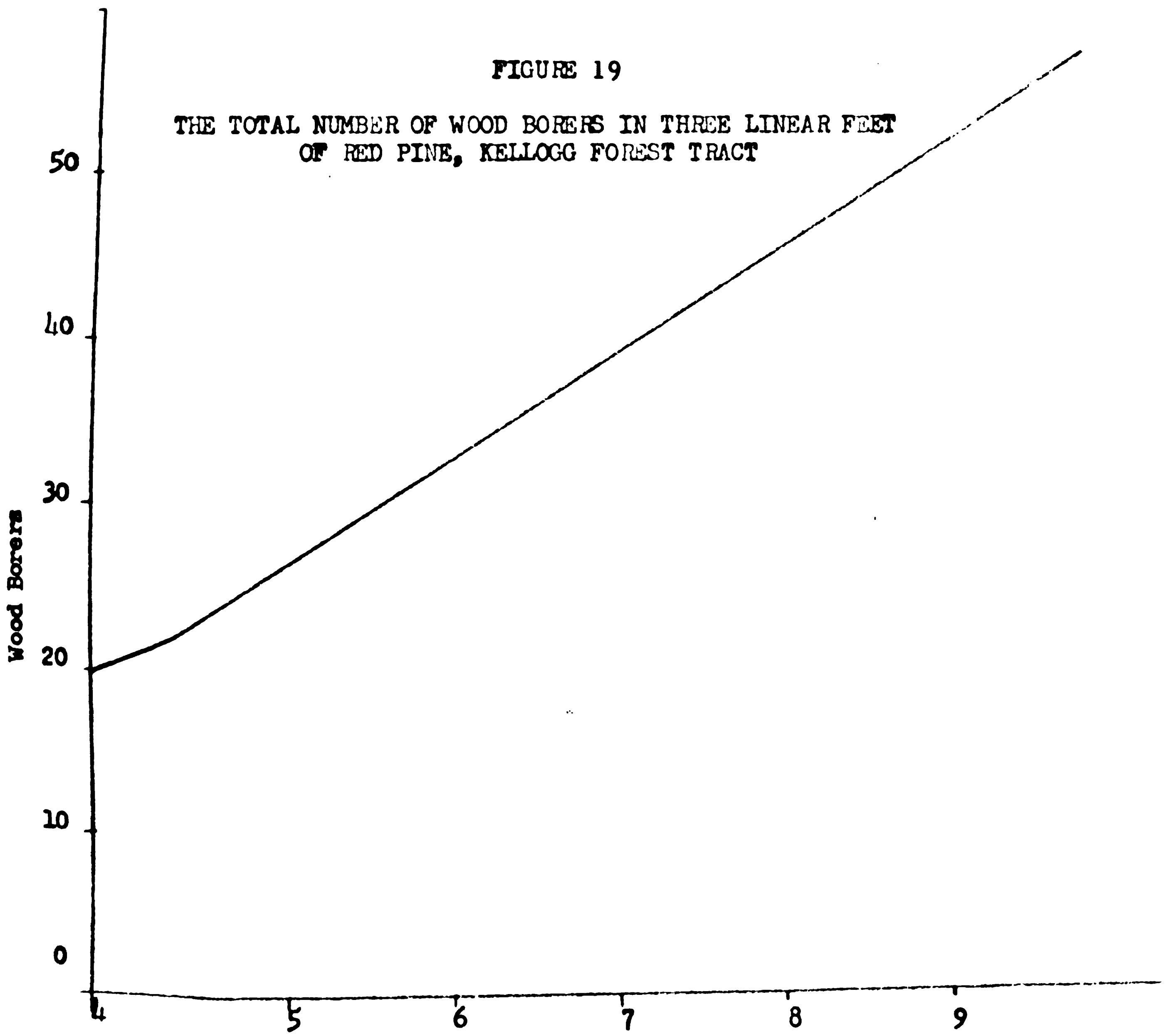


FIGURE 20

THE TOTAL NUMBER OF WOOD BORERS IN THREE LINEAR FEET OF JACK PINE, HIGGINS LAKE STATE FOREST

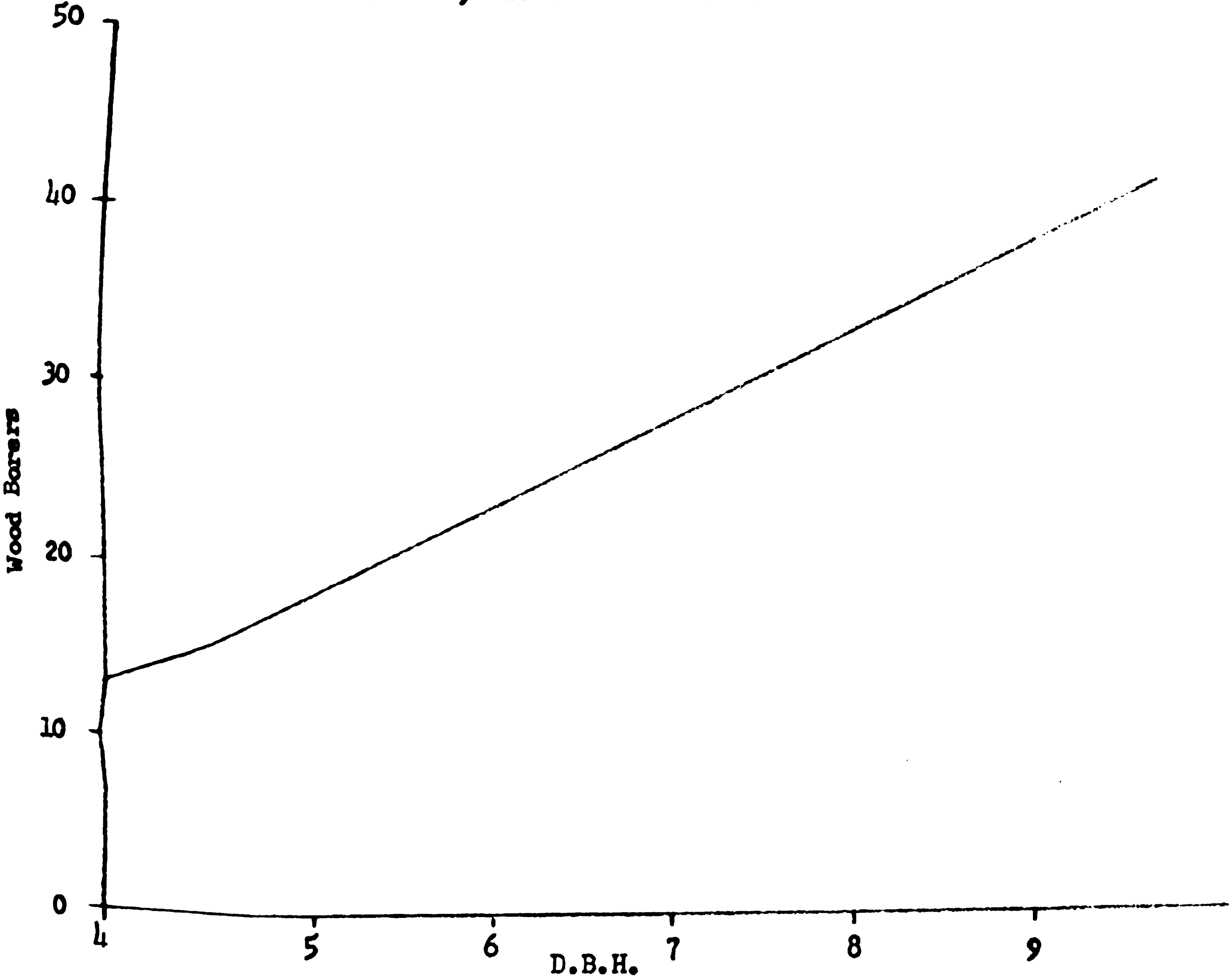
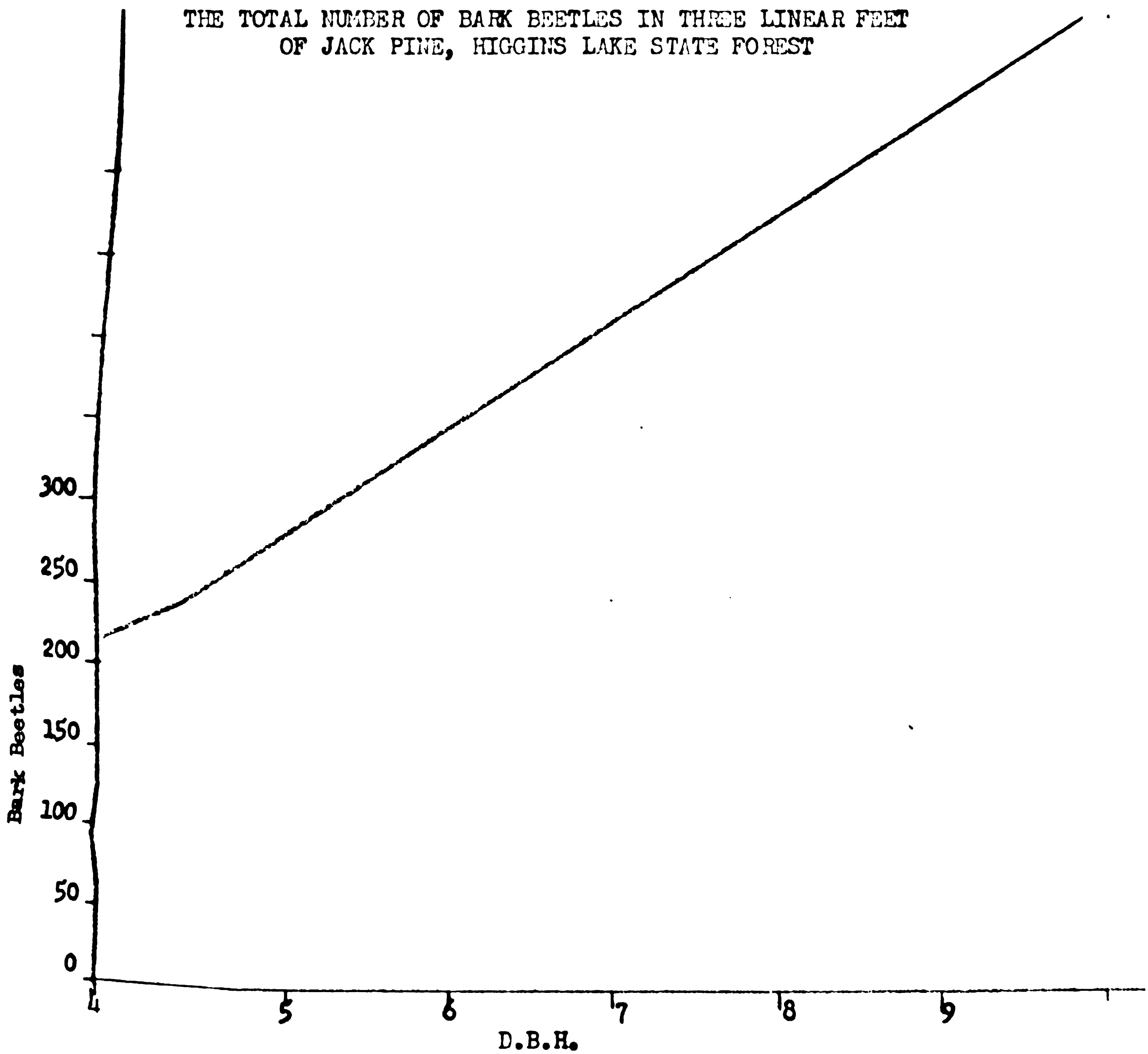


FIGURE 21

THE TOTAL NUMBER OF BARK BEETLES IN THREE LINEAR FEET OF JACK PINE, HIGGINS LAKE STATE FOREST



breast height of red and jack pine. These trees varied in diameter breast height from 4.3 inches to 5.8 inches in red pine, and 4.0 to 14.9 inches in jack pine. The regression coefficient, or the slope of the line, was determined by the following formula:

$$B = \frac{SXY - [\ (SX)(SY)\ /\ N\ ]}{SX^2 - [\ (SX^2)\ /\ N\ ]}$$

B = slope of line.
X = diameter of tree.
Y = number of beetles.
S = symbol for (sum of)
N = number of points (each point having an X and a Y value).

In statistics, the regression of Y on X is defined by the line (or the curve) describing the relation between mean value of Y and X.

These data show that under the conditions studied, red pine having a diameter breast height, for example, of 5.0 inches, shows approximately 104 bark beetles in 3 linear feet taken at different heights. In jack pine there were 250 bark beetles at the same diameter breast height, indicating greater concentration in the Higgins Lake area, or a tree susceptibility preference.

