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Predicting and Monitoring Spring Emergence of the Plum Curculio, Conotrachelus nenuphar (Herbst), (Coleoptera: Curculionidae) Using Tedders Weevil Traps, Flight Barrier Traps and Environmental Variables

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James W. Johnson
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PREDICTING AND MONITORING SPRING EMERGENCE OF THE PLUM CURCULIO, *CONOTRACHELUS NENUPHAR* (HERBST), (COLEOPTERA: CURCULIONIDAE) USING TEDDERS WEEVIL TRAPS, FLIGHT BARRIER TRAPS AND ENVIRONMENTAL VARIABLES

By

Chandra Lee Maleckas

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ABSTRACT

PREDICTING AND MONITORING SPRING EMERGENCE OF THE PLUM CURCULIO, *CONOTRACHELUS NENUPHAR* (HERBST), (COLEOPTERA: CURCULIONIDAE) USING TEDDERS WEEVIL TRAPS, FLIGHT BARRIER TRAPS AND ENVIRONMENTAL VARIABLES

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Factors affecting the onset of spring activity of the plum curculio in fruit orchards were investigated. A flight barrier with pitfall traps and a Tedders weevil trap were used to determine movement in fruit orchards. Spring trap capture indicated that plum curculio fly to traps, but crawling behavior was inconclusive. Tedders weevil traps were baited with nine fruit volatiles to test for their attractiveness to plum curculio. Compared to the unbaited traps, benzaldehyde showed significance in 1995. Using Tedders traps, a mark and recapture study found that probability of capture of plum curculio was, on average, 16% at night and 7% during the day. Traps placed closer to the release sight caught more plum curculio. Cumulative plum curculio captured were transformed into probits and regressed against sixteen transformed weather variables to develop an estimate of first plum curculio capture. Values for soil temperature, daylength, accumulated DD_{50} and daily rainfall predicted spring Tedders trap catch.

DEDICATION

To My Loving and Supportive Parents,

Aldon and Linda Maleckas

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CHAPTER 1

Introduction

Plum curculio, *Conotrachelus nenuphar* (Herbst), has been a pest problem for fruit growers since the time of the early settlers. They especially disliked the plum curculio because it destroyed choice varieties of plums and other stone fruits (Quaintance & Jenne 1912). Plum curculio damage was first noted in Philadelphia in 1736 and was thought to have spread from Pennsylvania to the western regions of the United States (Quaintance & Jenne 1912). Many unique methods have been used for plum curculio control from 1736 until the present. With the discovery of synthetic pesticides, the problem of the plum curculio was temporarily lessened but continues to be a major pest in tree fruits.

The plum curculio is classified as the second most important pest of deciduous tree fruit in eastern North America, superseded only by the codling moth, *Cydia pomonella* (L.) (Chapman 1938, Quaintance 1922). Snapp (1941) believed that *C. nenuphar* was the most serious pest of peach fruit in the eastern part of the United States. Scott & Quaintance (1911) stated that the damage done by plum curculio to stone fruit was comparable to the destruction of fruit by bacterial and fungus diseases. Oatman (1966) believed that plum curculio is the most important pest of sour cherry. This weevil injured 23% of a sour cherry crop in 1961 and 1962 (Oatman 1966). Detectable levels of plum curculio larvae in sour cherry make this fruit unsalable to cherry processors (USDA 1941). Our current political environment suggests that many insecticides used for chemical control of plum curculio will be lost. There are no adequate alternatives for control of plum curculio, therefore, it is critical to develop alternative management strategies for this serious pest.

Since researchers have been unable to develop a suitable method of monitoring the plum curculio, there is no way to determine precisely when overwintering individuals emerge in spring. The scant information existing on plum curculio movement into orchards from overwintering sites is conflicting. Currently, plum curculio control consists of a spray at petal fall, and a second spray at first cover (approximately 10-14 days after petal fall) whether there is damage or not (Jones et al. 1995). The emergence of the plum curculio has been known to be as late as second cover (10-14 days after first cover) in apple (John Wise, personal communication). The current method of spraying may result in inaccurately timed and, therefore, ineffective applications. The ability to monitor the plum curculio accurately and predict its movement would allow better timing of pesticide applications.

There is also a lack of information about potential chemical cues used by the plum curculio for host location. Due to their wide host range, an obvious attractant is difficult to determine. Studies have shown that plum curculio may be attracted to fruit volatiles (Butkewich & Prokopy 1993, Snapp 1928). It has been widely accepted that some environmental variables, such as wind, moisture and temperature have an influence on plum curculio's movement into the orchard and subsequent activity. However, there are conflicting opinions concerning which variables are significant. With an effective monitoring method, the time and type of movement into the orchard can be observed.

The overall objective of this research was to develop improved monitoring methods for the plum curculio. Two different trap designs were evaluated for capturing adult plum curculio. Volatile baits extracted from host plants were placed on traps to determine if they provide additional attraction to the plum curculio. Adult curculio were marked, released and recaptured to determine short-distance movement behaviors. Finally, weather variables were regressed against plum curculio trap catch to determine their ability to predict weevil emergence. Information gained in this study will aid in the overall attempt to understand the life cycle and habits of the plum curculio.

CHAPTER 2

Literature Review

Biology. The adult plum curculio is approximately 0.5 cm long with two elevated lines on each side of the middle of its elytron. The plum curculio is black, brown and white with the darker shades predominant (Brooks 1910). On each elytron there are two large black protuberances that roughen its appearance. The plum curculio's cryptic coloring and appearance have been likened to tree bark and dry buds (Brooks 1910). The beak is bent back under the body and is approximately equal to the length of the head and prothorax. The legs are brown, speckled with white, and the femur of the hind leg is thickened (Cook 1890).

The plum curculio, *Conotrachelus nenuphar* (Herbst), is a native North American insect. This annual threat to all commercial pome and stone fruits is widely distributed east of the Rocky Mountains and is especially abundant in the southern states. Plum curculio is unknown west of the Rocky Mountains (Snapp 1928). Native hosts of this insect are downy juneberry, common juneberry, thicket shadbush, shadbush, black chokeberry, hawthorn, allegheny plum, wild plum, beach plum, pin cherry, sand cherry, black cherry and choke cherry. The exotic fruit hosts include quince, apple, crabapple, sweet cherry, sour cherry, European plum, peach, Japanese plum, pear and European mountain ash (Maier 1990). Armstrong (1958) found apricot, nectarine, grape, gooseberry, blueberry, strawberry, currant, hawthorn and wild persimmon to be good hosts of the plum curculio. Quaintance & Jenne (1912) also found huckleberry, black knot galls, plum pockets and leaf curl galls to be suitable hosts.

Diapause and Overwintering. The adult plum curculio reportedly overwinters under leaves, grass, bark, sticks and rubbish in woodlands adjacent to orchards or along terrace rows and fences (Snapp 1930, Snapp 1928, Scott & Quaintance 1911, Brooks 1910). Overwintering in the plum curculio is divided between a diapause and a postdiapause phase. The adult weevil ceases diapause before the end of winter when low temperatures suppress activity in the field until April or early May and they enter the postdiapause stage. Undefined cues trigger postdiapause development and movement of the plum curculio. After the curculio comes out of its overwintering site during the postdiapause phase, it is crucial that the insects soon have food. Plum curculio died if conditions were not conducive for feeding when leaving their overwintering sites. McGiffen & Meyer (1986) documented the importance of what stage the trees were in when curculio moved into the orchard. The plum curculio is usually in the orchard in large numbers before and during bloom when it feeds on blooms, calyxes and the unfolding leaves (Brooks 1910). Following movement into the orchard, postdiapause ends after feeding (McGiffen & Meyer 1986). McGiffen & Meyer (1986) found that the respiration rate of plum curculio fed green apples increased dramatically, ending the postdiapause phase.

Mating Behavior. Plum curculio mate as early as 6 days old in the laboratory. Males are reproductively mature at this age but females do not become fertile until they are 8 days old (Johnson & Hays 1969). Males have been observed to mate with up to 16 different females within a month of emergence, the average being 10.4. Virgin males mated with approximately 4 females per day; nonvirgin males mated with 1-2 females per day. Throughout their lifespan, females mating 2-3 times produced more offspring than females mating once. All mating produced viable offspring if the female was over 8 days old (Johnson & Hays 1969).

Oviposition. Once plum curculio are in the trees they walk to oviposition sites on the fruit (LeBlanc et al. 1984). The eggs of the plum curculio are deposited within crescents cut by the female's mouthparts (Snapp 1928). The female then turns to oviposit in the crescent shaped scar. Turning again, the plum curculio pushes the egg to the base of the cavity, sometimes packing it with fruit pulp. Larvae are sometimes crushed and killed by the hardening grooves of the pit in stone fruits or the rapid tissue growth in pome fruits (Snapp 1930). Female plum curculio make more punctures than they lay eggs and may oviposit many times in the same fruit.

The female curculio is ready to oviposit as the calyx splits (about 90% petal fall) from the fruit (Snapp 1928). The egg of the plum curculio is elliptical in shape and has a smooth shiny surface. When the egg is "first laid it is pearly white but changes into a dingy, yellowish color" (Scott & Quaintance 1911). The female curculio can lay, on average, 145 eggs (Quaintance & Jenne 1912) within the first eight weeks after emergence when the majority of eggs are laid. Snapp (1930) indicated that there was no cessation of oviposition during pit hardening in stone fruits as originally thought. In fact, in apple there is no cessation of oviposition from initiation until the next generation emerged. Summer generation adults make feeding punctures on apple but do not oviposit.

Depending on weather, the incubation period of the egg ranges from one to two weeks; Howitt (1993) reported 10 days. Fruit damaged by oviposition usually falls to the ground during June drop where the larvae continue to feed before entering the ground to pupate. In peach, plum curculio eggs hatch in 2-12 days and the larvae bore towards the center or pit. Most peaches punctured by the plum curculio in the early season drop within a few weeks of shuck split. Once on the ground, larvae feed for two weeks after which they exit fruit to pupate in the soil (Snapp 1941).

The plum curculio have four instars, spanning approximately 16 days in the interior of the fruit. Upon leaving the fruit and entering the soil, the curculio remains in a prepupal stage for approximately 12 days, followed by a pupal stage of approximately 11 days and finally as an adult for about 7 days prior to emergence from the soil (Amis & Snow 1985). Pupation takes place in a soil cell about 0.5 cm under the surface (Snapp 1941). The full-grown larva is about 1 cm long and is a yellowish white color with a brown head (Snapp 1928). Upon emergence, adult beetles are a yellowish brown color that later darkens to dark brown and gray (Snapp 1930). The total life span of the plum curculio is about 12 - 14 months (Scott & Quaintance 1911).

Damage. Fruit injury results from adult feeding, oviposition and subsequent larval feeding (Scott & Quaintance 1911). Plum curculio can damage 1% of fruit in treated orchards and 40% or more in untreated orchards (Lafleur et al. 1987). The most susceptible area of the orchard is along the woodlots or fence rows (Brooks 1910, Oatman & Legner 1968). LeBlanc et al. (1984) showed that damage ranged from 17 - 25% along edge rows but dropped to 7% in central areas of apple orchards. Within the apple orchard, they also showed that damage was only in the upper half of the tree. In this study, damage was seen throughout the fruit trees for both years.

The adult female insect makes a crescent shaped wound in the fruit in which oviposition occurs; feeding damage also penetrates the skin of the fruit. Damaged fruit that does not drop is usually small and badly deformed with a condition called cat-facing (Porter et al. 1928). Besides being unsalable, this fruit continues to drain resources from trees. In peach, plum curculio feeding and oviposition wounds allow the brown rot pathogen to enter the fruit (Scott & Quaintance 1911).

Development of Immatures, Pupation. Weather conditions greatly influence developmental time of plum curculio. Whitcomb (1933) found that as temperature increased above a lower threshold of 13°C, the development rate of plum curculio immatures increased. Whitcomb (1932) discovered that the optimum temperature for development of the plum curculio was 24°C and that immature stages of plum curculio did not develop below 13°C.

Moisture may also affect the rate of success of pupation in the plum curculio. Snapp (1940) suggested that moist sandy soil in the absence of light provided the best environment for pupation. Quaintance & Jenne (1912) indicated that "adults do not emerge from dry soil and emergence is greatly reduced if moist soil is allowed to dry out." Snapp (1930) found that dry hard soil may kill plum curculio or delay adult emergence from soil. Soil moisture was more important for small larvae which are more prone to mortality during pupation (Jacklin & Yonce 1970).

Movement from Overwintering Sites to Orchards. To develop an effective monitoring or control program, it is necessary to determine how plum curculio move from overwintering sites to orchards. Many researchers believe that the plum curculio flies as opposed to walks into orchards upon emerging from overwintering sites (Quaintance and Jenne 1912, Lafleur et al. 1987). However, LeBlanc (1982) postulated that plum curculio are poor flyers. These discrepancies in the literature may be explained by differences in time of year and location (Racette et al. 1991). Choiunard et al. (1992) developed a spray program that involved spraying border rows to kill the plum curculio. In order for this method to be effective, the plum curculio had to be on the ground in the border rows, if the insects flew, the sprays would be ineffective.

Environmental Effects on Behavior. Beetles may move into the trees in response to a complex of factors including foliage and fruit development, increased humidity and reduced air movement (Doraiswamy 1982, Lafleur et al. 1987). Plum curculio's behavior varies with the season (Racette et al. 1991). Activity level and numbers of insects in the orchard rise throughout bloom until about a month after fruit set. At petal fall, plum curculio were found in the upper levels of the tree and remained relatively inactive during the day (Chouinard et al. 1991). At fruit set, plum curculio were active in late afternoon and early evening. After fruit set, the activity of the curculio decreases because the amount of movement needed to reach fruit decreases. Plum curculio seems to be active primarily during the night but observations indicated there was activity during both day and night (Racette et al. 1991). In orchards, when nighttime temperatures were low, plum curculio were relatively inactive (Chouinard et al. 1991). Hence, the amount of damage to fruit may be directly related to night temperatures.

