BIONOMICS OF THE SMALLER EUROPEAN ELM BARK BEETLE, *SCOLYTUS MULTISTRIATUS* (MARSHAM), IN MICHIGAN

By

Richard Charles Fox

A THESIS

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

DOCTOR OF PHILOSOPHY

Department of Entomology

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Approved Ray Hutson
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ABSTRACT

Since the detection and subsequent spread of the Dutch elm disease in Michigan, many uninvestigated problems concerning the bionomics of the major vector of the disease, the smaller European elm bark beetle, *Scolytus multistriatus* (Marsh.), have been encountered. These problems fostered the present studies.

The emergence patterns of the adult beetles, the primary objective of the study, were investigated and it was found that the insect has two complete generations in southern Michigan. First brood adult emergence commences in late May or early June with a peak emergence occurring about June 20. Second brood emergence begins in early July with a peak varying between July 29 and August 30 depending upon weather conditions. Adults are present throughout the summer months and have been found to confine their feeding to other than current season's twig growth--that is, to branch wood in at least its second growing season. Late season breeding activities are curtailed, apparently by prevalence of cooler temperatures and brood galleries constructed in mid-August vary significantly in length from those constructed by breeding adult females in late August and early September. The sex ratios of adults do not vary significantly from an equal distribution at any time during emergence periods.

Attempts to rear beetles under varying conditions in mechanically-chipped elm wood failed. Wood remains of this type can be considered safe from beetle development or attack.

Tests of a DDT-acetone emulsion diluted to foliar strength showed negligible phytotoxicity on trees varying in size from 30 to over 70 feet in height. The 19 trees on which the formulation was tested were sprayed in August, 1956 and in July, 1957 using both a hydraulic and a mist sprayer.

Eight Dutch elm diseased trees were treated with sodium arsenite and were allowed to remain in the field for 60 days. In no case were any of the eight trees successfully attacked by breeding females nor was any larval development completed.

Bioassay of commercially-sprayed trees was carried out using trees with varying amounts of treatment. It was found that in general, spray application had not been thorough enough to give adequate protection from feeding adult beetles. During this study, adults were reared in the laboratory in twigs as small as three-eighths of an inch in diameter.

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I. INTRODUCTION

The smaller European elm bark beetle, *Scolytus multistriatus* (Marsham), is well-known as the major vector of the Dutch elm disease, *Ceratocystis ulmi* (Buisman) Moreau. Exhaustive studies of this insect have been made in other states since the first diagnosis of the Dutch elm disease in the Cleveland, Ohio area in 1930 but the status of the pest in Michigan has been little investigated.

Since the discovery of the Dutch elm disease in Michigan in 1950, many problems have arisen in field control activities, problems for which no answer has been available under Michigan conditions. These initiated the present studies and fostered its objectives which were as follows:

1. To determine the seasonal cycles of *Scolytus multistriatus* (Marsham) under Michigan conditions.
2. To determine, if any, the seasonal variation in sex ratios of *S. multistriatus*.
3. To determine the extent of adult beetle feeding on new growth twigs.
4. To determine whether any significant variation occurs in the length of late season brood galleries.
5. To determine if mechanically-chipped elm wood is free from further beetle development or attack.
6. To evaluate the phytotoxic effects, if any, of a new spray formulation.
7. To investigate the possibilities of poisoning diseased trees to prevent further beetle development or attack.

8. To evaluate the protection from beetle feeding afforded by trees with varying amounts of spray deposit.

The primary function of this study was to work out the seasonal cycle of *S. multistriatus* under Michigan conditions. Other researches, although important facets of the over-all problem, were considered to be secondary to this initial objective.

II. HISTORICAL REVIEW

The smaller European elm bark beetle, *Scolytus multistriatus* (Marsham) was described by Thomas Marsham (1802) and was later found to be an important pest of elms in Europe by Eichhoff (1881).

Shortly after World War I, unusually large numbers of elms were observed dying in Holland, Belgium and France and in 1921, Schwarz (1922) isolated the causal agent and described it as a new species of fungus, giving it the name of *Graphium ulmi* Schwarz. Buismann (1933) discovered the ascigerous or perfect stage of the fungus, first in laboratory cultures and later from field material. She named it *Ceratostomella ulmi* Buismann. Recently, Hunt (1956) has revised this group of fungi and the Dutch elm disease causal agent is now known as *Ceratocystis ulmi* (Buismann) Moreau.

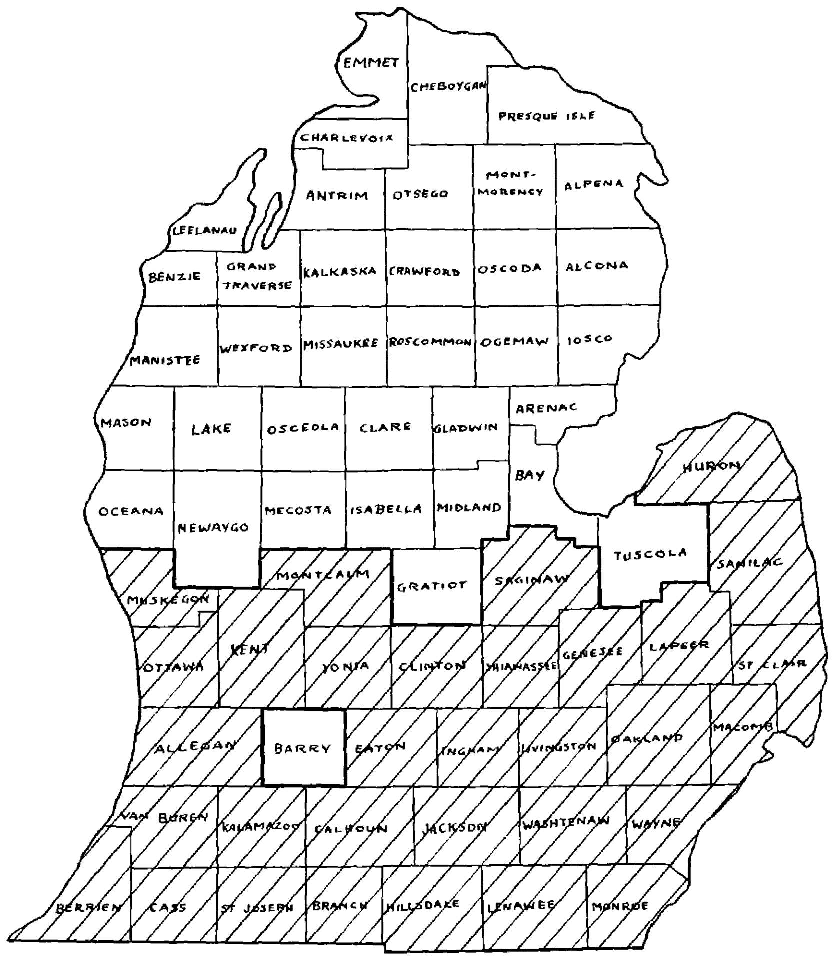
European workers found *Scolytus scolytus* (Fabricius) and *S. multistriatus* to be the major vectors of Dutch elm disease in Europe and Collins *et al.* (1936) have shown the same to be true of *S. multistriatus* in this country. The latter beetle had been reported by Chapman in Massachusetts in 1910 and from this paper and a later one (1911), it is evident that the insect had been introduced into the United States at a much earlier date, apparently on elm veneer logs from Europe. As far as is known to this date, although several interceptions have been made at ports of entry, the larger European elm bark beetle, *S. scolytus* (Fabr.), has never become established in the United States.

Irish (1930) and May (1930) reported the Dutch elm disease from Cleveland and Cincinnati, Ohio in 1930 and Beattie in New Jersey in 1933. Later in 1933, infested trees were found in New York and Connecticut. Gravatt and Fowler (1933) illustrated the probable means of entry of the disease into this country with their studies of emerging vector beetles from disease-infected logs imported from Europe.

Since 1930, the distribution of Ceratocystis ulmi (Buismann) Moreau has spread gradually from the centers in Ohio and New Jersey into Canada, New England, the Midwest and to an isolated area in Colorado. According to Holmes (1957), the Colorado infection area apparently has been eradicated for no new cases have been found. It is interesting to note in the Colorado area that the smaller European elm bark beetle itself is causing more actual tree mortality than is the fungus (Strong, 1957).

The first record of infection in Michigan occurred near the Belle Isle bridge in the city of Detroit in 1950. Since that date, diseased trees have been detected in all counties in Michigan south of Townline 10 except in Barry, Gratiot and Tuscola (Anonymous, 1957). The major centers of infection in the state appear to be in the southeastern part in the Greater Detroit area, the southwestern corner (Van Buren and Berrien counties) and in the Greater Grand Rapids area (see Map 1).

The distributional pattern of the smaller European elm bark beetle has changed accordingly as reported by Micha (1954) and Gentry (1954) and a more or less typical pattern has evolved in that generally, disease detection has followed initial beetle detection by about five years. The state of Wisconsin is a recent exception to this for



Map 1

Distribution of Dutch Elm Disease
in Michigan in 1957

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Beckwith (1953) made the first collection of S. multistriatus in Wisconsin in 1953 and the first positive Dutch elm diseased trees were reported by Chambers (1956) in 1956.

In Michigan, the first record of S. multistriatus was in Lenawee, Monroe, Washtenaw and Wayne counties in 1946 (Middleton, 1946) with this wide distribution indicating infestation at a much earlier date.
As mentioned above, the first record of the disease in Michigan was in 1950.

Since the initial detection in 1946 in the southeastern part of the state, the smaller European elm bark beetle has become distributed quite thoroughly over at least the southern half of the Lower Peninsula of Michigan. Its exact distribution in the State is not known at the present writing.

III. METHODS AND EQUIPMENT

A. Seasonal Development Studies

During the 1955 season, life history studies were made primarily in Ferndale (Oakland county) and Flint (Genessee county). Nine American elms, Ulmus americana L. were located in Ferndale and three of the same species in Flint. These trees were felled, field-infested and then cut into 12-inch lengths and placed in five-gallon, vented cans as shown in Figure 1. These were placed in semi-shaded areas out-of-doors to provide for development of the insects. Developmental progress was observed and recorded at two-day intervals on uncaged log specimens until larval galleries were well started. These larger logs, about three feet in length, were then placed in semi-shaded 30 gallon drums with fine bronze screen covers and then were observed at four-day intervals until the adults started to emerge. Emerging adults were removed at three to four day intervals until well past the emergence peak; at which time, removals were made at seven day intervals. Emerging adults were counted and recorded.

