TRAPPING AND MONITORING TECHNIQUES FOR PLUM CURCULIO, *CONOTRACHELUS NENUPHAR* (HERBST) (COLEOPTERA: CURCULIONIDAE), IN A SOUTHWESTERN QUEBEC APPLE ORCHARD

by

Jean-Pierre R. Le Blanc

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Doctor of Philosophy (Ph. D.)

Department of Entomology
McGill University, Montreal
Quebec, Canada

August 1982

© Jean-Pierre R. Le Blanc 1982

ABSTRACT

Ph. D. Jean-Pierre R. Le Blanc Entomology

TRAPPING AND MONITORING TECHNIQUES FOR PLUM CURCULIO, *CONOTRACHELUS NENUPHAR* (HERBST) (COLEOPTERA: CURCULIONIDAE), IN A SOUTHWESTERN QUEBEC APPLE ORCHARD

Six published sampling techniques, and six trapping and three monitoring techniques developed by the author, were tested in a southwestern Quebec insecticide-free apple orchard to determine a reliable trapping and/or monitoring technique for the plum curculio.

Adult captures in intercepting funnels were distributed, in time and space, according to the seasonal development and ecology of this insect. Females were found to oviposit, prior to fruit set, on mature Granny Smith apples attached at major branch junctions in standard McIntosh apple trees. Relationships between oviposition on these "monitoring" apples and "June" drop and harvest damage were found. Plum curculio damage was concentrated near potential over-wintering sites.

A superior Y-tube insect olfactometer was designed and used to test potential attractants for plum curculio. Two fungicides, benomyl and fenarimol, were found to have no effect on plum curculio during its summer soil phase.

RESUME

Ph. D. Jean-Pierre R. Le Blanc Entomologie

TECHNIQUES DE PIEGEAGE ET DE DEPISTAGE DU CHARANCON DE LA PRUNE, CONOTRACHELUS NENUPHAR (HERBST) (COLEOPTERA: CURCULIONIDAE), DANS UNE POMMERAIE DU SUD-OUEST DU QUEBEC.

Six techniques d'échantillonnage connues, six techniques de piégeage et trois de dépistage mises au point par l'auteur, ont été mises à l'épreuve dans une pommeraie non arrosée aux insecticides et située dans le sud-ouest du Québec afin de déterminer une technique fiable de piégeage et/ou de dépistage pour le charançon de la prune.

Les captures d'adultes dans des entonnoirs d'interception se sont distribuées, dans le temps et l'espace, en accord avec le développement saisonnier et l'écologie de cet insecte. Les femelles ont pondu, avant la nouure, sur des pommes Granny Smith mûres attachées à des fourches importantes de pommiers McIntosh standards. Des relations entre l'oviposition sur ces pommes "témoins" et les dommages à la chute de "Juin" et à la récolte ont été établies. Les dommages du charançon de la prune ont été plus prononcés près des sites probables des quartiers d'hiver de l'insecte.

Un olfactomètre plus fonctionnel a été mis au point et utilisé lors d'essais de substances attractives pour ce charançon. Deux fongicides, le benomyl et le fenarimol, n'ont pas démontré d'effet sur le charançon de la prune durant sa phase souterraine de l'été.

Short title:

TRAPPING AND MONITORING TECHNIQUES FOR PLUM CURCULIO

Jean-Pierre R. Le Blanc

TO MY PARENTS

Carmen and Pierre R. Le Blanc

May God bless them

ACKNOWLEDGEMENTS

I would like to acknowledge the many contributions, large and small, that made this undertaking a reality. I would especially like to thank my academic advisor, Dr. Stuart B. Hill for his judicious advice, continuous support and stimulating discussion.

I also would like to thank Dr. D. E. Bright, of the Biosystematics Research Institute of Agriculture Canada, for confirming the identification of my specimens, and at Macdonald College, Dr. M. A. Fanous and Dr. M. A. Curtis, with whom I had several fruitful discussions about statistical methods.

I am particularly indebted to the members of the Department of Entomology of Macdonald College: Dr. D. K. McE. Kevan and Dr. V. R. Vickery for their assistance in retrieving taxonomic papers, and Dr. R.K. Stewart, Dr. J. E. McFarlane, and Dr. W. N. Yule for their encouragement, answers to various questions and research suggestions. Special thanks are reserved for Mrs. Janet Taylor, our Administrative Secretary, for her countless services. I am also grateful to my fellow graduate students, Mr. Charles Vincent for support and suggestions and Dr. Guy Boivin (Agriculture Canada Research Station, Saint-Jean-sur-Richelieu, Quebec) for our exchange of trapping results, and suggestions and editorial comments during the preparation of this thesis.

I express my gratitude to the staff of Agriculture Canada Research Station, Saint-Jean-sur-Richelieu, Quebec. In particular to its former Director, Mr. J. J. Jasmin, who authorized my presence within the experimental farm facilities at Frelighsburg, Quebec, to Dr. L. J. Coulombe for his collaboration in the fungicide tests, and especially to Dr. R. O. Paradis, senior fruit entomologist, for his support, guidance and concern.

I am grateful to my colleagues at the Department of Biology of the Nova Scotia Agricultural College, for their moral support and to my Department Chairman, Dr. L. A. McFadden, for his encouragement and for allowing me to devote the necessary time required to complete this thesis. At the Nova Scotia Teachers College, Mrs. Marie Marshall deserves much credit and recognition for her faithful and competent typing of the manuscript.

Finally, I would like to acknowledge my wife, Angèle, for her unceasing support, encouragement and patience, three of the most critical factors in the completion of this project, and my daughter, Mélanie, for inspiration.

This research project was made possible by grants from the "Direction générale de l'enseignement supérieur du Ministère de l'éducation de la province de Québec" to the author, and grants-in-aid to Dr. S. B. Hill from Agriculture Canada and Agriculture Quebec.

CONTRIBUTIONS TO KNOWLEDGE

1. Four general sampling techniques (ultraviolet light-trap, suction apparatus, emergence cage, and soil sampling) were tested for the northern univoltine strain of *Conotrachelus nenuphar* (Herbst). Only the ultraviolet light-trap warrants further testing, however, this would be for the southern multivoltine strain.

2. It was established that the boll weevil (*Anthonomus grandis* Boheman) sex and aggregating pheromone (grandlure) has no cross attractiveness for *C. nenuphar* northern strain.

3. Intercepting funnels hung under apple trees were found to capture plum curculio adults in sufficient numbers (second only to jarring) to follow the seasonal development of this insect. The distribution of captures in the orchard indicated that such traps should be placed within 50 m of potential overwintering sites.

4. Tests with five other trapping techniques developed by the author (colour sticky traps, shelter traps on the tree and on the ground, and interception traps, one made out of PVC and the other using the boll weevil trap) revealed this insect's poor flying ability and apparent lack of a broad spectrum response to visual, olfactory and stereokinetic stimuli.

5. A superior Y-tube insect olfactometer was designed and used to test potential attractants for plum curculio.

6. Plum curculio females were found to oviposit, prior to fruit set, on mature Granny Smith apples attached at major branch junctions in standard apple trees.

7. Relationships between oviposition on these "monitoring" apples and "June" drop and harvest damage were found.

8. "June" drop and harvest damage assessments, carried out three years over the entire 1,7 ha orchard, revealed a definite concentration of curculio damage near potential overwintering sites.

9. Two fungicides, benomyl and fenarimol, were found to have no effects on plum curculio during its summer soil phase.

TABLE OF CONTENTS

LIST OF TABLES

Table		Page

Table		Page

LIST OF FIGURES

Figure		Page

1.0 INTRODUCTION

1.1 Background

Since insecticides became available they have remained the primary method of control for the plum curculio, *Conotrachelus nenuphar* (Herbst). Although over 2 000 references on plum curculio have been published, little information is available relating the population density of this insect to economic damage. However, as the plum curculio depends on the host fruit directly for its development, I suspect that the economic threshold will be found to be very low. Insecticide applications (presently one at the calyx stage and another eight to ten days after) are invariably made according to the local "spray calendar", *i.e.*, without knowledge of *C. nenuphar* presence or relative abundance. The potential problems associated with such a strategy include the development of insect resistance to chemical insecticides, resurgence of the pest, secondary pest outbreaks, and non-target effects comprising impacts on the environment and on human health, as well as economic penalties resulting from unnecessary applications.

The determination of economic injury levels and economic thresholds for major pests affecting important crops appears, together with the implementation of integrated systems of pest management that are less dependent on the use of chemical insecticides, to be a valid approach for resolving these problems. An early prerequisite for such a strategy is the design of reliable trapping and monitoring techniques capable of yielding accurate estimates of pest population density.

With respect to the development of alternatives to chemical control, LeRoux (1971) has reviewed the biological control attempts on pome fruit in North America for the period 1860 to 1970. He reported only two "gross" attempts to control C. nenuphar biologically, one with the braconid Aliolus curculionis (Fitch), and the other with the ichneumonid Tersilochus conotracheli (Riley), and no major attempts have been made, using these insects or others.

1.2 The Plum Curculio

In most modern general texts of entomology (e.g., Borror et al. 1981) Conotrachelus nenuphar (Herbst) 1797, is classified as follows:

Order: Coleoptera

Suborder: Polyphaga

Superfamily: Curculionoidea

Family: Curculionidae

Subfamily: Cryptorhynchinae.

This species was first described by Herbst (1797) under the name Curculio nenuphar. The synonymy of this species is given by Quaintance and Jenne (1912), Chapman (1938), and Schoof (1942).

As reported by Quaintance and Jenne (1912), the generic position of this insect changed several times and the genus Conotrachelus was accredited by some authors to Latreille, although this appears to be an error. Schoof (1942), on the other hand, noted that: "Dejean, 1835, erected the genus Conotrachelus, but merely listed the species included. Schönherr, 1837, was the first to bring together in a descriptive manner the known species of Conotrachelus".

According to Schoof (1942) the "type is probably in Zool. Mus. Berlin". I confirmed this by writing to the "Museum für Naturkunde der Humboldt-Uni., DDR 104 Berlin". Dr. Hieke replied informing me that the type is in their collection, but he noted that the series of C. nenuphar comprises seven specimens including the type which, however, is not marked. Hence one of these seven specimens should be selected as the lectotype.

Sixteen of the specimens that I collected, selected to represent the broad range of morphological variability, were sent to the Biosystematics Research Institute of Agriculture Canada for identification. Dr. D. E. Bright confirmed that all were Conotrachelus nenuphar (Herbst). The Institute retained four of the specimens and the remaining 12 were deposited in the Lyman Entomological Museum, Macdonald College of McGill University.

1.3 Pest Status of Plum Curculio

The total annual loss caused by plum curculio attacks upon its several food plants was reported to amount to "several million dollars" in the United States at the beginning of this century (Quaintance and Jenne 1912). Snapp (1930) reported that the 1920 outbreak in the peach orchards of Georgia "took a toll to the value of several million dollars". In fact, he reported that the produce from about half of Georgia's peach acreage was not marketed that year because of plum curculio damage. Chapman (1938) reported that plum curculio should be classed as the second most important pest of deciduous tree fruit, superseded only by the codling moth, Laspeyresia pomonella (L.).

Reporting on the principal arthropod pests occurring in apple orchards of midwestern and eastern North America, Croft (1978) listed plum curculio as an "annual key pest" together with the codling moth, Laspeyresia pomonella (L.), the red-banded leafroller, Argyrotaenia velutinana (Wlk.), and the apple maggot, Rhagoletis pomonella (Walsh). According to Croft an "annual key pest" is one that "attacks the fruit directly, nearly every year, and has limited potential for control by biological means".

In southwestern Quebec, Paradis (1955) reviewed the principal outbreaks of plum curculio between 1884 and 1954. He concluded that it generally causes significant losses to apple production two years out of five. In our region, however, this insect was reported to be in complete regression after 1955 (Paradis 1968). In 1969 a resurgence was reported to have started (Paradis et al. 1974; Paradis 1976; Paradis et al. 1977). At the present time in our region plum curculio is classified as one of the four "major pests" of apple orchards, i.e.; responsible for economic losses in the majority of our apple orchards if no treatments are applied (Paradis 1979).

1.4 Need for Trapping and Monitoring Techniques

Paradis (1979) noted that specific monitoring techniques are available for each of the three other major pests of our apple orchards – *Rhagoletis pomonella* (Walsh), *Orthosia hibisci* (Guen.), and *Panonychus ulmi* (Koch) –, but none are available for the plum curculio, and he concluded that the replacement of calendar sprays by directed control would result in a 20% reduction in the number of required insecticide and acaricide applications.

It is evident that the development of trapping and/or monitoring techniques for the plum curculio is critical if directed control is to be implemented and if integrated orchard pest management (IPM) is to become a reality. This need exists throughout the area in which plum curculio occurs. The importance of the curculio problem was underlined in a bio-economic study of its injury to apples (Hall 1974). Hall found that a "moderately" successful control programme (with two sprays) for the plum curculio alone, would result in a cost-benefit ratio of close to 20:1 one year after spraying has ceased and 60:1 the following year; he concluded that since "it is necessary to grade all fresh fruit before sale or storage...the increased expenses alone (caused by this operation) may turn even modest injury into devastating losses in net income".

Although some progress towards apple orchard integrated pest management has been made during the last decade - especially with the use of pheromone traps for Lepidoptera (Paradis 1979) - "A multiple-species control tactic is not yet available for a pest complex such as the codling moth, the red-banded leafroller, apple maggot, Rhagoletis pomonella (Walsh) and plum curculio, Conotrachelus nenuphar (Herbst). Such a control system will be essential for the midwestern and eastern North America apple pest complexes if pheromone measures are to compete effectively with broad-spectrum chemical control measures which provide these same benefits." (Croft and Hoyt 1978).

1.5 Thesis Outline

In view of the above situation I focussed on finding reliable trapping and/or monitoring techniques for the plum curculio. It was carried out mainly in a southwestern Quebec apple orchard (described below). Results are presented here under the following chapter headings: Literature Review, Published Sampling Techniques, Techniques Involving Thanatosis, Trapping Techniques Developed by the Author, Monitoring Insect Effects - the Granny Smith Apple Technique, Effects of Fungicides on Plum Curculio, and General Conclusions and Indications for Future Research.

1.6 The Experimental Orchard

The focal point of my field research was a 1,7 ha "experimental orchard" referred to as the I-west section of the Department of Agriculture of Canada Experimental Farm located at Frelighsburg, Quebec (45° 03' N, 72° 50' W).

This orchard had not been sprayed with insecticides (only fungicides) since the 1974 growing season, and <u>Conotrachelus nenuphar</u> was known to be present. The orchard consists principally of more than 200 standard trees of the McIntosh cultivar (90%), the rest being mainly of the Cortland cultivar (10%). The experimental orchard is bordered on three sides by a deciduous mixed woodland, the edge of which is expected to be a major overwintering site for this weevil. On its east side is a larger plot of conventionally sprayed apple trees (Fig. 1).

Each tree within the experimental orchard is referred to according to a grid system, A to N for orchard rows, and 1, 2, 3,... for the trees in each row, starting at the north end (Fig. 1).

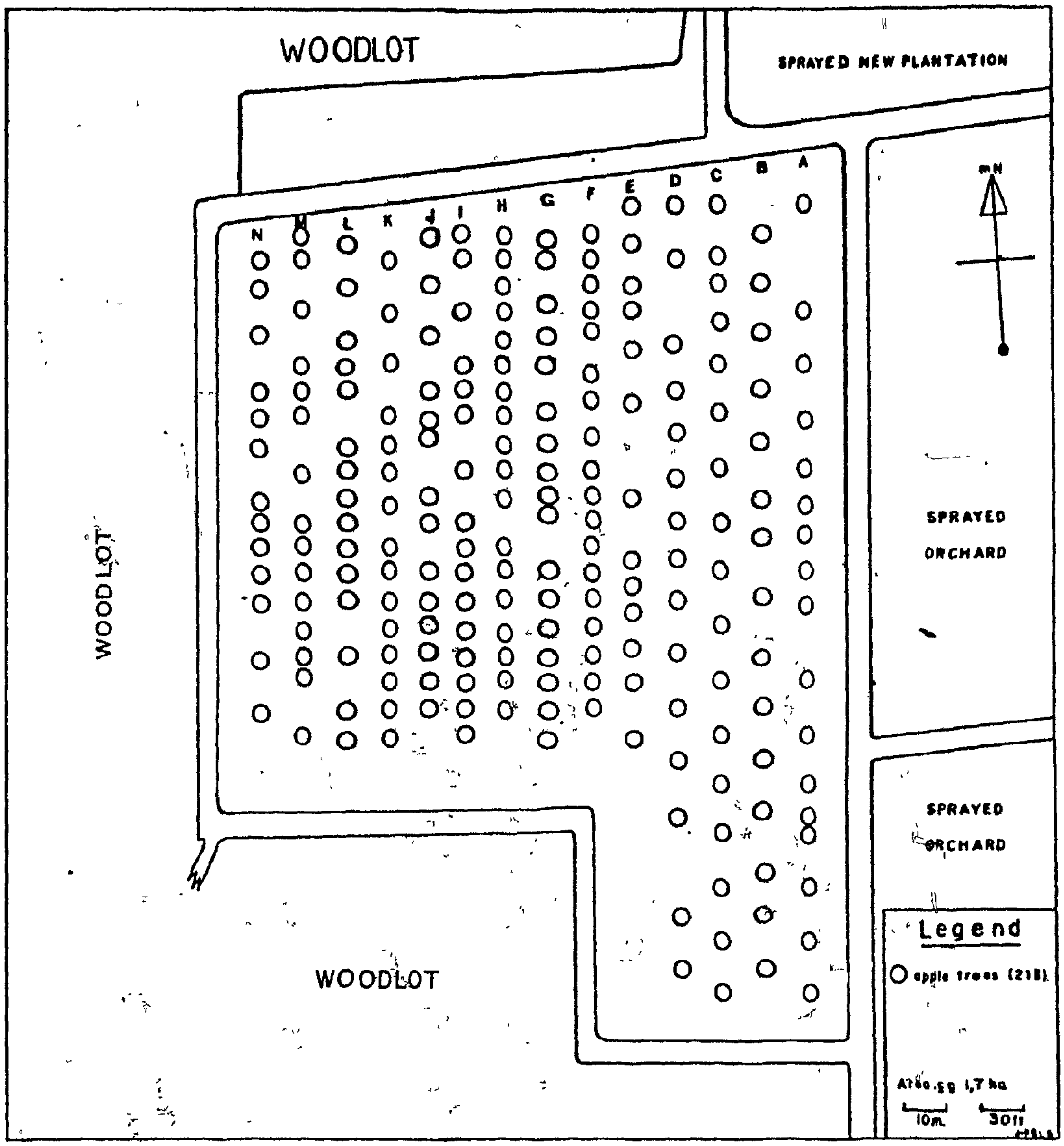


Fig. 1. Experimental orchard (1,7 ha) at Agriculture Canada Experimental Farm, Frelighsburg, Quebec. Orchard rows (A - N).

2.0 LITERATURE REVIEW

2.1 Introduction

The literature on Conotrachelus nenuphar (Herbst) is substantial. During the course of my work I collected over 2 000 references concerning this weevil. The present literature review, however, is limited to those articles of relevance to the development of trapping and monitoring techniques. It is arranged under the following major headings: Biology, Ecology, Fruit Injury, Behaviour, and Trapping and Monitoring Techniques. References dealing with specific techniques are cited in the appropriate chapters.

2.2 Biology

2.2.1 Life history

Tilton's (1804, cited in Anon. 1809) account of the habits of "Curculio" in Willich's Domestic Encyclopedia probably refers to C. nenuphar and is the first published record of this insect's biology; although he incorrectly stated that it overwinters as a grub.

After producing a series of papers on plum curculio dealing with such topics as egg-laying (Quaintance and Smith 1902), life history (Quaintance 1905) and control (Quaintance and Scott 1910), Quaintance published a 250 page "full account" entitled "The Plum Curculio" (Quaintance and Jenne 1912). This is still the major source of information about this insect, which Quaintance occasionally referred to as that "little Turk". Of particular value is his 440 reference annotated bibliography covering the period 1736 to 1911; together with his notes on synonymy, distribution, description of development stages, life history, habits, natural enemies, and control measures.

The essential features of C. nenuphar life cycle are as follows. In our region (southwestern Quebec) overwintering adults become active one to two weeks before full bloom of the McIntosh apple cultivar. Paradis (1956) observed this in cages within an orchard an average of 11 days prior to full bloom in this region; and Smith and Flessel (1968) obtained their first jarring captures on McIntosh trees an average of six days prior to full bloom at Geneva, New York.

Once they reach the host trees the beetles feed on petals and leaves, and mating occurs (Crandall 1905; Paradis 1957; Smith and Salkeld 1964). As soon as the fruit is set, females start to lay eggs and will oviposit into fruit as small as 0.6 cm diameter (Garman and Zappe 1929). Eggs hatch three to twelve days later, depending on temperature (Paradis 1956). The larvae feed solely within the fruit, which suffer premature abscission as a result of the larval feeding (Levine and Hall 1977). This, however, should not be considered as part of the "natural" physiological fruit drop (Detjen 1926).

Quaintance and Jenne (1912) described the larva and noted the occurrence of four larval instars; subsequent researchers have used average width of head capsules to distinguish them (Table 1).

The fourth instar larva leaves the fallen fruit shortly after "June" drop, enters the soil to a depth of about 30 mm to pupate and adults emerge in late summer (Chapman 1938). Thus, the soil under the host trees contains the fourth instar larva, the pupa and the adult of the new generation. The average length of this soil phase varies, depending upon soil temperature, from 28 to 33 days in southwestern Quebec (Paradis 1956). Most adults of the new generation emerge after mid-August in this region, move into the trees, and start feeding on the maturing apples (Paradis 1956).

Table 1. Variations in head capsule width (mm) of <u>Conotrachelus nenuphar</u> larval instars.

Larval instar					
I	II	III	IV	Source of material (strain)	Reference
0,28	0,45	0,69	0,96	Connecticut (northern)	Garman and Zappe 1929
0,26	0,45	0,62	0,92	Geneva, N.Y. (northern)	Chapman 1938
0,29	0,51	0,78	1,10	Niagara, Ont. (northern)	Armstrong * 1958

* This author based his findings on the largest number of cast head capsules, i.e., 97 to 146 per instar.

Feeding continues and by the first week of October curculios are no longer found on the trees (Le Blanc et al. 1981).

In addition to the larva, accurate descriptions of the egg, pupa, and adult are provided by Quaintance and Jenne (1912). Observations on the life history of plum curculio on apples in the United States are given by Brooks (1910), Crandall (1905), Dozier et al. (1932), Garman and Zappe (1929), Graham (1938), Lathrop (1949), Stearns et al. (1935), Riley (1870), and Whitcomb (1929; 1932).

Useful, though less complete, accounts are provided by Butler and Dozier (1929), Chapman and Hammer (1932), Cook (1890), Crosby et al. (1929), Driggers (1935), Filinger (1940), Frost (1942), Garman (1927; 1934), Garman and Townsend (1950), Jacklin and Yonce (1970), Johnson and Hays (1969), Knight (1922), Lathrop (1955), Mutchler and Weiss (1925), Petit (1904), Sanders (1928), Sarai (1969), Slingerland and Crosby (1914), Swaine (1909), Taylor (1909), Walsh and Riley (1868a), and Williams and Dozier (1929).

Canadian accounts of plum curculio life history on apples are provided by Armstrong (1958) for Ontario, and Paradis (1956) and Petch (1927) for southwestern Quebec. Earlier, less detailed accounts are given by Caesar (1917), Godbout (1933), and Huard (1916).

Snapp (1930) provided a comprehensive account of the life history of C. nenuphar on peach trees in Georgia patterned after the work of Quaintance and Jenne (1912). Snapp (1940), also published additional information on the occurrence of a second brood in that state. Other, less complete, accounts of plum curculio occurrence on peach in the United States are provided by Bobb (1952), Chandler and Flint (1935; 1939), Hutson (1933), Leiby and Gill (1923), Leiby and Harris (1924), Quaintance (1905), Smith

(1911), Steiner and Worthley (1941), and Wylie (1954).

Surprisingly little has been published on the life history of plum curculio on its natural host, Prunus spp.. A brief account on plums (or prunes) in the United States is provided by Cox (1951), and in Canada by Bethune (1907), and Saunders (1870); observations of plum curculio occurrence on cherries in Nova Scotia are reported by Brittain and Pickett (1933).

In addition, plum curculio occurs on blueberries and accounts are provided by Beckwith (1943), Fulton (1946), and Mampe and Neunzig (1967), who noted that although adults reared on blueberries were smaller than on other host fruit (peaches or apples) their fecundity was not reduced.

2.2.2 Univoltine and multivoltine strains

Plum curculio is univoltine north of Virginia and multivoltine (two and sometimes a partial third generation) to the south (Schoene 1936). Chapman (1938) mapped this difference (see Fig. 2) basing his conclusions on the observations of Snapp (1923) in Georgia, Chandler (1927) in Illinois, Petch (1927) in southwestern Quebec, Garman and Zappe (1929) in Connecticut and Stearns (1931) in Delaware, who hypothesized that the variable number of generations per year over plum curculio's range may be explained by differences in genetic make-up. While it is clear that our (southwestern Quebec) specimens are the univoltine strain, it is not known to what extent they differ from the southern multivoltine strain in terms of their biology and ecology.

2.2.3 Diapause

The southern multivoltine strain of plum curculio is capable of continuous reproduction. Smith (1957a; 1957b), for example, maintained a culture from North Carolina for over 40 generations without hibernation. Stevenson and Smith (1961) found that when crossing southern and northern strains, while the progeny of all crosses were viable, the level of fertility and fecundity of the F_1 generation varied. Efforts to achieve genetic control, by means of the reduced fertility and fecundity of certain crosses, were not successful (Padula and Smith 1971). These studies, however, did indicate that the two plum curculio strains, although showing some genetic differences, were not reproductively isolated.

The northern univoltine strain requires a period of hibernation for oviposition to take place, and the requirements for breaking the reproductive diapause of this northern strain vary over its range (Smith and Flessel 1968). Mampe and Neunzig (1967) found that they could break the diapause of second generation adults of the southern strain by placing females in a controlled environment chamber at 1,7°C for 120 days. While crossing field collected first generation adults of the southern strain with some from a strain reared in the laboratory for more than 15 years, Featherson and Hays (1971) found that, in general, the more "wild influence" in the genotype, the higher is the rate of diapause in the progeny.

Gaydon (1972) found that while southern strain first generation adults (from South Carolina) were approximately 85% reproductive, about 85% of the adults of the second generation exhibited reproductive diapause. In the laboratory, he found that photoperiods of 12 or more hours/24 hours produced reproductive adults while photoperiods of less than 12 hours/24 hours induced diapause in adults. In the field, similar studies demonstrated that a 16 hours/day photoperiod will result in the production of mainly reproductive adults. These findings could explain partly why in southwestern Quebec, where most adults of the new generation emerge after mid-August

(Paradis 1956), they exhibit a reproductive diapause and require hibernation to be able to oviposit the following spring.

2.2.4 Spring emergence and appearance in host trees

Spring emergence of hibernating plum curculios and their appearance in host trees has been related to certain soil and air temperature thresholds.

Quaintance and Jenne (1912) found that plum curculios became active after the mean air temperature reached 12,8^{O} to 15,6^{O}C for three or four days and became abundant on apple trees after several days at 15,6^{O}C or more. This was confirmed by Dozier et al. (1932) in Delaware, Chapman (1938) in New York, and Lathrop (1949) in Maine. A similar situation was found to hold true in peach orchards by Snapp (1930) in Georgia, and Graham (1938) in Maryland; Whitcomb (1929; 1933) in Massachusetts, however, found that adult activity is relatively insignificant when the daily maximum is below 23,9^{O}C.

Bobb (1949; 1952) in Virginia, found that adults, in cages within peach orchards, began to emerge when mean soil temperatures 7,6 cm below the surface reached approximately 10^{O}C; and Paradis (1956) in southwestern Quebec, found that adults in cages, within an apple orchard, started to emerge when air temperature reached 10,0^{O} to 15,6^{O}C and soil temperature 2,5 cm below the surface reached 13,3^{O} to 13,9^{O}C, and that emergence reached a peak at (air) 16,1^{O}C and (soil) 14,4^{O}C respectively.

Smith and Flessel (1968) critically reviewed these studies and, based on their own data, concluded that "the establishment of precise prerequisites for emergence will require more sensitive measurements of temperature and humidity than have generally been employed, giving due regard to the actual site of hibernation of the beetles".

Time of emergence of *C. nenuphar* has also been correlated with host tree phenology. Generalizations are more difficult to make than with temperature, however, as such relationships vary with host species and cultivar. Crandall (1905) in Illinois, reported first detection one week after petal fall (apple cultivar not specified) one year, and one week before full bloom the following year. During the former year he apparently used visual detection, while in the latter he jarred the trees. Quaintance and Jenne (1912) found that in some years emergence may be retarded until after petal fall (apple cultivar not specified). Garman and Zappe (1929) in Connecticut found, however, that emergence of the northern strain in field cages generally started when the blossoms of most apple varieties were turning pink, and that curculios began to appear on host trees between pink bud and calyx stages. Chapman's (1938) extensive jarring records concurred with these findings for the McIntosh cultivar in New York.

The most comprehensive study was carried out on the McIntosh cultivar in Maine (Lathrop 1949). He found that: (1) over a six year period 70% emergence (in cages within an apple orchard) was completed an average of 0,8 day prior to petal fall (range: 8,4 days before to 13,4 days after petal fall), (2) over a six year period 10% emergence was completed an average of 22,3 days prior to petal fall, (3) over a five year period, jarring records, however, revealed peak numbers of adults in the trees an average of 15 days after petal fall, while the most rapid increase in their numbers on apple trees was found to be three days prior to petal fall, and (4) this lapse of time between plum curculio emergence and its appearance on host trees may be accounted for by the occurrence of a definite period during which the beetle remains sluggish. Similar observations have been made by Chandler (1953), Paradis (1956), and Smith and Flessel (1968).

2.2.5 Oviposition

Number of eggs laid by individual females is very variable, from one to just over one thousand (Armstrong 1958; Brooks 1910; Crandall 1905; Paradis 1956; Quaintance and Jenne 1912; Quaintance and Smith 1902; Smith 1957a; Snapp 1930). In these studies, recorded maxima ranged from 122 to 1 016 eggs and minima from 1 to 126. Most first generation southern strain females were, however, found to lay more eggs than northern ones, an average of 215 eggs/female (based on seven experiments) compared with 123 eggs/female (based on 10 experiments) respectively (see especially Smith 1957a).

Control of plum curculio by means of the sterile male technique, using chemosterilants and gamma radiation, has been tested, but results have not been encouraging. These studies were inspired by the successful local eradication of the screwworm, *Cochliomyia hominivorax* (Coquerel), through the release of sterile males.

Apholate and tepa, alkylating agents, only reduced the production of plum curculio larvae at concentrations that caused high mortality to both males and females (Roach and Buxton 1965). While 2 kr of gamma radiation from a ^{60}Co source resulted in an 87% decrease in the F_1 progeny and a 31% decrease in the F_2, efforts to increase these amounts by raising the radiation dose were judged unlikely to be practical because at a dose of 10 kr 50% of the treated plum curculio males died within 10,3 days of the exposure (Lippold *et al.* 1968). Jacklin *et al.* (1970), using substerilizing doses of gamma rays (4 to 6 kr), concluded, however, that their results were "encouraging enough to warrant testing of the technique in the field".

Growth regulators, such as diflubenzuron, should be further investigated, as low doses of this chemical reduced pupation and eclosion in the laboratory, although preliminary field trials were inconclusive (Calkins *et al.* 1977).

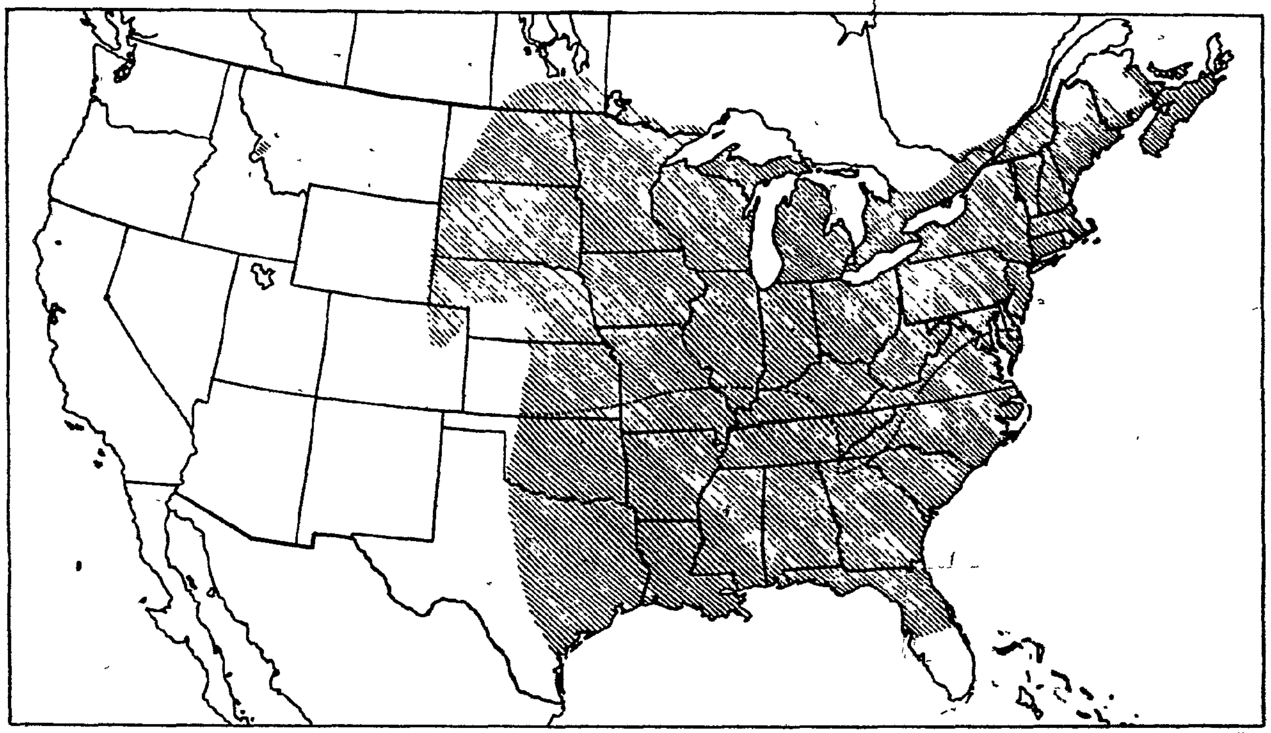
2.3 Ecology

2.3.1 Distribution

The plum curculio is native to Canada and the United States of America, its distribution coinciding with its native food plant, the wild plum (Crandall 1905). This author noted that it occurs within the area bordered by Canada to the north, the Gulf of Mexico to the south, the Atlantic Ocean to the east and the one hundredth meridian to the west, the exception being a record from Bitter Root Valley, Montana. This latter occurrence, however, was stated without foundation seven years later by Quaintance and Jenne (1912) who established more precisely the distribution limits of this insect pest, based on a collection of reports from several investigators.