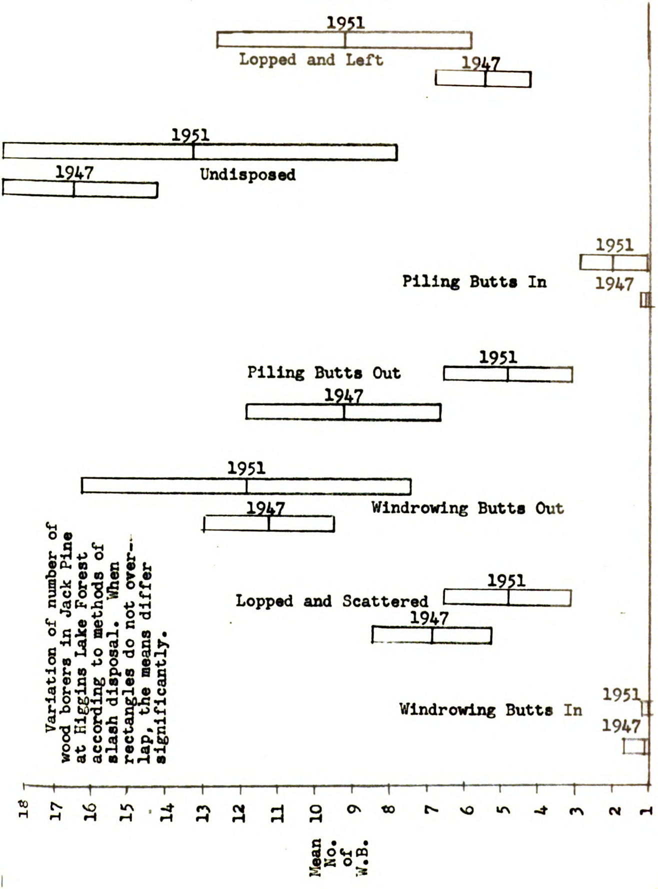
Results of the Slash-disposal Methods

As previously stated, five common methods of slash disposal were practiced in the Kellogg and Higgins areas to determine the best method of reducing insect populations of epidemic proportions in slash. Many tests and variations were tried during 1946 to 1951, but definite methods of slash disposal were recorded during 1947 and 1951. Costs must always be considered in any slash-disposal method, and therefore, regular methods were used. The only variation was in normal piling and normal windrowing, where, instead of throwing the larger part of the slash with the butt ends out, this was reversed, with butts in toward the centers.

Insect counts were made on all the different methods of slash disposal. These counts were taken at random on five 1-foot lengths of slash over a 2-year period, and were recorded as to number of wood borers and bark beetles.

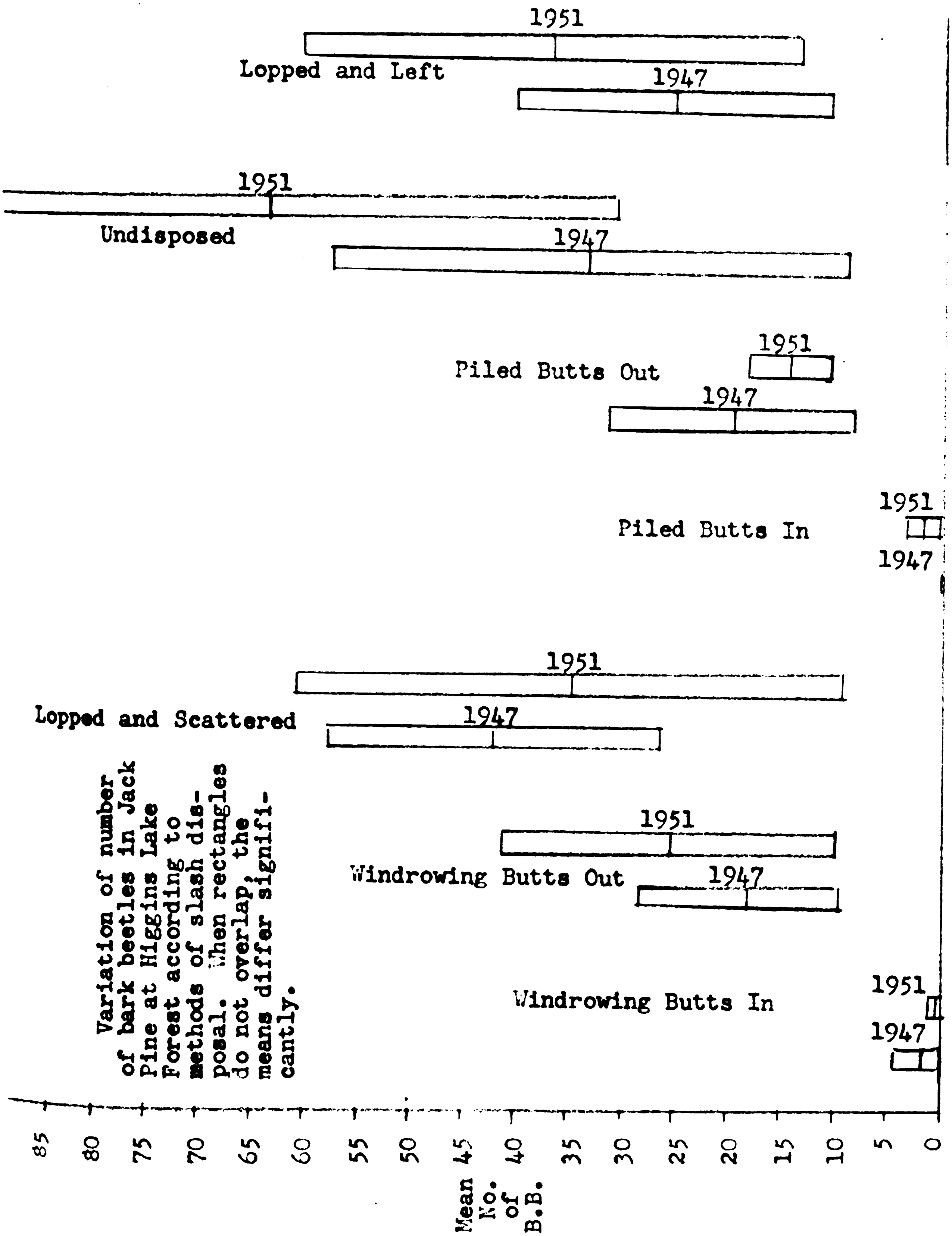
Statistical analysis of these counts by means of a graphical method is recorded in Figures 22 to 25. This is the graphical method of Dice and Leraas (22), discussed by Simpson and Roe (65) in 1939. According to this method, when the rectangles (which represent two standard errors each side of

Figure 22



Variation of number of wood borers in Jack Pine at Higgins Lake Forest according to methods of slash disposal. When rectangles do not overlap, the means differ significantly.

Figure 23



Variation of number of bark beetles in Jack Pine at Higgins Lake Forest according to methods of slash disposal. When rectangles do not overlap, the means differ significantly.

Figure 24

Variation of number of bark beetles in Red Pine at Kellogg Forestry Tract according to methods of slash disposal. When rectangles do not overlap, the means differ significantly.

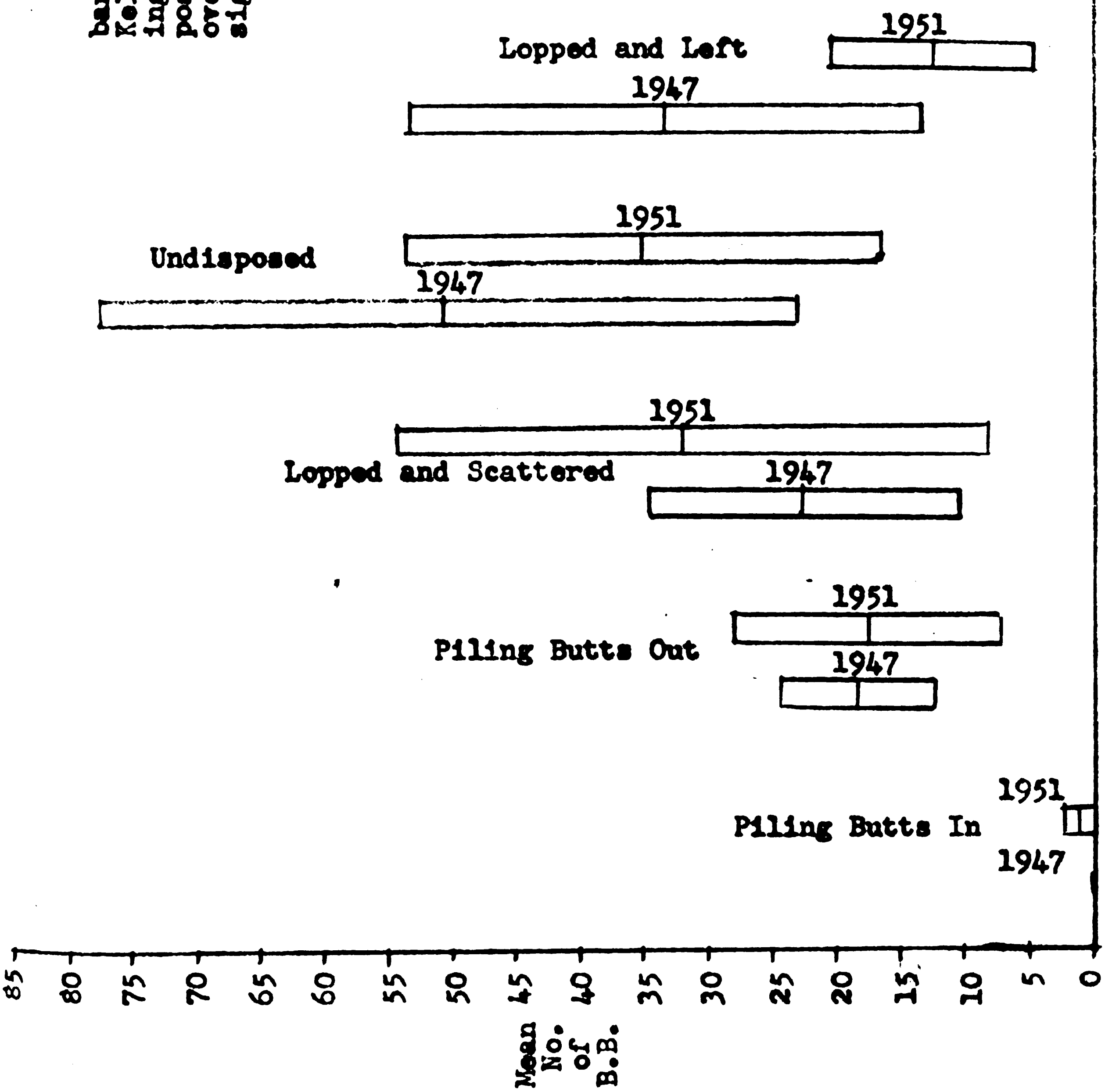
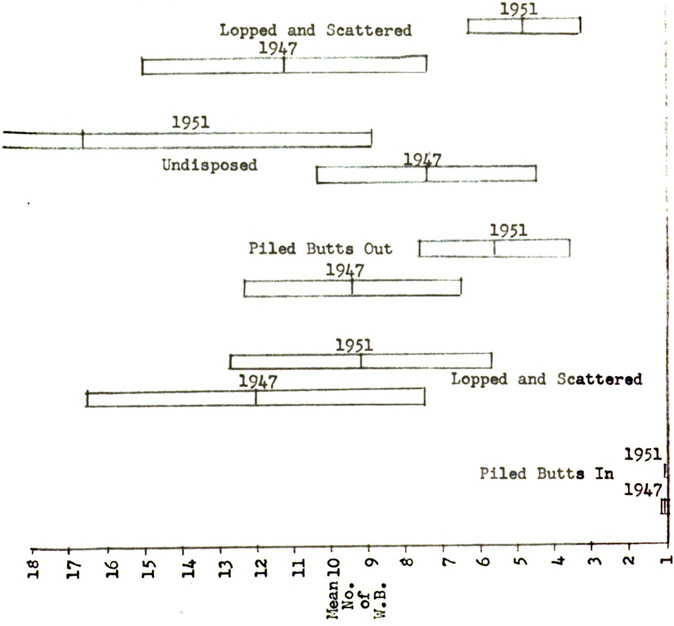


Figure 25

Variation of number of wood borers in Red Pine at Kellogg Forestry Tract according to methods of slash disposal. When rectangles do not overlap, the means differ significantly.



the mean) overlap, then the means do not differ significantly. The formula used is as follows:

$$\text{Sum of Squares} = S(X)^2 - [\ (SX)^2\ /\ N\ ]$$

S = "sum of"

N = number of items in sample

$$\text{Mean square} = [\text{Sum of squares}]\ /\ [N - 1]$$

$$\text{Standard Error} = \sqrt{\text{Mean square}\ /\ N}$$

or

$$\text{Standard Error} = \sqrt{\text{Sum of squares}\ /\ N(N - 1)}$$

The graphs then show two standard errors, one on each side of the mean, which indicate its significance.