The combination of wind, moisture and temperature may influence behavior more than any one factor (Racette et al. 1991). As foliage develops, air movement in apple trees decreases and humidity increases (Doraiswamy 1982, Lafleur et al. 1987). As air movement in the trees decreases, plum curculio moves to the upper canopy. The activity and movement of this insect may be limited by its need for humidity. Plum curculio tries to avoid dry and windy conditions (Garman & Zappe 1929). Environmental factors, such as vapor pressure deficit may affect plum curculio's flight behavior. When temperature is greater than the flight threshold, high vapor pressure deficits (warm days with low humidity) may inhibit movement (McGiffen & Meyer 1986). They found curculio flight activity to be low at extreme vapor pressure deficits and high at intermediate values. Increased temperature had a positive effect on rate of movement within trees. Temperature also has been observed to exert a strong influence on the development and activity of plum curculio and was an important factor in timing the application of control measures (Whitcomb 1933). Early authors suggested that spring dispersal in plum curculio occurred once the daily mean temperature reached 13°C (Quaintance & Jenne 1912, Snapp 1930). Lathrop (1949) found that spring movement in plum curculio is positively correlated with temperature and possibly relative humidity or rainfall. Smith & Flessel (1968) felt that water loss by plum curculio may inhibit movement. Howitt (1993) believed that there were three ways of predicting emergence that gave approximately the same results: mean temperature between 13°C and 16°C for three to four days, mean temperature above 16°C for several (three) days, and maximum temperature of 24°C for two consecutive days.

Another factor affecting emergence could be daylength. In the northern range of plum curculio, there is one generation per year. South of Virginia there are usually two generations per year, and diapause is triggered by short daylength during the adult stage

(Gaydon 1972). Chouinard et al. (1992) believed that daylength is more important in influencing the emergence of the plum curculio than temperature. Combining daylength with one or more variables could be a key to predicting emergence.

History of Control. Historically, many materials and methods have been used to kill the adult plum curculio. Quaintance and Jenne (1912) outlined a monumental list of the methods used by the early settlers. They include the following: seaweed under trees; thorough whitewashing of trees; sulfur and powder fired from a gun into treetops for several successive mornings; sulfur, lard and Scotch snuff mixed and rubbed on the trunk and larger branches; drenching the tree with putrid soapsuds, followed by dusting with lime; hanging putrid flesh, such as dead mice, in trees to be used by the beetles for oviposition; branches of tansy hung in trees; and burning woolen rags saturated with brimstone under trees. A standardization of methods occurred with the introduction of Paris Green, and London Purple. In one account, London Purple and Paris Green were sprayed on the orchards as many as five times every ten days with no real effect. It killed the insects but not before damage occurred. In peach London Purple, at the rate of one pound to two hundred gallons of Bordeaux mixture, defoliated the trees and killed the twigs (Cook 1890). Lime sprays, Paris Green, white arsenic and arsenate of lime (in water) were the next compounds tried for control. Quaintance & Jenne (1912) observed that none of these methods really worked but thought that they might be repellent to the plum curculio. Garman (1934) tested nicotine, pyrethrum, rotenone and lead arsenate. He found none to be very effective, but of the four, lead arsenate was the most effective. Garman (1934) also tested calcium arsenate and fluorine compounds (barium fluorosilicate and synthetic cryolite), but they did not work as well as lead arsenate. He proposed a spray formula using 1.4 kg of lead arsenate, fish or linseed oil and 377 L of water. Garman (1934) suggested adding zinc sulfate to the spray mix to decrease the risk of damaging the trees. He developed a spray regime for apple: "Spray 3 times beginning at calyx (petal fall) and make applications once a week or once in 10 days, if weather is warm spray every 7 days." A special plum curculio spray was developed with 4.5 kg lime, 1.8 kg lead arsenate and 0.9 L fish or linseed oil to 377 L of water (Garman 1934). Several other authors also developed similar spray programs to control the plum curculio using lead arsenate. Brooks (1910) suggested spraying with 1.4 kg arsenate of lead to 189 L of water. Snapp (1941) sprayed with lead arsenate at a rate of 0.9 kg lead arsenate and 3.6 kg hydrated lime when 75% of the petals had fallen. This spray was repeated in two weeks. Historically, there were no definitive ways of dealing with the plum curculio. As demonstrated by the variety of spray formulas above, researchers never found a single effective method for controlling the plum curculio.

Traditional Control. Traditional control of the plum curculio is now accomplished by spraying orchards three or more times a year with insecticides (Prokopy 1985). The first spray is at petal fall; the second, if needed, is 10-14 days later during oviposition (Howitt 1993. Chouinard et al. (1992) suggested that only the border rows of orchards rather than whole orchards need to be sprayed to control this insect. The pesticides currently used in apple for plum curculio control are Guthion, Imidan, Penncap-M, Pounce, Ambush and Asana. All are rated excellent by Jones et al. (1995). However, all of these pesticides are highly toxic to pollinators, creating a problem when spraying at petal fall. Part of the philosophy of Integrated Pest Management is to spray only when needed. This philosophy reduces pesticide inputs and damage to beneficials. The ability to monitor plum curculio movement from overwintering site and subsequent damage will enable growers to spray when it will have the greatest effect. "Plum curculio is considered a difficult pest to control and requires a full dose of an effective pesticide" (Howitt 1993). This is why definitive ways to predict and monitor this weevil's activity are needed.

Cultural Controls. Several cultural controls have been used to manage the plum curculio: removing trash and debris from the orchard and vicinity, cultivation of the ground to physically damage pupae and removing and destroying fallen apples (Scott & Quaintance 1911, Porter et al. 1928, Snapp 1941). Burning the adjacent wood's debris and jarring the trees to dislodge beetles have also been reported as control methods (Snapp 1941, Quaintance & Siegler 1922). Plums are thought to be the most attractive fruit to the plum curculio and Cook (1890) suggested planting plums as a trap crop near other fruit such as peaches and apples. The Ransom chip trap has also been used where pieces of bark or chips were laid around the base of trees and beetles resting underneath were collected (Cook 1890). Cook (1890) also suggested keeping a large flock of poultry, hogs or sheep among the trees or planting the orchard where there is much noise or disturbance. Snapp (1930) suggested killing the larvae by collecting fallen fruit drops and either destroying or exposing them to the sun. These methods are effective on a small scale but would require considerable time, cost and effort for a large fruit grower.

Natural Enemies. There has been little research done on biological control of the plum curculio. Quaintance and Jenne (1912) listed several hymenopteran parasites of plum curculio eggs and larvae. *Anaphoidea conotracheli* Girault, an egg parasite, had rates of parasitism on plum curculio varying from 12-85% depending upon the location. They also listed two larval parasites, *Triaspis curculionis* Fitch and *Triaspis curculionis* var.

rufus Riley. *Triaspis curculionis* parasitized larvae before they entered the soil or soon after at a parasitism rate of 3%. *Triaspis curculionis* var. *rufus* parasitized late season larvae in the soil at a 7% parasitism rate. An ichneumonid parasite, *Thersilochus conotracheli* Riley, feeds on the curculio larvae in the soil and remains in the cocoon until the following spring (Quaintance & Jenne 1912). In fruit a braconid parasite, *Microbracon mellitor* Say, lives externally on the plum curculio's larvae. The parasite kills the host before it exits to pupate. Several dipteran parasites were also listed by Quaintance and Jenne (1912). *Myiophasia aenea* Wiedemann, a tachinid fly with a parasitism rate of 1%, is only an occasional parasite of the plum curculio. They found another widely distributed dipterous parasite, *Cholomyia inaequipes* Bigot, with a parasitism rate of 7%. Quaintance and Jenne (1912) also listed ants, thrips, lacewings, carabid beetles, several species of wild birds and poultry as curculio predators. Mampe & Neunzig (1967) found two parasites of the plum curculio larvae in blueberry and wild plum. From blueberry, *Aliolus rufus* Riley was found to have parasitized 3% of the 207 plum curculio reared. From wild plum, *Aliolus curculionis* Fitch killed 5% of the 258 plum curculio reared. Both of these parasites have two generations a year making them unsuccessful biocontrol agents for univoltine plum curculio. They have not been tested against the southern bivoltine plum curculio. In a study using four strains of steinernematid nematodes, Olthof & Hagley (1993) found that some were quite successful against the plum curculio larvae. *Steinernema carpocapsae* var. *weiser* All was the most successful nematode, killing 72% to 95% of plum curculio. *Steinernema feltiae* (*S. bibionis*, Biosys strain no. 27) caused the same level of plum curculio mortality as did *S. carposapsae* at the rate of 50 nematodes/weevil, but plum curculio's mortality rate did not increase when more nematodes were added. *Steinernema carpocapsae* Mexican & Kapow strains caused the same level of mortality regardless of the rate of nematodes applied. The use of nematodes to control the plum curculio showed promise but required a better application method and more accurate timing of nematode applications. Tedders et al. (1982) tested one nematode and two fungi. The nematode, *Neoaplectana carpocapsae*, was ineffective against the plum curculio. The two fungi, *Beauveria bassiana* and *Metarhizuim anisopliae*, caused the same rate of mortality after 14 days, but *M. anisopliae* killed the insect faster and was judged to be more effective. None of these natural enemies have been worked into a commercially viable control approach.

Monitoring. Although there is a need for consistent and effective monitoring tools, they have not been developed. Currently, growers and consultants monitor the plum curculio several different ways with the goal of detecting the plum curculio before damage occurs. The oldest known method of jarring (Scott & Quaintance 1911), where researchers beat the tree limbs with a padded stick and collect the curculio that fall, is still practiced. However, achieving accurate results is difficult due to variation in tree shapes and sizes (Wylie 1951). LeBlanc et al. (1984) believe that plum curculio are affected by many things during jarring, such as size of drop cloth, strength of blows, size of jarred limb, height of the "jarrer", time of day and weather conditions. When the temperature exceeds 20 to 23°C, plum curculio usually fly away when jarred rather than fall onto the drop cloth (Snapp 1930, LeBlanc et al. 1984). Funnel traps have been used to collect the plum curculio; these exploit the thanotaxic behavior of the insect (Owens et al. 1982). Observing fruit for oviposition and nutrition scars was also used as a monitoring method (Le Roux 1961). Le Blanc et al. (1984) realized the need to monitor the plum curculio when it was moving into the orchard, not after it was already present. They placed Granny Smith apples in the orchards before bloom and monitored the number of oviposition scars. Payne et al. (1973) found that black light was highly attractive to plum curculio. Prokopy et al. (1980) hung sticky red balls that mimic apples in the trees and counted the number of curculio adhering to the balls. He found this method ineffectual because the plum curculio may escape or not contact the sticky surface. Monitoring plum curculio after it has entered the orchard requires frequent scouting. Examining developing fruit for fresh egglaying scars is very effective. Another method developed in Texas for the pecan weevil was used to monitor plum curculio emergence from the soil after pupation (Raney & Eikenbary 1969). Fruit was placed under the screen skirt of the trap, and a collection vessel is placed at the top. When the insects emerge from the ground, they crawl up the screen and into the collection vessels. This reveals when the second emergence of curculio has started. Methods used to capture and monitor the plum curculio have met with limited success.

Tedders Trap Monitoring. Tedders weevil traps for the pecan weevil in Georgia have shown some possibilities for monitoring the plum curculio. These traps catch large numbers of plum curculio when placed in the field to monitor pecan weevil (Tedders et al. 1994, Mizell et al. in press). There is a need for an effective monitoring strategy that predicts when plum curculio moves into the orchard and monitors activity all season long.

Sound Production as a Monitoring Tool. Plum curculio makes a high pitched sound that is thought to attract mates (Mampe & Neunzig 1966). It has not been determined whether the sounds are sex attractants. Mampe and Neunzig (1966) found that plum curculio were attracted to caged beetles of the opposite sex when stridulation occurred and that there was no attraction to nonstridulating beetles. It has also been suggested that stridulation is a way of locating a mate once they have moved into the trees where using chance encounters and vision would be difficult. Webb et al. (1979) believed that sound is produced when the insect is subjected to stress. These sounds can also be, "induced by handling the insect, sudden bright light, high temperatures or by immobilization" (Webb et al. 1979). Carlysle et al. (1975) determined that sound was produced, "by movement of the plectrum located on the ventral-medial surface of the left elytron." They also found that when parts of the stridulitrum were removed, plum curculio would adapt to using the area that was undamaged. Mampe & Neunzig (1966) explained this more clearly by saying, "sound was produced by rubbing the last abdominal tergite against the stationary elytra." It seems logical that plum curculio could use stridulation for both sex attractance, location or stress. Would using a trap that emitted sound be an effective method for growers? Prokopy et al. (1993) thought that a trap using these sounds to trap the plum curculio would be expensive because of the equipment needed. More research is needed on this subject before conclusions can be drawn.

Sensory Structures and Attractants. Visual and olfactory cues have been implicated in host and host-fruit location by the plum curculio. Alm & Hall (1986) studied the antennal sensory structures that proved to be extensive and compared the structures to olfactory receptors in other insects. Snapp & Swingle (1929) demonstrated the effect of peach attractants on the plum curculio. The attractants used were linalool, linalyl acetate, methyl alcohol and acetaldehyde. Distilled wild plum blossoms, wild cherry blossoms, wild crabapple blossoms, green peach fruit, ripe peach fruit and peach bark were also tested. In the forms used, these volatiles were unsuccessful in attracting the plum curculio. More recently, Butkewich & Prokopy (1993) explored using plum fruit and leaves as attractants comparing them to maple leaves, tomato fruit and a blank. They also tested apple leaves in clusters against apple fruit. Plum curculio were more attracted to fruit than to leaves, and they preferred fruit that had the skin punctured by previous oviposition. The plum curculio is a generalist concerning host choice and probably responds to a "constellation of interacting stimuli, both olfactory and visual" (Prokopy & Owens 1978).

Though much research has been done on the plum curculio, there are still areas of little, no or conflicting information. For instance, the literature does not agree on how or when the plum curculio moves into the orchard. There is still very little research about plum curculio activity in the orchard, where it can be found and at what times in the season. Even though there has been much speculation, researchers have not determined what triggers plum curculio's awakening and subsequent movement into the orchard. Finally, though many methods have been tried, there are no accurate and effective season long monitoring methods as for other orchard pests. Field and lab data are conflicting concerning behavior (Racette et al. 1990). These voids or discrepancies in the literature need definitive answers before comprehensive management strategies can be implemented.

CHAPTER 3

Characterization of Plum Curculio's, (Coleoptera: Curculionidae) Spring Movement Using Flight Barrier Traps with Levels and Tedders Weevil Traps

Abstract

Plum curculio's, *Conotrachelus nenuphar* (Herbst), spring movement into orchards was studied via a flight-barrier trap monitoring crawling and flight elevation and Tedders weevil traps monitoring weevil movement. The Tedders weevil trap captured more weevils and was found to be a much better trapping method for the plum curculio than the flight-barrier trap. Plum curculio were shown to fly into the orchard. No plum curculio adults were captured in pitfall traps, possibly due to this insects halting movement behavior. Plum curculio's flight was found to range from 0.6 m-1.2 m in the spring and 1.2 m-1.8 m in the fall. Dark gray Tedders weevil traps used in conjunction with tree trunks painted white increased trap catch of pecan weevil and may work to increase plum curculio trap catch. Future directions for plum curculio studies are also discussed.