Chapman (1938) provided further details of plum curculio distribution (Fig. 2). In the U.S.A. he extended its range into six States (including Montana) and in Canada into six provinces (Manitoba, New Brunswick, Nova Scotia, Ontario, Prince Edward Island and Quebec). He stated "The northernmost point in the species' range is Winnipeg, Manitoba, and vicinity, at approximately 50^{o} north latitude. The southern limit appears to be about 28^{o} north latitude, occurring both in Florida and Texas. Largo, Florida, is the southernmost record known to the writer.... With the exception of the isolated area in Montana, the western boundary of distribution falls near the 100th meridian from Texas to central Nebraska and along the 105th meridian from there northward. The eastern boundary is, of course, the Atlantic Ocean".

In Canada (Fig. 3) it appears to occur east of the Rocky Mountains wherever deciduous fruits are grown (Armstrong 1958). In Nova Scotia, however, it is only an important pest in unsprayed cherry orchards (Brittain



N.B.: The broken line indicates the boundary between the northern univoltine and the southern multivoltine strains of the plum curculio.

Fig. 2. Plum curculio, <u>Conotrachelus nenuphar</u> (Herbst), distribution in North America (Chapman 1938, p. 13 - reproduced with permission).

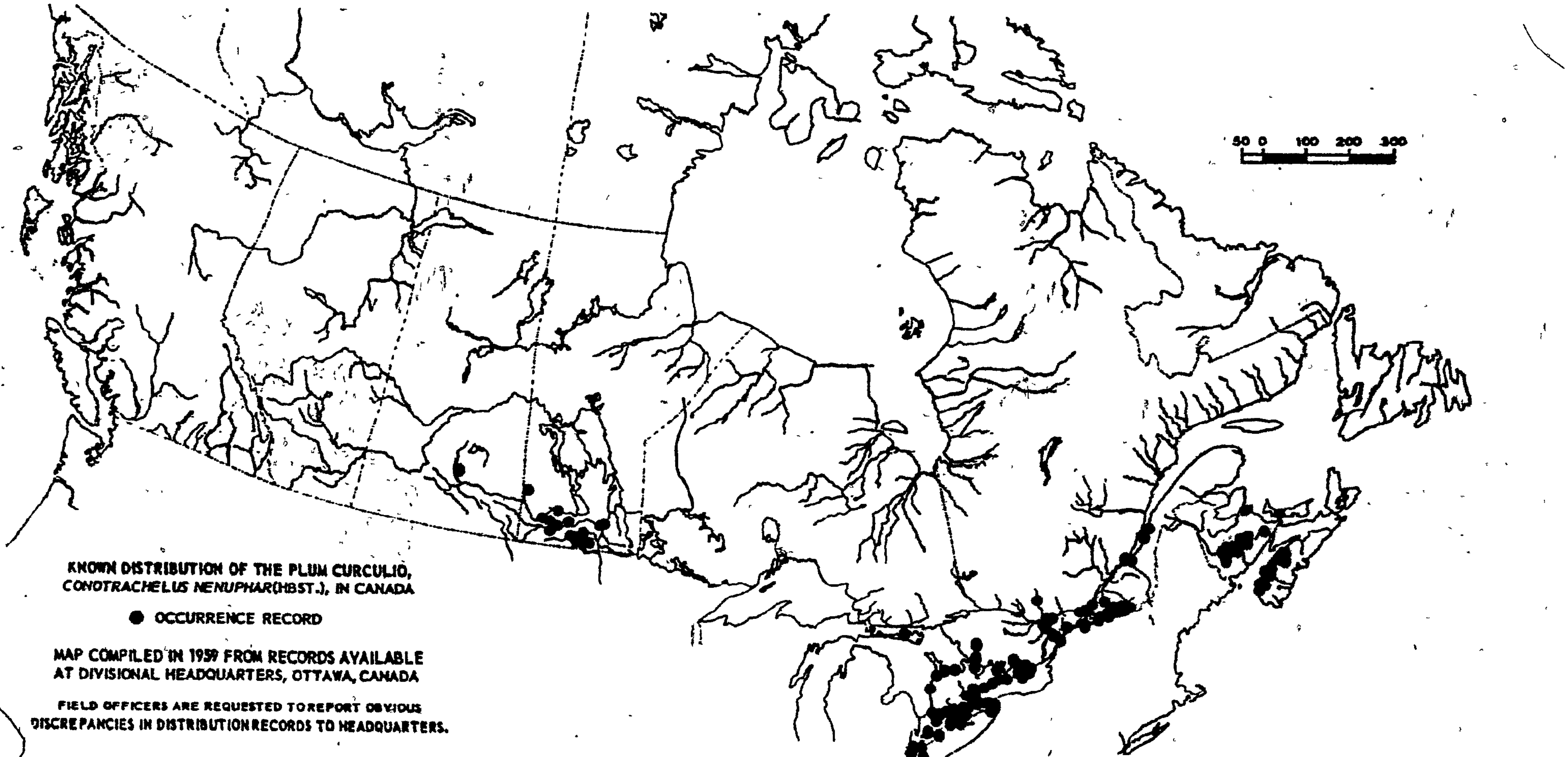


Fig. 3. Plum curculio, Conotrachelus nenuphar (Herbst), distribution in Canada (Insect Distribution Maps, CANADA, vol. 2, 1960-1964).

and Pickett 1933). In Quebec it is recorded as "fairly common" by Provancher (1877) and it is reported by Petch (1927) in the following 14 counties of Quebec: Beauharnois, Brome, Chateauguay, Deux-Montagnes, Huntingdon, Iberville, Ile d'Orléans, Jacques Cartier, Kamouraska, Missisquoi, Rouville, Sherbrooke, Stanstead, and Vaudreuil. Swaine (1909) was the first to record this pest in the Macdonald College apple orchard.

2.3.2 Commercial host plant preference

Host plants include nearly all commercially grown pome and stone fruits: plum, cherry, peach, apricot, apple, pear, quince and nectarine, and oviposition preference follows this order, except for nectarine for which there is insufficient data (Quaintance and Jenne 1912). In Quebec, Petch (1927) reported that curculios significantly damage apples, particularly early varieties, and he also noted their occurrence on pear, plum, cherry, and "haw and wild crab". Whitcomb (1929) confirmed their preference for early varieties (e.g., Duchess, Yellow Transparent and Gravenstein), and noted that McIntosh apples are less severely attacked. The preference for cherry over apples was apparent in the Annapolis Valley, Nova Scotia (Brittain and Pickett 1933), whereas in New York, Chapman (1938) found apple to be preferred second only to plum, which is generally considered as the original host of this insect (Cox 1951).

Experiments with the multivoltine strain in Arkansas demonstrated that while plum curculio prefers peach to apple in the field, this relationship is reversed in the laboratory (Wylie 1954). In the Niagara Peninsula, Ontario, while apricots and nectarines are the favoured host, the plum curculio can complete its life cycle on gooseberry (Armstrong 1958). Quaintance and Jenne (1912) had recorded this plant and huckleberry, grape, strawberry, currant and wild persimmon as occasional hosts. Blueberry has subsequently been added to this list (Beckwith 1943; Fulton 1946).

2.3.3 Natural reservoirs and resurgence.

In addition to its occurrence on cultivated fruits plum curculio is common on wild fruits. This partly explains the success of this species and, in particular, its ability to rapidly reinfest orchards in which spray programmes have been discontinued (Hagley et al. 1977) (see also: Chandler 1942; Glass and Lienk 1971; Hall 1974). Plum curculio has been recorded on wild plum (Prunus spp.), hawthorn (Crataegus spp.), and crabapple (Malus spp.) and also in black knot of plum (growths/ cankers) caused by the fungus Dibotryon morbosum (Schw.) Theiss. and Syd., on Prunus spp. (Chapman 1938 ; Quaintance and Jenne 1912; Whitcomb 1929). In addition to black knot, it has also been recorded from "plum pockets", these latter being caused by Taphrina communis (Sadeb.) Gies. (Wylie 1966).

Plum curculio occurrence on wild fruit may explain the variability in the level of control achieved by burning potential overwintering sites around orchards; while a 50% population decrease was reported by Graham (1938), Smith (1948) commented that the method was ineffective.

2.3.4 Dispersal (marking experiments)

Various studies using mark, release and recapture methods have been carried out to determine movement of plum curculio adults within orchards. First generation plum curculio adults disperse very little and most probably stay on the tree to which they migrate in the spring, while some may move to adjacent trees.

For example, of 649 marked (details not given) plum curculio released on a single tree in a peach orchard in Georgia bordered on three sides by woodlots, extensive jarring revealed that only 13 were found on trees 10 to 30 m away, a "few" being found on neighbouring trees, "most" remaining on the release tree (Snapp 1940). In an earlier experiment, involving 1 500 marked plum curculios, it was found that adults of the first generation remained in a peach orchard even after all the fruits were harvested (Snapp 1940).

In another experiment 200 plum curculio adults, marked with metallic powders, were released during May in a woodland at a common point 15 m from the edge of the orchard (Steiner and Worthley 1941). Recapture was achieved by frequently jarring trees within the orchard. While one beetle "moved" 146 m over 10 days and another "travelled" 205 m over 40 days, 80% of the recaptured beetles were jarred from the two trees nearest to the point of release.

Radioisotope tracers have also been used in plum curculio dispersal studies (Rings and Layne 1953; Rings 1954); although these experiments were designed more to determine the most suitable isotope than the dispersal behaviour of this insect. Of the 473 marked plum curculios released, 193 were recovered and their average flight distance (different for each of the five isotopes being tested) ranged from 19 to 42 m.

Dispersal of 718 marked (enamel lacquers) first generation plum curculios released within a blueberry field was also found to be very limited (Mampe and Neunzig 1967). Two of the recaptured individuals were found in a quiescent state near to their release point (distance not specified), suggesting "some" but "little" movement, from the field, made by adults entering hibernation.

2.3.5 Overwintering sites

Plum curculio are generally assumed to overwinter in surface soil and litter along the edges of woodlots adjacent to orchards. It has also been suggested that they might find similar shelter along hedge rows, fences, and stone walls or in rock piles within orchards. While very few beetles have actually been found within such locations, plum curculios have often been found to be most abundant in tree rows adjacent to woodlots (Graham 1938; Smith 1948; Snapp 1941; Stearns et al. 1935; Wylie 1954) and plum curculio damage has generally been found to be more abundant there (Crandall 1905; Crosby et al. 1929; Forbes 1906; Garman and Zappe 1929; Hutson 1933; Leiby and Harris 1924; Quaintance and Jenne 1912; Snapp 1930; Whitcomb 1929). Only Garman and Zappe (1929), Snapp (1940), and Bobb (1949) actually reported finding plum curculios at the edge of woodlots. Snapp, for example, found "many" (number not specified) hibernating plum curculios in the large quantities of debris collected during the winter from the edges of woods bordering peach orchards in Georgia. Beetles have also been found under litter within orchards. As some of these beetles have been observed to be still active, however, it is possible that they had not yet completed their fall migration, having been retarded in their journey by unfavourable weather conditions, particularly low temperatures. This appears to be the case with respect to the two records by Quaintance and Jenne (1912) of nine beetles found in the fall at ground level, under matted litter, in small depressions under apple trees, and of 23 beetles found in similar sites on other occasions. Despite this finding of 41 beetles within orchards, these authors nevertheless concluded that "unquestionably the bulk of the curculio adult population hibernates in trash in woods adjacent to orchards".

In rearing cages, when adequate shelter is provided, usually over 90% of the beetles hibernate within, and/or immediately under, the litter, the remainder going into the soil, rarely deeper than five centimeters (Table 2). Also, given a choice, beetles have been found to hibernate under maple and apple leaves (76% of 209 curculios) rather than under dried grass,

Table 2. Depth of overwintering sites of caged plum curculios.

Plum curculio strain	No. of caged curculios	Location of hibernating beetles (%)					Time of observation	Reference
		Within litter	Between litter and soil	In soil				
				< 2,5 cm	2,5 – 5,1 cm	> 5,1 cm		
Southern	111	50	30	20	0	0	November[1]	Snapp 1930
Southern	449	89	9	2	0	0	March[1]	Snapp 1930
Southern	143	0	38	49	5	8	March	Bobb 1949
Southern	not stated	0	100	0	0	0	Spring	Smith 1948
Northern	884	0	93	4	2	1	March	Armstrong 1958
Northern	761	0	95	5	0	0	April	Smith and Flessel 1968

[1]Note: 73% of all the beetles in this experiment emerged from hibernation during March, which suggests that they had started to move upwards during early March (Snapp 1930).

stones or corrugated paper (Whitcomb 1929). Their tendency to seek shelter was first reported by Quaintance and Jenne (1912) who noted that, when kept in glass jars, they tended to crawl out of sight between pieces of sod. Beetles probably only enter the soil when the litter layer does not provide adequate shelter (e.g., 2,5 cm) (see Smith 1948). Bobb (1949), however, found that in Virginia, 58 of 100 caged curculios hibernated within the second and third inch of soil (5,1 to 7,6 cm) in March. The cages contained only dead grass and winter mortality averaged 79%; therefore lack of shelter may have been responsible for this behaviour and for the high mortality. Snapp (1930) also found that most beetles (93%) died during the winter when no "shelter" was available. When such material (dried leaves) was available, only an average of 25% of the beetles died. The fact that some beetles survive the winter in soil is suggested, however, by the occasional finding in spring of some beetles in the trees with clay attached to their bodies (Garman and Zappe 1929).

A study by Lafleur and Hill (personal communication), currently in progress, using radioisotope tracers to mark plum curculio adults, is designed to accurately determine the actual overwintering site of this insect. Their study takes place in the southwestern Quebec apple orchard that was the focal point of my work.

2.4 Fruit Injury

2.4.1 Damage

The main economic damage to apples is caused by new generation adult plum curculios feeding on maturing fruit in late summer and thereby making them unmarketable as fresh fruit. On young fruit, however, these nutrition punctures (made by curculios coming out of hibernation) cause deformations (resembling cat facing), whereas on mature fruit the cavities made beneath the skin (by the curculios' long snout) make it impossible to store such apples (Paradis 1957).

In addition, oviposition and subsequent larval feeding within young fruit cause those affected apples to be shed at "June" drop (Detjen 1938; Levine and Hall 1977). While this could reduce the final harvest in years of poor fruit set, in other years it could augment the natural beneficial process of physiological thinning.

Detailed descriptions and photographs of nutrition and oviposition scars are provided by Chapman (1938) and Detjen (1938). The most accurate description of oviposition, confirmed by my own observations, is provided by Riley (1870) and comprises the following stages: (1) excavating a hole with the beak, (2) turning about face and then laying one egg in the hole, (3) turning again and pushing the egg into the hole with the snout, and (4) cutting a crescent-shaped slit just above the hole thereby creating a flap in the skin that prevents the growing fruit from crushing the egg. Other less accurate or less detailed descriptions are provided by Walsh (1867) and Quaintance and Jenne (1912). Crandall's (1905) observations of three ovipositing females confirmed the above pattern, and he further noted that it varied primarily in the time taken to complete the various operations, and, consequently, the total time taken for the egg-laying sequence.

2.4.2 Damage distribution

Injury to fruit by plum curculio is heaviest near orchard margins especially when they are adjacent to woodlots, the suspected overwintering sites (Chapman 1938; Crandall 1905; Crosby et al. 1929; Forbes 1906; etc., see "Overwintering sites" section of this review). Only two studies, however, have actually assessed damage throughout an entire orchard. Oatman and Legner

(1968) found the above generalization to be true in an insecticide-free, three acre (1,2 ha), sour cherry orchard in Wisconsin and LeRoux's study (LeRoux and Reimer 1959; LeRoux 1961) in an unsprayed 12,7 acre (5,1 ha) apple orchard in southwestern Quebec was, however, inconclusive. LeRoux's orchard was only bordered on one side by a woodlot, the other sides abutting commercial sprayed orchards; and he divided his orchard into four equal blocks, a design less capable of revealing a difference between central and marginal damage then if there had been a central block. Also, his observations of C. nenuphar damage, which was very low, were combined with data for four other insect pests, i.e., Archips argyrospilus (Wlkr.), Laspeyresia pomonella (L.), Coleophora serratella (L.), and Spilonota ocellana (D. and S.), together with mechanical injury to fruit from hail. The data for total plum curculio nutrition and oviposition damage derived from 16 sampling occasions over two years (eight/year) were analyzed for variance with respect to blocks, trees, levels within trees, quadrants of trees (cardinal points of the compass) and levels X quadrants. Significant variation due to blocks was found on two occasions (during the same year) and variation due to trees was found significant only on one occasion. Significant variation due to levels within trees, quadrants of trees, and levels X quadrants were found on three, four, and one occasion respectively. For none of the above significant variations was a multiple comparison procedure performed.

2.5 Behavioural Traits

Direct observation and subsequent utilization of insect behaviour in trap design has been a most productive approach to insect monitoring in the past (Prokopy, personal communication). Such observations for plum curculio have been made with respect to: thanatosis, stridulation, locomotion and diel activity.

2.5.1 Thanatosis

Plum curculio adults, together with many other Coleoptera, exhibit death feigning - also termed reflex immobilization or thanatosis by Wigglesworth (1972) - when disturbed. Cook (1890) was probably the first to scientifically record this behaviour when he wrote: "Whenever the weevil, or the limb on which it rests is jarred, the curculio draws up its legs and falls from the tree". Chapman (1938) supplemented his description of curculio death feigning with a detailed photograph of one individual assuming the position. This behaviour was much exploited in the past when jarring trees to detect beetles and thereby decide when control action was indicated.

2.5.2 Stridulation

Plum curculios stridulate by means of abdominal movements but they cannot do so if their elytra are immobilized or removed. Stridulation was first observed in C. nenuphar by Riley (1871) and described as mainly related to abdominal movements rather than hind leg movements by Snapp (1930). Mampe and Neunzig (1966) found that curculios are only attracted to sounds made by individuals of the opposite sex, and Carlysle et al. (1975) used scanning electron microscopy and sound analyzing equipment to illustrate the stridulatory apparatus' morphological differences for male and female plum curculio, together with the production of dissimilar sounds by each sex. Analysis of this weevil's "stress sounds" indicated that its stridulation capability is not only a displacement activity but may also have an aposematic value (Webb et al. 1980). The present state of knowledge about this behaviour in C. nenuphar seems to indicate, however, that acoustical techniques are unlikely to be useful in trap designs.

2.5.3 Locomotion

Plum curculio appears to fly only rarely, and is usually found crawling on the branches of trees (Hauschild and Prokopy 1977). Cook (1890), who was the first to publish observations on their movement, reported seeing plum curculios walking up tree trunks and also flying from the ground to the tree. Few subsequent observations have been made and the only quantitative study of plum curculio locomotion on trees is that of Owens et al. (1982) conducted in two unsprayed orchards (apple and plum) in Massachusetts. It seems from these observations that for traps to be successful, they would have to catch crawling rather than flying plum curculios.

2.5.4 Diel activity

Plum curculio feeds primarily at night when climatic conditions, particularly temperature, are favourable, although eggs are laid about equally during the day and night.

Crandall (1905) observed 17 pairs of curculios over four months in cages within the insectary; 1 037 eggs were laid during the day and 917 at night whereas the ratio for feeding punctures was 2 594:3 037. These observations were supported by those of Quaintance and Jenne (1912) and Snapp and Alden (1924). Gaydon (1972), however, observed evidence of mostly nocturnal activity. He found that at mid-day, resting southern strain curculios became active "soon" after a tarpaulin was placed over their cages in the field. He also noted that curculios became active in the trees (in South Carolina) earlier in the evening on cloudy days than on clear days. His use of a fluorescent dye for marking insects may, however, have made them easier to detect at night than in the day. In the more northern region of plum curculio's range this pattern may be modified, as the night temperature drops below the critical level for activity more often than in the south (Smith and Flessel 1968).

2.6 Trapping and Monitoring Techniques

No monitoring traps have been developed for plum curculio, jarring being the only method that has been used to indicate the presence and relative abundance of this insect. Thus, the results of the testing of 15 techniques in this study can unfortunately not be compared with those of previous researchers.

2.6.1 Visual observations

Direct observations of plum curculios within orchards are difficult because of their cryptic colouration (Taylor 1909). Gaydon (1972) used a fluorescent dye to try to overcome this problem and Lafleur and Hill (personal communication) are presently successfully using beetles labelled with ^{65}Zn to study their behaviour throughout the year in the same southwestern Quebec apple orchard I used for my work. Owens et al. (1982) will shortly be publishing their data for c.a., 128 hours of observations of 171 overwintered adults in plum and apple trees in Massachusetts, over four growing seasons. Cook's (1890) observations surprisingly remain the most detailed published account: "During June, at time of egg-laying, the beetles often spend the day, especially early in June, when the weather is cold, concealed under clods or chips, beneath the trees".

2.6.2 "Ransom chip" method

The habit of adults to hide under shelter has been used to trap them. Ransom (1870), an innovative and successful grower (peach, plum and cherry) in Michigan, being unable to find the "curculio" on his trees early in the spring, searched among the leaves, chips, sticks and stones on the ground under the trees and found them to be abundant. Based on this observation, he decided to provide the beetle with numerous artificial sheltering sites (mainly chips of various material), which he then turned over each day and hand collected the beetles as a control measure. Apparently this was successful as he reported collecting and killing 2 514 curculios in two hours from under 200 trees. Others, however, were less successful (see Cook 1890) and the method became part of orchard "folklore". Quaintance and Jenne (1912), for example, were only able to find 13 beetles in five days this way, whereas jarring yielded 309 adults during a comparable period of searching.

2.6.3 Jarring

Jarring evolved from being the only available method for controlling adult plum curculios (before insecticides were used) to the only method used for monitoring them; and this situation persists today.

One of the most innovative early jarring devices was "Dr. Hull's Curculio Catcher" (Walsh and Riley (1868b). A large inverted umbrella was attached to a wheel barrow; the umbrella had a slit allowing its insertion up to the tree trunk. The front end of the barrow was equipped with a bumper, and pushing the "machine" strongly against the tree jarred it sufficiently to cause curculios to fall into the umbrella, which acted as a catching funnel; these beetles were then removed and destroyed. This contraption was soon replaced by a sheet stretched on a light wood frame and the trees were then hit with a wooden (and later rubber) mallet (Cook 1890; Petit 1904). One of the problems is that curculios resting in cavities in the bark or in fruits, as these develop, are often not dislodged by jarring (Crandall 1905). Also, this technique is more practical for plum and peach trees than for standard apple trees, which have more high branches that cannot be jarred practically. In such case, the technique becomes a slow and tedious task (Brooks 1910). A lengthy early historical review of jarring is provided by Quaintance and Jenne (1912) together with an evaluation of the economic benefits to be derived from its usage. Unless cheap labor was readily available, however, jarring was rapidly replaced by improved spraying methods as they became available (Slingerland and Crosby 1914).

Jarring persisted, however, as the primary technique used to gather ecological data about this species (Snapp 1930), to time insecticidal sprays (Chapman 1938), and evaluate their efficacy (Chandler 1940). In a later study, however, Chandler (1948) found that the examination of June apples for plum curculio damage was more accurate for determining the effectiveness of insecticide sprays. Jarring has also been used in conjunction with mark, release and recapture techniques in blueberry fields in North Carolina (Mampe and Neunzig 1967).

The advantages, disadvantages and appropriate uses of jarring were reviewed by Wylie (1951) and further comments are provided in Chapter 3 of this thesis. For obtaining large quantities of plum curculio adults, rearing is a more productive method.

2.6.4 Attractant stimuli

Tests in the laboratory using the McIndoo olfactometer (McIndoo 1926) have not revealed any strong attractants for plum curculio, and pheromones are thought not to exist (Hoyt and Gilpatrick 1976) none having been isolated up to the present; although I am aware of only one research project that has examined this matter (Calkins, personal communication).

Many substances that might be expected to attract plum curculio have been found to be only slightly attractive, and others even slightly repellent. Nevertheless overwintered beetles appear to readily find suitable host trees in the spring. They have even been found (in Florida) to oviposit on green thinning apples (c.a., 2,5 cm diameter) hung in oak thickets isolated from the nearest plum thicket by 100 m of thick wood (Calkins et al. 1976).

During laboratory studies of the attractiveness of many tree parts (peach tree bark, leaves, fruit and blossoms) and chemicals, including peach distillate, only butyl acetate was found to be slightly attractive to plum curculios; although in the field no beetles were attracted to this substance over a 42 day period (Snapp and Swingle 1929a; 1929b). Other substances were, however, found to be slightly attractive in the field: salicylaldehyde early in the season and gallic acid late in the summer (Snapp and Swingle 1929b). The number of insects caught were so low, however, that these captures might be accounted for, by beetles accidentally falling into the traps.

One of the main problems (in the laboratory studies) was the unevenness of the air currents in the McIndoo olfactometer (Garman and Zappe 1929). Design changes made by the present author appear to have solved this problem and have clearly improved the apparatus (see Chapter 5).

Plum curculio adult females are reported to be active both during the day or night (Quaintance and Jenne 1912), and in cages, Garman and Zappe (1929) found adults to be "decidedly positive to light". Positive orientation to ultraviolet light has been reported with southern strain plum curculios held in cages in orchards (Payne et al. 1973), but experiments by the present author with the northern strain in an apple orchard provided contradictory results (Chapter 3); also, no records of light-trap catches of the pest were found in the literature.

3.0 PUBLISHED SAMPLING TECHNIQUES

3.1 Introduction

During four growing seasons, ranging from 1977 to 1980, six sampling techniques were tested for C. nenuphar. Four are general sampling techniques: ultraviolet (UV) light-trap, suction apparatus (D-vac), emergence cage and soil sampling. The other two involved specific insect baits: pep+eugenol, the lure for the Japanese beetle (Popilla japonica Newman), and grandlure, the sex and aggregating pheromone for the boll weevil (Anthonomus grandis Boheman). Jarring was also used to detect and collect plum curculio.

All these experiments were carried out in the 1,7 ha "experimental orchard" located at the Department of Agriculture of Canada Experimental Farm at Frelighsburg, Quebec. As noted in the Introduction of this thesis, in which this "experimental orchard" is generally described, reference to location within the orchard is made throughout this Chapter, and others, according to the grid system defined therein (Fig. 1).

3.2 Ultraviolet (UV) Light-trap

UV light-traps were used first by Robinson and Robinson (1950) to collect insects, especially nocturnal ones. They found that many species are attracted by radiation in the near ultraviolet region of the spectrum. Frost (1958) reported that the addition of baffles to the trap increases captures.

Using a UV light-trap, Frost (1957) reported capturing Curculionidae, however he did not indicate the genus or species. Quaintance and Jenne (1912) mentioned that C. nenuphar flies at night, especially on warm, calm nights, and Payne et al. (1973) found that laboratory reared southern strain plum curculios oriented to UV light, the degree of orientation decreasing as their distance from the light source increased. Because of these observations, I decided to test the UV light-trap for plum curculio.

3.2.1 Materials and methods

I used the Ward 4-baffle trap (No. 29W6002[1]) equipped with an eight watt blacklight fluorescent tube (GE F8T5BL[2]) with peak spectral radiation c.a. 360 nm. The collecting pail contained water, with a drop of liquid detergent added as a wetting agent, to prevent escape of captures.

In 1977 four of these traps were installed on the west side of the experimental orchard adjacent to the woodlot. Two were five meters above ground level in the crown of trees N-12 and M-7 and the other two at ground level under the drip line of trees N-14 and M-9 (Fig. 1). These locations were chosen because plum curculio damage is known to be most intense at such sites. A fifth trap was installed two meters above ground level in a plum tree (Prunus sp.) two kilometers north of the experimental orchard. The four traps in the orchard were powered by a 300 watt gasoline generator and the one in the plum tree by domestic electricity supply.

The four traps in the experimental orchard were operated from 2100 h to 0500 h the next morning on the following days: May 17, 18, 19 (full bloom), May 26 (fruit set) and June 7, 8 and 15. These periods were chosen because plum curculio usually emerges and migrates to host trees at

---

[1]Ward's Natural Science Establishment Inc., Rochester, N.Y..

[2]General Electric Company, Cleveland, Ohio.

the time of full bloom (Smith and Flessel 1968); oviposition begins at fruit set (Chapman 1938); and most oviposition scars, 80% in a study by Paradis (1957), are made in June. The trap in the plum tree was operated from 1900 h to 0700 h the next morning, for two to three nights a week, depending on weather conditions, between May 9 (plum tree full bloom) to June 15.

3.2.2 Results and discussion

Not a single plum curculio was captured in any of these five traps. This is surprising because curculios were detected during the day by jarring in the vicinity of the traps and, on May 25, 96 out of 120 small fruits (80%) collected from the plum tree were found to be damaged by plum curculio. The only hopeful sign was that, in the early morning of June 16, one plum curculio was found resting on the outside of the collecting pail of the trap in the plum tree.

The observations by Payne et al. (1973) regarding the orientation of the southern multivoltine strain to UV light were made on caged individuals located between nine meters and 853 m from the light source. These beetles were held in open ended wooden tunnels (61 cm long and 52 cm^2 in cross section), and could choose between moving toward either the UV source or ambient night luminosity. The regression of adult plum curculios response to UV light on the distance from the light source of caged individuals was established. The correlation coefficient (r) calculated for this linear relationship was $-0,95$ ($P < 0,01$). The maximum response, 93% of the beetles moving to the UV illuminated side of the tunnel, was recorded up to 37 m from the light source. Payne, however, did not test UV light-traps for capturing plum curculio, and no close range attraction tests have been reported in the literature. Also, other published records of UV light-trap catches contain no records of C. nenuphar captures.

My experiment, while not confirming or contradicting Payne's observations, does suggest a possible close range repulsion to high intensity UV light. Since my experiment took place at a time of year when the nights were still quite cool (experimental orchard air temperature mean minimum[1]: May 1977, 7,7°C; June 1977, 11,4°C), it is possible that plum curculio was not active then. Also, as these beetles are poor fliers (Hauschild and Prokopy 1977), the 4-baffle traps used may have inherent design limitations.

Detection of plum curculio for directed control purposes has to be achieved prior to fruit set, the time of the most efficient calendar spray for its control. At our latitudes, warm, calm nights are not frequent at that time of year (experimental orchard mean air temperature for May based on seven year records[1]: 11,5°C). Thus, it is unlikely that UV light-traps can be used to monitor this pest in our region. At more southern latitudes or with the multivoltine strain, however, it may be possible to use such traps, although experiments will first have to be conducted to find the best wattage and trap design.

3.3 Suction Apparatus

Vacuum suction machines for sampling arthropod fauna on vegetation were developed first by Johnson et al. (1955). Dietrick et al. (1959) modified the apparatus by adding a larger collecting cone equipped with an organdy net. A light backpack version, designed by Dietrick (1961), is now widely used and generally referred to as the D-vac.

---

[1] Frelighsburg Experimental Farm, Meteo Station No. 2, about 100 m east of the experimental orchard.

A D-vac was successfully used by Rivard *et al.* (1979) for sampling the strawberry weevil (*Anthonomus signatus* Say) in strawberry and raspberry plots located in the vicinity of the experimental orchard. Since plum curculio is well known for its reflex immobilization behaviour (see under "Jarring" in this chapter), the hypothesis that individuals could be found on the herbaceous stratum beneath apple trees was investigated.

3.3.1 Materials and methods

The suction apparatus used was the D-Vac Insect Net (No. 24[1]), equipped with a nylon organdy collecting bag. The suction cone opening is one square foot (929 cm^2). When used on ground vegetation the cone was held at about five centimeters above ground level for four to five seconds *per* unit sample. On accessible apple tree branches, the suction cone, being held upward, was moved along their underside as close as possible for eight to ten seconds *per* branch.

In 1978, the apparatus was used on the vegetation beneath 10 randomly selected trees in rows K, L, M, and N of the experimental orchard (Fig. 1). Also, 25 branches on trees on rows M and N were explored with the D-vac. These locations were chosen to maximize chances of capturing *C. nenuphar*: later assessment of "June drop" damage showed that 47% of the dropped fruits were damaged by plum curculio in this section of the orchard (see Chapter 6).

The experiment was performed during the morning of June 8, one week after fruit set, when plum curculio are most numerous on trees and actively ovipositing. Their presence was confirmed by the abundance of recent oviposition scars on the small fruits.

---

[1] D-Vac Corporation, Riverside, California.

Under each of the 10 selected trees I put the suction cone down 10 times: twice in each of the cardinal quadrants under the canopy and twice near the trunk. Each sample from one tree was removed from the cone for later examination. The 25 branches were submitted to the D-vac suction one after the other and this comprised the eleventh sample. The first 10 samples covered 9,3 m^2 of ground surface.

3.3.2 Results and discussion

Thorough hand sorting of the eleven samples revealed no plum curculio. This result is not surprising for the sample taken on the trees. The apparatus is not designed for aerial use, and curculios disturbed by the sound and vibrations may have dropped to the ground. On the other hand, this result is surprising for the 10 ground level samples. Firstly, the apparatus is known to be efficient in this type of habitat. Secondly, I expected that in addition to any individuals already on the ground, others, disturbed by the sound and vibrations of the D-vac, would fall from the trees, feign death on the ground for several minutes, and hence be captured also.

