This is to certify that the

thesis entitled

The Biology and Control of the American Plum
Borer (Pyralidae) on Tart Cherries in Michigan

presented by

David John Biddinger

has been accepted towards fulfillment
of the requirements for

M.S. degree in Entomology

Angus J. Howitt
Major professor

Date Aug 7, 1989

THE BIOLOGY AND CONTROL OF THE AMERICAN PLUM BORER (PYRALIDAE) ON TART CHERRIES IN MICHIGAN

By

David John Biddinger

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Entomology

1989

ABSTRACT

THE BIOLOGY AND CONTROL OF THE AMERICAN PLUM BORER (PYRALIDAE) ON TART CHERRIES IN MICHIGAN

By

David John Biddinger

The American plum borer, *Euzophera semifuneralis* (Walker) has been a major pest in cherry and plum orchards in Michigan since the early 1970's. The rapid spread of this cambium borer has been facilitated by the increase in tree wounding resulting from the extensive use of mechanical harvestors. Its wide geographical range and its extreme diversity in foodplants has allowed this insect to be a pest on many other fruit, nut, and ornamental crops throughout the U.S.

Extensive field and growth chamber observations found two generations a year in Michigan with peak adult emergences in mid May and in mid July with full grown larvae overwintering under the bark. A commercially available pheromone was developed with Dr. Wendell Roeloffs. *Venturia nigricoxalis* (Ichneumonidae) and a *Hirsutella* fungal pathogen were the most prevalent biocontrol agents. Control trials conducted over 4 years showed chlorpyrifos 4EC to give effective seasonal control on cherries and plums.

ACKNOWLEDGEMENTS

I wish to especially thank Dr. Gus Howitt, for allowing me this opportunity to work on a little known but very important pest. His perceptive advice and the financial support obtained from the Michigan Stone Fruit Decline Project was invaluable in opening up the complex world of fruit entomology to a field crop farm boy that couldn't tell a cherry tree from an apple when he first started. He has served as my professional mentor and one of my closest friends since the year I started with him as a student and on through the years I worked for him as his research assistant. He has taught me true dedication not only to the science of entomology, but also to the growers to whom we are responsible for giving answers to. I am one of the last of a long list of graduate students that Gus has guided over his almost thirty years as he has now started his well deserved retirement. He will leave an unforgettable impression on the fruit industry of Michigan and myself, as well as a monument to his efforts in the form of the Trevor Nichols Research Station.

I also wish to thank my family for their support and especially my mother and father, Sharon and John. They may have thought I was a little crazy chasing bugs when I was young, but they supported me and my father would even run around with a butterfly net on the tractor once in a while to catch something for me. I will always remember a certain "color tour" up north in October when they helped me dig out borers.

A special thanks to George Ayers for his advice on this project and for all the practical knowledge of entomology he has passed on to me in his classes and a thanks to Jim Miller for a word of encouragement when I needed it most. Thanks to Larry Bradford, John Hayden, Patti, and Marilyn for their friendship during my isolated years at Hart and to Bob, Beth, and Sue in the years after.

TABLE OF CONTENTS

LIST OF TABLES.. vi

LIST OF FIGURES....................................... viii

INTRODUCTION 1

LITERATURE REVIEW 6

METHODS AND MATERIALS 10

GEOGRAPHICAL DISTRIBUTION 12

DESCRIPTION OF LIFE STAGES 15
- Egg... 15
- Larvae 15
- Pupae 18
- Adult... 19

LIFE HISTORY OBSERVATIONS 26
- Egg... 26
- Larvae.. 27
- Pupae... 31
- Adult... 33
- Foodplants.. 35
- Larval Damage....................................... 36
- Pheromone Development............................... 50
- Natural Control..................................... 57

DISCUSSION OF BIOLOGY 69

CONTROL EXPERIMENTS AND RESULTS 72
- INTRODUCTION.. 72
- MATERIALS AND METHODS............................... 76
- CHEMICAL CONTROL.................................... 79
  - 1974 Field Evaluations............................ 79
  - 1985 Field Evaluations............................ 82
  - 1986 Field Evaluations............................ 87
  - 1987 Field Evaluations............................ 89
  - 1988 Field Evaluations............................ 91

DISCUSSION 93

SUMMARY 98

APPENDICES 102

Appendix 1: Artificial diet 102

Appendix 2: North American distribution 103

Appendix 3: Orchard damage survey 106

Appendix 4: North American Foodplants 108

LITERATURE CITED 110

LIST OF TABLES

Table 1. Average head capsule for the larval instars of the American plum borer.................. p.18

Table 2. Duration in days of the egg and immature stages of the American plum borer at 68 F in growth chambers................................ p.27

Table 3. The proportion of overwintering American plum borer larval instars in Michigan at the start of diapause (October 15, 1985.).......... p. 31

Table 4. Development time of American plum borer pupae in the field in Ocean County, summer generation 1986.................................... p. 33

Table 5. Lepidoptera associated with the American plum borer................................... p. 37

Table 6. Relationship of tree wounding to American plum borer infestation in western Michigan cherry orchards................................ p. 48

Table 7. Composition of field tested pheromones for spring 1985 .... p. 52

Table 8. 1974 full season control trial on tart cherries at Traverse City .... p. 81

Table 9. 1974 full season control trial on tart cherries at Traverse City .... p. 81

Table 10. 1985 full season control trial on tart cherries at Lake Leelenau .... p. 85

Table 11. 1985 full season control trial on tart cherries at Mears .... p. 85

Table 12. 1985 summer generation control trial on tart cherries at Lake Leelenau................. p. 86

Table 13. 1986 full season control trial on tart cherries at Lake Leelenau .... p. 89

Table 14. 1987 full season control trial on plum, Pullman.................................. p. 90

Table 15. 1988 full season control trial on plum, Pullman.................................. p. 92

LIST OF FIGURES

Figure 1. Distribution of the American plum borer in lower Michigan, 1989.................... 14

Figure 2. American plum borer egg................. 16

Figure 3. American plum borer larva 16

Figure 4. American plum borer pupa................ 20

Figure 5. American plum borer adult............... 20

Figure 6. American plum borer hibernacula and frass accumulated under tart cherry bark over many seasons 45

Figure 7A. American plum borer girdling damage on a tart cherry tree 45

Figure 7B. American plum borer girdling damage on a tart cherry tree 63

Figure 8. American plum borer pheromone concentration effectiveness.......................... 54

Figure 9. Chemistry of Dr. Roeloff's identification pheromone for the American plum borer.. 55

Figure 10. Approximate adult emergence of three borer pests of stone fruits in midwestern Michigan.............................. 56

Figure 11. *Hirsutella* mummified American plum borer larvae with fungal horns...................... 63

Figure 12. SMA cultured *Hirsutella* conidiospores and hyphae.................................. 67

Figure 13. SMA cultured *Hirsutella* hyphae and conidiospores.......................... 67

INTRODUCTION

Michigan has been the leading producer of tart cherries for over 75 years producing about 80% of the nation's annual production and is generally third in the nation for sweet cherry production at 20%, ranking only behind Washington and Oregon. The production of tart and sweet cherries for 1988 was 180 million pounds for tarts and 56 million pounds for sweets. This amounts to a yearly cash value of 42.3 and 18.4 million dollars respectively for each crop. The cherry industry is only exceeded by apples in dollar volume for fruit enterprises in the state. Because of danger of frost damage and winter kill in Michigan, almost all commmercial plantings of cherries are grown in the western part of Michigan along the shore of Lake Michigan where the so-called "lake effect" gives them protection from the cold. The major producing counties are Oceana, Mason, Manistee, Benzie, Leelenau, Grand Traverse, Antrim, and Charlevoix, all of which have light sandy soils. As of 1988, there were 44,000 acres of of tart cherries and 10,700 acres of sweet cherries in Michigan including nonbearing trees (Jim Nugent, 1989).

Begining in the early 1970's, the labor intensive practice of manual harvest employing mainly migrant workers, began to shift to the use of mechanical harvesters for economic reasons. It was found that using hydraulic clamps to shake the fruit from the trees into canvas collecting areas was much quicker and more economical. These clamps, however, tended to crush bark and cambium by their excessive pressure of over 1,000 pounds psi that in some cases killed tissue after multiple harvests and commonly left large cracks in the bark and cambium which served as sources of entry for insects and diseases. The combination of these factors was found during the 1970's to reduce the expected life of a cherry orchard in Michigan by almost a third, from over thirty years to about twenty years.

It was during this time a new cambium feeding lepidoptera borer, the American plum borer, E. semifuneralis (Pyralidae), took advantage of these openings through the bark into tree's cambium and became a major pest on cherries. It had probably been a minor pest on cherries in the state before mechanical harvesting, but its only avenues into the cambium before were through winter injury and pruning wounds. Even then, it was usually mistaken for the very similar and more abundant larvae of sessiids, including the lesser peachtree borer, Synanthedon pictipes (Sesiidae). The lesser peachtree borer (LPTB) also became more abundant as a result of the increase tree wounding, but control measures were already available for it. The biology of this pest was well known and a pheromone had been developed for the monitoring of this pest and for the timing of of insecticide applications.

Relatively little was known about the plum borer biology and for the most part, growers and extension personnel were unable to distinguish them from the sesiids. The damage the plum borer inflicted was blamed on the lesser peachtree borer and yearly control applications using chemicals timed to control that insect were for the most part wasted. In fact, by eradicating competition from this sesiid and eliminating most of the natural insect biocontrol of this pest, the plum borer with its multiple generations and somewhat gregarious tendencies increased so that colonies of over thirty individual larvae could be found on large trees. These large populations almost completely girdled entire orchards in less than ten years in such areas as the Leelenau peninsula. In addition, as a consequence of damage from occasional mechanical harvesting, the damage from this insect increased greatly on plums in Michigan as well.

Control of E. semifuneralis was complicated by the following factors: (1) Only very limited information was available on its biology, most of whichwas obtained from southern regions of the U.S. on other crops. Knowledge of flight periods of the female, where they laid their eggs, and how soon the larvae emerged and hid in the protective cracks and under the cambium away from any insecticide residues were very important. (2) A means of monitoring emergence to time applications either from the developmental times of all stages or from pheromone trapping was unavailable. (3) It was known that the standard June sprays of endosulfan or diazinon applied by hydraulic gun timed for the lesser peachtree borer were not effective on the plum borer and even with proper timing, the spring application would not give seasonal control. Later when the biology was determined, it was found that the previously unknown second generation adults emerged and laid eggs during the harvest period for cherries. Control after harvest was generally ineffective and the type and quantity of insecticide which could be applied close to or during harvest is restricted by Food and Drug Administration regulations because of possible residues on the fruit. Seasonal control of both generations was therefore desireable from a single spring application, and hence new insecticides needed to be evaluated.

The investigations reported in this thesis were conducted to determine the biology of the American plum borer and find a control for this pest attacking cherries in Michigan. The development of a program utilizing the principals of integrated pest management to minimize the number of applications and materials impacting the orchard system and maximizing natural biocontrol was considered of prime importance. It was hoped that a single early season application could be found to give seasonal control not only of the prime borer pest of cherries, but also the currently minor pests of the lesser peachtree and peachtree borers. Secondary in these investigations, was the biology and control of the plum borer in other crop systems througout the U.S. and especially plums in Michigan. Recent outbreaks of the plum borer in various ornamental trees in the east and nut trees in the west and southwest have pointed out the need for a complete understanding of this pest.

LITERATURE REVEIW

First described in 1863 as Neophopteryx semifuneralis by F. Walker, the American plum borer has been known under many names in both the taxonomic and economic literature. Redescribed no less than three times as Euzophera impletella (Zeller, 1881), Stenoptycha pallulella (Hulst, 1887), and Euzophera aglaella (Ragonot, 1887), the early literature is confusing. It was not until 1956, that Heinrich finally placed the western Euzophera aglaella as a color form and placed all the other synonyms in the literature together to give the first comprehensive list of food plants and worldwide distribution of Euzophera semifuneralis (Walker). The first published reference to the immature stages were made in 1890 by S. A. Forbes. He described the larvae as injuring Chinese plum in Illinois and gave it the common name "American plum borer" as it is known today. In 1901, E. D. Sanderson reported it as injuring apple and pear in Delaware and his few notes on its probable life history in that locality were the first real attempt to describe the biology of this insect. Sanderson's renaming of it as the "fruit tree bark borer" in this article was not accepted and it remained the American plum borer in the economic literature.

The most comprehensive attempt to describe the biology of the plum borer in publication to date was done by E. B.

Blakeslee for the U.S.D.A. in 1915. His work was concerned with apples and plum in Virginia where he reared and described in detail for the first time all of the life stages including the eggs. Blakeslee's paper was the first to mention what types of injury and other conditions favorable to the establishment of this borer. Some insights into the biology, such as fecundity and duration of some of the life stages under field conditions were given, as well as some of the natural predators and parasites. In addition, the first rough emergence graph of the first generation plum borer was determined from pupal emergence in the field. This graph was to be the only emergence data available until this project was started.

After Blakeslee, the American plum borer was still reported intermitantly in the literature as a minor pest of fruit trees, usually as part of a complex of sesiid borers from which its larvae were hard to separate for identification by both growers and extension agents alike. It has undoubtedly been ignored in the literature to some extent because of this confusion. Pierce and Nickels (1941) report it as one of two pests in top pruned pecan trees and give some control work on it as well as some rather questionable notes on the biology of it in Texas. Alvah Peterson (1948) included the first detailed drawings of the larvae in his work on the larvae of insects. Kelsey and Stearns (1960) give more control trials testing relatively modern pesticides for it and other borers on apple, but offered little in the way of biology.

The only comprehensive work done on the plum borer on stone fruits, in this case sour cherries, was done very recently in Wisconsin by Weiner and Norris (1983). This paper included not only control and sampling methods for the American plum borer but also for the lesser peachtree borer. These sampling methods, however, were based on the indirect and somewhat inaccurate method of observation of frass piles rather than direct observation of the larvae chiseled out of the cambium for positive identification. That method has been commonly used for borer evaluations in the literature rather than chiseling because of the extensive injury to the tree and the amount of labor it entails. Control with various pesticides and pesticide/paint mixtures did not give control of the plum borer because the life history was not adequately understood and no method for predicting the emergence of the adults was available.

A recent paper by Van Steenwyk, et al. (1986), presented a more successful program of control using pesticide/paint mixtures. This program was implemented for the control of the plum borer and a complex of three other borers attacking young almond trees in California. A sketchy biology of the moth for this area is also included but again used the observation of frass piles for evaluation and lacked definite emergence data needed to adequately time sprays for hatching first instar larvae. This resulted in the need for at least three separate applications per season at extremely high rates of insecticides mixed with the paint. Although some success was achieved with remedial treatments in this experiment, personal communication with Van Steenwyk and our own personal work in 1985-88 with borer control on cherries and plums in Michigan demonstrated that applications of chlorpyrifos 4EC based on catches from a newly developed, specific pheromone for the American plum borer gave seasonal control that was preventative in nature. These recommendations have been given in the Michigan State University annual Fruit Spraying Calendar Extension Publication No. E-109 for cherries since 1986.

Also available from MSU are some notes on the biology of the plum borer in it's North Central Regional Extension Publication No. 63. Stehr (1987) includes figures of the American plum borer in the section by H. Neunzig on the pyralidae and includes notes on foodplants noting stored sweet potatoes as a foodplant for the first time. The most recent edition of Insects that Feed on Trees and Shrubs (Johnston and Lyon, 1988), shows some excellent color pictures of most life stages as well as the damage. They report the plum borer as becomming a serious metropolitan pest on imported sycamore trees in eastern cities.

MATERIALS AND METHODS

Collection of Adults for Pheromone Development - The projected laboratory development of a pheromone for the American plum borer required large numbers of adult moths. To obtain the 400 pupae to be sent to Dr. Wendell Roeloff's laboratory in Geneva, New York, approximately 300 overwintering larvae and 200 pupae were collected from several different cherry orchards in the Hart/Shelby area of Oceana County during the months of March and April. Both stages were removed from the cambium with a hammer and long handled screwdriver with the larvae in their hibernacula being kept at room temperature (70 F) on moist paper towels in petri dishes until pupation. These pupae and those collected in the field as the season progressed were immediately placed in a household refrigerator at about 40 F to slow further developement. The pupae were kept on moist paper towels until May 6th when 400 pupae were sent to Dr. Roeloff's laboratory. About 20% of the both stages collected, the majority of which were larvae, died due to parasitism from ichneumons, fungal pathogens, or dessication.

