THE LIFE HISTORY AND BIOLOGY OF DIORYCTRIA ZIMMERMANI GROTE (LEPIDOPTERA: PHYCITIDAE) IN SOUTHERN MICHIGAN

Thesis for the Degree of M. S.

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ABSTRACT

THE LIFE HISTORY AND BIOLOGY
OF DIORYCTRIA ZIMMERMANI GROTE
(LEPIDOPTERA: PHYCITIDAE) IN SOUTHERN MICHIGAN

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This article reports the findings of studies on the biology and life history of the Zimmerman pine moth, Dioryctria zimmermani Grote in southern Michigan.

Cage studies were carried out to determine adult habits, activities and oviposition sites. Development of eggs was observed, as were larval activities upon eclosion. The vertical distribution of eggs on caged trees is described.

Vertical distribution of larvae and pupae on infested trees in the field is given and a discussion of potential factors contributing to this distribution follows. Development of larvae throughout the growing season is shown by means of the mean head capsule measurements on given dates and an attempt is made to determine the number of instars in the larval stage.

Occurence of parasitism in the egg stage and last larval stadium are discussed and the parasite species are given. To the authors knowledge this is the first report of parasitism in the egg stage.

The application of the findings to direct control of this species in high value plantations is discussed and reference is made to successful experimental control achieved on the basis of these findings.

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The relationships between D. *zimmermani*, D. *cambiicola* Dyar, and D. *abietivorella* Grote in regard to damage caused and biology of the species were observed and an analysis of this complex is presented.

THE LIFE HISTORY AND BIOLOGY

OF *DIORYCTRIA ZIMMERMANI* GROTE

(LEPIDOPTERA: PHYCITIDAE) IN SOUTHERN MICHIGAN

By

Robert B. Carlson

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INTRODUCTION

The Zimmerman pine moth, Dioryctria zimmermani Grote (Lepidoptera: Phycitidae) is thought to be a native Michigan insect, but only recently has it come to be regarded as a serious pest of pine in the state. Its rise to the position of a major pest has been occasioned by the extensive planting of Scotch pine (Pinus sylvestris L.) and Austrian pine (Pinus nigra Arn.) as Christmas trees. The increasingly competitive nature of this industry in Michigan requires that the growers produce quality trees in order that they can assure themselves of a market. Consequently, this pest has established itself as a factor. The incidence of Zimmerman pine moth in natural and planted stands of jack pine (Pinus banksiana Lamb.), and red pine (P. resinosa Ait.) has rarely been high enough to warrant concern by professional foresters in the state, but these endemic infestations have undoubtedly served as the initial source which gave rise to the current problem.

The damage done by the larvae of this insect takes several forms; (1) tunneling of terminal shoots in the spring and early summer frequently causing a dieback of the year's growth (2) tunneling under the bark of the main stem in the whorl area and subsequent girdling of the lateral branches at their base (plate I) and (3) complete girdling of the main stem, at or between the whorls, resulting in a burl-like growth above the point of injury (plate II). All three types of injury lead directly to a less desirable tree.

In 1958, when concern about this insect was first expressed, control recommendations were made to the growers on the basis of work

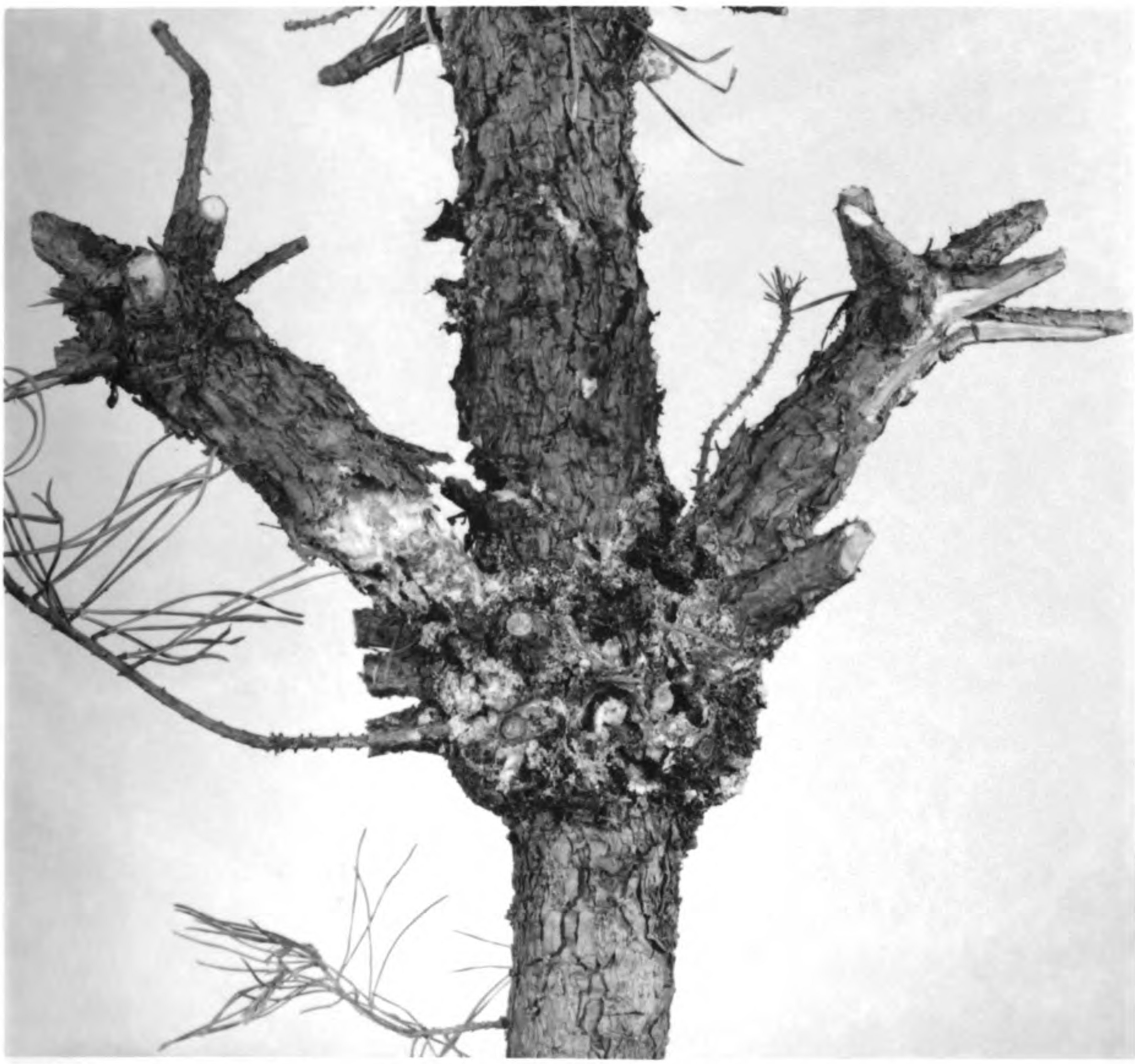


Plate I Girdling of lateral branches of Scotch pine by <u>Dioryctria zimmermani</u> Grote.

Plate II Girdling of main stem of Scotch pine by D. zimmermani.

done by Rennels (1959) and Schuder (1960), in Illinois and Indiana respectively. Failure of these recommendations to result in adequate control either on experimental control plots or commercial plantations in Michigan led to further tests using modifications of the recommendations. These tests also gave negative, or at best, poor results (Butcher and Carlson 1962).

This study of the biology and life history of the Zimmerman pine moth was undertaken in 1960 in an attempt to ascertain the reasons for failure to achieve control and to clear up some of the confusing aspects on its life history in Michigan. It was hoped that, as a result, an insight into timing of insecticide applications, and means of administering these applications, would be forthcoming.

REVIEW OF LITERATURE

Literature pertaining to the Zimmerman pine moth dates back to 1877, when Grote gave the original description of the species and named it in honor of Charles Zimmerman, who called his attention to it as a pest of pine. Subsequent literature has, to a great extent, been of a taxonomic nature, with a few notable exceptions. Two of these exceptions are the works of Brunner (1915) and Rennels (1959) in which the biology of the insects is treated at some length. Britton (1916) and Keen (1952) have also reported on biology, but the latters may be derivative.

Brunner, working in Montana and Idaho, states that the adults emerge from the pupal cases during the period from May 1 to September 15, and oviposition takes place during any of the milder months within this period. He reports that eggs are deposited in clusters, those laid during July hatch in two weeks; and the larvae develop into adults early the following spring. Eggs laid in the fall hatch in early spring and the larvae develop into adults during the following August and September.