Thus, it seems that the sound and vibrations from the machine do not cause plum curculio to fall off the branches. Also, that plum curculio does not occur on the herbaceous stratum beneath apple trees at that time. This was further confirmed by the work of another graduate student, Dr. Guy Boivin, who found no plum curculio, in 1979, during his mirid sampling program in the same experimental orchard. He sampled an 11,6 m^2 ground surface area with the D-vac, twice a week between May and September.

In view of these results no further experiments were carried out with the D-vac. It seems unlikely that suction apparatus can be used to effectively detect plum curculio.

3.4 Emergence Cage

Emergence cages of variable design are widely used by entomologists to capture insects escaping from soil and vegetation. In the following experiments I attempted to capture emerging overwintered adult plum curculios prior to their spring migration.

3.4.1 Materials and methods

For my experiments I used bottomless wooden frame cages, 80 cm x 80 cm and 30 cm high, covered with 16 mesh galvanized screen. There is a 20 cm wide sliding door in the roof of each cage. Cages were sunk five centimeters into the ground to prevent escape of emerging plum curculios.

In 1977 four of these cages were installed over trash and leaf litter at the edge of the adjacent woodlot, three along the west side of the experimental orchard and one on the south side. Two other cages were installed within the orchard under trees M-14 and H-1 (Fig. 1). In 1980 nine cages were installed three to four meters into the woodlot over trash and leaf litter; three per side, equally spaced, along the west, north and south sides of the orchard. The woodlot locations were chosen as they appeared to be the most likely overwintering sites for plum curculio.

In 1977 the cages were installed on May 9, four days before the pink bud stage, and in 1980 on April 22, one week before green tip. This earlier installation was to ensure that plum curculios awakening earlier than usual from overwintering sites would be captured. In 1977 the cages were examined on May 10, 12, 13, 17, 18, 20, 25, 27, 31 and June 2 (one week after fruit set) and in 1980 on April 29, May 7, 12, 13, 14, 15, 19, 23, 26, 27, 30 and June 5 (at fruit set).

3.4.2 Results and discussion

No plum curculios were found. As the total area under the cages is relatively small (about 4 m^2 in 1977 and 6 m^2 in 1980) it may be that overwintering adults were simply missed. This would be most probable if plum curculio exhibits an aggregated overwintering pattern. The ability of plum curculio to survive in these emergence cages and my ability to detect them was confirmed in two other experiments (Chapters 5 and 7). On these occasions either plum curculio damaged "June drop" apples or curculio larvae collected after dropping from them were introduced into similar cages located under trees in the experimental orchard or in the adjacent woodlot. After the curculios had pupated, hundreds of emerging adults of the new generation were collected in August, by hand or with an aspirator, from the screen and the wooden frame of the cages.

Thus, until more is known about the overwintering behaviour of this insect, further work with emergence cages is not likely to be productive.

3.5 Soil Sampling

The ideal sampling technique for plum curculio would be one that assesses population density of overwintered adults migrating to the orchard prior to fruit set. Knowledge of the location of overwintering sites would be useful background information for such an approach. By mid-October in southerwestern Quebec, the beetles have left the trees for their overwintering sites (Le Blanc *et al*. 1981). Thus, plum curculio adults were marked and released in the experimental orchard and soil samples were collected later to detect the overwintering sites.

3.5.1 Materials and methods

In 1979, 641 plum curculio adults reared from thinning apples in emergence cages were marked on one elytra with a dot of yellow lacquer; and 402 others were marked with a red dot. For ease of marking, insects were held in batches of 10 for 30 seconds in a refrigerator at 7°C. It took a whole day to mark the first group and the following morning no sign of toxicity of the lacquer had been detected. Some were observed flying in the holding cages and this was considered evidence of flight ability of the marked insects. The first group (yellow ones) was brought to the experimental orchard on August 30. The insects were released in six trees in the center part of the orchard by simply leaving the cages open on the ground near the trunks. Two hours later all cages were empty. The second group (red ones) was released on September 24. Marking plum curculio with "enamel" dots on the elytra was carried out successfully by Mampe and Neunzig (1967). They reported no ill effects on longevity or behaviour as a result of marking and three individuals recaptured the following season assured them of the durability of the marks.

Soil samples were taken on November 7, after migration and before snow cover, and examined for overwintering plum curculio adults. The samples were obtained by cutting with a knife around a square wooden template (64 cm^2) placed on the ground, Each sample was removed with a shovel, cut to 5 cm thick and put in a labelled polyethylene bag, making sure that the soil and the vegetation cover of the sample are not disturbed. The samples were kept at 5°C until extraction, which was conducted over the following month. Sample size was determined partly by the availability of extraction apparatus and because I considered that by using large numbers of small samples I would increase my chances of finding curculios. Relatively shallow samples were taken because Smith and Flessel (1968) had found that when provided with a vegatative cover less than 5% of the beetles hibernate in soil, 95% being found at the soil surface.

As some hibernating curculios have been found in the past within orchards (Quaintance and Jenne 1912) as well as in woodlots adjacent to orchards (Garman and Zappe 1929), samples were taken in both sites. Within the orchard 50 trees were randomly selected and three samples taken from the soil under each of them, one near the trunk, one under the drip line and one in the middle of the row between the selected tree and its closest neighbour. In the woodlot, samples were collected at three stations along each of five transects perpendicular to three sides of the orchard: one extending north and the other south from either end of row H, and three on the west side starting at trees N-2, N-8 and N-13 (Fig. 1). Three samples were taken at each of the three stations, which were 10 m, 40 m and 70 m into the woodlot. Thus, a total of 195 samples were collected.

The samples were all processed in a Hill (1969) modified Kempson et al. (1963) behavioural extractor (see also Behan 1972). Extraction was carried out until the samples were completely dry (three to four days).

3.5.2 Results and discussion

Beetles were found but no plum curculios. To check if any had remained in the samples these were hand sorted twice after first removing most of the dried soil by sieving; no curculios were found.

As a relatively small area of soil was sampled (9 600 cm^2 in the orchard and 2 880 cm^2 in the woodlot) it cannot be concluded that plum curculio does not hibernate in these areas. It was hoped that some individuals would be found (especially marked ones) in one of the areas sampled, thus indicating where to intensify the search the following spring.

As another graduate student, Mr. Gérald Lafleur, began a study of the overwintering behaviour of plum curculio in 1980 using radioactive labelling, no further soil samples were collected. If I had continued the experiment I would have collected many more samples from a wider range of habitats and extending further within the woodlot. Experiments would also be carried out to determine if plum curculios introducted into soil samples are extracted in the Hill extractor.

3.6 Lure for Japanese Beetle

An attractant and trap for the Japanese beetle (Popilla japonica Newman) were first developed by the USDA Bureau of Entomology (Courtney 1931).

In 1977 I obtained ten Japanese beetle traps and lure, pep+eugenol (2-phenylethyl propionate and eugenol, 7:3) (McGovern et al. 1970), from the Agriculture Canada Japanese Beetle Survey Program for Quebec. These were tested for their attractiveness to plum curculio.

3.6.1 Matérials and methods

The trap I used is similar in size, shape and colour to the commercially available Ellisco Trap[1] and consists of a metallic 4-baffle device, painted yellow, inserted above a collecting funnel. The lure is dispensed by a wick coming out of a small reservoir placed in the center of the baffles. The trap hangs from a metal gallows about 1,5 m above ground.

Two traps were located along the south edge of the experimental orchard, four along the west edge, two along the north edge and two near the center of the orchard. This way eight of the 10 traps were located along

[1]Ellisco Co Inc., Philadelphia, Pennsylvania.

edges of the orchard adjacent to the woodlot to intercept plum curculios migrating from their most likely overwintering sites. The traps were installed on May 9, 1977 (four days before pink bud stage) and monitored on May 10, 12, 13, 17, 18, 19, 20, 25, 27, June 2 and 10 (two weeks after fruit set). This covered the period of plum curculio mass emergence and migration to the orchard.

3.6.2 Results and discussion

Two plum curculios were captured on May 17, one day before full bloom, in one trap situated on the west side of the orchard. As this is hardly an encouraging result in an orchard known for its high population density of plum curculio, no further experiments were conducted with this trap.

3.7 Synthetic Pheromone for Boll Weevil

In the last two decades, as the chemical synthesis of insect pheromones was achieved, their use in surveys and control attempts increased rapidly. If the existence of such a chemical messenger could be demonstrated for either sex of the plum curculio it would provide us with a means of trapping them or of increasing the efficacy of other trapping devices. Unfortunately, when I initiated my work, isolation and identification of a plum curculio pheromone had not been reported, and this situation persists presently.

Since the late sixties, pheromones have been used successfully to monitor many Lepidoptera. While pheromones are specific, usually this is due not to differences in their chemical composition but rather to the ratio between their constituents. For example, 11-tetradecenyl acetate is the sex pheromone of female European corn borers, <u>Ostrinia nubilalis</u> (Hbn.), and it is optimally attractive to males when its (Z) and (E) isomers are present in the ratio 100:4 (Klun 1968). A related species, the smartweed borer, Ostrinia obumbratalis (Led.), is attracted, however, to a 1:1 mixture of these two isomers (Klun et al. 1973). Species related at the family level may also be attracted by the same chemical. Thus, the red-banded leafroller, Argyrotaenia velutinana (Wlk.), and the oblique-banded leafroller, Choristoneura rosaceana (Harr.), also have 11-tetradecenyl acetate as their sex pheromone, and again particular ratios of (Z) and (E) isomers determine the specificity of the pheromone (Roelofs and Arn 1968; Reolofs and Tette 1970). Even when a pheromone is "tuned-in" for a species by the proper mixture of its components, non-target captures of related species are often encountered. For this reason, I decided to test grandlure, the synthetic pheromone for the boll weevil, Anthonomus grandis Boheman, (Cross et al. 1969; Tumlinson et al. 1969), for its attractiveness for plum curculio.

3.7.1 Materials and methods

Through Dr. D. D. Hardee[1], I purchased this pheromone incorporated in 4 cm^2 slow release wafers (Hercon® dispensers[2]) at a concentration designed to last for at least 28 days in the field. Grandlure field attractancy tests for plum curculio were carried out with two different traps: a boll weevil trap[3] and a sticky trap[4]. An insecticide was used in the boll

---

[1] Pest Management Specialists Inc., Starkville, Mississippi.

[2] Herculite Division of Health Chem Corp., New York, N. Y.

[3] Story Chemical Corporation, Willoughby, Ohio.

[4] Model 1C, Zoëcon Corporation, Palo Alto, California.

weevil traps to prevent captures from escaping; a 4 cm^2 slow release insecticidal chip (Hercon® Insectape with Baygon®) containing propoxur in a 10% AI formulation was inserted in each trap collecting chamber. These were claimed to be effective for 28 days under field conditions (Hardee, personal communication).

In 1978, both trapping systems were tested in the experimental orchard and in a commercial orchard about eight kilometers to the south. Four boll weevil traps, three containing a pheromone wafer and an insecticidal chip, were installed in trees M-3, M-13 and K-6 within the experimental orchard (Fig. 1). A control, containing only an insecticidal chip, was hung in tree M-6. Two similar traps containing the pheromone and the insecticide were installed in the commercial orchard on the side adjacent to a woodlot. All six traps were installed in tree crowns (three to four meters above the ground) on May 10 (green tip). The first four traps were monitored on May 11, 16, 18, 20, 23, 24, 25, 26, 27, 28, 30, 31, June 3 and 7 (one week after fruit set). The two in the commercial orchard were monitored on May 11, 16, 20, 23, 27, 30, June 3 and 7. Two sticky traps, one with the pheromone and the other serving as control, were installed at eye level in trees N-13 and N-12, respectively, on May 25. These were monitored every day from May 26 to June 3. Another sticky trap containing grandlure was hung in a plum tree, two kilometers north of the experimental orchard and monitored on the same days as the two in the experimental orchard. Locations and dates of these tests were chosen to maximize chances of plum curculio captures.

3.7.2 Results and discussion

In all, five plum curculios were captured. Four on May 16, in boll weevil pheromone traps; three were in tree M-13 and one in tree K-6. The fifth curculio was captured on May 31 in the sticky trap hung in the plum tree. On June 3, new pheromone wafers were put in each trap, but no more plum curculios were captured. In addition to monitoring the traps I also examined the adjacent regions on the tree for individuals that might have been attracted by the pheromone, but that did not enter the trap. None were seen.

While the sticky trap seems unsuitable, the boll weevil trap holds some promise, and probably the next stage is to experiment with its location on the tree (see Chapter 5 for a fuller discussion). However, the pheromone was not strongly attractive for plum curculio. This could be questioned on the basis that the traps used were not designed originally for plum curculio, but no detection of curculios near the traps further supports this conclusion. Further studies of this pheromone using different ratios of the four components of grandlure should be carried out. The grandlure composition used in these tests was a mixture of its four components I, II, III and IV in a ratio of 30:40:15:15 (details are given in Tumlinson et al. 1969).

3.8 Jarring

At the beginning of my study, in 1977, excepting visual observations, jarring was the only published technique available for the detection and collection of adult plum curculios from host trees. Jarring had also been used as a control measure (Walsh and Riley 1868b) before the development of chemical insecticides.

The success of this technique is caused partly by this insect's behaviour of "reflex immobilization". This trait, exhibited by many Coleoptera, and particularly by plum curculio, is also termed thanatosis or more simply death feigning (Wigglesworth 1972).

When jarring was replaced as the means of control by chemical insecticides, its use persisted to detect and collect the pest. Jarring is generally accomplished by hitting the tree limbs sharply, once or twice, with a rubber mallet or a stick covered with rubber to minimize bark damage; dropping insects are collected on a sheet of contrasting colour, the drop cloth, held close under the jarred limb (Wylie 1951).

In this study wherever jarring is mentioned the following procedure is implied. A one square meter white drop cloth, on a frame of two diagonally inserted pieces of light wood was held close under the jarred tree limb. The limb was usually jarred by means of two sharp rapid blows with a 1,5 m long hardwood stick, four centimeters in diameter, the hitting end being covered by a piece of rubber.

Jarring results are affected by many variables: size of the jarred limb, size of the drop cloth, strength of the blows, height of the "jarrer", time of day and weather conditions, principally ambient air temperature and wind velocity. For example, when air temperature exceeds 22-23°C plum curculio will more often fly away rather than drop. If it is cooler but windy curculios will drop, but not necessarily onto the drop cloth. All these factors preclude standardization of jarring, a prerequisite for reliable methods of population density assessment and damage prediction. Other limitations of this technique for plum curculio sampling are discussed by Wylie (1951).

When the population density of plum curculio is relatively high (as in my experiment in which harvest damage was in excess of 20%), jarring is the simplest means for collecting adult curculios. Thus, it can be used to detect presence of the pest and, when jarring is carried out systematically in favourable locations and proper weather conditions, it can reveal time of appearance of the first individuals on the host trees. However, jarring in low population density areas, is a very tedious technique unlikely to be reliable for directed control purposes.

Because of the difficulties with standardization of the technique, records of jarring were not kept. Jarring was used, however, throughout the study to collect small numbers of adult plum curculios when they were needed for experimentation. When large numbers of adults were needed, they were reared from collected thinning apples, a far more efficient method, depending essentially on the number of damaged "June drop" apples collected.

In the next chapter three techniques that exploit this "death feigning" behaviour of plum curculio are presented.

4.0 TECHNIQUES INVOLVING THANATOSIS

4.1 Introduction

Certain limitations of jarring have been listed in the previous chapter. In this chapter, three experiments are described that aim to counteract these difficulties and to exploit, in different ways, the reflex immobilization behaviour of C. nenuphar.

In the first experiment the effect of decreasing evening temperatures on plum curculio dropping from host trees was investigated. The second experiment involved jarring small branches, detached from the trees, and the third measured the incidence of plum curculio dropping from the trees because of natural causes, principally wind.

4.2 Drop Cloth

During the period when jarring was used to control plum curculio, it was normal to jar each tree in its totality. For that purpose an upside down "umbrella", the diameter of the tree canopy, secured on a wheelbarrow equipped with a tree bumper, was used (Walsh and Riley 1868b). Later, large tarpaulins, or sheets of contrasting colour were spread under each tree, the tree trunk or branches being hit with a large mallet or a stick and the beetles collected and destroyed by physical means. In this experiment I wanted to examine the effect of decreasing evening temperature on the rate of plum curculio falling from host trees. It was expected that as the temperature dropped, to some particular threshold, the beetles would become less active and some would fall from the trees.

When ambient air temperature is relatively high (above 22°–23°C), plum curculios are more active and if disturbed many fly rather than fall and feign death. When temperatures are lower the beetles become less active and even quiescent. At such times they are more likely to drop when the wind vibrates the branches of the trees. My hypothesis was that, as a critical air temperature is reached during the evening or night, at least some plum curculios would drop from host trees.

The hypothesis was first tested in the laboratory. Small apple branches, c.a., 1,5 m) with curculios on them, were brought into a walk-in refrigerator in which the air was still. While none fell at 15°C, an average of seven out of ten fell, without shaking the branches, within the first 15 minutes at 10°C (the experiment was repeated three times).

4.2.1 Materials and methods

In 1977, a nine meter square drop cloth was spread under tree N-8 (Fig. 1). This tree was chosen because plum curculios were detected on it by visual observation during the day (1800 h). The drop cloth was cut open on one side to the center to accommodate the tree trunk. Velcro® was used to hold the slit closed. The corners of the cloth were anchored to the ground by small posts.

The drop cloth was examined every hour from 2100 h on June 15 until 0100 h the following day. Ambient air temperature decreased from 15°C to 10°C in the experimental orchard during this period and the wind was very light. Based on my laboratory observations this lowest temperature would appear to be adequate to test my hypothesis.

4.2.2 Results and discussion

Not a single curculio was detected on the drop cloth. Curculios may have dropped in the refrigerator because the temperature decrease was sudden, while in the field this decrease was gradual, extending over four hours. This may have given the curculios time to move to suitable shelters.

Alternatively some curculios may have fallen between inspection periods and simply escaped from the drop cloth.

In view of the negative result, the inconvenient time of sampling and restrictive requirements for a successful result, the experiment was not repeated.

4.3 Jarring Detached Branches

Previous observations by Paradis (1957) indicated that at least some plum curculios feed on the apple blossom. To test if the blossom might attract curculios that had just emerged from overwintering I decided to jar bunches of small apple branches - the development of which had been advanced in the greenhouse - placed in the experimental orchard prior to the natural blooming period.

4.3.1 Materials and methods

For the purpose of this test, in late April 1977, 300 branches one meter long were pruned from insecticide free McIntosh trees of the experimental orchard. They were immediately put in a large garbage pail containing water, to prevent air infiltration at the cut ends. Later the same day the branches were transferred into plastic pails installed in a greenhouse at the Agriculture Canada Research Station, Saint-Jean, Quebec. The pails contained an aqueous solution comprising nutrients and blooming promoters: 4,0% saccharose, 300 ppm 8-hydroxyquinolinol citrate, 30 ppm silver nitrate, 50 ppm aluminum nitrate (Rousselle, personal communication).

On May 6, when the branches were in full bloom, they were placed in the experimental orchard in ten pails, each containing 20 branches together with the same nutritive solution that was used in the greenhouse. Two pails were spaced equally on each side of the orchard and two were put near to the center. This design was chosen to provide information about the migration of overwintering adults to the orchard.

The branches were monitored for plum curculio over a five day period, first visually, and then by lightly shaking the branches over a piece of white cardboard. This operation was done twice a day, between 0800 h and 1000 h and also between 1700 h and 1900 h. These times were chosen to avoid high temperatures when the beetles would be more active, and more likely to escape detection. Monitoring was carried out on May 9, 10, 12 and 13 (during the orchard pink bud stage). On May 13 the branches in the pails lost their petals and the experiment was terminated.

4.3.2 Results and discussion

Plum curculio was not detected by this technique, although on May 6, the day when this experiment commenced, two plum curculios were jarred from a blooming plum tree, two kilometers north of the experimental orchard. Although weather conditions at this time were suitable for curculio emergence, jarring in the experimental orchard on May 9, 10 and 12 revealed no plum curculios. Thus, it cannot be concluded that such branches could not attract plum curculios because if they had been installed later, captures may have been obtained, although at that time the branches would have been in competition with the blossoms of the trees. Also, the fact that the pails were at ground level rather than in the crown of trees might have made them less attractive. The ability of 20 branches in a pail at ground level to attract insects was, however, apparent from the numerous pollinators that were found on the blossoms when searching for plum curculio.

Because of the negative result and of the difficulty in synchronizing blooming of the cut branches with plum curculio migration and pink bud stage in the orchard, the experiment was not repeated.

4.4 Intercepting Funnels

The final method based on thanatosis that I tested was suggested by the work of Steiner (1965). Steiner hung funnels in apple trees to collect falling arthropods killed by pesticidal sprays.

In my experiment large funnels were used to catch plum curculios falling from the trees because of natural causes, principally wind. The funnels were installed when plum curculios are likely to be migrating to the orchard between pink bud and full bloom stages, and, once there, feeding on leaves and blossoms, i.e., before they do any economic damage. At this time night temperatures often fall below 15°C, or even 10°C, and plum curculio dropping from the trees, due to wind, is likely to be at a maximum.

4.4.1 Materials and methods

Ten funnels were constructed (Fig. 4). The upper opening is 0,65 m^2 (i.e., 2/3 the size of a one meter square drop cloth) and consists of a plastic hoop to which is attached, by heat soldering, a cone made of heavy gauge (0,15 mm) green polyethylene. This colour was chosen to avoid contrast with the orchard cover, which might have repelled plum curculios from exploring the tree limbs above the funnel. The base of the funnel cone, bearing a circular two kilogram weight, is inserted in a plastic pail, sunk 30 cm into the ground. The pail contains a tripod to which a vertical metal rod, 45 cm long, is screwed to prevent the funnel base from blowing out of the pail. The pail is one quarter filled with a suspension of the insecticide permethrin[1] (0,2 g/1)[2] to which is added the wetting agent

[1] Ambush 25 WP, Chipman Inc., Stoney Creek, Ontario.

[2] Dosage of commercial product.

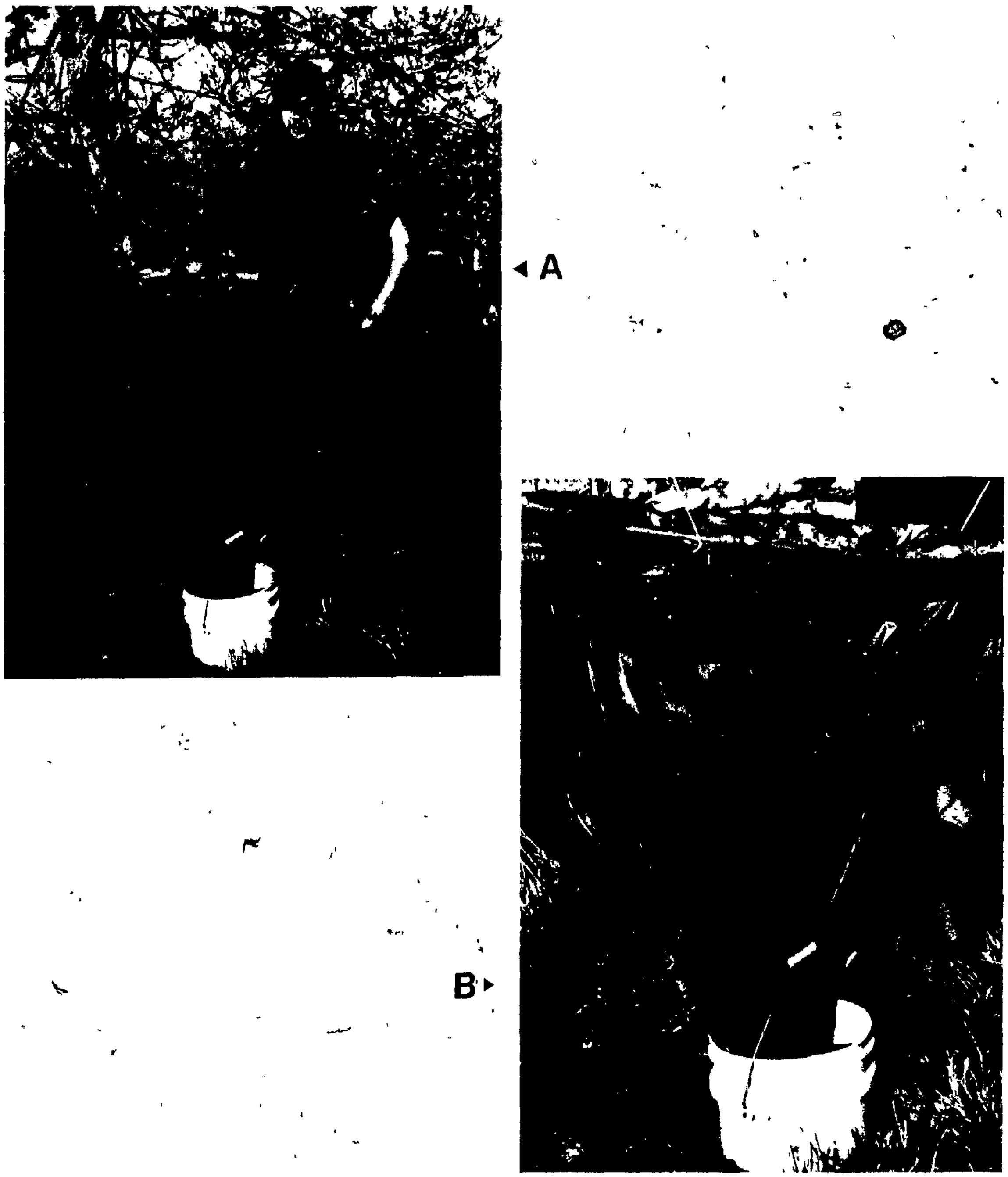


Fig. 4. (A) Intercepting funnel hung under an apple tree branch in the experimental orchard at Frelighsburg, Quebec, 1979. (B) Close-up.

Tergitol© NPX[1] (0,5–1,0 ml) to prevent escape of captured insects. The insecticide permethrin was chosen for its fast knockdown effect and low mammalian toxicity. The wetting agent Tergitol© was chosen because, in contrast to most liquid detergents, it is odorless at least to humans, and it was hoped it would be unlikely to influence plum curculio behaviour. Three ropes, attached to the hoop, were used to secure the funnel to a suitable tree limb.

The funnels were installed in the experimental orchard, one under each of 10 McIntosh trees (Fig. 5). The distance between each funnel and the adjacent woodlot was recorded. All the funnels were installed on May 7, 1979 (three days before the pink bud stage) and monitored once a week until October 15 (two weeks after harvest). Captures were removed by pouring the contents of each pail through a sieve into a spare pail. The liquid in the pails was replenished when needed and generally replaced every two weeks, or more often at times of heavy rain. Weekly captures were stored in labelled jars containing 70% methanol and sexed, at a later date, according to the method of Thompson (1932).

4.4.2 Results and discussion

Plum curculio adults were first captured by this method during the week prior to May 14 (full bloom, May 15). During the second week of October there were no captures and so the experiment was terminated. Although total number of captures is small (76 individuals in 10 funnels), their patterns of distribution in time and space were found to be related to the seasonal development of plum curculio and to its ecology, respectively.

---

[1]Union Carbide Canada Ltd, Toronto, Ontario.

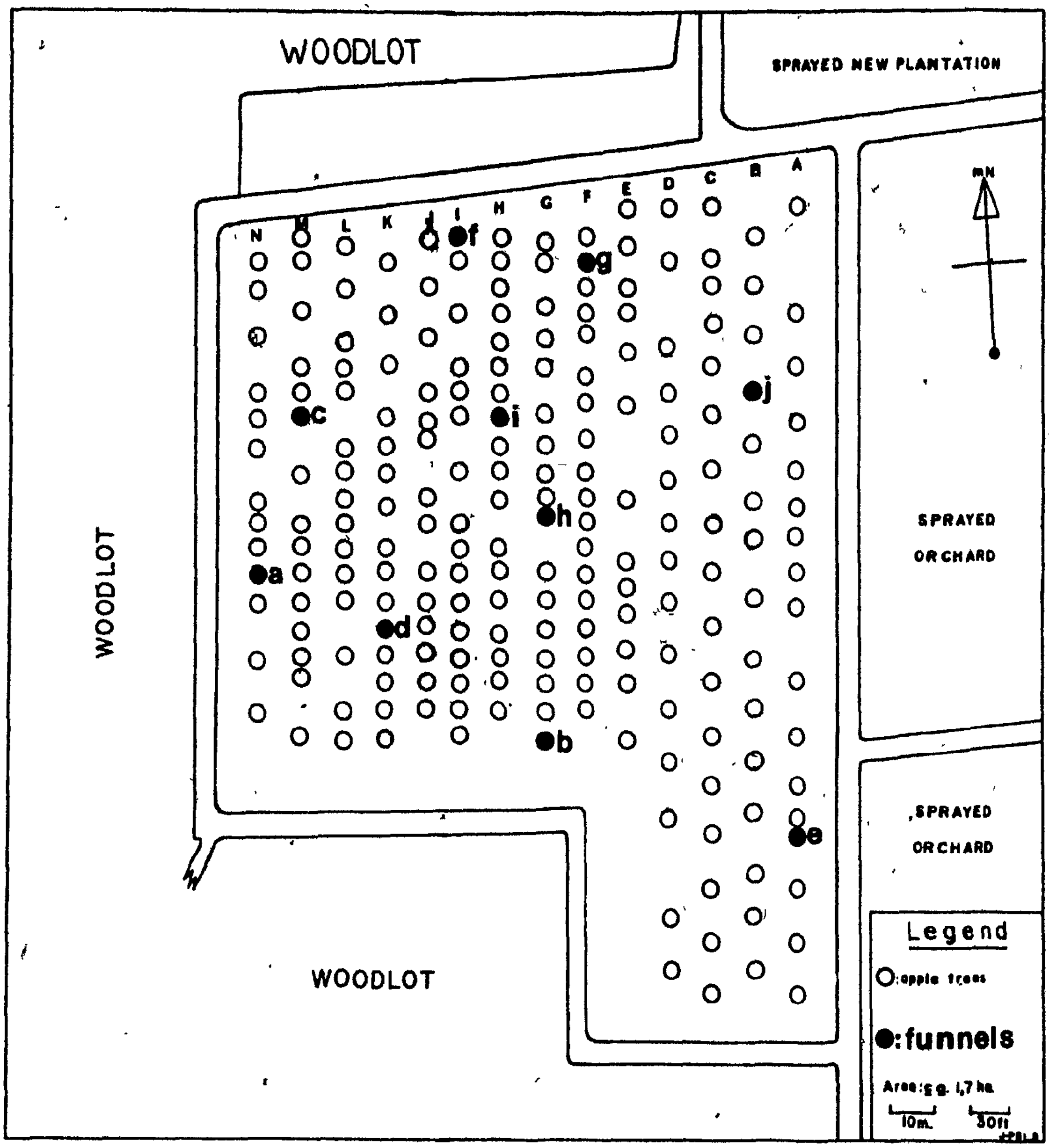


Fig. 5. Location of the 10 intercepting funnels (a-j) in the experimental orchard at Frelighsburg, Quebec, 1979.

4.4.2.1 Sex ratio of captures

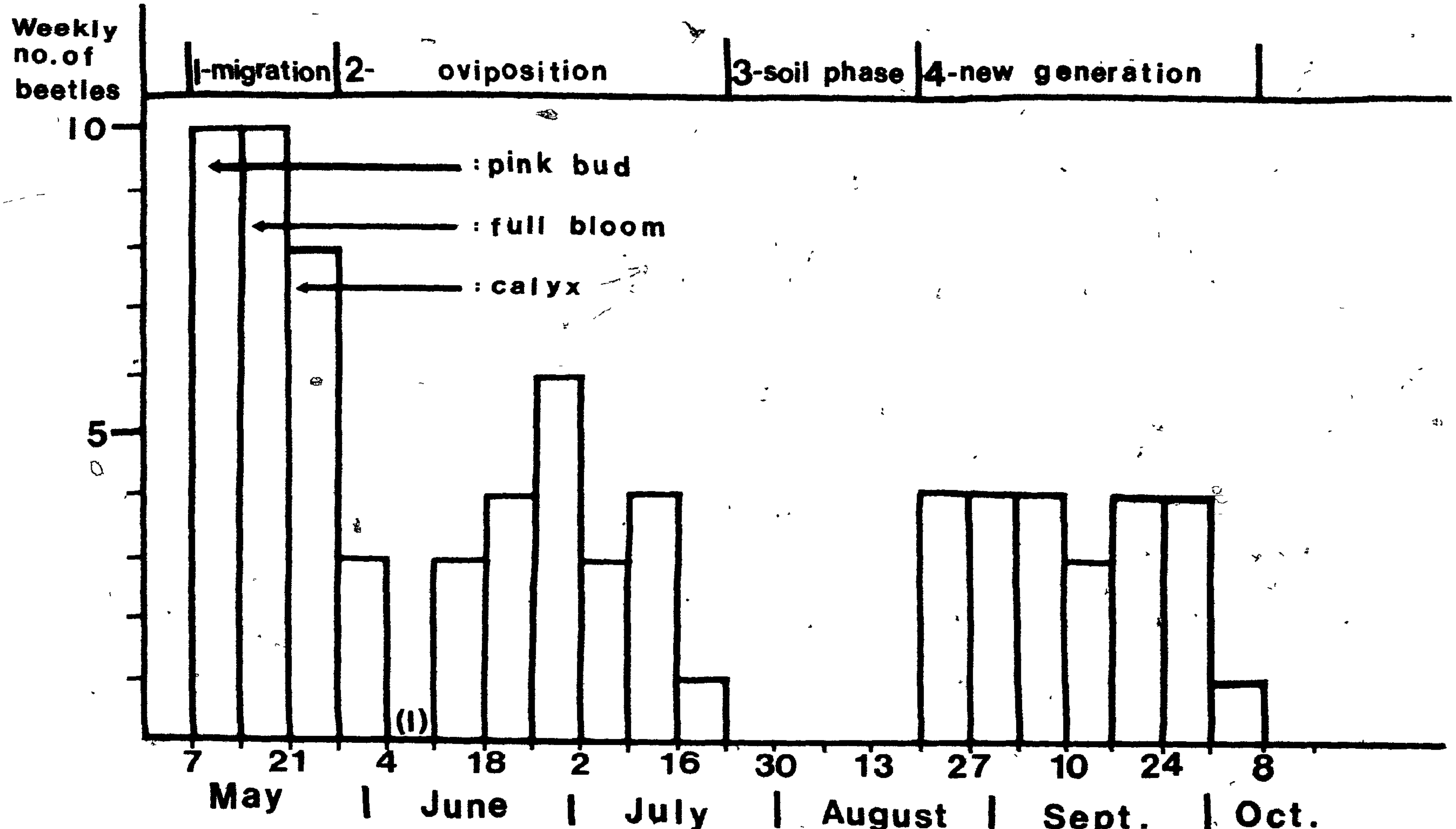
Except for the first week, when male:female capture ratio was 1:1, females generally outnumbered males (43:33 or 1,3:1 for the season). This ratio, however, was not significantly different from 1:1 (χ^2= 1,316)[1]. These findings contrast with Smith and Flessel's (1968) observations from jarring, that males appear earlier than females on host trees in spring; however, these data do support their finding, during their eight year study, of a seasonal dominance of females in jarring captures. Based on extensive observations, Smith and Flessel (1968) also reported that plum curculio sex ratio of emerging adults after pupation was 1:1. The slight, though not statistically significant, difference in the sex ratio of seasonal captures observed in the present study may be accounted for by variations due to sampling and/or female curculio's longer persistence on the trees and/or by a slightly higher winter mortality of males.