Culturing and Rearing Techniques - Later instar larvae were easily reared on strips of bark from cherry orplum, but dessication of the cambium, even in growth chambers with humidity control, prevented rearing the earlier instars on their natural food. Instead an artificial diet and rearing technique developed at Michigan State University for codling moth cultures was used (Cowles, 1986). Individual neonate larvae were transferred using a fine brush to the surface of the artificial diet, prepared as described in Appendix 1. The techniques for preparation and prevention of mold contamination followed as outlined in this master's thesis. The plum borer larvae preferred to form their hibernacula on the cardboard squares or in the diet rather than between the corrigations as did the codling moth. The life history studies generally required observations daily or every other day to check head capsule width under a stereo microscope with an ocular micrometer. This frequent opening of the rearing containers caused frequent mold contamination of the artificial diet,but larvae were transfered with paint brushes to fresh diet containers before the mold became a threat to the larvae.

Ovipositional and emergence cages were made from acetate plastic sheets glued to form a 9 cm diameter cylindar with tops and bottoms made of disposable plastic petri dishes with filter paper lining as with the codling moth cultures (Cowles, 1986). The plum borer adults would not, however, lay eggs on wax paper as did the codling moth. Instead, they prefered either rough strips of bark or rough brown paper toweling for oviposition. A 5% sucrose solution was provided for the adults in a 4 dram glass alchohol vials with an inserted dental wick. As soon as the females died or stopped laying eggs, the toweling or bark with the eggs was kept moist in disposable plasticpetri dishes until eclosion.

Field Studies - Studies into the duration of life stages under field conditions were made at Hart in Oceana county during the 1985 and 1986 seasons. Samples were taken twice a week of all stages except the adults were made on trees in nearby orchards and some observations were made on larvae reared on bark in cages on a screened porch. Observations on the development of pupae were made from fresh pupae found in the field and reared in cages on the porch. Growth chamber cultures were started in 1987 from a plum orchard in Allegan County near Pullman. All life stages were reared at 68 F, under 16L:8D photoperiod. Orchard surveys for infestation throughout the state consisted of sampling 10 random trees throughout an orchard for old emerged or dead pupae, live larvae and pupae, and larval mummies of the Hirsutella fungus. Surveys for adults were made with funnel type black light traps and virgin female or pheromone baited Phercon II traps.

GEOGRAPHICAL DISTRIBUTION

Walker (1863) first described the American plum borer from specimens collected in Columbia, South America. Since then it has been recorded in Mexico and most states in the United States and on up into southern Canada. Appendix 2 shows the distribution of this species throughout these regions. This list is the result of a reveiw of the literature and a personal survey of the curators and their holdings for state and regional collections.

A survey of the distribution of the American plum borer in the state of Michigan has shown the plum borer to be present in about 85% of all plum and cherry orchards in western Michigan. Damage surveys in these areas haveshown Cass, Allegan, Oceana, Mason, Manistee, Benzie, Grand Traverse, Leelenau,Atrim, and Charlevoix counties to be the most heavily infested. Holdings from the Michigan State University entomology museum, black light trap records from John Newman, and recent pheromone trapping surveys are shown in Figure 1 indicate the plum borer is found in 28 counties in the lower peninsula. Due to it wide range of foodplants, however, it is probably found in all counties of the lower peninsula on up into the upper peninsula.

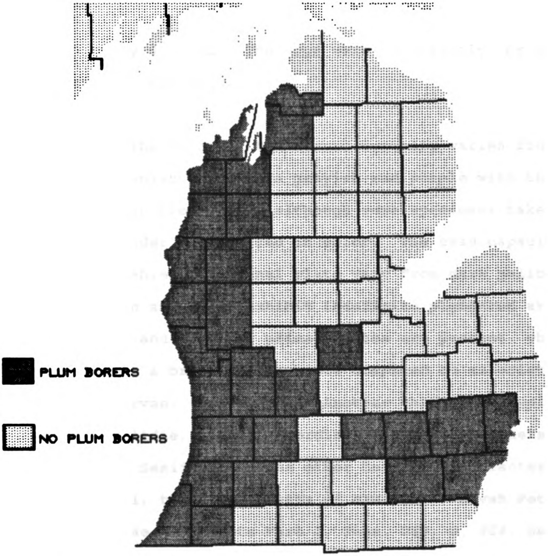


Figure 1. Distribution of the American plum borer in lower Michigan.

DESCRIPTION OF LIFE STAGES

EGG - The eggs are ovoid with a strongly reticulated surface of triangular facets. When first laid, the eggs are a dirty white in color which changes to a pink and eventually a deep redish pink as they develop. Unfertile eggs do not change from their original color and collapse inward within a few days of laying. The average dimensions of these eggs were 0.35 mm by 0.60 mm. The eggs were laid singly or in small clusters. See Figure 2.

LARVAE - The color of the larvae normally varies from a dusky greenish white to a grayish red purple with the dorsum darker than the venter, although some specimens taken were dark lavender or dark red in color. The head capsule, cervical shield, and anal plate vary from dark yellow to dark brown and often exhibit indefinite pigmented areas. Only long and distinct primary setae are present, which give the larvae a bristly appearance compared to associated sesiid larvae. See Fig. 3. Another character, typical of most pyralidae, are the biordinal, circular crochets on the prolegs. Sesiidae, on the other hand, are characterized by uniordinal, transverse bands of crochets. Alvah Peterson's 1948 Larvae of Insects Part I, figs. D&H, p. 204, has excellent line drawings of the larvae and the crochet's can be compared with those of the sessiids on the same page.

Figure 2. American plum borer egg.

Figure 3. American plum borer larva.

At normal distention, the diapausing last instar larvae from the field vary from 18 mm to 25 mm in length by about 3 mm in width for 100 larvae. The average head capsule width of 1.79 mm for 100 specimens with a range of 1.70-2.04 mm and a variance of 0.16 mm. The larvae pass through 7 instars, and the average head capsule width for 20 reared specimens of each instar preserved in alchohol and measured through an ocular micrometer were as follows:

Table 1. Average head capsule width for the larval instars of the American plum borer.

Instar	Mean	Range	Variance
1st	0.25 mm	0.24-0.26 mm	0.02 mm
2nd	0.40 mm	0.39-0.44 mm	0.03 mm
3rd	0.60 mm	0.56-0.63 mm	0.02 mm
4th	0.80 mm	0.74-0.82 mm	0.02 mm
5th	1.12 mm	0.93-1.29 mm	0.34 mm
6th	1.55 mm	1.40-1.59 mm	0.16 mm
7th	1.75 mm	1.71-2.04 mm	0.15 mm

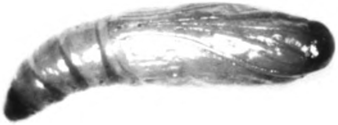
Pupae - The pupae are found within whitish silken cocoons under the bark near previous feeding sites of the larvae. For 20 pupae of each sex, the female pupae at an average length of 12.0 mm (range: 9.8-13.8 mm) were slightly larger than male pupae which averaged 11.00 mm (range: 7.3-13.0 mm). The pupae of the American plum borer can be distinguished from its most likely associated lepidopteran larvae in Michigan orchards, the lesser peachtree borer (S. pictipes), by its wing sheaths being smoothly fused to the rest of the pupae and a much more rounded last abdominal segment. The cocoons are also readily distinguishable. The lesser peachtree borer uses its frass as an integral part of the construction of its cocoon but the plum borer, even though it may form its silky white hibernacula amongst its frass, the frass is never used as a structural component of its hibernacula.

When first formed, the color of the pupae is a light olive green and the eyes of the pupae are the same color. After a couple of days, the overall color of the pupae changes to a light tan and the eyes quickly turn black. Within 24 hours of emergence, the color of the pupae changes to a dark brown and then to black just prior to emergence. All through these stages the wing sheaths, which extend about two thirds of the total body length, remain slightly lighter in color than the rest of the pupae. The spiracles are well defined and the last abdominal segment bears a variable number, usually about a dozen or so, of stout hooked spines that anchor the pupae to the cocoon. See Figure 4.

Adult - The adult males and females are typical looking rather dull grayish brown pyralids (See Fig. 5) The head, thorax, legs, and abdomen are a light gray with a slight bronze reflection when observed under a microscope. The forewings are a grayish brown with a broad, wavy vertical

Figure 3. American plum borer pupae.

Figure 4. American plum borer adult.



band of black and brown markings across the outer third of the wing. In some lighter specimens the black in this band appears to have some dark purple tints mixed in as well and a light dusting of white scales may appear along the costal area and the outer edge of the forewing. There is considerable variation in the color patterns of the fore wings, however, and frequently these markings are almost absent. This color variation has led to the naming of one color form as a seperate species that is known in the economic literature as the "Walnut Girdler" (Essig, 1929). Named Euzophera aglaeella by Ragonot in 1887, it has since been recognized (Heinrich 1956) as merely a color form that is much more common to the Western and Southwestern states and Mexico. This color form has paler redbrown areas and a more strongly contrasted blackish band in the forewing. Much more dusting of black scales are found throughout the forewing than its typical form in the Eastern and Central States. It does not qualify as a subspecies, however, because this form can be found in addition to integrades throughout the range of the typical dark form of semifuneralis.The hind wings are smoky colored with a black marginal line and dusky veins. The best detailed description of the adult is provided below by Heinrich (1956):

> "Forewing with basal and terminal areas dark to pale reddish brown more or less dusted with white along costa and (in very pale specimens) in apical terminal area; area between the transverse lines densely dusted with blackish scales; antemedial line more or less vertical to lower margin of

> cell, inwardly angled at lower fold, white bordered outwardly by black line; subterminal line somewhat irregular, usually outangled evenly at middle, white, bordered inwardly by a black line; discal black dots more or less obscured in the black dusting of median area, usually a white mark on discocellar vein; a line of black dots along terminal margin, confluent in some specimens, distinctly separted in others. Hind wing white to smoky fuscous, more or less darkened along terminal margin, at apex, and along some of the veins. Alar expanse 16.5-28 mm."

Blackslee (1915) gives the average mesurements for 10 specimens from Virginiaas: wingspread, 19.5; length of body, 8.4 mm; width of body, 1.4 mm. Sex of the adult specimens were not differentiated in any of the measurements, but the female adults were noted to be slightly larger on the average than themales. Average measurements taken from 10 wild collected nonsexed adults from Michigan were as follows: wingspread, 21.6 mm; length of body, 9.4 mm;width of body, 1.8 mm. Standard deviations were 1.70 mm, .93 mm, and .17 mmrespectively.

The three species of Euzophera are found in America north of Mexico besides semifuneralis are: magnolialis Capps, ostricolorella Hulst, and nigricantella Ragonot (Hodges, 1983). Of these, nigricantella is a rare species ocurring only in the southwest U.S. and Mexico and whose foodplant is unknown. The other two species are noted as pests of eastern forests in the U.S.D.A. Forest Service Miscellaneous Publication No. 1462 (1985). E. ostricolorella Hulst is the only species in this genus whose range might overlap with the plum borer in Michigan and is described as capable of girdling and killing all size trees of magnolia, tulip tree and yellow poplar. It has not yet been recorded in Michigan but it is known to range up into Ohio and tulip tree stands are available in southern Michigan. A color plate of this species is shown in Covell's Field Guide to the Moths of Eastern North America (1984). E. magnolialis was described by Capps (1964) only recently and its only known foodplant is magnolia on which it is described as a serious pest of magnolia seedlings in the southern U.S. in the Forest Service Publication. Both species are thought to be double brooded in the south and ostricolorella to be single brooded in the northern part of its range. Pine moths of the genus Dioryctria (Pyralidae) are most likely to confused with the plum borer in the northern part of its range but are pine feeders and are generally more colorful than the plum borer with more contrasting bands that are mixed with white across the front wings.

Due to a thick covering of scales on the abdomen, the genitalia of both sexes of the plum borer can be seen most readily after simmering the moths for about an hour in dilute KOH to dissolve the scales away. Identification of the plum borer by genitalia is essential in areas of its range where the other very similar looking members of this genus overlap. The following is Heinrich's description of the genitalia:

"Male genitalia with lateral projecting lobes of transtilla and lateral lobes of anellus more slender than those of other American species; cucullus of harpe narrower and more elongate; vinculum somewhat longer than broad; uncus evenly tapering. Female genitalia with bursa rather small and wrinkled over most of its surface."

LIFE HISTORY OBSERVATIONS

Egg - As shown in Table 2, the average length of the eggs stage was 8.3 days at 68 F with all 50 eggs hatching. At 56 F, only 43 out of 50 eggs hatched and the average length to hatch was much longer at 19.5 days +/- .91 with a range of 18-21 days. All of the eggs were laid on the rough surface of either the cardboard strips or brown paper towels with most being laid on the vertical surfaces of the sides and not on the bottom of the tube. None were laid on the smooth plastic of the cylinder or on the petri dish tops and bottoms. Females would not lay eggs on wax paper either. Wood strips seemed to be the preferred substrate for oviposition. However, removal proved almost impossible without rupturing the egg because of the strong cementum substance which firmly held the egg in place. Towels and cardboard proved the best materials for rearing since sections could be cut around the number of eggs desired. Only humidity of over 80% seemed to adversely affect egg hatch and otherwise was not a factor. Females are strongly attracted to the gummosis that stone fruits exuded from wounds in their bark and lay their eggs singly or in small clusters in or around this gummosis both in the field and the laboratory.

TABLE 2. Duration in days of the egg and immature stages of the American plum borer at 68 F in growth

chambers.

Stage	Av. Length (Days)	Range	No. of Observations
Egg	8.3	8-9	50
1st instar	3.5	3-6	10
2nd instar	4.0	3-6	10
3rd instar	4.8	4-6	10
4th instar	5.1	4-7	10
5th instar	5.5	4-8	12
6th instar	6.5	4-8	15
7th instar	7.7	4-14	15
Pupae (male)	14.3	12-17	25
Pupae (female)	15.3	11-19	25
Total Larval time	37.1	26-55	82

Larvae - After hatching, larvae of the American plum borer move immediately into sheltered moist areas near the cambium amidst frass accumulations from previous feedings if possible. If previous feeding areas are not available, then the hatching larvae will enter the damaged area and start shallow feeding under the nearby bark scales, in the case of apple, or just under the tough outer surface of the bark but with age move deeper till they reach the hardwood. The early instars are active feeders and develop quickly. All instars from the third to the last instar were found to be capable of constructing a hibernacula and overwintering.

Following up to several weeks of feeding in early spring, the overwintering larvae of the first spring generation begin to pupate within silken cocoons in the middle of April beneath the bark close to recent feeding sites. First brood larvae begin pupating in June. Just prior to formation of the pupa a prepupa is formed and undergoes a quiescent phase in which the larvae shortens in length and takes on a greenish cast. This phase lasts from 2 to 3 days.

The plum borer larvae are not aggressive feeders and tend to feed along the edge of fresh cambium, within the wound, whereas the lesser peachtree borer will bore tunnels into undisturbed wood and cambium. The feeding of both borers on cherry causes a flow of gummosis from the injured sapwood. The feeding of lesser peachtree borer results in a copious flow of sap with its frass scattered throughout the gummosis. The feeding of the American plum borer causes much less sap flow, mainly because it is feeding on already crushed and damaged material, and its frass is usually packed together in a sticky mass along the edge of the wound. The larvae of both species exhibit negative phototrophism and seek dark, sheltered areas at all times. Any intrusion on the plum borer by other species of larvae elicits a strong territorial behavioral response of aggresive forward movements and attacks with the head.

Weiner and Norris (1983) found almost 11% of the wounds in the cherry orchards they surveyed in Wisconsin to have both species of borers co-occur in a single wound. Out of 292 wounds evaluated and 552 larvae collected from those wounds, 54% were plum borer and 46% were lesser borer. The lesser borer was found in a greater number of wounds but with fewer larvae per wound than the plum borer. In a thirty orchard survey of plum, tart, and sweet cherries throughout western Michigan orchards (Appendix 3), 26 orchards had plum borer, 27 had lesser borer, and 27 had both species. The age of the orchard and especially how may years it had been mechanically harvested strongly correlated with the borer population. Younger orchards as a rule had fewer borers, but with age and repeated shaking the populations of both species increased rapidly.

The rearing of the entire life cycle of the plum borer in the laboratory on their natural food source of tree cambium proved extremely difficult. Short-term rearing of the last two instars taken from hiberanacula proved reasonably sucessful for some observations, but keeping the cambium tissue moist and tender for the early instars without disturbing them to change the food was not possible. The mortality of these early instars was extremely high from dessication or starvation if conditions were not optimum. Rearing on trunk sections sealed on each end with wax to try to prevent dessication of the trunks proved unsatisfactory.