Rennels, working in Illinois, presents a somewhat different version of the life history. He states that the moths emerge over a period from the latter half of July to the first half of August, and oviposition occurs for the most part during the month of August. Eggs are laid singly at the edge of sapsucker peck holes, on resin masses, and in terminal buds of Scotch pine. Eclosion takes place in 8-10 days and the larvae feed and move over the bark immediately after emergence.

During the winter inactive larvae can be found concealed in hibernaculum-like tents of resin and bark frass at the base of terminal buds and under bark flakes.

Keen (1952) has described the biology of Dioryctria ponderosae Dyar in the Nebraska National Forest. This insect was a misidentification by Heinrich of a color variety of D. zimmermani (Heinrich 1956). Keen states that the adults appear from late July to early September and deposit eggs singly on the underside of bark scales on the main stem of the tree or on lateral branches. The small larvae hatch in 1-4 weeks, depending on temperature, and spin small hibernacula under the bark scales in which they overwinter. The first evidence of attack appears the following spring in the form of a small quantity of larval castings on the bark surface followed by an exudation of pitch from the entrance hole. The issue is further confused here, however, since Keen also describes the biology of D. zimmermani under its proper name and the description varies from that given for D. ponderosae. This latter description of the biology closely follows that of Brunner and (as implied earlier) may be based on Brunner's findings, although no direct attribution is given.

Britton (1916) found the adults emerging from late June through early August in Connecticut, but does not mention anything else in regard to the life history except to comment on Brunner's work.

As can be seen by this brief review of the literature, there exist some discrepancies in the descriptions of biology and life history of this insect. Further discussion of these discrepancies will be included in the summary and will include facts brought out in the studies reported here.

CAGE STUDIES

In August of 1960 cage studies were initiated to determine whether captive moths would oviposit on caged trees. If they would it was thought that further information could be gathered on adult activity, location of eggs on trees, and the approximate time of hatching under these modified field conditions. Rennels (1959) had previously reported on unsuccessful attempts to get oviposition in large cages enclosing pine trees in Illinois.

Methods

A 6' by 6' by 12' cage was constructed in an experimental field on the Michigan State University campus. Two by fours were used for the frame which was then covered with 16 mesh fiberglass screen.

Two 4-foot Scotch pine were dug from a plantation, transported to the cage and transplanted. The trees were thoroughly watered each day to prevent drying.

In late July infested trees were removed from plantations and cut into sections. The damaged sections which were assumed to contain Zimmerman moth larvae or pupae were placed in a cardboard barrel to serve as an emergence chamber inside the cage. This barrel was fitted with a cone shaped screen covering, with a hole at the top of the cone to facilitate the escape of moths from the chamber and also to prevent moths from returning to the infested sections of trees to oviposit. The emergence chamber was checked daily for moths which failed to escape. None were found.

Observations on Emergence and Adult Behavior

Adult emergence in the cage followed the pattern shown in Figure 1. A total of 17 moths were observed to have emerged from the infested material and were active during the course of the study.

Adult activity was undoubtedly disturbed by confinement. Moths were observed predominantly on the 2 by 4's of the cage and only occasionally on the trees during the day. The moths would not fly unless actually pushed off the object upon which they were resting. Flights induced in this way were always short and directly to the first object in the path of the flight.

Activity of the moths in the evening began at 8:30 (± 10 minutes) on all the days in which initial activity was observed (August 12, 13, 15, and 18). At first they would begin moving their antennae. They then walked around on the object upon which they were resting, eventually flying from place to place in the cage. Even after complete activity had resumed, a good share of movement was accomplished by walking on the screen or frame of the cage.

Although Schuder (1960) states that the moths are not attracted to light traps in the field, the moths confined in the cage during the study showed definite movement toward incandescent light sources. For example, when the headlamps of a truck were directed on one end of the cage, the moths would congregate at that end. Also, when a flashlight (used for observation of moths after dark) was turned on, the moths would fly toward the light source. In view of Schuder's work, this could perhaps be explained as a point of escape from confinement, hence there was a tendency to move toward it.

Copulation was observed on five occasions, and in all cases the

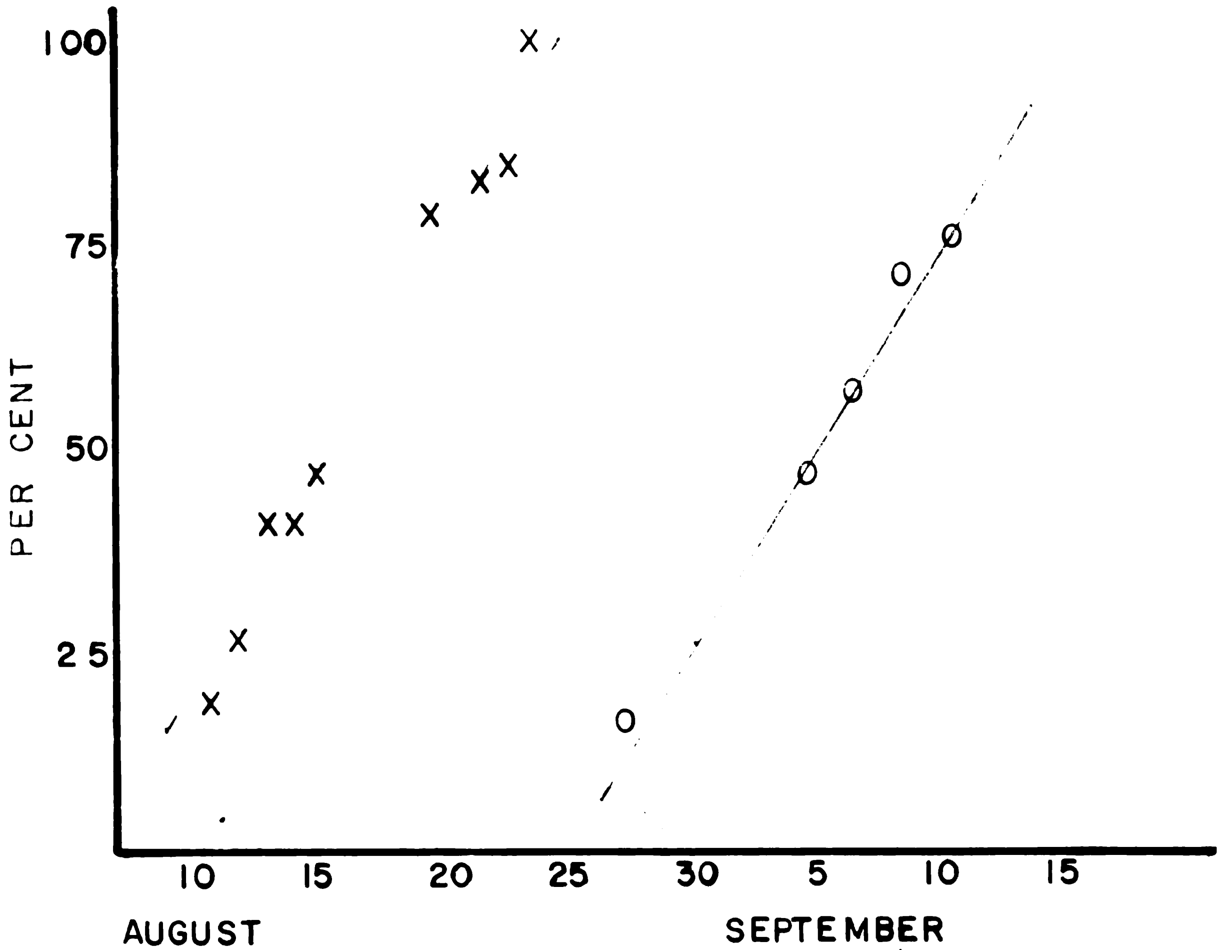


Figure 1. Duration of adult emergence (X) and eclosion in cage (O).

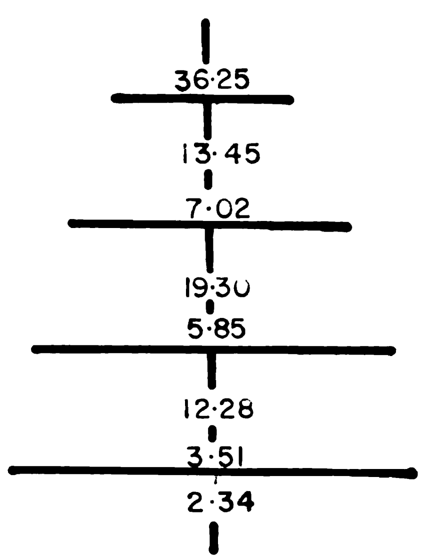


Figure 2. Vertical Distribution of eggs on cage trees (%).

copulating pairs were found on the screen or frame of the cage. The earliest that a copulating pair was found was 9:30 p.m.; and a pair first found at 10:15 p.m. were seen to cease copulation at 1:30 a.m. The position assumed by the moths has been described by Rennels (1959).