On August 2, 1955, one healthy, uninfested American elm 14 inches in diameter at breast height (D.B.H.) was felled and cut into four foot lengths and placed in partial shade near a woodlot on Michigan State University property near East Lansing (Ingham county). Within three days, boring dust as well as checks by bark removal indicated these

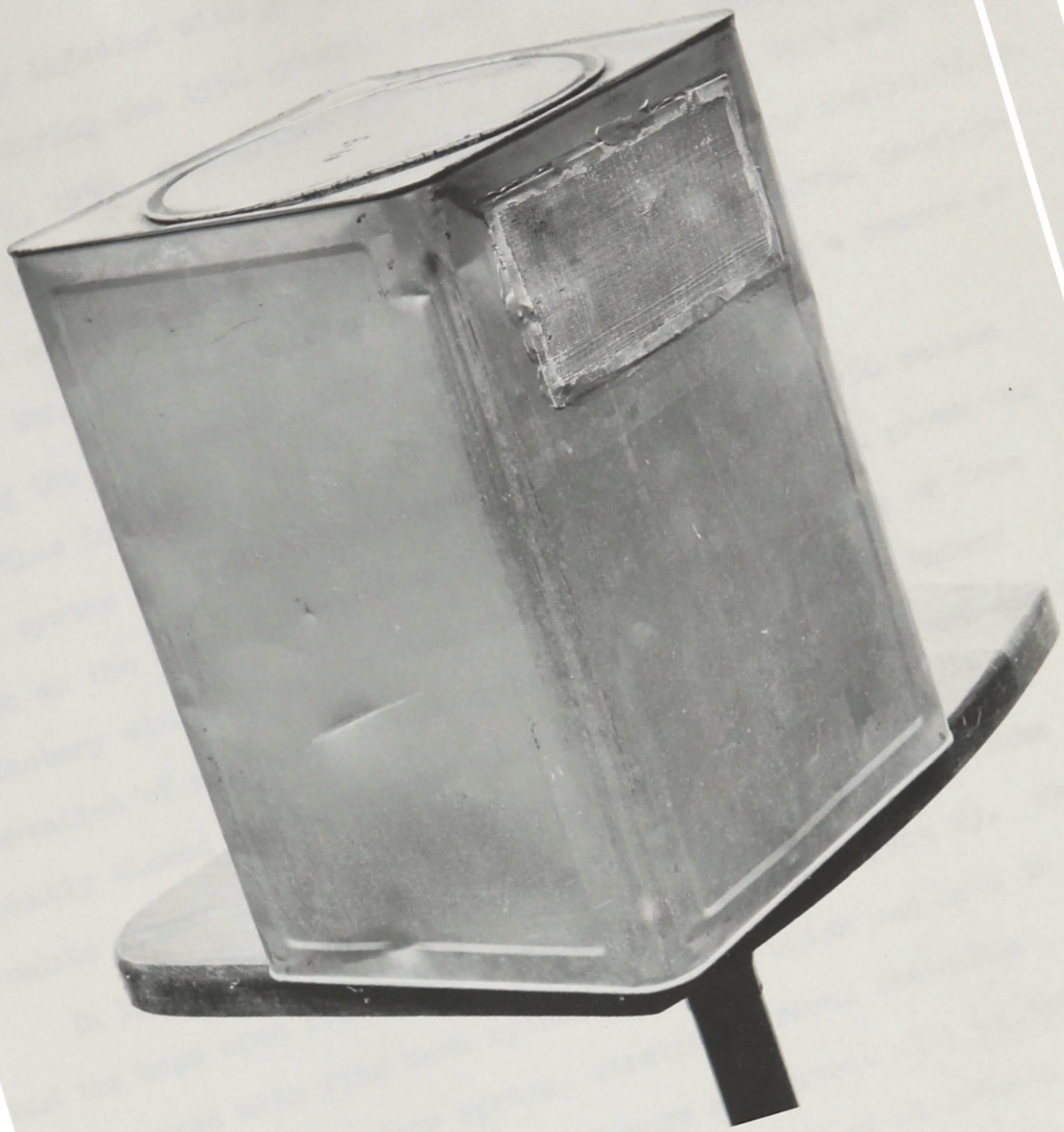


Figure 1

Five-gallon Vented Can Cage

logs to be heavily infested with *S. multistriatus*. This wood was then caged for study during the 1956 growing season.

On August 5, 1955, an American elm 12 inches D.B.H. which had blown over during a local windstorm near East Lansing on July 27, 1955 was also found to have been attacked by breeding adults after its destruction. Portions of this tree were also caged for observation of larval development during the late summer, fall and winter as well as for a source of adult beetles in 1956.

The system of cages was altered somewhat during the 1956 season inasmuch as the metal five-gallon cans used in 1955 did not prove too satisfactory either from the standpoint of ease of handling or from preservation of moisture in the enclosed wood. The latter factor evidently slowed the developmental processes of the larvae and did not simulate actual field conditions as closely as was desired.

In 1956, larger wood samples were caged in pasteboard drums that had the tops open for better air circulation (see Figure 2). The tops were covered with fine mesh nylon bobbinette which was held in place by coil-type screen door springs stretched around the drums. Smaller, wooden cages as shown in Figure 3 were also used. All of these cages were stored in partial shade on an open porch of an insectary where they were protected only to a small degree from rain and weather.

A specially-designed frameless tree cage patterned somewhat after that of Callaham and Miller (1952) as shown in Figures 4 and 5 was tested late in 1956 on standing trees and then used for development studies in 1957 along with 4' x 4' x 4' screen cages as shown in Figure 6.

Figure 2

Paste-board Drum with Open Top
20" x 30"

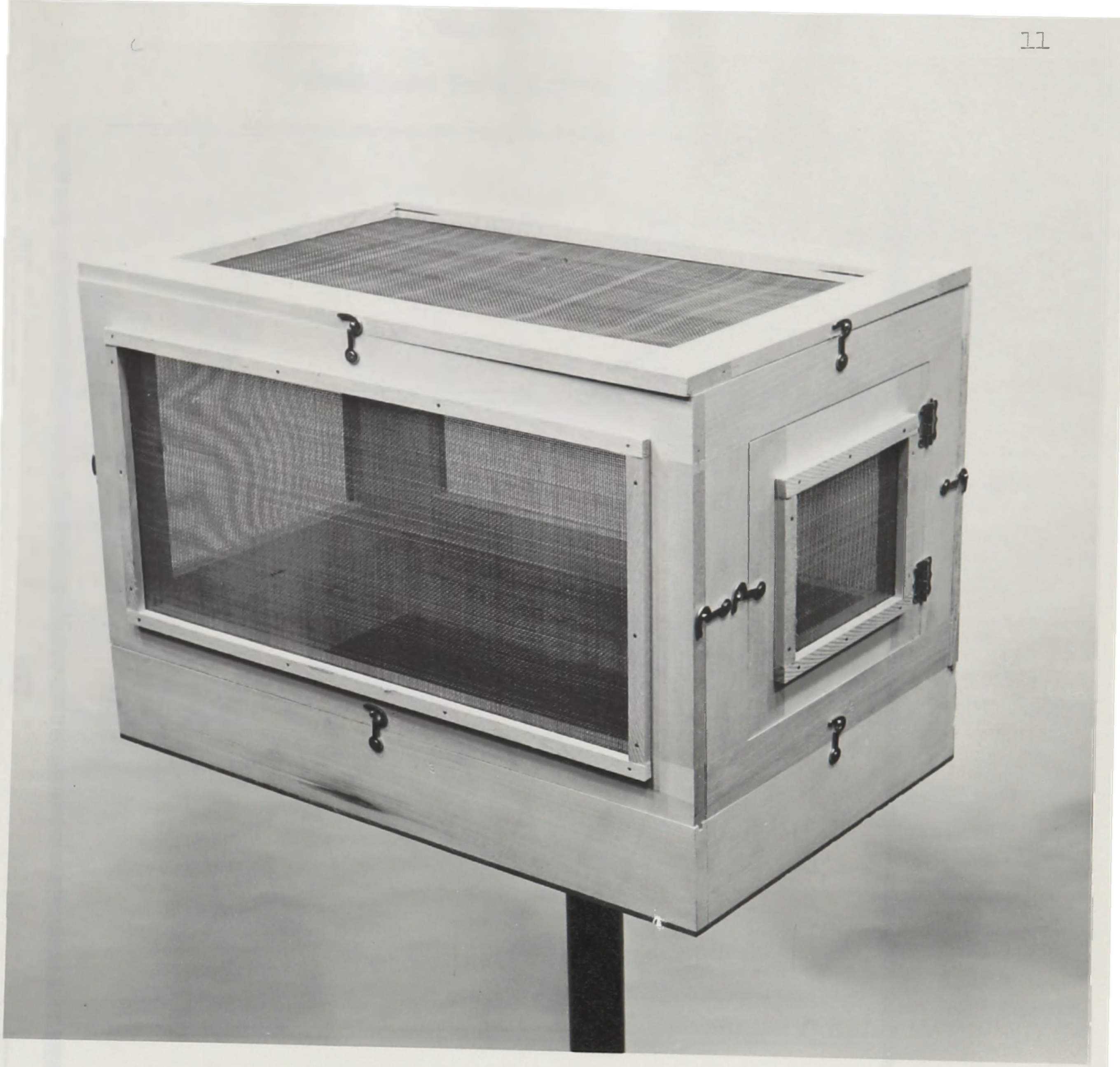
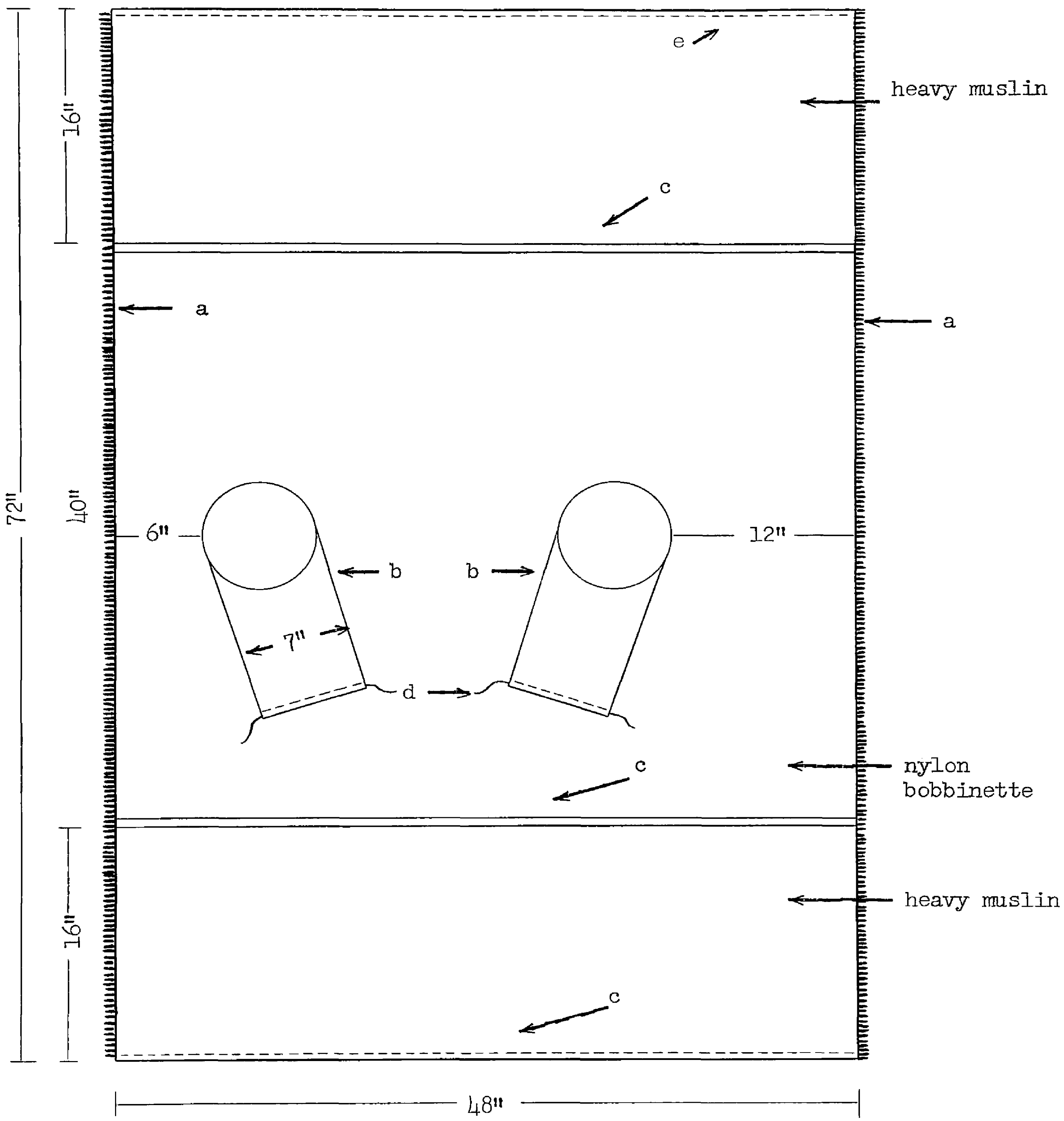