The artificial pinto bean diet described in Appendix I proved to be acceptable in growth chamber rearing and was used because it was already available on campus for codling moth cultures. Mid to late instar larvae taken from the field almost always preferred to starve before switching food to the artificial diet, but early instar larvae up to the third instar and especially newly emerged larvae readily accepted the diet and could complete their life cycle on it. The duration of the 7 larval instars is shown in Table 2. The average time of development for 10 larvae of the 1st instar larvae was the shortest for all instars at 3.5 days. All following instars had successively longer developemental periods to the 7th instar which was the longest, averaging 7.7 days for 15 larvae. Attempts at rearing the larvae through at 56 F were were unsuccesful because of high mortality in the early instars.

In the field, the 1st spring generation larvae usually hatch late in May or early June at around petal fall for tart cherries. Development usually takes about 4 to 5 weeks until pupation in early to mid July but generations can be strung out so that full grown larvae can still be found in early August. Second generation summer and overwintering larvae usually hatch in late July and early August and continue development into the fall till mid October when the trees harden off sap flow and hibernacula are formed.

The proportion of overwintering instars was determined by measuring the head capsules of larvae removed from tart cherry control evaluations at Hart on October15, 1985 and are presented in Table 3. Out of 119 larvae measured, it was found that 95% of the larvae overwintering were in the last two instars but a few larvae as young as the third instar were found. All of these overwintering instars were found to be capable of forming some sort of hibernacula although smaller instars tended to form only a very few threads. 84% of all the larvae were of the last instar and required little or no feeding with the majority never leaving the hibernacula in the spring but pupated inside. The rest of the larvae may need up to three weeks of further feeding at an average temperature of 68 F before pupation. This leads to a staggering of the spring adult emergence and summer development.

Table 3. The proportion of overwintering American plum borer larval instars in Michigan at the start of diapause (October 15, 1985).

Larval Instar	No. of Larvae	% of Sample	Approximate # of Days to Adult Emergence at 68 F.
7th	100	84	15
6th	13	11	23
5th	4	3	29
4th	1	>1	35
3rd	1	>1	40

Pupae - The length of the pupal period in the laboratory at 68 F, was found to average 14.3 days for 25 males and slightly longer at 15.3 days for 25 female pupae (Table 2). Only a few pupae survived at the cool temperature of 56 F and emerged in 40-50 days. When ready to pupate, the larvae generally withdraw from the feeding site along the edge of fresh cambium in the wound to spin a hibernacula in a more open area of the wound, preferably under the overhanging slab of dead bark or in a pile of old frass. Often dead slabs of bark can be pulled away from the trunk and turned over to reveal hundreds of hibernacula piled on top of each other in rows with the new hibernacula generally shielded under the old and closest to the bark. See Fig. 6.

In addition to protection from predation, the hibernacula also seems to play an important role in the emergence of the adults. Emerging adults from pupae whose hibernacula were removed for sexing the pupae, quite often had problems emerging without their pupal skins being anchored. Often the wings were deformed because the pupal skin was carried around by the moth and was not shed before the wings dried and stiffened. The stout hooks at the base of the pupae normally anchor the pupal skin to the cocoon while the adult quickly pulls free to begin expansion of the wings. After the emegence, the pupal skin protudes partially from the hibernacula and may remain firmly attached for several years in the field.

After 4 years of field observations in the fall and winter, only 2 overwintering pupae have been observed out of many thousands of larvae that were removed from cherries and plums for control evaluations. First generation spring pupae are generally found between April 8 and June 12 and the summer second generation pupae from June 26 to August 16. The average developmental times for field collected pupae under conditions as close tonormal field conditions as possible are shown in Table 4. These pupae, as outlined in the materials and methods, were collected in the field as larvae close to pupation and were placed along with their hibernacula in sealed test tubes in a shaded box in an outdoor screened house porch and were checked daily for emergence.

TABLE 4. Development time of American plum borer pupae in the field in Oceana County, summer generation 1986.

	Spring Pupae	Summer Pupae
Average length	30.0	15.1
Range	20-38	14-19
Standard Deviation	4.01	1.04
No. of observations	49	42

Adults - The adults generally emerged from their pupal skins during mid afternoon and were reared in clear plastic cages containing small dispensors of sugar-water with cotton wicks and lined with coarse brown paper towels and bits of bark and cambium. In these cages, the adults generally lived from a week to a maximum of 2 weeks and mated readily. From the placement of virgin females in small cages centered in a Phercon II sticky trap in various orchards around Oceana

County, mating was found to initiate early in the morning from 1:00 to 5:00 AM ending at dawn. This timing coincided with mating observed in cages place outdoors. Adults were readily attracted to black lights within an hour after sunset on throughout the night but were never found at mercury vapor lights.

The adults are strictly nocturnal in habit and are seldom seen in the field due, in a large part, to their cryptic coloration. In the resting position, they assume a twig-like pose by sitting motionless with the head and thorax held away from the twig or limb and the abdomen pressed tightly against the bark. Sweeping the orchard floor has never produced adults and for the most part the only adults observed during the day were freshly emerged adults. Their flight is an erratic flutter, usually over short distances. In captivity, between twenty and fifty eggs were laid by each female over a period of only a couple of days. The eggs were laid singlely or in small clumps on the paper toweling or strips of bark in the cages mainly at night. The eggs were never laid on the smooth plastic or on wax paper but only on rough surfaces. Females were observed to become physically excited and attracted to the aromatic smell given off by the gummosis material formed by cherry trees around wounds.

FOODPLANTS

The American plum borer has been found on a very diverse range of forest, ornamental, and fruit trees across Canada and the United States. Although a native insect, it clearly prefers the imported varieties of plum and cherry over the native species (Lockhead, 1918). Records for its foodplants in the Mexican and South American part of its range are lacking. While generally a cambium feeder, it can be found feeding in various growths such as cankers, callouses, and burr knots caused by diseases and physiological disorders of trees. While it can be found in the dead wood and stumps of its various foodplants, the plum borer can not live in dry materials. It can also be found in stored woody materials such as sweet potatoes. It has been infrequently found in woody stems of plants such as cotton and cornstalks in the southern part of its range. A list offoodplants compiled from the literature and personal observations for the American plum borer in various regions of the U.S. can be found in Appendix IV.

LARVAL DAMAGE

The rapid spread of the American plum borer, from relative obscurity to economic importance in Michigan, has been due almost entirely to the increase in tree wounding associated with the extensive use of mechanical harvesting of tart and sweet cherries in nearly all commercial plantings since the early 1970's. Its wide geographical range and extreme diversity of foodplants has also allowed the plum borer to take advantage of new horticultural practices such as the top-working of nut trees, pruning, grafting wounds, and the problems associated with the use of dwarf rootstocks such as burr knots. Injury caused by diseases, winter injury, and injury from cultural practices such as mower scrapes on trunks also provide entry and subsequent damage from this insect.

The first published references to the immature stages of the plum borer doing damage was in 1890 by S.A. Forbes who described the larvae as injuring Chinese plum in Illinois and gave it the accepted common name of American plum borer. It has since been reported in the ecomonic literature as a minor pest attacking apples, pears, cherries, pecans, almonds, walnuts, olives, and ornamental trees such as mountain ash and linden (basswood) trees. It has been known in the literature as the "fruit tree bark borer" and the "walnut girdler".

The plum borer was reported intermitently in the literature as a minor pest of fruit trees, usually as a part of a complex of lepidoptera borers, usually sesiids. These other lepidoptera larvae and especially the sesiids, are difficult to identify by non entomologists. It has undoubtedly been ignored in the literature to some extent because of the confusion with other lepidopteran pests. Some of these larvae it is known to associate with are shown in Table 5.

Table 5. Lepidoptera Associated with the American Plum Borer.

Pear borer	Thamnosphecia pyri (Harr.)	Kelsey & Stearns
Pecan borer or Dogwood borer	Synanthedon scitula (Harr.)	Pierce & Nichols, H. Reidel
Lesser peachtree borer	Synanthedon pictipes (Gr.& Rob.)	Weiner & Norris
Prune limb borer	Bondia comonana	Van Steenwyk
Peach twig borer	Anarsia lineatella	Van Steenwyk
Carpenterworm	Prionoxystus robinae	Van Steenwyk
Peachtree borer	Synanthedon exitiosa	IPM for Almonds

Unlike many other wood boring moths including the sesiids, which are commonly found in close association with it in fruit orchards, the plum borer must have an existing wound or other means of entrance through the rough outerbark to the cambium layer. Before the advent of mechanical harvesting on cherries, the plum borer was rarely found in significant numbers because the only means of entry were through cracks caused by winter injury, scrapes along the trunk caused by mowers, pruning wounds, or areas weakened by disease. Although pruning wounds were relatively common, the plum borer strongly prefers to infest trees along the lower trunk and scaffold limbs and not higher in the canopy. Winter injury used to be a more serious problem in the northern states on tree fruits, but the cultural practice of painting white paint around the trunks has helped to significantly reduce this avenue for entrance.

One of the most common means of entry for other tree crops besides mechanical injury was through areas of the cambium weakened by disease. These diseases usually consisted of a canker-like growths caused by diseases such as collar blight in apples and valsa canker in peaches, nectarines, and apricots. In its attacks on stone fruits, the plum borer larvae leave large wounds that are prime sites for Valsa Canker, a major disease on these in Michigan. Weiner and Norris (1983) pointed out borer activity as a favorablemeans of entry for the white rot fungus, Cytoporus versicolor, in tart cherries in Wisconsin. Moller and DeVay showed the plum borer to be an important vector of mallet wound canker, (Ceratocystis fimbriata), on almond trees in California. This almond disease is always associated with mechanical injuries to the bark and it was shown that ovipositing females attracted to the wounds could spread the disease to healthy trees. Adults who fed on the spores in infected wounds as larvae were shown to retain the fungus through pupation and emerge with it as adults and pass it to new wounds by excretion. Another way the disease could be spread was for the adult to contact the spores upon emergence from an infected area or to picked the up from other wounds during oviposition and transport them on their bodies to new locations. The larvae were also shown to be able to transport the spores both by contact and injestion-excretion, but for the most part the larvae do not move from the original wound. They may, however, increase the infected area by their feeding and prevent the infected tree from closing the wound with callous tissue to heal itself. Future studies may show the American plum borer to be a vector for a variety of tree fruit diseases in Michigan and other states as well.

Entrance through black-knot at any height in the canopy is very common in Michigan and surrounding states and is characterized by the reddish brown frass of the larvae. Lesser peachtree borer larvae are commonly found in black-knot as well. Very high populations of plum borer larvae, which once they have consumed most of the black-knot tissue and the surrounding live cambium, have been ocassionally reported in Michigan to move out to feed on the mature plum fruit to finish their larval development. The larvae have also reported to commonly attack a related disease, olive knot (Bacterium savastanoi), on olive trees in California as far back as 1917 by Essig even though the larvae were not properly identified as American plum borer until later.

Reports of the larvae of the plum borer attacking the graft unions of dwarf rootstocks on many fruit and nut crops are very common throughout the U.S. and Canada. A prime example of this has occured just recently on young grafted almond trees throughout California where, along with two other borers, the plum borer has become a minor pest in addition to a disease vector as previously mentioned. Trees damaged by this borer complex often split at the weakened crotch from the wind (VanSteenwyk et al, 1986). Pierce and Nichols (1941) describe in detail the serious problems caused by the pecan borer and plum borer on the graft unions of young pecan trees. They estimated two-thirds of 1,200 grafts and one third of the 3,000 patch buds placed on pecan trees were destroyed by these borers in an orchard at Gustine, Texas in 1933. The borers were also shown to cause much damage by girdling the basal portions of sprouts that have been previously patch-budded and that these girdled sprouts were often blown off the tree. In the cases of both almonds and pecans, the borer problem became insignificant as the tree grew older and the tissues of the scion and stock grew together. In Michigan, the plum borer in association with the dogwood borer has become an increasing problem on bench grafted apple seedling. Both species of larvae, often on the same graft wound, feed under and around the grafting wax at the union eventually girdling and killing the grafted areas.

Another consequence of dwarf rootstock in fruit trees, but especially apples, is the development of advantageous root growths known as burr knots up the trunks of certain varieties. These burr knots are attractive to the plum borer and sesiid pests including S. scitula known as the pecan borer or the dogwood borer in fruit and ornamentals and these two species are often found in close association on this food source in Michigan and the eastern states. Control strategies involving the use of napthalene acetic acid (NAA) employed for the killing of burr knots have been complicated by the the plum borer being even more strongly attracted to this freshly killed burr knot material, from which the dogwood borer will leave. Dogwood borer larvae may become numerous in an orchard but seldom feed beyond the burr knot area which usually disappears anyway as the tree ages. Mortality from the dogwood borer alone is rare in apples and treatment is not critical. Plum borer larvae, however, will continue to feed on the dead burr knot material killed by the NAA until it is entirely consumed. Then it will use this site to enter the living cambium and do significantly more damage than possible from the burrknot - dogwood borer interaction as the plum borer may eventually girdle the tree (H. Reidel, pers. comm., 1986).

In the southern regions, the plum borer's diet has expanded beyond cambial tissue to include stored woody materials such as sweet potatoes, cotton stems, and corn stalks. It has been commonly brought into extension offices recently in the south as a pest attacking stored sweetpotatoes in the home (Neunzig 1988, personal communication).

The injury to the cherry trees of Michigan caused by the hydraulic clamps of mechanical harvesters has been responsible for possibly the largest build-up of the plum borer and caused the most injury to any crop in the U.S.. Michigan grows 80% of the nations tart and sweet cherry crop along its western shore along Lake Michigan. Here the cherry industry has prospered since the turn of the century with little mention of the American plum borer until the cultural practice of manual harvesting changed for economic reasons in the early 1970's to the almost exclusive use of hydraulically powered mechanical harvesters. The resulting crushed and cracked cambium from this type of harvesting provided the ideal means of entry for the plum borer and harvest coincides with the second generation emergence and oviposition.

At first the increased infestations were not noticed because the larvae were thought to be the lesser peachtree borer, a similar larvae. The damage caused by the plum borer was also somewhat similar, although effects on the tree were not. The lesser peachtree borer's larvae tend to travel up and down the whole tree following natural cracks or pruning damage from the ground level of the tree to far up into the canopy. Thus it was considered a pest, but not a crippling one since the trees were tolerant of a considerable amount of this type of damage. Chemical controls applied at this time for what were thought to be LPTB larvae, killed only the relatively low levels of LPTB already present and had little affect on the plum borer population because the timing and materials were ineffective. The result was an almost pure culture of APB in areas such as Traverse City where LPTB used to be considered a major pest averaging 3 larvae per tree and now had been replaced with the plum borer with averages of up to 11 larvae per tree.

The plum borer larval damage is much different than damage caused by lesser peachtree borer larvae. It can not enter the cambium layer without help of some sort and once it has entered it first concentrates on feeding on the damaged tissue to enlarge the entry sites and to stop any healing of the site. This continued feeding induces gummosis from the tree trying to heal itself, which in turn attracts many more females to lay their eggs nearby. This results in large communities of larvae in which 20 or more larvae at one wound are not uncommon in many cherry orchards in Michigan.

These larvae confine their feeding almost exclusively to the area from the ground level of the trunk to the crotches of the scaffold limbs where the harvestor clamps have repeatedly injured the tree. The only noteable exception in Michigan is the infestations of black-knot in the upper canopy of plums. Feeding of the larvae continues to move horizontally around the trunk in a band typically about two feet thick until the trunk is eventually girdled (Fig 7A&B). Repeated shaking by harvesters along this area every year increases the number of suitable sites available in this relatively concentrated area, resulting in multiple colonies on a single trunk. These colonies will continue to feed for a couple of years after the tree has died. Since the outer bark is not fed on, it often serves as a shield protecting the larvae beneath long after tissue in this area has died from lack of nutrients and the larvae have moved considerible distances beneath it from their initial entry site.

Growers often not aware they have a problem because the trunk looks normal from the outside to casual observation. Huge sections of seemingly live bark, however, can often be pulled away to reveal almost completely girdled trunks with many generations of accumulated frass, old pupae and hibernacula beneath (Fig. 6). As more cambium tissue is

Figure 6. American plum borer hibernacula and frass accumulated under tart cherry bark over many seasons.

Figure 7A. American plum borer girdling damage on a tart cherry tree.

consumed over the years, the tree vigor is continually diminished and the unhealed wounds are left open for

ally

for

consumed over the years, the tree vigor is continually diminished and the unhealed wounds are left open for airborne and insect vectored diseases such as Valsa canker and others as mentioned before.