Oviposition

The act of oviposition was not observed in the cage studies. On the basis of observations made on adult activities, it is difficult to believe that there is no photoperiodicity associated with this act in the cage situation, even though Rennels (1959) observed none in the case of moths confined in screen covered glass jars.

Subsequent dissection of the trees revealed that oviposition had occurred, and a total of 178 eggs were found on the two trees. Figure 2 shows the distribution of these eggs, listing the percent of the total number of eggs for each position. The eggs were located predominantly on the main stem as shown and were found on the underside of bark scales, in crevices at the base of the lateral branches and 6 of these were found on one branch in the whorl once removed from the main stem.

Plate 3 shows two Zimmerman moth eggs which were deposited between the base of a dried needle and the main stem of a tree. The size of the eggs can be seen by comparison with the base of the needle.

Eclosion

Eclosion of eggs on the trees in the cage followed the pattern shown in Figure 1. The percentages used to determine the general pattern were obtained by dissection of the trees after the moths were no longer active in the cage and by counting the number of hatched and

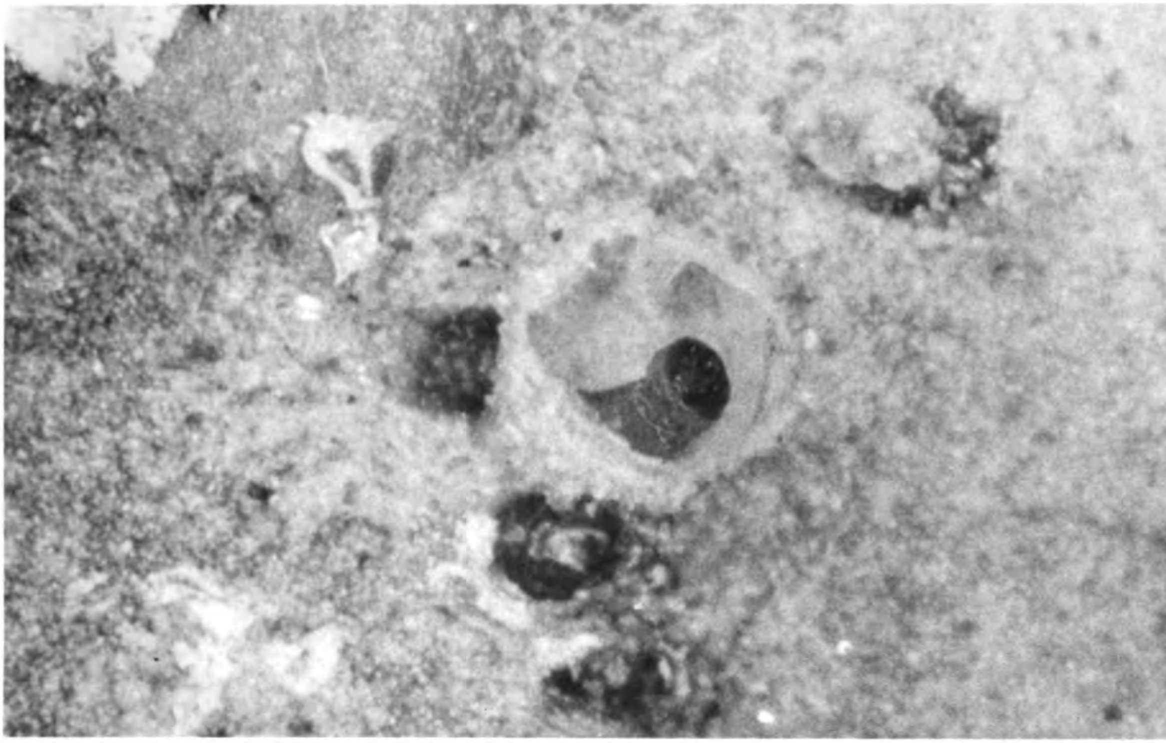


Plate III Larva of D. zimmermani in opened hibernaculum.

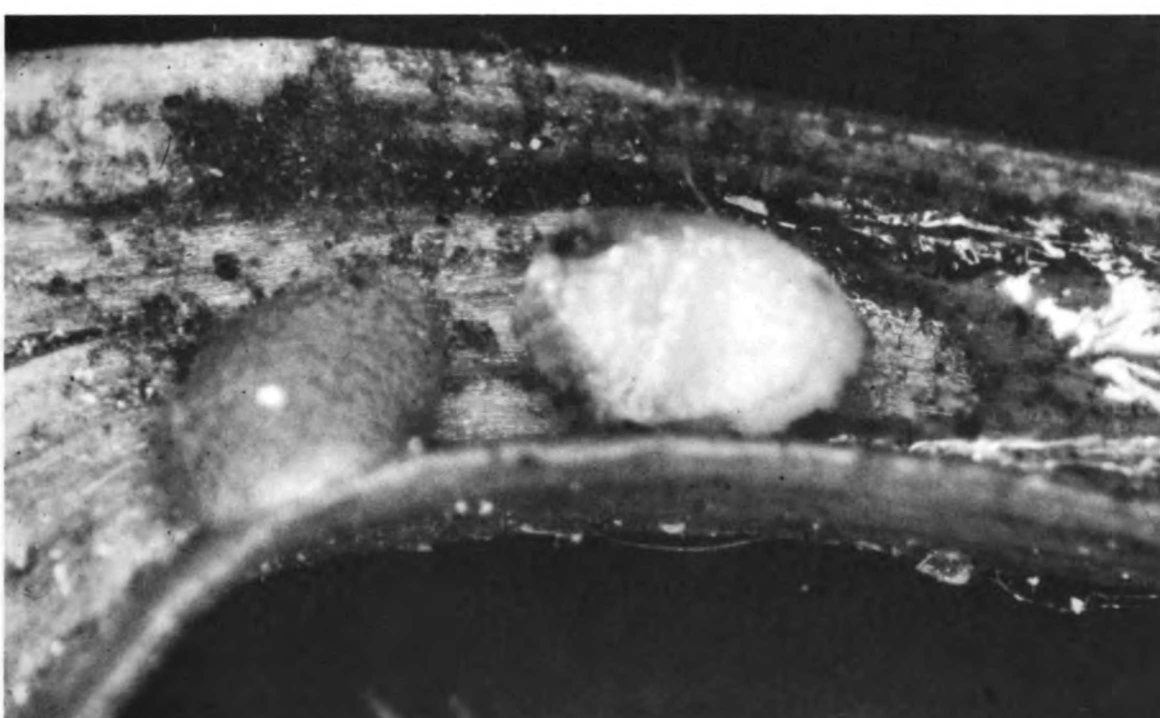


Plate IV Eggs of D. zimmermani.

unhatched eggs. These counts were made on one section of tree each day until both trees were completely dissected. The line was drawn by sight-fitting it to the points plotted, since not enough points were obtained to warrant use of more accurate statistical methods.

Unhatched eggs which were found on the trees during dissection were removed and placed in containers, so that development and eclosion could be observed. The eggs, which are slightly ovoid in shape and have somewhat of a rugose texture on the upper surface, changed from a creamy white to a pinkish white and finally to a deep reddish brown. The color changes appeared to take place in about 4 days in the laboratory but no one egg was followed through all of the changes. Eclosion took place approximately 7 days after the eggs had been observed in the creamy white stage but here again it was impossible to follow one egg through to eclosion. Separation of the larvae from the egg membranes took place about a day before eclosion, and larval movements were detected under a microscope approximately 2 hours before it could actually be ascertained that the larva had begun chewing its way out of the egg membranes. When emerging, the larvae would chew a small hole at the base of the egg and proceed to crawl out at this point. Their movement after freeing themselves from the egg was rapid, and generally toward a dark corner of the container.

Placement of newly hatched larvae on small sections of Scotch pine stems revealed that the larvae would seek the cover of a bark scale or crevice immediately. Movement from the first protective crevice found was generally under the bark scales, with very little movement on the exposed portions of bark. Further observation showed that as soon as a suitable protective area was found the larvae would begin to spin a small silken hibernaculum (Plate 4). In view of Rennel's statement that the larvae move around on the outer bark and feed at the base of terminal buds and on the outer bark before formation of a hibernaculum-like covering of resin and bark frass, a check of the position of the hibernacula on plantation trees was made. This check showed the hibernacula to be located in close proximity to hatched eggs in confirmation of the laboratory observations that the larvae do not do much moving after emergence from the egg. No evidence of fall feeding by the larvae was observed either in the lab or in the plantation.

