Flatheaded Apple Tree Borer (*Coleoptera: Buprestidae*) in Nursery-Grown Red Maples: Phenology of Emergence, Treatment Timing, and Response to Stressed Trees[1]

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Abstract

Emergence of adult flatheaded apple tree borers, *Chrysobothris femorata* (Olivier), from red maple (*Acer rubrum* L.) trees and cut bolts was monitored in central Kentucky from 1984–1986. A forecasting system based on accumulated degree-days (DD) was developed for predicting optimum treatment dates. Date of first emergence ranged from May 8 to June 6, corresponding to a mean accumulation of 412 Centigrade DD (742 F DD) calculated from a base temperature of 10°C (50°F). A single application of lindane or chlorpyrifos applied soon after adult borers began to emerge protected young red maple trees from infestation. Adult *C. femorata* were trapped in nurseries from May until August. Twenty-five species of adult Buprestidae representing 5 genera were attracted to experimentally stressed red maples. Although results were variable, stressed trees were generally more attractive and/or susceptible to borers.

Index Words: *Chrysobothris femorata* (Olivier), *Acer rubrum* L., pest management, degree days, red maple

Introduction

The flatheaded apple tree borer, *Chrysobothris femorata* (Olivier) (Coleoptera: Buprestidae), is a common and destructive pest of many species of deciduous shade, fruit and nut trees, especially those that are newly transplanted or otherwise under stress (4, 5, 6, 7, 8). During a period of intermittent drought from 1979 to 1983, nurserymen in Kentucky and neighboring states suffered severe economic losses due to infestation of young maple trees, particularly *Acer rubrum* L., by *C. femorata*. Many nurseries reported infestation rates of 30% or more, the infested trees either being killed outright or rendered unmarketable due to borer injury. During the same period we also observed outbreaks of the borer in red maples that had been recently transplanted to urban landscapes.

Adult *C. femorata* are flattened, metallic-colored beetles that emerge in spring and summer, mate, and oviposit around bark crevices on the trunk or larger branches (4, 6, 7). The larvae feed beneath the bark, damaging cambium, phloem, and outer sapwood and making irregular tunnels which are partially packed with sawdust-like frass. The full-grown larvae overwinter in the sapwood or heartwood, pupating the following spring. There is one generation per year.

Control of flatheaded borer larvae with insecticides requires that sprays be applied shortly before oviposition, so that the newly hatched borers ingest a lethal dosage while chewing through the bark at the point of egg attachment. A reliable estimate of the start of adult emergence is therefore essential. Forecasting models which relate adult phenology to degree-day accumulations have been developed for several borer species (1, 9, 10), but there is little published information regarding the phenology of *C. femorata* as a pest of nursery or landscape trees. Research was therefore undertaken to clarify the period of adult emergence of *C. femorata* from nursery-grown red maples and to develop a forecasting system for predicting optimum treatment dates. We also evaluated insecticidal control of the borer, and compared attraction of adult *C. femorata* and other buprestid borers to trees subjected to several kinds of experimental stress.

Materials and Methods

Phenology of Borer Emergence. Adult emergence was monitored for three growing seasons (1984–1986) by rearing beetles from infested red maple trees (2–4 cm (0.8–1.6 in) dia) and/or bolts (ca. 1 m (3 ft) long trunk sections) containing overwintering larvae or pupae. These were obtained from four nurseries located near Lexington, Taylorsville, Springfield, and Shelbyville, Kentucky. All trees used for beetle rearing had been transplanted as nursery liners in late winter of the preceding year and had become infested with *C. femorata* during the spring or summer.

In late March 1984, we transplanted 83 trees showing symptoms of borer infestation (cracked bark, packed frass and larval galleries) from the Shelbyville site to a 3 × 4 m (9.75 × 13 ft) plot in Lexington, and enclosed the trees in a 2 m (6.5 ft) tall screened field cage. An additional 30 bolts with borer galleries were cut from trees at the same site, sealed on the ends with molten paraffin, and held in a separate screened cage near the caged trees. Emerged adults were collected daily and sexed. The height and number of emergence holes on the trees was determined when emergence was completed. Because timing of emergence from trees and bolts was nearly identical, borers were reared from cut bolts only in 1985 (50 total bolts from 3 nurseries) and 1986 (61 bolts from 4 nurseries).