In Michigan, the 33% decline of life of the average tart cherry orchard from 30 years to 20 can be linked in large part directly or indirectly to the prescence of the American plum borer. A typical colony of approximately a dozen or so larvae have been observed to girdle a 6" scaffold limb in less than two years. Just how much girdling damage a tree can take before the yeild is significantly affected is not precisely known but varies with the type of tree and conditions such as irrigation and tree vigor. Trickle irrigated trees in the Traverse City area have been observed over 80% girdled without significant yeild losses noticed by the growers. It has been speculated that irrigated trees have a more moist cambial region and hence looser bark that is more likely to slip and crack from the shaker during harvest. This may account for the much higher incidences of damage and numbers of larvae in the Traverse City area where the majority of irrigated cherries in the state are found.

Weiner and Norris (1983) estimated 60.2% infestation of the chlorpyrifos treated tart cherry orchards, that now look to have been improperly timed, compared with 53.5% infestation in unsprayed orchards. In Michigan, where cherry trees are shaken at age 4-5 years, almost all orchards that had at least one season of shaker damage were found to be infested to some degree by the plum borer. A thirty orchard survey of 10 trees from each orchard in western Michigan is shown in Appendix 3. From this survey it was found that the older the orchard, and thus the more years of accumulating harvestor damage, the higher the population. The number of larvae per wound were not counted as in Weiner and Norris (1983) but the percent of the trees in the orchard wounded was noted and analyzed in Table 6. It was shown that the higher the percentage of wounded trees in the orchard, the higher the number of larvae per tree.

TABLE 6 Relationship of tree wounding to American plum borer infestation in western Michigan cherry orchards.

% trees wounded	mean # of larvae for orchard type sampled
0-20% (14 orchards)	.47c
20-50% (7 orchards)	1.46b
50-100% (8 orchards)	3.13a

* Means followed by the same letter were not significantly different by SNKMRT at alpha = .05.

In some areas of Michigan, plums are also shaken. This results in extremely high population of plum borer larvae sometimes exceeding 90/tree, but plums seem to be the most tolerant to damage of all tree fruits in Michigan. Sweet cherries are mechanically harvested only rarely in Michigan and still use manual labor resulting in the plum borer being much less of a problem on this crop. Because of the larger size of the trees and their tougher bark sweet cherries are harder to damage with shakers and seem to be more difficult for larvae to establish in and more tolerant of damage than the smaller tart cherry trees. Plum borer larvae have been also found occasionally in significant numbers on peaches in Michigan, but only rarely and in small numbers on apples, apricots, nectarines, and pears.

AMERICAN PLUM BORER PHEROMONE DEVELOPMENT

Before the development of a pheromone for monitoring, studies into the biology of this pest were difficult because of long adult emergence and almost overlapping generations. Almost all of the early work indicated that this moth was single brooded, although Blackslee (1915) mentioned the possibility of a second generation overlapping the spring generation. Pierce and Nickols (1941), however, indicated a possible 5 generations in central Texas. Although it is almost certain that more than two generations exist in the southern states, this number is probably too high and due to confusion with overlapping generations. Personal observations in central California almond orchards and communication with Robert Van Steenwyk (1988) indicate only two generations and possibly a partial third in that region. Pheromone capsules were sent to both California, South Carolina, and Ontario for monitoring purposes, but were either not placed or not monitored throughout the season. Two other members of this genus found in the south, _E_. _magnolialis_ and _E_. _ostricolorella_, are thought to be double brooded in the southern U.S. and so probably is the American plum borer.

During the spring of 1985, over 400 live pupae were excised with hammerand wood chisels from tart cherry orchards near Mears, Michigan and sent to Dr. Wendel

Roeloffs of Geneva, New York to provide material for the development of a sex pheromone for the American plum borer. Dr. Roeloffs was able to isolate a possible pheromone in less than three weeks employing an electroantennagraph to measure the excitibility of freshly excised male antennae to different chemical stimuli. Four different types of pheromone dispenser capsules containing the alchohol and aldehyde forms and mixtures of the two forms were sent for testing in early June in time for the last two weeks of first generation emergence. Blank septae were also sent and tested to check for cross contamination.

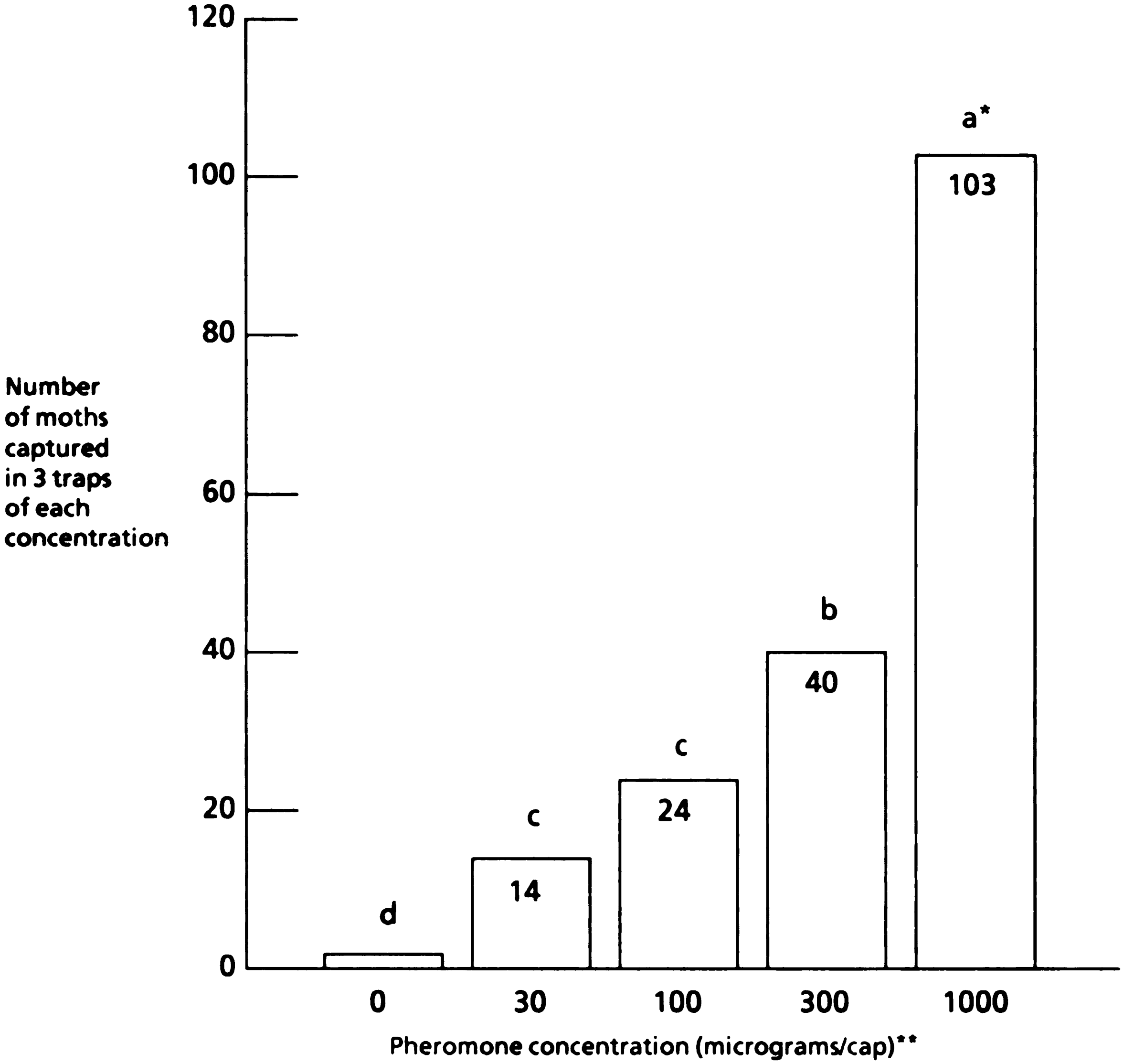
These capsules were set up in block treatments using Phercon II traps at two different 20 acre tart cherry orchards in Oceana county. The four treatments were replicated three times at each location and set up away from the edges of the orchard. Treatments within a replication were set up alonga single row with 50 feet between traps for all treatment and at least 300 feet between each replicate within the orchard. Extreme care was taken during initial set up and in all instances of handling the capsules to prevent any contamination between the different forms of pheromone. The traps were checked every other day and the trap catches recorded until the end of the flight period in mid June. At each observation the traps were rerandomized within each block, and moths trapped in the tanglefoot were either scraped out or the traps changed to avoid confusion in trap counts. Although peak emergence was over when the traps were first placed, trap catches were sufficient for evaluation. Only the last aldehyde formulation shown below in Table 5, caught any moths during this period. This formulation was the acetate corresponding alchohol form of the Indian meal moth pheromone that had been oxidized to an aldehyde. A total of 44 moths caught in the total of 6 traps in these locations over a two week period.

Table 7. Composition of Field Tested Pheromones for Spring of 1985.

1. Blank	
2. 500 ug	Z-9,E-12,14:Ald
+ 250 ug	+ Z-9,14:Ald
3. 500 ug	Z-9,E-12,14:OH
+ 250 ug	+ Z-9,14:OH
4. 500 ug	Z-9,E-12,14:Ald
+ 250 ug	+ Z-9,14:Ald
+ 500 ug	+ Z-9,E-12,14:0H
+ 250 ug	+ Z-9,14:OH

The effectiveness of varying concentrations of this formulation were evaluated on the summer generation emergence starting in July. Four concentrations and a blank were used again at the same locations and with the same experimental design for the second generation starting in early July through the end of September. The concentrations ranged from blank septum, 30 ug, 100 ug, 300 ug, to 1,000 ug per septum. The highest concentration of 1,000 ug or a milligram/septum proved to be by far the most effective (Fig. 8), and this concentration was standardized as the the commercial APB pheromone offered in 1986 by Zoecon@.

Gas chromatograph area counts by Dr. Roeloffs of all concentrations of the septa tested showed a 1:1.7 ratio of mono to diunsaturated aldehydes, a 1:1.6 ratio of mono to diusaturated alcohols, and a 1:2:1 ratio of total aldehydes to alcohols. Fig. 9 shows the structure of Dr. Roeloff's identification pheromone for the American plum borer. Subsequent pheromone trapping from 1986 through 1988 with the three pheromones produced a composite pheromone emergence graph for the three lepidopteran cambiun feeding pests of cherries, including both generations of the American plum borer and the overlapping generations of the lesser peachtree and peachtree borers (Fig. 10).



*Means followed by the same letter were not statistically different by Chi Square Test at t = .01.
**Same pheromone caps were used from July 6 - September 10, 1985.

Figure 8. American plum borer pheromone concentration effectiveness.

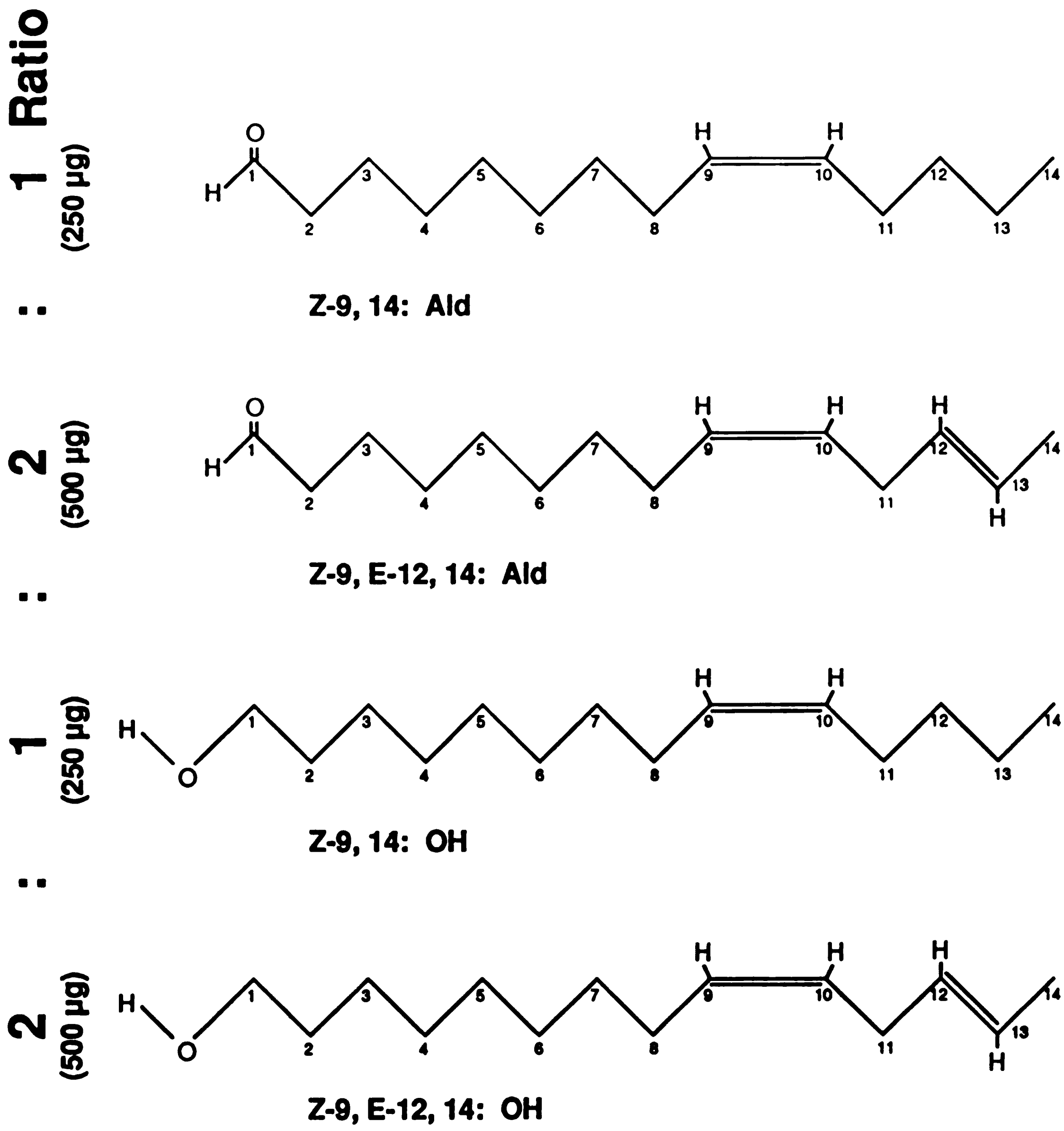


Fig 9. Chemistry of Dr. Roeloff's Identification Pheromone for the American Plum Borer.

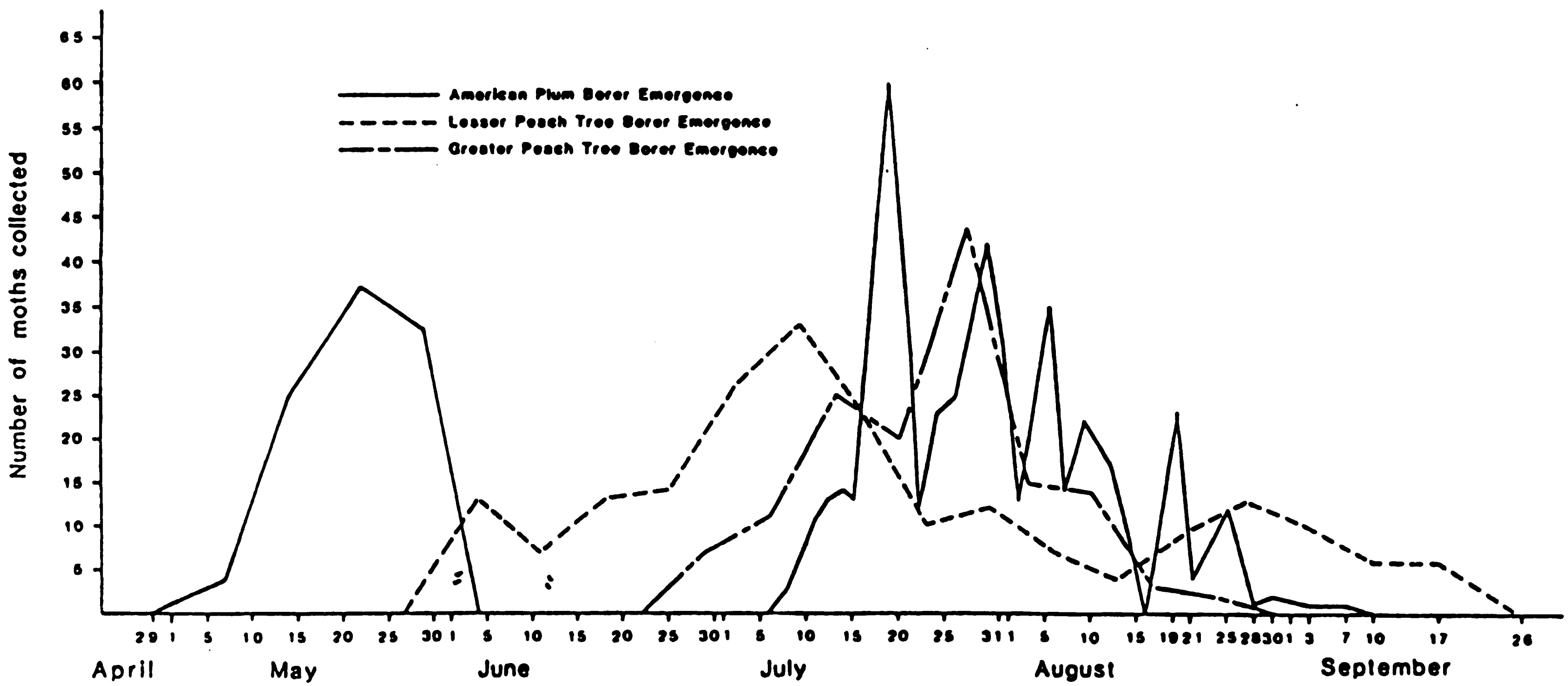


Figure 10. Adult Emergence of Three Borer Pests of Stone Fruit in Midwestern Michigan.