Figure 3

Wooden Cage
10" x 12" x 16"

Figure 4

Frameless Insect Tree Cage



a = 72" zipper half

b = muslin clean-out sleeve (variable length)

c = $1\frac{1}{2}$" muslin loop for wire insert

d = clean-out sleeve drawstring

e = $\frac{1}{2}$" hem

A B

Figure 5

Tree Cage in Place (A)

and Opened Up (B)

Figure 6

Screen Cages - 4' x 4' x 4'

The latter cages permitted entry of an observer and were used in part for observational data on development of immature stages of the study insect.

In using the tree cages, two 10-inch, forest-grown American elms were selected in a woodlot on University property. These trees had long, knot- and branch-free boles and were uninfested at the time of cutting on August 15, 1956. Four 10-foot sections were cut and placed like fence-posts in a partially-shaded area for field infestation. Other smaller logs were placed nearby but stacked on two-by-fours off the ground. All of these logs were allowed to remain uncaged over winter and early in the spring of 1957, the tree cages mentioned above were placed around a five to six foot portion of the stems and affixed in a previously-cut groove with number nine gauge wire so that there could be no escape of adult beetles. (see Figure 5A.) The bark exposed outside the cage was removed and destroyed.

On May 14, 1957, the large screen cages mentioned above were charged with infested wood, two logs across two-by-fours on the ground and three logs at right angles and laying on the previous two.

In both cases mentioned above, care was taken to orient the logs in the same direction with reference to the sun as they were when infested.

These cages were examined at four or five-day intervals from the time of positioning until early in August, 1957 after emergence of adult beetles was essentially completed. Larval and pupal development was observed and recorded and later, adult beetles were removed and counted and retained for use in sex ratio studies.

On May 20, 1957, four additional logs similar to those already in place as described above were set and allowed to remain uncaged for fourteen days at which time they were found to be heavily infested. These were caged with the above-described tree cages and as adults began to emerge in early July, these insects were removed and counted at about six day intervals. These adults were also retained for sex ratio studies.

During 1955 and the early part of 1956, adult beetles were captured from the cages with a manually-operated aspirator. This was found to be an unpleasant method due to the large amounts of dust and frass that entered the operator's mouth during the process. To circumvent this, a mechanical suction device was designed using an inexpensive vacuum brush operated by flashlight batteries. This gadget was originally designed for removing lint from clothing and can be purchased in any large department or hardware store. Refabrication is very simple and was accomplished as follows.

The bristles on the plastic head were removed and the plastic portion bearing the bristles cut away to allow unrestricted air flow. A number two plastic funnel cut to fit into the remaining opening was then solidly cemented into place. A piece of thin rubber tubing one and one-half by two and one-half inches long was stretched and fastened with rubber banding over the exhaust outlet of the vacuum brush or what was previously the lint trap. A collecting chamber was fashioned by removing the bottom from a one and one-half by three and one-half inch plastic vial. This was replaced by 30 mesh bronze screen which retained the smallest beetles but allowed most of the dust and frass to pass through. The free end of the rubber tubing could then be easily stretched over the collecting chamber, giving a "closed circuit" and also permitting easy removal of the chamber to empty its contents into a killing bottle. See Figure 7.

Although the adult beetles passed through the blower fan in the vacuum system, this caused little or no damage to them and inasmuch as these insects were used only for quantitative studies, this mechanism proved invaluable. Its size made possible removal of adults from all cages used in seasonal development studies in the mid and latter parts of 1956 and during the 1957 season and greatly facilitated this work. Quist (1957) has described a variation of this type of mechanism for collection of Eriophyid mites.

B. Determination of Seasonal Sex Ratios

Samples were taken from newly-emerged caged populations at various dates during the period of activity of the adult beetles. These collections, as seen in Table 2, extended from May 24, 1955 through September 25, 1957.

Chapman (1910) cites external morphologic differences in the males and females and Blackman (1934) in his revisional study lists the front of the head of the males as being flattened and covered with numerous fine, long, incurved yellow hairs while the females have a curved frontal area that is nearly devoid of hairs. Observation of adults in the field during gallery construction and copulation substantiated the ease of

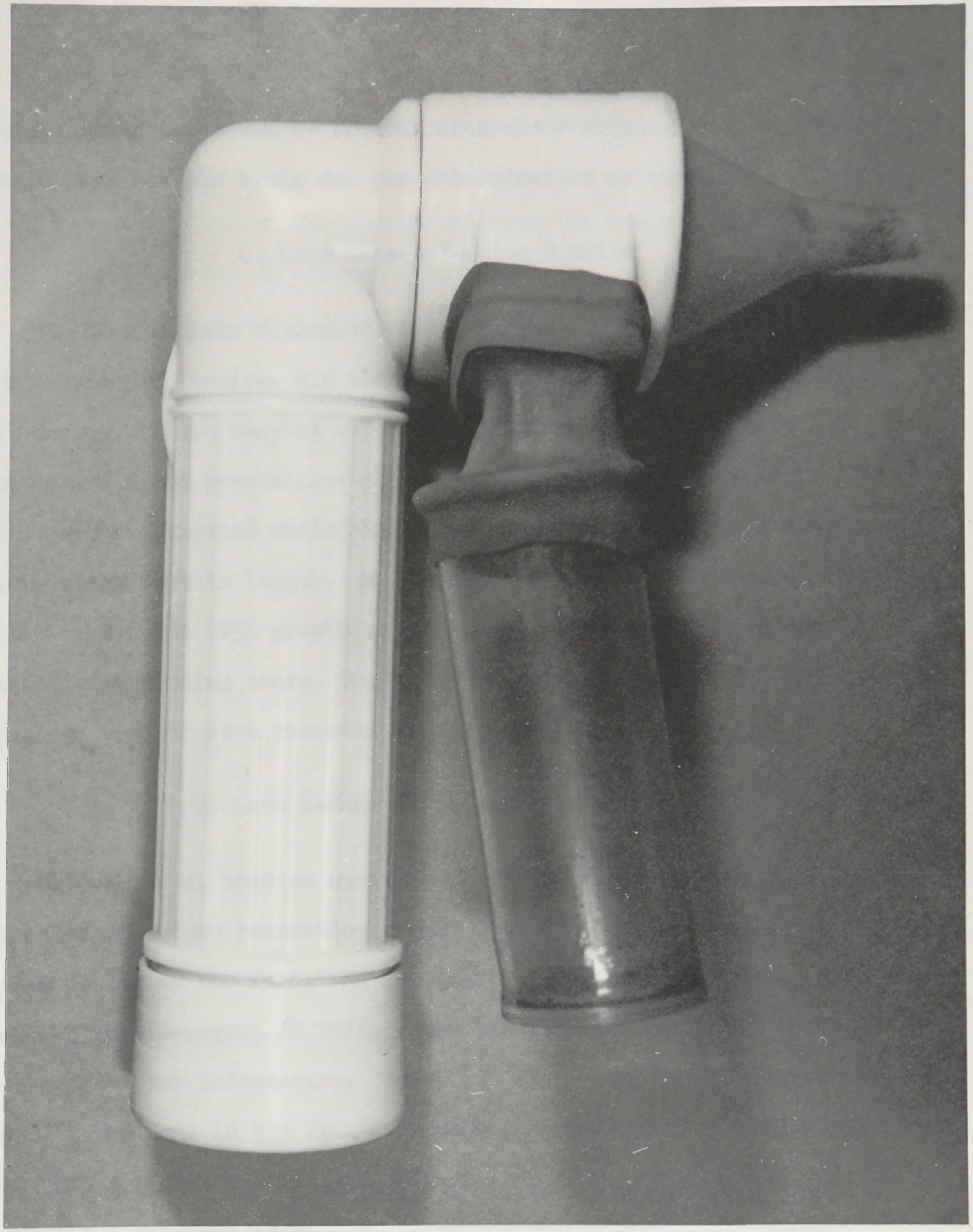


Figure 7

Vacuum Aspirator

distinguishing the sexes by frontal area observation. This morphologic feature then was the basis for sex determination as used in this study.

