Dogwood Borer (Lepidoptera: Sesiidae) Abundance and Seasonal Flight Activity in Apple Orchards, Urban Landscapes, and Woodlands in Five Eastern States

J. C. BERGH,[1] T. C. LESKEY,[2] J. F. WALGENBACH,[3] W. E. KLINGEMAN,[4] D. P. KAIN,[5] and A. ZHANG[6]

Environ. Entomol. 38(3): 530–538 (2009)

ABSTRACT The relative abundance and seasonal flight activity of dogwood borer, *Synanthedon scitula* Harris (Lepidoptera: Sesiidae), was measured using weekly records from traps baited with its sex pheromone and deployed in apple orchards, urban landscapes, and native woodland sites in New York, West Virginia, Virginia, North Carolina, and Tennessee in 2005 and 2006. The mean total number of moths captured per site in apple orchards was 3,146 ± 644 and 3095 ± 584 SE in 2005 and 2006, respectively, exceeding captures at urban sites by 16 and 13 times and at woodland sites by 210 and 206 times in 2005 and 2006, respectively. Mean total captures at urban sites exceeded those in woodland habitats by 13 and 16 times in 2005 and 2006, respectively. The mean duration (wk) of the flight period did not differ significantly between apple orchards (22.6 ± 0.6 SE) and urban sites (20.3 ± 1.2 SE). The onset of flight was somewhat later in New York (around early June) than further south (around early to mid-May), but moth captures continued into October in all states. Captures in apple orchards and at urban sites with higher populations were essentially continuous throughout the flight period, with substantial weekly fluctuations, and tended to show a bimodal pattern with peaks from late May through mid-July and from late August through mid-September. Captures at woodland sites tended to occur predominantly from mid-May through about mid-June and were very sporadic thereafter.

KEY WORDS *Synanthedon scitula*, pheromone trapping, apple, ornamentals, forest

Among the Sesiidae, the dogwood borer, *Synanthedon scitula* Harris, has a broad range of hosts (Johnson and Lyon 1991), including many species of deciduous trees and shrubs grown as ornamental plants or that occur in native woodlands in eastern North America. Most early research on dogwood borer focused primarily on its biology and management in flowering dogwood in nurseries and urban landscapes (Underhill 1935, Wallace 1945, Pless and Stanley 1967, Potter and Timmons 1981, Rogers and Grant 1990). In the 1980s, an emerging issue with dogwood borer infestations in eastern apple orchards spurred research on the pest in that agroecosystem (Riedl et al. 1985, Warner and Hay 1985, Weires 1986).

Early efforts to measure the abundance of dogwood borer in native habitats, urban landscapes, and apple orchards using commercially available pheromone lures generated reports of low captures, inconsistent results, and poor species specificity (reviewed in Bergh and Leskey 2003). Bergh et al. (2004) compared pheromone lures from different commercial sources in traps deployed in apple orchards. The products differed markedly in their attractiveness to and selectivity for dogwood borer, and even the most effective lure did not seem to accurately reflect the abundance of the pest in that habitat. Zhang et al. (2005) identified a blend of three compounds that comprise the dogwood borer sex pheromone, (*Z,Z*)-3,13-octadecadienyl acetate (ODDA), (*E,Z*)-2,13-ODDA, and (*Z,E*)-3,13-ODDA, that occur in an 88:6:6 ratio. In apple orchards, traps baited with this trinary blend or with the most attractive binary pheromone blend, 94:6 (*Z,Z*)-3,13-ODDA: (*E,Z*)-2,13-ODDA, captured significantly more male dogwood borer than those baited with the major pheromone component alone (Zhang et al. 2005) or with the most attractive commercial lure (Leskey et al. 2006). Traps containing these blends also captured many fewer individuals of nontarget species of sesiids than those baited with the best com-

Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture.

[1] Corresponding author: Virginia Polytechnic Institute and State University, Alson H. Smith, Jr. Agricultural Research and Extension Center, Winchester, VA 22602 (e-mail: cbergh@vt.edu).
[2] USDA–ARS, Appalachian Fruit Research Station, 2217 Wiltshire Road, Kearneysville, WV 25430-2771.
[3] North Carolina State University, Mountain Horticultural Crops Research and Extension Center, Fletcher, NC 28732.
[4] The University of Tennessee, Plant Sciences Department, 2431 Joe Johnson Dr., 252 Ellington PSB, Knoxville, TN 37996-4500.
[5] Cornell University, New York State Agricultural Experiment Station, 630 West North St., Geneva, NY 14456.
[6] USDA–ARS, Invasive Insect Biocontrol and Behavior Laboratory, BARC-W, 10300 Baltimore Ave., Beltsville, MD 20705.