Introduction

The plum curculio, *Conotrachelus nenuphar* (Herbst), is a mystery to many researchers. The conflicting information found between laboratory and field data adds to this confusion (Quaintance & Jenne 1912, Racette et al. 1990). More definitive methods of monitoring the curculio's behavior and activities during spring migration in the field are needed. The ability to detect how and when the plum curculio move into the orchard before fruit damage occurs would be valuable in developing monitoring and control methods. This lack of information from the end of diapause until the plum curculio moves into the orchard has prevented the development of Integrated Pest Management programs in fruit orchards (Hoyt et al. 1983, Whalon & Croft 1984, Lafleur & Hill 1987).

Many researchers believe that the plum curculio flies into the orchard upon emerging from overwintering sites. Quaintance and Jenne (1912) reported that plum curculio fly freely on warm nights. After emergence, vapor pressure deficit may affect plum curculio. McGiffen & Meyer (1986) developed flight response graphs of the plum curculio in response to vapor pressure deficit. When temperature is greater than the flight threshold, high vapor pressure deficits (warm days with low humidity) may inhibit movement. They found that curculio's flight response would be low at extreme vapor pressure deficits and high at intermediate values. By observation, Lafleur et al. (1987) believed that plum curculio moved primarily by flying. Meyer (1982) stated that takeoff response is an effective indicator of migration in insects that do not engage in trivial flight. Others disagree, thinking flight was a rare occurrence(Owens et al. 1982). LeBlanc (1982) postulated that plum curculio are poor flyers. Choiunard et al. (1992) developed a spray program that involved spraying border rows to kill the plum curculio. In order for this spray method to have been effective, the plum curculio had to be located on the ground. Therefore, if the insects flew, the sprays would be ineffective. These discrepancies in the literature may be explained by differences in time of year and location (Racette et al. 1991). To develop an effective monitoring or control program, the question of whether or not plum curculio fly into the orchards during migration needs to be answered.

To determine this behavior, an experiment was designed to monitor plum curculio using a flight barrier trap with varying heights, and a Tedders weevil trap to capture ground and crawling insects. This flight barrier trap monitored insects crawling into and out of the orchard. It also measured flight into and out of the orchard at 0.6 m intervals up to 1.8 m. This was compared to the Tedders trap which caught crawling and flying insects. These traps allow monitoring of all areas of possible emergence both crawling and flying.

This study will provide information to explain what the plum curculio are actually doing when they move and possibly explain if they are crawling or flying into the orchard. If flight is determined to be the mode of displacement, then the height and percentage of weevils that fly will also be measured. The two traps will also be compared to determine if either trap would be suitable as a possible monitoring device. This study may contribute the answers researchers have needed to reconcile conflicting information in this area.

Materials and Methods

Trap Designs. The Tedders weevil trap (Tedders & Wood 1994) (Figure 3.1) was used in this study because it showed significant attraction to plum curculio in the South where Tedders traps are used to monitor pecan weevil (Mizell et al. (in press)). A collection vessel, consisting of the top section of a boll weevil trap, was located on the apex of the Tedders trap. The boll weevil trap tops were modified by gluing two 2.5 cm long pieces of 0.6 cm panel stripping inside. This was developed to snap over the trap bottom to hold the trap tops more securely (Mizell et al. (in press)). A flight-barrier trap was also developed for this study to monitor all levels of plum curculio movement into the orchard (Figure 3.2). The flight barrier trap had four levels on either side, which measured migrational activity into and out of the orchard. Troughs collected insects flying at 0 m-0.6 m, 0.6 m-1.2 m and 1.2 m-1.8 m; pitfalls monitored the activity on the ground. Directions for the assembly of the flight-barrier trap are located in Appendix 2.

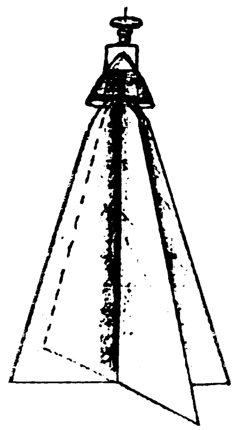

Figure 3.1. Tedders weevil trap, measuring approximately 1.2 m high.

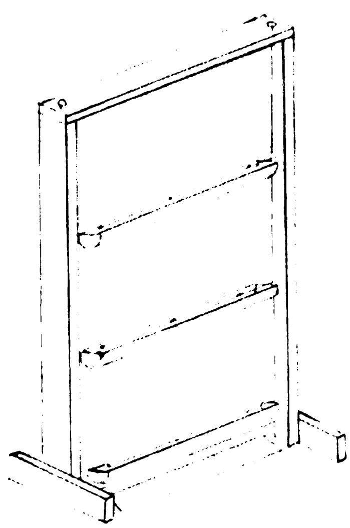

Figure 3.2. Flight-barrier trap with pitfall, measuring 1.8 m tall by 1.2 m wide.

Barrier Trap Maintenance. In 1994 the flight barrier traps were filled with water and then ethylene glycol was added, creating a 10 to 20 % solution. The ethylene glycol was added to kill and preserve the insects until they could be collected. It evaporated leaving the insects to decompose. A brine solution was substituted in 1995 (Winchester & Scudder 1993). The troughs were filled with water and 0.2 L-0.4 L of commercial water softener salt was added and dissolved. Too much salt coated the insects and too little allowed decomposition. Traps were periodically refilled with clean water and salt.

Site and Sampling. This study was conducted at the Trevor Nichols Research Complex in Fennville, Michigan. In 1994 traps were monitored once a week from April 21 to May 1, twice weekly from May 1 to September 1, and weekly from September 1 to November 4. The sites selected for study were all located in the Douglas farm section of the Trevor Nichols Research Complex. They included a peach orchard, a tart cherry orchard and a sweet cherry orchard. Criteria for selecting these sites were that they were next to a fence row or overwintering site and plum curculio damage had been a problem in the past. There were three replicates within each site. Each replicate included two flight barrier traps and two Tedders traps. In 1994 traps were placed in front of trees and between tree rows. This was to determine if there was a preferential area of plum curculio movement. For instance, do plum curculio orient on tree silhouette or is it a random movement into the orchard? Therefore, there were four treatments per replicate: (1) Tedders trap in front of the tree, (2) Tedders trap in the middle of the tree rows, (3) flight-barrier trap in front of the tree and (4) flight-barrier trap in the middle of the tree rows. Sites were a minimum of 12.1 m long with traps placed approximately 3 m apart. The distance varied depending on the randomization. The traps were rerandomized weekly.

In 1995 two trap sites were moved to grower's farms while one site was retained at the Douglas section of the Trevor Nichols Research Complex. The two farms (Robert Crane of Crane Orchards and John Mann) were located near Fennville, Michigan and were immediately adjacent to the Trevor Nichols Research Complex. The traps were monitored once weekly from April 8 to May 4, twice weekly from May 4 to July 20, and weekly from July 20 to October 20. The sites selected were an apple orchard located on John Mann's property, a tart cherry orchard located on Robert Crane's property and a sweet cherry orchard from the Douglas section of the Trevor Nichols Research Complex. The latter site was used the previous year and was proven to have a curculio population.

Considering the data in 1994, the design of the study was changed in 1995. The treatments in front and between trees had no significant effect and were eliminated. In 1995 the design was changed to three locations which contained two replicates, each with one Tedders and one flight barrier trap. The position used for 1995 was in front of the tree. This position was preferred by growers to the middle of the row in the two privately owned sites.

Data Analysis. Due to the diversity of insects trapped, only certain ones were identified. All Diptera and Lepidoptera were not identified. Curculionidae were sent away for identification (Appendix 3). In 1994 the sites' experimental design was a randomized complete block with the Douglas site having three replicates each containing four treatments. In 1995 the design had three locations with two replicates each containing two treatments. Both years were analyzed by ANOVA to determine differences in trap catch. The flight barrier trap was then analyzed separately by ANOVA to determine differences in plum curculio flight level.

Results and Discussion

Plum curculio showed no preference in 1994 between traps placed in front of trees or traps placed between rows ($F=0.05$, $df=1, 6$, $p<0.05$). Considering these findings, traps were only placed in front of trees in 1995 to simplify the study.

The Tedders weevil trap was more attractive and collected more plum curculio than the flight barrier trap. In 1994 the Tedders traps caught an average of 11 curculio compared to an average of 3 in the flight barrier trap (Figure 3.3). In 1995 the trend was the same with the Tedders trap catching an average of 55.5 and the flight barrier trap catching an average of 2.5 curculio (Figure 3.4).

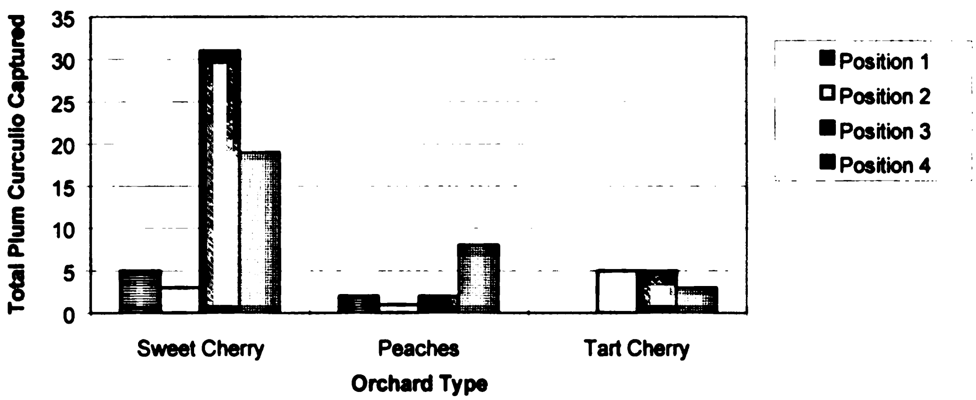

Figure 3.3. 1994 Total plum curculio captured in Douglas, Michigan in three different fruit orchards ($F=4.14$, $df=1, 6$, $p<0.05$). Positions 1-4 stand for (1) flight-barrier in front of tree, (2) flight-barrier in middle of tree row, (3) Tedders trap in front of tree and (4) Tedders trap in the middle of the tree row.

The Tedders trap was perhaps more attractive due to its nonreflective surface. Studies have shown that plum curculio are attracted to this kind of surface because it resembles tree bark (Tedders & Wood 1994). The traps themselves were painted dark gray which Mizell et al. (in press) determined to be the most attractive color to the plum curculio.

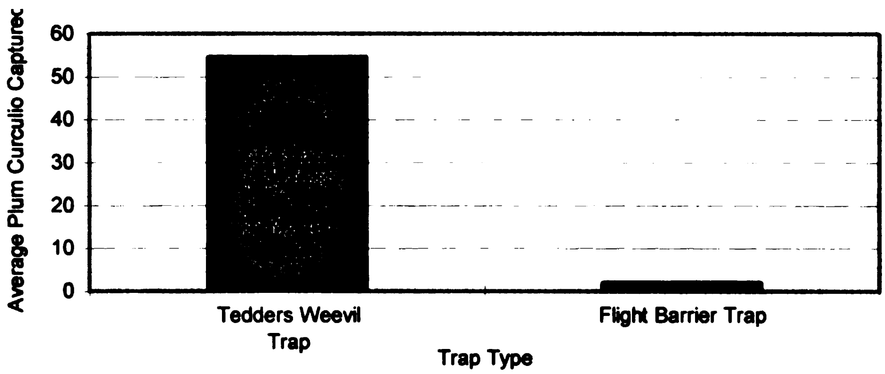

Figure 3.4. 1995 Total plum curculio captured in flight-barrier and Tedders weevil traps in Douglas sweet cherries ($F=11025.0$, $df=1, 1$, $p<0.05$).

The pecan weevil, *Curculio caryae* (Horn), is also attracted to this trap. Tedders & Wood (1994) believed that 84% of pecan weevil crawl or fly to the bark of the tree. They believe that weevil orientation is visually associated with poorly reflective surfaces such as tree trunks. This is possibly the case with the plum curculio.

The flight-barrier trap probably caught fewer insects due to its reflective properties. The troughs were white which Mizell et al. (in press) determined deter the plum curculio; the reflectiveness of the Plexiglas may have also deterred the plum curculio. This trap made out of a nonreflective surface might have been more attractive to plum curculio. Prokopy & Owens (1978) believed that visual monitoring traps that use reflective pigments will not work for plum curculio.

In the beginning of the study I speculated that if plum curculio walked to trees, they would be found in the pitfall traps. In 1994 the pitfalls were covered with a 1.3 cm wire mesh to keep animals out of the ethylene glycol. The plum curculio either avoided this mesh completely or walked over. In 1995 this mesh was removed but plum curculio were still not captured in the pitfalls. This does not mean that they do not crawl; it means that they do not run along the ground blindly. I observed plum curculio interacting with a

Tedders weevil trap with a stop-and-go type motion as they periodically reorient themselves. Miller (1979) also observed this behavior pattern with phorid flies.

Flight-barrier traps monitored plum curculio flight and crawling activity going into and out of the orchard. During 1994 spring movement into the orchard, the front panels from 0.6 m to 1.2 m caught a total of 6 curculio ($F=2.5$, $df=7, 30$, $p<0.03$). In fall of 1994, during movement back to overwintering sites, the panel from 1.2 m to 1.8 m caught a total of 3 plum curculio. The front 0-0.6 m panel caught 3 plum curculio in 1994. The front and back 1.2 m to 1.8 m panels caught a total of two plum curculio. All other panels, front and back for 1994, caught no more than one. In 1995 there were 3 plum curculio caught in the front 0.6 m to 1.2 m panel and 1 caught in the back 1.2 m to 1.8 m panel ($F=0.84$, $df=7, 7$, $p<0.5$). Although there were very low numbers caught in 1995, plum curculio were found at the same heights as 1994. This supports the hypothesis that plum curculio fly into and out of the orchard at a certain height.

Due to the small catch in the flight-barrier traps, the data are inconclusive as to the percentage of plum curculio that fly or crawl during spring movement. I believe that the spring flight of plum curculio moves into the orchard at 0.6 m to 1.2 m because they start out at the ground level. When the plum curculio moves back to its overwintering site, it is leaving the trees and therefore flies out at the height of 1. 2 m to 1.8 m. I can decisively state that there is plum curculio flight during spring migration. The question of exact percentages of plum curculio that fly or crawl during spring is left unanswered.