4.4.2.2 Captures in relation to plum curculio seasonal development

Maximum number of captures, with a weekly average of 7,8 individuals for the ten funnels, occurred in May when flowering buds passed from pink tip to fruit set (Fig. 6). At that time plum curculios become active, colonize apple trees, and begin to feed and mate. In both 1979 and 1980, on warm May days, plum curculios were observed mating in the apple blossoms. While this is the first recorded observation of this behaviour, it seems likely that apple blossoms might provide a focal point for bringing the sexes together.

---

[1] χ^2 = 3,84; α=0,05 and one degree of freedom.



(1) Traps upset by strong wind.

Fig. 6. Histogram of weekly capture of Conotrachelus nenuphar adults with 10 intercepting funnels in the experimental orchard at Frelighsburg, Quebec, 1979.

A second capture period (3,5 individuals *per* week), extending from June 11 to July 23 (Fig. 6), coincided with the peak oviposition period (June) and the physiological fruit drop (July). This decline in captures reflects the increase in overwintering adult mortality once mating and oviposition is completed. Very few individuals are thought to hibernate a second time (Paradis 1956).

During the last week of July and the first three weeks of August, when plum curculio pupates in the soil, no captures were recorded. This probably reflects the small amount of generation overlap for this insect in our region.

The final capture period (3,4 individuals *per* week) extending from the last week in August to the first week in October (Fig. 6), coincided with the emergence of the new generation. These sexually immature adults feed on maturing fruits until harvest when they start to migrate to their overwintering sites. Migration is completed by the time all the leaves have fallen.

Clearly the critical time for monitoring plum curculio to provide useful information for its control is before fruit set. At that time the ten funnels had captured 28 individuals, 37% of the total for the season. Such a density would be expected to cause immediate extensive damage to the young apples, and the subsequent larval development in the fruits to significantly increase the physiological fruit drop (Levine and Hall 1977) and probably also final yield. It is possible, however, that early damage to young fruit would constitute a beneficial thinning mechanism of apple trees. The maturing fruits, however, would have to be protected from damage by new generation adults by removing the dropped apples containing the next generation of plum curculios, or alternatively by applying an additional insecticide spray in August.

While the main capture period in 1979 was before fruit set only 28 individuals were collected and this is probably not adequate to accurately detect low population densities, which would be necessary for its use as a monitoring technique in directed control programmes. This is further emphasized by the fact that in 1979, harvest damage by plum curculio in the experimental orchard exceeded 68% (based on 2 500 apples).

4.4.2.3 Captures in relation to trap location

The most significant finding of this experiment was that number of captures of plum curculio increased as the distance between funnels and the woodlot decreased (Table 3). Thus, the five funnels nearest to the woodlot (within 46 m), captured 57 of the 76 individuals (75%). The significance of this finding was further examined statistically. Data concerning numbers of captures and distance of each trap from the woodlot, were transformed into their respective ranks. The Spearman rank correlation coefficient was then calculated according to Daniel (1978). The r_s statistic value obtained is -0,82 and is highly significant (α=0,01), i.e., plum curculio is most significantly captured within 50 meters of the woodlot. This is explained by the availability of appropriate shelter in the woodlot for overwintering adults.

These findings support the assumption of past workers that plum curculio might overwinter in woodlots adjacent to orchards (Chapman 1938; Crandall 1905; Paradis 1957). This assumption was based on the fact that damage by plum curculio was more often higher in rows adjacent to woodlots or to areas offering most shelter for overwintering curculios. In addition, Snapp (1930) and Stearns et al. (1935) observed that more plum curculios were jarred from trees in rows adjacent to woodlots; their data, however, are from studies carried out in peach orchards in Georgia and Delaware

Table 3. Relationship between number of adults of Conotrachelus nenuphar captured and trap distance to the adjacent woodlot; Frelighsburg, Quebec, 1979.

Funnels	Observed data		"Rank of data"[1]	
	Captures	Distance (m)	Captures	Distance
A	10	13	8	1
B	15	19	9	2
C	9	23	7	3
D	7	41	6	4
E	16	46	10	5
F	6	51	5	6
G	3	60	2,5	7
H	3	64	2,5	8
I	5	69	4	9
J	2	91	1	10

[1]"Ranks of data" are used to calculate the "Spearman" rank correlation coefficient: r_s

$$r_s = 1 - \frac{6\ \Sigma(d_i)^2}{n(n^2-1)}$$

d_i = difference in the ranks of the variables for one observation

n = number of observations = 10.

$r_s = -0,82$; highly significant ($\alpha = 0,01$). (Daniel 1978: pp. 300–306).

respectively, where the plum curculio is the southern multivoltine strain. Quaintance and Jenne (1912), working with the northern univoltine strain, found that more were jarred in May from the first row of peach trees adjacent to a woodlot in a Michigan orchard. This orchard comprised only 70 trees planted in six rows, and from early June to August curculios were uniformly distributed over the whole orchard. This may imply that a large enough orchard (more than one hectare) is necessary to observe this pattern on a seasonal basis; this is in agreement with Chapman's (1938) finding that in orchards comprising only a few rows "while the population may be quite uneven, peripheral concentration is less evident". Also, plum curculios may only colonize larger orchards to the extent needed for the females to lay all of their eggs. In such cases, control measures should be concentrated on perimeter rows, especially those adjacent to woodlots or other areas offering adequate shelter for overwintering sites. Data for plum curculio damage assessment in the experimental orchard (taken during three consecutive years) further support these conclusions (Chapter 6).

The major part of this section has been published (Le Blanc et al. 1981).

5.0 TRAPPING TECHNIQUES DEVELOPED BY THE AUTHOR

5.1 Introduction

Insect population density can be monitored by sampling. Some sampling techniques, for example the D-vac, require continuous operation thus, are mechanical. Other techniques, such as pheromone traps, rely on the response to stimuli and are behavioural techniques that both attract and retain insects (i.e., colour sticky traps); others simply retain those that they intercept (i.e., pitfall traps).

This chapter contains descriptions of several experiments using traps for *C. nenuphar* designed by the author. The first section deals with colour sticky traps, and the second with two "shelter" traps, one located on the tree and the other on the ground. Finally, the third section deals with laboratory and field tests of potential attractants for plum curculio.

5.2 Colour Sticky Traps

Sticky traps are firstly interception devices, like the fly paper used in buildings or the sticky bands around tree trunks. In addition, however, the size, shape and colour of the object on which the non-repellent adhesive substance has been applied has a significant effect on the success of the trap. Thus, it is common to test a variety of sticky trap designs (Prokopy 1968b).

5.2.1 Materials and methods

In the present study a conical shape was chosen instead of the more usual flat plate design, because, (1) it provides an intermediate between the vertical and the horizontal, and (2) it offers an omnidirectional catching surface. Seven colours were tested.

To make the trap, a paper template was made and used to cut cardboard pieces of identical size. Each piece was rolled and stapled in the shape of a truncated cone of the following dimensions: upper radius 3 cm, lower radius 6 cm, height 15 cm, and a catching surface of 432,5 cm^2. To hang these traps, each was inserted over an inverted plastic cup (6 cm of bottom diameter) with a hole in its center allowing it to be attached to a tree branch by a metal wire. The catching surface was completely covered with the non-repellent adhesive Bird Tanglefoot© [1], applied by means of a spray can.

Seven colours were tested; black, silver, pink, white, green, red and yellow (with three replicates of each). Yellow was tested because of its well-known attractiveness to many insects. The other colours were chosen for their similarity to different parts of the host tree: black bark and crevices, silver tip, pink buds, white petals, green young fruit and mature red apples.

In 1977, 12 trees (M-2 to M-13) in the west part of the experimental orchard were selected for the experiment (Fig. 1). These were known to contain populations of plum curculio. Each tree was divided vertically into three sectors, west, north-east and south-east. This provided 36 sectors in which the 21 traps could be installed. Trap allocation in these sectors was randomized, but in such a way that each colour appeared once in each of the three chosen compass orientations (Fig. 7). The traps were attached to peripheral branches in the upper half of the trees (4,5 - 5,0 m above ground level), in order to be as visible as possible. Jarring observations had already revealed that the upper half of the trees contained

---

[1] The Tanglefoot Company, Grand Rapids, Michigan.

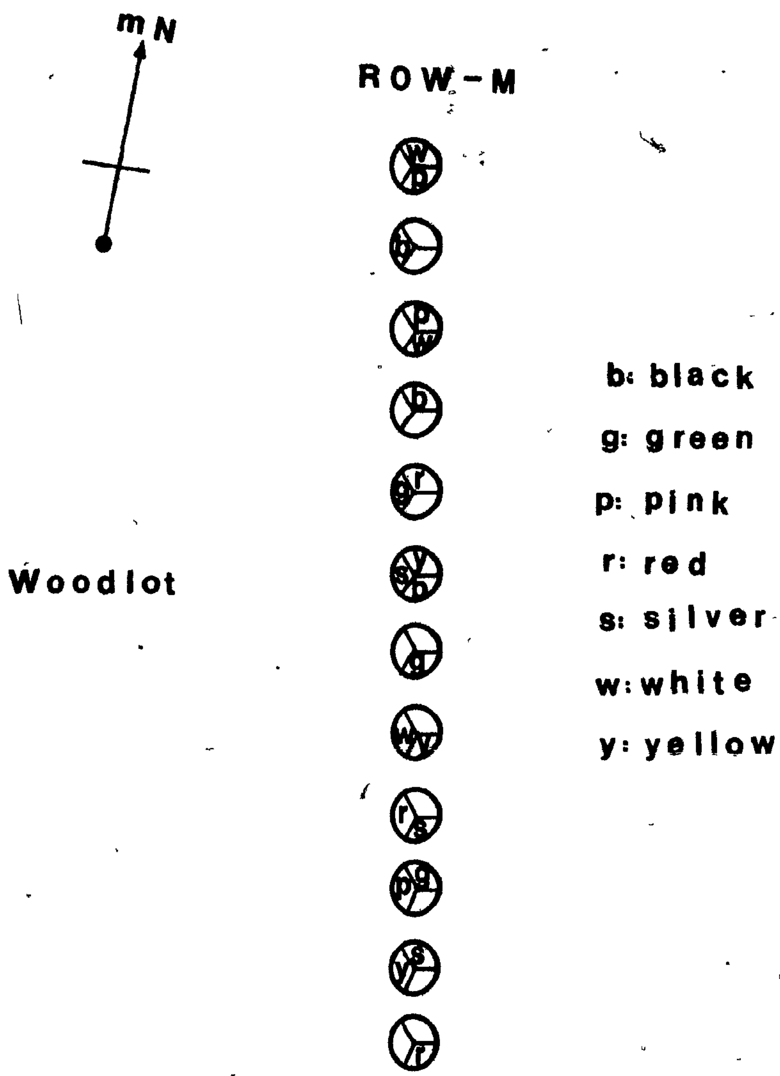


Fig. 7. Schematic view of row "M" of the experimental orchard at Frelighsburg, Quebec, 1977. Sticky colour trap locations.

more plum curculios than the lower half.

The 21 traps were installed on May 13 (pink bud stage) and monitored on eight occasions over a 31 day period: May 17, 19, 20, 25, 27, June 2, 10 and 16 (24 days after calyx).

5.2.2 Results and discussion

As no plum curculios were captured, visual response to colour could not be ascertained. However, since no curculios were caught by wind impaction, this result suggests that curculios do not fly this high above the ground level at that time. This supports Prokopy and Owens' finding (personal communication) that plum curculio is a poor flier. This conclusion is further supported by the work of another graduate student, Dr. Guy Boivin (personal communication), who found only four plum curculios early in the season of 1979 during a tarnished plant bug, Lygus lineolaris (P. de B.), monitoring programme in the same experimental orchard. He used 21 rectangular (18 cm x 14 cm) sticky traps painted white; 15 were located within the orchard and the other six in the adjacent woodlot. All were monitored weekly between early May and late October. As his traps were at 0,5 m above the ground, it is possible that curculios also do not fly at this level. These, and other direct observations, suggest that plum curculio either reaches the host trees by crawling up the trunk or, more likely, by making many short erratic flights (as I observed them flying many times) from under the tree canopy.

In view of this negative result no further experiments were carried out with colour sticky traps. Such free hanging traps seem inappropriate for plum curculio as they require their captures to be airborne. However, sticky traps were tested further for their interception ability by locating them directly on tree limbs (see Section 5.5.2)

5.3 Shelter Traps

The following two experiments were designed to trap plum curculio adults by providing them with artificial resting sites. In the first experiment, resting sites were provided on the trees at the time of year when the new generation adults emerge and colonize the trees. In the second experiment, resting sites were provided on the ground, early in the season, to detect whether overwintered adults seek shelter in the herbaceous stratum under the trees.

5.3.1 Shelter trap on the tree

In our region new generation adults emerge in August and feed on maturing fruits before migrating to their winter quarters in early October. Paradis (personal communcation) had observed that plum curculio adults are often found in the crevices between touching apples. I further noticed that beetles sheltering in these sites do not produce the usual characteristic curculio feeding punctures, but rather dig themselves into small "caverns", in which they spent much of their time. Always a single beetle was found in my observations of this phenomenon. These observations prompted the design of a shelter trap for plum curculio.

5.3.1.1 Materials and methods

The trap was made of wood (10 cm long and 10 cm in diameter) cut from wind damaged apple tree limbs. In each 50 holes were drilled (2 cm deep and 6 mm in diameter). The hole diameter was chosen to accommodate curculio adults, which are less than 6 mm wide. Each trap was attached to a major branch junction with a wire, two to three meters above ground level, in dense foliage.

In 1977, two traps were attached in each of ten trees (N-3 to N-12) in the experimental orchard (Fig. 1). This row was chosen because it is immediately adjacent to the woodlot, the most likely overwintering site for plum curculio. The two traps were attached at different branch junctions, one on the upper side and the other on the under side of a branch, on the woodlot side of the trees. The location of the trap was chosen to intercept curculios crawling on either side of the branches.

The traps were installed on August 17 and monitored at dawn and late afternoon on six occasions over a 13 day period: August 19, 23, 24, 25, 30 and 31. This period coincided with peak emergence of the new generation. The times of day chosen for inspection corresponded with the hours of minimal and maximal air temperatures, when I considered curculios most likely to be found in resting sites and/or less active.

5.3.1.2 Results and discussion

None were found, possibly because fruit and bark crevices are more attractive to curculios. This may be partly explained by their higher humidity because by the end of the experiment the wooden traps were quite dry. Further efforts to overcome this by soaking the traps in water were also unsuccessful as the wood did not readily retain the water and it gave off a strong odor. Because of the negative result, and long time required to carefully examine all the holes in each trap, this experiment was terminated.

5.3.2 Shelter trap on the ground

Ground dwellers, such as carabid beetles, commonly shelter beneath logs and stones. Consequently I decided to test the hypothesis that plum curculios that had fallen from the trees, or that were crawling towards the trees, might, on encountering ground shelters, remain under them for some period of time. This was further suggested by the "Ransom Curculio Remedy", an early "cure" for plum curculio (Ransom 1870). This required that all vegetation under the tree be removed and the ground levelled. Then material of all kinds (bark pieces, stones, corn cobs, pieces of leather, *etc.*) were laid on the bare ground. Early in the morning these "chips" (*e.g.*, Ransom Chips Process) were turned over and the hiding curculios collected by hand. Today such a control method would certainly be questioned, although it did suggest that a ground shelter trap could be used for detecting the pest.

5.3.2.1 Materials and methods

Very simple ground shelter traps were made: half-inch (1,27 cm) pine boards were cut in rectangular pieces (30 cm x 15 cm). Areas of equal size were prepared to receive these traps by cutting the vegetation as short as possible (one centimeter). This was done because insects under the boards, and those falling from them during inspection, would be difficult to find in long grass.

In 1978, 21 traps were made: 12 traps were installed under trees along three transects, two of which included the last four trees at each end of row M and the other perpendicular to the west side of the experimental orchard including trees K-7, L-8, M-7 and N-7 (Fig. 1). These three transects were extended into the adjacent woodlot, and nine other traps (three *per* transect) were added, six between the orchard and the woodlot and three others about one meter inside the edge of the woodlot.

The traps were installed on May 11 (green tip) and monitored three times a day (0700 h-0830 h; 1300 h-1430 h; 1700 h-1830 h) on eight occasions over a 23 day period: May 16, 17, 24, 25, 28, 30, June 3 and 7 (one week after fruit set). This period encompassed the time of peak spring migration to the orchard.

5.3.2.2 Results and discussion

As no plum curculios were found the method was abandoned. This result, particularly for the 12 traps within the orchard, suggests that plum curculio does not occur on the herbaceous stratum beneath apple trees at the time of the experiment, or that adequate protection is provided by the herbaceous cover. The apparent absence of plum curculio in the herbaceous stratum, however, was further supported by the negative result in the D-vac study (Chapter 3).

5.4 Attractant Assays (laboratory work)

5.4.1 Introduction

Potent attractants have been used by many researchers to increase trap captures; thereafter, preciseness and reliability of population density assessment and damage prediction are accessible objectives for the implementation of directed control programmes. Consequently, several substances were tested for their attractiveness to plum curculio in the laboratory. For this a modified Y-tube insect olfactometer was used.

Although McIndoo (1926) had successfully used a Y-tube olfactometer to test attractants for the Colorado potato beetle, Leptinotarsa decemlineata (Say), Garman and Zappe (1929) were unable to obtain reliable positive results with plum curculio. Unevenness of the air current passing into the stems of the tube was their reported major cause for inconsistent results. In the same year, however, Snapp and Swingle (1929a) reported successfully attracting plum curculios to butyl acetate in the laboratory, although they were unable to confirm this attraction in the field and so discontinued their laboratory studies. In another series of experiments with a Y-tube olfactometer these authors were unable to detect any attraction to plum curculio for various peach tree structures (i.e., bark, blossoms, leaves, and green fruits); in fact, they concluded that these structures were repellent (Snapp and Swingle 1929b).

As no modifications had been published, I decided to try to improve the design of the Y-tube olfactometer for use with plum curculio. Two models were tested (Version I and Version II).

5.4.2 Y-tube insect olfactometer, Version I

5.4.2.1 Materials and methods

McIndoo's Y-tube olfactometer (Fig. 8) was replicated according to the designer's specifications (McIndoo 1926) and the following six modifications were made (indicated by the numbers in parentheses in Figure 9): (1) single air inlet, (2) activated charcoal air purifier bottle, (3) identical air pathway in each stem, (4) use of distilled water for the gravity water siphon air pump and for the water bubblers, (5) odor dispensed by a wick in one of the water bubblers, the other equipped with a control wick that was dry or that carried the solvent used for the odor, and (6) eight watt fluorescent UV light instead of the filament 75 watt blue daylight bulb. This modified apparatus was then tested.

The individuals used in these preliminary tests were the plum curculio adults collected during August 1978 in the three control replicates of the fungicides effect tests (see Chapter 7). These 462 adults of the new generation were brought to the laboratory in carton cages and provided with pieces of insecticide-free McIntosh apples and distilled water. I wanted the insects used in the tests to reflect, as much as possible, the stage of overwintered spring migrating plum curculios. Therefore these beetles were exposed for two weeks to an 11 hour photoperiod; Gaydon (1972) reported

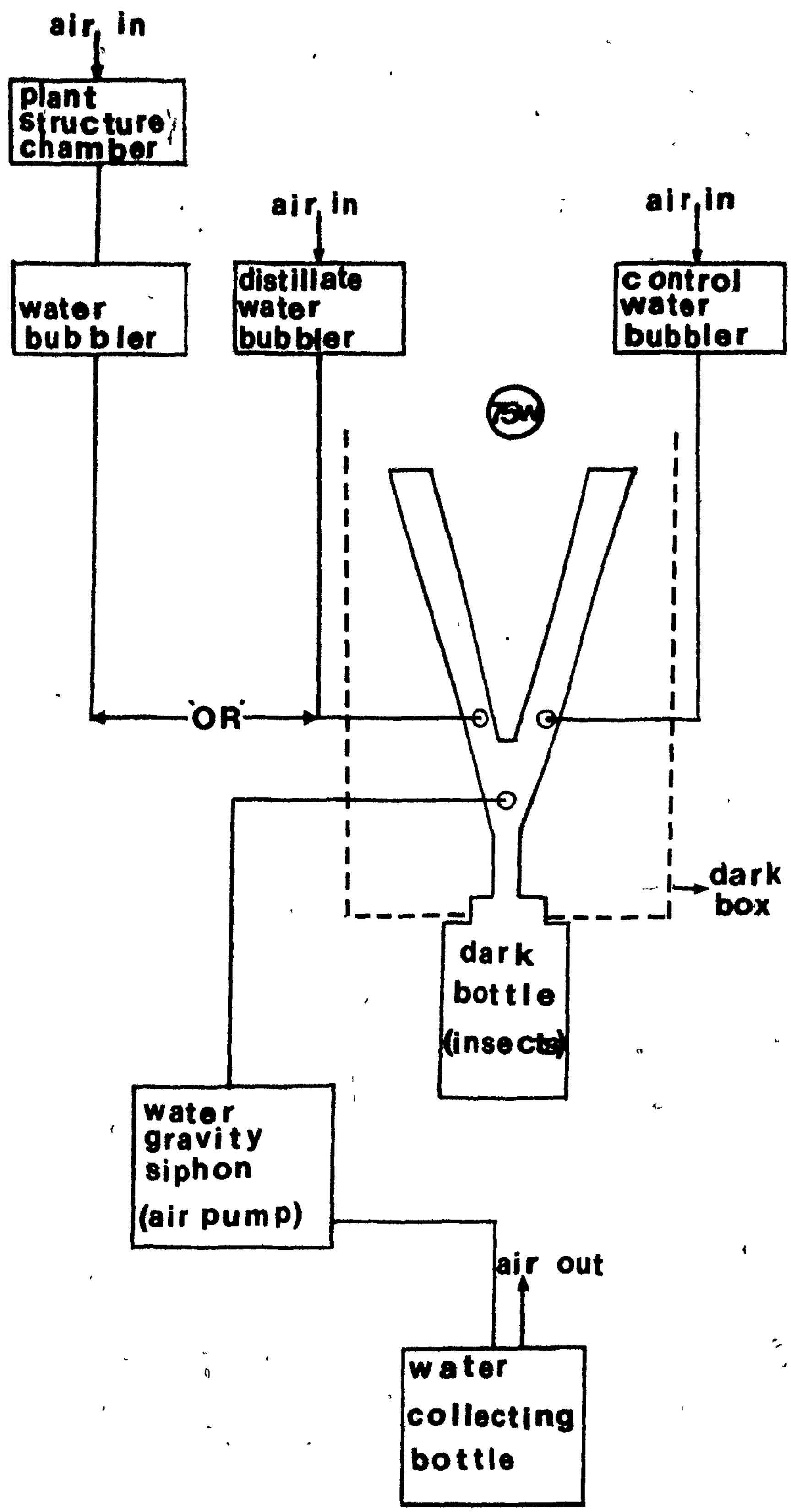


Fig. 8. McIndoo's Y-tube insect olfactometer (top view), (after McIndoo 1926).

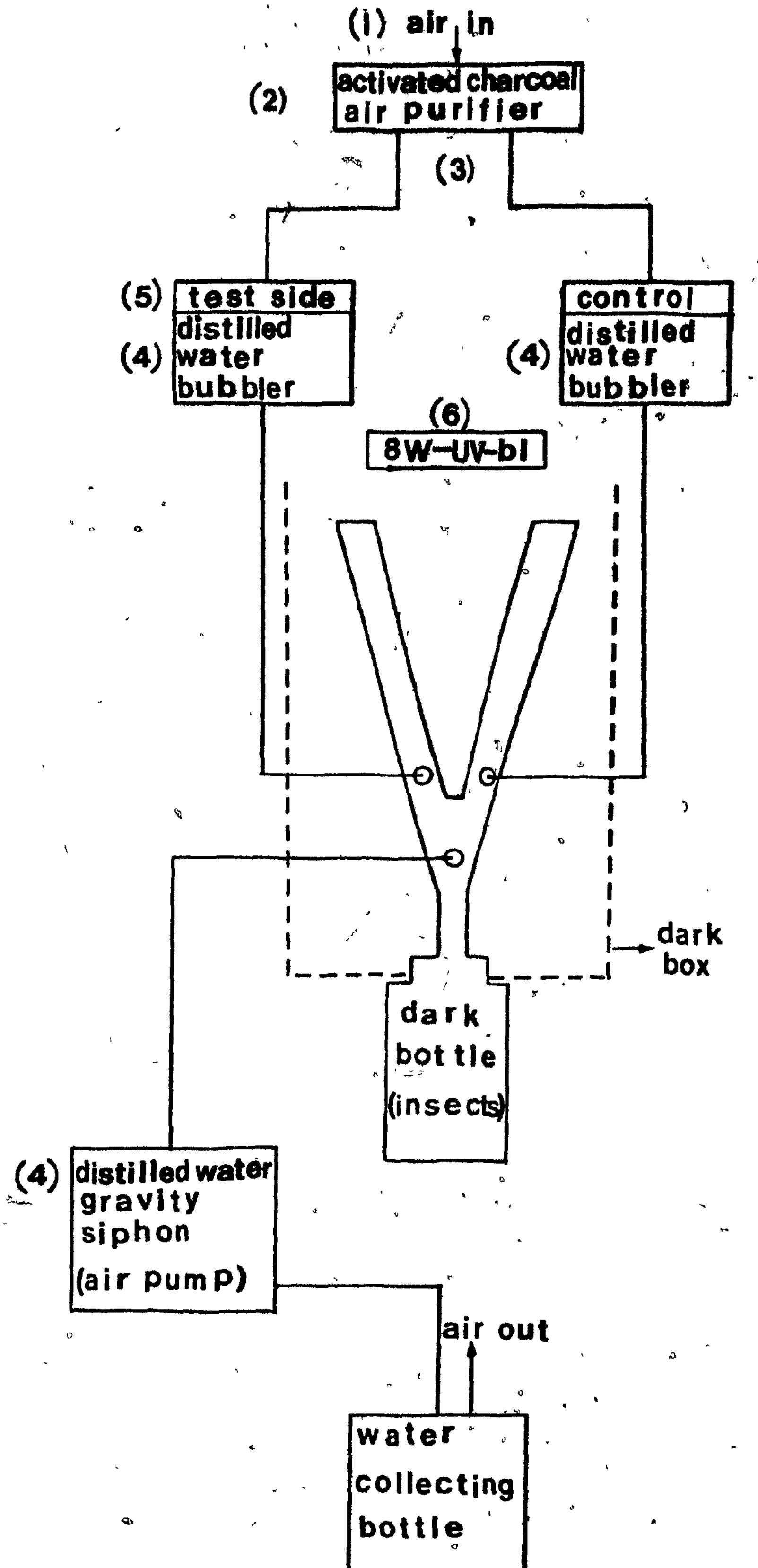


Fig. 9. Y-tube insect olfactometer, Version I, 1979 (top view). Numbers in parentheses, (1) to (6), correspond to modifications (see text).

that a 12 hour photoperiod or less would induce diapause in the multivoltine southern strain of the species. No data are available for our univoltine northern strain. In our region the natural photoperiod is about 12,5 hours in mid-September and diminishes to 11 hours in mid-October, when all plum curculios would have left the trees for their winter quarters.

Following this procedure, 150 beetles were put in each of two rectangular plastic trays (30 cm x 60 cm x 6 cm) filled with four centimeters of sterlized potting soil obtained from the Macdonald College greenhouse. Distilled water was added to the soil to provide adequate moisture. Each tray was covered by a screen and a polyethylene film to prevent (1) insect escape and (2) loss of moisture. The insects were then incubated at 4,0°-5,0°C for a period of 120 days to break the diapause. The trays were then brought out of the incubator and kept at 20°-21°C. After a three day "reactivation" period, the beetles became active. During the following two days 160 individuals were collected from the underside of the screen and put into carton holding cages provided with wicks containing distilled water, and with no food.

5.4.2.2 Results and discussion

First a series of preliminary tests was conducted to exclude the possibility of bias in the apparatus. Batches of 12 individuals were introduced into the olfactometer dark bottle; both water bubblers contained distilled water. Beetles leaving the dark bottle during the 20 minutes test period were recorded. Seven trials, comprising 84 individuals, were carried out. The last trial was extended for two additional 20 minute periods. The 20 minute aeration period is determined by the capacity of the gravity siphon air pump (i.e., the time it takes for the 23 l of distilled water to pass from one reservoir to the other). The results are given in Table 4. Only four beetles came out of the dark bottle during these tests. Although these four distributed themselves evenly between the two stems, they represented an insufficient number (5%) of responding beetles for odor tests to be performed.

The distilled water wicks were then removed from the holding cages and a second series of seven tests was carried out with batches of 10 individuals that had been deprived of water for one day. The results of these tests are presented in Table 4. In this experiment 29 (41%) of the 70 beetles tested came out of the dark bottle, and distributed themselves equally between the two stems of the Y-tube, thus revealing no bias in the apparatus. This result also suggested that depriving beetles of water prior to testing increases the number responding. The last of these runs was prolonged for five additional 20 minute periods. While this did not cause more beetles to respond, it was noted that the number of insects per stem varied during this longer aeration period. Thus, some beetles may change sides during prolonged tests or return to the dark chamber. Because of this, the 20 minute test period was used in all subsequent trials with this apparatus.

During a third series of eight tests, batches of 12 individuals deprived of water for four days, were tested to see if prolonged deprivation of water would increase the number responding. Results are also presented in Table 4. In this case 34 (35%) of the 96 individuals responded by coming out of the dark bottle. As this is less than for the group deprived of food and water for only one day, it was decided that the one day deprivation period prior to testing would be employed for all subsequent tests.

Table 4. Olfactometer Version I. Trial tests (no odor) and apple essence tests for C. nenuphar[1] in 1979. Room temperature 20°-22°C.

Numbers of beetles				Aeration time
Stem A (odor)	Stem B (control)	Not responding (dark bottle)	Total insects per test	In minutes
Not deprived first exposure, trial tests				
0	0	12	12	20
1	0	11	12	20
0	0	12	12	20
0	0	12	12	20
1	0	11	12	20
0	0	12	12	20
0	2	10	12	60
2	2	80	84	
Deprived one day, first exposure, trial tests				
4	2	4	10	20
1	3	6	10	20
2	1	7	10	20
2	3	5	10	20
2	1	7	10	20
1	3	6	10	20
2	2	6	10	120
14	15	41	70	
Deprived four days, second exposure, trial tests				
3	2	7	12	20
5	2	5	12	20
3	5	4	12	20
1	1	10	12	20
0	0	12	12	20
4	2	6	12	20
1	0	11	12	20
3	2	7	12	20
20	14	62	96	
Deprived one day, second exposure, test side wick +0,1 ml apple essence				
3	3	6	12	20
1*	2	9	12	20
2	7	3	12	20
1*	0	11	12	20
2	3	7	12	20
9	15	36	60	

[1]Northern univoltine strain from Frelighsburg, Quebec.

* Apparatus acetone wash; odor and control sides interchanged

Grand total for Version I: 87/226 or 38% responding (first series not included).

Trials were conducted to test the attractiveness of an apple essence odor. Batches of 12 individuals were used and the test was repeated five times only (because of a shortage of beetles). This apple essence was a 32 000 fold concentrate obtained from the Summerland Agriculture Canada Research Station, British Columbia. As it was a developmental product being examined for its attraction to deer, Odocoileus hemionus (Rafinesque), it was not possible to obtain data concerning the compound, other than that it was natural and very apple-like to human olfaction. The apple essence was introduced into the apparatus on a one centimeter long dental wick impregnated with 0,1 ml of the concentrate. This wick was attached with a small wire under the stopper of the water bubbler on the test stem of the Y-tube. Between each test the apparatus was washed with acetone; odor and control sides (bubblers) were interchanged. Results are presented in Table 4. Out of 60 beetles, 9 (15%) went into the odor branch of the Y-tube, and 15 (25%) into the control side; thus, suggesting a possible repellancy of the product. Beetles responding (coming out of the dark bottle) represented 40% of the total.

Because of the limited response, both in the preliminary trials and in the odor trial, and because certain possibilities for improvements in the design became apparent, it was decided to redesign the apparatus before carrying out further tests. Special modifications were required in relation to the UV light source, the pathway of air flow (and particularly of the exhaust air) and the attachment of the dark chamber to the Y-tube.