No apparent means of reducing insect populations were effective in the standard and accepted methods of slash disposal; whereas, of the methods used in this study, it is significant to note that in all cases where materials were windrowed or piled with the "butts in," a significant difference occurred in numbers of both bark beetles and wood borers.

Observations in the field indicated this trend in all plots unless piles or windrows exceeded 3 feet in height, although bark beetles were kept to a minimum up to 4 feet.

From the insect counts made, the undisposed method of slash disposal produced the greatest numbers of beetles, followed by "lopped and left," "lopped and scattered," and in most cases followed by normal windrowing and piling. It was significant to note that when the last two methods of slash disposal were reversed from normal by placing the "butts in" (toward the center), in all cases where slash did not exceed 40 inches in height, the insects were reduced significantly.

List of Insects Collected from
Red and Jack Pine Slash

	Family	Genus and Species	Common Name of Family
1.	Cerambycidae	Monochamus scutellatus (Say)	Roundheaded wood borer
2.	Cerambycidae	Monochamus titillator (Fab.)	Roundheaded wood borer
3.	Cerambycidae	Astylopsis guttata (Say)	Roundheaded wood borer
4.	Ichneumonidae	Ichneumon mesocentrus (Grav.)	Sawyer parasite
5.	Scolytidae	Ips pini (Say)	Bark beetle
6.	Scolytidae	Ips chagnoni (Sw.)	Bark beetle
7.	Scolytidae	Ips avulsus (Eichh.)	Bark beetle
8.	Scolytidae	Pityogenes plagiatus (Lec.)	Bark beetle

	Family	Genus and Species	Common Name of Family
9.	Scolytidae	Orthotomicus caelatus (Eichh.)	Bark beetle
10.	Scolytidae	Gnathotrichus materiarius (Fitch.)	Bark beetle
11.	Scolytidae	Trypodendron scabricollis (Lec.)	Bark beetle
12.	Tenebronidae	Hypophloeus sp.	Fungus beetle
13.	Histeridae	Platysoma sp.	Predacious beetle
14.	Curculionidae		
15.	Chalcididae		
16.	Vespidae		

Description of Coleoptera Collected and Reared

Family Cerambycidae

Monochamus scutellatus (Say)
[Synonyms: Cerambyx scutellatus
Say; Monochamus resutor Kirby]

The white-spotted sawyer, Monochamus scutellatus (Say) (Fig. 26). According to Dillion and Dillion (23), this species of

Figure 26. Adult female and male of the white-spotted sawyer, Monochamus scutellatus (Say). 2X.

Monochamine is the most common and most widely distributed, ranging from Alaska to Quebec and North Carolina.

Description (23):

> Elongate-ovate, somewhat robust, especially in females, cylindrical, elytra sub-convex; dark reddish-brown to piceous, somewhat shining; often bronzed; head, pronotum and base of elytra with thin, short, grayish-white pubescence, remainder of elytra in male usually with dense covering of grayish-brown pubescence, sometimes interspersed with patches of white scales, in female grayish-brown patches covering most of apical two-thirds of elytra and with more numerous and larger patches of white scales on apical three-quarters, sometimes arranged in three rather wide, indistinct bands; scutellum white tomentose, except basal center, which is glabrous, only rarely with fine glabrous space to apex; legs and antennae dark reddish-brown to piceous; antennae always distinctly lighter apically, in female usually annulate, at least narrowly so; legs usually with thin, grayish-white pubescence; beneath with long, fine, pale yellowish hairs, very dense on prosternum and with whitish scales, much denser in female than in male. Head sparsely, somewhat rugosely-punctate; front coarsely sparsely punctate; median impressed line from occiput to vertex, distinct, feeble from vertex to epistoma; antellae in male usually two and one-quarter or more times body length, in female usually one and one-quarter times. Pronotum slightly transverse; sides straight; base slightly wider than apex; lateral tubercles with short, blunt spines; two feeble apical and three feeble basal sulci; disk usually transversely rugose. Scutellum slightly transverse; sides distinctly rounded; apex broadly rounded. Elytra with sides slightly arcuate to apex; apices together rounded, not at all or extremely minutely produced at suture; base with indistinct tubercles, thence coarsely rugosely-punctate to middle, then more finely punctate apically. Mesosternum rounded; fifth sternite fringed and tufted in male and female apically. Length 8.75 - 25 mm., width 3.5 - 7.5 mm.

Life History: Normally, under Michigan conditions, the life cycle is 1 year, although it may be longer, depending on moisture or light. Most of the material collected from the cages completed the life cycle in 1 year. The adults appeared under field conditions from May to July at Higgins Lake State Forest and Kellogg Forestry Tract, larvae being active any time after early May.

The eggs are laid (Fig. 27) from about May to July, although adults may be found as late as September. Deposition of eggs is usually near the juncture of the branches to the trunks or twigs. The female cuts a transverse slit in the bark with her mandibles, turns about and deposits her egg, after raising the bark with her ovipositor, into and under the green inner bark. Eggs are usually laid singly, although some observations have been made where several eggs have been deposited at one place.

The eggs are whitish, opaque, elongate-oval, and about one-eighth inch long. The larvae (Fig. 28) are legless, white grubs having powerful mandibles, and soon excavate galleries, working first between the cambium and sapwood. Later the larvae (Fig. 29) enter the sapwood, and eventually the heartwood,

Figure 27. Egg and newly hatched larvae of M. scutellatus (Say). 4X.

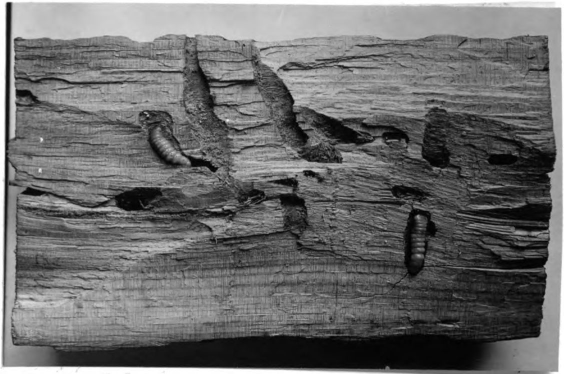


Figure 28. Larvae of M. scutellatus (Say). 1/3X.

Figure 29. Work between cambium and sapwood.

making a more-or-less semioval tunnel. Figure 30 shows the work of both Cerambycid and Scolytid larvae. Excelsior-like shreds of wood may be found in these tunnels. Much frass is evident where these larvae are working.

Generally, in Michigan, larval work ceases about the first of November, the winter being passed in this stage. Larval work begins again in early spring, usually April, depending on temperatures. Full-grown larvae are 1-1/2 inches or more in length (Fig. 31).

Pupation takes place soon after feeding in the spring. The larvae work toward the surface of the wood not far from the inner bark. This later serves as an exit for the adults. The larval entrance to the pupal chamber is lightly plugged with frass, and the larva retires to the deeper part of the burrow to pupate. Under normal conditions pupation requires about 12 days.

After transformation, the adults, with their strong mandibles, cut their way to freedom and emerge from a clean-cut round exit hole, as shown in Figure 32. At Higgins Lake, adults appeared the first week in May in 1951, but the bulk of the

Figure 30. Section showing work of cerambycid larvae and bark beetle association.

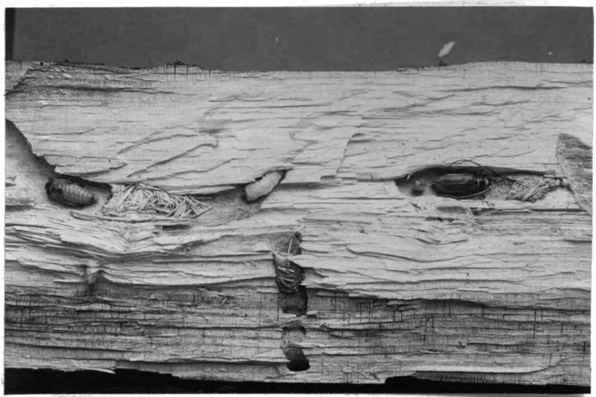


Figure 31. Pupa, larva, and adult of Monochamus scutellatus (Say).

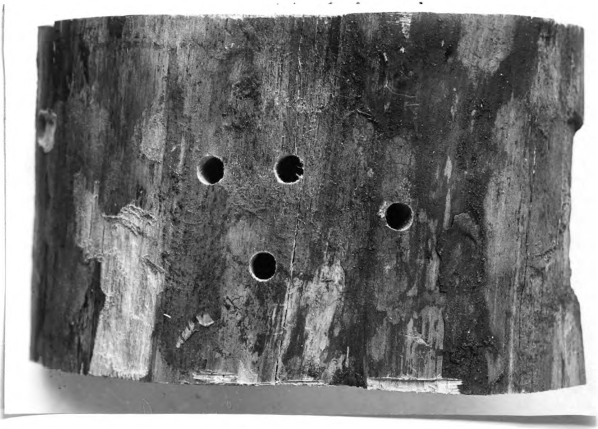


Figure 32. Adult exit holes of M. scutellatus (Say).

emergence occurred during the latter part of May and early June. These adults have previously been described.

The adults do feed somewhat, but the writer found no serious damage caused by these insects to standing trees.

Hosts: Hopping (41) gave the hosts as _Pinus strobus_, _P. resinosa_, _P. banksiana_, _Picea canadensis_, and _Abies balsamea_.

Monochamus titillator (Fab.)
[Synonyms: _Lamia titillator_ (Fab.);
Cerambyx titillator (Fab.)]

According to Dillion and Dillion (23), _Monochamus titillator_ (Fab.) (Fig. 33) is a separate species and can be distinguished from _M. carolinensis_ (Oliv.) by the following points:

> In _M. titillator_ the apical margin is subtruncate, forming a right or obtuse angle with suture, which is produced into a spine, rarely dentate; general size larger, from 17.7-30 mm., antennae in male three or more times body length, basal band of elytra consisting of two spots, the external one the smaller, and bases of both equidistant from base of elytra.
>
> In _M. carolinensis_ the apical margin is subrotund, forming an acute angle with suture, which is simply dentate, rarely shortly spined; size smaller, from 13-22.5 mm., antennae in male about two times body length; basal band of elytra consisting of two spots, the external one nearer to base of elytra, and they are equal in size.

Description (23):

> Elongate-ovate rather robust, subcylindrical, elytra subconvex; light to dark reddish brown, sometimes yellowish-

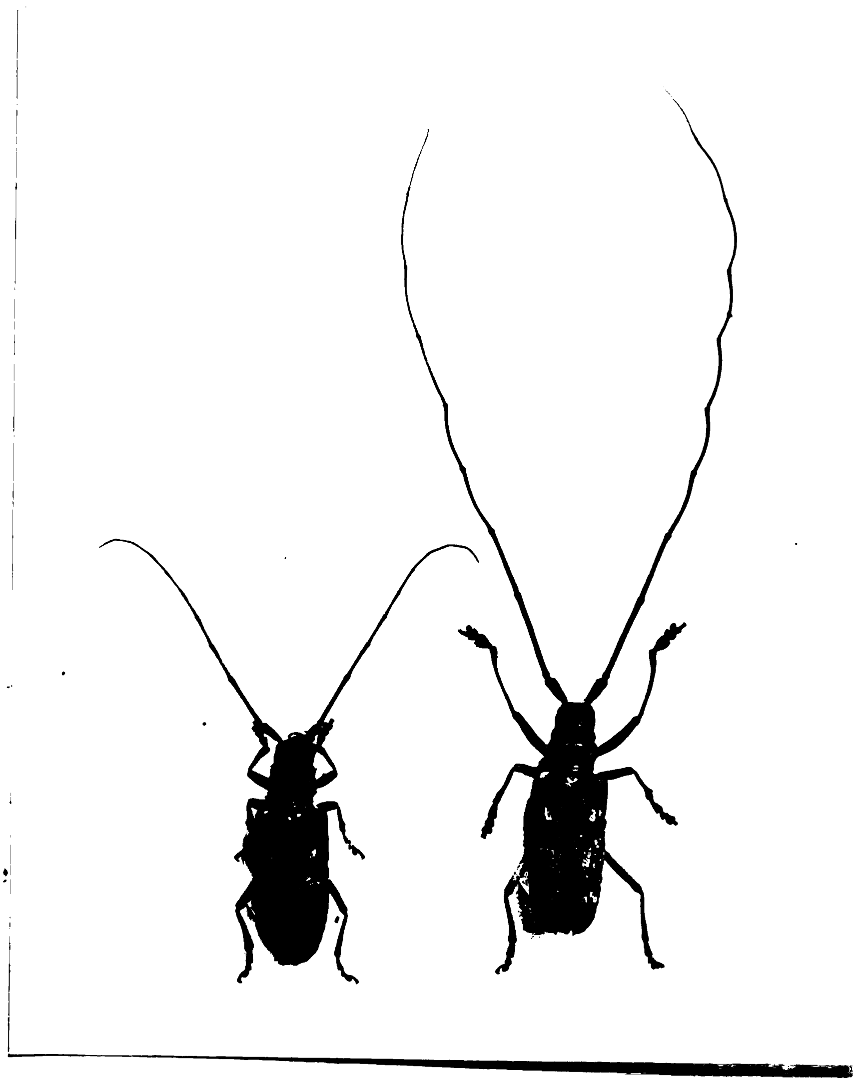


Figure 33. Adult female and male Monochamus titillator (Fab.).