Conclusions and Future Directions

The Tedders trap is an effective monitoring tool for the plum curculio. The Tedders trap placed in a fruit orchard would be able to effectively monitor plum curculio all season long. The flight-barrier trap is not an accurate method of monitoring the plum curculio for flight or crawling behavior. Trap catch in the flight-barrier traps indicates that there is plum curculio flight at certain heights in the spring and in the fall. The fact that plum curculio were not caught in the pitfall traps leads this researcher to believe that this method may be ineffectual. The flight-barrier trap was unsuccessful in season long monitoring of plum curculio. Neither trap position, front of tree or middle of tree row, was more effective than the other. The significance of this finding was that plum curculio disperse evenly over the edge of the orchard when moving in the spring. It was speculated that they may have clumped together or oriented directionally on trees.

In Tedders & Wood (1994), a study of Tedders traps and pecan weevil, they found that when the tree trunk behind the trap is painted white, the trap catch of weevils increases. I surmise that the plum curculio and the pecan weevil have very similar behaviors and therefore may respond to the same stimuli. The Tedders trap in combination with whitewashed tree trunks could increase the catch and become a more effective monitoring tool.

Additional research may include more frequent observations of the plum curculio's behavior involving the Tedders weevil traps. Mizell et al. (in press) calculated a plum curculio threshold of 2 weevils/trap/day as the treatment level in a peach system. This threshold needs to be tested in Michigan fruit systems to determine if it is accurate enough to use in the timing of control measures. Exploration into the movement of plum curculio into the Tedders trap's collection vessel is also important.

CHAPTER 4

Monitoring Plum Curculio (Coleoptera: Curculionidae) Using Tedders Weevil Traps Baited with Host Plant Volatiles

Abstract

A monitoring program to characterize spring movement of the plum curculio, *Conotrachelus nenuphar* (Herbst), was developed and tested in southern Michigan. In this study the effectiveness of fruit volatiles as attractants for the plum curculio was investigated. Tedders weevil traps, containing one of nine host-fruit volatiles and a blank control, were placed along the edge of apple and peach orchards. Monitoring results showed that plum curculio entered the orchard earlier and left later than previously thought. In 1994 methyl hexanoate, plum blossom extract and benzaldehyde caught more plum curculio than the control but were not significantly different. The other volatiles: allyl propionate, apple essence, cerone, mandelonitrile and propyl propionate were less attractive than the control and may be repellents. In 1995 only volatiles showing attractance in 1994 were used and a high weight volatile release treatment was added for each. As a result, benzaldehyde caught significantly higher numbers of plum curculio than the control. Gender identification was performed in 1995. Male and female plum curculio were captured equally in Tedders traps. Trap catch increased when the traps were baited with benzaldehyde. Due to the health hazards of benzaldehyde, further research is needed to determine a viable and safe method of release.

Introduction

Plum curculio, *Conotrachelus nenuphar* (Herbst), is an annual threat to commercial pome and stone fruits east of the Rocky Mountains. It causes significant economic loss due to oviposition, feeding damage and loss to "June Drop". This insect enters orchards prior to bloom and begins oviposition at fruit set. Its activity level and the numbers of insects in the orchard continue to rise throughout bloom until about a month after fruit set. During oviposition, crescent shaped scars irreparably damage the fruit. Most injured fruit drops from the trees. Though much is known about the plum curculio, there are still many questions left to be answered before this pest can be managed successfully (Whalon and Croft 1984).

Currently, growers and consultants monitor the plum curculio several different ways with the goal of detecting it before damage occurs. The method of jarring, where consultants beat the tree limbs with a padded stick and collect the curculio that fall, is still practiced. However, this technique is not sufficiently reproducible due to variation in tree shapes and sizes (Wylie 1951). Another method of monitoring plum curculio before it moves into the orchard is to place Granny smith apples in the orchard prior to fruit set and observe them for oviposition scars (Le Blanc et al. 1984). Prokopy et al. (1980) hung sticky red balls that mimic apples in the trees and counted the number of plum curculio adhered to the balls. Plum curculio may escape the sticky surface, making this method questionable (Prokopy et al. 1980). Monitoring plum curculio after it has entered the orchard requires frequent scouting. Examining developing fruit for fresh egglaying scars is very effective. The disadvantage of this method is that the insects are already in the orchards and causing damage.

Tedders weevil traps used to trap pecan weevil in Georgia have shown some possibilities for monitoring the plum curculio. These traps catch large numbers of plum curculio when placed in the field to monitor pecan weevil (Tedders et al. 1994). There is a need for an effective monitoring strategy that predicts plum curculio movement into the orchard.

There is no known pheromone for the plum curculio that attracts males consistently. Much research has been done on using traps to monitor the plum curculio with limited success. Funnel traps that exploited the death feigning behavior have been used (Owens et al. 1982). Plum curculio makes a high pitched squeak that is thought to attract mates (Webb et al. 1980). A trap that uses these sounds to trap the plum curculio would be expensive. Due to the plum curculio's host range, pinpointing the host cues that it uses for location is difficult.

Visual and olfactory cues have been implicated in host and host fruit location by the plum curculio. In a study conducted by Butkewich & Prokopy (1993), insects were released and allowed to choose between host and nonhost leaves and fruit. The plum curculio made more visits to the plum fruit and leaves than the nonhost tomato and wax models of fruit, indicating that host odor cues were used to locate host fruit at close range. Increasing the amount and source of the host odor cue may attract the plum curculio. The plum curculio is a generalist in regards to host choice (Table 4.1) and probably responds to a "constellation of interacting stimuli, " both olfactory and visual (Prokopy 1978).

Table 4.1. Native and exotic hosts of the plum curculio (Maier 1990, Armstrong 1958, Quaintance & Jenne 1912).

Native Hosts	Exotic Hosts
Downy juneberry *Amelanchier arborea*(Michaux) Fernald	**Quince** *Cydonia oblonga* Miller
Common Juneberry *Amelanchier canadensis* (L.) Medicus	**Apple** *Malus domestica* Borkhausen
Thicket shadbush *Amelanchier obovalis* (Michaux) Ashe	**Crabapple** *Malus* sp.
Shadbush *Amelanchier* sp.	**Japanese plum** *Prunus salicina* Lindley
Black chokeberry *Aronia melanocarpa* (Michaux) Elliot	**Pear** *Pyrus communis* L.
Hawthorn *Crataegus* sp.	**European plum** *Prunus domestica* L.
Allegheny plum *Prunus alleghaniensis* Porter	**Peach** *Prunus persica* (L.) Batch
Wild plum *Prunus americana* Marshall	**Mountain ash** *Sorbus aucuparia* L.
Beach plum *Prunus maritima* Marshall	**Sweet cherry** *Prunus avium* L.
Pin cherry *Prunus pensylvanica* L.	**Apricot** *Prunus armeniaca* L.
Sand cherry *Prunus pumila* L.	**Nectarine** *Prunus persica* var. *nucipersica*
Choke cherry *Prunus virginiana* L.	**Grape** *Vitis* sp.
Gooseberry *Ribes hirtellum* (Michaux)	**Strawberry** *Fragaria* sp.
Blueberry *Vaccinium* sp.	**Currant** *Ribes rubrum* (L.)
	Wild persimmon *Diospyros kaki* L.

Alm & Hall (1986) studied the antennal sensory structures that proved to be extensive and compared the structures to olfactory receptors in other insects. Snapp & Swingle (1929) demonstrated the lack of effect of peach attractants on the plum curculio. The attractants used were linalool, linalyl acetate, methyl alcohol and acetaldehyde. In addition: distilled wild plum blossoms, wild cherry blossoms, wild crabapple blossoms, green peach fruit, ripe peach fruit and peach bark were tested. These volatiles were unsuccessful in attracting the plum curculio, at least in the forms used. More recently, Butkewich & Prokopy (1993) explored using plum fruit and leaves comparing them to maple, tomato and a blank as plum curculio attractants. They also tested apple leaves in clusters against apple fruit. Plum curculio were more attracted to fruit than to leaves and preferred fruit that had the skin punctured by previous oviposition.

The objective of this study was to test host fruit compounds for attractiveness to the plum curculio. Because this insect feeds and oviposits on fruit, host fruit volatiles may be very important attractants. Studies in the past have indicated that the fruit was most attractive to this insect, therefore, plant volatiles from fruit were emphasized in this study. A volatile that is attractive and can consistently catch the plum curculio would be invaluable as a monitoring tool in the field.

Materials and Methods

Trap Design. Tedders weevil traps (Tedders & Wood 1994) were used in this study because they showed significant attraction to plum curculio in the South (Mizell et al. (in press)) and in Michigan. A boll weevil trap top located on the top of the Tedders trap served as a collection vessel (Figure 4.1). Tedders weevil traps were modified by attaching a wire dispenser to the boll weevil trap to hold a BEEM capsule containing the volatile. A gray film canister top which allowed shade for the baited BEEM capsule was punctured on the top of the wire. The boll weevil trap tops were further modified by gluing two 2.5 cm long pieces of 0.6 cm panel stripping inside. This was developed to snap over the trap bottom to hold the trap tops more securely. In 1995 another modification of the trap was to glue a film canister to the boll weevil trap top to allow for greater volatile release.

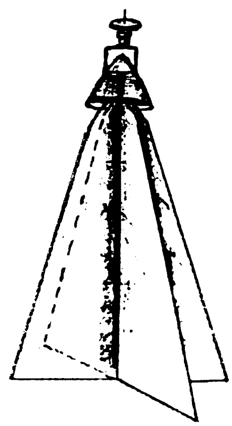

Figure 4.1. Tedders weevil trap with bait release modification, trap is approximately 1.2 m tall.

Baits. Benzaldehyde, mandelonitrile, methyl hexanoate, propyl propionate and hexane were all obtained from Aldrich Chemical Co., in Milwaukee, Wisconsin. Apple maggot lures were manufactured by Trece, in Salinas, California. Allyl propionate was obtained from Pfaltz & Bauer, Inc., Waterbury, Connecticut. Cerone was manufactured by Rhone-Poulene Agricultural Products Company Inc., Research Triangle Park, North Carolina. The formula for the cerone bait was 50% cerone and 50% distilled water. The mixture evolved ethylene, the volatile being tested. Plum blossom volatile was extracted from approximately 3 kg of blossoms picked in the field. The blossoms were lypholized overnight until brittle. The dry blossoms were extracted with hexane to release the volatile compounds. The blossom/hexane mixture was rotary evaporated and then diluted with hexane creating a 2% blossom extract solution. This mixture was used as the field bait.

Bait Release. In 1994 I placed volatiles in size 3 BEEM capsules (Sigma Chemical Co., St. Louis, Missouri) following the protocol of Dindonis and Miller (1981). The nine volatile baits were allyl propionate, apple essence, benzaldehyde, cerone, mandelonitrile, methyl hexanoate, propyl propionate, plum blossom extract, hexane and a blank control. The capsules were filled three quarters full with approximately 0.4 to 0.5 g of the baits. The capsules were placed in the wire holders and allowed to evaporate. Baits were replaced one to six times throughout the season as they evaporated.

Based on results from 1994, only benzaldehyde, hexane, methyl hexanoate and plum blossom extract were used in 1995. These were all placed in BEEM capsules following the same procedure used in 1994. In addition to this, a high release bait method using film canisters was introduced. Only benzaldehyde, methyl hexanoate and plum extract were used at this high release weight. Hexane was not released at the higher weight since it was only present in the study due to its use in the plum blossom extract. Both the hexane treatment and the blank trap were used as controls. Holes were punched around the top edge of the film capsule to allow the volatiles to escape. When full, the capsules contained up to 3 g of bait. These baits were refilled every two to six weeks throughout the season.

The release rates of these volatiles were measured twice a week by weighing the capsule containing the volatile on a Mettler balance (Dindonis & Miller 1981). Three replicates of each of eight volatiles were placed on a wooden mass dispenser in a setting similar to the traps. The volatiles were weighed for two months or until they had completely evaporated. No release rates were calculated for apple essence, controls and the high release method.

Site and Sampling. In 1994 this study was conducted at the Trevor Nichols Research Complex in Fennville, Michigan. The sites selected were two apple orchards and one peach orchard. The sites were a minimum of 100 m long and were adjacent to a forest or a fence row where the weevils overwinter. Traps were placed at 10 to 15 m intervals and were located under the outside edge of the canopy of the fruit tree, approximately 1.5 m from the trunk. Ten traps, each with one of nine volatile treatments and a blank control, were placed at each site. Traps were placed at randomized locations, and trap tops were moved to new randomized locations at weekly intervals. In 1994 the traps were monitored for plum curculio weekly from April 21 to May 1, twice weekly from May 1 to September 1, and weekly from September 1 to November 4.

In 1995 only one site was located at the Trevor Nichols Research Complex in Fennville, Michigan. The other two sites were located on farms owned by Robert Crane and John Mann, two growers located adjacent to the Trevor Nichols Research Complex. Traps were placed at the same spacing and positions as in 1994. Sites were selected by the initial criteria of being adjacent to a plum curculio overwintering site and having past curculio damage. Each of the locations contained two sites. Each site contained four traps at the 0.4 to 0.5 g weight of volatile and three traps at the 3 g weight. They also contained a blank control. Trap tops were rerandomized weekly. In 1995 traps were monitored weekly from April 8 to May 4, twice weekly from May 4 to July 20, and weekly from July 20 to October 20.

In 1994 and 1995 trees were jarred to compare the number of plum curculio in the trees to the number in the traps. Jarring was accomplished by hitting each tree with a rubber coated stick on three different limbs and collecting the number of plum curculio that fell. Only trees on the perimeter of the orchard were jarred. Five trees were jarred per site. In 1994 the jarring surface was a 60 cm diameter tap tray with a handle on the underside. In 1995 a shake cloth, approximately one meter square, was substituted for this board.

Fruit was also monitored in 1994 and 1995 for the initial onset of oviposition. Five randomly selected trees were observed at each site. Fifty fruit were observed and the scars were counted. The phenology of the trees in all the sites was also recorded to compare to plum curculio activity level.

A new variable was added to the study in 1995. The weevils were sexed to determine if either females or males showed preferences to any volatile. I also wanted to know if either sex showed more attractance to the traps. Weevils were sexed according to the procedure in Thomson (1932).

Data Analysis. All weevils collected were sorted and identified (Appendix 3). In 1994 the experimental design was a randomized complete block. There were three blocks, each containing nine volatile treatments and a blank control. In 1995 the experimental design was also a randomized complete block that had three locations with two replicates each containing seven treatments and a blank control. In both 1994 and 1995 data collected were analyzed by ANOVA for season totals per treatment, and throughout the season by date and treatment. In 1995 data concerning the sex differentiation and the separate volatile attraction of weevils by sex was also analyzed by ANOVA. A Tukey Kramer mean separation test was performed on the ten treatments in 1994 and the eight treatments in 1995 to determine significant differences. In 1994 the peach block was removed from the analysis due to insufficient plum curculio catch. In 1995 the growers' orchards were also removed from analysis due to insufficient catch.