C. Late Season Feeding Studies

Starting in late September, 1956, samples of branches from the upper crowns of American elm trees were collected in Birmingham, Flint and Lansing. These samples were all collected outside of control project areas where field populations of _S. multistriatus_ were very high. The branches collected varied in length from two and one-half feet to nearly seven feet in length. No attempt was made to standardize these collections. The 1956 growth on each of these samples was carefully examined for feeding scars, the twigs measured to the nearest one-quarter inch, and results were recorded for each twig.

D. Late Season Brood Gallery Variation

Observational studies during the 1955 season indicated that brood galleries of second generation adults tended to be shorter as the weather became cooler in the fall. No qualitative studies were made in 1955 but starting in mid-August of 1956, freshly-cut, uninfested logs were placed in the field for infestation. Four logs of near-uniform size were placed just off the soil in the open at weekly intervals, two oriented east and west (one in partial shade and the other in full sun) and two oriented north and south (one in partial shade and the other in full sun). Each group of four logs remained in the open for six to eight days at which time a new fresh-cut group was put in the same place and the then-infested logs caged.

The procedure after all groups had been exposed was as follows:

1. The logs were autoclaved for 15 minutes and the bark removed.

2. Each log was cleaned to the wood.

3. Each brood gallery on each log was measured with dividers and the lengths recorded in millimeters.

4. The surface area of each log was measured in square inches and recorded.

5. The directional placement and sun exposure of each log was recorded.

E. Developmental Studies in Chipped Wood

On June 23, 1955, specimen material was collected from wood that was heavily infested with S. multistriatus (Marsh.). Larval galleries were established and adult females were also actively constructing brood galleries. This infested wood was run through an Asplundh 12-inch wood chipper and twelve containers of the resultant chips were recovered. The containers used were the ventilated-type can described in the seasonal history study methods above.

These cans were treated as follows:

Series 1. Four cans were placed upright on the ground at the bottom of the chip pile.

Series 2. Four cans were placed in the center of the pile and covered on all sides and oriented so that the cage would not collect precipitation.

Series 3. Four cans were left in the open on top of the chip pile in such a way that precipitation would not collect in the cage.

A similar can containing a twelve inch by four inch unchipped log sample cut from the same tree was placed with each group of four cans. This unchipped wood served as a check. These treatments were designed to simulate a chip sample at each of three layers in the chip pile.

This caged material was allowed to remain in the chip pile for 60 days when the cans were opened and the chips examined carefully for evidence of further beetle development.

A fourth series of studies introduced 25 two to three-day old, healthy adults into each of eight closed cages containing freshly-chipped elm wood. These cages were kept in a constant temperature room at about 75° Fahrenheit at a relative humidity of approximately 45 percent for 60 days at which time the cages were opened and examined as described above. Four pieces of unchipped elm wood were treated in a like manner to serve as a check of the procedure.

F. Phytotoxicity of a New Spray Formulation

In August, 1956 and July, 1957, phytotoxicity tests using the following spray formula were carried out:

DDT	32.4 percent by weight
Xylene	58.6 percent by weight
Acetone	6.8 percent by weight
Triton X-100	2.2 percent by weight

The first spray applications were made to open-grown trees on August 14, 15, 16, 1956. Both hydraulic and mist sprayers were used to test any possible difference in these two types of application. Dilution was made to approximately one percent DDT in the hydraulic sprayer and to six percent DDT in the mist blower. In all, 19 American elms varying in height from 30 to 90 feet were sprayed with application purposely being more thorough than that normally encountered in Dutch elm disease control work.

Further testing on the same trees with the same formulations and equipment was carried out on July 10 and 11, 1957, to spray these trees at an earlier date when the foliage was not as fully matured as in the 1956 tests.

G. Chemical Poisoning of Diseased Trees

On July 25, 1955, four American elm trees (showing positive disease symptoms and being actively attacked by breeding adults of *S. multistriatus*) were located in a remote part of the city of Ferndale. Using a 42.5 percent sodium arsenite solution (four pounds of arsenic trioxide per gallon at 60° Fahrenheit), these trees were treated as follows:

Tree 1 a diseased nine-inch D.B.H. American elm. A soil application using a 1:1 sodium arsenite-water mixture was applied in a one-foot deep trench dug three feet from the tree trunk around the entire tree. A total of two gallons of the mixture was used.

Tree 2 a diseased, eight-inch D.B.H. American elm. Full strength sodium arsenite was sprayed on the trunk which was frilled to a height of eight feet. The bark of this area was thoroughly drenched with spray.

Tree 3 a diseased six-inch D.B.H. American elm.
An eight-inch wide frill was cut in the bark three feet from the ground and then thoroughly drenched with full-strength sodium arsenite.

Tree 4 a diseased six-inch D.B.H. American elm.
A frill three feet wide was cut in the bark of the trunk and then thoroughly drenched with full-strength sodium arsenite.

Tree 5 a healthy six-inch D.B.H. American elm.
A three foot frill was cut in the bark and drenched with full-strength sodium arsenite. This tree was to serve as a check.

Weekly observations of these trees were made by removing bark areas where entrance holes were observed. Short period checks like this were made so that if beetle development was not deterred by the treatment, the trees could be destroyed before contaminated adult beetles emerged. These inspections were made until late September when the trees were felled for further analysis. At this time, samples from branches in the crown were collected for chemical analysis. At this time also, a healthy American elm, eight inches in diameter and growing in the same area, was felled and branch samples were similarly taken to serve as a basis for comparison of arsenic trioxide content. All of these samples were analyzed in the laboratories of the State Chemist in Lansing for arsenic trioxide content.

After felling, four four-foot log samples were taken from each tree from the trunks or larger branches and later examined in the laboratory for successful beetle galleries.

In late June, 1956, three additional diseased trees in Flint were treated similarly to Tree #2 in the 1955 experiments. These trees were

10, 14 and 15 inches D.B.H. respectively. Chemical analysis of the branches was not possible but weekly observations of the trees were made until early October when the trees were felled and four three-foot log samples were removed from the trunk of each tree and returned to the laboratory for examination as above.

H. Bioassay of Sprayed Trees

Modifying the techniques of Matthysse et al. (1954) and Whitten (1957), a method was devised to test the protection present on American elm trees that had been sprayed a given number of times according to current control recommendations. Several variations of treatment were studied as listed below:

1. Eight trees averaging 40 feet in height which had received one application of dormant-strength insecticide.

2. Eight trees averaging 50 feet in height which had received a dormant and a foliar application.

3. Eight trees averaging 40 feet in height which had received two dormant-strength applications.

4. Five trees averaging 70 feet in height which had received a dormant and a foliar application for two years.

5. Sixteen trees averaging 50 feet in height which had received a dormant and a foliar application for two years.

6. Four trees averaging 50 feet in height which had received a dormant and a foliar application for three years.

Adults of *S. multistriatus* were reared in 20 inch by 30 inch paper drums (see Figure 8) from field infested wood in a constant temperature room at about 75° Fahrenheit and 45 percent relative humidity. This was similar to the method described by Griswold (1948). As adults

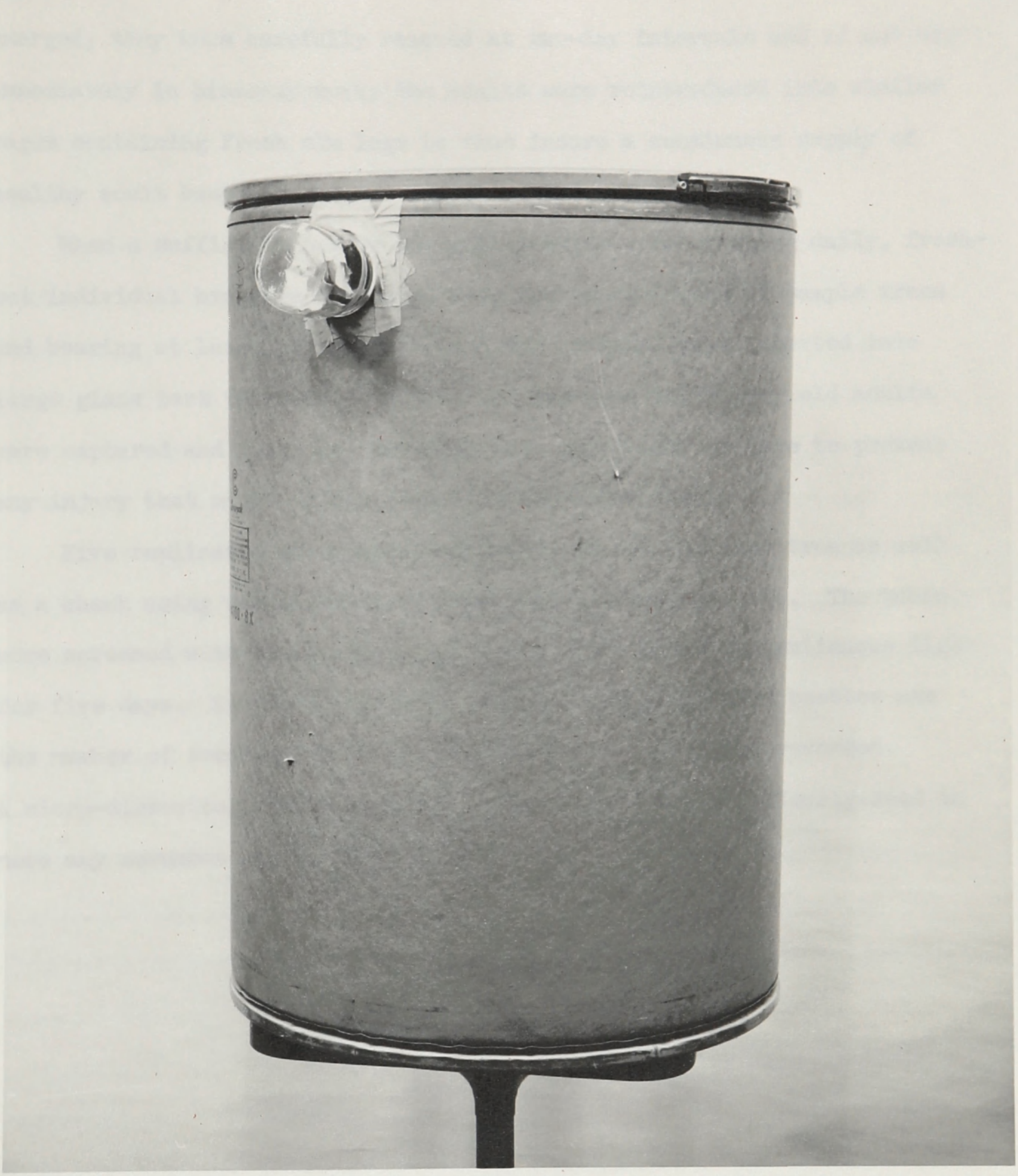


Figure 8

Rearing Drum - 20" x 30"

emerged, they were carefully removed at two-day intervals and if not used immediately in bioassay work, the adults were reintroduced into similar cages containing fresh elm logs to thus insure a continuous supply of healthy adult beetles.