mercial lure (Leskey et al. 2006). Furthermore, Zhang et al. (2005) verified a previous report (Greenfield 1978) that a geometrical isomer, (*E*,*Z*)-3,13-ODDA, of the main pheromone component is a strong behavioral antagonist; addition of 0.5% (*E*,*Z*)-3,13-ODDA to the trinary pheromone blend significantly reduced captures of male dogwood borer. Bergh et al. (2004) showed that all of the commercial pheromone lures evaluated for attractiveness to dogwood borer contained substantial amounts of (*Z*,*E*)- plus (*E*,*Z*)-3,13-ODDA, and Leskey et al. (2006) found that the most attractive commercial lure contained 1.2% (*E*,*Z*)-3,13-ODDA.

A review of the literature on the seasonal flight activity of dogwood borer in different habitats by Bergh and Leskey (2003) showed shorter annual flight durations in northern versus southern locations, with unimodal flight patterns in the north (Ontario through Connecticut) and bi- or multimodal flight in the south (Kentucky through Georgia). Potter and Timmons (1983) suggested that the early and late flight peaks observed in Kentucky reflected the emergence of dogwood borer primarily from dogwood and apple, respectively, and that emergence from apple occurred mainly in August and September. Pfeiffer and Killian (1999) also showed an early peak of trap capture from nonapple hosts in Virginia, but both early and later peak captures were from apple.

The significantly improved attractiveness and species specificity of the trinary pheromone blend is expected to provide greater resolution to the relative abundance and seasonal period of adult dogwood borer activity across habitat types and geographic locations than has been possible previously. Accurate assessment of these factors will enable better understanding of the risk that dogwood borer poses to the commercial production and protection of its hosts in managed urban landscapes and commercial apple orchards. In turn, this knowledge is critical for developing behaviorally based management strategies. Toward that end, this paper reports a study in which traps containing lures formulated with the trinary sex pheromone blend were used to monitor dogwood borer in three habitats among five eastern states over 2 consecutive yr.

Materials and Methods

Study Sites. Monitoring was conducted in apple orchards, urban landscapes, and native woodland sites in New York, West Virginia, Virginia, North Carolina, and Tennessee. Two sites per habitat were used in all states except New York, where one site per habitat was used, and all sites were used in 2 consecutive yr (2005–2006). The orchard sites in New York, West Virginia, Virginia, and North Carolina were under active management programs for arthropod and disease pests during both years of the study, although none received an insecticide application that specifically targeted dogwood borer. In Tennessee, an abandoned apple orchard was used as one location, and the second orchard was actively managed for insect pests other than dogwood borer.

General site characteristics were as follows

New York—Orchard: 3.2 ha of 15- to 17-yr-old 'Empire' and 'Jonagold' on M.26 rootstock, Wayne Co. Urban: New York State Agricultural Experiment Station campus, Geneva. Woodland: second growth forest bordering mature forest, Seneca Co.

West Virginia—Orchard 1: 9.3 ha of 11-yr-old 'Gala' and 'Ginger Gold' on M.26 rootstock, Berkeley Co. Orchard 2: 200 ha of 10-yr-old 'Gala' on M.26 rootstock, Berkeley Co. Urban 1: 323-ha Shepherd University campus containing flowering dogwood and mixed hardwoods, Shepherdstown. Urban 2: 500-ha National Conservation Training Center campus containing mixed ornamentals and hardwoods, Shepherdstown. Woodland 1: 7 ha of mixed hardwoods in Bolivar Nature Park, Harpers Ferry. Woodland 2: 104 ha of mixed hardwoods and cedar in Yankauer Nature Preserve, Jefferson Co.

Virginia—Orchard 1: 2.0 ha of 15-yr-old 'York' and 'Golden Delicious' on M.7 rootstock, Frederick Co. Orchard 2: 1.6 ha of 9-yr-old 'Gala' and 'Golden Delicious' on M.26 rootstock, Frederick Co. Urban 1: 22.7-ha cemetery containing mature hardwoods, ornamentals, and conifers, Winchester. Urban 2: 70-ha municipal park containing native hardwoods and conifers, Winchester. Woodlands 1 and 2: private hardwood woodlots, Frederick Co.

North Carolina—Orchard 1: 8.1 ha of 14-yr-old 'Gala', 'Fuji', 'Golden Delicious', and 'Ginger Gold' on M.26 rootstock, central Henderson Co. Orchard 2: 2 ha of 5-yr-old 'Honey Crisp' and 'Jonagold' on M.9 rootstock, central Henderson Co. Urban 1: ≈1.0-ha experimental block at the North Carolina State University (NCSU) Experiment Station campus containing a variety of mature and immature deciduous ornamentals, Henderson Co. Urban 2: 5.0-ha section of golf course containing scattered ornamental trees, Hendersonville. Woodland 1: >80 ha of mixed hardwood forest, southeastern Buncombe Co. Woodland 2: ≈1.0-ha mixed hardwood woodlot on NCSU Experiment Station campus, Henderson Co.