brown; head sparsely covered with white or yellowish hairs, sometimes with an indistinct median line of yellowish or fulvous; pronotum with sparse, white or yellowish-white pubescence, and with an indistinct vitta each side of median line of yellowish or fulvous pubescence, and a wide vitta over each lateral tubercle, these sometimes very irregular; scutellum rather sparsely clothed with fine whitish or yellowish tomentum, median line glabrous; elytra sparsely clothed with white or fulvous pubescence, with three irregular bands of white pubescence, the basal band composed of two spots on each elytron, the outer one usually smaller, sometimes fulvous, both of these spots usually equidistant from base; disk with small irregular patches of dense, fine brown pubescence; beneath reddish to yellowish-brown with small, irregular patches of yellowish white pubescence; legs and antennae reddish-brown, yellowish-white pubescent, antennae lighter apically. Head rugose and coarsely punctate; median impressed line distinct from occiput to between antennal tuburcles, less distinct to epistoma; front coarsely, sparsely punctate; antennae three or more times body length in male, in female about one and one-quarter times. Pronotum slightly transverse; sides straight; base slightly wider than apex; one distinct transverse sulcus at base and apex, sometimes two indistinct ones present, apical internal one not interrupted; three small tubercles on disk, median tubercles largest and slightly behind the other two; disk finely, transversely rugose; lateral tubercles with short, subacute spines. Scutellum slightly transverse, occasionally feebly elongate; sides slightly arcuate; apex broadly rounded. Elytra with sides slightly curved; apex subtruncate, at suture distinctly dentate or spined, apical margin forming a right or obtuse angle with suture; base with few tubercles, thence coarsely, rather rugosely punctate, puncture finer apically. Mesosternum rounded; fifth sternite fringed and tufted in male, very heavily in female. Length 17.5-30 mm.; width 4.5-9.5 mm.

Distribution: Northern states east of Mississippi, south to Florida and Cuba, west to Texas, and in British Columbia.

Life History: The discussion of the life history of M. scutellatus (Say) can be applied very closely to M. titillator in Michigan, there being but little variation as to habits and injury caused.

Hosts: Pinus strobus, P. palustris, Abies balsamea, and reared from P. banksiana from Higgins Lake State Forest.

Astylopsis guttata (Say)
[Synonyms: Astylopsis sexguttata (Say); Astylopsis commixta (Hold); Astylopsis punctata (Hold); Leptoslylus sexguttata (Say); Leptoslylus commixtus (Say)]

This cerambycid (Fig. 34) has been found commonly associated with other wood-boring insects, according to Craighead (14), throughout the eastern United States. It has been found working in pines and spruces, and Blackman and Stage (3) have reared this species from tops and limbs of larch.

Description (4):

> Elongate-oblong, robust, brownish, irregularly mottled with grayish pubescence; elytra with an elongate dark spot behind base, another behind middle, sometimes becoming a bar, and a third near apex; antennae and tibiae annulate. Thorax finely, densely and deeply punctured, the disk with five small, blunt rounded elevations. Elytra each with two or three finely elevated costae each of which, together with suture, bears a row of distinctly placed black points. Length 7-10 mm.

Figure 34. Astylopsis guttata (Say).

Life History: Adults were found coming from cages of red pine at the Kellogg tract and presumably had a 1-year life cycle, although Blackman and Stage (3) found it to be extended over 2 years. These insects were of secondary importance, although they were recovered in numbers.

Distribution: A. guttata has been reported from Canada, District of Columbia, Wisconsin, Michigan, and Indiana.

Family Scolytidae

The family Scolytidae is the most important group of insects, from the standpoint of slash. Practically all countries having trees have at one time or another written about or discussed one or more species of this family (42). Truly, all foresters and forest entomologists have been, and are, concerned with bark beetles. Today, this group of insects is the most important group with which we must be concerned in the United States. According to Craighead (16), more trees are killed by this group than by any other group of insects. Only a comparatively small number of species of bark beetles ordinarily attack and kill vigorous trees. A majority of species, however, breed in recently cut trees, stumps, broken limbs, or in decadent, dying, or dead trees or portions of trees.

Losses in northeastern United States are great, but in the Western states this condition is even more serious because of factors such as terrain, mature timber, and vast forests of uniform species.

Chamberlin (9) stated that some 550 species have been described, and that perhaps many more are undescribed.

In Chamberlin's manual (9) he stated that these forest species may be divided into three groups according to habit:

1. Those species working in the cambium of trees.

2. Those species which excavate tunnels in the solid wood.

3. A number of species with habits other than those mentioned above. Some are cone borers, while others girdle twigs or work in roots.

At the Kellogg Forestry Tract and Higgins Lake State Forest, eleven species of Scolytidae were reared from red and jack pine. Some of them are of economic importance in our silvicultural and management practices. The descriptions of those found follow.

<u>Ips pini</u> (Say)
[The eastern pine engraver]

According to Chamberlin (9), this species (Fig. 35) was described as <u>Bostrichus</u> by Say, and subsequently treated as a member of the genus Tomicus by numerous authors, but, in 1904, Smith, in his Catalogue of the Insects of New Jersey, page 363, placed it in the genus Ips.

Synonyms: <u>Ips dentatus</u> (Strum); <u>Ips pallipes</u> (Strum); <u>Ips praefrictus</u> (Eichh.).

Description (9):

> Length 3.5-4.2 mm. Front convex, granulate; pronotum slightly longer than wide, finely punctured behind and asperate in front; elytral striae scarcely impressed with small punctures. There are four declivital teeth on each margin; 2nd and 3rd teeth of declivity similar and acute. Male more coarsely granulate in front and 3rd tooth longer, stouter, and slightly curved. Males are slightly smaller than the females.

Distribution: Canada, Northern states from Maine to Minnesota, Alaska, and perhaps other Western states.

Hosts: <u>Pinus strobus</u>, <u>P. resinosa</u>, <u>P. banksiana</u>, <u>Picea canadensis</u>, and probably other species of pines and spruces.

Economic Importance: This species is usually considered of secondary importance, but can build up under favorable conditions to cause heavy damage and destruction to living trees.

Figure 35. Ips pini (Say). 16X.

Ips chagnoni (Swaine) [Fig. 36]

Description (9):

4-4.8 mm. in length. The sides of the prothorax and the elytra are nearly parallel. The pronotum is slightly wider than the elytra, and the insect is clothed with thick stoutish red hairs. The sutures of the antennal club are rather angulate. The pronotum is longer than wide and is broadly rounded behind. The elytra is punctate-striate.

Distribution: East Canada and the northern part of New York, New England, Minnesota, and Michigan.

Hosts: Pinus strobus, P. resinosa, P. banksiana, Picea canadensis.

Economic Importance: This species works in the main trunk and larger limbs of weakened, dying, and recently cut trees. Saplings and tops (slash) are preferred, showing a preference for thin-barked trees. They may build up in slash to epidemic proportions.

Ips avulsus (Eichh.) [Fig. 37]
[Synonym: Tomicus avulsus (Eichh.)]

Description:

2.1-2.8 mm. in length and 2.6 times as long as wide. Reddish-brown insect, with a lighter colored elytra. The front of the head is convex. The first suture of the antennal club is bisinuate, the second is widely angulate at the center.

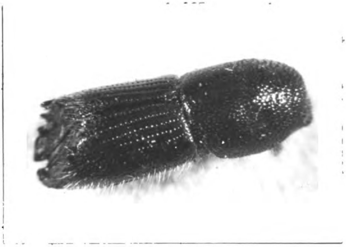


Figure 36. Ips chagnoni (Swaine). 16X.

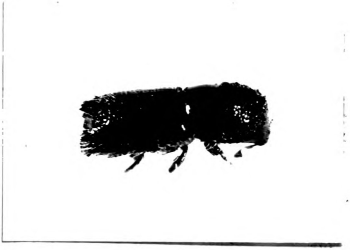


Figure 37. Ips avulsus (Eichh.). 16X.

The pronotum is longer than wide, the asperate region extending well behind the middle at the sides. The elytra is deeply punctate-striate with the interspaces slightly convex. The declivity is moderately excavated, strongly punctured, with the sides having four teeth, the first minute.

It is distinguished by its small size and feebly developed declivital armature with the apical margin but slightly produced.

Distribution: Pennsylvania to Florida and westward; also found in Michigan.

Hosts: Various species of pines.

Economic Importance: Attacks branches 1 to 6 inches in diameter. This species is less aggressive than other Southern forms, although considerable numbers were present in cages. This insect works in the outer sapwood, and it is especially important in slash.

<u>Pityogenes</u> <u>plagiatus</u> (Lec.) [Fig. 38]
[Synonym: <u>Xyleborus</u> <u>plagiatus</u> (Lec.)]

Description:

Size 1.85 - 2.10 mm. in length. The front is flattened with a triangular patch of pubescence, the rest of the area shining. The thorax is a little longer than wide, with the sides parallel behind, anterior area moderately asperate. The sides of the elytra subparallel. The declivity is steep and abrupt, moderately excavated, with the sutures elevated, the lateral elevation high with a pair of teeth above near the suture and a second pair of larger ones near the apex of the third interspace. The teeth of the declivity are much larger in case of the male.

Figure 38. Pityogenes plagiatus (Lec.). 16X.

Distribution: Quebec, south to West Virginia, west to the Lakes states.

Hosts: Various species of pines.

Economic Importance: Tunnels are found between the bark and sapwood, scarring both. This species builds up in slash.

Orthotomicus caelatus (Eichh.) [Fig. 39]
[Synonyms: Tomicus caelatus (Eichh.);
Tomicus xylographus (Fitch); Tomicus
decretus (Eichh.)]

Description:

The adult beetle is reddish-brown to black in color; 2.3 - 3.3 mm. long, 2.8 times as long as wide. The front of the head is convex above, transversely depressed below, strongly granulate and with a rather faint longitudinal carina; the pronotum is densely asperate on more than the anterior half, strongly, deeply, and rather closely punctured posteriorly; the elytral striae are impressed, deeply coarsely and closely punctured, the interspaces deeply, uniserilly punctured, with those near the declivity nearly as coarse and numerous as on the stria; the declivity is concave, coarsely punctured, with three teeth at each side, the second and third coarser and not on the lateral margin, which is more or less coarsely granulate or tuberculate and is not sharply elevated. The declivity of the male is more concave and the armature is coarser.

Distribution: Eastern Canada, south through the eastern United States to Florida and Mississippi.

Hosts: Pine, Spruce, and Larch.

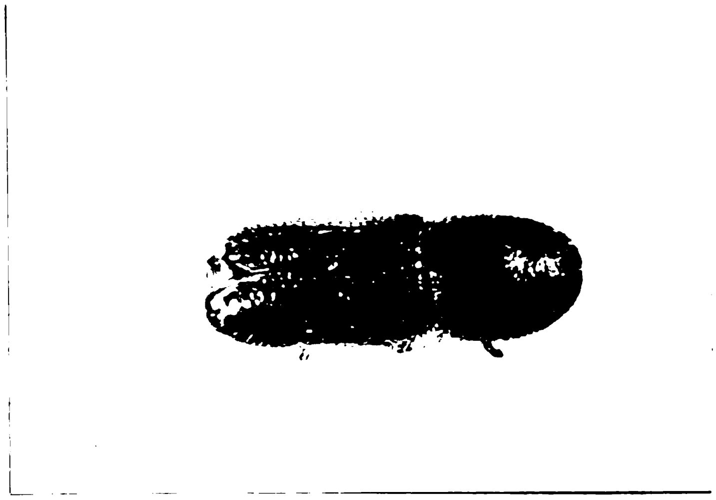


Figure 39. Orthotomicus caelatus (Eichh.). 16X.