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Daily degree-day (DD) accumulations were calculated from January 1 by the method of Baskerville and Emin (3), using temperature data from the weather station nearest the nursery from which the trees or bolts were taken for accumulations up to the date of harvest, and using Lexington data thereafter. Daily degree-day summations to first emergence were calculated using 7 potential base temperatures from 1.67° to 18.3°C (35° to 65°F). Arnold (2) showed that the temperature yielding the lowest coefficient of variation between years is the appropriate base temperature for use in heat summation models. This method has been used in developing forecasting models for several other borers (1, 9, 10).

Insecticidal Control in Nurseries. On June 13, 1985, one week after emergence of the first adult *C. femorata* in cages, young (2–4 cm (0.8–1.6 in)) red maple trees (cv. 'Red Sunset') growing in nurseries in Shelbyville or Springfield were treated with lindane, bendiocarb, or chlorpyrifos, or were left unsprayed (controls). The trees had been planted in late winter 1985. Treatments were replicated four times at each site in a randomized complete block (RCB) design (Table 2). There were 100 trees per treatment at each site (800 total trees). Bark was sprayed to runoff using a 7.6 l (2 gal) compressed air sprayer. To compare the efficacy of one vs. two applications, half of the trees within each block were retreated two weeks later on June 27. Trees were examined in late November for characteristic borer symptoms (swollen and/or cracked bark, galleries with packed frass). Trees were classified as infested or not infested. Because there were no significant differences in rate of infestation with one vs. two applications for any treatment at either site (χ^2 contingency tests, $P>0.05$), data for one and two applications were pooled within treatments, and the proportion of trees infested was compared by χ^2 contingency tests (12) between individual treatments and controls at each site.

Stress Experiments. Three experiments were conducted to investigate the response of *C. femorata* and other buprestid borers to stressed trees. In the first test, 20 red maples cv. 'Red Sunset' (4–6 cm (1.6–2.4 in) dia) that had been growing for 3 years in the Shelbyville nursery were divided among 4 treatments: 1) Root-pruned. A circular trench (ca. 0.5m (1.6 ft) deep, 1m (3 ft) dia) was dug around each tree to sever the main feeder roots. This treatment was intended to simulate transplant shock and to induce moderate water stress. 2) Wounded. Trees were struck twice with the edge of a spade on opposite sides of the trunk ca. 30 cm (1 ft) above the ground to expose the outer sapwood and create shallow wounds ca. 2.5 (1 in) wide × 10 cm (4 in) long; 3) Defoliated. Trees were ca. 80% defoliated by hand (trees refoliated within 3 weeks); and 4) Control. The experimental design was a RCB with 5 single tree replicates per treatment. A 30 cm (1 ft) wide plastic sheet was wrapped around the trunk of each tree at 30–60 cm (1–2 ft) height and coated with Tree Tanglefoot to trap incoming adult borers. Trees were stressed on May 3, and banded on May 13, 1985. Adult *C. femorata* and other Buprestidae were removed from sticky bands bi-weekly until June 14, cleaned with hexane, and sent to Dr. S.G. Wellso (USDA-ARS, Purdue University) for identification. Beetle counts were subjected to analysis of variance following square-root transformation, and treatment means were separated by Tukey's test (12).

In the second experiment, 76 red maple liners (ca. 2–3 cm (0.8–1.2 in) dia) that had been planted in the Shelbyville nursery in February 1985 were assigned to four treatments: 1) lift and replant. This treatment disturbed the developing root system and simulated transplant stress; 2) wounded; 3) defoliated; or 4) control. The procedures for wounding and defoliation were the same as in the first experiment. The experimental design was a RCB with 19 single tree replications. Stresses were imposed on May 3, 1985 and trees were inspected in October 1985 and 1986 for evidence of *C. femorata* infestation. Data analysis was as described earlier for the insecticide evaluations.