Tennessee—Orchard 1: ≈1.0 ha of abandoned orchard on size-controlling rootstock showing burr knots, but for which other horticultural details were unavailable, Knox Co. Orchard 2: ≈0.8 ha of 2-to-8 yr-old 'Arkansas Black', Fuji', 'Gala', 'Jonathan', 'Jonagold', and 'Pink Lady', on M9, M26, and M7 rootstocks, Knox Co. Urban 1: 1.1-ha University of Tennessee Gardens, University of Tennessee Knoxville West Campus, containing several species of mature *Cornus*, central Knox Co. Urban 2: residential neighborhood on the Dogwood Trail in Knoxville, containing mature maple, hickory, oak, and *C. florida*. Woodland 1: 915-ha Oak Ridge Forest, University of Tennessee Forest Resources Research and Extension Center, containing mixed broadleaf deciduous species, northwestern Knox Co. Woodland 2: ≈30-ha woodlot on the Little Tennessee River containing mixed broadleaf deciduous species, central Knox Co.

Table 1. Capture of male dogwood borer moths in pheromone-baited traps deployed in apple orchards, managed urban landscapes, and woodlands in five eastern states, 2005–2006

State	Site	Total no. of moths captured in two traps per site: Orchard		Urban		Woodland	
		2005	2006	2005	2006	2005	2006
New York	1	1,558	2,260	235	278	13	4
West Virginia	1	4,023	4,933	71	66	10	14
	2	4,923	3,664	2	15	1	7
Virginia	1	3,674	4,612	85	202	25	32
	2	2,956	3,721	163	183	14	52
North Carolina	1	5,599	4,377	115	147	8	4
	2	4,675	3,636	732	970	22	12
Tennessee	1	107	24	257	201	26	6
	2	802	628	136	42	15	1
Mean ± SE moths captured per site		3,146 ± 644	3,095 ± 584	200 ± 72	234 ± 96	15 ± 3	15 ± 6

Pheromone Lures and Trapping. The trinary blend of purified dogwood borer sex pheromone components was formulated in red rubber septa (1 mg pheromone/lure) according to Zhang et al. (2005). Lures were shipped by overnight courier to each cooperator and stored in a freezer until deployed in delta style sticky traps (Suterra, Portland OR). Analyses of field-aged lures (Zhang et al. 2005) and annual monitoring data (C.B., unpublished data) have shown that the release of dogwood borer pheromone from red rubber septa is very slow and that lures remain effective for an entire field season. Consequently, lures used in this study were not replaced within each season.

Two pheromone-baited traps were deployed at each site in advance of the beginning of the dogwood borer flight period. Traps were suspended from tree branches at a height of ≈1.5–1.8 m above the ground (Bergh et al. 2006) and were separated by distances ranging from 50 to >300 m among sites. The number of male dogwood borer captured was recorded at approximately weekly intervals until captures had ceased or dropped to near zero. Some investigators manually removed all insects from the trap liners when weekly captures were low and replaced the liners when weekly captures were high or when the liners became dirty or showed excessive wear; others replaced the liner in all traps weekly.

Although voucher specimens of moths collected in this study were not retained, Dr. Tom Eichlin (Senior Insect Biosystematist, CDFA, Plant Pest Diagnostic Branch, Sacramento, CA; retired) examined the moths captured in traps baited with the trinary pheromone blend and deployed in orchards in West Virginia, Virginia, and North Carolina in 2004. His evaluation of hundreds of specimens confirmed that virtually all were *S. scitula.* Nontarget sesiids, *Podosesia aureocincta* Purrington and Nielson, *Synanthedon rileyana* Hy. Edwards, and *Vitacea polistiformis* Harris, were captured infrequently, usually as single individuals and were easily distinguishable from dogwood borer. Voucher specimens of dogwood borer moths reared from larvae collected by D. Frank from orchards in Frederick Co., VA, in 2007 reside in the Virginia Tech Department of Entomology insect collection.

Degree-Day Accumulations to First Capture. Potter and Timmons (1983) and Riedl et al. (1985) reported that 4°C was the most appropriate base temperature for computing cumulative degree-days to points in the annual emergence and flight of dogwood borer. Because dogwood borer overwinters only as larvae in various stages of development (Riedl et al. 1985, Bergh and Leskey 2003) and does not exhibit an obligatory diapause (Wallace 1945, Pless and Stanley 1967), both studies initiated degree-day accumulations from 1 October. In this study, daily minimum and maximum temperatures (°C) were obtained from publicly accessible records for a single location per state that was considered representative of all trapping locations in each. Using the University of California Davis Biometeorology Program (http://biomet.ucdavis.edu/DegreeDays/DegDay.htm), the single-sine method (Baskerville and Emin 1969) was used to determine the cumulative degree-days from 1 October (base 4°C) to first capture at all sites in 2005 and 2006.