Economic Importance: This beetle is not usually of economic importance, although it is able to breed successfully in sappy bark in freshly cut trees, and to resist the flooding of its burrows with pitch. It should, however, be classed as of secondary importance, in that it often attacks weakened trees and completes their destruction, and in concert with other bark beetles attacks and kills apparently healthy trees. This is particularly true in the Higgins Lake area, because of the weakening of jack pine by the spruce budworm.

Gnathatrichus materiarius (Fitch) [Fig. 40]
[Synonym: Gnathotrichus corthyloides (Eichh.)]

Description:

Average length 3.06 mm. Elongate, narrow, cylindrical; head faintly punctured with a few pale hairs; pronotum one-fourth longer than wide; front margin armed with rather low serrations; anterior area with rows of low asperities; posterior area depressed, feebly shining, finely reticulate and sparsely punctate. Elytral punctures minute; upper part of declivity with a shallow, longitudinal depression along the suture.

Distribution: Eastern states and eastern Canada, Ontario to Florida, west to Michigan, Minnesota, Arkansas, and Texas.

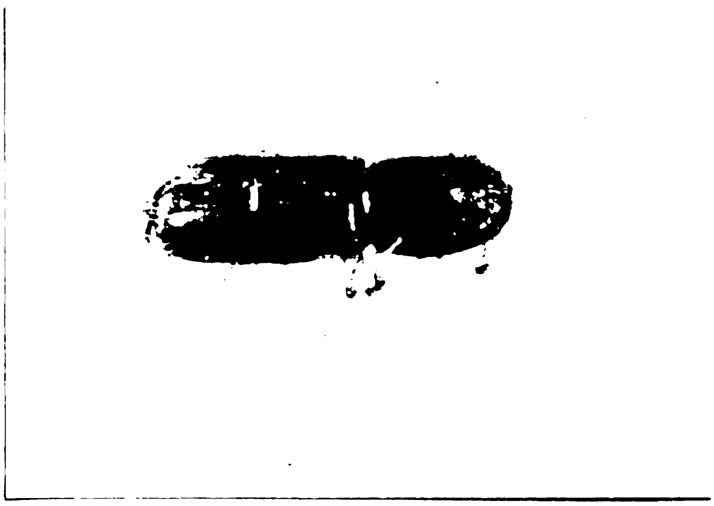


Figure 40. Gnathatrichus materiarius (Fitch). 16X.

Hosts: All pines, spruces, larch, firs, and cedars within its range.

Economic Importance: Usually do not attack living trees, but may do considerable damage to logs left unsawed too long. It works also in weakened trees, causing their death.

Trypodendron scabricollis (Lec.) [Fig. 41]
[Described as a Xyloterus]

Description:

Dark reddish-brown in color; female 3.6 mm. long, male 3.1 mm. long. The head of the female is convex, roughly granulate, with a distinct median carina below; the antennal club is large, light brown, with the basal corneous portion extended at the middle and separated from the distal portion by a strongly angulate line; the eye is completely divided; the prothorax is one-fourth wider than long, with the sides arcuate, and the anterior outline obtusely subangular, strongly and coarsely asperate in front with the asperities continuing at the sides nearly to the posterior line but becoming gradually smaller; elytra distinctly punctate striate, with the striae slightly impressed, the punctures shallow and rather coarse, interspace sparsely and very minute punctured; the declivity is convex with strial puncture slightly smaller but distinct with the first and third interspace slightly elevated, the first granulate, the second flat.

Distribution: New York to Mississippi, and westward to New Mexico.

Hosts: Pines, hemlock; also witch-hazel.

Figure 41. Trypodendron scabricollis (Lec.). 16X.

Economic Importance: Beetles breed in injured or slowly dying pine trees, often being found in the injured larger limbs of trees otherwise healthy. When they occur in the trunk region, their burrows greatly lessen the timber value, and when in injured branches, they hasten death. The burrows are stained black by the ambrosial fungus, and this often spreads in surrounding wood, causing bluish stains. They also aid in slash disposal by letting fungi in. This insect is usually considered important in breaking down slash, as well as causing damage when in epidemic proportions.

Miscellaneous Insects

Family Tenebrionidae

Hypophloeus sp. [Synonym: Corticeus sp.]. According to Craighead (20), the adults and larvae of Hypophloeus sp. (Fig. 42) are found in the runways of bark beetles in infested trees, especially pines, where they occur as associates. Many of the earlier investigators believed these forms to be parasitic, but Struble (71), after conducting numerous tests with fungi and beetles, reported them in 1930 to be entirely phytophagous. The beetles appear as soon as the primary invading bark beetles'

Figure 42. Hypophloeus sp. 16X.

tunnels and ventilation holes are completed. The adults are small, cylindrical, elongate, reddish-brown or black, and about 4.6 millimeters long. The larvae are elongate, fleshy forms, less than 8 millimeters long. The terminal segment is brownish, and often nearly semicircular in shape.

Economic Importance: They help materially in slash disposal, due to their faculty for introducing or aiding in fungi activities.

Family Histeridae

Platysoma sp. (47). Many of the genus Platysoma (Fig. 43) were collected from the slash. Most of the members of this family have the integument very hard and steel-like. They have clubbed antennae and short, stout legs, which they can tuck away beneath themselves much in the same manner as turtles do.

According to Struble (71), this genus Platysoma is elongate, parallel, considerably flattened, and shining. The adults have been seen feeding on the adults of D. brevicomes (Lec.). Both larvae and adults were found in the burrows of Dendroctonus

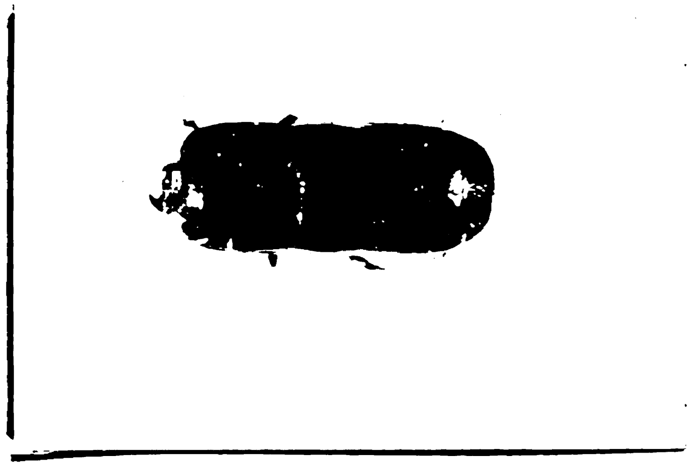


Figure 43. Platysoma sp. 16X.

and Ips, and no doubt feed also on the eggs and larvae of bark beetles.

This beetle probably aids in the destruction of slash disposal, as well as being a predator, as shown by Struble.

Miscellaneous Groups

Other groups such as Curculonidae, Vespidae, Ichneumonidae, Chalcididae, and Diptera were collected from the caged material, and no doubt played a very important part in the disposal of the slash by making conditions more favorable for fungi and other plant-destroying organisms to act.

Climatic Data

There are many physical reactions which might be the limiting factors in the insects' environment, and perhaps the most important of these is temperature.

Wood-boring and bark beetles have a definite zone of temperature in which they are active. Many workers in forest entomology have demonstrated this with several species of insects, as temperature requirements vary with species. According to Graham (34), the optimum temperature for most

insects is in the neighborhood of 26 degrees centigrade, and estivation usually begins at from 38 to 45 degrees centigrade. This, of course, can vary, as he has found one of the wood borers resisting temperature up to 52 degrees centigrade for short periods of time. The low fatal temperature varies with both species and season.

Hopkins (1920, 1939) developed what is known as Hopkins' bioclimatic law. This law states:

> Other conditions being equal, the variation in time of any seasonal event in temperate North America occurring in the spring and early summer is at the general rate of four days later for each degree of latitude northward, or five degrees of longitude eastward, or 400 feet of altitude upward. In the late summer and fall conditions are reversed.

This law shows why, on the basis of temperature alone, geographical barriers might exist.

Temperatures vary greatly at short geographical distances. Many factors such as soil, water, altitude, radiation, and shade contribute to their variance. Wood-boring beetles and bark beetles are unable to move rapidly from place to place, and therefore, temperatures are utilized in controlling certain of these insects. For instance, solar radiation is a modification of the ordinary peeling method, which involves the spreading of the bark in direct contact with the sun rays. This is effective when air temperatures are a plus 85 degrees Fahrenheit, in order to produce bark temperature of 115 to 120 degrees Fahrenheit. Shade, moisture, and many other phases of temperature may be used to advantage in their control. Temperatures not only regulate the geographical distribution of an insect, but also they regulate the rate of development, biotic potential, its behavior, form, and structure. Apart from its direct effects, temperature influences other factors such as light and moisture. The distribution of insects and other animals in many parts of the world is closely related to temperature. This is not only true of forest insects, but others as well. Chaudhry (10) found that the development and fecundity of the oriental fruit moth, which was studied under several controlled temperatures of 50.5 to 95 degrees Fahrenheit, had an optimum range of temperature of 75 to 85 degrees Fahrenheit. It could develop at 95 degrees Fahrenheit only under high humidities. The incubation period was lowest under 70 percent relative humidity at temperatures of 65 to 95 degrees Fahrenheit. At low temperatures of 50.5 to 60 degrees Fahrenheit, the eggs developed best at 100 percent relative humidity. The eggs tolerated an exposure of 40 hours at 98 degrees Fahrenheit, and 21 hours at 105 degrees Fahrenheit, but their incubation period increased by 24 to 40 hours, as compared to those kept throughout at an optimum temperature. This indicates that this insect is not regulated entirely by temperatures, but is influenced also by humidity.

Much work has been done with forest insects along this line. For example, we know that different parts of a tree, log, or slash vary greatly as to internal temperature, thus making for susceptibility or resistance to certain wood-boring insects (32).

Moisture also plays an important part in the activity of insects. In the problem of slash disposal as here presented, moisture and temperature, as influenced by shade, may be the determining factor in the susceptibility to insect infestations. Favorable moisture conditions are necessary in the development of certain insects, and again, each species of insects has a definite moisture requirement. For instance, powderpost beetles require a very limited amount of moisture, whereas other fungus beetles and ambrosia beetles require high moisture for their development. Certain wood-borer cycles may be extended for many years by a lack of moisture, as has been shown by Howard (42).

Climatological data such as temperature and rainfall supplied by the United States Weather Bureau was recorded monthly for the Kellogg and Higgins Lake areas, and a comparison is shown in Table XIII, and also in Figures 44 to 49.

The abundance of forest insects, as well as other insects, is influenced by weather conditions (64). Forests are also influenced by weather conditions as to their susceptibility to insect attack. Dry weather may retard tree growth-inducing conditions favorable for infestation of certain bark beetles and wood borers, whereas cool weather or wet weather may result in an abundance of plant food and overcome effects of insect attack by producing vigorous, rapidly growing trees. Rapidly growing trees suffer less from insect injury than do those of low vigor. From the standpoint of this problem, high moisture conditions make possible the outbreaks of entomophagous organisms, such as disease-causing bacteria and protozoa. In addition, bark and sapwood rot fungi such as Stereum spp. (Figs. 50 and 51), Polyporus abietinus (Dicks) Fries and others, which grow more abundantly under moist conditions, become limiting

TABLE XIII

ANNUAL MEAN TEMPERATURE AND TOTAL PRECIPITATION

Year	Kalamazoo, Mich.		Higgins Lake, Mich.	
	Annual Mean Temp. (° F.)	Total Precip-itation (inches)	Annual Mean Temp. (° F.)	Total Precip-itation (inches)
1946	51.3	30.16	44.4	30.36
1947	48.8	38.64	43.0	32.84
1948	49.7	32.16	43.9	32.95
1949	51.5	33.50	45.1	32.84
1950	48.5	42.24	41.9	37.58
1951	48.7	38.46	42.6	38.56