BIOLOGICAL CONTROL

Biocontrol plays an important part in the control of the plum borer in the cherry and plum orchards of Michigan. Several species of insectivorousbirds were important in the control of the plum borer. The most prominent ofthese were the downy woodpecker, Dendrocopos pubescens, and the yellow-shafted flicker, Colaptes auratus, which could be commonly found working the trunks of plums especially in the spring and summer months. In the fall, nuthatches (Sittidae) and related insect feeders were seen to probe the wounds and splits seeking quiescent larvae and hibernaculae. Blackslee (1915) also noted woodpeckers as being important predators of the plum borer on apples in Virginia. Infrequently, shrews (probably Blarina brevicauda) were also found under the loose bark of shaker wounds in the late fall feeding on the overwintering hibernacula and in the spring feeding on the pupae.

The most commonly noted parasites of the plum borer have been the ichneumon wasps. Blackslee (1915) lists some of members of this family in his study and indicates one of these as an Idechthis sp. as being very common and accounting for over 13% of 104 larvae reared from the field. These were described later as Idechthis nicricoxalis by Cushman (1915) and are now placed under the genus Venturia. Also noted as a parasite was Itoplectis marginatus (Prov.)

from Georgia that Cushman (1921) later placed with the additional synonym of Scambus marginatus as being Ephialtes aequalis (Provacher). This species is now known as Coccygomimus aquilonius (Cresson). Also listed by Blackslee in 1915 was an unidentified Pimpla sp. which Cushman later in that same year identified as Ephialtes aequalis (Provancher). This species is very common in Michigan but was not reared from the plum borer in this study. Also noted as far less common parasites were Mesostenus thoracicus (Cresson) and Mesostenus gracilis Cress. which occur in Michigan but were not reared in this study.

Venturia nigricoxalis was by far the most commonly reared ichneumon parasite of the plum borer reared in Michigan. This ichneumon could be found in almost all infested orchards surveyed throughout the state. It was found to have two generations with emergence coinciding with the plum borer adult emergence with both species peaking in May and July, but with the borer having a relatively drawn-out emergence and the parasite a relatively short emergence period. Since the adults of this wasp were relatively short lived in the laboratory, it is assumed that the eggs were laid soon after on the very early instars of the plum borer. Death of the borer larva and pupation of the wasp took place during the pre-pupation period of the plum borer and only one parasite per larvae ever survived to this stage. V. nigricoxalis were most commonly found in older, more heavily damaged orchards where chemical control programs were somewhat neglected but could be found in some numbers in all but the most intensively sprayed orchards. Percent parasitism in the state ranged up to 25% in these older semi-abandoned orchards, but averaged abount 10-15% in most orchards.

Another ichneumon found for the first time in Michigan and reared for the first time on the American plum borer was Campoletis pyralidis Walley. First described as an undetermined species of Campoletis from larvae reared on Acrobasis (Pyralidae) larvae (Finlayson, 1967), it has only recently been described from adults (Walley, 1970). It is listed as an eastern U.S. species that occurs up into Canada and westward to Ohio, but was a new state record for Michigan and was not known to occur on the genus Euzophera before this study. Only one specimen was reared from an overwintering spring generation larva. One suspected ichneumon parasite that was very common in the same orchards and in the same trees as the plum borer but was only reared on the lesser peachtree borer, S. pictipes, was Liotryphon variatipes.

Two species of spider predators were also found to help in the control ofthe American plum borer in this study. Both were from the family Thomisidae known as the crab spiders and although many species of spiders from this family were common in the galleries under cherry bark, only those individuals that were actually found feeding on the borer larvae were saved for identification. The first of these was a Coriarachne species of which only immatures were saved and could not be identified to species. This species was the most common of the two and the specimens found feeding were all found in early to mid October, overwintering as immatures. The second was Xysticus triguttatus Keyserling which is listed (Turnbull et al.,1965) as ranging through most of Canada and throughout all but the western U.S.. Adults of this species were found feeding in mid April as adults and it is probable that they overwinter in this stage. Both species were not found during the summer months in these galleries and were presumed to move out into the orchard to hunt for prey. Neither of these species were found to specialize on borer larvae, and were only rarely found feeding on the smaller instars or sick individuals.

Only a single species of beetle larva was found to be predaceous on the plum borer larvae in their galleries under the bark of cherry and plum in Michigan. This was Tenebriodes corticalis (Melsheimer) which is an important predator of various forest insects such as Scolytidae. Blackslee (1915) reported this species as a predator of the plum borer in his study with apples. This insect is reported to range throughout the U.S., Canada, Mexico, and Guatemala (Barron, 1971). The larvae were commonly found feeding on all larval instars but mainly in older trees with extensive galleries. These trees tended to be found in abandoned and neglected orchards. This species was found to overwinter as full grown larvae under the bark until spring. These larvae pupated in April and May into the hard-bodied, black adults that are also predaceous but were never observed feeding on borer larvae. The adults are thought to be nocturnal.

Ants were also noted in this study and by Blackslee (1915) to play significant roles as predators. Ant nests were common in older, extensively damaged cherry and plum trees in Michigan and borers of any sort were rarely found in such trees. At this stage, the trees were not producing a commercial crop so that the benefits were minimal. One final parasite of the plum borer that Blackslee mentions reared from the plum borer is a species of nematode referrred to as a hairworm identified as a possible Mermis species but was not noted in this study.

Finally, a Hirsutella sp. was found to be common on the plum borer in orchards throughout the fruit growing areas of the state. Speare (1912) recognized this genus as belonging to the Stilbaceae of the Fungi Imperfecti and later Petch (1932) found the sexual stages of one species of Hirsutella that is classified as a Cordyceps. Since that date several species of Hirsutella have been found to be the conidial or imperfect stages of species of Cordeceps (Charles, 1937).

<u>Hirsutella</u> is characterized by slender, erect, clavae from which phialides arise. These phialides have an inflated base and one or occasionally two long thread-like sterigmata, each bearing a single apical conidium. The conidia are surrounded by a gelationous substance which causes them to adhere in clusters.

Most infected larvae of the plum borer were found with long external hyphal "horns" growing outward from the larvae and sometimes attaining more than twice the length of the larvae (Fig 11). The cadavers of the larvae first became extremely hard and rigid soon after death as the internal organs were quickly quickly converted to hyphae and then later the hyphal horns emerged through the oral and anal openings, appendages, genital openings and sometimes laterally through the body wall. Many of the mummified larvae found in the field never seemed to develop fungal horns. Fresh mummies brought indoors required moisture before developing these horns and those collected fresh in the fall required a cold period as reported by Charles (1937) for <u>Hirsutella</u> <u>subulata</u> Petch on codling moth in Virginia.

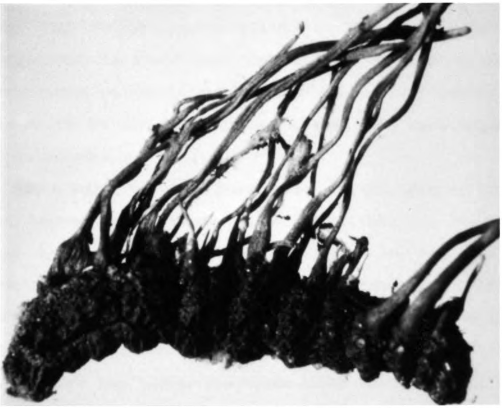
Fresh mummies of the plum borer with and without horns could be found in both the spring and summer generations of the plum borer indicating this pathogen may be capable of at least two generations per year. In both generations, the larvae were generally killed by the pathogen before pupation

Figure 7B. American plum borer girdling damage on a tart cherry tree.

Figure 11. *Hirsutella* mummified American plum borer larva with fungal horns.

t

rva



although about a half dozen pupae with the characteristic fungal horns were also found. In the field, development of the fungal horns and spore release coincided with adult emergence and egg laying. This meant that larvae from the overwintering first generation that were infected in the spring died before pupation in early July and developed these horns during peak emergence about two weeks later. The infected larvae of this summer generation then died in October as the larvae began to build their overwintering hibernacula but did not develop horns until adult emergence in mid May of the following year. Mummies of the overwintering larvae required a cold period of about two weeks as reported by Charles (1937) for H. subulata before development, but the summer generation did not. Almost all of the larvae killed in the summer by this pathogen were in their last instar but those larvae of the overwintering generation were killed in whatever instar they happened to be in when diapuase began and were often of earlier instars.

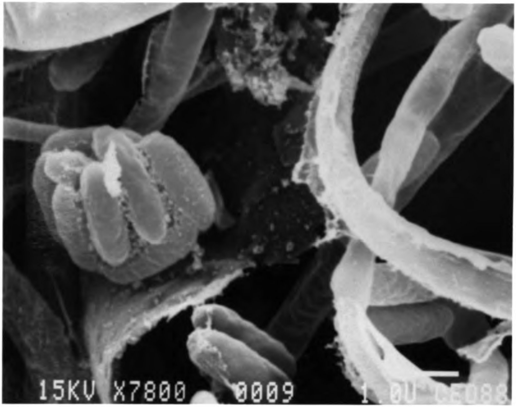
Trees with heavy infestations of the fungus on the borer larvae could often be distinguished by the white fungal horns protruding through cracks in the bark to disseminate their spores. In a plum orchard in Allegan County, Michigan, 114 out of 278 larvae or 41%, were killed by this pathogen before pupation. In this same orchard almost 16% of the lesser peachtree borer were also killed by this pathogen. Two larvae out of about one hundred dogwood borer, S. scitula, larvae were also found with what appeared to be this pathogen in apple orchards of Oceana County. Hirsutella sp. was most commonly found in association with the plum borer in cherries and plums in Michigan but a Hirsutella species was also found occasionally on the lesser peachtree borer and plum borer in peach orchards as well.

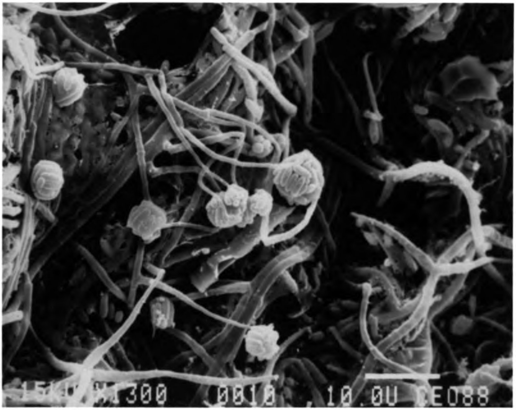
In the orchard survey (Appendix 3), 15 out of 26 orchards that had plum borer, or 58%, were found to have this fungal pathogen present. This survey also indicates that this pathogen seems to be density dependent, since it is by far the most prevalent in those orchards with the highest populations of the plum borer.

Laboratory cultures of this pathogen were easily reared on SMA food media and although it did not develop fungal horns, it grew very rapidly in a very white, thick fungal carpet. It generally did not produce conidial spores until it had used up most of its food source. Figures 12 and 13 show electron microscope pictures of the conidiophores and the hyphae from SMA culture.

Figure 12. SMA cultured Hirsutella conidiospores and hyphae.

Figure 13. SMA cultured Hirsutella hyphae and conidiospores.


15KV X7800 0009 1.0U CE088


15KV X1300 0010 10.0U CE088

DISCUSSION OF BIOLOGY

A much more complete biology of the American plum borer is now available. It was found to have a much more diverse range throughout the U.S. and Canada than previously thought and an extremely diverse range of foodplants. Much of the information on the plum borer has appeared in the form of a few sentences in obscure publications from many different fields such as forestry, fruit, and ornamentals and has never before been pulled together to give a more complete understanding of this ubiquitous insect. Improper identification as just another well-known sessiid or other such lepidoptera pest, has led to the plum borer being overlooked in the literature. This has also been compounded by its common association as part of a complex of other lepidoptea.

Even when known as a serious pest, as in the case of cherries in Michigan, incomplete knowledge of the biology and lack of a monitoring tool such as a pheromone has hampered studies. The developement of the pheromone by Dr. Roeloffs and the subsequent field testing in Michigan has been and will be a powerful tool in monitoring for this insect not only in Michigan but for its entire range and will help complete our knowledge of this pest. Hopefully this pheromone will also attract the other pest species of this genus or give clues into developing a specific pheromone for them as well. A knowledge of flight periods is also valuable to extension personel and grower attempting to control this pest.

The development of a method for rearing plum borer larvae on a readily available codling moth diet and the establishment of the developmental periods at a specific temperature for all stages is a good beginning for establishing a base temperature and the development of a phenology model. The rearing of all stages at four additional temperatures and a fecundity study on length of adult egg laying and distribution over time would complete most of the information needed for such a model.

A more complete understanding of the various biocontrol agents consisting mainly of ichnuemons and a Hirsutella fungal pathogen would be very interesting and, with proper timing of control measures such as fungicides and insecticides, biocontrol might help to enhance commercial control of this pest as it approaches the 20% level in some low insecticide input orchards. Studies into the Hirsutella fungal pathogen alone would be worthwhile as a separate project since it does not appear to match any of the known species in the literature, although it comes close to Hirsutella subulata. This pathogen also appears to be able to use the lesser peachtree and dogwood borer larvae as hosts. None of the Hirsutella in the literature have been reported as using sessiid larvae as hosts before. The 30 orchard survey reported in Appendix 3 has shown this pathogen to be present in the majority of cherry orchards throughout the state and often giving up to 50% control.

The damage the plum borer inflicts on its various hosts over time also needs to be researched. This study observed girdling of scaffold limbs over a period of two or three years and found that the life of a cherry orchard was reduced, in part by the plum borer, from 30 to 20 years. It is unknown however, as to how much girdling damage a full grown cherry tree can take before a significant loss of yield occurs or mortality increases. Trap catches need to be related to damage figures and thresholds for treatment set for these catches to be useful by the grower and to prevent unnecessary applications. These thresholds and the tolerance levels also have to take into account the possiblity of the plum borer as being a disease vector as shown by Moller and DeVay (1968) in almonds. If the plum borer proves to be a significant vector of fruit diseases, and is able to transport diseases from one orchard to another, then economic thresholds will be much lower than if they are established for the cambium feeding damage alone. Some of the behaviorally very similar species of sesiids on fruit and ornamentals, such as the lesser peachtree borer and dogwood borer, might also be suspect as vectors it the plum borer proved to be one.

CONTROL EXPERIMENTS AND RESULTS

INTRODUCTION

Historically, as a minor pest until the mid 1900's, control of the American plum borer has not recieved much attention in the literature. Most of the early literature recommends the digging out of larvae by hand or killing them by pushing wires up into the burrows (Slingerland, 1914) and then covering the damaged area with a wound spray or paint mixture. This method was still recommended as late as 1972 in U.S.D.A. Home and Garden Bulletins #190. Perhaps the earliest control method using chemicals was the recommendation by Forbes in 1891 of a preventative soap, soda, and carbolic acid mixture for possible summer control. Insecticide trials were also mentioned as having failed, but were not specified. Sanderson (1901) wrote of smoothing the bark with scrapers and using washes of whale-oil soap or a thick caustic soap mixed with carbolic acid to prevent egg laying, but still relied heavily on hand- picking the larvae. Blackslee (1915) in his milestone work on the biology of this pest for the U.S.D.A, recommended only the cutting away of the sheltering dead bark and the painting of these wounded areas. He stated that nothing could be expected in the way of control from poisonous washes.