Statistical Analysis. Using sites as replicates, the total number of dogwood borer males captured per year and habitat and their interaction were compared by analysis of variance (ANOVA) and Tukey's honestly significant difference (HSD) test, using log transformed moth counts. The duration of the annual flight period was compared between orchard and urban habitats, using the same tests as above but based on non-transformed data. Because few adults were captured in woodland habitats and captures at individual sites were often separated by several weeks, data from woodland sites were excluded from this analysis. All comparisons were considered significantly different at $P < 0.05$.

Results

There was a significant effect of habitat ($F = 67.79$; df = 2,48; $P < 0.0001$) on the total number of male dogwood borer captured. Neither the year in which trapping was conducted ($F = 0.04$; df = 1,48; $P = 0.834$) nor the interaction effect between habitat and year ($F = 0.20$; df = 2,48; $P = 0.818$) were significant. The mean total number of moths captured per site in apple orchards exceeded captures at urban sites by 16 and 13 times and at woodland sites by 210 and 206 times in 2005 and 2006, respectively (Table 1). Mean total captures at urban sites exceeded those in wood-

Table 2. Onset and duration of capture of male dogwood borer moths in pheromone-baited traps deployed in apple orchards and managed urban landscapes in five eastern states, 2005–2006

State	Year	Site	Orchard		Urban		Capture duration (wk)	
			First to last capture	Degree-days to first capture	First to last capture	Degree-days to first capture	Orchard	Urban
New York	2005	1	8 June to 29 Sept.	818	8 June to 29 Sept.	818	17	17
	2006	1	5 June to 10 Oct.	719	5 June to 10 Oct.	719	19	19
West Virginia	2005	1	17 May to 11 Oct.[a]	1,043	24 May to 19 Sept.	1,110	22	18
		2	17 May to 11 Oct.[a]	1,043	24 May to 13 June	1,110	22	4
	2006	1	2 May to 25 Oct.	961	16 May to 3 Oct.	1,101	26	21
		2	30 May to 18 Oct.	1,273	8 May to 29 Aug.	1,027	21	17
Virginia	2005	1	13 May to 7 Oct.	966	20 May to 9 Sept.	1,045	22	17
		2	13 May to 7 Oct.	966	20 May to 7 Oct.	1,045	22	21
	2006	1	5 May to 20 Oct.	966	5 May to 6 Oct.	966	25	23
		2	5 May to 13 Oct.	966	5 May to 6 Oct.	966	24	23
North Carolina	2005	1	10 May to 17 Oct.	1,280	18 May to 17 Oct.	1,384	24	23
		2	10 May to 24 Oct.	1,280	18 May to 24 Oct.	1,384	25	24
	2006	1	24 April to 23 Oct.	1,116	24 April to 2 Oct.	1,116	27	24
		2	1 May to 25 Sept.	1,179	8 May to 28 Aug.	1,255	24	25
Tennessee	2005	1	10 May to 14 Sept.	1,589	10 May to 18 Oct.	1,589	19	24
		2	10 May to 18 Oct.	1,589	10 May to 18 Oct.	1,589	24	24
	2006	1	9 May to 12 Sept.	1,569	9 May to 13 Oct.	1,569	20	23
		2	9 May to 19 Oct.	1,569	9 May to 13 Sept.	1,569	24	19
Mean ± SE capture duration (wk)							22.6 ± 0.6a	20.3 ± 1.2a

Means followed by the same letter are not significantly different at $P = 0.05$.

[a] Traps in West Virginia may have slightly underestimated the onset of dogwood borer flight in apple orchards in 2005, because relatively large numbers of moths were captured during the first week of monitoring. Degree-days to first capture were accumulated from 1 Oct. using base 4°C.

land habitats by 13 and 16 times in 2005 and 2006, respectively (Table 1).

With the exception of one orchard site in West Virginia in 2006, where first moth capture was recorded on 30 May, the onset of male flight in New York orchards occurred ~4–6 wk later than in the other states. In all states, the first capture of moths in urban habitats most often occurred either simultaneously with or within 1 wk of first capture in apple orchards (Table 2). The onset of male captures in apple orchards and urban habitats was generally consistent within each state between 2005 and 2006 and the predictive value of the date of first capture or degree-days to first capture seemed to be similar. Degree-day summations from 1 October showed a trend toward increasing numbers of accumulated heat units on the date of first capture from north to south (Table 2). The period from first to last moth capture (wk) did not differ significantly between orchards and urban sites ($F = 2.97$; df = 1,34; $P > 0.093$), and the duration of flight in apple orchards and urban sites in New York tended to be somewhat shorter than in those habitats further south.