The final stress experiment was conducted at a nursery near Taylorsville in 1986. The procedures were identical to the first experiment, except that trees were stressed and banded on April 29. Sticky bands were replaced at 3-week intervals on May 20, June 11, July 2, July 23, and August 14, and the numbers of *C. femorata* and other adult Buprestidae were determined as before.

Results and Discussion

Phenology of borer emergence. The emergence period of adult *C. femorata* from young maple trees and/or bolts lasted ca. 3 weeks, with the first beetles appearing ca. four weeks earlier in 1985 and 1986 than in 1984 (Fig. 1). In comparison, Fenton (6) reported that, in Oklahoma, *C. femorata* adults emerged from unspecified logs between early May and early August, with considerable variation between years.

Dates of first emergence of adults in 1984–86 and associated DD accumulations are summarized in Table 1. Degree days were calculated from 1 January using a base temperature of 10°C (50°F), since that base temperature provided the lowest coefficient of variation in DD accumulations between years. Borer emergence began after an average accumulation of 412 centigrade DD (742 Farenheit DD), or about 3 weeks after the first leaves of nursery-grown red maples reached full expansion and about the time that American holly (*Ilex opaca* Ait.) began to bloom. Although the calender date of first emergence varied by almost a month between different years of the study (Fig. 1), the maximum difference in cumulative DD to first emergence between

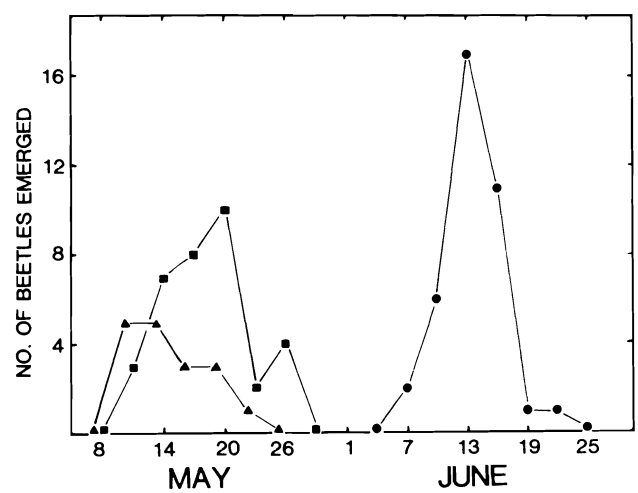

Fig. 1. Emergence pattern of adult *C. femorata* from caged red maple trees and/or bolts obtained from nurseries in central Kentucky in 1984 (●), 1985 (■), and 1986 (▲).

Table 1. Degree day (DD) requirements for first emergence of adult *C. femorata* from nursery-grown red maples in central Kentucky

Year	Date of first emergence	DD accumulation[z]	
		Centigrade	Farenheit
1984	6 June	427	770
1985	10 May	404	726
1986	8 May	406	731
Mean ± SE	18 May	412 ± 7	742 ± 14

[z]DD were computed from 1 January using 10°C (50°F) base temperature

years was only 56 DD, which corresponds to variation of about 2 days. This indicates that estimates of adult *C. femorata* emergence based on cumulative DD will be much more accurate than those based on average calender date, especially in years with unseasonably cool or warm spring temperatures.

All of the emergence holes on the caged maple trees were found on the main trunk, with 75% occurring at < 60 cm (2 ft) height and 97% occurring within 1m (ca. 3 ft) of the ground. Generally, only one beetle emerged from each tree (92%), although a few trees yielded two (6%) or three (2%) beetles. Males began to emerge 3–4 days before females. No other species of Buprestidae emerged from the infested trees or bolts.

Insecticidal Control in Nurseries. The current USDA guideline for control of *C. femorata* on maple (11) is lindane applied in late May and repeated 4 times at 3-week intervals. However, our results (Table 2) indicate that a single treatment with lindane or chlorpyrifos (Dursban®) applied within one week after the adults begin to emerge will protect nursery-grown red maples from infestation. Both of these insecticides are currently registered for borer control. Bendiocarb (Turcam®) was significantly less effective than the other insecticides at the Shelbyville site ($\chi^2 = 8.87$, $P<0.01$). As mentioned earlier, there were no significant differences in infestation rate with one vs. two applications for any treatment at either site. The infestation level in unsprayed trees was 30% at Shelbyville, and 9% at Springfield.