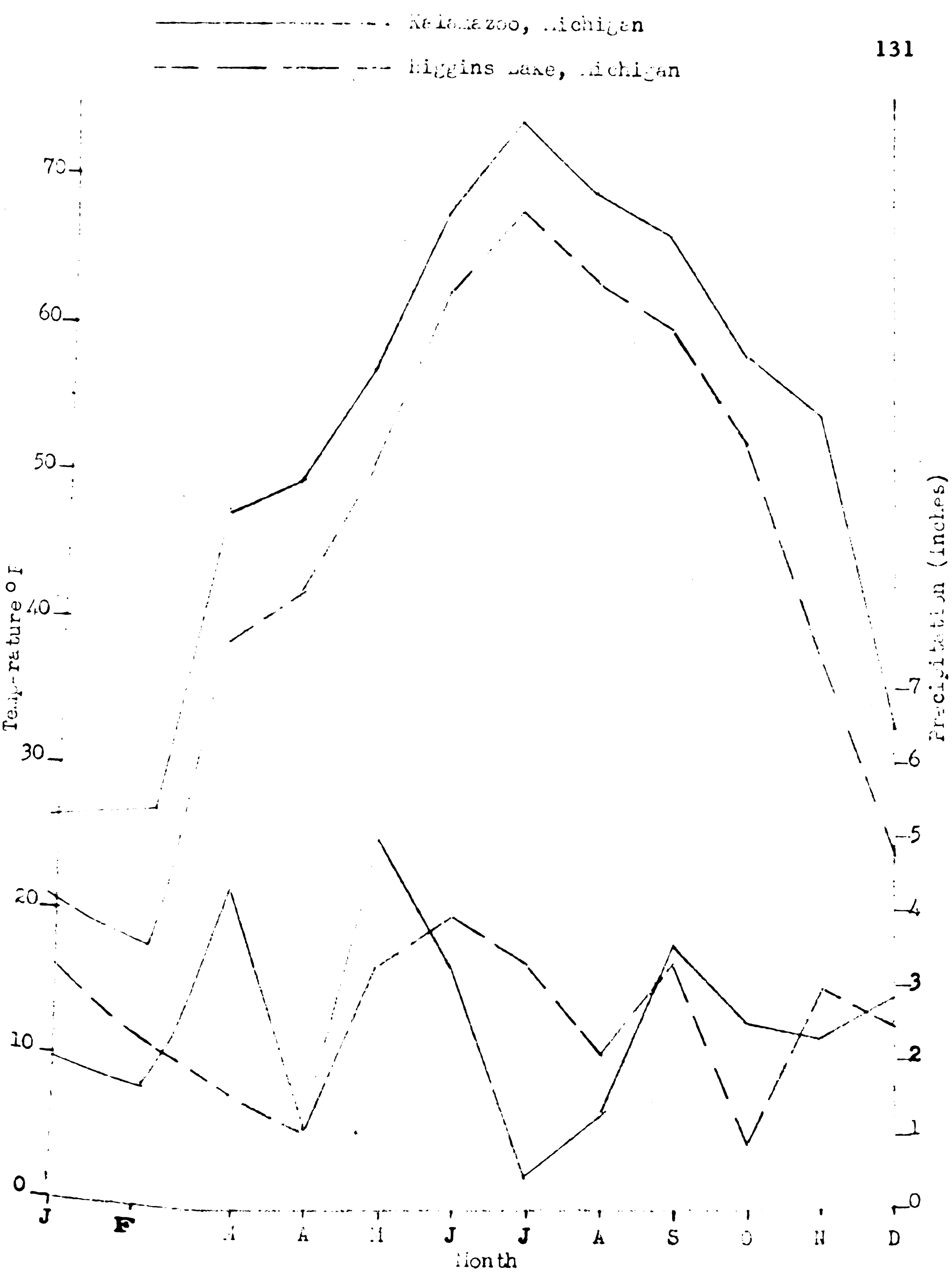


Figure 44
Monthly Mean Temperature and Precipitation
For Kalamazoo and Higgins Lake, Michigan 1946

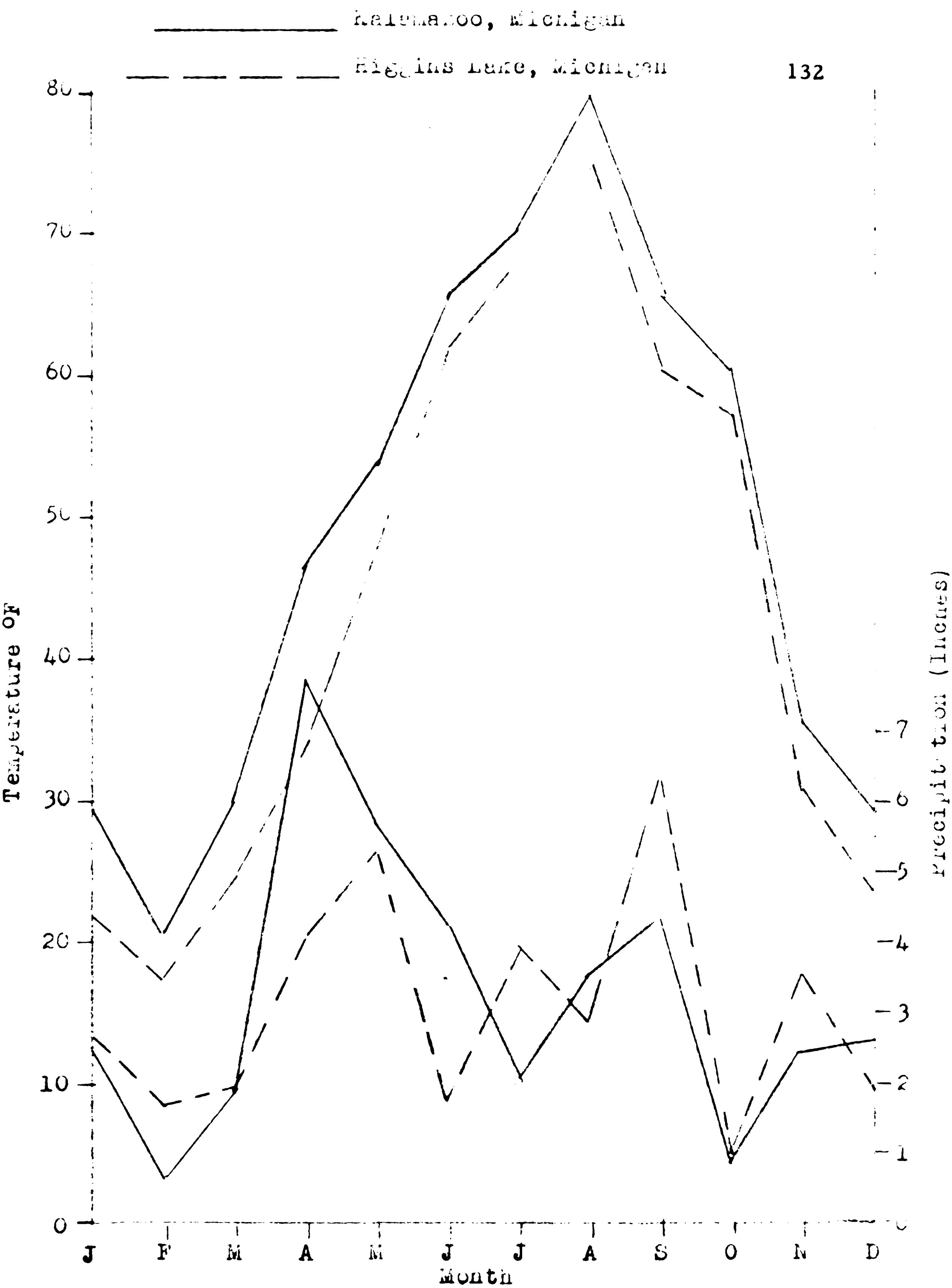


Figure 45
Monthly Mean Temperature and Precipitation
For Kalamazoo and Higgins Lake, Michigan 1947

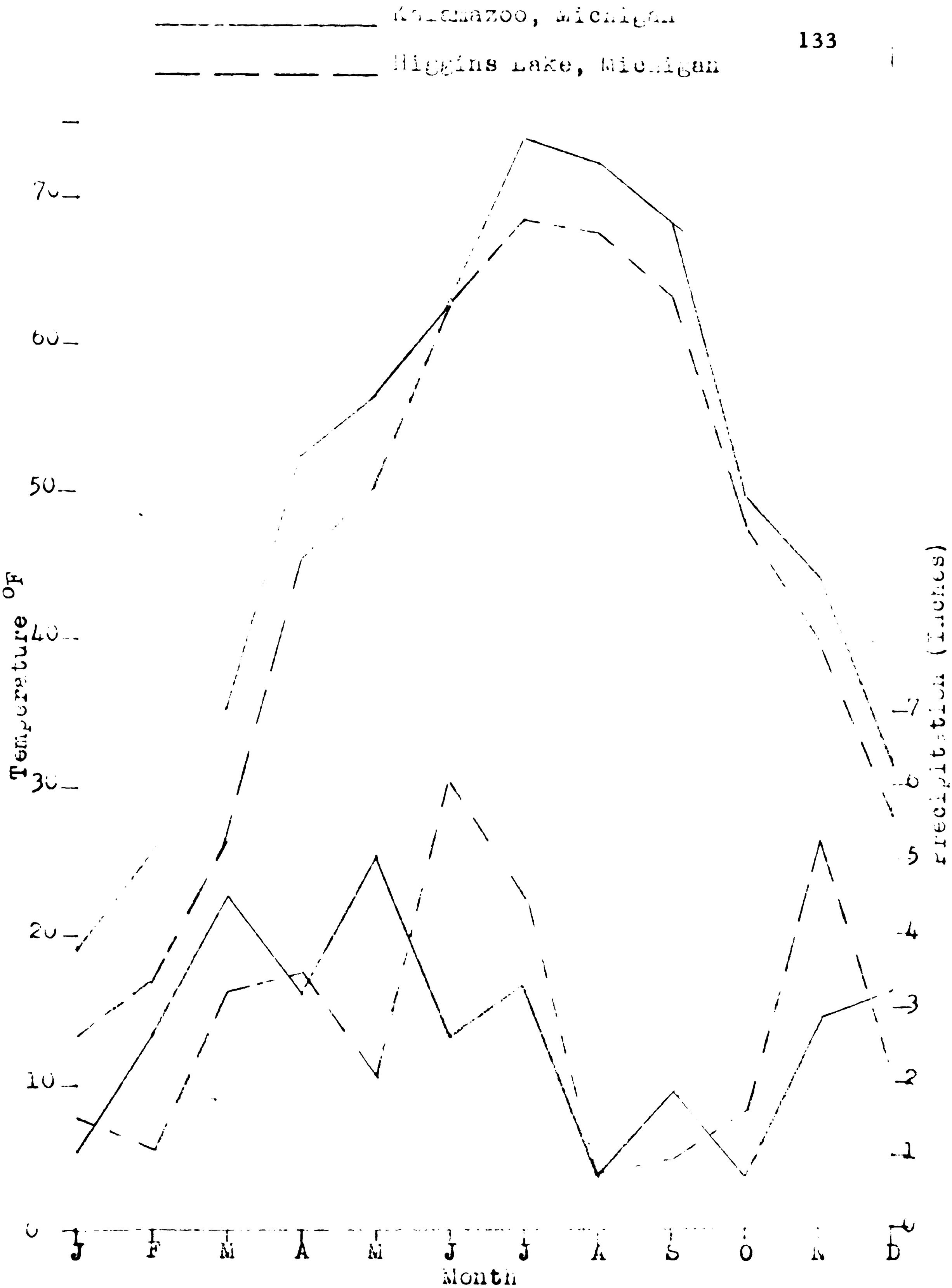


Figure 46
Monthly Mean Temperature and Precipitation
For Kalamazoo and Higgins Lake, Michigan 1948