5.4.3 Y-tube insect olfactometer, Version II

5.4.3.1 Materials and methods

Taking into consideration what was learned from the preliminary tests performed with the first version of the olfactometer, a second version was built (Version II) (Fig. 10). This incorporated the following 14 modifications: (1) the air purifier is a glass column (50 cm long and 2 cm in diameter) containing finer ground activated charcoal to increase surface area, (2) at both ends of this column there is 3 cm of cotton wool to prevent room dust from entering and charcoal dust from leaving the column, (3) single water bubbler (200 ml of distilled water in a 500 ml Erlenmeyer flask), (4) both Y-tube stems are open at their distal end and collecting chambers (250 ml glass bottles acting as pitfall traps) are inserted over their end to prevent insects from moving back or changing sides during the experiment, (5) air flow is split at the exit of the water bubbler; each branch is connected to one of the collecting chambers, i.e., the air flows are originating from the far end of each of the two Y-tube stems and charged there by the odors (or their solvent as control); this permits exposure of the insects for a variable time and also allows insects in the control stem to still turn back until they have fallen into the trap, (6) test odors can be introduced into one of the collecting chambers by either an impregnated wick or as a liquid preparation in a 0,1 ml dispenser vial; in this case the control would contain the solvent (note in Figure 10 that the incoming air is charged with odor from these dispensers before entering the Y-tube), (7) the UV light is dimmed by black cardboard bearing a slot (2 cm x 6 cm) and a rotating plate, placed in front of the slot, has openings of various sizes making the light stimulus flicker randomly to prevent insect fatigue or habituation, (8) a one centimeter in diameter hole was made at the stem's junction facing the light source, and a 1,5 mm thick clear fused silica chip was glued with epoxy to permit transmittance of ultraviolet radiations, (9) the length of the main stem of the Y-tube was increased by 10 cm to provide the insects with a longer

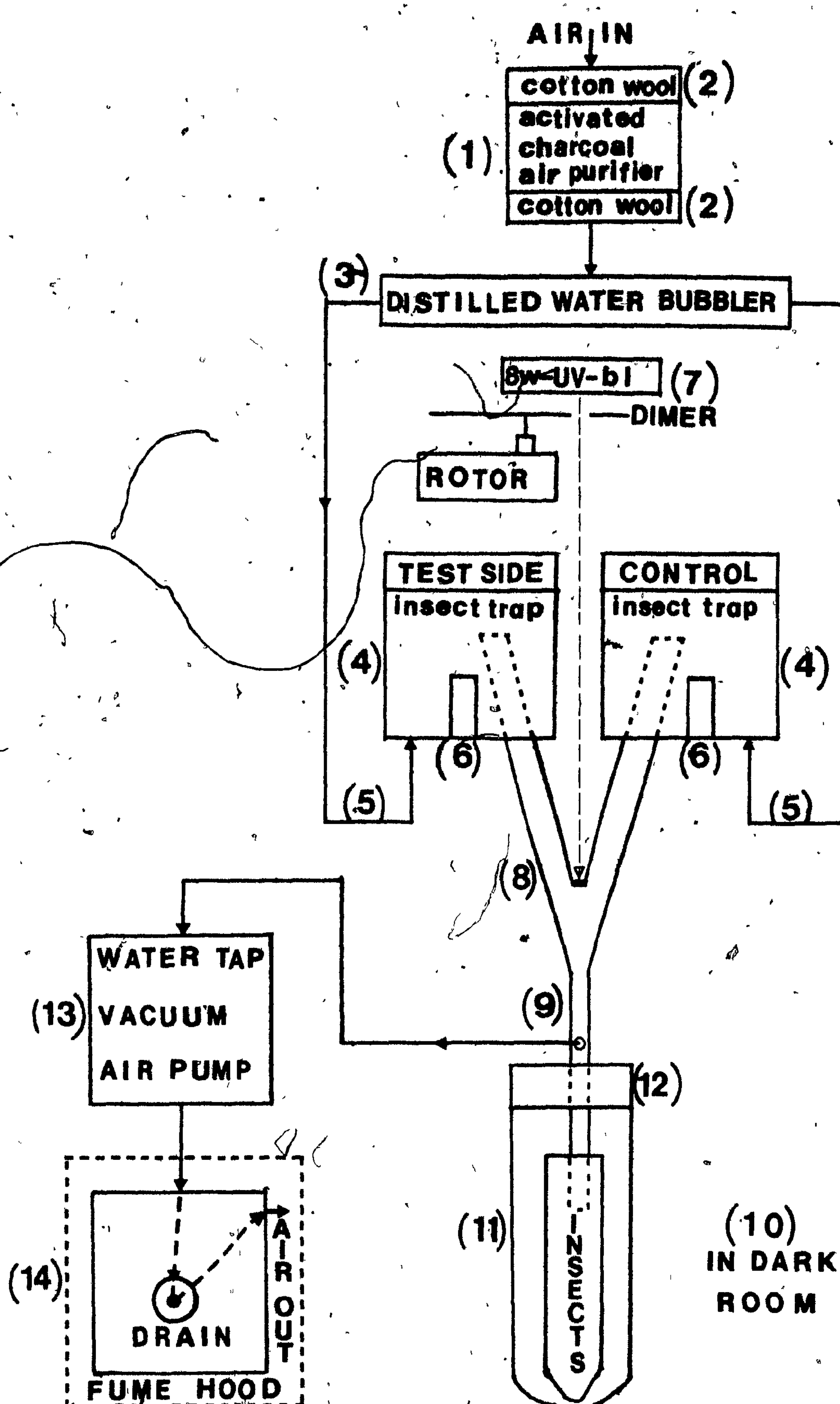


Fig. 10. Y-tube insect olfactometer, Version II, 1980 (top view). Numbers in parentheses, (1) to (14), correspond to modifications (see text).

distance (time) to orient to the odor, (10) the dark box covering the apparatus was discarded in favour of using a completely dark room, (11) the insects are introduced into the main branch of the Y-tube in a metal test tube inserted over its end, permitting them to enter the main branch without any obstacle (a glass test tube is inserted over the metal one and attached to a rubber stopper on the main branch to avoid air leakage), (12) all rubber stoppers are covered with a paraffin film that is changed between each experiment to avoid impregnation by residual odors, (13) a water tap vacuum pump permits variable air flow speed and duration of aeration period, and (14) the water outlet of this pump is inserted into a sink drain inside a fume hood that is continuously operated, thus, permitting immediate evacuation of used air.

Some of the insects that were tested in this second olfactometer were reared in the field from damaged thinning apples that had been placed in emergence cages under trees in the woodlot adjacent to the experimental orchard. From mid-August 1979 until mid-September, new generation adults were collected in these cages under chips of corrugated paper placed over the apples that had been left there to provide humidity and food. More than 2 200 adult plum curculios were collected. Half of these were used in the soil sampling experiment (Chapter 3) and the other half was brought into the laboratory and treated in the same manner as those used in the tests with the Version I olfactometer. However, to be able to bring insects out of hibernation in small numbers instead of starving them in bulk, they were placed in plastic covered cups containing a mixture of sterilized soil and peat moss (1:1) obtained from the Macdonald College greenhouse. Fifty cups, each with 20 beetles, were incubated. As Smith and Flessel (1968) had reported that high moisture was as damaging as low humidity in such artificial hibernation experiments, each plastic cover was perforated by small holes to prevent water condensation. Five cups, without insects, were placed on top of the others to monitor moisture status, which remained satisfactory throughout the incubation period. Unfortunately the location of these cups caused evaporating water from under to keep them moist while the ones below, containing the insects, dried. Only 52 of the 1 100 beetles survived in this relatively dry environment. These were used in a series of five tests with Avon[1] A-5002 apple blossom perfume oil (composition retained by the Company). To ensure volatilization of the fragrance a saturated water solution of the perfume oil was mixed with ethanol (95% pure), as a co-solvent, in a 4% concentration; the control for these tests comprised a 4% ethanol aqueous solution.

Because of the shortage of beetles, 325 plum curculios were obtained from the Agriculture Canada Research Station in Vineland, Ontario. These curculios, however, were the multivoltine strain that had been reared from thinning apples and had not hibernated. These were used in four series of four tests each to examine response to natural and synthetic odors.

5.4.3.2 Results and discussion

To verify if the various modifications of the olfactometer were indeed improvements, the following tests were performed. However, in view of the reduced number of available beetles, it was decided to carry no preliminary tests and to rely on those done with Version I that revealed no bias of the Y-tube itself.

Fifty of the beetles saved from the unsuccessful hibernation procedure were used to carry out four trials (three with 10 and one with 20 individuals) to test the attraction for plum curculio of Avon A-5002 apple

---

[1] Avon Canada, Pointe-Claire, Quebec.

blossom perfume oil. Results are presented in Table 5. From these tests plum curculios seem attracted to the odor in a ratio of 5:2. It is significant to note that 37 (74%) of the 50 beetles tested responded (came out of the dark test tube) in these trials with the modified apparatus. This suggests that the modifications were beneficial.

With the multivoltine strain of plum curculio four series of four trials each were performed to test the following materials: apple buds (pink bud stage) collected from McIntosh branches advanced in the laboratory, green thinning apples (McIntosh), 0,1 ml of pure (95-99%) isoamyl isovalerate impregnated on a one centimeter long dental wick (this substance is used in the food industry to mimick apple flavour) and, Avon A-5002 apple blossom perfume oil (in the same manner as previously reported).

Results of these tests are presented in Table 6. Both apple tree structures appeared to repel plum curculio, an unexpected result but in agreement with the observations of Snapp and Swingle (1929b) with peach tree structures. Isoamyl isovalerate seemed neutral. Most surprising, however, was the result with the perfume oil, which was repellent to the multivoltine strain of the plum curculio in a ratio of 3:2 (Table 6), while it had been seemingly attractive to the univoltine northern strain in a ratio of 5:2 (Table 5). One could speculate that while the univoltine strain is found primarily on apple in our region, the multivoltine strain infests mainly peach in the south. The small number of tests performed, however, prevented any statistical verification of this hypothesis.

While the odor trials were inconclusive it is significant to note that in the series of trials with Version II of the olfactometer, 202 (63%) of the 320 beetles tested responded. This is a 25% net improvement over results obtained with Version I. While further modifications would probably be beneficial, lack of beetles and other essential resources, and the fact

Table 5. Olfactometer Version II. Perfume oil attractant tests for *C. nenuphar*[1] in 1980. Room temperature 20°-21°C.

Numbers of beetles				Aeration time
Stem A (odor)	Stem B (control)	Not responding (dark tube)	Total insects *per* test	In minutes
Avon A 5002 perfume oil, control ethanol				
Beetles starved one day, first exposure				
5	2	3	10	60
5*	1	4	10	60
6	2	2	10	60
11*	5	4	20	60
27	10	13	50	

[1]Northern univoltine strain from Frelighsburg, Quebec.

* Apparatus acetone wash; odor and control sides interchanged. Grand total for Version II: 37/50 or 74% responding (with northern strain).

Table 6. Olfactometer Version II. Host tree structures and perfume oil attractant tests for *C. nenuphar*[1] in 1980. Room temperature 20°-21°C.

Numbers of beetles				Aeration time
Stem A (odor)	Stem B (control)	Not responding (dark tube)	Total insects per test[2]	In minutes
Advanced pink buds; control nil				
0	11	9	20	60
7*	8	5	20	60
7	7	6	20	60
6*	11	3	20	60
20	37	23	80	
Green thinning apples; control nil				
1	10	9	20	60
8*	6	6	20	60
0	9	11	20	60
4*	10	6	20	60
13	35	32	80	
Isoamyl isovalerate 0,1 ml on dental wick; control dry wick				
5	5	10	20	60
5*	6	9	20	60
7	6	7	20	60
7*	6	7	20	60
24	23	33	80	
Avon A 5002 perfume oil; control ethanol				
3	5	12	20	60
6*	8	6	20	60
8	6	6	20	60
4*	10	6	20	60
21	29	30	80	

[1]Southern multivoltine strain reared at Vineland Agriculture Canada Research Station, Ontario.

[2]All beetles starved one day, first exposure.

* Apparatus acetone wash; odor and control sides interchanged. Grand total for Version II: 202/320 or 63% responding (with southern strain).

that the growing season was approaching, led to the decision to terminate laboratory experiments infavour of field trials to test attractant odors.

5.5 Attractant Assays (field work)

5.5.1 Introduction

Based on the trapping techniques tested so far, Chapters 3, 4, and 5, and my direct observations of the pest in the field and those of other investigators (Prokopy and Owens, personal communication), it became increasingly evident that plum curculio focusses its activities on the host tree, spending most of its time on it after early spring migration to the orchard, generally commencing at pink tip. In fact, I suspect that most beetles remain on the tree on which they first land in the spring, or on it and its closest neighbours.

This apple pest's poor flying ability, and apparent lack of a broad spectrum response to visual and olfactory stimuli, did not hold out much hope for finding an effective trap. It appeared, however, that its most likely mode of locomotion after migration to the apple trees is exploratory random crawling on tree branches up to the blossoms and/or the young fruit clusters. This suggested that interception traps located at major branch junctions should be tested. Consequently two field experiments were designed to test interception traps.

The first experiment involved a trap combining a number of factors; colour, shape, odor, and also the location of the trap on the tree. In the second experiment, artificial and natural odors were tested using the boll weevil traps (Chapter 3), equipped with wick dispensers and further tested trap location on the tree.

5.5.2 Polyvinyl chloride (PVC) plastisol interception trap

PVC plastisol has been used successfully as a slow-release plastic formulation of the cabbage looper, Trichoplusia ni (Hbn.), pheromone, cis-7-dodecenyl acetate (Fitzgerald et al. 1973). Advantages of using plastisol are that the trap can be of any colour, size or shape, and that the rate of odor release can be controlled by varying its concentration in the plastisol.

5.5.2.1 Materials and methods

Two batches of PVC plastisol were prepared according to the recipe provided by Fitzgerald et al. (1973). The first batch was separated into four portions to determine the appropriate amount of attractant to add to the plastic. In three of these portions isoamyl isovalerate[1], a substance used in the food industry for artificial apple flavour (taste and odor), was added to yield 1, 5, and 10% concentration by weight, the fourth portion being the control. Prohibitive labour costs prevented replication. The four portions were mixed and processed on a commercial mill[2] for two minutes, the mill's rollers being at 150°C (isoamyl isovalerate boiling point is 191°–194°C), to produce strips one millimeter thick. The strip obtained from each portion was then cut into a rectangular piece (30 cm x 15 cm). This thickness was chosen to permit the traps to be bent over a tree branch and the size to entirely cover a major branch junction such that its three parts would be in contact with the trap.

---

[1] 95–99% pure, ICN Pharmaceuticals Inc., Plainview, New York.

[2] All ingredients (except isoamyl isovalerate), apparatus and labour were provided by Carlew Chemicals Ltd., Montreal.

The four strips were hung in a fume hood at 25^{o} ± 1,5^{o}C and 20 ± 5% relative humidity. Release rate of isoamyl isovalerate was estimated by weighing (in mg ± 0,1 mg) the samples weekly over a 21 day period. Weight loss from the control sample was subtracted from weight loss of the plastisol/attractant strips, because some of the plasticizer and stabilizer added to the plastic resin in the fabrication process could be lost by volatization.

The second batch of plastisol, which was to be used to test the attractant in the field, was separated into two portions, after an odorless green colourant was added to the mix to mimick, as close as possible, the young green apples. Isoamyl isovalerate (10% by weight) was added to one of the portions, the other being used as the control. This concentration was chosen because it was estimated to last sufficiently long (see Fig. 11) for the proposed field trials. The PVC strips, obtained from the two portions, were cut into rectangles (30 cm x 15 cm x 1 mm) to provide 15 scented traps and 15 control traps. These were then kept in a freezer at -35^{o}C (isoamyl isovalerate melting point is -78^{o}C) until needed.

Thirty trees (McIntosh) in the experimental orchard were randomly selected and scented and control traps were allocated to them alternately. The traps were attached over major branch junctions (on the upper half of the trees) by two galvanized wires, one at each end. A band (5 cm x 10 cm) of odorless adhesive, Tangletrap® [1], was placed centrally on both sides of each trap. These traps were installed on May 14, 1980 (pink bud stage), and examined for plum curculio presence twice a week until petal fall, and then once a week until the end of August, i.e., for 3,5 months.

[1] The Tanglefoot Company, Grand Rapids, Michigan.

5.5.2.2 Results and discussion

In the first series of experiments weight loss measurements indicated that isoamyl isovalerate was released from the plastisol over an extended period. After 21 days, loss of this chemical was 39%, 38% and 32% for the 1%, 5% and 10% concentrations respectively. As the 10% concentration appeared to be the longest lasting, it was chosen for the field tests. Data, corrected for weight loss in the control, are plotted in Figure 11. After an initial high level of release of the attractant during the first week, the rate of release decreased during the second and third weeks. Also, release rate decreased in approximate proportion to concentration; thus, the 5% concentration released about five times the amount of the 1% concentration and the 10% one about twice that of the 5% one. These results confirm those obtained by Fitzgerald et al. (1973) and seem characteristic of polymer formulations.

In the field trials, however, only two plum curculios were captured, both on May 19 (three days before full bloom), one on a control trap and the other on a scented trap. The one captured on the control was on the top side of the trap, indicating that it could have fallen onto it, and the one on the scented trap was captured between the trap and the branch, suggesting it may have crawled under the trap for shelter. This second capture represented the way in which it was hoped that these traps would catch plum curculios.

The lack of captures suggests that isoamyl isovalerate, which was shown to be neither attractive or repellent to the multivoltine southern strain of plum curculio in the laboratory, was also not attractive in the field, at least at the 10% concentration.

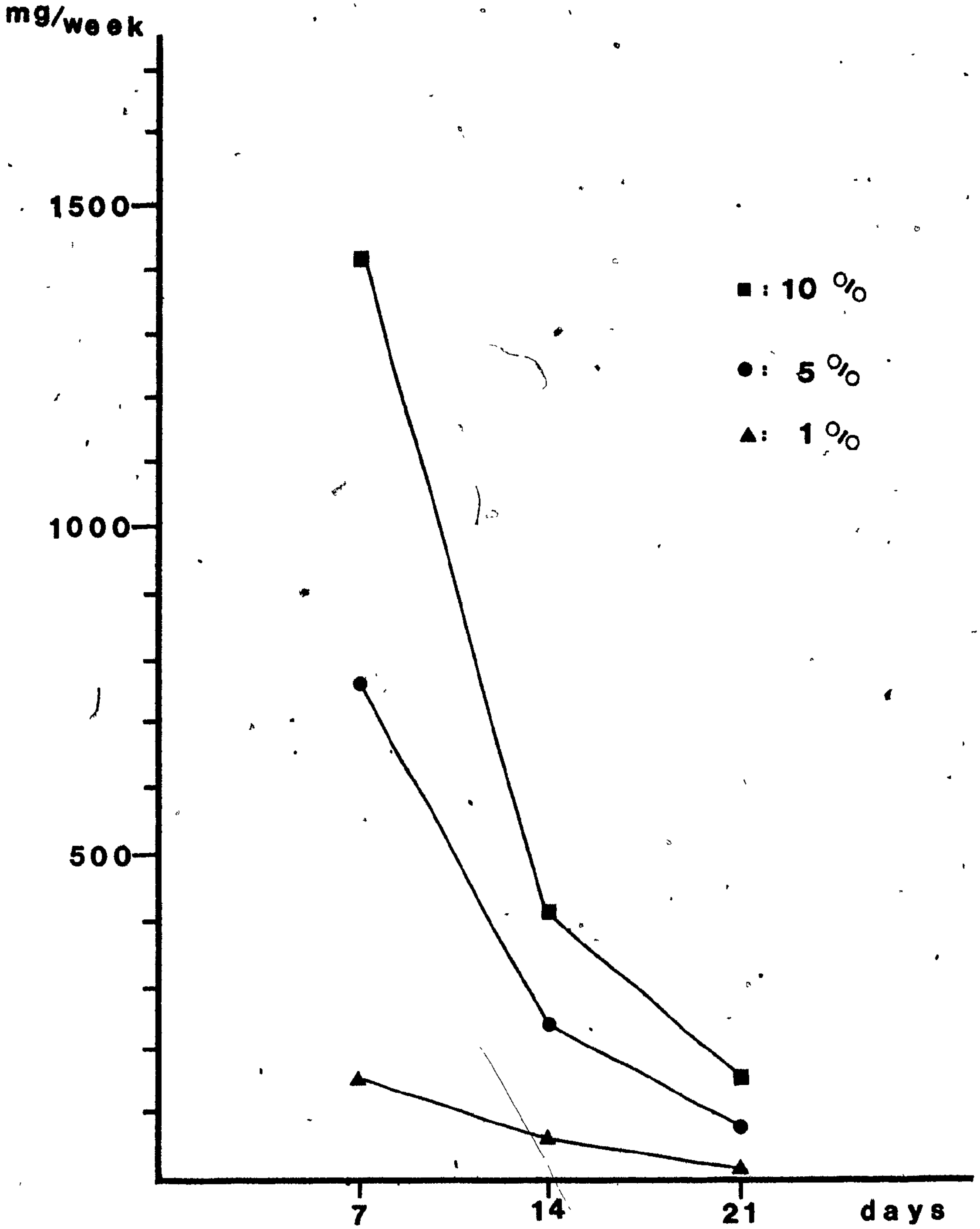


Fig. 11. Release rate of isoamyl isovalerate from PVC strips hung in a fume hood at 25° ±1,5°C.

5.5.3 Boll weevil trap used as interception trap

In 1977, tests with free hanging boll weevil traps[1], with grandlure as an attractant, were unsuccessful in capturing plum curculio (Chapter 3). In 1980, further tests were carried out with this trap but, in this case, two other potential attractants were tested and the traps were nailed to the trees, so that they could function as interception traps. This was in response to my observations, and to those of other investigators (Prokopy and Owens, personal communication), that plum curculios crawl on the branches more than they fly from one branch to another.

5.5.3.1 Materials and methods

The attractants were held in a dispenser-reservoir device, comprising a 10 ml vial containing a piece of pipe cleaner that carried the attractant to a small piece of sterilized cotton inserted in the mouth of the vial. This vial was then inserted in the center part of the base of the trap in which a hole was drilled to accommodate it. The two attractants tested in the field were: (1) apple juice extract, obtained by centrifuging whole apples (Cortland cultivar) with a domestic juicer, and (2) Avon A-5002 apple blossom perfume oil using the formulation tested in the olfactometer Version II. The apple extract was prepared in sufficient amounts for the needs of the experiment and kept frozen at -5°C in 30 ml quantities, the amount required to replenish all the vials. Also, to prevent captures escaping from the traps, a four centimeter square insecticidal chip[2] was

---

[1] Story Chemical Corporation, Willoughby, Ohio.

[2] "4-month" Insect Strip, Green Cross Products, Division of Ciba-Geigy Canada Ltd, Toronto, Ontario.

added to each trap; this slow-release material contained the insecticide dichlorvos in an 18,6% AI formulation.

The experiment was performed within another insecticide-free orchard on the Frelighsburg Experimental Farm. The orchard is located one kilometer north of the experimental orchard and is quite similar in size, shape, variety, and age. However, it is adjacent to a woodlot only on its north side. An infestation of plum curculio had been noticed in this orchard during the previous year. Accordingly 13 trees, adjacent to the woodlot, were selected for this experiment.

Five traps were charged with the perfume oil, three with the apple juice extract and five others served as controls. This number of controls were used because it was suspected that the trap would even be successful solely as an interception device. For the five traps, containing the perfume oil, and for the five control traps, containing only the insecticidal chip, three of each were nailed on major rising branches, two meters above ground, and two were nailed onto tree trunks, one meter above ground level; for the three traps, containing the apple juice extract, two were on branches and one on a tree trunk. The traps were installed on May 22 (full bloom) and examined weekly until October 23, i.e., for five months.

5.5.3.2 Results and discussion

During the 1980 growing season, the 13 traps captured 24 plum curculio adults; bi-weekly number of captures are presented in Figure 12. Although total number of captures is less than one third that obtained (76) in the intercepting funnel experiment (Chapter 4), their distribution pattern does correspond to plum curculio's seasonal development. However, in view of this smaller number of total captures the pattern is not as clear as that revealed by the intercepting funnel results; only three distinct

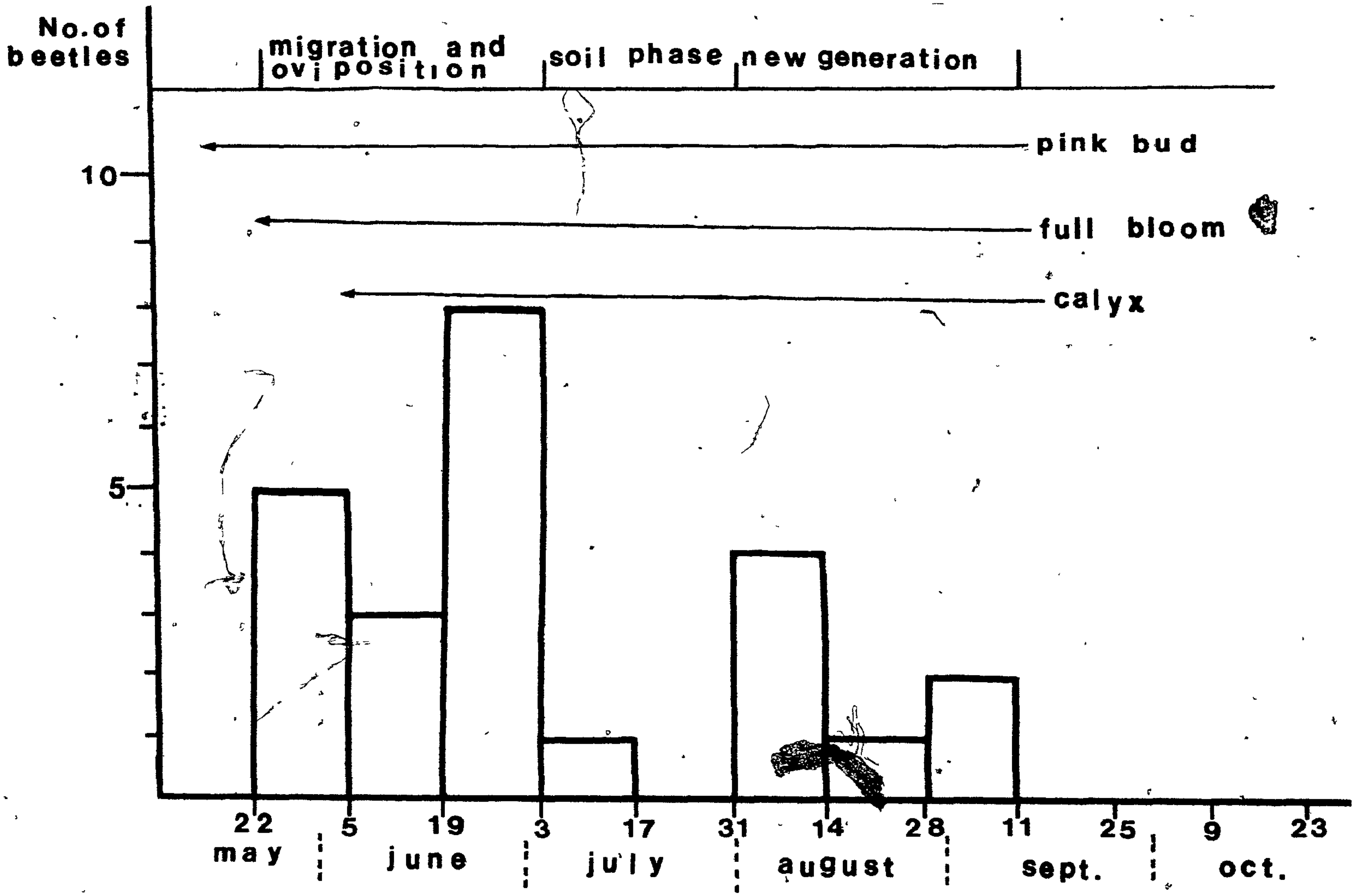


Fig. 12. Histogram of bi-weekly total captures of <u>Conotrachelus nenuphar</u> adults in 13 boll weevil traps nailed to the trees at Frelighsburg, Quebec, 1980.

capture periods are evident. The first period, with 16 captures (67%), extended from May 22 (full bloom) until July 3, and corresponded to plum curculio migration and oviposition. The second period, from July 3 to July 31, which comprised one capture (4%), corresponded to this weevil's soil stage. Finally, the third period, from July 31 to September 11, with seven captures (29%), corresponded to the appearance of the new generation.

Difference in numbers of captures, with respect to the two attractants and the control is shown in Figure 13. In addition, catches on branches are compared with those on the tree trunk. As controls captured more plum curculios (an average of 2,6 individuals per trap) than perfume oil traps (0,4 individual) and almost as many as the apple juice extract ones (3,0 individuals) it must be concluded that the "attractants" were not effective. It is significant, however, that in each group of traps, almost all captures were obtained in those traps located on the branches. These two observations suggest that trap location is critical and that the trap operates merely as an interception device. Also, the presence of certain substances (e.g., perfume oil) may act as repellents.

It is recommended that future efforts to design efficient traps for the plum curculio focus on interception traps that could be located on rising branches (or at the junction of two rising branches); also that further experiments be conducted to find attractant colours, sizes, shapes and odors.

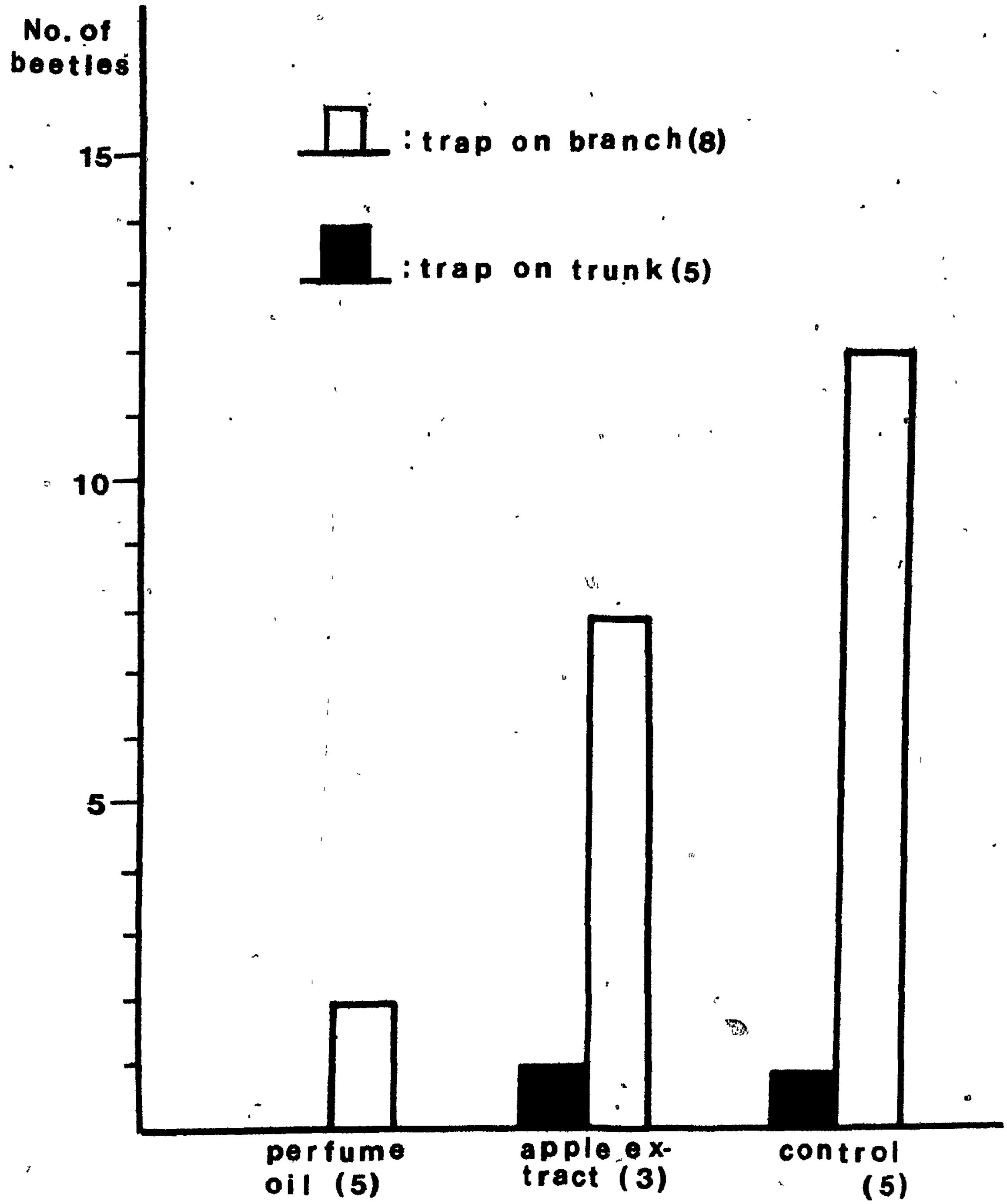


Fig. 13. Total captures of Conotrachelus nenuphar adults in 13 boll weevil traps with two attractants and two positions at Frelighsburg, Quebec, 1980.

6.0 MONITORING INSECT EFFECTS - THE GRANNY SMITH APPLE TECHNIQUE

6.1 Introduction

During the first year of my study (1977) seven techniques for sampling Conotrachelus nenuphar were tested (Chapters 3, 4, and 5). The results, while discouraging, did indicate that plum curculio adults are very difficult to trap.

My initial aim was to obtain relative population indices that could be correlated with fruit damage, thereby providing a reasonable tool for decision making in directed control programmes. Graham (1948) working with the codling moth, Carpocapsa (=Laspeyresia) pomonella (L.), found, however, that "satisfactory comparison of treatments can be made on the basis of the number of injured fruits", i.e., on the basis of insect effects. Also, the distinctive semi-circular egg-laying scars made by plum curculio females and the irregular feeding punctures made by the adults of the new generation on maturing fruits had been used by LeRoux (1961) to evaluate C. nenuphar damage on apples in a southerwestern Quebec orchard. Furthermore, Calkins et al. (1976) had previously used green thinning apples hung in plum and oak thickets to study the spatial and temporal oviposition patterns of plum curculio, although this had not been developed into a practical monitoring technique.