Stress Experiments. Seven different species of adult Buprestidae belonging to three genera were captured on the sticky bands in the first stress experiment. Species represented were: *Agrilus cladrastis* Knull (52.8% of total), *A. crataegi* Frost (2.8%), *Chrysobothris azurea* Lec. (19.4%), *C. femorata* Olivier (2.8%), *C. quadriimpressa* LaPorte & Gory (2.8%), *Anthaxia viridifrons* Gory (16.7%), *A. viridicornis* (Say) (2.8%). Because the number of *C. femorata* captured was too small for analysis, counts of all Buprestidae were pooled and compared across treatments (Fig. 2). All stress treatments attracted significantly more total buprestids than did control trees, which attracted no adult borers. Recently defoliated trees were particularly attractive to buprestids.

By the end of the 1985 growing season only 3 of the 76 trees in the second stress experiment had become infested with *C. femorata* larvae (2 lift and replant, 1 defoliated). However, a number of additional trees became infested in 1986, i.e., during the growing season following the year in which they were stressed. Infestation rates in October 1986 were 42.1% (8/19) for trees that had been stressed by lifting and replanting, 10.5% (2/19) for wounded trees, 42.1% (8/19) for defoliated trees, and 15.8% (3/19) for control trees. The difference between the infestation rates of lifted and replanted or defoliated trees relative to that of control trees approached statistical significance ($P=0.07$, pairwise X^2 contingency tests).

Many more *C. femorata* and other Buprestidae were caught in the final (1986) stress experiment than in the first study, possibly because the Taylorsville study site was bordered by a more heavily wooded area. A total of 1208 buprestids representing 5 genera and 24 species was captured. In order of decreasing abundance the 12 most abundant species were: *Agrilus cladrastis* (43% of total), *Agrilus fallax* Say (29.1%), *C. femorata* (7.6%), *Anthaxia viridifrons* (5.0%), *Agrilus masculinus* Horn (3.1%), *Agrilus lecontei* Saunders (3.1%), *C. azurea* (2.2%), *C. sexsignata* (Say) (1.2%), *Acmaeodera tubulus* (Fabricius) (1.2%), *C. quadriimpressa* (1.0%), *Agrilus obsoletoguttatus* Gory (1.0%), *Anthaxia otiosus* Say (1.0%). Additional species captured, each representing <1% of the total, were: *Agrilus subcinctus* Gory, *A. difficilis* Gory, *A. bilineatus* (Weber), *A. putillus* Say, *A. cliftoni* Knull, *A. defectus* LeConte, *A. transimpressus* Fall, *C. rugosiceps* Melsheimer, *C. viridiceps* Melsheimer, *Anthaxia cyanella* Gory, *A. viridicornis*, and *Actenodes acornis* (Say).

Table 2. Efficacy of one vs. two insecticidal applications for preventing infestation of red maple by *C. femorata* in two nurseries in central Kentucky.

Treatment	kg ai/378.5 liters (lbs ai/100 gal)	No. of applications[z]	Shelbyville		Springfield	
			No. trees treated	No. infested	No. trees treated	No. infested
chlorpyrifos 2E (Dursban®)	0.91 (2.0)	1	50	0	50	0
		2	50	1	50	1
lindane 20%EC (Lindane®)	0.82 (1.8)	1	50	1	50	0
		2	50	0	50	0
bendiocarb 76WP (Ficam®)	0.91 (2.0)	1	50	5	50	0
		2	50	6	50	1
control	---	---	100	30	100	9

[z]Date of first application was June 13, 1984. Trees receiving two applications were re-treated on June 27.

[y]At each site, the proportion of trees infested (no. infested/no. treated) is significantly lower for each treatment than for control (based on X^2 contingency tests for individual treatments vs. control, $P = 0.05$). Data for one vs. two applications were pooled for analysis.