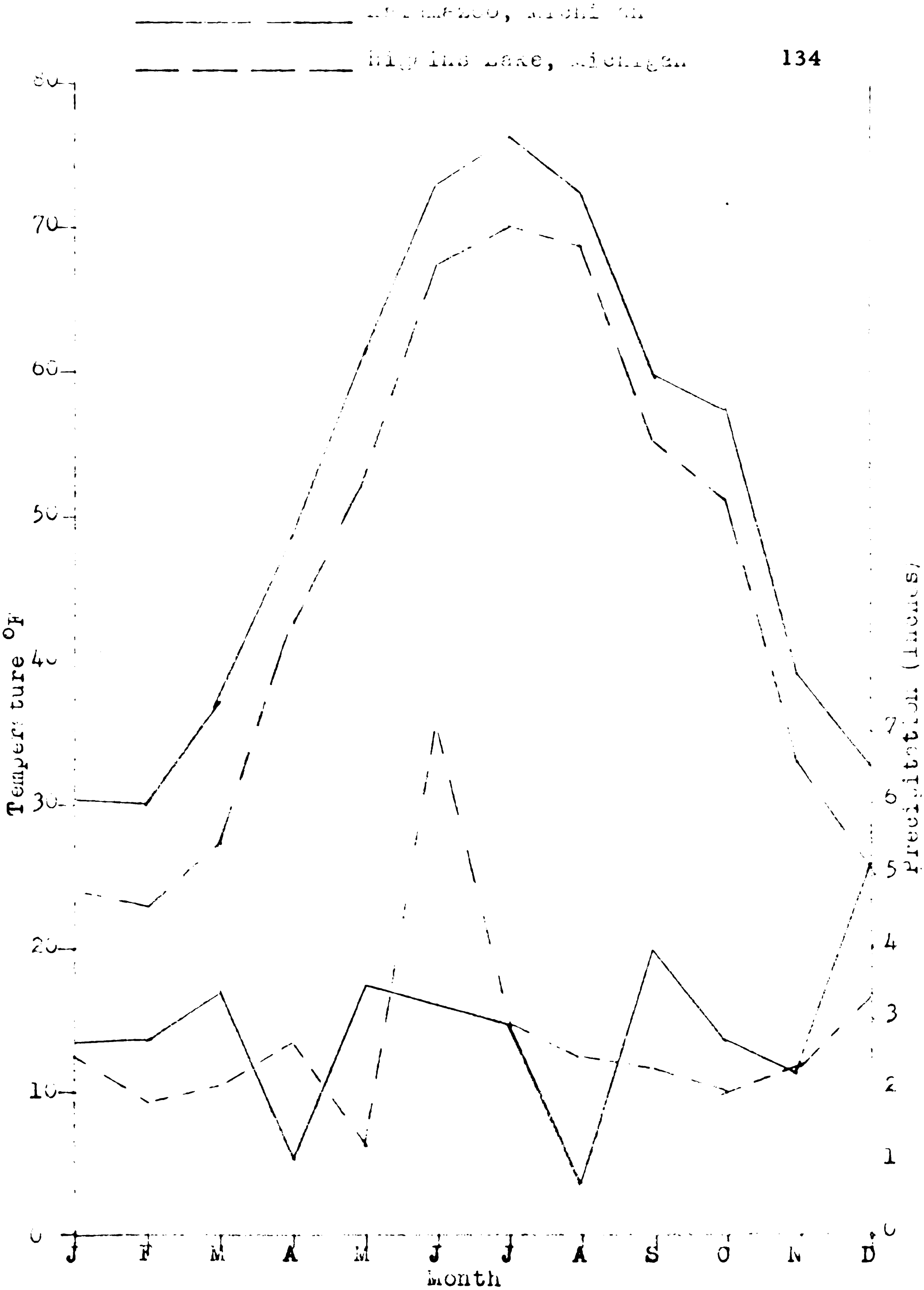


Figure 47
Monthly Mean Temperature and Precipitation
For Kalamazoo and Higgins Lake, Michigan 1949

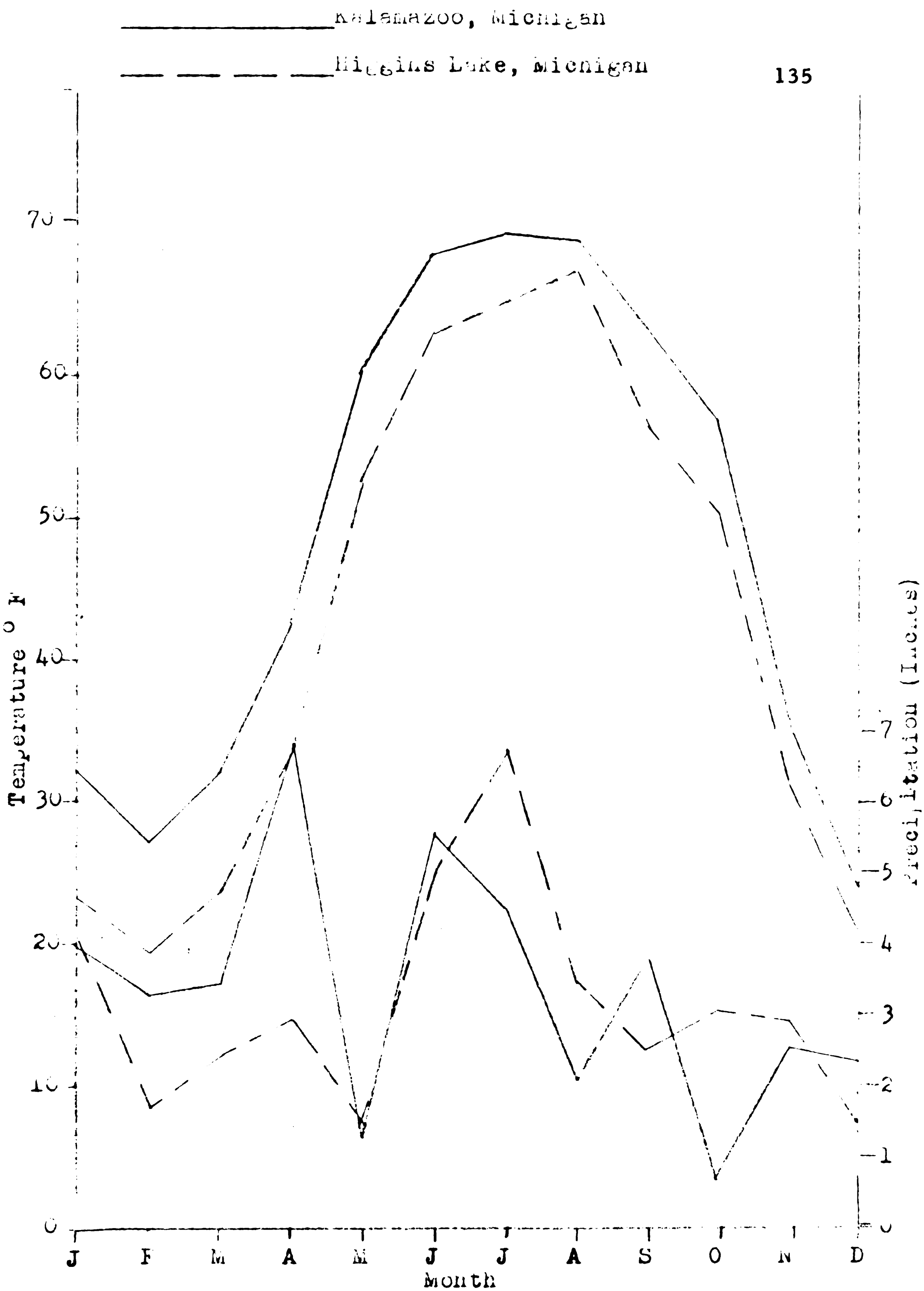


Figure 48
Monthly Mean Temperature and Precipitation
For Kalamazoo and Higgins Lake, Michigan 1950

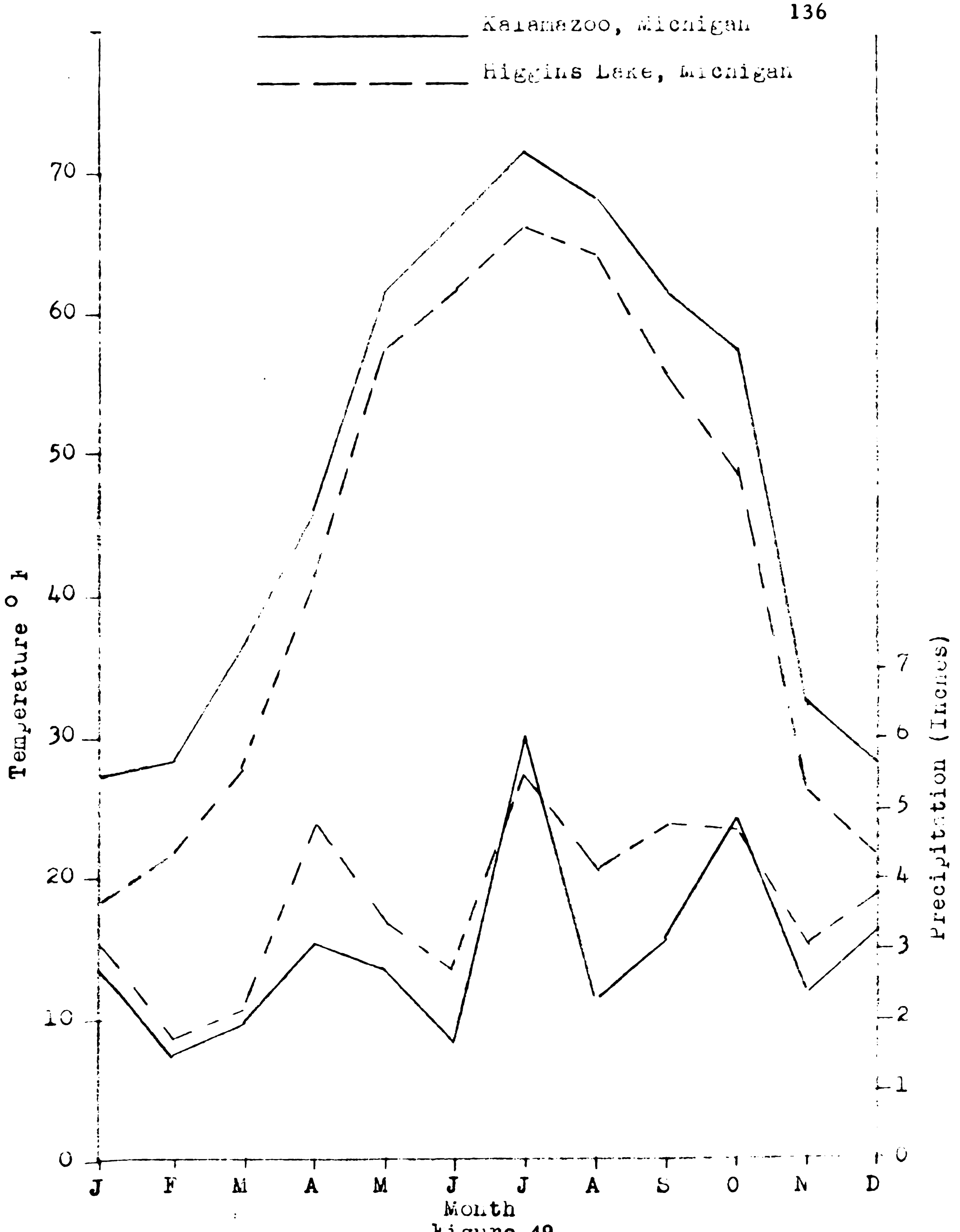


Figure 49
Monthly Mean Temperature and Precipitation
For Kalamazoo and Higgins Lake, Michigan 1951

Figure 50. Polyporus abietinus on jack pine.

Figure 51. Stereum sp.

factors in the number and kinds of wood borers and bark beetles present in the handling of slash disposal (12, 19, 36, 41, 76).

Table XIII shows that the Kalamazoo area had about nine inches more precipitation over the 6-year period than did the Higgins Lake area, and also about a plus 9 degrees Fahrenheit difference in average temperature over the same period, which are important for the development of entomophagous organisms.

According to Graham (34), climate is the result of the combined action of all the physical factors of the environment over a long period of time and, as far as meteorological evidence is concerned, is relatively stable in the same locality.

Weather, on the other hand, is the result of the combined action of all the physical factors of environment at any given time, and varies from hour to hour, day to day, and week to week. Weather influences the abundance of insects and the rate of development from year to year, and from season to season, in every locality. With insects of the forest, as well as with others, weather conditions are exceedingly important in regulating their abundance.

The increase in moisture from 1946 to 1951 no doubt aided in slash breakdown, particularly as it applied to the proposed methods of slash disposal.

DISCUSSION OF RESULTS

The preceding data show that there is a direct correlation between insect infestations and the methods of slash disposal. There were two major types of insects, the wood borers and bark beetles, which were of primary importance in this study. For simplicity, the fungus beetles and predacious beetles were included with the bark beetles. The young larvae of the Family Cerambycidae (25), often called sawyers, due to their boring in green logs and slash, causes considerable damage to pulp and logs left in the woods for indefinite periods of time. They may build up in the slash in epidemic proportions and cause infestations in any weakened trees, rendering the finished product unsuitable for lumber. The two most commonly found Cerambycids in red pine (*Pinus resinosa*) and jack pine (*Pinus banksiana*) plantations were *Monochamus titillator* Fab. and *M. scutellatus* Say.

There were seven species of bark beetles reared in the cages and collected in the field studies, some of economic importance, some secondary, and others beneficial in the breakdown of the slash. Of the seven species collected, Ips pini Say, I. avulsus Eichh., Pityogenes plagiatus Lec., and Orthotomicus caelatus Eichh. were the species of the greatest economic importance. These five species were the ones recovered consistently in the slash and standing trees over the 5-year period, and were actually reinfesting and killing standing red and jack pine.