Results and Discussion

In 1994 two apple orchards and one peach orchard were selected to test the hypothesis that plum curculio are attracted to host fruit volatiles. Out of the nine volatile treatments, benzaldehyde caught the most weevils (Figure 4.2). Four of the nine treatments caught more plum curculio than the control trap. The blank control trap was attractive to the plum curculio. The five treatments that caught the least number of weevils were allyl propionate, apple essence, cerone, mandelonitrile and propyl propionate.

In 1994 the two apple sites caught more plum curculio than the peach site (Figure 4.2). The peach site was removed from the analysis due to the low catch of plum curculio. There were few or no plum curculio in this orchard. Further study is needed to determine why such low numbers of plum curculio were captured in this peach orchard. In the southern United States plum curculio is a major pest of peach and is commonly a problem for peach growers in Michigan. Peach is a stone fruit that contains benzaldehyde and mandelonitrile, two of the compounds tested in this study.

In 1995 there were three apple orchards selected for study. Two growers' orchards and one located at the Trevor Nichols Research Complex. Out of all the treatments, the high amount of benzaldehyde caught significantly more plum curculio than the control trap (Figure 4.3). The regular amount of benzaldehyde caught the second largest amount of curculio but was not significantly different from the control. Based on these results, benzaldehyde is at least somewhat attractive to plum curculio and may have potential as a monitoring aid.

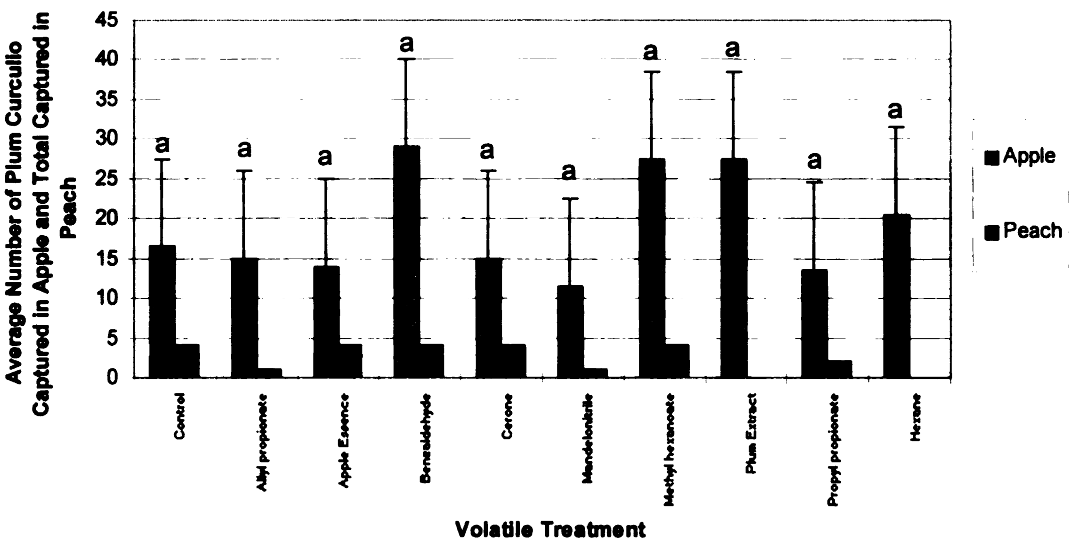

Figure 4.2. Average of the total seasonal trap catch in 1994 of plum curculio for two apple blocks compared to total catch of plum curculio in peach ($F=3.6$, $df=9, 9$, $P<0.05$). Means followed by the same letter are not significantly different (Tukey-Kramer, $F=3.6$, $df=9, 9$, $p<0.05$).

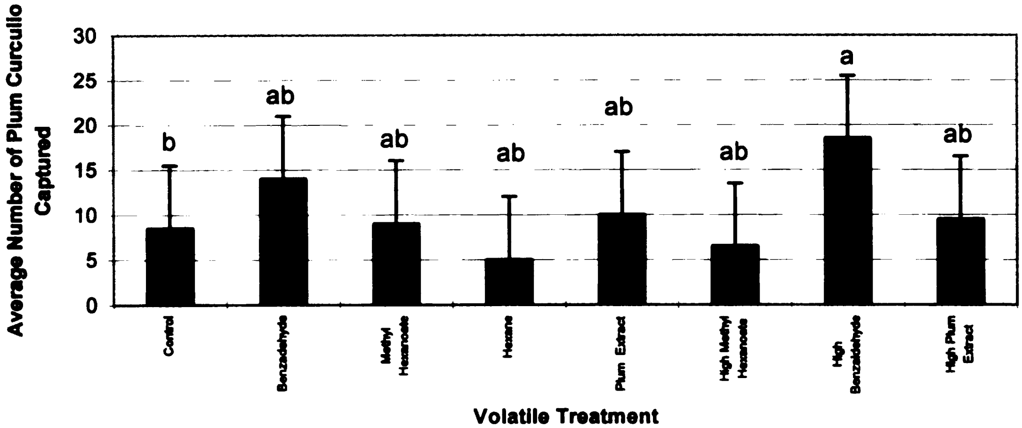

Figure 4.3. Average of the total seasonal trap catch of plum curculio in a Douglas apple orchard in 1995. Means followed by the same letter are not significantly different (Tukey-Kramer, F=35.3, df=7, 7, $p<0.05$).

There was no significant difference between total male and female Tedders trap catch; the ratio was approximately 50/50 (Table 4.2). There was no difference in attraction to volatiles between male and female plum curculio. Again, benzaldehyde was the only volatile that showed a significant attraction (F=4.1, df=7, 15, $p<0.05$). If there had been a behavioral difference based on sex, this trapping method could have been used to influence the population.

Table 4.2. Comparison of average total seasonal Tedders weevil trap catch of plum curculio for two replicates, between male and female weevils in 1995. Column values followed by the same letter are not significantly different (F=2.3, df=1, 15, $p<0.05$).

Treatment	Males	Females
Control	3.5a	5.5a
Benzaldehyde	8a	7.5a
Methyl Hexanoate	4a	4.5a
Hexane	1.5a	5a
Plum Extract	5.5a	5a
High Methyl Hexanoate	2a	4.5a
High Benzaldehyde	9a	11.5a
High Plum Extract	5a	3.5a

In 1994 and 1995 the season long monitoring using volatiles was accompanied by limb jarring. Plum curculio proved present at the times predicted for their activity. In figure (4.4), the large peaks denote an increase in oviposition activity and feeding damage in orchards. On May 24, 1994, (accum. DD_{50}=55) when bloom occurred in the orchards, the plum curculio became more active. On June 14, 1994, (accum. DD_{50}=136) fruit set occurred and plum curculio's activity peaked. Appearance of the progeny from the overwintering generation was reflected at the last peak in August (accum. DD_{50}=1822). Date was significant because of the day to day variance in the amount of plum curculio catch.

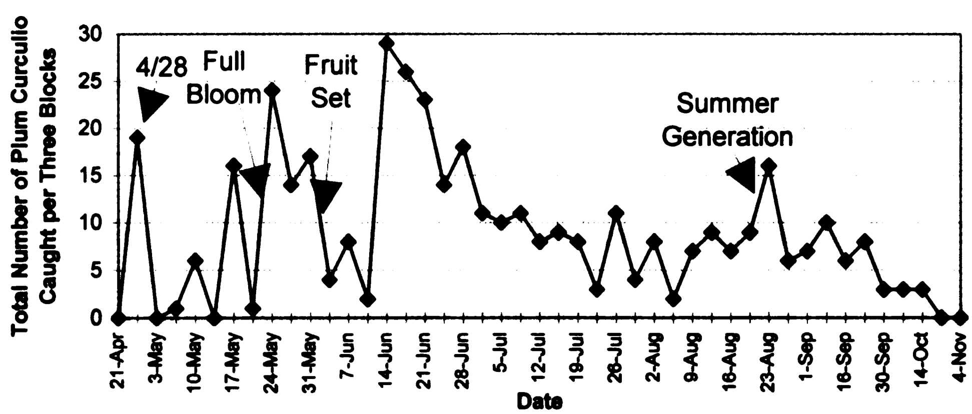

Figure 4.4. Total catch of plum curculio collected from Tedders traps in 1994 (F=2.4, df=44, 44, p<0.05).

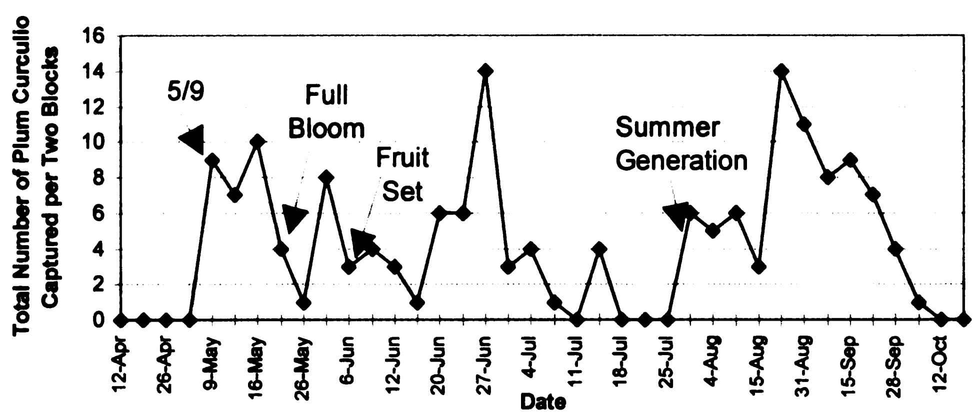

Figure 4.5. Total catch of plum curculio collected from Tedders traps in 1995 (F=2.4, df=26, 26, p<0.05).

In 1995 the behavior of the plum curculio was somewhat different than in 1994. Full bloom occurred at May 23, 1995, (accum. DD_{50}=166) and the trap activity showed that plum curculio had already moved into the orchard (Figure 4.5). At fruit set on June 6, 1995, plum curculio activity dropped until fruit reached 1.3 cm diameter then increased. The progeny from this generation appeared on July 25, 1995, which was earlier than in 1994.

Fruit monitoring results in 1994 showed no oviposition in the peach site and a steadily increasing number of oviposition punctures in apple in both of the sites. In 1995 the two sites selected in the growers' orchards yielded no oviposition damage to fruit; this coincided with Tedders trap catch. The research farm site had a steadily increasing number of oviposition scars in 1995. Both years showed no oviposition damage before Tedders trap catch. Oviposition damage started when fruit had set.

Jarring produced little in comparison to Tedders trap catch during both 1994 and 1995. It was very difficult to find any plum curculio in the trees. No plum curculio were found in the orchard before trap catch occurred. Unfortunately, after Tedders trap catch it was difficult to find any in the orchard to prove that they were present. This may have been due to operator inexperience with jarring. Jarring is difficult due to variances in tree shapes and sizes (Wylie 1951). LeBlanc et al. (1984) believed that plum curculio are affected by many things during jarring, such as size of drop cloth, strength of blows, size of jarred limb, height of the “jarrer”, time of day and weather conditions. Plum curculio usually fly away when jarred rather than fall onto the drop cloth when the temperature exceeds 20 to 23°C (Snapp 1930, LeBlanc et al. 1984).

In 1995 there were no curculio found in growers' orchards, subsequently, no analyses were done. These growers may have previously sprayed according to Extension recommendations and, consequently, had low plum curculio populations in the test year. Follow-up fruit monitoring showed no oviposition damage detected in these growers' orchards.

In 1994 plum curculio moved into the orchard weeks earlier and left months later than actually believed. Plum curculio may not leave an orchard sight if weather is favorable and food sources are still plentiful. Their remaining in the orchard may be a result of the study being conducted in research orchards where the fruit was not harvested. It could also be related to the lack of spraying in the research orchards for several years.

To gather information on volatile release, three replicates of volatiles were weighed and placed in the field to measure evaporation in 1994. This was done to predict when volatiles were about to evaporate and to determine if the volatiles were being released from their polyethylene capsules. It was important that the volatiles did completely evaporate. A continuous reservoir in the polyethylene capsule insured a steady release of the volatile. A bait that could be left out in the field for the whole season would be ideal.

I found that four of the baits released volatiles at a steady rate. They were methyl hexanoate, plum blossom extract, propyl propionate and hexane. Plum blossom extract and hexane volatilized within two weeks during the hottest part of the summer and needed to be filled frequently. Methyl hexanoate and propyl propionate volatilized more slowly, taking several months. Allyl propionate, cerone, benzaldehyde and mandelonitrile did not release at a constant rate.

The compounds used in this study are all contained in fruit, blossoms and leaves of host trees that had similar chemical properties. Allyl propionate and mandelonitrile gained weight. Mandelonitrile is a precursor to benzaldehyde which oxidizes to benzoic acid. Mandelonitrile was not observed to form a complete solid in the field. Benzaldehyde and cerone maintained the same weight throughout the study. Although benzaldehyde oxidizes to benzoic acid it did not appear to gain any weight in the field. The lack of weight loss in benzaldehyde due to volatilization may have been masked by a weight gain from oxidation to benzoic acid. Cerone is a growth regulator and gives off ethylene in aqueous solutions. Even though benzaldehyde did not show consistent volatilization, it attracted the most plum curculio. Benzaldehyde showed the most promise for use as a monitoring tool in the field.

Conclusions and Future Directions

The Tedders weevil trap as a monitoring tool for plum curculio and various other weevils (Appendix 3) works well by itself. Using a volatile bait, such as benzaldehyde, makes it even more effective. The use of this trap on a commercial level, with or without benzaldehyde, would be a beneficial tool for Integrated Pest Management providers, consultants and scouts. The ability to predict and monitor plum curculio's movement and activity in fruit orchards would allow better timing of spray applications, reduced pesticides inputs and lower overall costs.

More research is needed to determine plum curculio damage threshold levels using Tedders trap catch. The methods of release for the volatile benzaldehyde need to be improved and research conducted on the optimum amount that is attractive to the plum curculio.