Hamilton (1933) gave the first true insecticide recommendations for this pest of mixtures of 1 quart soluble pine tar and and 1 pound paradicloro-benzene mixed with an equal part of water. He reported excellent results on infestations of this and other pests on linden trees but reported it was phytotoxic to new growth. Recognizing that hand scraping of tree bark and digging in the cambium was too costly and labor intensive for many trees, and harmful to the trees, Pierce & Nichols (1941) initiated the first intensive control study of this pest but used as similar mixture of crude cottonseed oil and para-dichlorobenzene. This was reported to be effective against shallow feeding larvae only. Larvae were observed to vigorously leave the burrows within thirty minutes of application after contact which usually resulted in death. Larval feeding in burrows that extented several inches beyond the point of entrance were not affected.

They also reported that in the types of graft wounds the plum borer larvae preferred to infest in Texas pecan trees. It was found that the inlay bark graft method for grafting was superior to regular bark grafting because by that method the scions could be closely fitted to the stock and easily covered with wax to protect from entrance from the larvae. The larvae were found to enter through cracks in the wax or through uncovered areas so all grafting and pruning wounds were reccommended to be thoroughly covered with a grade of grafting wax that would maintain a good seal over the wound until healed over or the graft had grown to form a good union. The mixing of PDB in the grafting wax was not found to be any more effective than plain wax.

Kelsey and Stearns (1957) were the first to use of dilute treatments of relatively modern insecticides with high pressure handguns to penetrate into the natural cracks and and crevices of bark and into the burrows and relatively inaccesible damaged areas under the dead bark. The materials used were DDT and parathion and were reported to give good control for up to 2 years by the authors. Considering, however, that the population was low atless than 1 plum borer larvae per 7 Lodi apple trees in the untreated trees and that the evaluations were done in July, which in Delaware should have coincided with the peak emergence of the second generation adults and left no larvae available for evaluation, these results do not appear conclusive.

The most modern control works to date have been by Weiner and Norris (1983) on tart cherries in Wisconsin and Van Steenwyk et al. (1986) on almond trees in California. Weiner and Norris, in sampling over 500 wounds for boththe lesser peachtree borer and the plum borer, proposed two methods of population estimation of both species in an orchard. Both of these methods depended on "constants" representing the average number of borers per wound found in their orchards. These constants were 1.93 for APB and 1.28 for LPTB. In Michigan tart cherry orchards, however, these values were found torange in tables 8 through 15 from a ratio of 3.7 APB to .94 LPTB in the mid and southwesten cherry growing areas of Michigan to 10.7 to almost zero in the northern orchards around Traverse City where the LPTB has almost been totally replaced by the plum borer. The counting and identification of larvae from frass piles for control work that they used, while non-destructive and less labor intensive, was found to be inaccurate in Michigan. The painting of wounds with white paint did show definite control but there was a problem of adequate coverage in old wounds with extensive sheltered areas of damage under old dead bark. Paint can only serve as a shield to the penetration of the cambium by the newly emerged larvae or possibly as a deterrant to egg laying by the adults, but it can not seal off sheltered areas of extensive damage typically associated with shaker damage on cherries and plums. An insecticide must be used to prevent the larvae from reaching these areas of santuary.

Van Steenwyk also used the method of counting frass piles for evaluation for a complex of 4 borers on almonds. A total of 3 applications of white latex painted mixed with high rates of 5 different compounds were tested over 2 seasons and gave good control of the complex but no breakdown on the results were given by species because of this method of evaluation. Lorsban was evaluated in the first season with excellent results, but carbaryl was choosen for the final season's tests and for the final recommendation because it was less expensive in the case of multiple applications (Van Steenwyk, personal communication 1985 & 1988).

MATERIALS AND METHODS

These studies were conducted in numerous tart cherry, sweet cherry, and plum orchards throughout Michigan. Most of the field tests of this study were conducted in the predominant cherry growing areas of the state around the Grand Traverse Bay area and the Hart-Shelby area of Oceana County. Prior control efforts by Dr. Howitt in 1974 are presented in Tables 8 and 9. The experiments in these two tables were conducted in two 300 tree blocks within a mile of each other and were located in Grand Traverse County 4 miles north of Acme. In 1985, two chemical trials presented in tables 10 and 12 were conducted for this study in a 20 acre block of 22 year old tart cherries in section 14 of Leland township of Leelanau County. An untested portion of this same orchard was used again in 1986 for the experiment presented in table 13. In 1985, the experiment in tabel 11 was carried out on a 60 acre block of 30 year old tart cherries in section 22 of Golden township of Oceana County, 1 mile west of Mears, MI. The experiments presented in tables 14 and 15 were conducted in 1987 and 1988 respectively in a 25 year old plum orchard in Pullman township of Allegan County 3 miles west of Pullman.

All materials applied for control before the development of the pheromone in June of 1985 were timed by pupal emergence counts in the field as with tables 8 and 9, or with questionable notes on the biology in the literature. All materials were applied as coarse dilute sprays by hydraulic gun at 150 to 200 psi to the point of runoff from the ground level of the trunk up into the crotch and lower scaffold limbs. The rates are expressed in terms of material/100 gallons.

Evaluations for season long control were conducted in October. This proved to be the most appropriate time for evaluation because the white hibenacula of the diapausing larvae had been formed and the majority of the larvae were late instar. Evaluations for control of only the first generation plum borer were preformed in late June when most of the larvae were full grown or were in the pupal stage. Evaluations were made with hammers, long-handled screwdrivers and wood chisels to dig all larvae and pupae out of the cambium for positive identification as American plum borer, lesser peachtree borer, or peachtree borer.

Other evaluations that were done in such crops as almonds in California have used only observations of frass piles to determine control without any digging or direct observations of the insects. This does not work on cherry or plum where the larvae may be deeply entrenched in the cambium far from any wound or cracks where frass piles may be pushed out. That method does not take into consideration frass piles from other insects such as the LPTB which may or may not be controlled to the same degree as the plum borer.

Various stickers and ultraviolet light screens were used in combination with many of the test chemicals. A 50% aqueous mixture of polyvinyl butyral and white latex paint, now known and marketed as Treemax@, was used to prolong the life of the pesticide, act as a UV screen, and reduce winter injury. Vapor Guard@ and Bond@ (anti-dessicants that also act as UV screens and stickers) were used in combination with insecticides as well. The 4EC formulation of chlorpyrifos was used rather than the 50WP because of its more prolonged activity in wood. TD-2207@ is microencapsulated chlorpyrifos. All control experiments were statistically evaluated using the Student-Newman-Kuel multiple range test with a 95% confidence level.

CHEMICAL CONTROL RESULTS

CHEMICAL CONTROL

1974 Field Tests

In the early 1970's following the widescale use of mechanical harvestors and the resulting infestation and damage by borers, funding was provided to Dr.Angus Howitt at Michigan State University to support a graduate student to investigate the biology of this insect and to develop a control strategy onthe American plum borer. A masters student did initiate the project and with Dr. Howitt's help some control trials were initiated but the student's masters program was terminated early in the study.

The failure of the growers to control E. semifuneralis with conventional air-blast sprayers in their cover sprays in tart cherry orchards suggested the application of pesticides applied to the trunk area with a hydraulic gun at low pressure since the adults did not seem to be picking up the materials from the ground cover or the canopy.

The experiments shown in tables 8 and 9 were conducted in Grand Traverse County during the 1974 season in 2 tart cherry orchards heavily infested with the American plum borer and were available for analysis. A single application to the trunk and scaffold limbs was made for each of 6 different chemicals in a completely randomized design with 10 replications or trees per replication. These trees were

10 replications or trees per replication. These trees were evaluated on August 22.

The standard spray for lesser peachtree borer control at the time was endosulfan wettable powder (WP) applied with a hydraulic gun to the trunks and lower scaffold limbs at about 150 to 200 psi. Endosulfan was therefore selected as the standard, but other work had shown that the emulsifiable concentrate (EC) formulation of this material had a somewhat longer residual life on bark. Therefore, the 2EC was used at a rate of .75 lb active/100 gallons finished spray in both experiments. The new EC formulation of chloropyrifos made especially for wood protection and known as Dursban@ wasalso selected. This material was applied at a rate of 1.5 lb active/100 gallons in table 8 and half that rate at .75 lb active in table 9. Theother materials were used because all possessed the long residual actionthat was deemed necessary for control. Two soil insecticides, fonofos and carbofuran were applied at 1 lb and .25 lb active material/100 gallons respectively. In addition, an experimental compound from Noram@, NC-2596 4EC was applied at both the 1 lb and .5 lb rates active/ 100 gallons. A flowable formulation of carbaryl and an EC formulation known as Sevimole were also included and applied at 1 lb and .5lb active/100 gallon respectively.

Table 8. 1974 full season control trial on tart cherries at Traverse City.

Treatment	Form. /100 gal	Mean # of APB/Tree	Mean # of LPTB/Tree
1. check		5.7 a	1.5a
2. carbaryl 4EC	1,893 ml	3.3 ab	0.7 b
3. endosulfan 2EC	1,419 ml	2.8 b	0.7 b
4. NC 2596 4EC	946 ml	2.7 b	0.5 b
5. chlorpyrifos 4EC	1,419 ml	1.9 b	0.1 b
6. fonofos 4EC	946 ml	1.1 b	0.8 b

* Applied 22 May, evaluated 22 August, 1974. Single trees replicated 10 times in a completely randomized design.

** Means followed by the same letter were not significantly different from each other by SNKMRT at alpha = .05.

Table 9. 1974 full season control trial on tart cherries at Traverse City.

Treatment	Form. /100 gal	Mean # of APB/Tree	Mean # of LPTB/Tree
1. check		4.7 a	2.6a
2. carbaryl 4F	946 ml	2.3 ab	2.4a
3. endosulfan 2EC	1,419 ml	1.9 ab	1.3ab
4. NC 2596 4E	473 ml	1.8 ab	1.1ab
5. carbofuran 4F	473 ml	0.6 ab	3.0a
6. chlorpyrifos 4E	710 ml	0.4 b	1.6ab

* Applied 22 May, evaluated 22 August, 1974. Single trees replicated 10 times in a completely randomized design.

** Means followed by the same letter were not significantly different from each other by SNKMRT at alpha = .05.

1985 Field Tests

Previous biology studies and control work by Dr. Howitt indicated that the plum borer was probably double brooded in Michigan but the exact timing of these generations was only approximate without the development of a pheromone for monitoring purposes. It was known from field evaluations and from catches from black lights, that the adults could be caught from late May into August and the summer generation seemed to peak around harvest in mid July. It was desirable to avoid all applications later in the season at harvest because of the problems associated with chemical residues. Another reason was that the most promising material in earlier tests, chloropyrifos, was phytotoxic to foliage in the EC formulation when applied to sweet cherries after petal fall.

Because of these problems, control programs for this pest in Michigan were concentrated on a single application directed at peak adult emergenceand egge laying of the first generation in the spring for seasonal control. Additionally, it was hoped that a chemical with long residual action would give control of the lesser peachtree borer emergence which peaks a month later in June. The timing of the application was for first emergence and was obtained by a combination of caged virgin females and daily observations of pupae in the field. This timing was found to coincided with the white bud stage of tart cherries in all fruit growing regions of Michigan.

Since chlorpyrifos had given good control at 1.5 lb active/100 gallons, it was again choosen as the standard but the rate was doubled to 3.0 lb active/100 gallons for enhanced control of the second generation on the extremely high populations in the Traverse City area orchards. The pyrethroid fenvalerate was also choosen for evaluation because of its high toxicity to lepidoptera larvae and adults. It was applied at a rate of .3 lb active/100 gallons. The paint mixture known as Treemax@ was choosen as an additive to both insectides as well as applied alone to test the pure insecticide, insecticide-paint mixture, and paint alone strategies for control. Additionally the polyvinyl butyrol in this mixture was designed to form an elastic film for better coverage with the paint that would prevent UV degradation of the insecticides but still allow the tranfer of gases to the bark tissue and did not cause phytotoxicity. The material known as Vapor Guard@ also was to serve as an UV screen, but was also a sticker to help adhere the insecticide more tightly to the bark and prevent residue loss due to seasonal erosion.

The control evaluations in Tables 10 & 11 were conducted to determine if a single application of these materials timed for the first generation would give seasonal control of high and medium populations in the two major cherry growing areas of Michigan. The trial shown in Table 10, consisted of single tree replicated 7 times in a completely randomized design with at least one buffer tree in all directions around each treated tree. Table 11 shows the results of a trial consisting of a randomized completed block design replicated 4 times with buffer trees between each block and with 4 out of 8 trees per block being evaluated. Both trials were applied at the white bud stage of the tart cherry. The control evaluation shown in Table 12 was applied in a different area of the same orchard as the trial in Table 10, but in single unreplicated blocks of 32 trees in a row with two buffer rows between treatments. Applications in this experiment were timed for the emergence of the second generation by employing the recently develped experimental pheromone and from field observations. The objective of this experiment was to determine if spring applications directed at both the spring and summerbrood gave comparable control to an application timed specifically for the emergence of the summer generation. All treatments were evaluated in mid October.

Table 10. 1985 full season trial on tart cherries at Lake Leelenau.

Treatment	Form/100 gal	Mean # of APB /Tree
1. fenvalerate 2.4EC	473 ml	8.14 a
+ Treemax	+ 50% aqueous solution	
2. Check		7.00 a
3. fenvalerate 2.4EC	473 ml	4.43 ab
+ Vapor Guard	+ 946 ml	
4. fenvalerate 2.4EC	473 ml	2.57 ab
5. chlorpyrifos 4EC	2,838 ml	0.86 b
6. chlorpyrifos 4EC	2,838 ml	0.57 b
+ Tremax	+ 50% aqueous solution	
7. chlorpyrifos 4EC	2,838 ml	0.43 b
+ Vapor Guard	+ 946 ml	

* Applied 22 May, evaluated 15 October, 1985. Single trees replicated 7 times in a completely randomized design.

** Means followed by the same letter were not significantly different from each other by SNKMRT at alpha = .05.

Table 11. 1985 full season control trial on tart cherries at Mears.

of Treatment	Form /100 gal	Mean # of APB /Tree	Mean # LPTB/Tree
1. Check		3.70 a	0.94 a
2. fenvalerate 2.4EC	473 ml	1.56 b	0.31 a
3. fenvalerate 2.4EC	473 ml	1.31 b	0.43 a
+ Vapor Guard	+ 946 ml		
4. chlorpyrifos 4EC	2,838 ml	0.68 b	0.12 a
+ Treemax	+ 50% aqueous sol.		
5. chlorpyrifos 4EC	2,838 ml	0.06 c	0.12 a
+ Vapor Guard	+ 946 ml		
6. chlorpyrifos 4EC	2,838 ml	0.06 c	0.06 a

* Applied 16 May, evaluated 14 October, 1985. Randomized complete block design consisting of 4 blocks/treatment with 4 trees per block being evaluated.

** Means not followed by the same number were not significantly different from each other by SNKMRT at alpha = .05.

Table 12. 1985 summer generation control trial on tart cherries at Lake Leelenau.

Treatment	Form/100 gal	Mean # of APB/Tree
1. Check		10.70
2. Treemax	50% aqueous sol. (50 gal ai)	3.60
3. fenvalerate 2.4EC + Treemax	473 ml + 50% aqueous sol.	3.00
4. fenvalerate 2.4EC	473 ml	1.37
5. chlorpyrifos 4EC + Treemax	2,838 ml + 50% aqueous solution	1.00
6. fenvalerate 2.4EC + Vapor Guard	473 ml + 946 ml	0.85
7. chlorpyrifos 4EC	2,838 ml	0.75
8. chlorpyrifos 4EC + Vapor Guard	2,838 ml + 946 ml	0.14

* Applied 6 August, evaluated 15 October, 1985. Single unreplicated blocks of 32 trees, with only a select subsample of 8 trees showing borer damage being evaluated from each block. Same orchard as in Table 10.