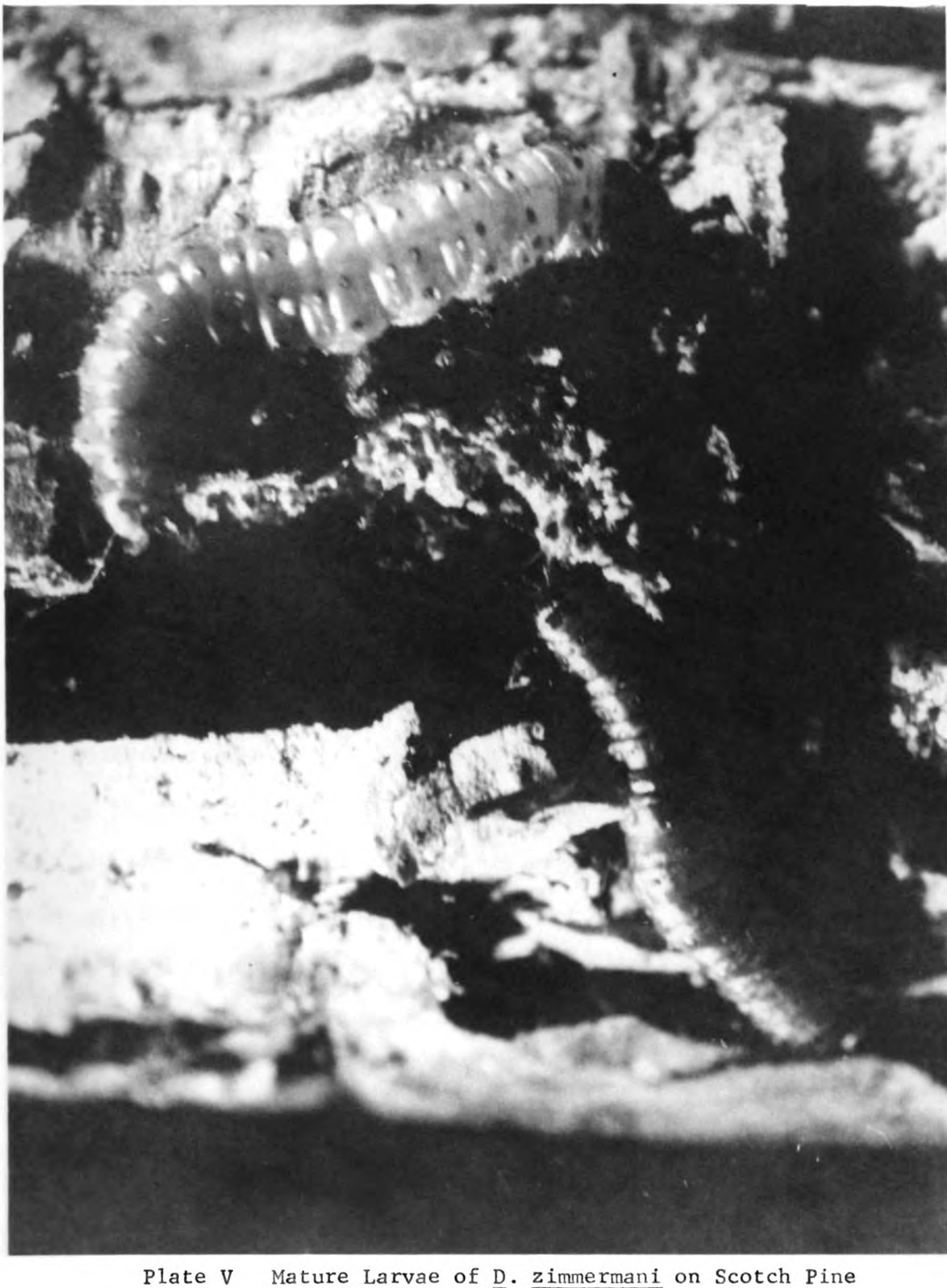


Plate V Mature Larvae of D. zimmermani on Scotch Pine

LIFE HISTORY AND DEVELOPMENT IN SOUTHERN MICHIGAN

The majority of observations made on the life cycle of the Zimmerman moth were made near West Olive in Ottawa County on the southwestern edge of the state. However, the author's attention was called to a relatively heavy infestation near St. Charles in Saginaw County, (east central Michigan) in the summer of 1961. Some data collected from this location will be included for comparative purposes.

The Zimmerman moth has a one year life cycle in lower Michigan. It overwinters as a first or second instar larva in a silken hibernaculum under bark scales or in crevices at the base of lateral branches. In contrast to Brunner's (1915) observations in Montana, no overwintering eggs were found while dissecting trees during the winter months.

Adult Emergence and Activity

Adult emergence in the West Olive study area for the years 1959 to 1961 is shown in Figure 3. The emergence pattern for 1961 in the St. Charles area is also shown for comparative purposes; and it is seen to be approximately a week ahead of the West Olive emergence for that year. Speculation on this suggest that perhaps the modifying influences of Lake Michigan on the climate in the West Olive area slows the development of the larvae in this area during the summer months; however, further studies will have to be made before this can be confirmed.

The secretive nature and nocturnal habits of the adults, complemented by an effective camouflage coloring, make field study difficult. An occasional moth was induced to fly during the day by

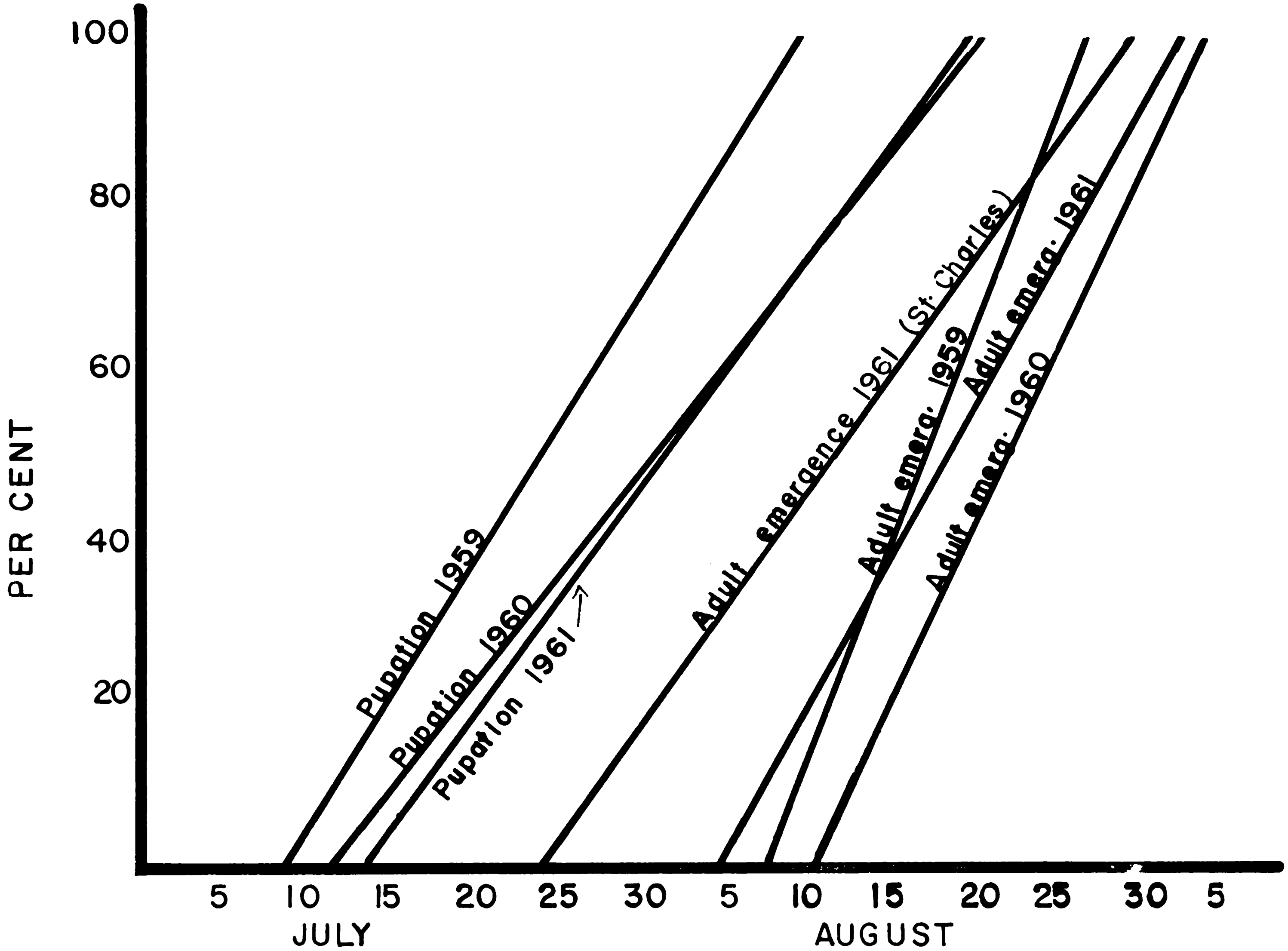


Figure 3. Duration of pupation and adult emergence in plantations.

shaking trees; but considering the rarity of this occurrence even at times when moths should have been in peak abundance in heavily infested plantations, it is tentatively suggested that the moths do not, in general, remain on the trees during the daylight hours.