CHAPTER 5

Development of a Predictive Emergence Model for the Plum Curculio, *Conotrachelus nenuphar* (Herbst), from Environmental Data

Abstract

Sixteen weather variables were regressed against cumulative plum curculio capture to determine if any have predictive value. For comparison purposes, data of cumulative plum curculio were transformed to probits and weather variables were transformed to $\log_{10}$. A 95% confidence interval was calculated for the value of y = 1.91, a probit value for 0.1% (an estimation of the date of first curculio emergence). From 1994 to 1995 none of the weather variables fell within the 95% confidence interval, although cumulative DD_{50} interval were only 0.3 units apart. Other variables, such as soil temperatures at 15 cm and 30 cm may deserve future attention because these values fell just outside the confidence intervals. Daylength was highly correlated for both years, but there were large differences in the confidence intervals. With only two years data this experiment lacks the precision to develop an accurate predictive model. Further study concerning the Tedders trap and weather data needs to be done and incorporated in these results.

Introduction

Environmental factors greatly influence the phenology of the plum curculio. Temperature, moisture levels, wind and daylength may all affect initiation of plum curculio's emergence, feeding and reproduction. Plum curculio must feed soon after emergence during postdiapause. When plum curculio were fed green apples their respiration rate increased dramatically, thereby, ending the postdiapause phase (McGiffen & Meyer 1986). If they were unable to find food at this time they died. The importance of when emergence occurs and what stage the trees are in is proven by McGiffen & Meyer (1986). Researchers have been unsuccessful predicting plum curculio's emergence by correlating it with environmental data. It is possible that several environmental variables interact to affect time of emergence which means that plum curculio will emerge at different times each year.

Early authors suggest that spring migration by plum curculio occurred when the daily mean temperature was 13°C (Quaintance & Jenne 1912, Snapp 1930). Lathrop (1949) found that spring migration is positively correlated with temperature and another weather variable. Whitcomb (1933) stated, "that temperature exerted a strong influence on the development and activity of this insect and was an important factor in timing the application of control measures." Howitt (1993) believed that there were three ways of predicting emergence that gave approximately the same results: mean temperature between 13°C and 16°C for three to four days, mean temperature above 16°C for several (three) days and maximum temperature of 24°C for two consecutive days. Temperature clearly has some unknown impact on plum curculio's activity.

Soil moisture in the environment may also affect plum curculio's emergence. Quaintance & Jenne (1912) indicated that adults do not emerge from dry soil and emergence is greatly reduced if moist soil is allowed to dry. Smith & Flessel (1968) felt that water loss by plum curculio may inhibit movement. When temperature is greater than the flight threshold, high vapor pressure deficits (warm days with low humidity) may inhibit migration. Meyer (1982) stated that takeoff response is an effective indicator of migration in insects that do not engage in flight regularly. McGiffen & Meyer (1986) used a regression model to predict flight response based on vapor pressure deficit. They found that curculio's response would be low at extreme vapor pressure deficits and high at intermediate values. Moisture in the air appears to affect the plum curculio before, during and after emergence.

Another factor affecting emergence could be daylength. In the northern United States plum curculio complete one generation per year. South of Virginia there are usually two generations per year, and diapause is triggered by short daylength during the adult stage (Gaydon 1972). Daylength may be a factor in the northern generation's emergence patterns. Chouinard et al. (1992) believed that daylength is a more important influence of plum curculio's emergence than temperature. Combining daylength with other variables may be the key to predicating emergence.

The development of the plum curculio is believed to be synchronized with the development of its host plant, fruit trees. A relationship between host plant phenology and one or several weather variables is suggested. The objective of this study was to develop a simple and easily used method for commercial orchards to predict curculio's emergence before damage occurs. Weather variables collected for the season include daylength, soil temperatures at 15 cm and 30 cm, temperature, DD_{42} and DD_{50}, relative humidity, vapor pressure deficit, leaf wetness, rainfall, wind speed, wind run and wind direction. These weather variables were chosen because the data are easily accessible to growers and previous studies suggested that they may have some affect on emergence.

Materials and Methods

Site and Sampling. This study was conducted at the Trevor Nichols Research Complex (TNRC) in Fennville, Michigan during the summers of 1994 and 1995. Data recorded in Chapter 4 were used for the analysis in this research. Plum curculio were collected from Tedders weevil traps following the protocol described in Chapter 4. The sites selected in 1994 were two apple orchards located in the Douglas portion of TNRC. In 1995 plum curculio were sampled in apple using two replicates of Tedders weevil traps placed in the Douglas section of TNRC. Insects were removed twice weekly from traps throughout the season.

Data Collection and Calculations. Wind direction, wind speed, leaf wetness, rainfall, soil temperatures at 15 cm and 30 cm, relative humidity and temperature were monitored by an Envirocaster (Neogen Food Tech. Coop.) Agricultural Weather Station located at the Fennville site of the TNRC. All data were collected hourly and converted into daily maximum, minimum and mean values. Phenology of the orchard was also monitored and compared with weather variables.

Daylength, vapor pressure deficit, cumulative rainfall and DD_{42} and DD_{50} were calculated. Vapor pressure deficit was calculated by a method from Lowe (1976). Wet bulb and dry bulb thermometer values were used to calculate the saturation pressure for wet bulb. When the wet bulb value is less than the dry bulb value for a given time period, vapor pressure deficit is calculated by the equation: {Saturation Pressure - (0.66 + 0.000759 x Wet Bulb) x (Dry Bulb - Wet Bulb)}. Daylength was calculated using a program written in 1988 by John Hendrickson. This program uses latitude, longitude and the median of the specific area to calculate sunrise and sunset values for any place on earth. From this data the length of daylight was calculated and converted into hours and minutes. Degree days were calculated by the Envirocaster using integration. Cumulative rainfall was calculated by summing all previous rain events before the day in question. Wind run is the cumulative total for daily wind speed. Three day maximum averages were calculated by averaging maximum temperature of the target day and the two previous days.

Data Analysis. Thirteen days of data were analyzed beginning with last date of collection just prior to curculio capture and ending three collection days later. Total cumulative curculio capture was transformed into cumulative percent capture. Due to the sigmoidal trend of this data it was then transformed into probits (Finney 1962). The sixteen weather variables were transformed to $\log_{10}$. Regression equations were then calculated between probit transformed cumulative capture data (y) and the various weather variables (x) (Herms et al. 1990).

Using the regression equations, x for probit (y) = 1.91 (an estimate of date of first emergence) was calculated. To test the accuracy of each variable in 1994 and 1995, 95% confidence intervals (CIs) were calculated around the value of 0.1% cumulative plum curculio capture (Finney 1962). If the confidence levels overlapped, the relationship between plum curculio's emergence and the particular weather variable was not significantly different from one year to the next. Apple tree phenology was compared to the most significant variables to see if there was any correlation.

Results and Discussion

None of the 95% confidence intervals overlapped when the two years were compared (Table 5.1). However, cumulative DD_{50} and soil temperatures at 15 cm and 30 cm were almost significant and deserve consideration for inclusion in a multiple regression model. These variables each explained at least 50% of the variation in date of first emergence each year ($r^2 \leq 0.5$) (Table 5.1).

Wind run, wind speed and wind direction may have been insignificant because of where they were measured. Wind variables were measured approximately 1.5 m above the ground. Plum curculio were located in the first few inches of the leaf litter or soil at this time and would have been minimally impacted by wind at this height. Wind run is calculated using wind speed, therefore, if wind speed was not significant, wind run would not be either.

The temperature variables: maximum temperature, mean temperature, three day maximum temperature average and soil temperatures at 15 cm and 30 cm were also insignificant. The first three temperature variables were compared to cumulative plum curculio capture because they were used in the predictive models of Howitt (1993). He found that mean temperature between 13°C and 16°C for three to four days, mean temperature above 16°C for several (three) days and maximum temperature of 24°C for two consecutive days may predict plum curculio's emergence. In this study, none of these variables had a significant effect on emergence. However, soil temperatures at 15 cm and 30 cm were almost significant and may be candidates for inclusion in a multiple regression model.

Table 5.1. Regression equations, regression coefficients and values at 95% confidence intervals for weather variables in 1994 and 1995.

Year	Description of Weather Variable	Regression Equation	r^2	0.1% Cumulative Curculio ± 95%CI
1994	Maximum Temperature (C)	y = 13.5x-7.4	0.5	36.7 ± 0.01
1995	Maximum Temperature (C)	y = 10.1x-8.6	0.3	10.9 ± 0.02
1994	Three Day Max. Temp. Ave. (C)	y = -9.4x+15.9	0.5	31.6 ± 0.01
1995	Three Day Max. Temp. Ave. (C)	y = 19.4x-19.9	0.5	13.4 ± 0.009
1994	Mean Temperature (C)	y = -6.5x+10.9	0.6	24.7 ± 0.01
1995	Mean Temperature (C)	y = 11.5x-8.4	0.4	7.9 ± 0.02
1994	Soil Temp. at 15 cm (C)	y = -22.5x+27.6	0.6	13.7 ± 0.006
1995	Soil Temp. at 15 cm (C)	y =32.2x-31.2	0.6	10.7 ± 0.006
1994	Soil Temp. at 30 cm (C)	y = -26.7x+31.4	0.4	12.7 ± 0.006
1995	Soil Temp. at 30 cm (C)	y = 34.5x-33.0	0.7	10.2 ± 0.005
1994	Mean Rel. Hum. (%)	y = 20.0x-31.4	0.2	46.4 ± 0.006
1995	Mean Rel. Hum. (%)	y = 3.3x-2.1	0.03	15.5 ± 0.09
1994	Mean Vapor Pressure Deficit (mb)	y = -12.8x+16.6	0.6	14.1 ± 0.01
1995	Mean Vapor Pressure Deficit (mb)	y = 14.0x-9.7	0.5	6.8 ± 0.02
1994	Daily Rainfall (in)	y = -0.9x+4.1	0.08	298.0 ± 0.04
1995	Daily Rainfall (in)	y = 2.4x+6.3	0.4	0.01 ± 0.02
1994	Cumulative Rainfall (in)	y = 23.4x-3.6	0.9	1.7 ± 0.05
1995	Cumulative Rainfall (in)	y = 113.8x-84.5	0.9	5.74 ± 0.002
1994	Leaf Wetness (hrs)	y = 0.7x+4.5	0.02	0.0002 ± 0.04
1995	Leaf Wetness (hrs)	y = -0.9x+4.2	0.04	422.8 ± 0.04
1994	Mean Wind Speed (mph)	y = -6.1x+9.4	0.3	16.4 ± 0.02
1995	Mean Wind Speed (mph)	y = 2.5x+2.7	0.1	0.5 ± 0.06
1994	Mean Wind Run	y = -6.1x+17.8	0.3	392.8 ± 0.01
1995	Mean Wind Run	y = 2.6x-0.8	0.1	11.8 ± 0.21
1994	Mean Wind Direction (in degrees)	y = -1.7x+9.2	0.007	18498.0 ± 0.02
1995	Mean Wind Direction (in degrees)	y = 4.8x-6.4	0.08	52.6 ± 0.02
1994	Cumulative DD_{42}	y = 29.8x-63.1	0.6	151.0 ± 0.002
1995	Cumulative DD_{42}	y = 21.6x-17.5	0.9	197.1 ± 0.004
1994	Cumulative DD_{50}	y = 21.0x-35.8	0.5	62.7 ± 0.005
1995	Cumulative DD_{50}	y = 15.4x-25.7	0.9	62.3 ± 0.007
1994	Daylength (min)	y = 400.0x-1164.9	0.7	826.1 ± 0.0002
1995	Daylength (min)	y = 425.7x-1246.5	0.8	855.7 ± 0.0001

Leaf wetness, daily rainfall, cumulative rainfall, relative humidity and vapor pressure deficit may have influenced plum curculio's emergence, but the relationship was not statistically detectable. Leaf wetness would seem to have little direct impact on plum curculio. The amount of water on leaves in the trees would have little effect on an insect in the ground. Daily rainfall may be a trigger even though it was unable to be correlated. It is surprising that cumulative rainfall was not significant since insects, in general, are very sensitive to the moisture in their environments. Studies indicate that vapor pressure deficit has an influence on plum curculio's migration and flight (McGiffen & Meyer 1986); however, this study suggests it may have little effect on date of emergence.

Table 5.2. Phenological stages of apple trees in 1994 and 1995 in a Douglas apple orchard.

Description of Apple Tree Stage	1994	1995
Silver Tip	4/19	4/12
Green Tip	4/24	4/17
1/4" Green	4/27	4/21
1/2" Green	5/2	5/4
Tight Cluster	5/9	5/8
First Pink	5/12	5/13
Full Pink	5/16	5/15
First Open Flower	5/18	5/16

In 1994 curculio were first captured on April 28 with the last date of zero capture being April 24. In 1995 the first capture of curculio was on May 9 with the last date of zero capture being May 4. In 1994 emergence occurred somewhere between green tip and quarter inch green stage in apple (Table 5.2). In 1995 first catch occurred between half inch green and tight cluster. Therefore, plum curculio's activity does not appear to be correlated with a single phenological event. Plum curculio migrated into the orchard between green tip and tight cluster in this study. The general practice for plum curculio control is to spray after full bloom or wait until fruit set and first damage. This practice may be putting growers at risk since plum curculio may be in the orchard earlier or later than originally believed.

The fact that no single weather variable was significant at the 95% level does not mean they have no influence on plum curculio's emergence. In 1994 and 1995 emergence occurred between green tip and tight cluster, but this is not always the case. Plum curculio have been known to move into the orchard as late as second cover in apple (John Wise, personal communication). Plum curculio appear to need a rainfall event of about 0.5 cm, daylength to have reached 14:00 hours, soil temperature to be approximately 10-13°C and cumulative DD_{50} of 62 before they will emerge (Table 5.1). In 1994 soil temperature reached this threshold on April 24; 14:00 hours of daylength occurred on April 25; the degree day threshold was reached on April 25; and 0.46 cm of rainfall occurred on April 24. Plum curculio could have emerged any time after April 24. An April 28 collection revealed emergence had occurred between April 24 and April 28. In 1995 soil temperature reached the threshold on May 5; 14:00 hours of daylength occurred on May 5; the degree day threshold was reached on May 7; and 0.64 inches of rain fell on May 4. All thresholds were fulfilled by May 7, and emergence did occur between May 7 and May 9. A multiple regression model incorporating these variables may be useful in predicting plum curculio's emergence.

Conclusions and Future Directions

In order to develop a predictive model for plum curculio's behavior, weather variables consistently correlated with plum curculio emergence need to be found. Degree day accumulation (DD_{50}), soil temperature and daily rainfall may all affect plum curculio's emergence. However, this is difficult to determine due to the variation in plum curculio's emergence patterns. In both 1994 and 1995 emergence occurred on approximately the same date. To test and refine this predictive model, future researchers need to compare soil temperature at 15 cm, daylength, cumulative DD_{50} and daily rainfall to the plum curculio captured by Tedders traps for many years. More research needs to be done to confirm that the plum curculio will emerge during a certain day, time or event. With only two years data this experiment lacks the precision to develop an accurate predictive model.