The objectives of the three year experiment reported here were to obtain the following information by monitoring for insect effects: (1) time of plum curculio migration to the orchard, (2) its presence and abundance prior to apple fruit set, and (3) detection of relationships between these findings and damage assessment both at "June" drop and harvest. The establishment of such relationships was considered to be the first step towards replacing preventative "calendar" spraying against *C. nenuphar* by directed control. The experimental design selected for the study was intended to yield information that would accurately indicate "when" and "where" to apply controls, *e.g.*, insecticides.

6.2 Preliminary Work

During the 1977 growing season, a method employing mature Granny Smith apples for monitoring effects of *C. nenuphar* was developed. These apples were chosen for the following reasons: (1) their green colour (as females normally oviposit into the young green fruit) and for their size (*c.a.* 5 cm diameter), which offers a larger oviposition surface than green thinning apples, (2) their easy visibility in the trees, (3) their commercial availability prior to natural fruit set in our region, and (4) their freshness, having been recently harvested in South America. These apples were also found to stay fresh longer in the field than local apples that had been stored over winter (see below).

For the first experiment I used 21 Granny Smith apples. Prior to their installation in the experimental orchard, these apples were thoroughly washed in lukewarm water to remove any pesticide residues. Seven apples were dipped into melted Tanglefoot® [1], to test if they would capture *C. nenuphar* adults. This was attempted because Prokopy (1968a) was successful in estimating the apple maggot, *Rhagoletis pomonella* (Walsh), adult abundance in apple orchards with red wooden sticky spheres suspended from apple tree branches. The 14 others were installed intact to verify if they would attract plum curculios for oviposition. Of these 14 apples, four were

---

[1] The Tanglefoot Company, Grand Rapids, Michigan.

attached with a galvanized wire, five centimeters below a tree branch and 10 were installed at major branch junctions. All of the apples were placed in the upper half of seven trees (N-3 to N-9) in the most westerly row of the experimental orchard (see Fig. 1), adjacent to the surrounding woodlot. This location was chosen to maximize detection of the apples by plum curculio. Each of these trees had one sticky and two non sticky apples. The Granny Smith apples were installed on June 23 and examined on three occasions over a 19 day period: June 24, 29 and July 12.

On June 24, three plum curculio oviposition scars were detected, five more on June 29 and six additional ones on July 12, for a total of 14, all on non sticky apples (see Fig. 15,B). No adults were captured on the seven sticky apples. This confirmed my earlier observations with colour sticky traps (Chapter 5) that this insect is not readily trapped by such devices. It is also important to note that the 14 egg-laying scars occurred on seven of the 10 apples installed at major branch junctions (i.e., 3, 2, 1, 2, 1, 2, and 3), none on the four hanging apples. This suggests that plum curculio females reached the Granny Smith apples by walking along the tree branches rather than by flying to them. Consequently, in all subsequent experiments Granny Smith apples were placed at major branch junctions.

After 19 days, ten (71%) of the 14 uncoated Granny Smith apples were still in adequate condition for the detection of egg-laying scars. This coincides with the 20-day average (five years) period between pink bud stage and fruit set for standard trees in the experimental orchard; this being the time when C. nenuphar must be monitored. Consequently, because "they remained in good condition", Granny Smith apples were used in all subsequent experiments.

Finally, it is significant to note that the 14 egg-laying scars were made at a time when the Granny Smith apples were in competition with thousands of young green apples, the natural oviposition sites for plum curculio. Thus, it was expected that even more oviposition scars might be obtained on Granny Smith apples that are present prior to natural fruit set, i.e., when alternative oviposition sites are not available. What remained to be discovered was whether females would, in fact, lay eggs at this earlier time. Based on those preliminary results a more extensive experiment was conducted to test the feasibility of using Granny Smith apples to monitor populations of plum curculio.

6.3 Materials and Methods

6.3.1 Experimental orchard

The reader may refer to the Introduction of this thesis (section 1.6) for a complete description of the experimental orchard. It is, however, represented here again, including additional information related to the experimental design and the scout-trees location (Fig. 14).

6.3.2 Experimental design

The experimental orchard was divided into five sectors (roman numerals, Fig. 14) of approximately 45 trees each: the four sides and the center. This design was chosen to study spatial distribution of plum curculio effects (egg-laying scars on Granny Smith apples) and of its damage at "June" drop and fall harvest. In each of these five sectors (considered here as treatments), five scout-trees, all McIntosh, were randomly chosen (Fig. 14). In addition, the crowns of the 25 scout-trees were divided horizontally into upper and lower half and vertically into four equal quadrants, according to the four cardinal points of the compass. This provided eight scout-apple locations *per* tree, and 200 for the entire orchard. In 1979 and 1980, the design was simplified and scout-apples (100) were

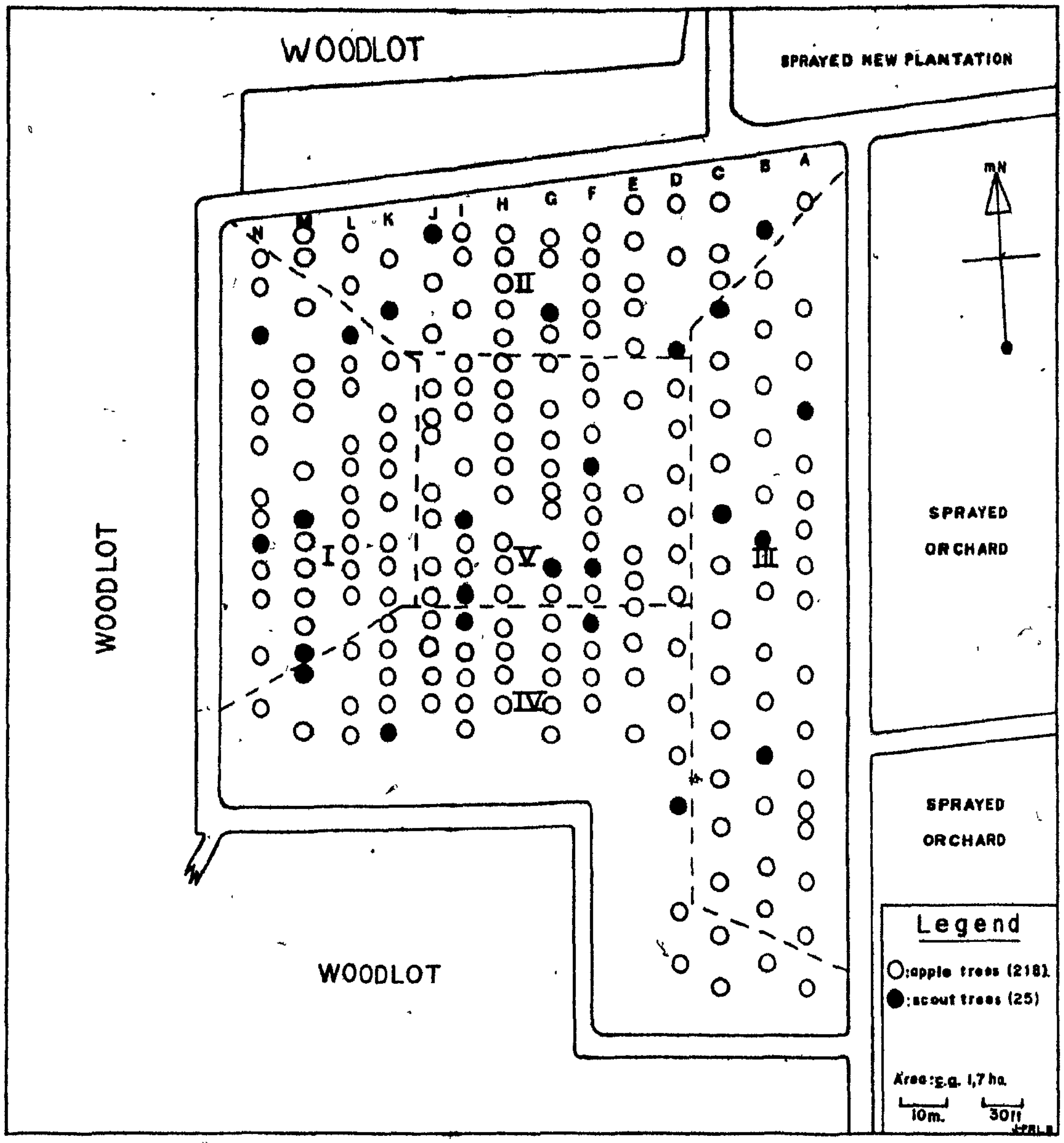


Fig. 14. Experimental orchard, Frelighsburg, Quebec, 1978-1980. Orchard sectors (I-V) and scout-tree locations.

installed only in the upper half of scout-trees.

6.3.3 Scout-apples (Granny Smith)

The scout-apples used in each of the three years were of the Granny Smith cultivar, chosen on the basis of the results of the preliminary 1977 experiment. These apples were imported from Chile, and purchased wholesale, during the last week of April, from the same fruit broker each year. There were exactly 100 apples per box, each approximately five centimeters in diameter. They were stored in a walk-in refrigerator at $5^{0}\pm1^{0}C$ until needed.

Installation of these scout-apples at major branch junctions required that a metal needle be first driven through the central part of each apple core. This facilitated insertion of the galvanized wire, 30 cm long, without damaging the apple skin; for secure retention of the apple by the wire a hexagonal galvanized nut (14 mm wide and 6 mm thick) was attached at one of its ends, the free end being secured around the branch junction. This type of attachment permitted the insertion of scout-apples into the "V" part of major branch junctions (see Fig. 15,A).

During each growing season, scout-apples were installed at pre-pink bud stage (McIntosh cultivar) and examined every two days until the first egg-laying scars were detected (see Fig. 15,C). A final examination was performed two days after the calyx stage in 1978 and 1979 and early on the morning of the third day in 1980, because of a heavy rain the second day. This timing of the final examination corresponds to fruit set and is the latest moment at which a decision regarding spraying has to be taken.

During the final examination, every scout-apple showing one or more plum curculio egg-laying scar(s) was recorded. This unit was chosen because of the variability of the number of egg-laying scars per scout-apple observed during the 1977 preliminary experiment.

6.3.4 Other experiments

During the 1979 growing season, in order to test the technique at low plum curculio population densities, five local commercial sprayed orchards were also monitored. In each of these orchards five randomly chosen scout-trees (in rows adjacent to woodlots) received four Granny Smith scout-apples (one *per* cardinal point of the compass) installed in the upper half of trees. These apples were installed at pre-pink bud stage and examined for plum curculio oviposition scars two days after the calyx stage.

In addition, during the 1980 growing season, two insecticide-free orchards were monitored in a similar way; one at the Frelighsburg Experimental Farm, one kilometer north of the experimental orchard (described in the section on the boll weevil trap in Chapter 5) and the other at l'Acadie, less than 10 km west of the Saint-Jean, Agriculture Canada Research Station.

6.3.5 Damage assessment

Plum curculio damage in the experimental orchard was assessed at two different moments during each of the three growing seasons. This was done also during 1979 in the five commercial orchards and during 1980 in the two insecticide-free orchards.

The first damage assessment was carried out after the physiological fruit drop had occurred. This natural phenomenon of premature apple fruit abscission is often referred to, initially by New England growers, as "June" drop, because invariably in that region it occurs during this month. At our higher latitudes, however, it takes place more often during the first two weeks of July. It was important to record plum curculio damage at that time because the young fruit bearing active plum curculio larvae fall at June drop (Levine and Hall 1977). Thus, high plum curculio infestation can result in a significant decrease in yield at harvest.

In the experimental orchard June drop infestation was assessed by randomly collecting 25 fallen apples *per* cardinal point of the compass under each of the 25 scout-trees. In this way, 2 500 apples were collected (500 *per* orchard sector) each growing season and those with one plum curculio egg-laying scar or more were recorded. This assessment was performed on July 12 in 1978, July 3 in 1979 and July 10 in 1980.

Plum curculio damage was also assessed at harvest. This damage includes firstly, oviposited apples in which plum curculio larvae did not develop (because eggs were infertile or aborted, or in which the larvae were killed by the pressure of the rapidly growing fruit) - these bear crescent shaped egg-laying scars that have healed, resulting in a shield-like necrosis on the skin of mature fruit - and secondly, nutrition punctures - circular holes made through the apple skin by this beetle's long beak - made by the emerging adults of the new generation. In these nutrition punctures the pulp under the puncture is excavated and the skin around the hole shows a dark halo of necrosed tissues (making it relatively easy to identify). Both of these types of damage render apples unmarketable for fresh consumption. Such damage may also make those apples more susceptible to disease or shorten their storage life.

In the experimental orchard harvest damage was assessed by randomly collecting 25 apples *per* cardinal point of the compass, 18 from the tree and seven fallen ones for each of the 25 scout-trees. In this way, 2 500 apples were collected (500 *per* orchard sector) during each growing season, and those with either one or more shield-like skin necrosis and/or one or more plum curculio feeding puncture were recorded. This assessment was performed on September 15 in 1978, September 17 in 1979 and September 19 in 1980.

In addition, in 1979, similar June drop and harvest plum curculio damage assessments were carried out in the five commercial orchards on June 29 and September 19 respectively. In the two insecticide-free orchards in 1980, plum curculio June drop and harvest damage were assessed on July 10 and September 18 respectively.

6.4 Results and Discussion

6.4.1 Monitoring at different vertical levels in the trees

During 1978, while Granny Smith scout-apples were installed in upper and lower halves of the trees, egg-laying scars were detected only on apples in the upper halves of the trees. Accordingly, the experimental design was immediately simplified and the variable "tree level" eliminated. Thus, the analysis of results for the three growing seasons is based on 100 scout-apples installed in the upper half of the trees (Fig. 15,C and D).

LeRoux (1961) detected significant differences in the vertical distribution of plum curculio damage later in the growing season: mid-July in 1958 and late July in 1959, and again in mid-September in 1959. This might suggest that plum curculios favour different levels in the trees at different times of the year. It should be noted, however, that LeRoux's observations were of plum curculio populations at a much lower density.

6.4.2 Summary of results

Results are presented in Tables 7, 8, and 9. The first column of each table indicates the orchard sectors (I to V). The second column identifies each scout-tree according to the adopted grid system, A to N for orchard rows and 1, 2, 3... for the trees in each row, starting at the north end (Fig. 14). Column three, four and five correspond respectively to the 1978, 1979, and 1980 growing seasons. For each of the five orchard

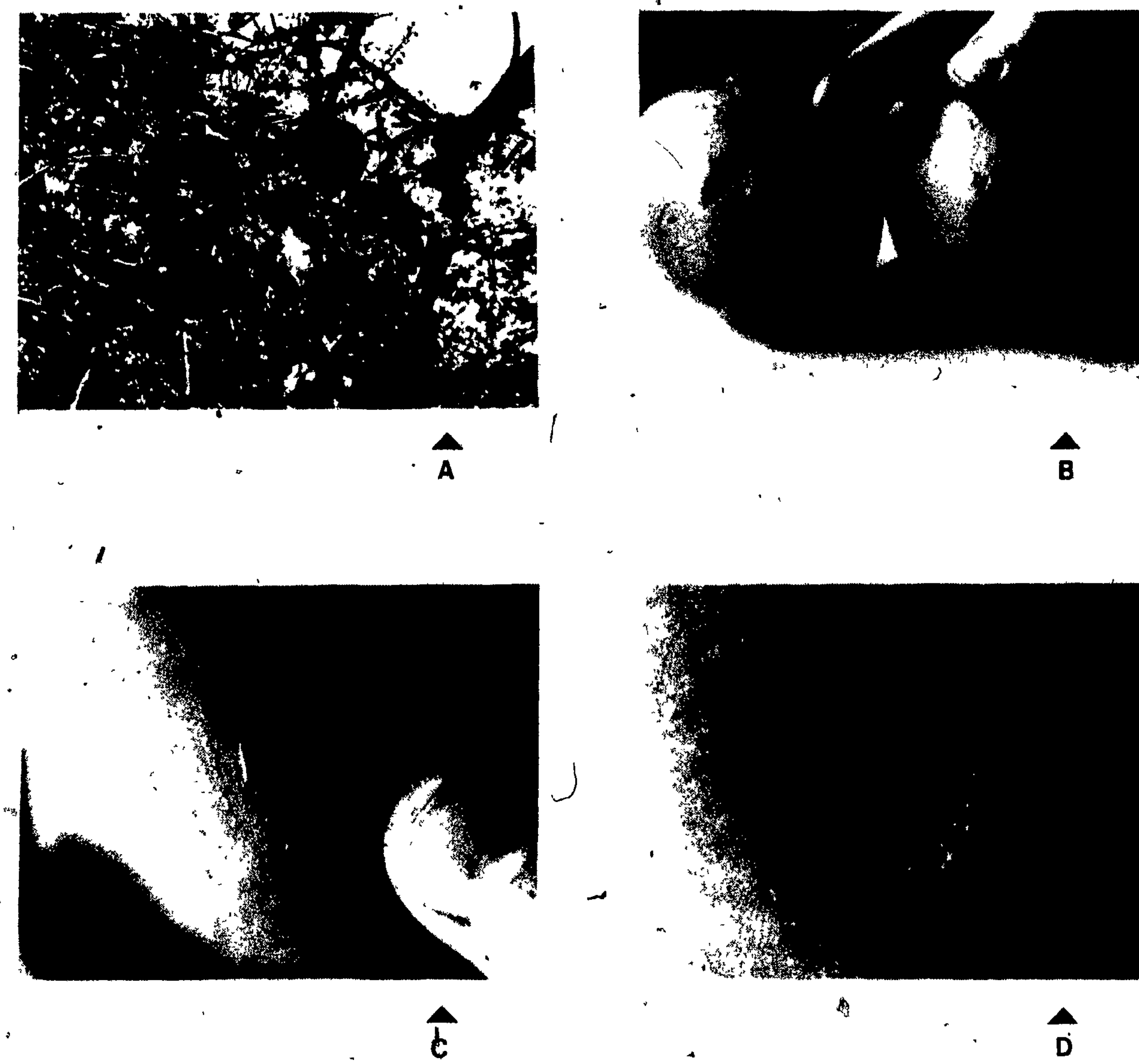


FIG. 15. PLUM CURCULIO OVIPOSITION SCARS ON GRANNY SMITH SCOUT-APPLES HUNG IN THE EXPERIMENTAL ORCHARD AT FRELIGHSBURG, QUEBEC, 1977-1980. (A) SCOUT-APPLE IN TREE, (B) OVIPOSITION SCARS, 1977, (C) OVIPOSITION SCARS, 1980, (D) <u>IDEM</u>.

Table 7. Incidence of scout-apples (4/tree; 1/quadrant) with plum curculio oviposition scars at fruit set.

Sector	Scout-trees[1]	June 1 1978					May 23 1979					June 4 1980				
		N	S	E	W	T	N	S	E	W	T	N	S	E	W	T
I	M 13	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
	N 9	0	0	0	0	0	0	0	0	0	0	0	1	1	0	2
	M 8	0	1	0	0	1	0	0	0	0	0	1	0	0	0	1
	L 3	0	0	0	1	1	0	0	0	0	0	0	0	1	0	1
	N 3	0	0	1	0	1	0	0	0	0	0	0	1	1	0	2
		0	1	1	1	3	0	0	0	0	0	1	2	3	1	7
II	K 2	0	0	0	0	0	0	0	0	0	0	1	0	0	1	2
	J 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	G 3	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
	D 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	B 1	0	0	0	0	0	0	1	1	1	3	0	0	0	0	0
		0	0	0	0	0	0	1	1	1	3	1	0	0	2	3
III	C 4	0	0	0	0	0	0	0	1	0	1	0	1	0	0	1
	A 4	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
	C 8	0	1	0	0	1	0	0	1	0	1	0	0	0	0	0
	B 7	0	0	0	0	0	0	0	0	1	1	1	0	0	0	1
	B 11	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0
		0	1	0	0	1	1	0	2	1	4	1	2	0	0	3
IV	D 13	1	1	0	1	3	1	1	0	1	3	0	1	0	1	2
	F 15	1	0	0	0	1	0	0	0	0	0	0	0	0	1	1
	I 12	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0
	K 15	0	0	0	1	1	0	0	0	0	0	0	1	0	0	1
	M 14	0	0	0	0	0	0	0	0	0	0	0	1	1	0	2
		2	1	0	2	5	1	1	1	1	4	0	3	1	2	6
V	I 11	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0
	I 8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	F 9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	F 13	0	0	0	0	0	0	1	1	0	2	0	0	0	0	0
	G 11	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0
		0	0	0	0	0	0	3	1	0	4	0	0	0	0	0

[1]See Fig. 14.

Table 8. Incidence of June drop apples (100/scout-trees; 25/quadrant) with plum curculio oviposition scars.

Sector	Scout-trees[1]	July 7 1978 N	S	E	W	T	July 3 1979 N	S	E	W	T	July 10 1980 N	S	E	W	T
I	M 13	9	13	15	7	44	23	25	23	25	96	21	19	18	18	76
	N 9	13	11	9	19	52	23	23	24	17	87	18	19	13	19	69
	M 8	12	12	14	11	49	17	18	23	21	79	17	19	22	16	74
	L 3	7	6	10	9	32	16	18	18	18	70	15	12	9	17	53
	N 3	16	13	14	15	58	25	20	21	25	91	22	19	19	17	77
		57	55	62	61	235	104	104	109	106	423	93	88	81	87	349
II	K 2	0	5	9	3	17	15	14	14	11	54	11	17	14	8	50
	J 1	9	10	7	8	34	18	13	19	18	68	15	11	13	13	52
	G 3	4	5	6	3	18	9	19	10	12	50	7	9	6	6	28
	D 3	6	4	6	1	17	10	10	6	6	32	12	9	9	14	44
	B 1	10	12	8	7	37	15	12	6	15	48	9	6	11	12	38
		29	36	36	22	123	67	68	55	62	252	54	52	53	53	212
III	C 4	6	5	8	8	27	9	12	9	8	38	14	10	7	9	40
	A 4	2	3	1	0	6	8	8	6	7	29	4	7	5	7	23
	C 8	9	5	14	7	35	5	9	6	4	24	5	6	6	5	22
	B 7	3	4	0	3	10	12	14	9	3	38	14	9	8	9	40
	B 11	19	13	16	17	65	22	19	21	21	83	14	17	15	13	59
		39	30	39	35	143	56	62	51	43	212	51	49	41	43	184
IV	D 13	8	10	12	9	39	17	16	14	17	64	13	17	15	18	63
	F 15	8	6	11	10	35	18	19	16	20	73	4	6	8	5	23
	I 12	2	3	1	3	9	20	16	16	18	70	8	12	10	10	40
	K 15	10	14	15	10	49	23	22	23	23	91	19	18	16	21	74
	M 14	19	16	14	25	74	21	18	19	21	79	19	15	21	14	69
		47	49	53	57	206	99	91	88	99	377	63	68	70	68	269
V	I 11	1	2	2	0	5	12	12	14	14	52	9	11	8	7	35
	I 8	6	7	10	10	33	16	17	15	21	69	7	4	7	5	23
	F 9	0	1	0	0	1	12	15	16	14	57	4	5	5	3	17
	F 13	8	9	9	11	37	9	14	19	9	51	8	10	5	6	29
	G 11	0	0	2	3	5	9	19	25	14	67	3	8	8	8	27
		15	19	23	24	81	58	77	89	72	296	31	38	33	29	131

[1] See Fig. 14.

Table 9. Incidence of harvest apples (100/scout-tree; 25/quadrant, 18 on the tree and 7 fallen ones) with plum curculio oviposition scars and/or nutrition punctures.

Sector	Scout-trees[1]	Sept. 15 1978					Sept. 17 1979					Sept. 19 1980				
		N	S	E	W	T	N	S	E	W	T	N	S	E	W	T
	M 13	13	6	9	6	34	17	21	17	18	73	15	19	25	16	75
	N 9	8	9	20	7	44	16	16	19	19	70	19	14	19	16	68
I	M 8	8	9	10	9	36	21	19	16	19	75	21	16	22	17	76
	L 3	10	12	12	4	38	22	19	18	20	79	15	19	17	15	66
	N 3	10	12	18	14	54	20	20	22	22	84	21	20	20	22	83
		49	48	69	40	206	96	95	92	98	381	91	88	103	86	368
	K 2	8	10	13	8	39	17	19	18	14	68	11	11	12	9	43
	J 1	10	10	15	10	45	16	15	17	20	68	9	10	12	11	42
II	G 3	11	10	5	9	35	19	15	15	15	64	8	7	9	8	32
	D 3	2	10	8	8	28	16	18	16	21	71	10	8	10	11	39
	B 1	18	13	17	17	65	14	16	12	15	57	9	10	10	11	40
		49	53	58	52	212	82	83	78	85	328	47	46	53	50	196
	C 4	9	10	12	7	38	19	14	17	16	66	10	15	11	11	42
	A 4	5	8	4	5	22	12	12	13	6	43	10	13	10	8	41
III	C 8	6	2	5	11	24	12	8	14	9	43	11	13	7	11	42
	B 7	8	10	10	9	37	15	12	15	11	53	12	11	13	13	49
	B 11	10	16	16	13	55	23	16	21	25	85	11	12	14	13	50
		38	46	47	45	176	81	62	80	67	290	54	64	55	56	229
	D 13	19	17	11	15	62	17	19	16	13	65	16	12	14	14	56
	F 15	17	20	13	12	62	21	18	18	19	76	13	14	16	14	57
IV	I 12	11	15	10	7	43	21	21	16	14	72	13	12	12	15	52
	K 15	18	15	19	16	68	20	21	18	20	79	14	16	18	17	65
	M 14	13	12	15	17	57	22	24	22	19	87	16	15	17	17	65
		78	79	68	67	292	101	103	90	85	379	72	69	77	77	295
	I 11	8	7	5	9	29	10	14	16	15	55	3	5	8	4	20
	I 8	12	11	10	9	42	18	22	19	16	75	5	5	7	6	23
V	F 9	4	7	7	9	27	19	19	18	21	77	1	2	5	0	8
	F 13	9	9	15	7	40	17	11	18	12	58	8	8	5	2	23
	G 11	3	10	15	3	31	16	14	17	18	65	9	8	7	9	33
		36	44	52	37	169	80	80	88	82	330	26	28	32	21	107

[1] See Fig. 14.

sectors in each of the growing seasons, horizontally derived (row) totals correspond to a particular scout-tree and vertically derived (column) totals to a particular cardinal point of the compass; also, for each orchard location a grand total is given.

6.4.3 Monitoring differences according to tree quadrants

My null hypothesis was that frequencies of plum curculio oviposition scars on Granny Smith apples and frequencies of "June" drop and fall harvest damaged apples would be found to be independent of the cardinal points of the compass. In order to test this the three annual sets of data per quadrant (plum curculio oviposition scars on Granny Smith apples and the two damage assessments) were submitted to rows and columns tests of independence using the G-Test proposed by Sokal and Rohlf (1981:pp. 731-747).

As this type of analysis of frequencies is used throughout this experiment a working example based on the data of the 1980 harvest damage (see Table 9, data of September 19, 1980), is presented to illustrate the technique. The column totals for each quadrant are summed together to generate total number of damaged apples per quadrant for the entire experimental orchard; this number is based on 625 collected apples. The four totals thus obtained, corresponding to the four cardinal points of the compass, were then used to generate Table 10, which gives the frequencies of damaged apples per quadrant. The statistic G is equal to 2[$\Sigma f \ln f$ (for the cell frequencies) - $\Sigma f \ln f$ (for rows and columns totals) + $n \ln n$], where n=grand total (2 500). The degrees of freedom for the G-Test are equal to (rows - 1)x(columns - 1), as for a chi-square test. The calculated G value is compared with a chi-square distribution critical value at the level α=0,01 for the given number of degrees of freedom. The null hypothesis is rejected at the α level when the calculated G value exceeds the critical

Table 10. Frequencies of plum curculio damaged apples per quadrant at harvest, 1980.

Quadrant	Apples		Total	% damaged
	Damaged	Undamaged		
North	290	335	625	46,4
South	295	330	625	47,2
East	320	305	625	51,2
West	290	335	625	46,4
Total	1 195	1 305	2 500	

Calculated G value = 3,98 not significant,

$\chi^2_{0,01}$ = 11,35 for three degrees of freedom.

chi-square table value. Thus, in this case, as G is 3,98 and the critical chi-square table value is 12,84 at α=0,005 and 11,35 at α=0,01 and three degrees of freedom, the null hypothesis cannot be rejected at either of these levels. In other words, at these levels of significance, the per quadrant variation in harvest damage frequencies in 1980 can be explained by chance variation in the samples, and it cannot be assumed that the apples in any one of the four quadrants of scout-trees are more significantly damaged by plum curculio than in any other one. The eight other analyses were performed in the same way. The nine analyses correspond to the three sets of data obtained during each of the three growing seasons. The nine calculated G values are presented in Table 11, with their corresponding significance.

Clearly there is no statistical evidence for significant differences between the frequencies of plum curculio egg-laying scars on Granny Smith apples or frequencies of plum curculio damaged apples at June drop and harvest according to the cardinal points of the compass. Thus, in further analyses, this variable was not considered.

This result is in accordance with LeRoux's findings (1961). In his experiment only on four out of 16 sampling occasions did he find significant differences amongst quadrants; three in 1958 (mid and late July, and mid-August) and one in 1959 (early August).

6.4.4 Monitoring differences according to orchard sectors

6.4.4.1 Correlation between plum curculio effects on Granny Smith apples and June drop and harvest damage assessments, and between damage assessments

Table 11. Value and significance of the statistic G, as calculated for frequencies of Granny Smith apples showing plum curculio oviposition scars, and of plum curculio June drop and harvest damaged apples obtained from the cardinal points of the compass; Frelighsburg experimental orchard, Quebec.

Data set / year	Calculated G value	Significance
Granny Smith apples		
1978	1,48	ns *
1979	2,22	ns
1980	2,26	ns
June drop apples		
1978	3,14	ns
1979	1,70	ns
1980	1,40	ns
Harvest apples		
1978	10,90	ns
1979	2,14	ns
1980	3,98	ns

* Not significant; $\chi^2_{0,01}$ = 11,35 for three degrees of freedom.

In directed control the decision as whether to spray must be made prior to the appearance of actual damage. This is particularly true in pomiculture where curative control is not acceptable because of the extremely low economic threshold, damage having to be maintained below one percent at harvest for fresh market apples. Thus, an effective trap must provide the needed information prior to the occurrence of actual damage. From the above data it is clear that Granny Smith scout-apples permit detection of C. nenuphar presence in orchards since 9, 15 and 19% of these apples were found bearing plum curculio egg-laying scars during the three growing seasons of my study. The various dates and phenological stages of the McIntosh cultivar at which the Granny Smith apples were installed and monitored in the experimental orchard are given in Table 12. Included are the periods of detection of the first egg-laying scars and of the final examinations when the data used in these analyses were recorded.

It is significant to note that the first plum curculio egg-laying scars on Granny Smith apples coincided with the time at which the trees were in bloom. This activity of females of the species, however, does not coincide with the time of this insect's migration to host trees. The dates over the four year period (1977 to 1980) at which plum curculio adults were first detected in the experimental orchard by any method are given in Table 13.

In general, plum curculios are present in the orchard from about pink bud stage, but egg-laying on Granny Smith apples was not observed to start until full bloom. Also, egg-laying on host-tree apples obviously cannot begin until after fruit set. The fact, however, that oviposition can start before fruit set supports the use of the Granny Smith scout-apple technique, although jarring is superior for detecting the early presence of individuals. Jarring, however, is less reliable for forecasting damage

Table 12. Summary of the monitoring of plum curculio effects with Granny Smith scout-apples. Dates and phenological stages of the McIntosh cultivar; Frelighsburg, Quebec.

Growing season	Installation of scout-apples at pre-pink bud stage	Monitoring of scout-apples (pink bud stage)	Detection of first egg-laying scar and its location (full bloom)	Final examination (calyx)
1978	May 18	May 20,23,25,26 (May 20)	May 26, M-8 (May 25)	June 1 (May 30)
1979	May 8	May 10, 12, 14 (May 10)	May 14, D-13 (May 15)	May 23 (May 21)
1980	May 14	May 19,21,23,26,28 (May 15)	May 28, M-8 (May 22)	June 4 (June 1)

Table 13. Dates and phenological stage of the McIntosh cultivar at the time of the first plum curculio detection by any method in the experimental orchard; Frelighsburg, Quebec.

Growing season	First detection	Pink bud stage	Location (tree)	Detection method
1977	May 17	May 13	c.a. M-9	Scarab trap (Chap. 3)
1978	May 16	May 20	M-13, K-6	Boll weevil trap (Chap. 3)
1979	May 8	May 10	F-6	Mirid sticky trap (Chap. 5)
1980	May 15	May 15	F-15	Jarring

(see Chapters 2 and 3, for a discussion of its shortcomings). In 1978 the first egg-laying scar on a Granny Smith apple was detected 10 days after the first plum curculio adult was captured, six days after in 1979 and 13 days after in 1980. This delay is explained by the spring mating of this species, as reported by many researchers. This suggests, however, that host trees are probably the main focus for mating and supports my opinion that trapping and/or monitoring should be performed on host-trees. Most important is the fact that plum curculio effects on Granny Smith apples were always detected about the time of full bloom, prior to the calyx stage, and therefore before the critical time of decision making regarding spraying.

Plum curculio effects on Granny Smith apples monitored at the final examination were correlated with June drop damage and harvest damage assessment values. Also, the two damage assessment values were correlated together. For these analyses the variables are: (1) for effects on Granny Smith apples, the percentage of scout-apples per orchard sector (the four sides and the central portion of the experimental orchard) showing one or more plum curculio egg-laying scar, (2) for June drop damage, the percentage of apples per orchard sector showing one or more plum curculio egg-laying scar and, (3) for harvest damage, the percentage of apples per orchard sector showing one or more plum curculio oviposition shield-like necrosis of the skin and/or one or more nutrition puncture. Correlations between variables averaged over three growing seasons and five sectors are as follows: (1) Granny Smith scout-apples and June drop damaged apples, (2) Granny Smith apples and harvest damaged apples and, (3) June drop damaged apples and harvest damaged apples. The statistic used is the Spearman rank correlation coefficient (r_s) (Daniel 1978). The data are summarized in Table 14 and the rank correlation coefficients, their significance and

Table 14. Summary of Granny Smith, June drop and harvest apples showing plum curculio effects, and expressed as percentage per orchard sector per year, Frelighsburg, Quebec.