Oviposition and Eclosion

Neither oviposition nor progress of eclosion was observed in the field situation. The distribution of eggs on the plantation trees followed closely the distribution shown in Figure 2 for caged trees but due to the difficulty of making a complete sampling of eggs on plantation trees and the similarity of distribution found in preliminary comparison, no attempt was made to obtain comparative data.

Larval Activity and Development

Fall Activity. As seen in laboratory observations and subsequent checks of plantation trees, the newly hatched larvae gave no indication of feeding before spinning hibernacula in which they overwintered. Eggs were usually found in close proximity to hibernacula during dissection of plantation trees in the winter and it appeared that the only movement by the larvae after hatching was into a more protected situation; such as the deeper recesses under bark scales, or more deeply into crevices. The hibernacula which were observed were variable in shape, evidently conforming to the shapes of the crevices in which they were spun.

Resumption of Activity in the Spring. In 1961, resumption of activity by larvae of the Zimmerman moth was quite uniform in that no larvae were found to have emerged from the hibernacula on May 1. On

May 7, the next sampling date, all of the larvae observed had emerged. These observations were made on three trees for each of the dates in question, and all of the trees were selected at random with respect to position in the plantation. On this basis it is assumed that the observations reflect the actual situation and not merely differences in trees due to differences in the amount of solar radiation received, or to some other such factor that could contribute to the resumption of larval activity. As shown in Figure 4 this initiation of spring activity corresponded closely with the initiation of terminal growth of Scotch pine in the same plantation. The terminal growth of Scotch pine was determined by measurement of the terminal bud on each of 20 trees, and the mean of these measurements was plotted for each date.

The larvae, which feed in the phloem region of the main stem, begin entering the inner bark almost immediately after emergence from the hibernacula. It was observed that the succulent tissue between the base of lateral branches and the main stem and the succulent scar tissue around wounds were favorable areas for entry. It is assumed that these comparatively large masses of soft tissue supply a generous amount of soft food for the larvae until they are far enough along in their development to enable them to tunnel the harder tissues between the bark and wood. Small amounts of frass near the point of feeding are the first indication of larval feeding. This is followed by exudation of small quantities of pitch at the point of entry.

The first gross indication of damage by the Zimmerman larvae appears in mid-June, when the tunneled terminals begin to "flag" or bend over, and take on a yellowish-green color above the point at which the larvae are feeding. It is not known precisely when the

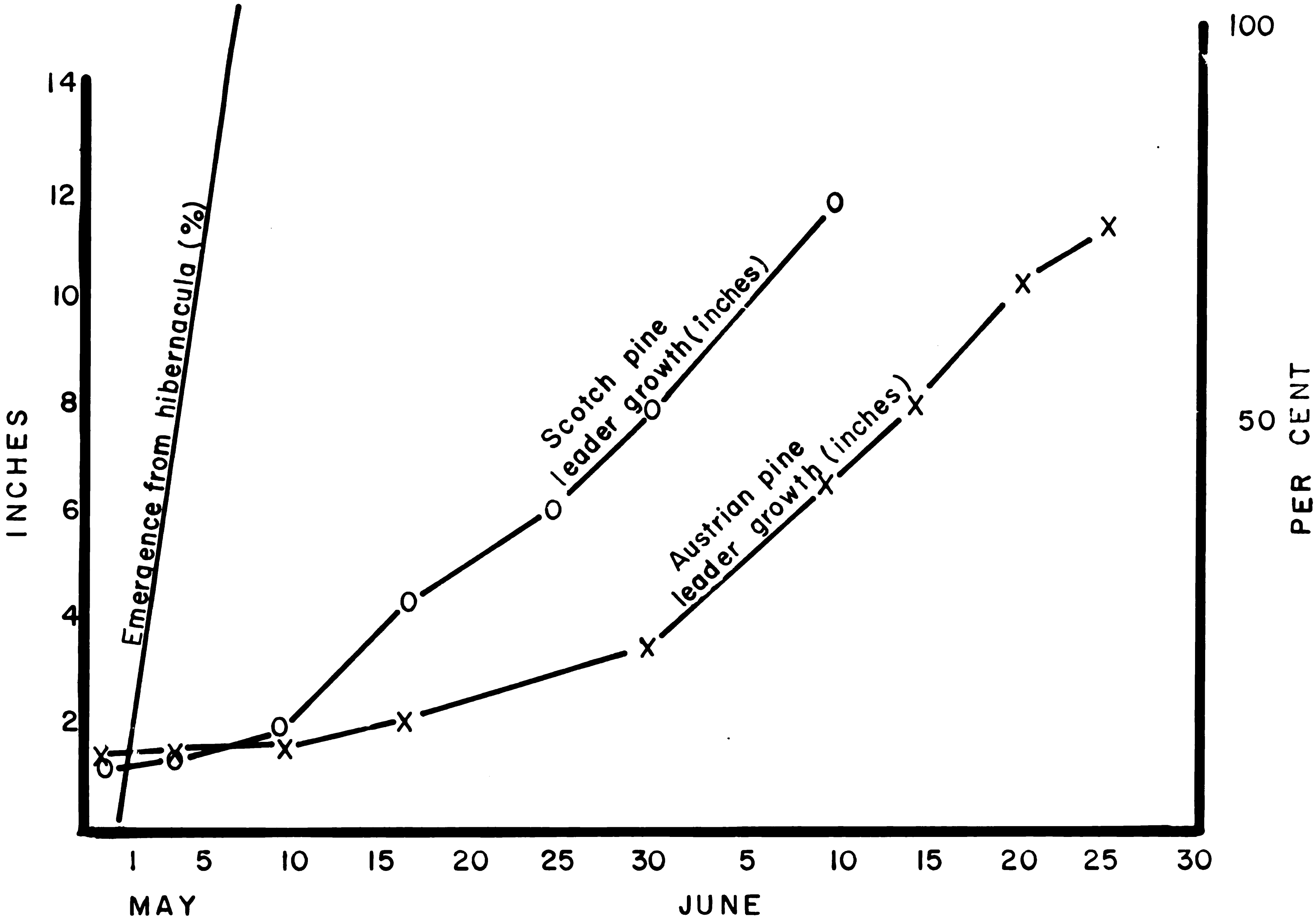


Figure 4. Initiation of spring activity of larvae as compared to terminal growth of Scotch and Austrian pine.

larvae initiate feeding in the terminals, but judging from the size of the larvae at the time the damage first appears and the lack of any obvious entrance hole, it is assumed that this feeding begins soon after the larvae emerge and while the terminal shoot is still quite short.

The predominant direction of tunneling in terminals is downward, and when the larvae reach the base of the terminal the first whorl is usually girdled. Exit holes have been observed in the first whorl area after it has been girdled, but it is not known whether the larvae that have emerged move down and re-enter the stem, succumb to predators or parasites, or die due to a lack of food caused by their inability to regain a feeding position. This topic will be discussed further in the section of the vertical distribution of larvae on the trees during summer months.