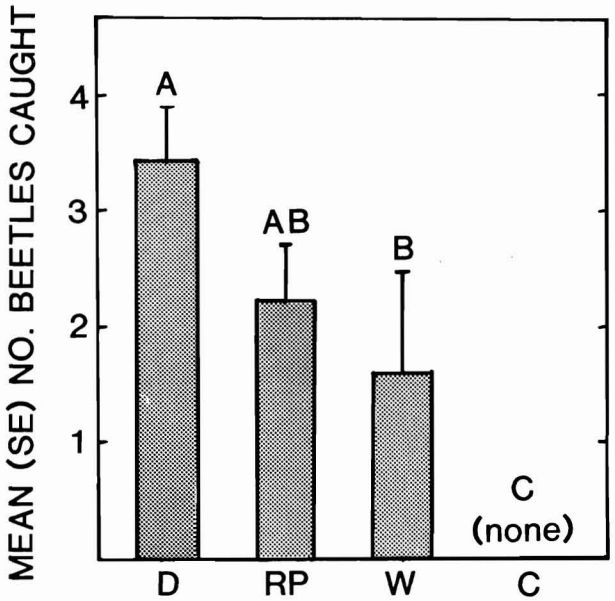

Fig. 2. **Response of adult Buprestidae to experimentally stressed red maple trees, May 13 to June 14, 1985. D = defoliated, RP = root-pruned, W = wounded, C = control.**

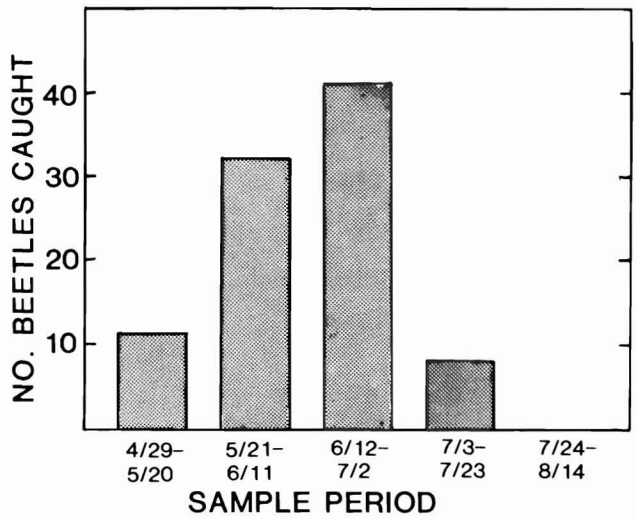

Fig. 3. **Seasonal capture of adult *C. femorata* on sticky band traps on nursery-grown red maple trees, Taylorville, KY, 1986.**

This diversity is surprising in that relatively few buprestid species are associated with maples (S. Wellso, personal communication) and because most of the species collected have not been reared from *A. rubrum* (13). For example, *A. cladrastis*, the most abundant species we captured, is associated with American yellowwood (*Cladrastis lutea*), and *A. fallax* is a pest of honeylocust (*Gleditsia triacanthos inermis*). These observations suggest that at least some buprestids may respond to relatively non-specific volatile cues, and then discriminate between suitable and non-suitable hosts after landing on the tree.

Adult *C. femorata* were captured on the experimental trees from early May until late July, with peak activity occurring during the June 11 to July 2 sample interval (Fig. 3). The pattern of capture was similar on stressed and control trees, which suggests that the data reflect seasonal flight activity rather than changes in the attractiveness of the stressed trees.

Although there was a trend in 1986 for higher capture rates on stressed trees, the trap catches were highly variable and differences between treatments were not significant for any of the three most abundant species, including *C. femorata*, or for total Buprestidae (Table 3). Because of a severe drought in central Kentucky in 1986, it is probable that all of the trees, including controls, were more stressed than those used in the first (1985) experiment.

Throughout these studies we observed great variation in borer populations between different nurseries and in different years. For example, additional insecticide evaluations involving 1420 total trees were conducted at two nurseries in 1985 and 1986, but were inconclusive due to very low (1–2%) incidence of borers in control trees. During the same period, infestation rates as high as 40% occurred at other sites. Clearly, more research will be needed before the severity of *C. femorata* outbreaks in a particular year or at a particular site can be predicted.