In the New York orchard, there was not a clear or consistent indication of distinct peaks that might be interpreted as either uni- or bimodal flight (Fig. 1). In West Virginia, Virginia, and North Carolina, where large numbers of moths were captured in each of two orchard sites, there tended to be fairly close concurrence in the peaks and troughs of mean weekly captures between sites (Fig. 1). Across the orchard sites in those three states, there seemed to be a general tendency for mean weekly captures to show an initial peak of emergence and flight activity from late May through mid-July and a second major peak from late August through mid-September, although substantial weekly fluctuations within each season were not uncommon. Captures at those urban sites with relatively large moth counts (Fig. 2) exhibited similar temporal patterns to those in apple orchards. Captures at woodland sites (Fig. 3) tended to occur predominantly from mid-May through about mid-June. Thereafter, weekly captures among the woodland sites were inconsistent in both years.

Discussion

Our use of traps baited with the trinary blend of dogwood borer pheromone components in several habitats across multiple states in consecutive years has enabled resolution or confirmation of some of the questions and issues regarding the relative abundance and seasonal flight patterns of dogwood borer. Our data confirmed that dogwood borer populations in typical commercial apple orchards were many times greater than in other habitats, and several reasons may be invoked to explain this. Importantly, apples are typically grown in monoculture on a relatively large scale, presumably with accompanying effects on pest density. Most new apple orchards consist of cultivars propagated on size-controlling rootstocks, enabling higher densities of trees per acre. The increasing use of these rootstocks in North America has been cited as the proximate cause of the increased pest status of dogwood borer in apple orchards (Riedl et al. 1985, Weires 1986), paralleling a situation that occurred in Europe with the apple clearwing moth, *Synanthedon myopaeformis* (Borkh.) (Dickler 1976). Apple variet-