Vertical Distribution of Larvae and Pupae on Plantation Trees

The distribution of larvae and pupae on Scotch pine during the summer of 1960 was determined by dissection of trees and marking the position of each larvae or pupae found. Plotting the percent of total larvae found over the course of the summer yielded a distribution as shown in Figure 5. When the data were broken down into percent of monthly totals for each period and similarly plotted as shown in Figure 5 some interesting trends are seen. In the spring and early summer (May - June) the distribution of larvae is relatavely uniform over the trees, with a slightly higher percentage in the upper whorl. This even distribution was also seen in the position of eggs on the caged trees (Figure 2). As the season progressed a tendency is seen

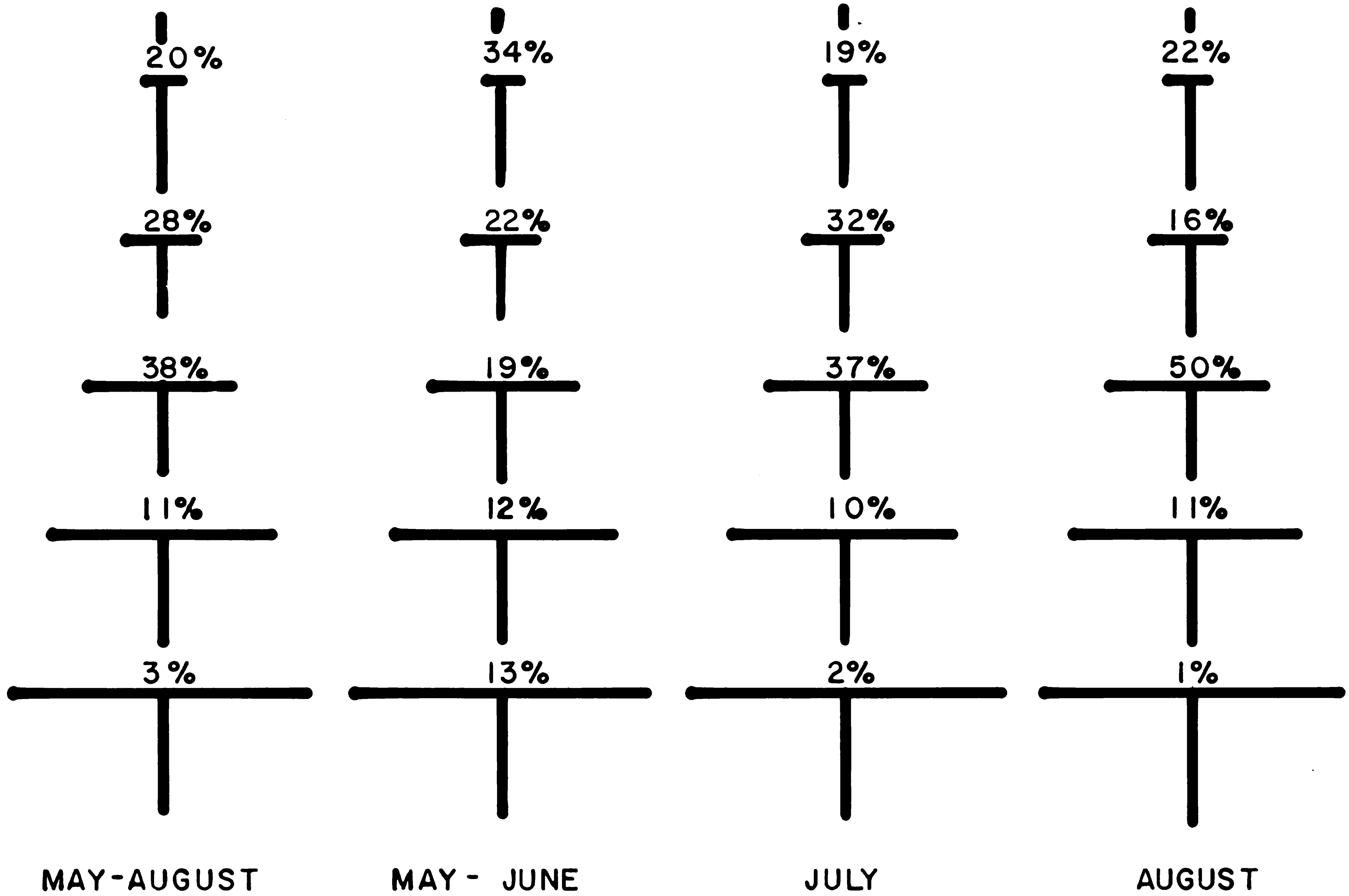


Figure 5. Vertical distribution of larvae and pupae on plantation grown Scotch pine.

for an increase in the percentages in the middle whorls with a subsequent reduction of percentages in the upper and lower whorls.

The reasons for these trends are open to speculation; however, there are a few points which can be brought out in regard to this phenomenom. It is felt that these changes could be explained in any of the following three ways: 1) It could result from higher larval mortality in the upper and lower whorls 2) There may be movement by the larvae toward the center whorls or 3) It could be a result of a combination of the first two factors. In regard to the first possibility, Rennels (1959) states that larvae rarely reach maturity in the main stem until the bark reaches a thickness of 0.15 inches, which would explain a high mortality factor in the upper whorl. However, he then goes on to state that observations have not confirmed a similar high mortality rate in the thin bark at the base of the terminals. Observations made in this study have shown that larvae do emerge from under the thin bark in the upper whorls and these larvae could presumably re-enter the tree at a point further down the stem and hence support the second explanation above. Brunner (1915) states that in general the larvae do not remain in the phloem area of the tree throughout their development but emerge from the area of the first point of entry and then re-enter at another point.

From these observations it would appear that both of the first two explanations make sense. The third, and more general explanation, could be used to explain most of the findings reported here.

Larval Development

Head capsule measurements were made on larvae collected in 1960 and 1961, in an effort to determine the number of instars the larvae pass through in the course of development. The measurements when plotted on a bar graph gave a distribution as shown in Figure 6. It can be seen that the graph reveals only two definite peaks; one at 0.25 mm., which is the first instar since all measurements made on larvae immediately after hatching from the eggs were included in this group. The other, at 2.0 mm., is undoubtedly the last instar since all larvae collected after July 20 and up until complete pupation were in this group. There is some indication that two more peaks are present at 0.375 mm. and 0.525 mm. and if these peaks are assumed to be real and the concept of geometric increase in width of head capsules for successive larval instars is applied, two additional instars should occur at approximately 0.8 mm. and 1.3 mm. The graph shows a slight indication of the presence of these latter two instars but not clearly enough to draw any firm conclusions. Using this data it is tentatively proposed that there are six stadia in the development of the Zimmerman larvae but further collections and measurements will be needed to verify the assumption.

Pupation

During the three years in which counts were made, pupation of Zimmerman moth larvae began during the second week in July and reached completion by the second week in August (Figure 3).

When the larvae have reached maturity and are ready to pupate, an enlargement is made in the larval tunnel and an exit point for the emerging moth is made. This exit is provided by the larvae chewing away the outer bark from the inside until only a thin cap of bark