When a sufficient number of adult beetles were emerging daily, fresh-cut individual branches collected from the center crown of sample trees and bearing at least 10 two-year or older crotches were inserted into large glass test tubes (50 x 400 mm.). Ten one- to two-day old adults were captured and inserted into each tube using extreme care to prevent any injury that might affect their feeding activities.

Five replicates of sprayed twigs were tested for each tree as well as a check using unsprayed twigs from trees of similar size. The tubes were screened with cloth (lawn) and allowed to remain in continuous light for five days. At the end of this period, living and dead beetles and the number of feeding scars on each twig were counted and recorded. A micro-dissecting needle was used to prod beetles not obviously dead to note any movement which would indicate life.

IV. PRESENTATION AND DISCUSSION OF DATA

A. Seasonal Cycle

Figure 9 shows the adult emergence patterns during the summer seasons of 1955-1957. In this figure, the numbers of emerging adults during 1955, 1956 and early 1957 have been accumulatively grouped to give composite 10 to 14 day values as shown in Table 1 and as plotted on the line graph. The numerical values for the latter part of the 1957 season are presented as recorded at approximate six-day intervals.

No attempt was made to record the immature stages of the subject insect quantitatively inasmuch as the primary objective was to determine seasonal adult cycles in order to improve direction of control operations. Observations of immature forms were made throughout this study to substantiate the patterns of the emerging adults.

As can be seen in Figure 9, there are two clearly defined peaks of adult emergence—one in late June and the other in late July to late August. Field observations of immature forms indicate these to be distinctly separate generations with the lag of peak emergence over the three different years obviously a result of weather conditions.

In 1955, as seen in Table 2A the advance of the climatic seasons was very early. The average temperatures compared with a monthly mean compiled from 1921-1950 are higher for all months in 1955 except November and December. Generally speaking, the weather warmed up in

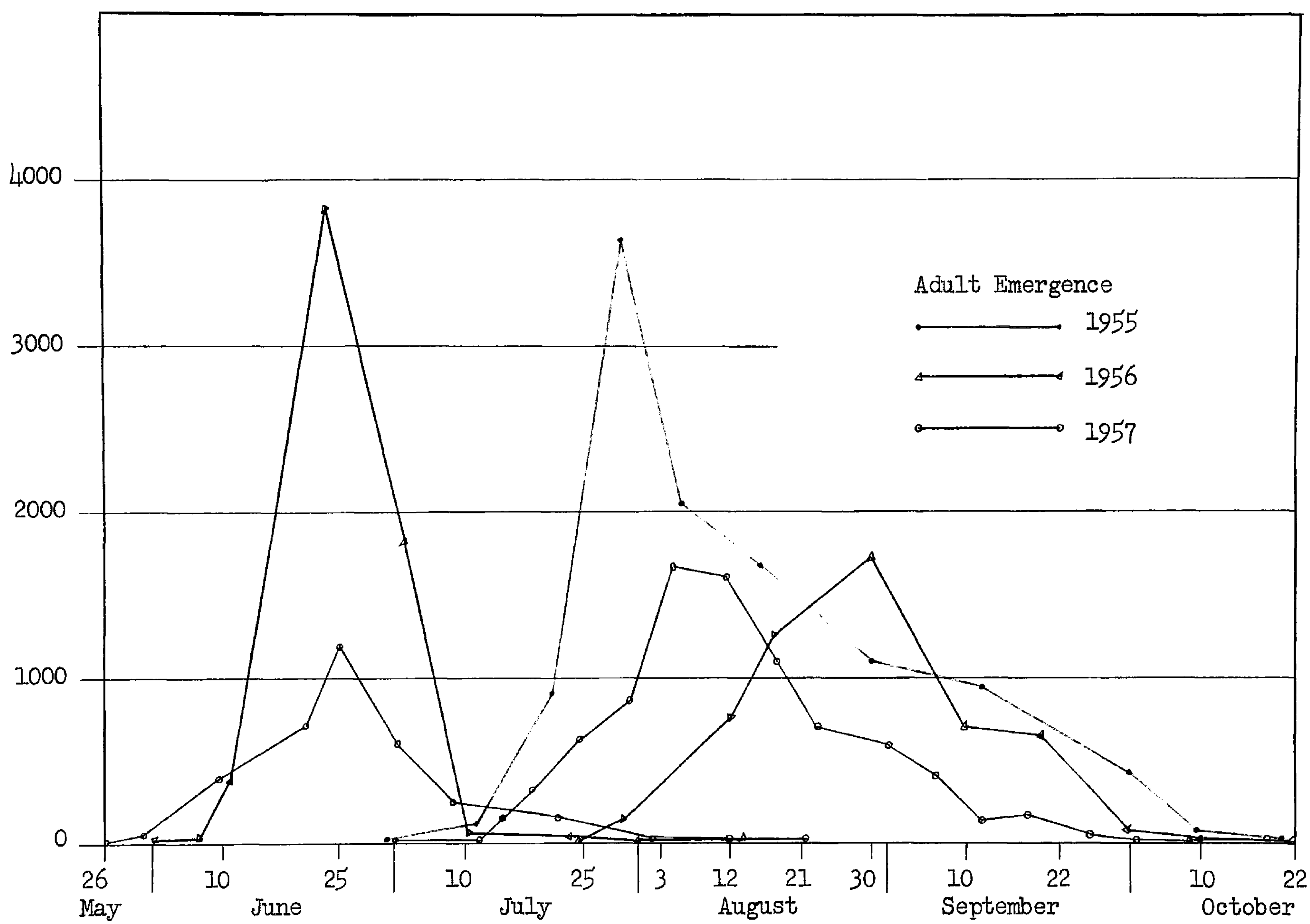


Figure 9

Pattern of Emergence of Adults of S. <u>multistriatus</u> (Marsh.) during 1955, 1956 and 1957

Table 1

Emergence Dates and Numbers of Adults of S. multistriatus

Emergence Date	1955 2nd Brood Adults	1956 1st Brood Adults	1956 2nd Brood Adults	1957 1st Brood Adults	1957 2nd Brood Adults
26 May				0	
31 May				44	
1 June		0			
6 June		7			
11 June		434		410	
19 June				750	
21 June		3825			
25 June				1200	
30 June	4				
1 July				590	0
2 July		1802			
10 July				240	0
12 July	92	68			
16 July					180
19 July					330
22 July	956				
23 July		30	0	130	
25 July					670
29 July	3640				
31 July					890
1 August		11	154		
2 August				4	
6 August					1670
8 August	2054				
12 August					1620
13 August		0	766	0	
18 August	1699				1080
20 August		0	1271	0	
24 August					710
30 August	1132		1746		
1 September					590
7 September					410
10 September			724		
13 September					140
14 September	439				
20 September			377		160
27 September					40
1 October	218				
2 October			90		
3 October					0
10 October	43		3		0
20 October	8		0		0

Table 2A

Monthly Average Temperatures for 1955, 1956, 1957
East Lansing, Michigan*

Year	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1955	24.6	26.6	34.3	54.5	61.0	67.7	77.8	75.4	63.9	54.6	35.3	25.7	50.1
1956	24.1	26.1	31.0	44.6	56.4	70.2	69.8	70.0	60.0	57.4	39.3	32.7	48.5
1957	20.1	29.1	36.0	48.9	57.0	69.0	72.8	69.8	61.6	49.6	39.4	32.4	48.8
Monthly mean	23.8	24.2	33.2	45.3	56.5	67.4	71.1	69.0	61.8	50.5	37.9	27.1	47.3

Table 2B

Monthly Total Precipitation for 1955, 1956, 1957
East Lansing, Michigan*

Year	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1955	1.47	1.89	2.97	1.56	2.53	3.81	3.99	4.08	1.29	3.06	3.78	0.78	30.21
1956	0.80	2.84	2.76	4.27	5.60	1.80	2.69	3.20	0.53	0.28	1.24	1.47	27.48
1957	1.98	1.38	2.08	3.72	5.17	2.88	7.55	1.29	1.08	3.73	2.75	2.80	36.41
Monthly mean	1.87	1.81	2.57	2.83	3.75	3.37	2.28	2.68	3.05	2.45	2.30	2.12	31.08

*Data from U. S. Weather Bureau, East Lansing station.

March and stayed above normal throughout the summer months. Likewise, except for July and August, the precipitation was below normal as seen in Table 2B.

The combination of these two meteorological factors resulted in a first record of adult emergence on May 20 in Ferndale (Gale, 1955). This also made possible the beginning of second brood adult emergence on about June 30, 1955 with the resultant peak emergence as seen in Figure 9 on about July 29. Under the most favorable conditions, a partial third generation could have been developed in 1955 for, accompanying the early spring, the temperatures remained above normal during September and October. However, no indications of this were evident in the field even though careful observations of immature forms were made during these months. That is, only larval forms were observed although Morofsky (1957) reports overwintering of this insect in the imago form. This latter condition has not been observed by the author in the three years that these studies were conducted.