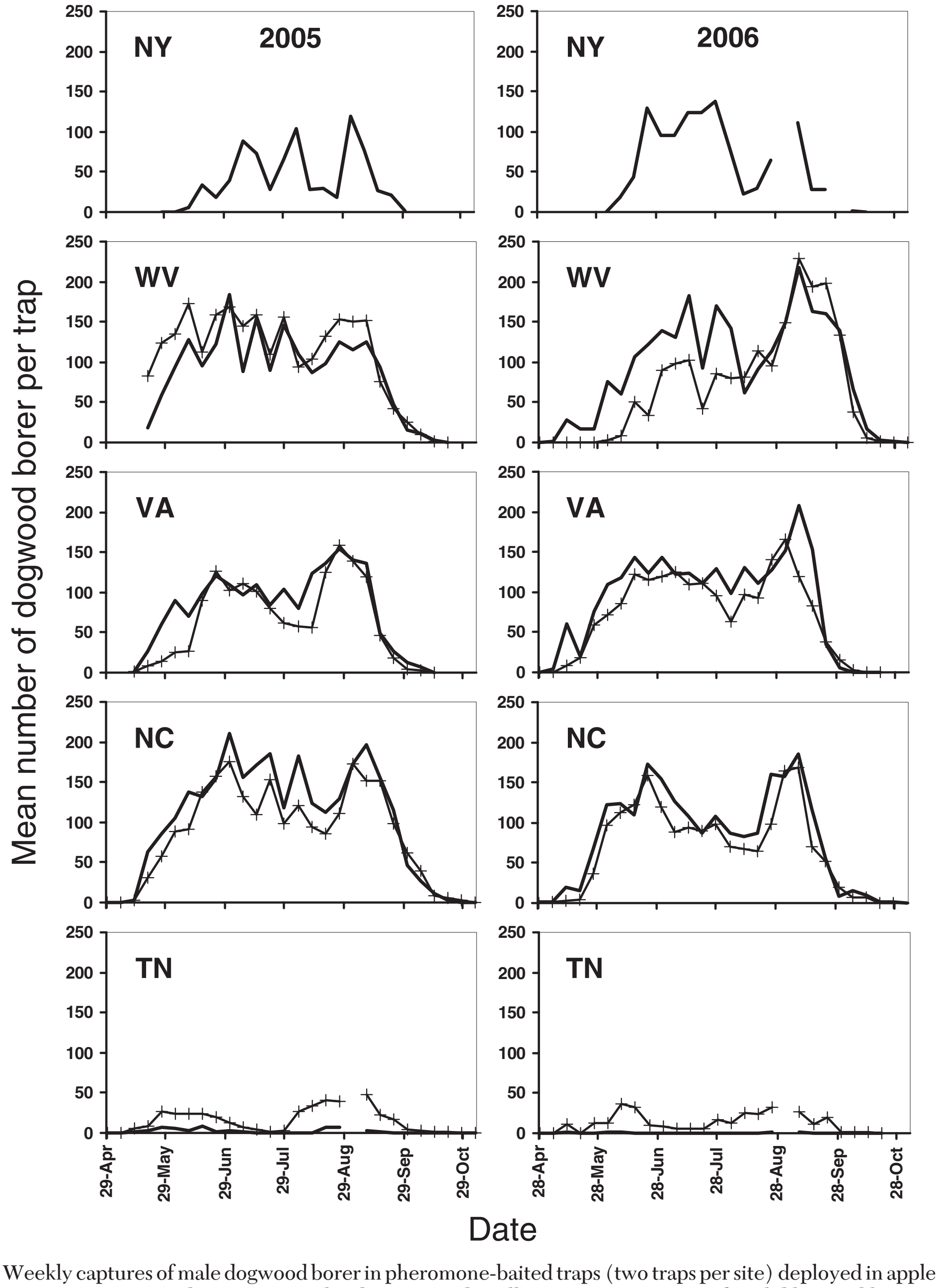

Fig. 1. Weekly captures of male dogwood borer in pheromone-baited traps (two traps per site) deployed in apple orchards in five eastern states in 2005 and 2006. Two orchards were used in all states except New York; solid line and line with crosses represent orchards 1 and 2, respectively. Broken lines denote weeks when moth captures were not recorded.

ies propagated on size-controlling rootstocks tend to produce burr knots on the rootstock shank (Rom 1970, 1973) and, in some varieties, also on the trunk and scaffold limbs as trees mature (Marini et al. 2003). Infestation of young trees by dogwood borer typically begins in burr knots at the tree base and new orchards can be attacked in the first year of planting (Leskey and Bergh 2005). Leskey (unpublished data) found that the developmental duration of dogwood borer larvae feeding in burr knots on young, potted apple trees held outdoors was much shorter than has been reported previously for development on dogwood (Pless and Stanley 1967). In Europe, Dickler (1976) reported that larval *S. myopaeformis* developed more rapidly in apple burr knots than in other apple tissues. Although further verification of a shortened developmental duration on apple burr knot tissue is necessary, this may translate to bivoltinism in apple orchards, at least in the more southern portions of its range, and contribute to higher populations.