Sector[1]	Granny Smith apples (20/sector)				June drop apples (500/sector)				Harvest apples (500/sector)			
	1978	1979	1980	%	1978	1979	1980	%	1978	1979	1980	%
I	15,0	0,0	35,0	16,7	47,0	84,6	69,8	67,1	41,2	76,2	73,6	63,7
II	0,0	15,0	15,0	10,0	24,6	50,4	42,4	39,1	42,4	65,6	39,2	49,1
III	5,0	20,0	15,0	13,3	28,6	42,4	36,8	35,9	35,2	58,0	45,8	46,3
IV	25,0	20,0	30,0	25,0	41,2	75,4	53,8	56,9	58,4	75,8	59,0	64,4
V	0,0	20,0	0,0	6,7	16,2	59,2	26,2	33,9	33,8	66,0	21,4	40,4

[1]See Fig. 14.

the $(r_s)^2$, which might give a measure of how much of the variation in one variable is explained by the variation in the other, in Table 15.

Clearly, from these results the percentage of Granny Smith apples with plum curculio egg-laying scars is significantly correlated with the percentage of damaged June drop and harvest apples, these two last percentages correlating significantly together. This suggests that the use of Granny Smith scout-apples as a detecting tool of possible future harvest damage is feasible. On the other hand, correlation analysis can be misleading, and sometimes a correlation in time or space, rather than between the observed variables, underlies high values of correlation coefficients.

Accordingly, to further verify this relationship, it was of interest to see if it was possible to demonstrate a dependence between the first variable (Granny Smith scout-apples showing plum curculio oviposition activity) and the two others (June drop and harvest damaged apples) regardless of time or space (orchard sector) at or in which they were measured. Since the number of Granny Smith apples showing plum curculio oviposition activity varied for all of the experimental orchard during the three growing seasons from zero to seven, it was possible to re-group the data into three classes as follows: (1) those orchard sectors with 0, 1, or 2 Granny Smith apples showing plum curculio effects prior to fruit set, (2) those with 3, 4 or 5 and, (3) those with 6 or 7. The June drop and harvest numbers of damaged apples for the corresponding sectors were then totalled on an experimental orchard sector basis for the three growing seasons. A rows and columns test of independence using the G-Test was performed. The data are summarized in Table 16 and the calculated G values and their significance in Table 17.

Clearly in both cases, the null hypothesis, that frequencies of

Table 15. "Spearman" rank correlation coefficient values when Granny Smith apples, June drop and harvest damaged apples showing plum curculio effects are correlated.

Variables correlated	r_s	$(r_s)^2$
Granny Smith and June drop apples	0,80 *	0,64
Granny Smith and harvest apples	0,90 *	0,81
June drop and harvest apples	0,90 *	0,81

* Significant at $\alpha=0,05$ for three degrees of freedom (Daniel 1978:pp 300-306).

Table 16. Summary of frequencies of plum curculio damaged June drop and harvest apples per class of Granny Smith apples showing plum curculio effects prior to fruit set, Frelighsburg, Quebec.

Granny Smith apple class showing plum curculio effects	June drop apples				Harvest apples			
	damaged	undamaged	total	% damaged	damaged	undamaged	total	% damaged
0, 1, or 2	901	1 599	2 500	36,04	1 045	1 455	2 500	41,80
3, 4, or 5	1 974	2 026	4 000	49,35	2 250	1 750	4 000	56,25
6 or 7	618	382	1 000	61,80	663	337	1 000	66,30
Totals	3 493	4 007	7 500		3 958	3 542	7 500	

Table 17. Value and significance of the statistic G as calculated for frequencies of plum curculio June drop and harvest damaged apples for classes of Granny Smith apples showing plum curculio effects prior to fruit set.

Variable	Calculated G value	Significance
June drop apples	219,14	*
Harvest apples	215,36	*

* Significant at $\alpha=0{,}01$; $\chi^2_{0,01}$ and two degrees of freedom = 9,21.

June drop and harvest damaged apples is independent of the classes of Granny Smith apples showing plum curculio effects prior to fruit set, must be rejected. Thus, the relationships indicated by the rank correlation coefficients (Table 15) appear to be real. This suggests that more work is warranted with the Granny Smith scout-apples technique to further clarify these relationships and to evaluate the most appropriate number of scout-apples required *per* orchard to detect plum curculio presence and predict its damage levels.

Monitoring with Granny Smith apples was also carried out in five commercial sprayed orchards during the 1979 growing season. For these experiments the results are uniform: no plum curculio egg-laying scars were detected on any of the 20 scout-apples in each orchard. In addition, June drop and harvest damage assessments, based on 500 apples collected at each period *per* orchard, revealed no damage by *C. nenuphar*. Either plum curculio was totally absent from these orchards or at such low population densities (because of the spraying programmes) that this monitoring technique and damage assessment procedures were not efficient enough to detect its presence. Most probably the damage assessments represent reality, but the monitoring prior to fruit set still remains to be evaluated in low population density situations. For this the technique would have to be tested in orchards in which insecticidal spraying would have been recently stopped; these orchards, however, were very scarce in our region during the period of this study.

In 1980, the Granny Smith monitoring technique was also tested in two insecticide-free orchards; the results are summarized in Table 18. Comparisons of these results with those of the experimental orchard could be criticized, but it is significant to note that they agree, however, with

Table 18. Summary of Granny Smith apple monitoring of plum curculio effects and damage assessment at June drop and harvest for two insecticide-free orchards during the 1980 growing season.

Orchard	Granny Smith apples showing plum curculio effects, based on 20.	June drop damaged apples, based on 500 apples.	Harvest damaged apples, based on 500 apples.
Frelighsburg	25%	66%	72%
L'Acadie	20%	52%	60%

the general pattern observed in the experimental orchard. For example, detection of plum curculio oviposition activity on Granny Smith apples prior to fruit set is followed by a significant amount of damaged apples at June drop and harvest; also, June drop and harvest damage are consistent with respect to each other. No statistical significance, however, can be inferred concerning these isolated cases.

6.4.4.2 Analysis of damage assessment at June drop and harvest in the experimental orchard

It appeared important to examine further the data of damage assessment to extract all possible relevant information, more particularly concerning the distribution of damage throughout the experimental orchard. This mainly because, while timing of chemical control measures against C. nenuphar is adequately dictated by apple tree phenology, little is known concerning the areas within an orchard where those control measures should be applied.

Year by year an overall analysis of damage frequencies amongst the five sectors within the experimental orchard at June drop and harvest were performed. The frequencies of damaged apples (at June drop and harvest) recorded amongst the five sectors of the experimental orchard (its four sides and its central portion) (roman numerals on Figure 14) were submitted to rows and columns tests of independence using the G-Test. The data are summarized in Tables 19, 20, and 21 and the calculated G values obtained for each of these eight analyses and their significance are presented in Table 22.

Since $\chi^2_{0,005}$ = 14,86 for four degrees of freedom, each of the calculated G values in Table 22 are significant at $P<0,005$, and the null hypothesis, that frequencies of damaged apples is independent of the

Table 19. Frequencies of plum curculio June drop damaged apples per experimental orchard sector per year, Frelighsburg, Quebec.

Year	Sector[1]	Apples Damaged	Apples Undamaged	Total	% damaged
1978	I	235	265	500	47,0
	II	123	377	500	24,6
	III	143	357	500	28,6
	IV	206	294	500	41,2
	V	81	419	500	16,2
Total		788	1 712	2 500	
1979	I	423	77	500	84,6
	II	252	248	500	50,4
	III	212	288	500	42,4
	IV	377	123	500	75,4
	V	296	204	500	59,2
Total		1 560	940	2 500	
1980	I	349	151	500	69,8
	II	212	288	500	42,4
	III	184	316	500	36,8
	IV	269	321	500	53,8
	V	131	369	500	26,2
Total		1 145	1 355	2 500	

[1]See Fig. 14.

Table 20. Frequencies of plum curculio harvest damaged apples per experimental orchard sector per year, Frelighsburg, Quebec.

Year	Sector[1]	Apples Damaged	Apples Undamaged	Total	% damaged
1978	I	206	294	500	41,2
	II	212	288	500	42,4
	III	176	324	500	35,2
	IV	292	208	500	58,4
	V	169	331	500	33,8
Total		1 055	1 445	2 500	
1979	I	381	119	500	76,2
	II	328	172	500	65,6
	III	290	210	500	58,0
	IV	379	121	500	75,8
	V	330	170	500	66,0
Total		1 708	792	2 500	
1980	I	368	132	500	73,6
	II	196	304	500	39,2
	III	229	271	500	45,8
	IV	295	205	500	59,0
	V	107	393	500	21,4
Total		1 195	1 305	2 500	

[1]See Fig. 14.

Table 21. Frequencies of plum curculio June drop and harvest damaged apples per experimental orchard sector for the three growing seasons, 1978, 1979, and 1980, Frelighsburg, Quebec.

Sector[1]	Apples: Damaged	Apples: Undamaged	Total	% damaged
June drop				
I	1 007	493	1 500	67,1
II	587	913	1 500	39,1
III	539	961	1 500	35,9
IV	852	648	1 500	56,8
V	508	992	1 500	33,9
Total	3 493	4 007	7 500	
Harvest				
I	955	545	1 500	63,7
II	736	764	1 500	49,1
III	695	805	1 500	46,3
IV	966	534	1 500	64,4
V	606	894	1 500	40,4
Total	3 958	3 542	7 500	

[1] See Fig. 14.

Table 22. Summary of calculated G values for frequencies of June drop and harvest damage analyses from the experimental orchard sectors, Frelighsburg, Quebec.

Sets of damage assessment (year)	Calculated G values	Significance
June drop		
1978	147,67	*
1979	272,08	*
1980	230,70	*
Harvest		
1978	78,17	*
1979	55,05	*
1980	328,38	*
Overall		
(1978, 1979, 1980)		
June drop	523,09	*
Harvest	280,85	*

* Significant at α=0,01; $\chi^2_{0,01}$ and four degrees of freedom = 13,27.

experimental orchard sectors, must be rejected each time. In other words, the frequencies of plum curculio damaged apples at June drop and harvest, vary by more than chance, from sector to sector in the experimental orchard and are dependent of these sectors, i.e., their location.

Inspection of the frequencies of June drop and harvest damaged apples in percentage seems to indicate that orchard sectors I and IV, (those immediately adjacent to the surrounding woodlot, thus closer to areas offering adequate overwintering sites for large populations of *C. nenuphar*), are more susceptible to plum curculio attack. It would be more useful, however, to find out which of these differences in plum curculio damage amongst the experimental orchard sectors are statistically significant. This would not only indicate where to strengthen our monitoring efforts but could suggest where control measures should be concentrated.

To find out which experimental orchard sectors are significantly different from others with respect to their frequencies of June drop and harvest plum curculio damaged apples, each set of damage assessment was subjected to an *a posteriori* simultaneous test procedure (STP) of homogeneity (of sets of experimental orchard sectors) proposed by Sokal and Rohlf (1969:pp 582-585). Such an analysis tests the independence of selected subsets of orchard sectors by revealing those subsets that are homogeneous and those that are not. In other words, this STP analysis allows one to determine which orchard sectors are significantly different from the others. This procedure is analogous to an analysis of variance (a significant G instead of a significant F) followed by a multiple comparisons procedure (an STP analysis instead of a Duncan's (1955) MRT).

The experimental orchard sectors that are significantly different from others with respect to their frequencies of June drop and harvest plum curculio damaged apples are shown in Table 23. As for the previous G-Tests performed on this data, these results are presented for each growing season and for an overall three year analysis for both periods of damage assessment.

These results strongly suggest that sectors I and IV are most susceptible to C. nenuphar attack. On the average these two sectors, immediately adjacent to the surrounding woodlot, were the ones also with the highest rates of C. nenuphar egg-laying activity detected on Granny Smith scout-apples prior to fruit set (16,7% and 25,0% respectively), and persistently the ones with the highest damage percentage at June drop and harvest, on a yearly and overall basis. This supports the general assumptions of previous workers about the locations of plum curculio overwintering sites (still to be accurately determined) and the highest susceptibility of orchard areas in the immediate vicinities of such sites. Most importantly, however, it strongly indicates where to concentrate monitoring and control efforts for a directed control scheme.

Furthermore, in sector V (the central area of the orchard) plum curculio egg-laying activity on Granny Smith scout-apples is at its lowest (6,7%). Accordingly, it is in this orchard sector that June drop and harvest plum curculio damage is almost always at its lowest level, indicating that trees in the central portion of the orchard are less susceptible to C. nenuphar attack; as if plum curculio females migrating into the orchard in the spring from their hibernating quarters would lay their eggs in the first host-trees encountered, their egg complement being depleted without necessitating infestation of more remote trees.

This experiment suggests that, in general, if a 1,7 ha orchard does not have its central area significantly infested by the pest, a larger orchard would have a central area even less affected by C. nenuphar, simply because, in this latter case, the central area of the orchard would be more

Table 23. Summary of significantly different experimental orchard sectors with respect to their frequencies of June drop and harvest plum curculio damaged apples, Frelighsburg, Quebec.

June drop damage assessment				Harvest damage assessment			
Year	Sector*	% damaged		Year	Sector*	% damaged	
	I	47,0	a**		IV	58,4	a**
	IV	41,2	a		II	42,4	b
1978	III	28,6	b	1978	I	41,2	b
	II	24,6	b		III	35,2	b
	V	16,2	c		V	33,8	c
	I	84,6	a		I	76,2	a
	IV	75,4	b		IV	75,8	a
1979	V	59,2	c	1979	V	66,0	b
	II	50,4	c		II	65,6	b
	III	42,4	d		III	58,0	b
	I	69,8	a		I	73,6	a
	IV	53,8	b		IV	59,0	b
1980	II	42,4	c	1980	III	45,8	c
	III	36,8	c		II	39,2	c
	V	26,2	d		V	21,4	d
	I	67,1	a		IV	64,4	a
	IV	56,8	b		I	63,7	a
Overall 78-79-80	II	39,1	c	Overall 78-79-80	II	49,1	b
	III	35,9	c		III	46,3	b
	V	33,9	c		V	40,4	c

* See Fig. 14.

** Those percentages followed by the same letter are not significantly different at $\alpha=0,05$. (STP analysis) (Sokal and Rohlf 1969:pp 582-585).

isolated and remote from the overwintering sites. In order to detect such a behavioural pattern it was necessary to use an experimental design with a distinct central area, as employed in this study.

One should be extremely prudent, however, about making broader generalizations on this matter, because my findings are only valid for orchards of almost square layout with adjacent peripheral woodlots or with other appropriate plum curculio overwintering sites such as fences, rock piles, hedge rows, _etc_.. For orchards with a different layout, however, my findings could suggest that monitoring and control measures should be concentrated in the vicinities of such similar sites, even if they occur in the central area of orchard. For example, some orchards have been planted in the past around man-made rock piles (resulting from soil preparation), strictly for convenience, and these sites may host significant plum curculio populations during winter.

Finally, these results suggest two further experiments that could be performed: (1) the control measures could be applied in the most plum curculio prone areas of orchards and adjacent rows when appropriately located Granny Smith scout-apples detected plum curculio presence, and (2) for orchards in which the spray programme is in force, the second of the two sprays against _C. nenuphar_ would be directed only towards susceptible areas; it would be difficult, presently, to do the same for the first calendar spray (calyx stage) because other apple pests are often part of this spray target; the second one, however, is also used to control the oystershell scale, _Lepidosaphes ulmi_ (L.), which in our area is classified as an occasional apple pest (Paradis 1979). These two experiments would necessarily include particular plum curculio June drop and harvest damage assessments, carried out on at least 500 randomly collected apples from susceptible areas. Such a method is most likely to reveal presence of C. nenuphar and also be a guideline for planning the following growing season's monitoring and control activities.

7.0 EFFECTS OF FUNGICIDES ON PLUM CURCULIO

7.1 Introduction

This study, performed during the 1978 growing season, examined the action of the fungicides benomyl and fenarimol on plum curculio during the soil phase of this beetle's life cycle. After completing its development inside the apple, the larva leaves the fallen fruit and burrows into the soil to a depth of about 30 mm (Chapman 1938). This soil phase, during which the insect undergoes pupation, ends with the emergence of sexually immature adults of the new generation. The soil phase extends over 30 days, generally between mid-July and mid-August in our region (Paradis 1956).

This experiment was conducted because, due to lack of space on the Frelighsburg Experimental Farm, the experimental orchard, which had been designated for the plum curculio research, had to be shared with Dr. L. J. Coulombe of the Agriculture Canada Research Station in Saint-Jean, Quebec, who was testing fungicides against the apple scab, _Venturia inaequalis_ (Cke.) Wint.. It was agreed that these tests would be repeated in the same way during the three years (1978, 1979 and 1980) that the plum curculio research had been planned to avoid adding a further variable and any associated bias. The possibility that the fungicides might affect the plum curculio, however, remained.

Of the eight fungicides being tested in May 1978, benomyl and fenarimol were selected for examination. Benomyl was chosen because of its well-known biocidal effect on earthworms (Stringer and Wright 1976), mites (Childers and Enns 1975; Poe and MacFadden 1972) and certain insects (Binns 1970; Colburn and Asquith 1973; Tomlin 1977). Fenarimol was chosen because nothing was known about its insecticidal properties. The other fungicides, tested against the apple scab by Dr. Coulombe, were: captan, dodine, glyodine, methyl thiophanate, metiram, and triforine.

7.2 Materials and Methods

7.2.1 Field work

The fungicides used by Dr. Coulombe in the experimental orchard were commercial products sold under the names Benlate® and Bloc®. Benlate®, a product of E.I. duPont de Nemours and Co., is a wettable powder containing benomyl as the active ingredient in a 50% concentration. Bloc®, a product of Elanco Products Co., Division of Eli Lilly and Co., is an emulsifiable concentrate containing fenarimol as the active ingredient in a 12,5% concentration.

In one of Dr. Coulombe's treatments benomyl was applied as a mixture with fenarimol at 0,40 kg/ha and 0,30 l/ha (0,20 kgAI/ha and 0,04 lAI/ha), respectively. In another treatment, fenarimol was applied alone at 0,60 l/ha (0,08 lAI/ha). Each treatment was applied eight times between mid-May and the end of June 1978. Spraying was done with a Swanson sprayer releasing 4,49 hl/ha of mixture at a pressure of 1734 KPa. There were three replicates of each treatment, each plot containing an average of five trees (McIntosh cultivar) surrounded by buffer trees and having been randomly selected in the experimental orchard.

The effects of the two fungicides on the survival of 4th instar larvae, pupae and adults of C. nenuphar in the soil under the treated trees was investigated. Six emergence cages (described in Chapter 3) were installed under the drip line of the trees; one in each of the three replicates of the two treatments and three other cages were placed under unsprayed trees (controls) at the edge of the adjacent woodlot. The cages were installed on July 5, and sunk five centimeters into the ground to prevent escape of plum curculios; the first larvae were introduced into the cages on July 9.

Plum curculio larvae were obtained from infested fallen apples collected on July 5 and 6 from an insecticide-free orchard two kilometers north of the experimental orchard. This was to avoid depletion of the plum curculio population in the experimental orchard. Of the 42 750 apples collected, 18 750 (44%) bore at least one crescent shaped oviposition scar, typical of plum curculio.

These "plum curculio" apples were divided into five batches by weight, each containing approximately 3 750 damaged apples. On July 6, these were placed in five corresponding wooden boxes and installed inside the adjacent woodlot for the collection of emerging plum curculio larvae, according to the method described by Paradis (1956). The bottom of each box comprised a one centimeter wire mesh screen above a linen sheet to catch the falling larvae and prevent them from entering the soil. The linen was in direct contact with the soil to provide enough moisture to avoid larval mortality from desiccation. To further minimize larval mortality, dropped larvae were collected and recorded twice a day at 0700 h and 1900 h, between July 7 and 29.

Collected larvae were equally distributed twice each day between the emergence cages. By the end of July, 350 larvae had been introduced into each emergence cage. Between August 9 and September 19 each of these cages was inspected daily to collect and record any emerging plum curculio adults. Those recovered from the six cages in the treated plots were returned to their orchard of origin, while those from the control plots were kept for future laboratory attractant tests (Chapter 5).

7.2.2 Laboratory work

The most likely fungicide to demonstrate an insecticidal effect was benomyl. Unfortunately, in none of the treatments, was benomyl sprayed alone. Consequently its effects on C. nenuphar larvae were examined in the laboratory. Water suspensions of the product were prepared at two concentrations (0,680 and 1,370 g/l; 0,340 and 0,685 gAI/l); one was slightly less and the other slightly more than the concentration of benomyl sprayed in the field. Filter papers impregnated with these suspensions were placed in covered petri dishes. Filter paper impregnated with distilled water and dry filter paper was used as the control.

Of the 359 fourth instar larvae collected on July 22, 348 were divided between 12 petri dishes (29 each). This permitted three replications of the four treatments.

The dishes were examined once every hour for the first six hours and then after 9, 24, and 52 hours when the experiment was terminated. By this time most of the larvae in the three dry controls had become inactive.

Larval mortality was assessed by recording those larvae that did not respond to touching with an entomological needle as dead.

The 154 larvae that survived either of the benomyl treatments were put together in a screen covered pail containing moist soil and peat moss and kept in the insectary of the Experimental Farm. The pail was examined daily, from August 9 until September 19, to collect and record emerging adults.

7.3 Results and Discussion

7.3.1 Larval emergence rate from collected apples

On Figure 16 is shown the daily dropping of C. nenuphar 4th instar larvae from the apples in the five boxes installed inside the woodlot. The first larvae were obtained on July 9 and the last ones on July 26. Of the 3 520 larvae collected, 3 150 were distributed equally between the nine emergence cages and 349 were used in the laboratory test. In addition, 11 were discarded and 11 were lost during manipulations.

If it is assumed that each of the 18 750 damaged apples placed in the wooden boxes had only one oviposition scar (i.e., one egg), then the 3 520 fourth instar larvae represents a survival of 19%. Similarly two eggs would give a survival of 9,5% and a corresponding mortality of 91,5%; this representing the summation of infertile eggs, egg mortality, and first to third instar larval mortality. This latter is probably nearer reality as most of the apples collected had one to three oviposition scars. It is suspected that the main mortality factors are: (1) crushing of young larvae by rapid fruit growth, and (2) the action of direct sunlight upon fallen fruits (Crandall 1905).

The three almost equal peaks in numbers of collected larvae (Fig. 16) probably reflect a succession of favourable and unfavourable climatic conditions during the preceding oviposition period. Also, since larvae were collected twice a day (to avoid desiccation) numbers of larvae obtained in early mornings could be compared with those obtained in early evenings. The ratio of total larvae falling from the fruit during the night to those falling during the day was 2 200:1 320 or 1,67:1. As this ratio is highly significantly different from a 1:1 ratio, (χ^2=219,5 and corrected for contin-

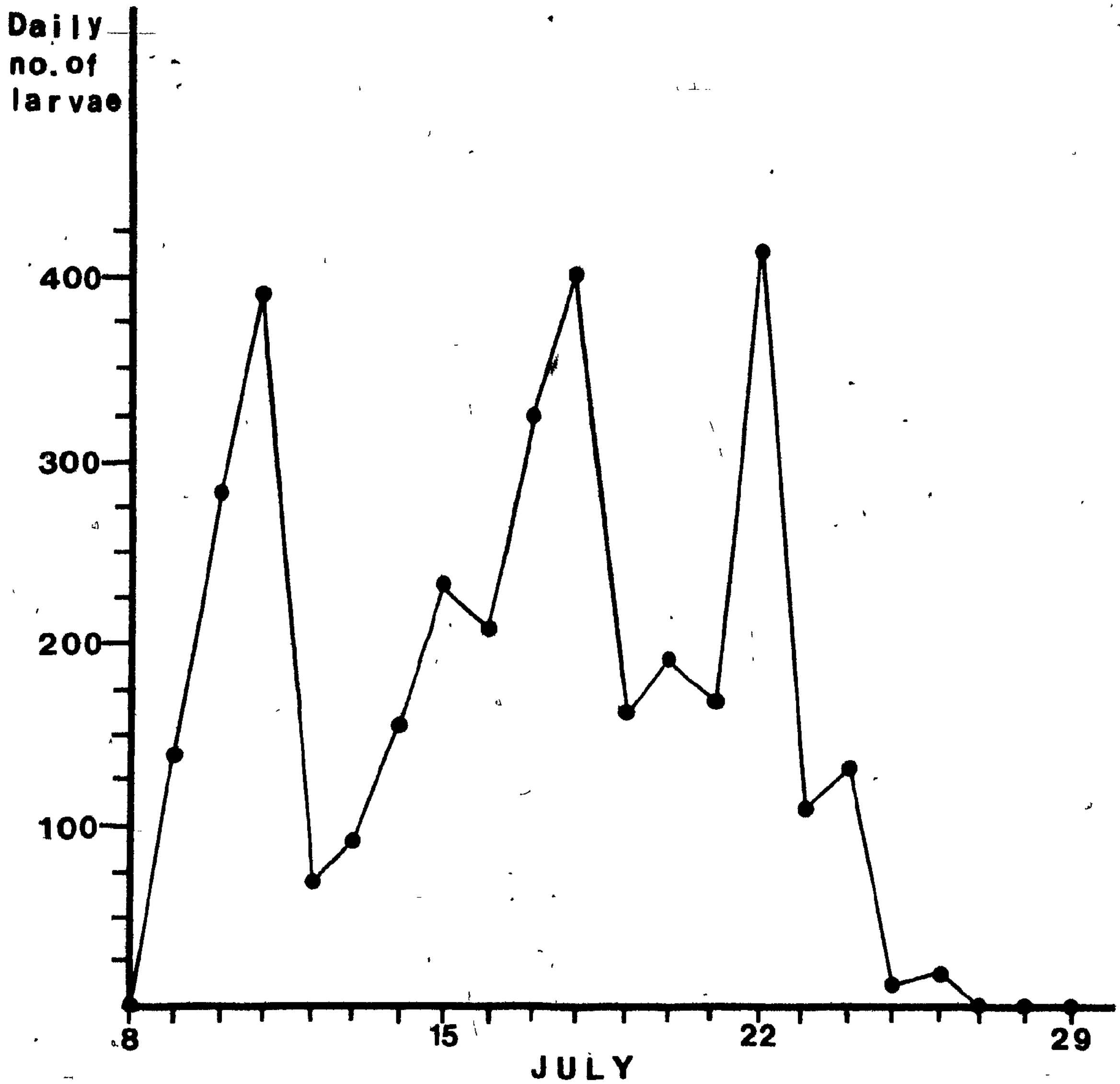


Fig. 16. Daily numbers of Conotrachelus nenuphar 4th instar larvae dropping from 18 750 infested apples held in cages and collected at Frelighsburg, Quebec, 1978.

uity of distribution)[1] it can safely be concluded that more larvae dropped during the night.

7.3.2 Adult emergence rate from the soil

On Figure 17 is shown the daily emergence of C. nenuphar adults of the new generation in the nine emergence cages. The first adult emerged on August 14 and the last ones were recovered on September 18; the total number of adults was 1 117.

To estimate natural mortality during the soil phase, only data from the three control replicates should be considered. Of the 1 050 larvae introduced into these cages, 462 (44%) were recovered as adults. Natural mortality in soil may, however, be slightly lower than 56%, as a few beetles may have escaped detection.

7.3.3 Effects of the fungicides benomyl and fenarimol on the soil phase of plum curculio

Of the 1 050 larvae introduced into the three emergence cages installed in plots treated with the mixture of benomyl and fenarimol, 325 larvae (31,0%) reached the adult stage, while for the 1 050 larvae in the fenarimol plots, 330 (31,4%) were recovered as adults; this compared with a survivorship of 44,0% in the control cages (Table 24).

These 13% and 12,6% differences in survivorship between the two treatment means and the control mean cannot, however, be regarded as significant because of the wide variation among the replicates, especially in the fenarimol plots (Table 24). This suggests that more replicates (possibly

---

[1] χ^2=6,63; α = 0,01 and one degree of freedom.

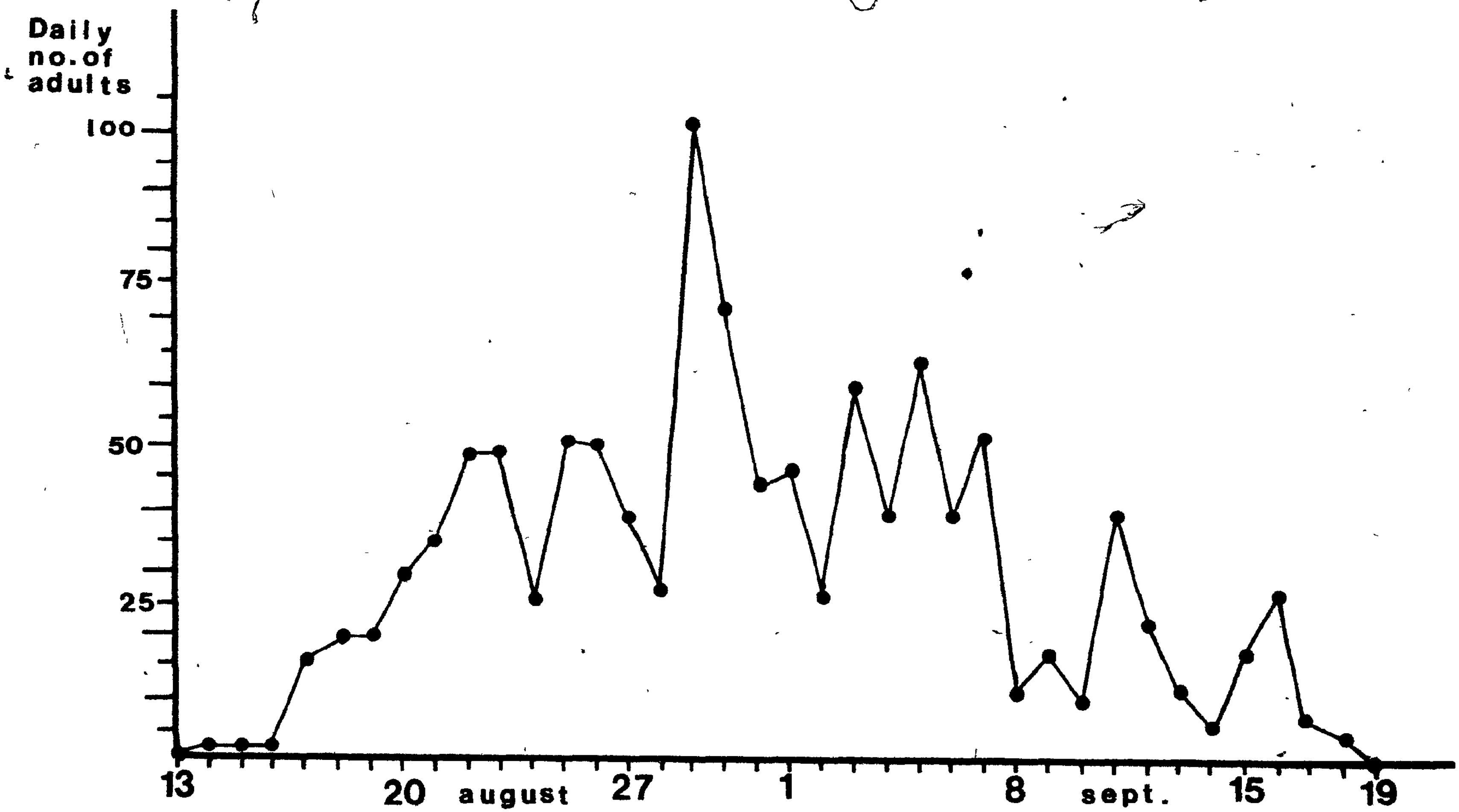


Fig. 17. Daily numbers of Conotrachelus nenuphar adults emerging from the soil in nine emergence cages at Frelighsburg, Quebec, 1978.

Table 24. Estimates of survival of *C. nenuphar* during its summer soil phase when exposed to fungicides present in the soil by dripping under apple trees in the experimental orchard; Frelighsburg, Quebec, 1978.

Treatments *	% survival/replicate			
	I	II	III	Mean ± SE
Benomyl 50WP 0,40 kg/ha and fenarimol 12,5EC 0,30 l/ha	41,1	16,3	35,4	31,0 ±13,0
Fenarimol 12,5EC 0,60 l/ha	57,4	13,7	23,1	31,4 ±23,0
Control	33,7	47,7	50,6	44,0 ±9,0

* Dosage of commercial products

with fewer individuals) would constitute a more appropriate experimental design. However, if similar results were obtained during subsequent comparable growing seasons, some insecticidal effect against plum curculio could be attributed to these fungicides.

7.3.4 Effect of benomyl on plum curculio 4th instar larva in the laboratory

Average mortality after 52 hours exposure to benomyl (0,680 and 1,370 g/l) impregnated filter papers and fungicide-free wet and dry filter papers was 16,1%, 6,7%, 14,9% and 75,9% respectively (Table 25). Clearly there is no statistically significant difference between benomyl treatments and the wet control. Lack of moisture, however, did significantly increase mortality.

Of the 154 larvae that survived exposure to benomyl treatments, 116 (75%) reached the adult stage in the insectary. This result is comparable with the one of Smith and Flessel (1968), who found that 65% of *C. nenuphar* larvae (not exposed to benomyl), put in moist soil and peat moss, reached the adult stage. This suggests that benomyl does not adversely affect this part of the plum curculio life cycle. Effects on fecundity, however, were not examined.

Some parts of this chapter have been published (Le Blanc *et al.* 1979).

Table 25. Estimates of mortality of C. nenuphar 4th instar larva exposed to benomyl for 52 hours

Treatments[1]	% mortality/replicate			Mean
	I	II	III	$\bar{X}$
Benomyl 50WP 0,680 g/l	13,8	20,7	13,8	16,1[a][2]
Benomyl 50WP 1,370 g/l	6,9	0,0	13,8	6,9[a]
Control (water)	10,3	13,8	20,7	14,9[a]
Control (dry)	93,1	72,4	62,1	75,9[b]

[1]Dosage of commercial product

[2]Treatments with no significant difference (p=0,05) between means are followed by the same letter. Duncan multiple range test after an arc sin $\sqrt{\%}$ transformation (Duncan 1955).