Development in 1956 was a direct contrast to that in 1955. Whereas temperatures in the spring of 1955 were above normal, temperatures in March, April and May of 1956 were below normal with an above-normal amount of precipitation. The cold, rainy weather caused slow larval development in the spring and when, suddenly, in late May and June, warmer weather occurred briefly, development was very rapid and a very short emergence period of adults occurred. The peak of emergence was reached quickly and little "taper-off" occurred which is abnormal as compared to 1955 and 1957.

After first brood adult emergence, and during early larval activities, the weather again became unseasonably cold and rainy. Average temperatures in July as can be seen in Table 2A were nearly two degrees colder which naturally slowed larval development. Precipitation was above normal and again this combination of unusual weather slowed larval and pupal development and resulted in the much-delayed peak emergence of adults in the latter part of August. It can be noted here that a slow build-up to the August peak occurred with a following rapid reduction rather than the gradual reduction as indicated by the curves for second brood emergence for 1955 and 1957.

Weather conditions for 1957 were somewhat more normal than the two previous years although average temperatures were slightly above normal and during April and May, total precipitation was much greater. This latter factor is undoubtedly responsible for the large numbers of larvae that died in their galleries as a result of attack by an unidentified fungus. Emergence patterns in 1957 followed those of previous years quite closely although the peak emergence of second brood adults occurred slightly later than in 1955 but about 25 days earlier than in 1956.

The emergence patterns for Michigan populations of S. multistriatus agree in part with Finnegan's (1957) findings for the same insect in southwestern Ontario; in Michigan, developmental dates are somewhat earlier. Finnegan also states that there is one and a partial second generation in southwestern Ontario. In Michigan, the success of second generation brood gallery construction and larval development is high, giving rise to the vast majority of the next season's first brood adults.

It has been shown then that there are two complete generations of this insect in southern Michigan.

The ability of these insects to locate and infest suitable wood in which to establish brood galleries should be noted at this point. In August, 1956 while preparing logs for field infestation, freshly-cut, insect-free logs were readied at 3:00 P.M. in the afternoon and were inspected between 9:30 and 10:00 A.M. on the following morning. At the time of inspection, these logs were literally swarming with beetles of both sexes and hundreds of females had already burrowed through the outer bark and had begun constructing their egg galleries. This demonstrates the need for prompt destruction of elm wood during the summer months!

B. Determination of Seasonal Sex Ratios

The present investigation was conducted to determine whether sex ratios of adults of the smaller European elm bark beetle varied significantly during any part of the total emergence period. Inasmuch as field evidence has shown this to be a monogamic species, the ratio of males to females should be approximately equal. Prior to this study, such information was not available for Michigan populations but if a variation were present, it should be considered an important factor in the reproductive potential of the insect at different times of the season or for different broods.

Table 3 shows 1) the sex determination values for 13,226 adult beetles of *S. multistriatus*, and 2) the sex ratio and the chi-square values as determined using the method outlined by Snedecor (1957).

Some authors define the term "sex ratio" as the number of males divided by the number of females. However, in this study, the term "sex ratio" represents the proportion of females to the total population although Graham (1952) contends that this usage is confusing.

It can be seen in Table 3 that the sex ratio of adult females varied from a low of 0.44 on July 13 to a high of 0.57 on September 21 with a total sex ratio of 0.502. It should be noted also that for the three dates (24 May, 30 July and 25 September) on which large numbers of adults were collected, the sex ratios are 0.51, 0.50, and 0.49 respectively. This is highly indicative of an even production of males and females in the over-all population.

Examination of this table shows no indication of a trend away from a 0.50 sex ratio. There are of course collections which appear to vary significantly from an even sex ratio but these are usually a result of small samples and in each case, the next sample returns to or near a 0.50 sex ratio following the laws of chance. This can be seen for the collection data on July 13 when the sex ratio dipped to 0.44 while for the collections of July 20 and July 30, the sex ratio values were 0.48 and 0.50 respectively. Each of the latter two total collection numbers were larger and should be expected to give a more representative sample.

Likewise, to compare data for collections that appear to be moving toward a larger percentage of females, on September 14, a sex ratio of 0.50 was obtained from collected adults and on the next two dates, September 18 and September 21, a larger number of females was obtained giving a sex ratio of 0.54 and 0.57 respectively. The latter values

Table 3

Sex Ratio Values for Adults of S. multistriatus (Marsh.) and Chi-Square Test

Date	Locality	Number of Males	Number of Females	Total	Sex Ratio	Chi-Square
24 May 1955	Ferndale	2320	2390	4710	0.51	1.04
12 June 1957	E. Lansing	31	36	67	0.54	0.37
16 June 1955	Flint	138	138	276	0.50	0.00
18 June 1957	E. Lansing	39	39	78	0.50	0.00
1 July 1957	E. Lansing	131	129	260	0.50	0.02
5 July 1957	E. Lansing	41	37	78	0.47	0.20
9 July 1957	E. Lansing	75	90	165	0.54	1.36
13 July 1957	E. Lansing	61	48	109	0.44	1.55
20 July 1955	Flint	187	176	363	0.48	0.33
30 July 1955	Ferndale	1249	1259	2508	0.50	0.03
10 Aug. 1956	Ferndale	411	360	771	0.47	3.37
17 Aug. 1956	Flint	237	235	472	0.50	0.00
27 Aug. 1956	E. Lansing	221	200	421	0.48	1.04
30 Aug. 1956	E. Lansing	20	17	37	0.46	0.24
5 Sept. 1956	Flint	58	71	129	0.55	1.31
14 Sept. 1957	E. Lansing	63	62	125	0.50	0.00
18 Sept. 1956	Flint	128	149	277	0.54	1.59
21 Sept. 1957	E. Lansing	54	71	125	0.57	2.31
25 Sept. 1957	E. Lansing	1153	1102	2255	0.49	1.15
Totals		6587	6639	13,226		15.91

Total sex ratio = 0.502

Total Chi-square (x) = 15.91

Chi-square for total (y) = 0.20

Chi-square for heterogeneity = (x - y) = 15.71

were from smaller samples but apparently indicate a higher proportion of females. On the following date, September 25, a large sample of 2255 adults returns the sex ratio to a value of 0.49.

These ocular comparisons do not present as convincing a picture as do the values for the computed chi-squares as seen also in Table 3. At no point does a chi-square value occur which is significant at the 5% level.

The most positive analysis here comes from consideration of the total chi-square and the chi-square for the total. The difference in these values or chi-square for heterogeneity shows a remainder of 15.71 with 18 degrees of freedom. This is not significant at the 5% level of heterogeneity. Therefore, the data in Table 3 can be considered to be homogeneous throughout and there is no evidence to indicate that there is any difference in sex ratios at any time during the seasons of adult emergence.

C. Late Season Feeding Studies

The more recent control recommendations of the United States Department of Agriculture (Whitten, 1957) which call for a dormant application of DDT once-a-year rather than the dormant plus foliar recommendation of previous years (Anonymous, 1953) suggested this study.

Although Banfield (1941) has pointed out that the incidence of late season inoculations is less than those found earlier due to a change in the length and location of long vessels in the wood and Collins (1938) has studied the feeding habits of the beetle, little mention is made as to whether or not any feeding by adult beetles on present season's new growth occurs. Such feeding, if abundant, would be of great importance in considering a single dormant spray application inasmuch as all new growth would be unprotected from the feeding of second brood adults.

As previously stated, collections were made late in the season of 1956 with the aim of obtaining an over-all picture of late season feeding. At the time, it was decided that if abundant feeding scars were noted on new growth, collections during the following season could be made to determine at what time during the season this feeding occurred most frequently. The results of this study as can be seen in Table 4, show that on 7322 twigs collected in three cities from 50-90 miles apart, only two feeding scars were detected. This was considered to be evidence that feeding by adults is very selective, and for this reason, more detailed investigations were abandoned.

D. Late Season Brood Gallery Variation

Tables 5A, 5B and 5C show the results of the studies of late season brood gallery variation. It should be noted here that although fresh logs were exposed for infestation after September 12 as previously outlined, no infestation occurred on these logs so they were not included in the tables.

Table 5A shows the analysis of variance. As indicated by the f value of 9.56, there exists at the 1% level a highly significant difference in these data and Duncan's (1957) multiple range test has shown the position of this difference. That is, the mean gallery length for logs attacked

Table 4

Frequency of Feeding By Second Generation Adult Beetles of *S. multistriatus* on New Growth Twigs

Location of Sample	Number of Twigs of New Growth	Total Length of New Growth (in Inches)	Average Length of New Growth (in Inches)	Number of Feeding Scars	Remarks
Lansing	648	1876.50	2.90	0	
Lansing	720	696.50	0.97	0	
Lansing	187	437.75	2.34	0	
Lansing	243	681.75	2.81	0	
Lansing	94	135.25	1.44	0	
Lansing	149	247.50	1.66	0	
Lansing	154	242.75	1.58	0	
Lansing	204	515.25	2.53	0	
Birmingham	133	263.25	1.98	1	On a twig 1.25 In. long
Birmingham	174	540.25	3.10	0	
Birmingham	381	1008.50	2.65	0	
Birmingham	546	829.50	1.52	0	
Birmingham	350	1375.50	3.93	0	
Birmingham	495	729.50	1.47	0	
Birmingham	432	673.75	1.56	0	
Birmingham	380	475.00	1.25	0	
Flint	169	399.75	2.36	0	Six scars in axils of new and old growth
Flint	63	120.50	1.91	0	
Flint	327	597.00	1.82	0	
Flint	328	631.75	1.93	0	
Flint	122	116.00	0.95	0	
Flint	150	244.75	1.63	0	
Flint	239	966.75	4.04	1	On a twig 4.00 inches long
Flint	196	228.75	1.17	0	
Totals	7322	14,033.75	1.92	2	

Table 5A

Total Gallery Length and Analysis of Variance

Date	Total Gallery Length (mm.) (X)	Number of Galleries (n)	Mean Length (mm.)
22 August	2353	110	21.4
29 August	605	34	17.8
6 September	437	26	16.8
12 September	1053	66	16.0
	Variance	Degrees Freedom	f
Between Groups	282	3	9.56**
Within Groups	29.5	242	

**Significant at the 1% level.

Table 5B

Total Gallery Length by Direction and Sun Exposure

Direction	Sun Exposure	Total Gallery Length (mm.)
N-S	Full Sun	1936
N-S	Partial Shade	1916
E-W	Full Sun	513
E-W	Partial Shade	76

Table 5C

Greatest Single Log Infestation per Date

Date	Log Number	Direction	Sun Exposure	Number of Galleries	Total Length (mm.)
22 August	3	N-S	Full Sun	44	903
29 August	2	N-S	Partial Shade	16	263
6 September	2	N-S	Partial Shade	14	236
12 September	2	N-S	Partial Shade	65	1038

between August 22 and August 29 is significantly different from the other three dates and not one of the latter three is significantly different from each of the other two when considering the data at hand. This is not to say that a difference might not occur with a larger sample but it cannot be shown with these data.