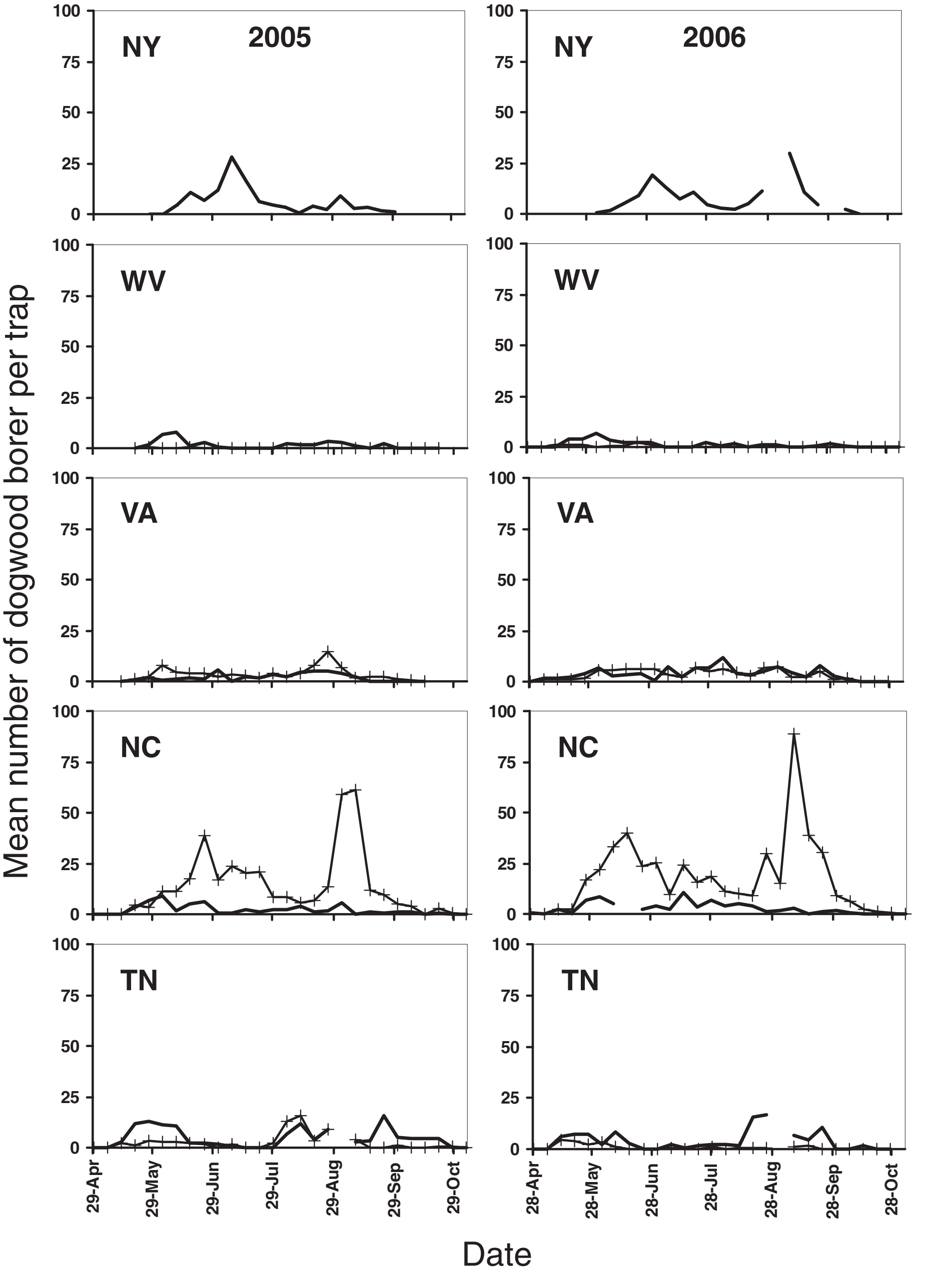

Fig. 2. Weekly captures of male dogwood borer in pheromone-baited traps (two traps per site) deployed in managed urban landscapes in five eastern states in 2005 and 2006. Two urban sites were used in all states except New York; solid line and line with crosses represent sites 1 and 2, respectively. Broken lines denote weeks when moth captures were not recorded.

Total dogwood borer captures in managed urban landscapes were quite variable among sites, although captures between years showed much greater consistency. The golf course site in North Carolina yielded the highest numbers of borers in both years, totaling 1,702 moths. Given that our traps provided an indication of only one half of the larval population (i.e., males), the number of moths captured at that site may indicate a potentially troublesome infestation of the ornamental plants maintained there, although larval count or moth capture thresholds for dogwood borer from any host plant have not been established and are complicated by the diversity of potential host plants in the urban settings. Differences among the urban sites in the apparent size of dogwood borer infestations may have been in part caused by the host plants present. As with commercial apple varieties, ornamental crabapples on size-controlling rootstocks also pro-