In the pruning and thinning areas at the Kellogg tract, the types of slash-disposal methods used are indicated in Tables V and IX. It has been demonstrated by actual counts that these methods are very conducive to insect "build up" to epidemic proportions. The method of lopping and scattering afforded ideal conditions, particularly where tops to a 3-inch diameter were left exposed. Here again, healthy trees in the vicinity may withstand the attack, but trees weakened from various causes soon become infested and killed.

At the Kellogg Forestry Tract and Higgins Lake State Forest, the insect species identified as primary exerted a very definite selection for the bark of trees in weakened or dying conditions, caused by the types of girdling done in this experiment as well as in the slash studies. This can also be

exemplified in the Higgins Lake area, where most of the Scotch pine has been killed by bark beetles after a severe outbreak of spruce budworm, and at the present time much of the jack pine in this area also is becoming heavily infested with bark beetles, due to previous injury brought about by spruce budworm infestation.

The attraction of bark beetles to dying trees is highly significant, and is not within the scope of this study. It is generally stated that unless precautionary measures are taken with the slash left on the ground after certain disposal methods, a distinct insect menace may occur to the remaining forest. Slash from conifers left to rot on the ground may hinder forest reproduction. A heavy layer of conifer slash may prevent seeds from reaching the mineral soil, but the greatest menace of slash is the hazard to which it subjects reproduction in the event of fire or insect infestations. Zon and Greeley (79) and Zon and Cunningham (80) stated that it is desirable, particularly on account of the fire hazard, to have cut-over land cleaned up, either by disposing of the slash entirely, or by reducing it to such an extent that it can do relatively little harm.

In any type of slash disposal, the cheapest and most effective insect-control method is close utilization, as shown in Table V and VI. Many more bark beetles are shown to be present in the slash of larger diameters, and also in trees weakened naturally, or girdled. The procedure of utilizing all timber down to a 3-inch diameter in thinning and pulpwood operations is standard today in Michigan.

The slash-disposal policy for the national forest (11) in the Lakes states has for its primary purpose (according to Spaulding [69]), reduction of the fire hazard, but recognizes that slash disposal can be so managed as to assist in tree reproduction, and to also decrease insect infestation.

The insect-population studies as shown in Tables XI and XII, where trees were girdled or attacked naturally, as was the case in the Kellogg tract, was an attempt to accurately study the numbers and kinds of insects present in each area, and to show how soon infestation may result. This procedure demonstrated in the two areas studied that completely girdled trees were attacked the second year. These studies also gave definite information on habits and association of insects.

It is of economic importance to note that there were more insects in the slash in the Higgins Lake area than in the Kellogg area. This difference in insect numbers may be attributed to the site, species of trees, temperature, and precipitation. Perhaps the most outstanding cause of insect abundance was due to the weakening of the jack pine by the spruce budworm and Anomola in the Higgins area. These weakened trees furnished a suitable habitat for an abundance of various insects.

The parts of the trees chosen and the size of the slash available for attack by bark beetles and other insects is somewhat comparative in nature, as shown in Figure 17. Some were found in the lower trunk, others in the upper part of the tree and smaller limbs or twigs. It was noted that Pityogenes plagiatus Lec. and Ips avulsus Eichh. were found to be present in the medium-sized limbs of slash in the Higgins Lake area. Orthotomicus caelatus Eichh. and Ips chagnoni Sw. were present in the lower trunk in the Kellogg area, whereas the Ips pini group and Gnathotrichus materiarius Fitch. predominated in the larger parts of the tree in the Higgins Lake area. It must be noted that many of the Tenebrionidae, which must be considered from a beneficial standpoint in breaking down the slash, were found in the upper parts of the trees and in the slash material. The species of genus Hypophloeus (Tenebrionidae) most commonly found were collected in passageways of bark beetles in infested trees. Larvae of this genus are not gregarious in the wood, according to Craighead (20).

The family Histeridae, of which many are fungus beetles, was represented in the slash with the genus Platysoma. This genus must be considered beneficial, as many adults feed on bark beetles and also aid in breaking down the slash by working in the tunnels and egg niches of bark beetles.

The Cerambycidae, which were collected in nearly all parts of the trees and slash, consisted of the Monochamus titillator Fab. in the red pine and M. scutellatus Say in the jack pine.

In the case of the Cerambycidae larvae taken from the prunings of red and jack pine (Tables V and VI), more were found in the red pine. This was the case in all the types of field and cage materials studied.

The numbers and kinds of bark beetles reared in the codling-moth cages (Fig. 5), in both the slash material (Tables

IX and X), and the five 1-linear-foot logs shown in Tables VII and VIII, indicated that more bark beetles were present in the jack pine than in the red pine. This again may be due to several reasons, such as the species, the site, temperature and moisture present in the slash, but it was noted that the red pine at the Kellogg area did not produce any Ips pine Gay, Ips avulsus Eichh., Pityogenes plagiatus Lec., Gnathetrichus materiarius Fitch, or Trypodendron scabricollis Lec. However, Ips chagnoni Sw. and Orthotomicus caelatus Eichh. predominated in these cases and caused the damage in this area. Both of the latter species were present in the Higgins Lake area only in jack pine.

In the use of the regression coefficient or slope of the line it is significant to note that these data show an increase in bark-beetle infestation in direct ratio to the diameter of the tree. This relation is better shown by the use of a regression curve, as has been shown in Figures 18 to 21.

Many other factors such as soil, temperature, rainfall, climatic conditions, or pulpwood operations may be the determining factor. An example of this may be seen in the annual mean temperatures and total precipitation, as shown in Figures

44 to 49, from 1946 to 1951, during which time this study was made as compiled. Table XIII indicates that from 1946 to 1951 there was a decided increase in rainfall and a decrease in annual mean temperature. Much work has been done on the relationship between temperature and moisture and certain insects. Each species of insect has a definite temperature and moisture range within which it is able to live and reproduce. This is true not only of the insect, but any living organism. Graham (34) stated that environmental resistance is the sum of all the factors in an environment that tend to reduce the rate of multiplication of any organism. This is particularly true of wood-boring insects, as the rate of development varies entirely within a definite temperature and moisture zone.

From the soil samples taken at the Kellogg tract in Compartment 6B, where living trees were killed by bark beetles, there were no significant differences in the pH, calcium carbonate, or potassium. It is possible that there might be some significance in the available phosphorus as a cause of beetle infestation, due to the buffering of the cell sap. The pH of the cell sap is normally acid, and the value is sometimes determined by a buffering phosphate system. This reaction may not be significant in this case, as moisture may have been the determining factor. The 25 to 30 percent slope of samples three and four may have limited the buffering effect.

It was demonstrated that the most significant management practices used in the methods of handling slash were of primary importance in this study. In any management or silvicultural plan, the forester is always working toward an ideal type of forest.

Control of insect damage through cultural practices has been the aim of forest entomologists and foresters, alike. The following statement by Balch (2) in regard to silvicultural control illustrates this by stating, "Control by cultural methods can only be satisfactorily achieved where the optimum conditions of growth for the insect differ from those of the host." Many other factors which man cannot control or predict, such as climatic conditions, may affect this statement. Poor management or silvicultural methods may aid in the neglect of the forest. In the case of this study, this was especially true where trees were weakened by other causes and slash-disposal methods. The ecological relationship between insects and forests under silvicultural management has many problems. These include types, vigor, pure stands versus mixed stands, age classes, site, ecological studies of tree and insects, and many others.

The problem of slash disposal is highly controversial, and until the past few years was considered primarily from the fire-hazard standpoint, cost, and convenience. We cannot control all insects by cultural methods, but it is a known fact that food for some of the wood-boring insects can be eliminated by peeling, proper time of cutting, sun curing, and many other methods of handling. The problem of proper slash disposal can also prevent many of our insect troubles. The methods of slash disposal used at the Higgins Lake and Kellogg areas, where insect counts were made, indicated that previously all slash-disposal methods except one had been used primarily, as previously stated, for fire control, with little, if any, thought of insect damage. Recommendations of "lopped and scattered," "windrowed," "piled," and "lopped and left" are still common practices. Many cutting operations do not specify disposal, and in both areas studied this was ideal for increased populations of wood-boring and bark beetle infestations.

It was noted by other workers such as Keen (44), Swaine (73), and others that shade, either natural or by covering logs with boughs, seemed to decrease insect activities and populations. Field observations in the two areas studied indicated that where slash was shaded or covered to any extent, very few insects were present, and upon making cage and field counts, a decided decrease was noted. Slash-disposal methods of common practices were checked, and one new method of windrowing and piling was done. There were shown to exist statistical differences in regards to insect populations and disposal techniques. Normal windrowing or piling is done with the butt end of the slash out, which exposes the larger part of the slash. This area of the slash contains enormous numbers of insects, which evidently may build up to epidemic proportions in pure stands of conifer plantations, as is the case at Higgins Lake State Forest and the Kellogg Forestry Tract. By reversing the common method of slash disposal by putting the "butts in," it is significant to note that in all cases (Figs. 22 to 25), this method of handling slash reduced the insects to exceedingly low numbers. Undisposed slash produced the greatest numbers of beetles, followed by windrowing, but by windrowing with the "butts in," the populations were significantly reduced. It was observed, however, that when any method of slash disposal exceeded 36

to 40 inches in height, again populations increased in the upper part of the slash from lack of moisture. It was also noted that if this slash could be made resistant by this method of slash disposal through the first susceptible period, no insects were present in the slash the following year. For example, at the Higgins Lake area, under pulpwood operations where cuttings were made during the late fall and early spring, it was demonstrated that by windrowing of ''butts in'' toward the center, no insect problem was evident except in the regular methods of disposal. No insects attack slash properly disposed of the following fall. This indicates that time of cutting and methods of disposal can cause insect outbreaks of epidemic proportions in our platations. Any method which may control broods of insects in trees is of economic importance. However, no one method may be a cure-all in controlling all species of bark beetles or wood borers in all trees in all localities, but may fit individual conditions. Proper management can aid in our protection program from the insect standpoint, but slash of jack and red pine may remain a fire hazard for many years after pruning, pulpwood, or thinning operations. For example, as indicated in this study, a significant reduction of insect populations in red and jack pines by means of a modification of slash-disposal methods has been effected in Michigan.

Chemical controls of forest insects are not new, but at the present time considerable work is being done with chemicals on forest insects. The reason for this is the public demand, which many times is necessary to prevent total losses of plantations. Where properly supervised and conducted, chemical controls can be used to decrease epidemic outbreaks. It has been demonstrated that by spraying of slash with DDT and other chemicals, insect populations can be controlled, but under forest conditions, costs must be considered. Insecticides can and are being used, and they provide a different tool which may be used in saving millions of trees, as has been already demonstrated in sawfly work here in Michigan. Graham stated that, "insecticides must be used with caution and only when and where they are required to save losses that otherwise cannot be avoided."

Other controls, such as indirect controls by parasites, viruses, and predators, are also important, and much work is being done along these lines against forest insects.

The main factors which are of major importance to entomologists are the causes which may influence the increase or decrease of insect infestations. Any silvicultural, management, or cultural method which presents a decline in insect populations will add to our present knowledge of protection of our plantations.

SUGGESTED RECOMMENDATIONS FOR INSECT CONTROL BY SLASH DISPOSAL

The following suggestions refer specifically to red pine and to jack pine in Michigan plantations. Presumably these suggestions are applicable to other coniferous stands.

1. No slash should be left "undisposed," "lopped and left," or "lopped and scattered."

2. Slash should be "windrowed" or "piled," with butts in (toward the center of the windrow or pile), rather than with butts out, as in standard procedure.

3. Windrows or piles should not exceed 40 inches in height.

SUMMARY

1. Red pine and jack pine were the two species of trees in plantations in which the insects were studied in relation to slash disposal.

2. The two wood borers *Monochamus titillator* Fab. and *M. scutellatus* Say. predominated in the slash, and attacked weakened trees. Also, seven species of bark beetles belonging to the Family Scolytidae were present in numbers in the slash, and also found in weakened trees, causing their death.

3. The tree-killing insects which were found in the slash were mostly in the exposed larger limbs and butts.

4. Many of the dark beetles, fungus beetles (Tenebrionidae), and preducious beetles (Histeridae) are of economic importance in aiding in slash disposal, and also in decreasing the numbers of harmful bark beetles.

5. Temperature and moisture aid in decomposition of slash, decreasing the susceptibility for insect infestations.

6. The most important factor in this study was the peroper handling of the slash, as in all cases of slash disposal where the slash was piled or windrowed with the butts in or heavily shaded, a significant decrease in both wood borers and bark beetles was evident.

7. Time of cutting, pruning, or thinning were also significant.

8. In our regular silvicultural and management practices, many of our destructive forest insects can be held in endemic proportions by certain slash-disposal methods to prevent infestation of living trees in our plantations.

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