<u>1986 Field Tests</u>

Field work in 1986 concentrated on biology and rearing studies, but favorable tests from the previous year indicated that the spring application of chlorpyrifos 4EC gave excellent season-long control of both generations of the plum borer. Although the urgency to control this pest had led to a recommendation for control in the 1986 Michigan State University Fruit Spraying Calendar (extension bulletin E-154), it was still necessary to repeat the Lorsban spring versus Lorsban summer generation applications to see if the season long control results from 1985 were reproducible. An untreated area of the same tart cherry orchard used for the trials presented in Tables 10 & 12 for the previous year was also selected for the evaluation presented in Table 13.

The emulsifiable concentrate formulation of chlorpyrifos was again used at the same 1985 rate of 3 lb active or 3 quarts formulation/100 gallons. Because the previous years applications at white bud had proved to be toxic to honey bees foraging on the trees and dandelions of the orchard floor during bloom and some bee kills were noted in hives in the orchards, materials were applied at petal fall. The timing was thus changed from first adult emergence at white bud to nearly peak emergence at petal fall. It was believed that, although the 7-9 day duration of the egg stage would allow early emerging adults to escape a petal fall application, materials applied atthis time would still impinge on the larvae emerging from eggs deposited by these adults. Therefore, a single application of chlorpyrifos was directed at the first generation at this time for one treatment and a second treatment received an identical application at this time and again in mid July timed forthe second generation.

Only two other materials were evaluated in Table 13 and both were applied post-harvest to determine if control over a single generation could be achieved with these less expensive materials. One material tested was a flowable formulation of trimethacarb. A mixture of the longer lasting formulation of carbaryl known as Sevin XLR@ was evaluated at 3 lb active/100 gallons in combination with the spreader/sticker known as Bond@. Single trees were replicated 7 times in a completely randomized design were used for this experiment with buffer trees between all treatments and all materials were evaluated in mid October.

Table 13. 1986 full season control trial on tart cherries at Lake Leelenau.

Treatment	Form. /100 gal	APB Generation at Application	Mean # of APB/tree
1. Check			8.18 a
2. trimethacarb 3.3F	3,441 ml	2nd	5.33 a
3. carbaryl XLR + Bond	2,839 ml + 946 ml	2nd	5.25 a
4. chlorpyrifos 4EC	2,839 ml	1st	0.42 b
5. chlorpyrifos 4EC	2,839 ml	2nd	0.00 b

* Materials for the 1st generation plum borer were applied on 13 May and materials for 2nd generation control on July 14, 1986. Single trees replicated 7 times in a completely randomized design.

** Means followed by the same letter were not significantly different from each other by SNKMRT at alpha = .05.

1987 Field Tests

With the control problem on cherries considered resolved, emphasis shifted to control of the American plum borer attacking plum. An extremely high infestation of this pest near Pullman in Allegan County was leased for testing purposes. This orchard consisted of older trees that had an extremely high incidence of black-knot disease in the canopy. The trunks were lightly damaged and cracked from shaker damage from previous years. Pre-season evaluation of 10 trees produced populations of up to 60 larvae on a single trunk area of a tree and a moderate infestation of many plum borer and lesser peachtree borer larvae feeding and overwintering in the black-knot of the canopy. Previous years foliar cover sprays of azinphosmethyl had not shown any affect on the population residing in the black-knot.

A chlorpyrifos treatment of 3 lb active/100 gallons and a high rate ofendosulfan at 3.5 lb active/100 gallons were chosen as the standards. All materials were applied at petal fall for plums which is generally close to petal fall for cherries. Included in the trials were the long lasting formulations of carbosulfan 4EC applied at 1 lb active/100 gallons and diazinonat 1.5 lb active/100 gallons. In addition a micro-encapsulated formulation of chlorpyrifos known as TD-2207 was tested at the 2.75 lb active/100 gallons. The plots were set up as single trees replicated 5 times in a completely randomized design with buffer trees between treated trees. All materials were evaluated on October 16.

Table 14. 1987 full season control trial on plums, Pullman.

Treatment	Form. /100 gal	Mean # of APB/Tree	Mean # of LPTB/Tree
1. chlorpyrifos 4EC	2,839 ml	13.4 a	0.0 b
2. Check		8.6 ab	3.0 a
3. TD-2207	2,839 ml	6.2 ab	0.4 b
4. carbosulfan 4EC	50 ml	4.0 ab	0.8 b
5. endosulfan 50WP	3,140 g	3.0 b	0.0 b
6. diazinon 50WP	1,360 g	2.8 b	0.4 b

* Applied 13 May, evaluated 16 October, 1987. Single trees replicated 5 times in a completely randomized design.

** Means followed by the same letter were not significantly different from each other by SNKMRT at alpha = .05.

1988 Field Tests

Failure of the standard chlorpyrifos cherry program to give control on plums in 1987, indicated the need for the evaluation of new strategies for control on plums. Failure was believed to be attributed to chlorpyrifos not adhering to the smoother bark of the plum and/or from high reinfestation from uncontrolled borer in the black-knot of the canopy. Therefore, double applications for each generation with the standard rates of chlorpyrifos were evaluated against the standard single application employed in the cherry program. In addition, the trials included the standard rate of chlorpyrifos in combination with the previously tested UV screen/sticker known as Vapor Guard. The first generation applications were applied on May 18th at petal fall and the second generation applications were timed for peak emergence on July 11th as indicated by pheromone catches. The plot consisted of single trees replicated 5 times in a completely randomized design with buffer trees between treatments. All materials were evaluated mid October.

Table 15. 1988 full season control trial on plum, Pullman.

Treatment	Form/100 gal	Mean # of APB/Tree
1. chlorpyrifos 4EC (spring application only)	2,839 ml	21.4 a
2. chlorpyrifos 4EC + Vapor Guard	2,839 ml + 946 ml	1.5 c
3. chlorpyrifos 4EC (spring and summer appl.)	2,839 ml	5.2 b
4. diazinon 50WP	1,814 g	13.4 ab
5. Check		10.0 ab

* Treatments # 1,2, & 4 were applied 5/18 at petal fall during the peak 1st generation APB emergence. Treatment #3 was applied on 18 May and also during the peak 2nd generation APB emergence on 11 July, 1988. Single trees replicated 5 times in a completely randomized design.

** Means not followed by the same letter were not statistically different from each other by SNKMRT at alpha = .05.

DISCUSSION

The first indications of control of the American plum borer control were found back in 1974. Compared to current 3 quart/100 gallon recommendation, the lower rates of chlorpyrifos were still able to give a statistically significant degrees of seasonal plum borer control on tart cherries. When compared to the the accepted standard for control of the lesser peachtree borer, endosulfan, chlorpyrifos gave equivalent or better control of both the plum borer and lesser peachtree borer. Several other control experiments conducted by Dr. Howitt on these two pests in the intervening years supported the results of these two experiments and indicated chlorpyrifos to be the most effective pesticide in controlling borers.

With this preliminary data available, the current project was initiated in 1985 as a part of the Michigan Stone Fruit Decline project. During this season, chlorpyrifos and fenvalerate were tested for control of both generations of the plum borer and chlorpyrifos was found markedly superior in giving seasonal control. Fenvalerate did give good to excellent control in all cases for the first generation, but did not have long enough residual activity for seasonal control of both generations. Chlorpyrifos did, however, give seasonal control against extremely high populations of the American plum borer and lesser peachtree borer even without the additives to enhance sticking and reduce degradation and these were deemed an unnecessary for control of the plum borer on cherries. While a pheromone was still being developed for monitoring purposes, the timing of applications chlorpyrifos EC at 3 lbs active/100 gallons at white bud was found to give acceptable control and an emergency recommendation was made in the Michigan State University Fruit Extension Spray Calendar E-154 was give for the 1986 growing season.

In the 1986 season, the problem of bee kills associated with the white bud application of chlorpyrifos was addressed. This was solved with no significant loss of control by merely moving the application date ahead by about 2 weeks to petal fall. Monitoring for the first time with a newly developed, but commercially available, pheromone confirmed the timing and biology of this pest. Chlorpyrifos was shown conclusively to give seasonal control of both generations. Control was not found to taper off over the second generation as fenvalerate did, but a single spring application of chlorpyrifos at petal fall was shown to give control of the second generation plum borer equivalent to a single application applied in July timed specifically timed for that generation only. Other materials were also tested for control of only the second generation, but gave inadequate control.

This excellent control program of chlorpyrifos on cherries, however, was not found to be acceptable for plums when tested in 1987. In this trial, chlorpyrifos 4EC and its microecapsulated formulation known as TD-2207 failed to give control. Only very high rates of endosulfan and diazinon gave any degree of control. This orchard had by far the highest incidence of of American plum borer yet found in the state with up to 90 larvae per tree. Control was further complicated by an extremely an extremely high infestation of black-knot in the canopy of the entire orchard. This black-knot was heavily infested with both the plum borer and lesser peachtree borer and served as a refuge area from pesticides as normal broadspectrum materials delivered concentrate by airblast in a normal grower program had little or no effect on the populations. Trunk applications controling the first generation in the spring were unable to control heavy pressure from large populations of adults reinfesting from the canopy above. The smoother bark of plums, further complicated control, as the materials tested did not seem to adhere to the bark as well as they did in the rougher bark of mature cherry trees.

In 1988, two strategies were employed to control for the American plum borer on plum : 1) double applications of full rates of chlorpyrifos with one application timed for the spring and one application timed for the summer generations; and 2) increasing the effectiveness of a single spring application of chlorpyrifos by enhancing the sticking of the Lorsban to the smoother plum bark and eliminating ultraviolet light as the major source of degradation with a spreader/sticker and UV screen known as Vapor Guard@ by Miller Co.

The single early season application of Lorsban failed again to give control again, but the double application gave acceptable commercial control. The Lorsban and Vapor Guard combination proved to give outstanding control with a single more conveinient and less costly application that double applications. The normal, recommended rate of Thiodan for other sesiid pests was tested as a standard, but failed to give control.

Because of this work, it now recommended by the Michigan Extension Service and place on the label by Dow Chemical Company. This recommendation states that chlorpyrifos 4EC applied at the rate of 3 quarts per 100 gallons of water and applied dilute using a hydraulic gun at 200 psi to the trunk and lower scaffold limbs at petal fall will control the American plum borer attacking cherries. For plums, either a double application of Lorsban at the same rate timed for each of the adult emergences, (petal fall and mid July), is recommended for control of the plum borer, or a single petal fall dilute application of the same rate of Lorsban plus a quart of Vapor Guard/100 gal.

Depending on the size of the trees and the percentage of the trees infested or damaged, this method of application usually requires from a quarter to a half gallon of finished material per tree with a normal commercial handgun at 200 psi.

Chlorpyrifos has been the only pesticide evaluated to date capable of giving seasonal control of the American plum borer on cherries or plums in Michigan. More evaluations of the various residue enhancers and UV screens in combination with chlorpyrifos and other materials are needed to give alternatives to growers. These tests should serve as a starting point for control of the plum borer on its many other host trees and most notably the nut trees such as almonds and pecans. Other materials or programs that may be less harmful to the environment and selective enough to allow the available biocontrol to work, need to be evaluated as well. The possibility of multi-seasonal control should also be researched. Chlorpyrifos may give control of the plum borer and other borers for more than one year, thus requiring applications only every 2 or 3 years. Tissue analysis of the bark and target area of the wound could be sampled regularly over a period of two or more years to study the effects of pesticide degradation over time and the effects of the various additives on the rate on degradation.

SUMMARY

Much of the biology of the relatively obscure American plum borer, Euzophera semifuneralis, has been completed in this study. Culturing this insect on an artificial diet at a fixed temperature has shown the plum borer to have 7 larval instars with head capsule widths that have been determined. Developmental times for the egg and all immature stages were also determined in these lab experiments. Field studies revealed two slightly overlapping generations in Michigan and a literature reveiw suggests only two generations throughout the U.S. Generalized developmental times for the field were also determined for Michigan from field observations and the proportions of stages of overwintering larvae were determined which helped explain the overlapping emergences of the two generations. A base temperature was not found nor was a degree day model developed however. Several species of ichneumon parasties and a new fungal pathogen of the genus, Hirsutella, were found that were widespread throughout the state and gave some appreciable measure of biocontrol.

An extensive review of the literature revealed a much greater range of foodplants and more extensive geographical range throughout the U.S. and Canada than previously thought. Heinrich's 1956 revision of the taxonomic literature brought many of the synonyms for the plum borer

and related species together for the first time. This paper has been the first real attempt to bring much of the economic literature together. The various attempts at control of the plum borer in the literature on several different crops and the methods for application and evaluation were reviewed and improvements suggested. A thirty orchard survey of the state showed the plum borer to be present in almost all mechanically harvested cherry orchards in Michigan and that the most damage and highest incidences of infestation were found in the older orchards that had recieved numerous years of repeatedshaker damage.

A specific pheromone was developed by Dr. Wendell Roeloffs at Geneva, New York, and was field tested in Michigan. First the specific ratios of the alchohols and esters were determined and then, over the second generation, the most effective concentration was selected. The development of this pheromone has made accurate monitoring of this pest for control and survey purposes possible for the scientist and grower alike for the first time.
Control trials over a four year period, using many different compounds,determined chlorpyrifos to be the most effective material. On tart cherries, a single dilute handgun application of chlorpyrifos to the trunk and lower scaffold limbs in the spring at petal fall was shown to give seasonal control. None of the other materials tested including fenvalerate gave season long control with a single

application. On plums, the single application control program that worked so well on cherries, failed for various reasons. It was determined in another seasons work that double applications applied in the spring and summer for peak egg laying period or the addition of the residue enhancer and UV screen known as Vapor Guard@ from Miller Co. gave acceptable control on plums.

This paper accomplished its immediate goals of providing an acceptable control program for a major pest that cost Michigan growers millions of dollars each year and by providing a pheromone to use as a monitoring tool for growers and researchers alike. Thresholds for treatment relating to adult trap catch have not yet been established and many questions regarding the actual degradation of chlorpyrifos over time have not yet been addressed. It is still unknown as to whether the control program will give multiseasonal. A major study into the possibility of the plum borer and the other sesiid borers being vectors of diseases needs to be initiated as well. All indications in the literature indicate this insect will continue to be a pest on fruit, nut, and ornamental trees in the future and may become an increasinly worse pest in some cases where modern cultural practices favor their development. The immediate threat by the American plum borer to the cherry and plum industry of Michigan has now been considered solved, but as with any insect many important questions remain unanswered.

Appendix I.

213	g	Pinto Beans
32	g	Brewer's Yeast
3	g	Ascorbic Acid
2	g	Methyl Paraben
1	g	Sorbic Acid
1.75	g	Aureomycin
2	ml	Formaldehyde
13	g	Agar
25	ml	Vitamin Solution
650	ml	Distilled Water

Vitamin Solution - these ingredients are combined and brought up to 800 ml with distilled water, then frozen until ready to use in 25 ml aliquots.

16.0	g	Inositol
.8	g	Niacin
.8	g	Calcium panthotenate
.4	g	Riboflavin
.2	g	Pyridoxine HCl
.2	g	Thiamine HCl
.2	g	Folic Acid
.02	g	Biotin
.02	g	Vitamin B-12

Pinto beans are soaked overnight, boiled for 1 min in a fresh change of distilled water, then drained. Agar powder is added to 650 ml of boiling water and allowed to completely dissolve. All ingredients are then combined in a blender and mixed until only small fragments of beans remain.

Appendix II.

North American Distribution of the American Plum Borer

Alabama	NOT RECORDED		
Alaska	NOT RECORDED		
Arizona	Baboquivari Mts. Chiricahua Mts. Garces Huachuca Mts. Palmerlee Scotsdale Yavapai Co. Phoenix	Apr., May Apr., May Apr. May Apr., May Apr., May May June	Heinrich, 1956 Heinrich, 1956 Heinrich, 1956 Heinrich, 1956 Heinrich, 1956 Heinrich, 1956 Kimball, 1915
Arkansas	No Locality		Blackslee, 1915
California	Corningi Inyo Co. Loma Linda Ventura Co. Placerville Putah Canyon Merced Co. Stanislaus Co. Sacremento Co. Places Co.	Jan. June, July Sept. July Jan., May Nov. Apr., May Apr., May Apr. May Feb.	Heinrich, 1956 Heinrich, 1956 Heinrich, 1956 Heinrich, 1956 Heinrich, 1956 Heinrich, 1956 Van Steenwyk et al., 1986 Van Steenwyk et al., 1986 Van Steenwyk et al., 1986 Berkley Museum Collection
Colorado	Denver	June	Heinrich, 1956
Connecticut	East River	July, Sept.	Heinrich, 1956
Delaware	Woodside	May, June, Sept.	Sanderson, 1901
Distr. of Columbia	Washington	May, Sept.	Heinrich, 1956
Florida	No locality		Hulst, 1980
Georgia	Fort Valley Myrtle	 March	Heinrich, 1956 Blackslee, 1915
Hawaii	Not Recorded		
Idaho	Not Recorded		
Illinois	Decatur Sangamon Co.	Apr. May - Aug.	Heinrich, 1956 Forbes, 1891
Indiana	Bedford	Apr.	Heinrich, 1956
Iowa	NOT RECORDED		
Kansas	Lawrence Onaga Big Bend	May Aug.	Heinrich, 1956 Heinrich, 1956 Michigan State Collection
Kentucky	No Locality		Neunzig, pers. comm. 1988
Louisiana	NOT RECORDED		

Appendix II, continued.