It appears from these data that, as cooler temperatures occur in the fall, the energies of the females wane and egg gallery construction is thus curtailed. This means that if these late season eggs hatch and the resultant larvae survive the winter, their numbers will be many fewer per egg gallery than those resulting from earlier formed egg galleries.

The data in Table 5B and 5C make it appear that logs with the long axis oriented in a north-south direction are preferred as brood logs to those oriented in an east-west direction. From these data also, there is an indication contrary to the belief of many investigators that logs lying in partial shade are more desirable as brood logs than are those in full sun. While these data are merely an indication, at no time during these studies did the author experience difficulty in having logs heavily field-infested while lying in full sun.

E. Developmental Studies in Chipped Wood

Destruction of diseased wood by use of a mechanical wood chipper has been a highly controversial subject in Michigan in recent years, particularly in cases where branch material was beetle-infested at the time of cutting. Some field workers as well as researchers have advocated burning all chips to prevent possible beetle development or attack while others have maintained that beetle development would neither be initiated nor continued in chips due to the changed condition of the host medium. This latter viewpoint has had many supporters but no experimental data has been available to either support or discredit either side of the controversy.

The importance of this is basic to the field worker. That is to say if larvae of S. multistriatus in any numbers could complete their development in chipped wood, whether they were there at the time of, or subsequent to, chipping, many additional expensive man-hours would have to be devoted to a sanitation program in a community. If the larvae could not survive in chips, expenditures could be reduced if a chip destruction program were being conducted.

Table 6 presents the results of this study. In Series 4, the number of adults represent those introduced into the test cans. In four of the eight cans, although 25 adults were introduced, all were not recovered even though the contents of the cans were carefully examined.

As explained earlier, these series of chip-filled cans were buried at different levels in a pile of chips as it was formed in a more or less normal field operation. As can be seen from Table 6, in no case in either Series 1, 2 or 3 did any adults emerge from chipped materials although in Can Number 1 in Series 2 (these cans were in the middle of the pile), two adults were found but no evidence could be found in any of the chips to indicate that these had completed their development and

Table 6

Observations On Beetle Development In Mechanically Chipped Wood

Series Number	Can Number	Number of Adults	Evidence of Beetle Development	Notes
1	1-1	none	none	Chips heavily molded
	1-2	none	none	Chips heavily molded
	1-3	none	none	Chips heavily molded
	1-4	none	none	Chips heavily molded
	Check	none	none	Logs heavily molded
2	2-1	2 dead	none	Adults heavily covered with fungus; wood chips slightly molded
	2-2	none	none	Chips covered with mold
	2-3	none	none	Chips covered with mold
	2-4	none	none	Chips slightly molded
	Check	59 dead	slight	Adults covered with mold; many larvae in galleries molded and dead; logs heavily molded
3	3-1	none	none	Chips very dry
	3-2	none	none	Chips very dry
	3-3	none	none	Chips very dry
	3-4	none	none	Chips very dry
	Check	87 living 259 dead	normal	Apparently normal development
4	1	25 dead	none	Chips dry; bark mostly tight
	2	24 dead	none	Chips dry; bark mostly tight
	3	25 dead	none	Chips dry; bark mostly tight
	4	25 dead	none	Chips dry; bark mostly tight
	5	21 dead	none	Chips dry; bark mostly tight
	6	23 dead	none	Chips dry; bark mostly tight
	7	25 dead	none	Chips dry; bark mostly tight
	8	24 dead	none	Chips dry; bark mostly tight
	Check 1	489 dead	normal	Development normal
	Check 2	607 dead 38 living	normal	Development normal
	Check 3	236 dead	normal	Development normal
	Check 4	421 dead	normal	Development normal

emerged. These undoubtedly were adults that escaped crushing during the chipping operation.

These series of cages can be summarized as follows:

1. Series 1 - Moisture conditions at the bottom of the chip pile plus heat generated was too great for beetle survival. These conditions fostered an extensive growth of fungi which contributed to the unfavorable conditions for beetle development as can be seen from the check log within which no beetle development took place.
2. Series 2 - A situation somewhat less intense than in Series 1 but still unfavorable for beetle survival in the chipped wood. Some development was discernible in the check log but none in the chipped wood.
3. Series 3 - The check log apparently retained sufficient moisture for larval development although this development was obviously retarded due to the few living beetles remaining in this can after 60 days. The cans containing the chips dried out very rapidly and thus any larvae that survived the chipping operation died of desiccation.

In Series 4, which were laboratory tested, much the same situation existed. In these cans, no evidence could be found of brood gallery construction. The introduced beetles apparently died without attempting to construct brood galleries in an unsuitable location although those adults introduced into the cans used as checks reproduced and developed normally as far as could be ascertained.

F. Phytotoxicity of a New Insecticide Formulation

Present recommendations of the Central States Forest Experiment Station (Whitten, 1956) for the control of the bark beetle carriers of the Dutch elm disease call for the use of the following formula:

DDT	-	32.4 percent by weight
Xylene	-	58.6 percent by weight
Acetone	-	6.8 percent by weight
Triton X-100	-	2.2 percent by weight

This formulation is designed and recommended for dormant use with the DDT diluted to 12 percent. The acetone component makes the formulation more desirable because application can be made at lower temperatures than with the formerly recommended formulation containing white oil in place of the acetone. In the Central States recommendation, no mention is made of the use of the above formulation as a foliar spray.

In Michigan, most agencies practicing Dutch elm disease control are following a two-spray (one dormant and one foliar) treatment using a 25 percent DDT-white oil formulation. In some areas in which control measures have been applied for three or four years, it is likely that these areas would want to employ a single dormant spray on some trees and a two-spray treatment on others. In order to reduce purchasing costs, it is also not unlikely that purchasing agents would want to buy only one formulation. Considering this, if the above formulation is chosen for its obvious dormant advantages and then used as a foliar spray regardless of its disadvantages, no data involving phytotoxicity is available.

In Table 7, phytotoxic effects of spraying elm trees with this formulation are shown. When interpreting this table, it should be noted that phytotoxic effects are given for both 1956 and 1957. These are results of August spraying in 1956 and of early July spraying in 1957. Descriptions of injury were interpreted as follows:

Slight Injury - infrequent leaves with burned margins; not evident at a distance of 50 feet.

Noticeable Injury - less than 25 percent of leaves with little green tissue remaining--others in injured areas as above; evident at more than 50 feet; minor dropping of leaves.

The tested formulation caused essentially no injury to trees 50 feet and larger in height. Some evidence of injury is listed in Table 7, especially to leaves on lower limbs that were generously oversprayed. This injury probably would not have occurred if the trees had been sprayed in a normal field manner.

Evidence of injury was found on trees smaller than 50 feet in height but again not to a serious degree although these trees were also oversprayed.

Since the advent of this formulation and its use in certain cities in Michigan and other states, it has been found impractical for use in

Table 7

Phytotoxicity of a New Insecticide Formulation

Type of Sprayer	Tree Number	Size (in feet)	Evidence of Phytotoxicity 1956	1957
	1	80	no evident injury	slight injury to lower leaves
	2	80	no evident injury	slight injury to lower leaves
	3	70	no evident injury	slight injury on on low branch
	4	35	no evident injury	slight injury to lower leaves
Hydraulic	5	35	no evident injury	no evident injury
Sprayer	6	40	no evident injury	no evident injury
	7	30	slight injury in lower half	slight injury on low leaves
	8	30	slight injury in lower half	slight injury on low leaves
	9	50	no evident injury	no evident injury
	10	50	no evident injury	slight injury on lower leaves
	1	90	no evident injury	no evident injury
	2	90	no evident injury	no evident injury
	3	60	slight injury to lowest leaves	
	4	50	no evident injury	slight injury to lower leaves
Mist	5	50	no evident injury	slight injury to lower leaves
Blower	6	30	slight injury to lower leaves	noticeable injury to lower leaves
	7	30	no evident injury	slight injury to lower leaves
	8	70	no evident injury	no evident injury
	9	70	no evident injury	no evident injury

residential areas because of damage to automobile finishes and house paint. When the insecticide dries, it cannot be washed off or removed from a painted surface without resorting to the use of a paint thinner. For this reason, it is used now only in park and recreational areas where this problem is not encountered. In these areas too, if this formulation were used at foliar strength, any possible phytotoxic effects would not be as important as in a residential area where injury is quickly noticed and emphasized by those opposing the use of insecticidal control of the bark beetle carriers of the Dutch elm disease.

G. Chemical Poisoning of Diseased Trees

Located within the known distribution area of the Dutch elm disease in Michigan are many state and privately-owned game project areas, recreation areas and state parks. The problem of removal of diseased trees to comply with Michigan State Department of Agriculture Regulation Number 613 imposes an extreme hardship upon the supervisors of these areas inasmuch as this work usually needs to be accomplished at the peak of the use period when workers in these areas are already overburdened with maintenance work. For this reason, state park and game project area supervisors have been unable to comply with the letter of the law in many cases. These men in turn have made suggestions for developing a technique that could be applied to diseased trees to make them unsuitable as a breeding medium for the bark beetle vectors of the disease.
If such a technique were devised, tree removal and destruction could be

accomplished during slack seasons in the above-mentioned areas as well as in farm woodlots.

Sodium arsenite was chosen as the test chemical because it is recognized as one which kills trees quickly and results in early loosening of bark--an obvious quality necessary to obtain the result desired. In addition, because of limited chemical testing facilities, only one chemical could be used.

The results of this study are shown in Tables 8 and 9. In Table 8, Trees 3, 4, 5 and the check tree were not sampled as thoroughly as Trees 1 and 2 because of lack of analytical facilities.