Significance to Nursery Industry

Research in Kentucky showed that a single, properly-timed application of lindane or chlorpyrifos (Dursban®) will protect young red maple trees from infestation by the flatheaded apple tree borer. Bark sprays should be applied soon after the adults begin to emerge to mate and lay eggs, so that a lethal residue is present to kill the newly-hatched larvae as they chew through the bark at the point of egg attachment. Date of first emergence of adult borers from nursery-grown maples in central Kentucky ranged from May 8 to June 6 (avg. date: May 18) in 1984–86. A predictive model based on accumulated degree-days was developed which can provide a reliable estimate of the optimum treatment date, even during years of unseasonable temperatures (degree-day records are available from most local Cooperative Extension offices). The borer emergence period lasts about 3 weeks, but adults may be present in the nursery

Table 3. Capture of adult Buprestidae on experimentally stressed red maple trees, Taylorsville, KY, 1986.

Stress	Mean (±SE) no. captured[z]			
	C. femorata	*Agrilus cladrastis*	*A. fallax*	Total Buprestidae
Defoliated	5.8 ± 2.6	28.4 ± 3.9	22.0 ± 6.9	80.2 ± 14.9
Root-pruned	5.8 ± 1.6	26.4 ± 4.3	12.8 ± 2.7	67.2 ± 8.9
Wounded	3.8 ± 1.2	27.8 ± 3.3	21.0 ± 3.9	83.2 ± 9.6
Control	2.8 ± 0.7	23.8 ± 3.1	14.6 ± 2.3	60.8 ± 9.6

[z]Treatment means within each column do not differ significantly from control ($P > 0.05$)

from May until August. Red maple trees that had been stressed by root-pruning, transplanting, wounding, or defoliation were generally more attractive to flatheaded apple tree borer and other flatheaded borers than were non-stressed trees.

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Inheritance of Resistance to Fire Blight in *Malus* Crosses[1]

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Abstract

In eight interspecific and intraspecific *Malus* crosses, segregation of seedlings after greenhouse inoculation with *Erwinia amylovora* indicated that resistance to fire blight was polygenically controlled. In certain interspecific and intraspecific crosses, high percentages of resistant seedlings were recovered suggesting that sources of fire flight resistance are available in the cultivated apple as well as in other small-fruited *Malus* species.

Index words: apple, crabapple, *Erwinia amylovora*, interspecific hybridization

Introduction

Fire blight, a serious disease of *Malus* species, is widely distributed in the United States and is spreading to other parts of the world. Fire blight is caused by the bacterial organism *Erwinia amylovora* (Burr.) Winslow et al.

The significance of understanding the genetic control and inheritance of this disease is due to the fact that its control by using chemical sprays and cultural practices is difficult. Therefore, breeding for resistance to fire blight has become an essential objective. Gardner et al. (2) reported that resistance to fire blight is polygenically controlled and also presented evidence that resistance in *Malus* X*sublobata* PI 286613 (613) and *M.* X*robusta* No. 5 (R5) was conditioned by few dominant genes with additive effects. Korban et al. (3) also found that resistance to fire blight, in crosses among various genotypes of the cultivated apple (*Malus* X*domesitca* Borkh.), was polygenic with additive gene effects.

In this study, we report the genetic control and inheritance of fire blight resistance in both interspecific and intraspecific crosses of *Malus*.

Materials and Methods

To prepare the inoculum, cells of *E. amylovora* strain Ea 273 (provided by H.S. Aldwinckle, New York Agricultural Experiment Station, Geneva) were transfered to 15 ml of Modified Emerson's medium (MEM) (4) consisting of glucose (1 g/l), sodium chloride (2.5 g/l), yeast extract (1 g/l), and nutrient broth (8 g/l). Cells were incubated at 25°C (77°F) in a shaker bath at 90–110 osc/min. After 24 hr, cultures were at mid-log phase and cells were streaked onto MEM agar plates. These were incubated at 30°C (86°F) for an additional 24 hr and then cells were gently washed from the agar surface with sterile distilled water and suspended to a concentration of 4×10^7 cells/ml and used for inoculation.

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