Maine	NOT RECORDED		
Maryland	Plummers Island	May	Heinrich, 1956
Massachusetts	No Locality		
Michigan	See Fig. 1		
Minnesota	NOT RECORDED		
Mississippi	Jackson Tishomingo	Feb. Nov.	Heinrich, 1956 Heinrich, 1956
Missouri	St. Louis	June	Heinrich, 1956
Montana	Not in MSU Collection		Phillips, pers. comm.
Nebraska	NOT RECORDED		
Nevada	NOT RECORDED		
New Hampshire	Hampton		Heinrich, 1956
New Jersey	Hackensack Montclair Morristown	Nov. May, Aug. June	Heinrich, 1956 Heinrich, 1956 Heinrich, 1956
New Mexico	Mesilla Roswell	Apr. Apr.	Heinrich, 1956 Heinrich, 1956
New York	Lancaster Kinderhook Ithaca McLean	Aug. - Sept. Aug. - Sept. Aug. - Sept. Aug. - Sept.	W.T.M. Forbes, 1923 W.T.M. Forbes, 1923 Leonard, 1926 Leonard, 1926
North Carolina	Southern Pines Tryon	Mar., Apr. May	Heinrich, 1956 Heinrich, 1956
North Dakota	Not in NDSU Collection		Balesbaugh, pers. comm. 1988
Ohio	Columbus		Kellicot, 1891
Oklahoma	NOT RECORDED		
Oregon	NOT RECORDED		
Pennsylvania	No locality		Neunzig, pers. comm. 1988
Rhode Island	NOT RECORDED		
South Carolina	Anderson Raleigh	Oct. Aug.	Heinrich, 1956 Brimley, 1938
South Dakota	Not in SDSU collection		Balsbaugh, pers. comm. 1988
Tennessee	Henderson Co.		Michigan State Univ Collection

Appendix II, continued.

Texas	Blanco Co. Brownville Brownwood Justine Kerrville Paris Plano San Benito San Diego Shovel Mts. Victoria Zavella Gustine Scurry Co.	Oct. Oct. Oct. June Apr. Sept. Sept. July May Mar., Apr. Apr. Apr. Apr. - Sept. Mar., Apr.	Heinrich, 1956 Heinrich, 1956 Heinrich, 1956 Heinrich, 1956 Heinrich, 1956 Heinrich, 1956 Heinrich, 1956 Heinrich, 1956 Heinrich, 1956 Heinrich, 1956 Heinrich, 1956 Heinrich, 1956 Pierce and Nichols, 1941 Bottimer, 1926
Utah	Bellevue	May	Heinrich, 1956
Vermont	NOT RECORDED		
Virginia	Cape Henry Vienna Winchester	July May Apr. - June	Heinrich, 1956 Heinrich, 1956 Blackslee, 1915
Washington	No Locality	Apr., May	Blackslee, 1915
West Virginia	No Locality		Blackslee, 1915
Wisconsin	Door Co.	May - Sept.	Weiner, 1983
Wyoming	NOT RECORDED		
Canada British Columbia	 Alberni Vancouver Isl.	 July Aug.	 Heinrich, 1956 Heinrich, 1956
Mexico	Sonora		Heinrich, 1956
South America Columbia	 Mariquita Honda	 Aug. Apr.	 Blackslee, 1915 Blackslee, 1915

Appendix III

American Plum Borer Damage Survey of 30 Michigan Cherry and Plum Orchards

Orchard location	Pupal cases	Live APB	Hirsutella mummies	Orchard Condition: age, % trees wounded, general care, LPTB
Grand Traverse Co. Yuba Rd.	72	13	5	10 + yr., 50-100% wounding, poor, LPTB present
Grand Traverse Co. Amon's - M-31	24	3	4	10 yr., 20-50% wounding, very good, LPTB present
Grand Traverse Co. Three Mile Rd.	36	11	11	8-10 yr., 20-50% wounding, very good, LPTB present
Leelanau Co. Bingham Twp.	0	0	0	3-5 yr., 0-20% wounding, very good, no LPTB
Leelanae Co. Horn Rd.	310	100	0	25 + yr., 50-100% wounding, good, no LPTB
Leelanau Co. M-22 near Revolt Rd.	37	11	0	6-8 yr., 20-50% wounding, good, no LPTB
Leelanau Co. Peshawbestown	16	12	0	8-10 yr., 0-20% wounding, good, no LPTB
Leelanau Co. Northport	4	1	2	6-8 yr., 0-20% wounding, very good, few LPTB
Leelanau Co. Empire	31	3	4	8-10 yr., 20-50% wounding, fair, LPTB present
Benzie Co. M-22 near Grace Rd.	7	1	0	5-10 yr., 0-20% wounding, good, few LPTB
Benzie Co. 665 at M-31	16	3	0	6-10 yr., 0-20% wounding, good, many LPTB
Benzie Co. Joyfield at M-31	14	2	0	6-8 yr., 0-20% wounding, good, LPTB present
Antrim Co. Quarterline at O'Dell	64	16	2	8-10 yr., 50-100% wounding, fair, LPTB present
Charlevoix Co. Norwood Rd.	1	1	0	6-8 yr., 0-20% wounding, good, no LPTB
Charlevoix Co. M-66 at Rainey Rd.	4	2	0	8-10- yr., 0-20% wounding, fair, few LPTB
Charlevoix Co. Bernard Rd.	0	0	0	6 yr., 0-20% wounding, good, no LPTB, 1st year shaken

Appendix III, continued.

Orchard location	Pupal cases	Live APB	Hirsutella mummies	Orchard Condition: age, % trees wounded, general care, LPTB
Charlevoix Co. Bernard Rd.	17	16	2	30 + yr., 50-100% wounding, fair, few LPTB. Sweet cherries
Manistee Co. NineMile at M-31	29	10	1	6-10 yr., 50-100% wounding, fair, primarily LPTB
Mason Co. M-31 near Chauvex	7	12	1	6-8 yr., 20-50% wounding, good, LPTB present
Oceana Co. Van Burean at M-31	32	29	0	10 yr., 50-100% wounding, very poor, many LPTB
Oceana Co. Old M-31 at Hart	22	31	2	8-10 yr., 0-20% wounding, good, LPTB present
Oceana Co. West of Mears	91	37	6	25 + yr., 50-100% wounding, poor, many LPTB
Oceana Co. Garfield Rd.	1	2	0	8-10 yr., 0-20% wounding, good, no LPTB
Allegan Co. 62nd St.	9	50	2	10-15 yr., 20-50% wounding, fair, LPTB present
Allegan Co. T. Nichols Exp. Sta.	14	10	2	15 yr., 0-20% wounding, good, many LPTB, trees never mechanically harvested
Allegan Co. 109th St.	479	255	106	20-25 yr., 50-100% wounds, poor, LPTB & APB present in large numbers in the extensive black knot in canopy as well as the trunk, plums that have been shaken for several years
Berrien Co. Carmody Rd.	25	13	1	15-20 yr., 20-50% wounding, good, LPTB present
Cass Co. M-62	25	29	0	8-10 yr., 50-100% wounding, fair, LPTB present
Van Buren Co. 64th at 46th	0	0	0	5 yr., 0-20% wounding, very good, no LPTB
Van Buren Co. Lawrence near Red Arrow	0	0	0	8-10 yr., 0-20% wounding, good, few LPTB

Appendix IV

Foodplants of the American Plum Borer in North America

CONVOLVULACEAE Sweet potato (stored tubers only)	Impomoea batatas Lam.	N. Carolina
EBENACEAE Persimmon	Diospyros virginiana L.	Ohio
FAGACEAE Pin Oak Southern Live Oak	Quercus palustris Muenchh. Quercus virginiana Mill.	Texas Texas
GINKGOACEAE Ginkgo	Ginkgo biloba L.	
GRAMINEAE Corn stalks	Zea mays L.	Texas
HAMAMELIDACEAE Sweetgum	Liquidambar styraciflua L.	
JUGLANDACEAE Pecan Hickory Black Walnut River Walnut	Carya illinoensis C. Koch Carya sp. Juglans nigra L. Juglans microcarpa Berland	Califonia, Texas New York N. Mexico, Arizona, Utah
MALVACEAE Cotton stems	Gossypium hirsutum L.	Mississippi
MORACEAE Mulberry	Morus alba L. Morus spp.	
OCEACEAE Olive	Olea europea L.	California
PLANTANAECEAE Sycamore London Plane Tree	Plantanus occidentalis L. Plantanus acerifolia Willd.	 Eastern U.S.
ROSACEAE Almonds Apple Apricot Flowering Crab Common Pear Mountain Ash Peach Plum Sweet Cherry Tart Cherry Pln & Wild Cherries Wild Plums	Prunus dulcis (Mill) Malus domestica L. Prunus america L. Malus spp. Pyrus communis L. Sorbus americana Marsh. Prunus persicae Batsch. Prunus domestica L. Prunua avium L. Prunus cerasus L. Prunus spp. Prunus spp.	California Delaware, Michigan, N.York, Virginia Michigan, California Michigan Delaware Michigan Michigan, New York Mich., Wisconsin, Calif., British Columbia, Ontario, N. York Michigan, Wisconsin, California Michigan, Wisconsin, Claifornia Michigan, Ontario British Columbia, Ontario, Michigan

Appendix IV, continued.

SALICACEAE		
Willow	Salix spp.	
Poplar	Populus spp.	Illinois
TILIACEAE		
Basswood	Talia spp.	New Jersey
ULMACEAE		
Elm	Ulmus spp.	Texas
Black-knot of plum	Dibotryon morbosum	Michigan, California
Olive-knot	Pseudomonas savastanoi	California

LITERATURE CITED

Blackslee, E.B. 1915. American plum borer. U.S.D.A. Bull. 261., 13pp.

Bottimer. 1926. Notes on some lepidoptera from eastern Texas. J. of Agric. Research. 33, 803

Brimly, C.S. 1938. The insects of North Carolina. N. Carolina Department of Agriculture. p. 301.

Capps, Hahn W. 1964. Description fo a new species of Euzophera Zeller attacking magnolias and note on two related species. The Florida Entomologist. Vol. 47, No. 1, pp. 49-52.

Covell, Charles V., Jr. 1984. A field guide to the moths of eastern North America. (The Peterson field guide series) p. 406. Plate 59.

Cushman, R.A. 1915. Proc. U.S. Nat. Mus. 48, 512.

Cushman, R.A. 1921. The north american ichneumon-flies of the tribe Ephialtini. Proc. U.S. Nat. Mus. 58, 338-9.

Essig, E.O. 1917. The olive insects of California. Univ. of Calif., College of Agriculture, Agricultural Experiment Station, Bulletin No. 283. p. 57-8.

Essig, E.O. 1929. Insects of Western North America. p.710.

Finlayson, Thelma. 1967. Taxonomy of final-instar larvae of the hymenopterous and dipterous parasites of Acrobasis spp. (Lepidoptera: Phycitidae) in the Ottawa region. Canad. Entom. 99: 1233-1271.

Forbes, S. A., 1890. The American Plum Borer 'Euzophera semifuneralis' Walk., Psyche, vol.5, p.295-299.

Forbes, S. A., 1891. The American plum borer, "Euzophera semifuneralis Walk." In 17th Rpt. State Ent. Ill., for 1889 and 1890, p.26-29,pl.2,figs,1,3,5.

Forbes, W.T.M., 1923. Lepidoptera of New York and Neighboring States, Cornell Mem., vol.68, p.631.
Hamilton. 1933. Nat. Shade Tree Conf. Proc., 9:67.

Heinrich, Carl. 1956. American moths of the subfamily Phycitinae, U.S. Nat. Mus. Bull. 207., 1-581. (272-74, 451-3, 341)

Hodges, et al. 1983. Checklist of the Lepidoptera of America North of Mexico, p.84.

Hulst, Geo. D., 1887. New species of Pyralidae. In Entomologica Americana, v.3, no. 7, p. 129-138. Described Stenoptycha pallulella Hulst, from 6 males and 5 females, N. Y., N. C., Utah, Wash. Ter., p.137.

Hulst, Geo. D., 1890. Phycitidae of N. America, Trans. Am. Ent. Soc., p. 175-7.

Johnston, W.T. and H. H. Lyon. 1988. Insects that feed on trees and shrubs. Cornell Univ. Press, Ithaca, N.Y., p. 252.

Kellicot, 1891. D. S. Notes on two borers injurious to the mountain ash. Can. Ent., v.23, no.11, p.250-251, Nov.

Kelsey, L. P., and Stearns, L. A., 1957?. Control of Pear Borer and American Plum Borer in Apple Trees., J. of Econ. Ent., Vol. 53, No.2, p. 276-78.

Kimball, Andrew. 1915. Arizona Commission of Agriculture and Horticulture, Seventh Annual Report, p. 33-34.

Leonard, Mortimer D. 1926. A list of the insect of New York. Cornell Univ. Agricultural Experiment Station Publication, Memoir 101. p. 583.

Lochhead. 1918. Ent. Soc. of Ontario Ann. Rep., Vol. 48, No. 36, p. 88.

Marshall & Musgrave. 1937. Can. Ent. 69: 104.

Michigan State Univ. Extension Publication No. E-109. 1986-9. Fruit Spraying Calendar.

Moller, W.J. and DeVay, J.E., 1968. Insect Transmission of Ceratocystis fimbriata in deciduous fruit orchards. Phytopathology. 58:1499-1508.

North Central Region Extension Publication No. 63.

Peterson, A. 1948. Larvae of insects. An introduction to Nearctic species. Part 1. Lepidoptera and plant infesting Hymenoptera. figs. D - H, p.204.

Pierce, W.C. and Nickels, C.B., 1941. Control of Borers on Recently Top-Worked Pecan Trees., J. of Econ. Ent., 34:522-526.

Ragonot, 1887. Diag. N. American Phycitidae, p.14.

Sanderson, E. D., 1901. Three orchard pests. Delaware College Agric. Exp. Sta., Bull. 53: p.9-13, fig. 5-6.

Slingersland, M. V., and Crosby, C. R., 1914. Manual of Fruit Insects., p. 253-4.

Stehr, F. W., ed., 1987. Immature Insects. p. 491.

Schwartz, P.H., 1972. Insects on deciduous fruits and tree nuts in the home orchard., U.S. Dept of Agriculture Home and Garden Bulletin No. 190, p. 20.

Turnbull, A.L., et. al., 1965. The spider genus Xysticus C.L. Koch (Araneae: Thomisidae) in Canada. Canad. Ent. 97: 1243-4.

University of California Publication No. 3308. 1985. Integrated pest management for almonds. p. 86-8.

U.S.D.A. 1985. Insects of eastern forests. U.S. For. Serv. Misc. Publ. 1426. p. 186-7.

Van Steenwyk, Robert A., et al., Borer control in young almond trees. California Agriculture, vol. 40., no. 3 & 4., March-April 1986.

Walker, F., 1863. List of Specimens of Lepidopterous Insects in the Collection of the British Museum, pt. 27, Crambites and Tortricites, p. 57. London. Described as Nephopteryx semifuneralis Walk.

Walley, G. Stuart, 1970. A new nearctic Campoletis parasite of Pyralidae (Hymenoptera: Ichneumonidae). Canad. Ent. 102: 1528-1530.

Weiner, Linda F. and Norris, Dale M., Evaluation of sampling and control methods for lesser peachtree borer (lepidoptera: sesiidae) and American plum borer (lepidoptera:pyralidae) in sour cherry orchards. J. Econ. Entomol. 76:1118-1120 (1983).

Zeller, P. C., 1881. Columbische Chiloniden, Crambiden und Phydicen. In Horae Societatis Entomologicae Rossicae, v.16, p. 154-256, pls. 11-12. Described as Euzophera impletella Zeller, p. 234-236, pl. 12, fig. 40.