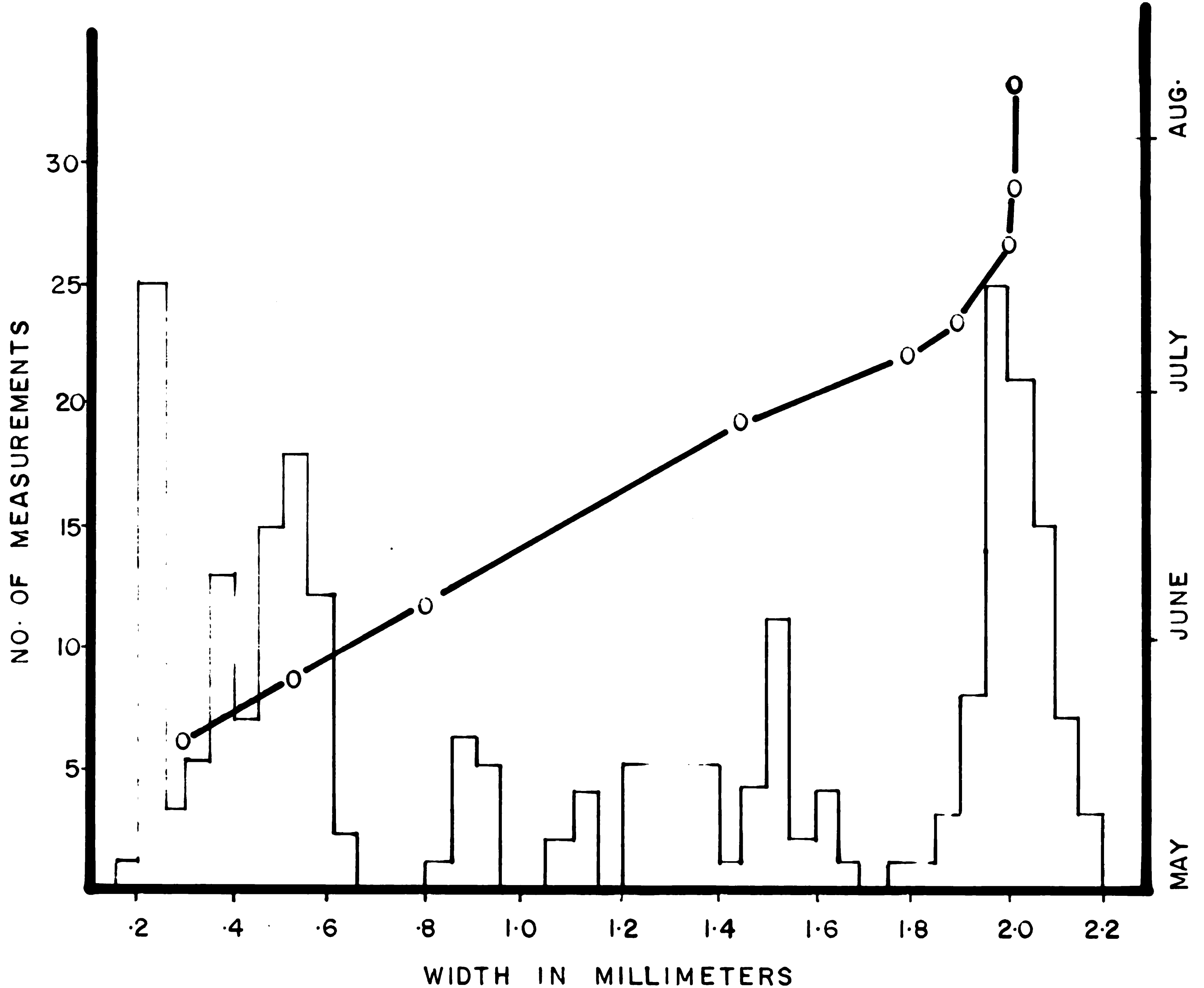


Figure 6. Frequency of widths of head capsules (bar) and seasonal development by mean head capsule width (line), of larvae of the Zimmerman moth.

tissue is left over the enlarged chamber. As will be shown in the section on mortality by parasites, the larvae frequently will take off a little too much bark tissue and a hole in the cap will result. This is a seemingly important factor in the natural control of this pest.

Rennels (1959) states that the insect remains in the pupal stage 15-16 days in Illinois. Brunner (1915), on the other hand, gives the length of time in Montana as exactly 29 days, under very varying temperatures and during all seasons. No observations were made in Michigan on the exact length of time the insect spends in the pupal stage, but by extrapolation from Figure 3, using the period from 50 percent pupation to 50 percent adult emergence, the following intervals are derived:

1959 - 23 days

1960 - 22 days

1961 - 16 days

Since these approximations fall between Rennel's and Brunner's observations, probably Rennel's presumption that differences in the length of the pupal period are due to temperature differences is justified assuming that the temperature in Michigan would be between the ranges in Illinois and Montana. In view of Brunner's firm stand on a uniform pupal period for all variations in temperature it would seem advisable to investigate this further.

NATURAL CONTROL BY PARASITES

Rennels (1959) states that there were seldom more than 1 to 5 percent of the larvae and pupae parasitized in any of the plantations which he studied in Illinois. In 1961, counts of parasitized eggs and larvae of the Zimmerman moth were made in both the West Olive and St. Charles areas in order to estimate the importance of these factors in Michigan.

Larval Parasites

Zimmerman pine moth larvae, because of their protected existence under bark of trees, presumably would not be susceptable to attack by many parasites during the spring and early summer. Collection of larvae during these periods confirmed this presumption in that no parasitized larvae were found prior to the first week of July 1961. As the larvae reached maturity, however, the incidence of parasitism increased sharply. Table 1 shows the data collected in St. Charles and West Olive during August of 1961.

The correlation between a sharp increase in parasitism and the reaching of maturity can perhaps be explained by the habits of the larvae upon reaching maturity. When the larvae are ready to pupate an enlargement is made in the feeding tunnel and an exit point for the emerging moth is fashioned by the larvae chewing away all but a thin layer of bark over this enlargement. Often times the larvae will take off too much and the result is a hole in the bark exposing the mature larvae to the outside. This hole could make it easier for the parasites to reach the host and lay their eggs.

Table 1. Numbers of normal and parasitized larvae* found during August 1961.

	West Olive		St. Charles	
Date	Normal	Parasitized	Normal	Parasitized
August 1	--	--	15	14
August 8	14	14	--	--
August 9	--	--	13	16
August 16	18	8	--	--
August 22	--	--	13	10
August 25	13	12	--	--
Percent of Total	43	57	51	49

*Pupae found were classed as normal larvae.

The predominant parasite attacking larvae in the final stadium was a small Hymenopteran,

This species accounted for better than 90 percent of all the parasites found in both study areas.

accounted for the remaining parasites found.

Since data on larval parasites has been collected for only one year, the effect of parasites on the populations of Zimmerman moth is not known. Consequently the reduction of damage attributable to parasitism cannot yet be evaluated. It would appear, however, that since the majority, if not all, of the larval parasitism occurs in the last stadium after the damage for any one year has been done, the effect would not be proportional to the percentage parasitized.

Despite the inability to make any definite statements as to the degree of control parasites exert on the populations of *D. zimmermani*, it seems evident that this control is a more important factor in the plantations included in this study than it was in those which Rennels carried out his work and on the basis of extremely low parasitism found in 1959 and 1960 pupal collections it appears to be on the increase.

Egg Parasites

During dissection of trees in the fall of 1961, eggs of the Zimmerman moth were found which were dark black in color and appeared to be parasitized. These eggs were collected and placed in vials. A minute parasite subsequently emerged from some of these eggs. These parasites were identified as

In all, 28 out of 66, or approximately 45 percent, of the eggs found in the plantation at West Olive were parasitized. Due to the fact that the parasitized eggs are black, while the hatched eggs are a clear white color, they are somewhat easier to see and consequently the percentage given may be a little high. The care with which the trees were dissected, however, leads the author to believe that the error due to this color difference is negligible.

This is the first reported parasite attacking the eggs of the Zimmerman moth and it appears to be a significant limiting factor at least in the West Olive plantation. A few eggs which appeared to be parasitized were also found in the St. Charles area but adult parasites failed to emerge from these. No attempt was made to determine the percent parasitism in the St. Charles area due to time involved in the dissection of trees in order to locate the eggs.

OTHER SPECIES OF *DIORYCTRIA* IN ASSOCIATION WITH *D. ZIMMERMANI*

This investigation on the biology of the Zimmerman pine moth has been made somewhat more difficult by the presence of at least one, and perhaps two, other species of *Dioryctria* in the plantations in which the work was carried out.

Dioryctria abietivorella Grote

This species determined by the author on the basis of pupal characteristics (Ross 1959), has been found in both the West Olive and St. Charles study areas. The larvae of this species has caused previous confusion due to the fact that they seem to prefer trees previously attacked by *D. zimmermani* and feed in the tunnels made by the latter. It appears that damage is of a secondary nature, for the most part, since only rarely were the larvae found feeding in undamaged bark and in these cases their tunnels were offshoots of the tunnels made by *D. zimmermani*. Further confusion had resulted from the presence of partially grown larvae at times in the fall when *D. zimmermani* larvae were supposedly in the hibernacula. This has led observers to believe that the Zimmerman moth overwintered in variable stages of larval development in Michigan.

Dioryctria cambiicola Dyar

Again using the paper by Ross mentioned above, the author has determined the presence of *Dioryctria cambiicola* in the study areas. However, no definite biological differences between this species and

D. zimmermani were observed nor was it possible to distinguish the two species in either the adult or larval stage. According to Heinrich (1956) the only taxonomic difference between the species is the color of the hind wing, and this is at best of dubious value. Heinrich lists them as distinct species, but expresses doubt as to the validity of this separation, (except as possibly different races). Since Munroe (1959) agrees with these observations, it was assumed by the author that the failure to make a more distinct separation between them in the larval stage would in no way detract from the biological study or its application to control work.

APPLICATION OF FINDINGS TO CONTROL WORK

As was stated in the introduction, this study was undertaken with the objective of clearing up some of the confusion that has existed regarding the biology of the Zimmerman pine moth in Michigan. It was hoped that such information would provide an insight into failure of recommended control measures. The foregoing sections have accomplished, to the best of the author's knowledge, the first part of this objective and these biological facts will now be analyzed for possible effective control recommendations.