CHAPTER 6

Mark and Recapture of Plum Curculio (Coleoptera: Curculionidae) to Determine Orientation to Tedders Weevil Traps

Abstract

A mark and recapture study was designed to measure movement of plum curculio from a release point. Wind direction was noted and compared to plum curculio capture. Nine Tedders traps were placed in two concentric rings at distances of 2 m and 4 m from the release site. Two releases, 100 plum curculio on June 26, 1995, and 104 plum curculio on July 10,1995, were made at 9:00 p.m. (EDT). The Tedders traps were observed every 12 hours for five days and weekly for three weeks thereafter. Approximately 25% of the total plum curculio were captured immediately after release. The traps placed 2 m from the release site caught the most insects. The volatile baits appeared to have no effect on movement. Approximately twice the number of plum curculio were captured during the nighttime than the day. The probability of capture was 7-9% during the day and 15-16% at night. Plum curculio were captured more frequently in the traps placed on the downside of the wind.

Introduction

Currently the methods used to monitor plum curculio are not effective. Few studies have been completed observing plum curculio movement and activity in the orchard. These two factors have stalled the development of overall Integrated Pest Management (IPM) programs in fruit orchards for plum curculio (Hoyt et al. 1983, Whalon & Croft 1984).

Recently the Tedders weevil trap (Tedders & Wood 1994) used to monitor the pecan weevil in Georgia was shown to catch significant numbers of plum curculio (Mizell et al. in press). This trap, in conjunction with host plant volatiles, was shown to be attractive to the plum curculio. This trap has been shown to capture plum curculio as they emerge and throughout the season. Information needs to be gathered about effective placement of this particular trap and how the plum curculio behaves around it before comprehensive IPM monitoring and management programs may be developed.

In an effort to obtain more information about the plum curculio's interaction with the Tedders weevil trap, a study was designed using marked release and other similar methods. The objectives for this study were to, 1) determine how attractive the Tedders weevil traps are to the plum curculio, 2) find the percentage of plum curculio caught from a test population, 3) determine if distance affects the attractiveness of the traps and 4) determine if benzaldehyde makes the traps more effective than unbaited traps. The answer to these questions could forward the study of control measures for the plum curculio.

Materials and Methods

Trap Design. Tedders weevil traps were used in this study (Tedders & Wood 1994) (Figure 6.1). A boll weevil trap top located on the top of the Tedders trap served as a collection vessel (Figure 6.1). Two modifications were made to the trap to allow bait release. A size 3 BEEM capsule was attached to the top of the trap top with a bent wire.

A film capsule top was placed over the top of the BEEM capsule for shade. A second bait release method using a film capsule on the trap top to hold the volatile was developed.

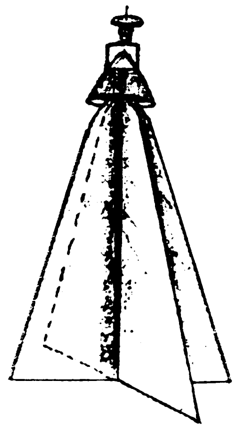

Figure 6.1. Tedders weevil trap with modifications, trap is approximately 1.2 m tall.

Bait Release. The volatile baits used in this study were benzaldehyde at a weight of 0.4 g to 0.5 g (treatment 2), benzaldehyde at a weight of 2 g to 3 g (treatment 3) and a blank control (treatment 1). The volatile lures were contained in a BEEM capsule using the protocol of Dindonis & Miller (1981). Film capsules were used for high volatile release. Four holes were punched around the edge of the film capsule to allow greater volatilization. Benzaldehyde (99% pure) was obtained from Aldrich Chemical Co., Milwaukee, Wisconsin.

Site and Sampling. The study was conducted in the summer of 1995 at the Trevor Nichols Research Complex in Fennville, Michigan. The field site selected was a planting of young trees consisting of apple and crabapple varieties that were approximately 5 years old. The site was a square planting 6.7 m x 6.4 m. Trees were planted approximately 1.5 m to 2.0 m apart.

The weevils used for marking and releasing had been trapped from field populations. Approximately 50% of the plum curculio released were captured by jarring the apple and plum trees with a rubber covered stick onto a one meter square cloth. The other 50% of insects released were collected from Tedders weevil traps already located in the field. Upon collection, the weevils were stored in Styrofoam containers and fed green apples every week until release.

Insects were marked by gently blowing small amounts of fluorescent powder on their bodies. Approximately twenty were in each container, and all containers were marked separately. The first 100 plum curculio released were marked with pink fluorescent paint; the next 104 were marked with yellow fluorescent paint. Preliminary studies showed that a light dusting of powder had no effect on weevil survival or activity. Only insects that were observed to be alive and active were marked and released.

Experiment. Eighteen traps were placed in an area 6.7 m x 6.4 m. The study plot was divided into 2 concentric circles surrounding the point of release (Figure 6.2). The first circle contained nine traps and was located 2 m away. The second circle also contained 9 traps but was located 4 m away. Trap placement was staggered so no traps were placed directly in front of another. Each circle contained three replicates of 0.4 g-0.5 g benzaldehyde, 2 g-3 g benzaldehyde and a blank control. The release point consisted of a smooth white board 25 cm x 25 cm. Plum curculio were liberated by placing them on the release site and allowing them to disperse.

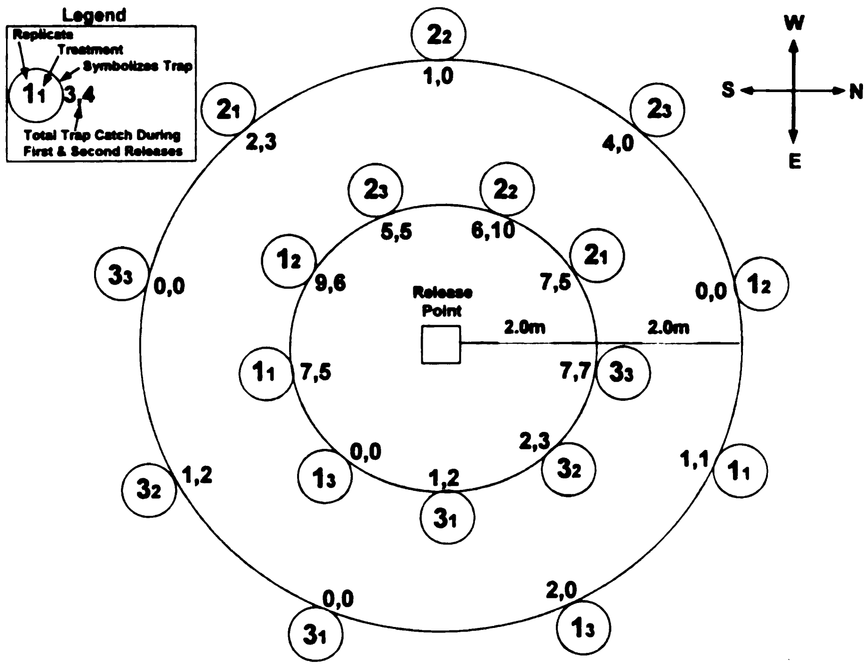

Figure 6.2. Placement and treatment number of Tedders weevil traps in marked release study.

On June 26, 1995, 100 plum curculio were released; 104 plum curculio were released July 10, 1995. Release of plum curculio occurred at 9:00 p.m., eastern standard time. Traps were monitored every 12 hours for five days and once weekly for three weeks thereafter. Insects were identified as the marked individuals and removed from the study.

Data Analysis. Data was analyzed by ANOVA to determine significance of distance and treatment. Probability of capture during the day and night was calculated using a method described in Hayne (1949) under removal trapping. The equation used is $y = p(P - x)$ where P = original population, p = the probability of capture, y = number captured during the period and x = number previously captured and removed before beginning of period in question. Total percent capture for each release was also calculated.

Results and Discussion

The effect of distance on trap capture was significant for both release dates (Figure 6.3). Significantly more insects were caught in the beginning of the week than towards the end. This was understandable because the population was declining and the chance of encountering a trap was decreasing. For both release dates more insects were caught in the first trap zone than the second. The second zone probably caught less because most plum curculio encountered a trap in the first zone. In a field situation it appears that plum curculio will enter the first traps encountered. The closer the traps are to the release site, the more plum curculio captured.

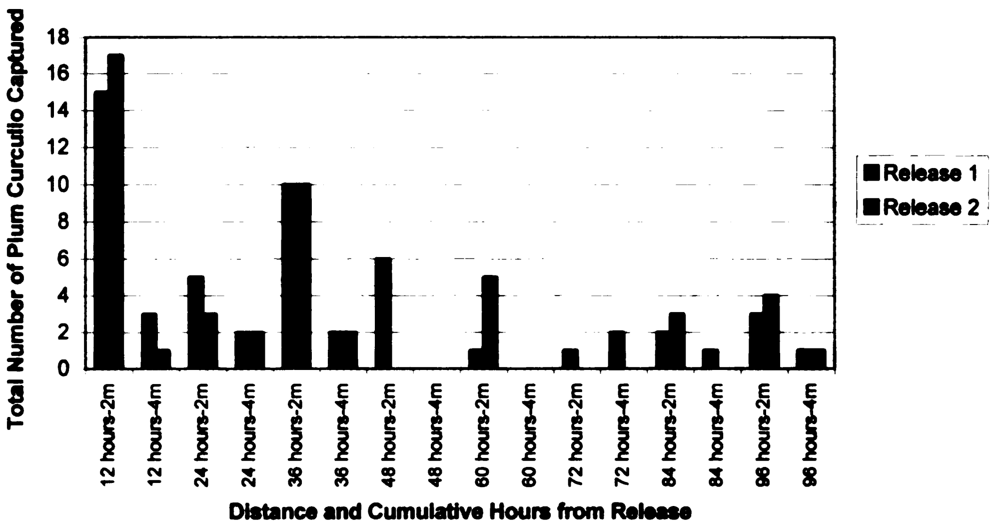

Figure 6.3. Total number of plum curculio captured during twelve hour periods for release dates June 26, 1995, and July 10, 1995 ($F=19.5$, $df=1, 94$, $P<0.05$) ($F=24.9$, $df=1, 94$, $P<0.05$).

The attractiveness of the Tedders weevil traps was also determined for night and day collection periods. For the first release the probability of recapture was 8.8% for day and 16.4% for night. For the second release the probability of recapture was 7.0% for daytime and 15.0% for nighttime. These percentages were for a twelve hour period. The overall recapture rate for the total population was 55.0% for release one and 49.0% for release two. Release one, zone one caught 79.6% of the total curculio captured and zone two caught 20.4%. Release two, zone one caught 87.5% of captured curculio and zone two caught 12.5%.

There were no significant differences in the three different treatments used in this study. Benzaldehyde was used because results reported in Chapter 4 demonstrated that it made the traps more attractive. In this study, volatile baits did not add attractiveness to the traps. This may be due to the traps being closer to the release site and/or the volatile not dispersing. The trap itself shows some measure of attractiveness to plum curculio, but it was not significantly enhanced by benzaldehyde. For the June 26, 1995, release the wind had a direction of 136° (blowing to the Northwest) and a rate of 1.9 kph. The benzaldehyde may have dispersed and never reached the plum curculio on the ground. The release site itself showed some interesting characteristics. There were no plum curculio captured that were not released in this study. This implies that there were no or very low plum curculio populations in this area. This was not surprising because the release site had no fence rows and low plum curculio damage in the past few years in the surrounding pears and apples. It may also be that it is unnatural for curculio to move into trees in July.

Contradiction between significance of the volatiles in Chapter 4 and this study may be explained by the following scenarios. The insects that were released had probably completed oviposition, therefore, volatiles might not have been as attractive to them. The length of the study may be a factor. Chapter 4 studies were conducted from the time of emergence until diapause. If the Chapter 4 study had been done for only five days, the volatiles might not have been significant. Plum curculio may be more sensitive to host plant volatiles in the early season when it is critical to replenish their energy and food reserves from overwintering. Most of the insects collected had fed on apple. There may have been little incentive to find more fruit. In summary, the insects used in this study may not have been as attracted to stimuli that simulate food and oviposition sources.

Conclusions

The Tedders weevil traps were shown to be attractive to the plum curculio. Probability of capture, 7-9% during the day and 15-16% at night, demonstrated that plum curculio were more active and, therefore, encountered traps more frequently at night. Mark and recapture studies with plum curculio indicated that traps placed closer to release sites captured more weevils, therefore, traps placed closer to overwintering sites may capture more weevils. More plum curculio were captured on the northwest side of the plot. Plum curculio appeared to move in the same direction as the wind. The plum curculio may have sensed the volatile baits transported in the wind and moved accordingly. The volatile baits had no apparent effect on trap capture in this study.

APPENDICES

APPENDIX 1

Record of Deposition of Voucher Specimens*

The specimens listed on the following sheet(s) have been deposited in the named museum(s) as samples of those species or other taxa which were used in this research. Voucher recognition labels bearing the Voucher No. have been attached or included in fluid-preserved specimens.

Voucher No.: 1995-7

Title of thesis or dissertation (or other research projects):

Predicting and Monitoring Spring Emergence of the Plum Curculio, Conotrachelus nenuphar (Herbst), (Coleoptera: Curculionidae) Using Tedders Weevil Traps, Flight Barrier Traps and Environmental Variables

Museum(s) where deposited and abbreviations for table on following sheets:

Entomology Museum, Michigan State University (MSU)

Other Museums:

Investigator's Name (s) (typed)

Chandra L. Maleckas

Date

*Reference: Yoshimoto, C. M. 1978. Voucher Specimens for Entomology in North America. Bull. Entomol. Soc. Amer. 24:141-42.

Deposit as follows:

Original: Include as Appendix 1 in ribbon copy of thesis or dissertation.
Copies: Included as Appendix 1 in copies of thesis or dissertation.
Museum(s) files.
Research project files.

This form is available from and the Voucher No. is assigned by the Curator, Michigan State University Entomology Museum.