8.0 GENERAL CONCLUSIONS AND INDICATIONS FOR FUTURE RESEARCH

While the specific conclusions relating to each of the experiments conducted during the course of this work are presented in the respective chapters, it is relevant now to make some general comments and indicate areas where future research work is warranted.

Plum curculio is clearly a difficult insect to trap. Its poor flying ability and apparent lack of a broad spectrum response to visual, olfactory and stereokinetic (thigmotaxis) stimuli, and reported lack of long range auditory response, do not hold much hope for finding an effective trap.

This is further underlined by the failure of the six published sampling techniques, reported in Chapter 3, to capture adults. This is particularly discouraging because four of these techniques are regarded as general methods. Jarring, on the other hand, persists as the best technique to detect first appearance and relative abundance of plum curculio adults within host trees. It is a tedious and time consuming method, however, and is unlikely to yield estimates of <u>C. nenuphar</u> population density that are accurate enough to be useful for the establishment of economic thresholds. It should be noted, however, that because quality standards for storage and marketing of the fresh produce are so high, such a threshold would be very low. It may even constitute the mere detection of plum curculio within the orchard.

The use of intercepting funnels, however, was found to be more practical than jarring and should be tested further within 50 m of potential overwintering sites in orchards with low population densities of the plum curculio. Results with the funnels also indicated the need for an accurate determination of overwintering site(s) of the plum curculio. This would certainly increase the efficacy of any monitoring techniques by optimizing trap location. Research now needs to be conducted to determine the plum curculios' pathway of spring migration from the overwintering sites to their food plant, and also to determine their primary mode of locomotion at that time, e.g., flying or walking.

As these beetles locate their food and oviposition sites on the host trees by walking along the branches, the boll weevil trap, used as an interception trap (nailed to the branches, Chapter 5), or other interception devices, should be investigated further.

In addition, the search should continue for stimuli that might attract males and females to the host plant early in the spring. Clearly these beetles must be attracted to the trees by some stimuli at this time. Further clues may be provided by the plum curculio habit of nibbling the flower petal and, in some cases, mating in the blossoms. The improved insect olfactometer (Chapter 5), developed during the course of this work could be useful in such a study. A more potent stimulus than ultraviolet light, however, capable of making the majority of the curculios leave the dark test tube and enter either of the apparatus' branches should first be identified.

Until an effective trap, specific to C. nenuphar, is discovered, recording this insect's "effects" on Granny Smith apples could be used as a reasonably reliable monitoring technique. While not as efficient, or easy to work with, as pheromone traps, this technique can be used to forecast plum curculio damage. It has the important advantage of detecting plum curculio presence on host trees prior to fruit set. To be effective, the first calendar spray against C. nenuphar, must be applied at the calyx, or at the latest immediately before fruit set.

The significant rank correlation established between oviposition on these "monitoring" apples and damage, particularly harvest damage, is evidence that plum curculio oviposition scars on the Granny Smith apples can be used to predict future damage; this was further supported by the demonstration that harvest damage was not independent of the number of Granny Smith apples showing plum curculio effects prior to fruit set. These findings suggest that further experiments with the Granny Smith scout-apple technique should be conducted to clarify this relationship, and to permit its practical use for the detection of plum curculio and to predict future damage by this insect.

During the course of this work it became clear that plum curculio damage was concentrated within the experimental orchard in those areas adjacent to potential overwintering sites (i.e., within 50 m of adjacent woods). Thus, it may only be necessary to apply controls for plum curculio to the trees (an equivalent of five to six rows inside the orchard depending on monitoring results) adjacent to potential overwintering sites. This should be tested (perhaps starting with the second calendar spray), as, if successful, it would considerably reduce the cost of plum curculio control.

It is my belief that the plum curculio still warrants more research, especially with respect to its ecology and behaviour. The following comment made by Stern (1973:p. 267) seems particularly appropriate for the plum curculio: "Of course there are pests for which years of trial and error studies are required to develop proper sampling techniques." In the meantime the Granny Smith scout-apple technique seems to be the most reliable monitoring method available.

9.0 BIBLIOGRAPHY

Anonymous. 1809. Curculio. Mass. Soc. for Promoting Agric. Georgick Papers for 1809. Boston, 1809: 15-19.

Armstrong, T. 1958. Life-history and ecology of the plum curculio, Conotrachelus nenuphar (Hbst.) (Coleoptera: Curculionidae), in the Niagara Peninsula, Ontario. Can. Entomol. 90: 8-17.

Beckwith, C. S. 1943. Insects attacking blueberry fruit. N. J. Agric. Exp. Stn. Circ. 472: 4 p.

Behan, V. 1972. M. Sc. thesis. The effects of urea on Acarina and other arthropods in Quebec black spruce (Picea mariana Mill) humus. Department of Entomology, Macdonald College of McGill University, 175 p.

Bethune, C. J. S. 1907. Insects affecting fruit trees. Ont. Dept. Agric. Bull. 158: 47 p.

Binns, E. S. 1970. Aphicidal activity of benomyl. Annu. Rep. Glasshouse Crops Res. Inst. 1969: 113.

Bobb, M. L. 1949. Hibernation of the plum curculio in Virginia. J. Econ. Entomol. 42: 19-22.

Bobb, M. L. 1952. The life history and control of the plum curculio in Virginia. Va. Agric. Exp. Stn. Bull. 453: 30 p.

Boivin, G. Personal communication. Agriculture Canada Research Station, Saint-Jean-sur-Richelieu, Quebec, J3B 6Z8.

Borror, D.J., D.M. DeLong, and C.A. Triplehorn. 1981. An Introduction to the Study of Insects. 5th ed. Saunders College Publishing, Philadelphia, 827 p.

Brittain, W.H., and A.D. Pickett. 1933. Injurious insects of Nova Scotia, Part 1, fruit insects. Nova Scotia Dep. Agric. Entomol. Div. Bull. 12: 123 p.

Brooks, F.E. 1910. Three snout beetles that attack apples. W. Va. Univ. Agric. Exp. Stn. Bull. 126: 105-124.

Butler, H.G. and H.L. Dozier. 1929. Life-history studies of the plum curculio. Trans. Peninsula Hort. Soc. 42: 111-117.

Caesar, L. 1917. Insects attacking fruit trees. Ontario Dep. Agric. Bull. 250: 49 p.

Calkins, C.O. Personal communication. U.S. Dep. Agric. ARS. Gainesville, Florida 32604.

Calkins, C.O., M.D. Huettel, and M. McKoy. 1976. Spatial and temporal distribution of oviposition by plum curculios, *Conotrachelus nenuphar*. Fla. Entomol. 59: 205-209.

Calkins, C.O., A.J. Hill, M.D. Huettel, and E.R. Mitchell. 1977. Effect of diflubenzuron on plum curculio populations in laboratory and field tests. J. Econ. Entomol. 70: 463-466.

Carlysle, T., J.C. Webb, C.O. Calkins, and H.R. Agee. 1975. Morphology of the stridulatory apparatus and sound production in the adult plum curculio. J. Georgia Entomol. Soc. 10: 363-373.

Chandler, S.C. 1927. Second brood of plum curculio (Conotrachelus nenuphar) reared in Illinois. J. Econ. Entomol. 20: 740.

Chandler, S.C. 1940. Control of plum curculio on peach in Illinois. J. Econ. Entomol. 33: 451-453.

Chandler, S.C. 1942. Plum curculio on peach following a total crop failure. J. Econ. Entomol. 35: 106-107.

Chandler, S.C. 1948. Plum curculio control with chlordane and benzene hexachloride. Down Earth 4(1): 14-15.

Chandler, S.C. 1953. Timing plum curculio sprays on apple. J. Econ. Entomol. 46: 506-509.

Chandler, S.C. and W.P. Flint. 1935. Insect enemies of the peach in Illinois. Ill. Nat. Hist. Surv. Circ. 26: 38 p.

Chandler, S.C. and W.P. Flint. 1939. Controlling peach insects in Illinois. Ill. Nat. Hist. Surv. Circ. 33: 40 p.

Chapman, P.J. 1938. The plum curculio as an apple pest. N. Y. Agric. Exp. Stn. Geneva Bull. 684: 75 p.

Chapman, P.J. and O.H. Hammer. 1932. Apple insects in the Hudson Valley and the Lake Champlain fruit districts. N.Y. Agric. Exp. Stn. Geneva Bull. 606: 32 p.

Childers, C.C. and W.R. Enns. 1975. Field evaluation of early season fungicide substitutions on tetranychid mites and the predators Neoseiulus fallacis and Agistemus fleschneri in two Missouri apple orchards. J. Econ. Entomol. 68: 719-724.

Colburn, R. and D. Asquith. 1973. Tolerance of Stethorus punctum adults and larvae to various pesticides. J. Econ. Entomol. 66: 961-962.

Cook. A.J. 1890. The plum curculio. Mich. Agric. Exp. Stn. and State Agric. Coll. Bull. 66: 8 p.

Courtney, O.K. 1931. Trapping for the Japanese beetle (Popilla japonica Newman) during the season 1929 and 1920. J. Econ. Entomol. 24: 219-226.

Cox, J.A. 1951. The plum curculio as a prune pest. Penn. Agric. Exp. Stn. Bull. 539: 30 p.

Crandall, C.S. 1905. The curculio and the apple. Ill. Agric. Exp. Stn. Bull. 98: 467-560.

Croft, B.A. 1978. Potentials for research and implementation of integrated pest management on deciduous tree-fruits. In Smith E.H. and D. Pimentel, editors. Pest Control Strategies. Academic Press, New York, 101-115.

Croft, B.A. and S.C. Hoyt. 1978. Considerations for the use of pyrethroid insecticides for deciduous fruit pest control in the U.S.A. Environ. Entomol. 7: 627-630.

Crosby, C.R., W.D. Mills, and W.E. Blauvelt. 1929. Protecting orchard crops from diseases and insects. Agric. Exp. Stn. Cornell Univ. Bull. 498: 78 p.

Cross, W.H., D.D. Hardee, F. Nichols, H.C. Mitchell, E.B. Mitchell, P.M. Huddleston and J.H. Tumlinson. 1969. Attraction of female boll weevils to traps baited with males or extracts of males. J. Econ. Entomol. 62: 154.

Daniel, W.W. 1978. Applied Nonparametric Statistics. Houghton Mifflin Company, Boston, 503 p.

Detjen, L.R. 1926. Physiological dropping of fruits. Del. Agric. Exp. Stn. Bull. 143: 47 p.

Detjen, L.R. 1938. Physiological dropping of fruits. III, Plum curculio injury to young fruits in relation to physiological drop. Del. Agric. Exp. Stn. Bull. 212: 87 p.

Dietrick, E.J. 1961. An improved backpack motor fan for suction sampling of insect populations. J. Econ. Entomol. 54: 394-395.

Dietrick, E.J., E.I. Schlinger, and R. van den Bosch. 1959. A new method for sampling arthropods using a suction collecting machine and modified Berlese funnel separator. J. Econ. Entomol. 52: 1085-1091.

Dozier, H.L., L.L. Williams, and H.G. Butler. 1932. Life-history and habits of plum curculio in Delaware. Del. Agric. Exp. Stn. Bull. 175: 43 p.

Driggers, B.F. 1935. The plum curculio (Conotrachelus nenuphar Herbst). N.J. Agric. Exp. Stn. (New Brunswick) Circ. 349: 4 p.

Duncan, D.B. 1955. Multiple range and multiple F tests. Biometrics 11: 1-42.

Featherson, N.H. and S.B. Hays. 1971. Diapause in crosses of a laboratory and a wild strain of the plum curculio, Conotrachelus nenuphar. J. Georgia Entomol. Soc. 6: 95-101.

Filinger, G.A. 1940. Combatting fruit pests in Kansas. Kans. Agric. Exp. Stn. Circ. 199: 45 p.

Fitzgerald, T.D., A.D. St. Clair, G.E. Daterman, and R.G. Smith. 1973. Slow release plastic formulation of the cabbage looper pheromone cis-7-dodecenyl acetate: release rate and biological activity. Environ. Entomol. 2: 607-610.

Forbes, S.A. 1906. Spraying apples for the plum curculio. Ill. Agric. Exp. Stn. Bull. 108: 265-286.

Frost, S.W. 1942. Common insect larvae that attack the apple in Pennsylvania. Penn. Agric. Exp. Stn. Bull. 420: 30 p.

Frost, S.W. 1957. The Pennsylvania insect light-trap. J. Econ. Entomol. 50: 287-292.

Frost, S.W. 1958. Insects captured in light traps with and without baffles. Can. Entomol. 90: 566-567.

Fulton, B.B. 1946. Dusting blueberries to control the cranberry fruitworm. J. Econ. Entomol. 39: 306-308.

Garman, P. 1927. The problem of curculio control in Connecticut apple orchards. J. Econ. Entomol. 20: 196-200.

Garman, P. 1934. Control of the plum curculio on fruit trees. Conn. Agric. Exp. Stn. New Haven Circ. 99: 47-53.

Garman, P. and J.F. Townsend. 1950. Control of apple insects. Plum curculio, Conotrachelus nenuphar (Hbst.). Conn. Agric. Exp. Stn. Bull (New Haven) 552: 63-66.

Garman, P. and M.P. Zappe. 1929. Control studies on the plum curculio in Connecticut apple orchards. Conn. Agric. Exp. Stn. Bull (New Haven) 301: 373-437.

Gaydon, D.M. 1972. Ph.D. thesis. Studies of behavior of the plum curculio Conotrachelus nenuphar (Herbst), in the South Carolina piedmont. Clemson University, S.C.: 89 p. (Diss. Abstr. B. Sci. Eng. 34(2)B: 703).

Glass, E.H. and S.E. Lienk. 1971. Apple insect and mite populations developing after discontinuance of insecticides: 10-year record. J. Econ. Entomol. 64: 23-26.

Godbout, F. 1933. Spraying the commercial orchard. Quebec Dep. Agric. Bull. 124: 31 p.

Graham, C. 1938. The plum curculio. Md. Agric. Exp. Stn. Bull. 419: 309-345.

Graham, L.T. 1948. Criteria of effect used in determining codling moth injury. J. Econ. Entomol. 41: 70-75.

Hagley, E.A.C., L.G. Monteith, D.H.C. Herne, and R. Trottier. 1977. Pest population buildup in apple orchards following omission of insecticide and acaricide sprays. Proc. Entomol. Soc. Ont. 108: 7-11.

Hall, F.R. 1974. Bioeconomics of apple pests: cost appraisal of crop injúry data. J. Econ. Entomol. 67: 517-521.

Hardee, D.D. Personal communication. Pest Management Spécialists Inc., Starkville, Mississippi.

Hauschild, K.I. and R.J. Prokopy. 1977. The plum curculio: an introduction and summary of preliminary field observations, 1976. Fruit Notes 42(4): 5-7.

Herbst, J.F.W. 1797. Curculio nenuphar. Natursystem aller bekannten in-und auslandischen Insekten-Käfer, 7: 29-30.

Hill, S.B. 1969. Ph.D. thesis. The ecology of bat guano in Tamana Cave Trinidad, W.I.. University of the West Indies, Trinidad, 310 p.

Hoyt, S.C. and J.D. Gilpatrick. 1976. Pest management on deciduous fruits: multidisciplinary aspects. In Apple, J.L. and R.F. Smith, editors. Integrated Pest Management. Plenum Press, New York, 133-147.

Huard, V-A. 1916. Les Principales espèces d'insectes nuisibles et de maladies végétales. Quebec. Dep. Agric. Bull. 23: 75 p.

Hutson, R. 1933. Insect pests of stone fruits in Michigan. Mich. Agric. Exp. Stn. Sp. Bull. 244: 40 p.

Jacklin, S.W. and C.E. Yonce. 1970. Emergence, longevity, and fecundity of adult plum curculio reared from two sizes of larvae at two temperatures in soil with a range of moisture. J. Econ. Entomol. 63: 673-674.

Jacklin, S.W., E.G. Richardson, and C.E. Yonce. 1970. Substerilizing doses of gamma irradiation to produce population suppression in plum curculio. J.Econ. Entomol. 63: 1053-1057.

Johnson, A.W. and S.B. Hays. 1969. Laboratory mating behavior of the plum curculio. J. Econ. Entomol. 62: 438-440.

Johnson, C.G., T.R.E. Southwood, and H.M. Entwistle. 1955. A method for sampling arthropods and molluscs from herbage by suction. Nature 176: 559.

Kempson, D., M. Lloyd, and R. Ghelardi. 1963. A new extractor for woodland litter. Pedobiologia 3: 1-21.

Klun, J.A. 1968. Isolation of a sex pheromone of the European corn borer. J. Econ. Entomol. 61: 484-487.

Klun, J.A., O.L. Chapman, K.C. Mattes, P.W. Wojtkowski, M. Beroza, and P.E. Sonnet. 1973. Insect sex pheromones: minor amount of opposite geometrical isomer critical to attraction. Science 181: 661-663.

Knight, H.H. 1922. Studies on insects affecting the fruit of the apple with particular reference to the characteristics of the resulting scars. Agric. Exp. Stn. Cornell Univ. Bull. 410: 447-498.

Lafleur, G. and S.B. Hill. Personal communication. Department of Entomology, Macdonald College of McGill University, Quebec, H9X 1C0.

Lathrop, F.H. 1949. Biology of the plum curculio in Maine. J. Econ. Entomol. 42: 12-18.

Lathrop, F.H. 1955. Apple insects in Maine. Main Agric. Exp. Stn. Bull. 540: 88 p.

Le Blanc, J.-P.R., L.J. Coulombe, and S.B. Hill. 1979. Action des fongicides benomyl et fenarimol sur le charançon de la prune, Conotrachelus nenuphar (Hbst.) (Coleoptera: Curculionidae). Phytoprotection 60: 93-98.

Le Blanc, J.-P.R., S.B. Hill, and R.O. Paradis. 1981. Essais de piégeage du charançon de la prune, Conotrachelus nenuphar (Hbst.) (Coleoptera: Curculionidae), dans une pommeraie du sud-ouest du Québec. Ann. Entomol. Soc. Que. 26: 182-190.

Leiby, R.W. and J.B. Gill. 1923. The plum curculio on peaches in North Carolina, its life-history and control. N.C. Agric. Exp. Stn. Bull. March: 23 p.

Leiby, R.W. and J.A. Harris. 1924. The plum curculio on peaches and its control. N. Carol. Ext. Serv. Ext. Circ. 144: 16 p.

LeRoux, E.J. 1961. Variation between samples of fruit, and of fruit damages mainly from insect pests, on apple in Quebec. Can. Entomol. 93: 680-694.

LeRoux, E.J. 1971. Biological control attempts on pome fruit (apple and pear) in North America, 1860-1970. Can. Entomol. 103: 963-974.

LeRoux, E.J. and C. Reimer. 1959. Variation between samples of immature stages, and of mortalities from same factors, of the eye-spotted budmoth, Spilonota ocellana (D. & S.) (Lepidoptera: Olethreutidae), and the pistol casebearer, Coleophora serratella (L.) (Lepideptera: Coleophoridae), on apple in Quebec. Can. Entomol. 91: 428-449.

Levine, E. and F.R. Hall. 1977. Effect of feeding and oviposition by the plum curculio on apple and plum fruit abscission. J. Econ. Entomol. 70: 603-607.

Lippold, P.C., F.L. Gambrell, and L.M. Massey, Jr.. 1968. Effects of ionizing radiation on the European chafer, the plum curculio, and the large milkweed bug. Ann. Entomol. Soc. Am. 61: 151-158.

Mampe, C.D. and H.H. Neunzig. 1966. Function of the stridulating organs of Conotrachelus nenuphar (Coleoptera: Curculionidae). Ann. Entomol. Soc. Am. 59: 614-615.

Mampe, C.D. and H.H. Neunzig. 1967. The biology, parasitism, and population sampling of the plum curculio on blueberry in North Carolina. J. Econ. Entomol. 60: 807-812.

McGovern, T.P., M. Beroza, T.L. Ladd, Jr., J.C. Ingangi, and J.P. Jurimas. 1970. Phenylethyl propionate, a potent new attractant for Japanese beetle. J. Econ. Entomol. 63: 1727-1729.

McIndoo, N.E. 1926. An insect olfactometer. J. Econ. Entomol. 19: 545-571.

Mutchler, A.J. and H.B. Weiss. 1925. Beetles of the genus Conotrachelus known to occur in New Jersey. N.J. Bur. Stat. and Insp. Circ. 87: 22 p.

Oatman, E.R. and E.F. Legner. 1968. Distribution of plum curculio injury in a sour cherry orchard and sampling procedures for determining the extent of injury. J. Econ. Entomol. 61: 436-438.

Owens, E.D., K.I. Hauschild, G.L. Hubbell, and R.J. Prokopy. 1982, (In press). Behavior of plum curculio adults on host trees in nature. Ann. Entomol. Soc. Amer. 75:

Padula, A.L. and E.H. Smith. 1971. Reproductive incompatability between univoltine males and multivoltine females of the plum curculio. Ann. Entomol. Soc. Am. 64: 665-668.

Paradis, R.O. Personal communication. Agriculture Canada Research Station, Saint-Jean-sur-Richelieu, Quebec, J3B 6Z8.

Paradis, R.O. 1955. La lutte contre le charançon de la prune, Conotrachelus nenuphar (Hbst.), parasite du pommier dans le sud-ouest du Québec. 37th Que. Soc. Prot. Plants Rep.: 88-100.

Paradis, R.O. 1956. Observations sur le cycle évolutif du charançon de la prune, Conotrachelus nenuphar (Hbst.) sur la pomme dans le Québec. Ann. Entomol. Soc. Que. 2: 60-70.

Paradis, R.O. 1957. Observations sur les dégâts causés par le charançon de la prune, Conotrachelus nenuphar (Hbst.), sur les pommes dans le sud-ouest du Québec. Can. Entomol. 89: 496-502.

Paradis, R.O. 1968. Considérations sur les arthropodes ravageurs des pommeraies dans le Québec. Proc. 13th Int. Congr. Entomol. 2-9 August 1968; Moscow: Publishing House "Nauka", 1971, 1: p. 540.

Paradis, R.O. 1976. Essais de traitements insecticides contre le charançon de la prune, Conotrachelus nenuphar (Herbst), dans les pommeraies du sud-ouest du Québec. Phytoprotection 57: 15-22.

Paradis, R.O. 1979. Comment réduire l'emploi des pesticides en vergers de pommiers. Phytoprotection 60: 69-78.

Paradis, R.O., I. Rivard, and M. Mailloux. 1977. Les ravageurs des cultures fruitières dans le sud-ouest du Québec en 1976. Ann. Entomol. Soc. Que. 22: 123-125.

Paradis, R.O., B. Parent, I. Rivard, and M. Mailloux. 1974. Les ravageurs des cultures fruitières dans le sud-ouest du Québec in 1973. Ann. Entomol. Soc. Que. 19: 113-114.

Payne, J.A., J.L. Blythe, H. Lowman, and C.E. Yonce. 1973. Response of laboratory-reared adult plum curculios to ultraviolet radiation. Ann. Entomol. Soc. Am. 66: 1007-1009.

Petch, C.E. 1927. The plum curculio (Conotrachelus nenuphar Herbst.) and its Control in Quebec. Can. Dep. Agric. Circ. 27: 4 p.

Petit, R.H. 1904. Insects injurious to fruits in Michigan. Mich. Agric. Exp. Stn. Sp. Bull. 24: 71 p.

Poe, S.L. and S. McFadden. 1972. Effect of benomyl and surfactants on populations of the two spotted spider mite on dwarf marigold. J. Georgia Entomol. Soc. 7: 167-170.

Prokopy, R.J. Personal communication. Department of Entomology, University of Massachusetts, Amherst, Ma. 01003.

Prokopy, R.J. 1968a. Sticky spheres for estimating apple maggot adult abundance. J. Econ. Entomol. 61: 1082-1085.

Prokopy, R.J. 1968b. Visual responses of apple maggot flies, Rhagoletis pomonella (Diptera: Tephritidae): orchard studies. Entomol. Exp. Appl. 11: 403-422.

Provancher, L. 1877. Petite Faune Entomologique du Canada. Vol. I, Les Coléoptères. C. Darveau, Québec; (529-530).

Quaintance, A.L. 1905. The principal insect enemies of the peach. U.S. Dep. Agric. Yearb. Agric. 1905: 325-348.

Quaintance, A.L. and E.L. Jenne. 1912. The plum curculio. U.S. Dep. Agric. Bur. Entomol. Bull. 103: 250 p.

Quaintance, A.L. and E.W. Scott. 1910. The one-way method in the control of the codling moth and the plum curculio. U.S. Dep. Agric. Bur. Entomol. Bull. 80: 33 p.

Quaintance, A.L. and R.I. Smith. 1902. Egg-laying record of the plum curculio. U.S. Dep. Agric. Bur. Entomol. Bull. 37: 105-107.

Ransom, W.B. 1870. Great discovery, curculio extermination possible! In Riley, C.V. and G. Vasey, editors. Amer. Entomol. Bot. 2: 225-226.

Reed, E.B. 1870. Insects affecting the plum. Entomol. Soc. Ont. Annu. Rep. 1: 53-61.

Riley, C.V. 1870. The plum curculio (Conotrachelus nenuphar, Herbst.). In Riley, C.V. and G. Vasey, editors. Amer. Entomol. Bot. 2: 130-137.

Riley, C.V. 1871. The common plum curculio C. nenuphar. Annu. Rep. Nox. Ins. Missouri 3: 11-29.

Rings, R.W. 1954. Comparative effectiveness of five radio-isotopes as tracers in studying dispersal of Conotrachelus nenuphar (Hbst.). Ohio J. Sci. 54: 231-236.

Rings, R.W. and G.W. Layne, Jr.. 1953. Radioisotopes as tracers in plum curculio behavior studies. J. Econ. Entomol. 46: 473-477.

Rivard, I., G. Mailloux, R.O. Paradis, and G. Boivin. 1979. Apparitions des adultes de l'anthonome du fraisier, Anthonomus signatus Say, en fraisières et framboisières du Québec. Phytoprotection 60: 41-46.

Roach, S.H. and J.A. Buxton. 1965. Apholate and tepa as chemo-sterilants of the plum curculio. J. Econ. Entomol. 58: 802-803.

Robinson, H.S. and P.J.M. Robinson. 1950. Some notes on the observed behaviour of Lepidoptera in flight in the vicinity of light-sources together with a description of a light-trap designed to take entomological samples. Entomol. Gaz. 1: 3-15.

Roelofs, W.L. and H. Arn. 1968. Sex attractant of the red-banded leafroller moth. Nature 219: 513.

Roelofs, W.L. and J.P. Tette. 1970. Sex pheromone of the oblique-banded leafroller moth. Nature 226: 1172.

Rouselle, G. Personal communication. Agriculture Canada Research Station, Saint-Jean-sur-Richelieu, Quebec, J3B 6Z8.

Sanders, P.D. 1928. The plum curculio. Md. Agric. Exp. Stn. Bull. 298: 181-184.

Sarai, D.S. 1969. Seasonal history of the plum curculio in the Missouri Ozarks. J. Econ. Entomol. 62: 1222-1224.

Saunders, W. 1870. Extract from a report on the plum curculio (*Conotrachelus nenuphar*). Can. Entomol. 2: 137-139.

Schoene, W.J. 1936. Partial second brood of plum curculio in Virginia. J. Econ. Entomol. 29: 571-573.

Schoof, H.F. 1942. The genus *Conotrachelus* Dejean (Coleoptera, Curculionidae) in the north central United States. Ill. Biol. Monogr. 19(3): 170 p.

Slingerland, M.V. and C.R. Crosby. 1914. Manual of Fruit Insects. The MacMillan Company, New York; 503 p. (243-251).

Smith, C.F. 1948. Plum curculio control in North Carolina. J. Econ. Entomol. 41: 220-227.

Smith, E.H. 1957a. A method of rearing the plum curculio under laboratory conditions including some biological observations. J. Econ. Entomol. 50: 187-190.

Smith, E.H. 1957b. The plum curculio. Traditional pest becomes a "Guinea Pig". Farm Res. 23(3): 2-3.

Smith, E.H. and J.K. Flessel. 1968. Hibernation of the plum curculio and its spring migration to host trees. J. Econ. Entomol. 61: 193-203.

Smith, E.H. and E.H. Salkeld. 1964. Ovary development and oviposition rates in the plum curculio, Conotrachelus nenuphar (Coleoptera: Curculionidae). Ann. Entomol. Soc. Am. 57: 781-787.

Smith, J.B. 1911. Insects injurious to the peach trees in New Jersey. N.J. Agric. Exp. Stn. Bull. 235: 43 p.

Snapp, O.I. 1923. Recent developments in plum curculio investigations in Georgia. J. Econ. Entomol. 16: 275-283.

Snapp, O.I. 1930. Life history and habits of the plum curculio in the Georgia peach belt. U.S. Dep. Agric. Tech. Bull. 188: 91 p.

Snapp, O.I. 1940. Further studies on the plum curculio in the Georgia peach belt. J. Econ. Entomol. 33: 453-456.

Snapp, O.I. 1941. Value of the petal-fall application of lead arsenate in controlling the plum curculio on peach in the South. J. Econ. Entomol. 34: 418-419.

Snapp, O.I. and C.H. Alden. 1924. Dusting and spraying peach trees after harvest for control of the plum curculio. U.S. Dep. Agric. Bull. 1205: 19 p.

Snapp, O.I. and H.S. Swingle. 1929a. Preliminary report on attrahents for peach insects. J. Econ. Entomol. 22: 98-101.

Snapp, O.I. and H.S. Swingle. 1929b. Further results with the McIndoo insect olfactometer. J. Econ. Entomol. 22: 984.

Sokal, R.R. and F.J. Rohlf. 1969. Biometry. The Principles and Practices of Statistics in Biological Research. W.H. Freeman and Company, San Francisco, 776 p.

Sokal, R.R. and F.J. Rohlf. 1981. Biometry. The Principles and Practices of Statistics in Biological Research. 2nd ed. W.H. Freeman and Company, San Francisco, 859 p.

Stearns, L.A. 1931. The broods of the plum curculio, Conotrachelus nenuphar Herbst, in Delaware. J. Econ. Entomol. 24: 62-66.

Stearns, L.A.; L.L. Williams, and W.R. Haden. 1935. Control of the plum curculio in Delaware. Del. Agric. Exp. Stn. Bull. 193: 28 p.

Steiner, H. 1965. Eine einfache Methode die Wirkung eines Pflanzenschutzmittels auf die Fauna von Obstbäuman festzustellen. Entomophaga 10: 231-243.

Steiner, H.M. and H.N. Worthley. 1941. The plum curculio problem on peach in Pennsylvania. J. Econ. Entomol. 34: 249-255.

Stern, V.M. 1973. Economic Thresholds. Annu. Rev. Entomol. 18: 259-280.

Stevenson, J.O. and E.H. Smith. 1961. Fecundity and fertility of two strains of the plum curculio, reciprocal crosses and the F_1 generations. J. Econ. Entomol. 54: 283-284.

Stringer, A. and M.A. Wright. 1976. The toxicity of benomyl and related 2-substituted benzimidazoles to the earthworm Lumbricus terrestris. Pestic. Sci. 7: 459-464.

Swaine, J.M. 1909. Insectes nuisibles signalés dans la région de Montréal en 1908. 1st Que. Soc. Prot. Plants Rep.: 18-25; 49-50.

Taylor, E.P. 1909. Spraying apples for curculio and codling moth. Missouri Fruit Exp. Stn. Bull. 21: 69 p.

Thompson, J.R., Jr. 1932. Sex differentiation of adults of Conotrachelus nenuphar. J. Econ. Entomol. 25: 807-810.

Tomlin, A.D. 1977. Toxicity of soil applications of the fungicide benomyl and two analogues, to three species of Collembola. Can. Entomol. 109: 1619-1620.

Tumlinson, J.H., D.D. Hardee, R.C. Gueldner, A.C. Thompson, P.A. Hedin, and J.P. Minyard. 1969. Sex pheromones produced by male boll weevils: isolations, identification, and synthesis. Science 166: 1010-1012.

Walsh, B.D. 1867. The common curculio and its allies. Practical Entomol. 2(7): 75-81.

Walsh, B.D. and C.V. Riley. 1868a. The curculio and its habits. Amer. Entomol. 1: 11-14.

Walsh, B.D. and C.V. Riley. 1868b. Dr. Hull's curculio catcher, Amer. Entomol. 1: 220-221.

Webb, J.C., C.O. Calkins, T. Carlysle, and J. Benner. 1980. Analysis of stress sounds produced by the plum curculio, Conotrachelus nenuphar (Herbst) (Coleoptera: Curculionidae). J. Georgia Entomol. Soc. 15: 419-427.

Whitcomb, W.D. 1929. The plum curculio in apples in Massachusetts. Mass. Agric. Exp. Stn. Bull. 249: 26-52.

Whitcomb, W.D. 1932. The relation of temperature to the activity and control of the plum curculio in apples. Mass. Exp. Stn. Bull. 285: 16 p.

Whitcomb, W.D. 1933. Relation of temperature to the development of the plum curculio in apples. J. Econ. Entomol. 26: 415-419.

Wigglesworth, V.B. 1972. The Principles of Insect Physiology. 7th ed. Chapman and Hall, London, 827 p.

Williams, L.L. and H.L. Dozier. 1929. Life-history studies of the plum curculio in relation to fruit infestation in 1929. Trans. Peninsula Hort. Soc. 42: 39-42.

Wylie, W.D. 1951. Technique in jarring for plum curculio. J. Econ. Entomol. 44: 818.

Wylie, W.D. 1954. The plum curculio on peaches in Arkansas. Arkansas Agric. Exp. Stn. Bull. 542: 46 p.

Wylie, W.D. 1966. Plum curculio, non fruit hosts and survival (Coleoptera: Curculionidae). J. Kans. Entomol. Soc. 39: 218-222.