The data in Table 8 appear to be rather inconclusive. Tree #1 shows no appreciable arsenic trioxide at any point while Tree #2 appears to have translocated large amounts of this chemical in all tissues. Trees 3 and 4 although sampled only in the upper crown indicate that a certain movement of the chemical has taken place. The presence of a much lower amount of chemical in the treated healthy tree (Tree 5) as compared with Tree 2 is unusual also. It should be pointed out here that with the exception of Tree 1 which received a soil treatment, all other trees varied in only two ways essentially--first, the unknown length of time that they had been diseased and secondly, the width of the bark frill. Regarding the first point, these trees were treated within seven days of field detection of disease within them. Undoubtedly, this had a great bearing upon the amount of arsenic trioxide translocated due to variance in the degree of vascular clogging in the stems.

Table 8

Arsenic Trioxide Content In Branches Of Chemically-Treated Dutch Elm Diseased Trees

Tree Number	Sample Area and Arsenic Trioxide Content (p.p.m.)								
	Lower Crown Twigs	Lower Crown Branch Bark	Lower Crown Branch Wood	Mid-Crown Twigs	Mid-Crown Branch Bark	Mid-Crown Branch Wood	Upper Crown Twigs	Upper Crown Branch Bark	Upper Crown Branch Wood
1	6.4	29.9	10.0	7.2	5.6	4.2	1.2	9.6	2.0
2	150.0	164.0	135.0	285.0	275.0	85.0	290.0	400.0	145.0
3							4.0	3.6	2.0
4							2.4	3.2	4.0
Check 5							60.0	65.0	14.0
Check 6							0	Trace	0

Table 9

Beetle Development in Chemically-Poisoned Trees

Tree Number	Location	Log Sample Number	Total Number of Beetle Galleries	Number of Completed Brood Galleries	Number of Completed Larval Galleries
1	Ferndale	1	128	0	0
		2	73	0	0
		3	81	0	0
		4	57	0	0
2	Ferndale	1	93	0	0
		2	69	0	0
		3	58	0	0
		4	27	0	0
3	Ferndale	1	103	0	0
		2	88	0	0
		3	70	0	0
		4	68	0	0
4	Ferndale	1	72	0	0
		2	40	0	0
		3	34	0	0
		4	21	0	0
5	Ferndale	1	82	0	0
		2	67	0	0
		3	33	0	0
		4	14	0	0
6	Flint	1	90	0	0
		2	61	0	0
		3	70	0	0
		4	13	0	0
7	Flint	1	117	0	0
		2	109	0	0
		3	84	0	0
		4	56	0	0
8	Flint	1	132	0	0
		2	120	0	0
		3	101	0	0
		4	75	0	0
	Totals		2306	0	0

The second difference, width of bark frill, appears also to play an important part in intake of chemical inasmuch as Tree 2 was frilled to a height of eight feet and the entire area was treated with chemical whereas in all other test trees, frilling was much less extensive. As seen in Table 8, this latter tree contained the greatest amount of arsenic trioxide.

Regardless of the type of treatment, however, the most striking feature of this study is the complete lack of larval development in the treated trees. It can be seen here that each tree was attacked by female beetles but not a single brood gallery was completed nor did any of the eggs that were laid hatch. By contrast, trees less than 20 feet away which had not been chemically treated were heavily infested with normally developing larvae.

This study presents a most unusual test result--one which the author wishes neither to support nor to refute. The test certainly suggests the value of further study.

H. Bioassay of Sprayed Trees

Field workers in Michigan and in other states have no yardstick by which to evaluate their efforts in controlling the bark beetle vectors of the Dutch elm disease other than to spray their trees "thoroughly" and hope for the best. The purpose of this facet of this over-all study was designed neither to dictate to the field man how long he should spray his trees nor how many gallons of spray he should apply to a tree of a given size for adequate control. It was designed, however, to determine from bio-analysis of regularly-sprayed trees whether control operations up to that date had been properly carried out or if a more thorough spray application should be necessary.

Whitten (1945) as early as 1945 pointed out the effectiveness of DDT in preventing the feeding of *S. multistriatus*. This work has later been enlarged upon by Whitten and also Matthysse *et al*. (1954) until at the present time, this insecticide in an emulsion formulation is almost universally used in Dutch elm disease control work. This is true of Dutch elm disease control projects in Michigan communities.

In most cases, in Michigan, two applications, a dormant and a foliar spray, are recommended mainly because bark beetle populations are very high in most areas. The expense of the foliar spray is considered justifiable in terms of over-all population reduction as well as contributing to the residual build-up of DDT. However, as stated before, field supervisors have no way of knowing whether or not their spray crews are operating efficiently.

As shown in Table 10, a great variation in mortality occurred in nearly all samples. For example in Group I, the total of living beetles varied from 10 to 40 and in Group V, the range was from zero to 20. This theoretically should not be the case since each tree in each test group was essentially similar to the others, both in aspect and height. However, the human factor is without a doubt the answer to this variation inasmuch as rarely if ever will a spray operator spray even the same tree the same way twice in succession. This, though not the essence of the data in Table 10, is an important factor to keep in mind.

Consideration of the mean value in each group indicates that a significant difference in these treatments should be present and as indicated in Table 11, the f value at the 1% level is highly significant. By using Duncan's multiple range tests, the location of the significant differences in these treatments can be shown.

As seen then in Table 12, Group V differs from all other groups except Group IV. This should be interpreted to mean that although the arithmetic means of Group IV and Group V differ (12.0 and 7.8 respectively) and the average heights of the trees differ (over 70 feet and 50 feet respectively), the results of the treatments do not present a significant difference. It should be noted here that the trees in both groups were sprayed with a mist blower which is considered to give better spray coverage on larger trees and although no data are present to verify it, the trees in Group IV represent magnificent specimen trees on the Michigan State University campus. These are sprayed very thoroughly each year, which probably accounts for their better comparative showing.

Likewise, Group IV differs from Group III, Group II and Group I but not from Group VI. This is to be expected in the first part inasmuch as the trees in Group IV were sprayed twice-a-year for two years and Groups I, II and III did not receive as extensive a treatment. The lack of a significant difference between Groups IV and VI presents a confused picture however, for one would logically expect trees averaging 50 feet

Table 10

Bioassay of Commercially Sprayed Trees

Group Number	Tree Number	Number of Living Beetles for the Five Replications		
I	1	31		
	2	40		
	3	27		
	4	30		
	5	38		
	6	32		
	7	29		
	8	10	n=8	Total = 237
II	1	21		
	2	20		
	3	23		
	4	31		
	5	31		
	6	29		
	7	25		
	8	36	n=8	Total = 216
III	1	26		
	2	35		
	3	22		
	4	19		
	5	30		
	6	27		
	7	21		
	8	5	n=8	Total = 185
IV	1	11		
	2	6		
	3	12		
	4	19		
	5	12	n=5	Total = 60
V	1	11		
	2	4		
	3	5		
	4	1		
	5	5		
	6	0		
	7	1		
	8	14		
	9	20		
	10	5		
	11	10		
	12	15		
	13	3		
	14	16		
	15	0		
	16	14	n=16	Total = 124
VI	1	14		
	2	24		
	3	16		
	4	20	n-4	Total = 74

Table 11

Analysis of Variance for Comparison of Six Spray Treatments

	Variance	Degrees of Freedom	f
Between Groups	759.4	5	15.23*
Within Groups	49.8	43	

*Significant at the 1% level.

Table 12

Results of Duncan's Multiple Range Comparisons of the Six Spray Treatments Analyzed in Table 11

I II	II III	III IV	IV V	V VI*
I III	II IV*	III V*	IV VI	
I IV*	II V*	III VI		
I V*	II VI			
I VI*				

Note: Those Group Number comparisons followed by an asterisk are significant at the 5% level. Those not followed by an asterisk are not significant.

in height and sprayed twice-a-year for three years to exhibit better control than trees averaging over 70 feet in height that had been sprayed twice-a-year for only two years. This, however, is not the case and can suggest only one thing to the author. This is that the trees sampled for Group VI were not as thoroughly sprayed as the trees sampled in Group IV.

Group V presents the only treatment type sampled that can be considered adequate in any respect, and here, only six tests out of 16 had less than five living beetles and only two showed complete kill. This to the author suggests only one conclusion regarding these tests i.e., the sampled trees were not adequately covered with insecticide.

It was noticed during these bioassay studies that surviving females were inclined to construct brood galleries by boring into the cut end of the twigs being tested. Eggs were laid as shown in Figure 10 and successful attempts to rear larvae in these twigs in the laboratory were made although there was a high percentage of failures. The twigs in which larvae were reared varied from three-eighths to five-eighths of an inch in diameter. This obviously occurred under high population pressure and might never occur under even the most optimum field conditions. However, it definitely is a factor that should not be overlooked by field supervisors in charge of sanitation programs.

Figure 10

Brood Gallery and Ovipositing Adult Female in a one-half inch twig.
Position of an egg is shown by arrow.

V. SUMMARY AND CONCLUSIONS

Since the detection and subsequent spread of the Dutch elm disease in Michigan, many uninvestigated problems concerning the bionomics of the major vector of the disease, the smaller European elm bark beetle, Scolytus multistriatus (Marsh.), have been encountered. These problems fostered the present studies.

The emergence patterns of the adult beetles, the primary objective of the study, were investigated and it was found that the insect has two complete generations in southern Michigan. First brood adult emergence commences in late May or early June with a peak emergence occurring about June 20. Second brood emergence begins in early July with a peak varying between July 29 and August 30 depending upon weather conditions. Adults are present throughout the summer months and have been found to confine their feeding to other than current season's twig growth--that is, to branch wood in at least its second growing season. Late season breeding activities are curtailed, apparently by prevalence of cooler temperatures and brood galleries constructed in mid-August vary significantly in length from those constructed by breeding adult females in late August and early September. The sex ratios of adults do not vary significantly from an equal distribution at any time during emergence periods.

Attempts to rear beetles under varying conditions in mechanically-chipped elm wood failed. Wood remains of this type can be considered safe from beetle development or attack.

Tests of a DDT-acetone emulsion diluted to foliar strength showed negligible phytotoxicity on trees varying in size from 30 to over 70 feet in height. The 19 trees on which the formulation was tested were sprayed in August, 1956 and in July, 1957 using both a hydraulic and a mist sprayer.

Eight Dutch elm diseased trees were treated with sodium arsenite and were allowed to remain in the field for 60 days. In no case were any of the eight trees successfully attacked by breeding females nor was any larval development completed.

Bioassay of commercially-sprayed trees was carried out using trees with varying amounts of treatment. It was found that in general, spray application had not been thorough enough to give adequate protection from feeding adult beetles. During this study, adults were reared in the laboratory in twigs as small as three-eighths of an inch in diameter.

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