In looking at the biology of this insect four main factors must be taken into account: 1) The eggs are for the most part laid on the main stem of the tree and always in protected areas such as under bark scales or in crevices. 2) The eggs are laid over a period of at least 2-3 weeks and upon eclosion the larvae spin hibernacula without undergoing much movement on the outer bark. 3) No evidence of fall feeding by the larvae was observed. 4) Emergence of all of the larvae from their hibernacula occurred over a period of one week and entrance into the bark tissue followed soon after.

The first, and perhaps the most important, ramification of the above statements is that in order for any control effort to be successful the spray must be directed at the main stem. It must also penetrate into the cracks and crevices in order to reach the insect since it appears that at no time is any extensive movement done on the exposed portions of the tree.

The next consideration must be the timing of the spray application.

In analyzing the biological facts it would seem that a fall spray program directed at the larvae would be dependent upon a long residual effect to cover the (approximate) 3 week period of eclosion. A spring program, on the other hand, would not require as long a residual effect since emergence from the hibernacula covers a much shorter span of time, approximately 1 week.

Another possible advantage of a spring program would be the possibility of killing larvae while still in the hibernacula, provided a lethal concentration of the toxicant could contact them in either the liquid or vapor phase.

The main problem to be expected in a spring program would perhaps be one of predicting the time of larval emergence from the hibernacula. Indications are, however, that further work may yield a method of predicting this emergence by its relation to initiation of terminal growth of the trees in the plantation.

On the basis of the above analysis, experimental control tests were initiated in the spring of 1961, the results of which are in press (Butcher and Carlson 1962). These test showed beyond a reasonable doubt that extremely effective control can be attained with a stem drench spray applied before the larvae initiated spring activity. The results were far superior to any previous control attempts using a fall program and consequently will form the basis for future recommendations to the Christmas tree industry for control of this pest.

SUMMARY

The Zimmerman pine moth has currently established itself as a serious pest of high value plantation grown pine in areas of lower Michigan. The damage done by this insect includes tunneling of the terminal shoots, tunneling of the phloem region of the main stem, and girdling of lateral branches at their base by tunneling of the phloem region at the whorls. In the first instance, evidence of the presence of the pest appears as a flagging of the terminals about the middle of June, while in the latter two cases pitch masses and frass accumulations along the main stem appear in the latter part of July.

Previous work done on the biology of this species has introduced some discrepancies in seasonal development. Considering the fact that the studies reported in the literature review were done in widely separated geographical areas, most of these discrepancies can perhaps be explained by climatological differences in the areas in which the studies were done. One point that cannot be explained in this way is Brunner's (1915) statement that eggs are deposited in clusters. It is this author's opinion that Brunner based his statement on the misinterpretation of the fact that he frequently found "six or more larvae less than 3/8 inch long in one infested spot". This opinion is based on the fact that Brunner did not describe the eggs even though all other stages of the insect's development were described in some detail. This also leads to the questioning of the statement that some overwintering is done in the egg stage in Montana. No other investigator has observed this type of overwintering.

In Michigan, Dioryctria zimmermani undergoes one generation per year. The adults emerge from mid-July to the first part of September and after copulation the females lay eggs under bark scales or in crevices on the main stem of the trees. These eggs are laid singly and upon eclosion the larvae spin hibernacula in which they overwinter. Spring activity began the first week of May in 1961 and the larvae began entering the bark tissue almost immediately. For the most part it appears that the larvae remain in the phloem region of the tree throughout their development. Pupation begins about mid-June and is completed by mid-August.

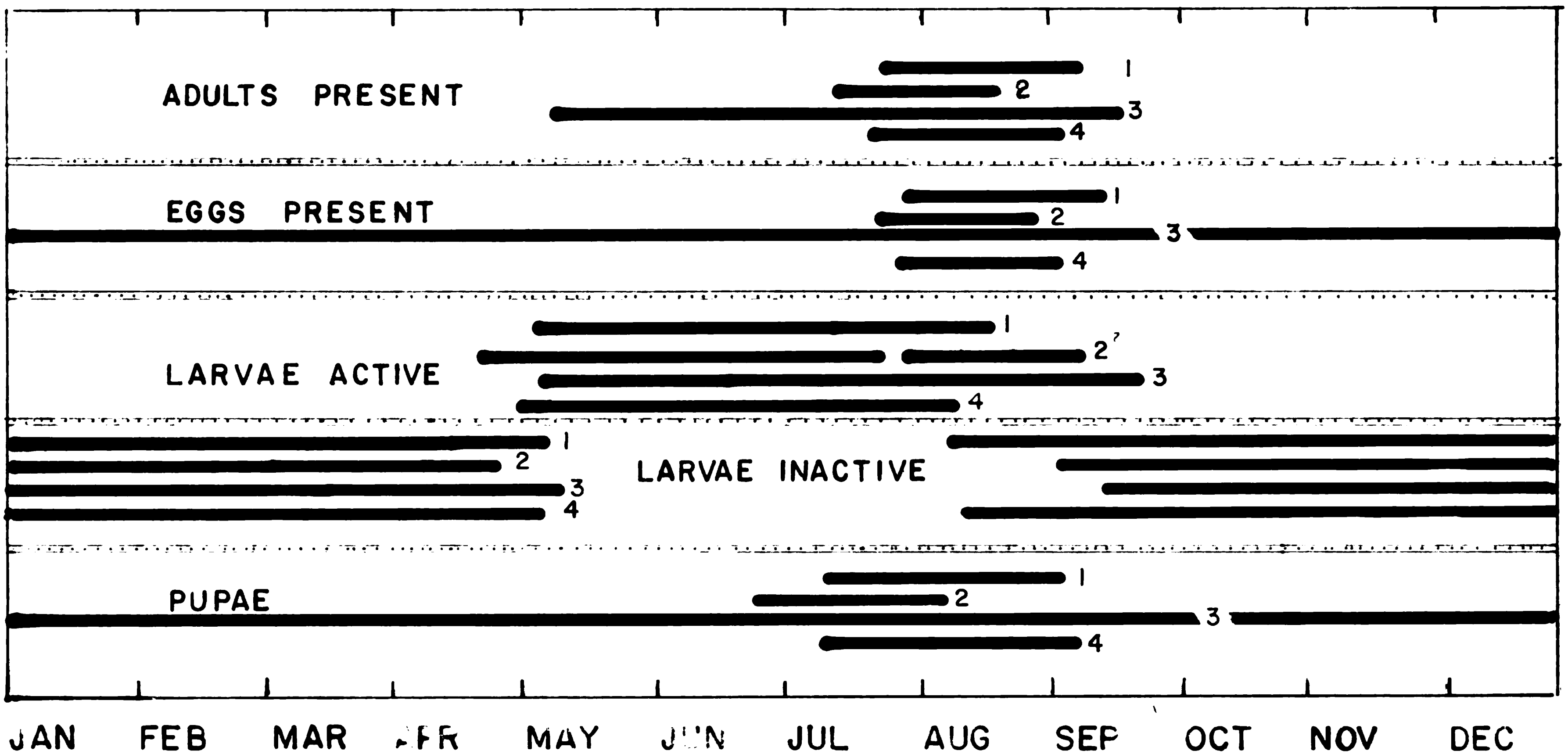
It is interesting to note that this description of the life history corresponds closely to that of Keen (1938, 1952) for an insect which was mistakenly described under the name Dioryctria ponderosae. This lends further credence to assumptions expressed in the literature review that Keen's description of the life history of D. zimmermani was based on the work of Brunner. Figure 7 gives a summary of the development of the Zimmerman pine moth through the year as derived from the above mentioned literature. In all cases the date of termination of any one stage is given as an approximation since presumably they would vary from year to year.

Natural control of this pest by parasites appears to be restricted to control of the last instar larvae and the eggs. Larval parasites found were

with the former being abundant. Egg parasites found for the first time were

These appear to be quite effective in that approximately 45 percent of the eggs examined from the West Olive area were parasitized.

Figure 7. Seasonal development of Dioryctria zimmermani Grote in various geographical areas of the United States.



1. Michigan
2. Illinois (Rennels 1959)
3. Montana (Brunner 1915)
4. Nebraska (Keen 1952)

Dioryctria _abietivorella_ was present in the study areas but it is assumed to be a secondary pest which did not contribute significantly to the damage. The possible presence of _D_. _cambiicola_ was also noted. However, due to the dubious taxonomic status of this species and the similarity of its life history and biology to that of _D_. _zimmermani_, the author has not attempted to separate it from _D_. _zimmermani_ in the presentation of findings.

The control of Zimmerman pine moth in high value plantations of pine in Michigan has been obtained experimentally as a consequence of the information obtained in this study, and is reported in detail elsewhere.

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