Voucher Specimen Data

Page 1 of 7 Pages

All labels read: MICH. Allegan Co., Douglas, 130th St., T3N R16W Sec. 21

Species or other taxon	Label data for specimens collected or used and deposited	Number of: Eggs	Larvae	Nymphs	Pupae	Adults ♀	Adults ♂	Other	Museum where deposited
Conotrachelus nenuphar	May 17, 1994, v15						1		
	May 17, 1994, t112f						1		
	May 17, 1994, v18						1		
	May 24, 1994, v110						1		
	May 17, 1994, t111f						1		
	May 27, 1994, v19					1			
	May 17, 1994, v12					1			
	May 24, 1994, v24					1			
	May 17, 1994, v12					1			
	May 27, 1994, v15					1			
Cophes fallax	June 17, 1994, v23								
	July 12, 1994, v23								
	May 23, 1995, d123f								
	June 20, 1995, ct21								
Sitona cylindricollis	May 17, 1994, t221f								
	May 27, 1994, t111b								
	May 31, 1994, t111f								
	May 24, 1994, t211f								
	April 28, 1994, t221f								
	May 9, 1995, d22gf								
Idiostethus tubulatus	May 23, 1995, ct21								
Gymnetron tetrum	June 7, 1994, v33								

(Use additional sheets if necessary)

Investigator's Name(s) (typed)

Chandra Maleckas

Date

Voucher No. 1995-7

Received the above listed specimens for deposit in the Michigan State University Entomology Museum.

J. Mark Scriber cmb 4/8/96

Curator Date

Voucher Specimen Data

Page 2 of 7 Pages

All labels read: MICH. Allegan Co., Douglas, 130th St., T3N R16W Sec. 21

Species or other taxon	Label data for specimens collected or used and deposited	Number of: Eggs	Larvae	Nymphs	Pupae	Adults ♀	Adults ♂	Other	Museum where deposited
Conotrachelus anaglypticus	June 14, 1994, v19								
	June 7, 1994, v13								
	June 7, 1994, v11								
	July 1, 1994, v19								
	June 6, 1995, dv22								
	June 17, 1994, v21								
Otiorhynchus sulcatus	August 16, 1994, t121f								
	July 23, 1994, v310								
	June 10, 1994, v32								
	July 23, 1994, v39								
	September 16, 1994, v25								
	July 26, 1994, v31								
	August 2, 1994, v36								
	August 2, 1994, v34								
	July 23, 1994, v37								
Barypeithes pellucidus	May 27, 1994, v31								
	June 10, 1994, v310								
	June 7, 1994, t311b								
	July 12, 1994, t14								
	June 7, 1994, v38								
	June 21, 1994, t24								
	June 17, 1994, v110								

(Use additional sheets if necessary)

Investigator's Name(s) (typed)

Chandra Maleckas

Date ____________

Voucher No. 1995-7

Received the above listed specimens for deposit in the Michigan State University Entomology Museum.

J Mark Scriber, cmb 4/8/96

Curator Date

Voucher Specimen Data

Page 3 of 7 Pages

All labels read: MICH. Allegan Co., Douglas, 130th St., T3N R16W Sec., 21

Species or other taxon	Label data for specimens collected or used and deposited	Number of: Eggs	Larvae	Nymphs	Pupae	Adults ♀	Adults ♂	Other	Museum where deposited
Gymnetron netum	June 14, 1994, t112b								
Rhynchaenus mixus	July 28, 1994, v16								
	June 28, 1994, v14								
	May 10, 1994, v19								
	May 3, 1994, v19								
Hypera punctata	September 7, 1995, t212b								
Rhynchaenus pellicornis	May 3, 1994, v16								
Rhinoncus pericarpius	May 9, 1995, dv21								
	May 6, 1995, ct21								
	May 23, 1995, mt21								
Acalyptus carpini	May 17, 1994, t223b								
Otiorhynchus ovatus	July 19, 1994, t32gf								
	August 5, 1994, v37								
	June 21, 1994, v25								
	June 14, 1994, t12gf								
Ceutorhynchus punctiger	May 17, 1994, t111b								
	June 7, 1994, t212b								
	May 3, 1994, t321b								
	June 7, 1994, t21gf								
Calomycterus setarius	July 23, 1994, v18								
Anthonomus nigrinus	August 5, 1994, t321b								
Cryptorhynchus fuscatus	September 16, 1994, v25								

(Use additional sheets if necessary)

Investigator's Name(s) (typed)

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Date

Voucher No. 1995-7

Received the above listed specimens for deposit in the Michigan State University Entomology Museum.

J. Mark Scriber 4/8/96

Curator Date

Voucher Specimen Data

Page 4 of 7 Pages

All labels read: MICH. Allegan Co., Douglas, 130th St., T3N R16W Sec. 21

Species or other taxon	Label data for specimens collected or used and deposited	Number of: Eggs	Larvae	Nymphs	Pupae	Adults ♀	Adults ♂	Other	Museum where deposited
Sphenophorus zeae	September 30, 1994, v21								
	June 27, 1995, dv21								
	June 27, 1995, dv21								
	June 7, 1994, t321f								
Hypera nigrirostris	May 5, 1995, mv25								
	May 31, 1994, t221b								
	April 28, 1995, cv12								
	April 28, 1995, mv15								
	July 12, 1994, t23								
Madarellus undulatus	May 17, 1994, t113f								
	May 24, 1994, v31								
	May 31, 1994, t13								
	June 21, 1994, v210								
Dorytomus pervicollis	June 6, 1995, cv24								
	June 6, 1995, cv24								
Hypera meles	May 9, 1995, dt21								
	May 17, 1994, v16								
	May 17, 1994, t213f								
Sitona hispidulus	May 12, 1995, dv24								
	May 24, 1994, v11								
	August 2, 1994, t122b								
	May 17, 1994, v33								
Tyloderma nigrum	May 31, 1994, v18								

(Use additional sheets if necessary)

Investigator's Name(s) (typed)

Chandra Maleckas

Date

Voucher No. 1995-7

Received the above listed specimens for deposit in the Michigan State University Entomology Museum.

J Mark Scriber cmb

Curator

Date 4/8/96

Voucher Specimen Data

Page 5 of 7 Pages

All labels read: MICH. Allegan Co., Douglas, 130th St., T3N R16W Sec. 21

Species or other taxon	Label data for specimens collected or used and deposited	Number of: Eggs	Larvae	Nymphs	Pupae	Adults ♀	Adults ♂	Other	Museum where deposited
Lixus concavus	May 31, 1994, t213f								
	June 17, 1994, t121f								
Phylloblus oblongus	May 27, 1994, t112f								
	May 17, 1994, v22								
	May 24, 1994, v31								
	May 24, 1994, v12								
	May 24, 1994, v36								
	June 17, 1994, v26								
	June 7, 1994, v19								
	May 13, 1994, v35								
	June 14, 1994, v16								
Listronotus sparsus	May 24, 1994, v14								
	May 26, 1995, mv21								
	July 1, 1994, t111b								
	May 31, 1994, v12								
	June 7, 1994, v11								
Phyxelis rigidus	June 7, 1994, t212b								
	September 16, 1994, v39								
	May 27, 1994, t32gb								
	May 16, 1995, mv25								
	May 6, 1994, t33								
Larinus planus	August 19, 1994, t112f								
Anthonomus quadrigibbus	June 7, 1994, v37								

(Use additional sheets if necessary)

Investigator's Name(s) (typed)

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Date

Voucher No. 1995-7

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J Mark Scriber cmb

Curator

Date 4/8/96

Voucher Specimen Data

Page 6 of 7 Pages

All labels read: MICH. Allegan Co., Douglas, 130th St., T3N R16W Sec. 21

Species or other taxon	Label data for specimens collected or used and deposited	Number of: Eggs	Larvae	Nymphs	Pupae	Adults ♀	Adults ♂	Other	Museum where deposited
Sphenophorus pervulus	June 17, 1994, t11gb								
	May 20, 1994, t221f								
Listronotus oregonensis	May 24, 1995, d121b								
	May 13, 1994, t11gb								
	May 24, 1994, v18								
	May 24, 1994, v31								
Euparius marmoreus	June 17, 1994, t21gb								
Sphenophorus minimus	June 17, 1994, v27								
	June 10, 1994, t32gb								
	June 7, 1994, t32gb								
	June 7, 1994, t21gf								
	June 28, 1994, t22gf								
Hypera postica	May 9, 1995, dv16								
	May 13, 1994, t313f								
	May 21, 1995, dv25								
	June 6, 1995, mv26								
Conotrachelus crataegi	May 10, 1994, v27								

(Use additional sheets if necessary)

Investigator's Name(s) (typed)

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J Mark Scriber 4/8/96

Curator Date

Voucher Specimen Data

Page 7 of 7 Pages

All labels read: MICH. Allegan Co., Douglas, 130th St., T3N R16W Sec. 21

Species or other taxon	Label data for specimens collected or used and deposited	Number of: Eggs	Larvae	Nymphs	Pupae	Adults ♀	Adults ♂	Other	Museum where deposited
Myrmex chevrolati	July 22, 1994, v33								
Hyloblus pales	May 31, 1994, t33								
Trigonorhinus altermatus	June 10, 1994, v31								
Ceutorhynchus rapae	May 17, 1994, t223b								
Trachyphioeus bifoveolus	May 27, 1994, t32gb								
	May 31, 1994, t32gb								
	September 7, 1994, t33								
	September 7, 1994, t33								
	September 7, 1994, t222f								
	May 28, 1994, t32gf								
	July 22, 1994, t223f								
	June 7, 1994, t21gf								
	May 13, 1994, t322b								
Polydrusus sericeus	June 17, 1994, v22								
	July 1, 1994, v22								
	July 1, 1994, v210								
	August 9, 1994, v19								
	July 28, 1994, v25								
	July 1, 1994, v22								
	June 21, 1994, v28								
	June 21, 1994, v19								
	July 28, 1994, t33								
	June 24, 1994, t311f								

(Use additional sheets if necessary)

Investigator's Name(s) (typed)

Chandra Maleckas

Date

Voucher No. 1995-7

Received the above listed specimens for deposit in the Michigan State University Entomology Museum. Cmb

J. Mark Scriber 4/8/96

Curator Date

APPENDIX 2

Barrier Trap Assembly

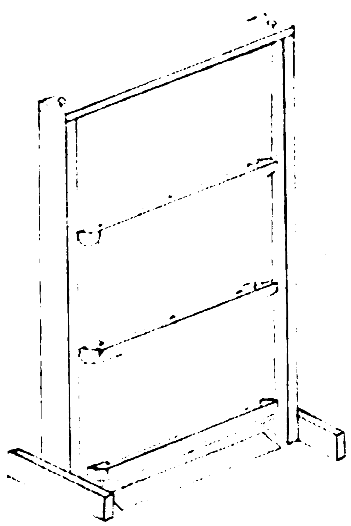

Figure 3.2. Flight-barrier trap with pitfall, measuring 1.8 m tall by 1.2 m wide.

Table 2.A. Materials needed for assembly of one flight-barrier trap.

Quantity	Description
1	4 x 6 ft sheet of clear Plexiglas
4	6'x 2"x 4" boards (we used house stud boards)
8	4' sections of house rain guttering
16	End caps for rain guttering
2	Eye hooks
35'	Rope or clothesline cut in four equal sections
6-8	5" to 6" bolts
18-24	<5" bolts
1	Tube of caulk
1 Box	Nails or screws

Procedure:

(1) Select two 6' x 2" x 4"s and cut a 3/4 to 1 inch deep groove in the middle of one 4 inch side. The cut should be wide enough for the width of the Plexiglas to be inserted.

(2) Place one 6' edge of the Plexiglas in one of the 2" x 4" grooves and drill 3 to 4 holes through the wood and plastic evenly spaced along the 2" x 4". Repeat for other 6' side. Make sure the holes are far enough from the edge and that they go through the Plexiglas. Using the 5" to 6" bolts secure the two 2" x 4"s to the plexiglass.

(3) Cut one of the remaining 2" x 4"s to connect the 2" x 4"s in (2) across one of the 4' sides. This is nailed to the top ends of the 2" x 4"s for stability and to prevent the trap from twisting. This will be the top of the trap. Using the remaining 2" x 4"s, cut two pieces at least 2' long. Nail them perpendicular to the outer edge at the bottom of the 6' x 2" x 4"s. These are the supports that make the trap free standing. Stand the trap on its supports and install the troughs.

(4) Measure the distance between the two 6' x 2" x 4"s, which should be vertical, allowing for the edge caps. Cut the troughs to that size. The distance may be slightly shorter than four feet.

(5) Place two troughs cut to the appropriate size against the bottom edge of the front and back of the Plexiglas. Drill several holes through the bottom edge of the Plexiglas and the opposing top edges of the two troughs and attach with the short bolts. This trough measures insects flying from 0-2 ft. It is meant to sit on the ground but not be a pitfall. Attach the remaining levels at two feet intervals.

(6) Caulk the inside seams of the troughs to prevent leakage.

(7) Screw the two hook eyes into the opposite ends of the top trap board. Tie two ropes of equal length to each of the two screw eyes. Make loops in the other end of the rope and stake them down.

APPENDIX 3

List of Curculionidae Found in Tedders and Flight-Barrier Traps at Trevor Nichols Research Complex, Fennville, Michigan in 1994 and 1995. All Specimens determined by R. S. Anderson.

Cophes fallax (LeConte)
Listronotus oregonensis (LeConte)
Sphenophorus minimus Hart
Sphenophorus pervulus Gyllenhal
Anthonomus quadrigibbus Say
Larinus planus (Fabricius)
Listronotus sparsus (Say)
Hypera postica (Gyllenhal)
Phylloblus oblongus (Linnaeus)
Sitona hispidulus (Fabricius)
Hypera meles (Fabricius)
Dorytomus pervicollis Casey
Phyxelis rigidus (Say)
Madarellus undulatus Say
Polydrusus sericeus (Schaller)
Sphenophorus zeae Walsh
Hypera nigrirostris (Fabricius)
Trachyphioeus bifoveolus (Beck)
Tyloderma nigrum (Casey)
Conotrachelus crataegi Walsh
Otiorhynchus sulcatus (Fabricius)
Barypeithes pellucidus (Boheman)
Ceutorhynchus punctiger Gyllenhal
Ceutorhynchus rapae Gyllenhal
Acalyptus carpini (Herbst)
Otiorhynchus ovatus (Linnaeus)
Euparius marmoreus (Olivier)
Trigonorhinus altermatus (Say)
Hyloblus pales (Herbst)
Myrmex chevrolati (Horn)
Calomycterus setarius Roelofs
Anthonomus nigrinus Boheman
Cryptorhynchus fuscatus LeConte
Lixus concavus (Say)
Conotrachelus anaglypticus (Say)
Idiostethus tubulatus (Say)
Rhynchaenus mixtus (Blatchley)
Rhynchaenus pallicornis (Say)
Rhinoncus pericarpius (Linnaeus)
Hypera punctata (Fabricius)
Gynmetron netum (Germar)
Gymnetron tetrum (Fabricius)
Sitona cylindricollis Fahraeus

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