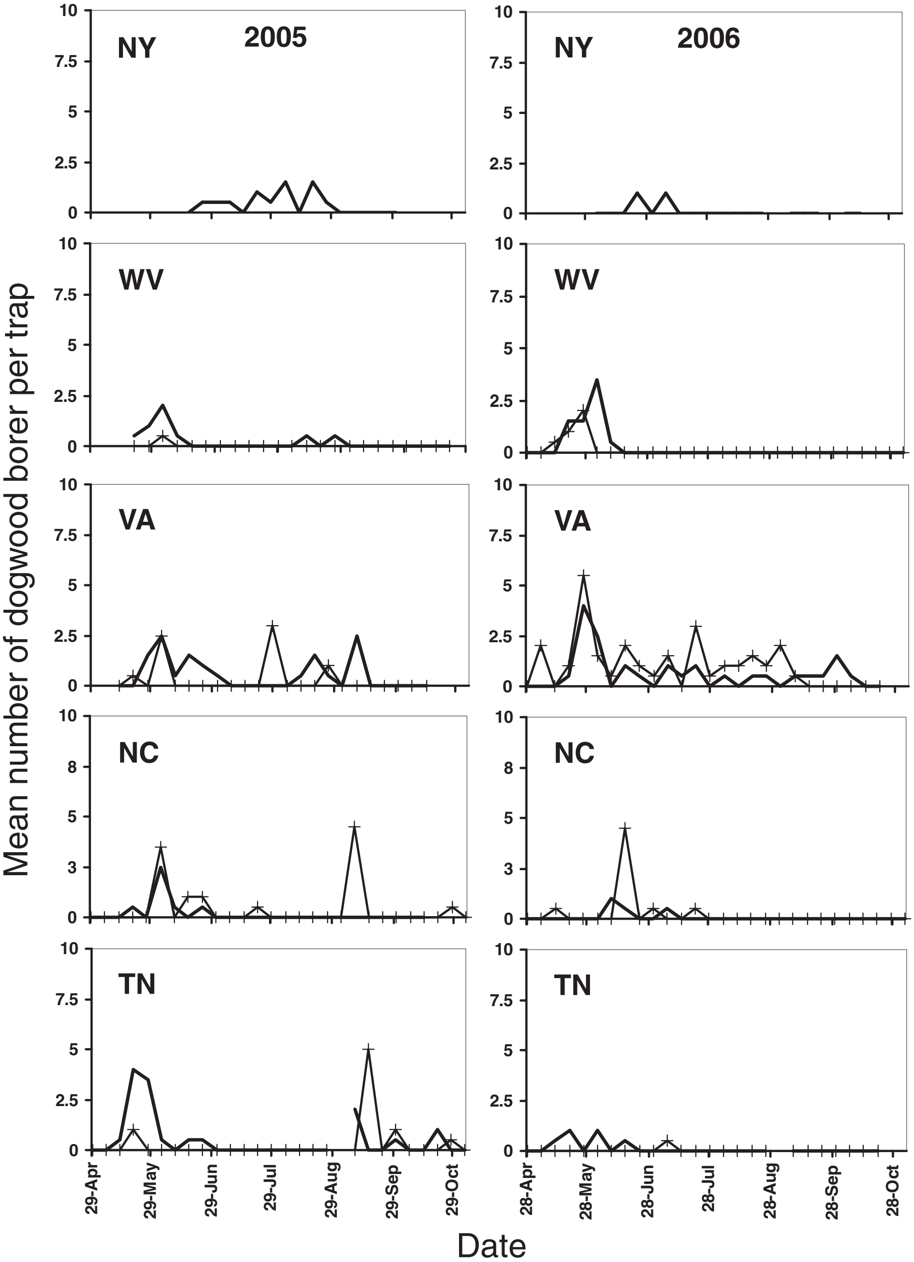

Fig. 3. Weekly captures of male dogwood borer in pheromone-baited traps (two traps per site) deployed in woodlands in five eastern states in 2005 and 2006. Two woodland sites were used in all states except New York; solid line and line with crosses represent sites 1 and 2, respectively. Broken lines denote weeks when moth captures were not recorded.

duce burr knots at the tree base. Leskey and Bergh (2005) showed that at least some varieties of these are highly susceptible to damage from dogwood borer. Another important factor that likely influences the extent of infestation of deciduous ornamental plants in urban settings is the intensity of landscape management. Flowering dogwood and other hosts become susceptible to attack when activities such as mowing, pruning, and weed management damage tree bark (Potter and Timmons 1981, Rogers and Grant 1990). Several studies have reported preferential oviposition by mated female dogwood borer near damaged areas on dogwood (Herrick 1904, Engelhardt 1932, Wallace 1945). The lack of such damage to flowering dogwood and other host plants in woodlands has been invoked to explain the low incidence of dogwood borer infestation of trees in that habitat (Underhill 1935) and the low numbers of moths trapped at woodland sites in this study, despite a diversity of potential host plants, tend to support that contention.

Our trapping data showed evidence of a bimodal pattern of seasonal emergence and flight in apple orchards and urban landscapes. While confirming earlier reports of bimodal flight (Potter and Timmons 1983, Rogers and Grant 1991, Pfeiffer and Killian 1999, Eliason and Potter 2000), these data dispel previous suggestions that the early and late peaks reflect differential emergence from different hosts. Dogwood borer emerged from apple orchards continuously and in substantial numbers over a prolonged period each year and exhibited early and late peaks that could not be ascribed to emergence from other hosts. Similarly, in urban settings where there were substantial populations of dogwood borer, moths were captured continuously for several months, and the early and late peaks were not caused by the influence of emergence from hosts in other habitats. As for apple, the underlying reason(s) for bimodal flight of dogwood borer in urban landscapes remains poorly understood and not adequately addressed, highlighting the need for further examination of its developmental rate, survivorship, and fitness on different hosts.

Potter and Timmons (1983) concluded that degree-day accumulations beginning on 1 October and based on a lower threshold temperature of 4°C provided a reasonably accurate prediction of the onset of flight. Using the same parameters, Riedl et al. (1985) reported that the cumulative degree-days to first capture seemed more variable than the date of first capture and suggested that the latter was a better predictor. Although our study was not designed to address the utility of cumulative degree-days to predict first flight, a post hoc analysis suggested that either calendar date or region-specific degree-day summations provided reasonable indications of first capture in orchards and urban habitats (Table 2). The data showed average summations for urban sites in North Carolina (1,285 ± 64 [SE] DD) that were remarkably similar to those reported by Potter and Timmons (1983) for Lexington (1,256 ± 8 DD) and Louisville (1,286 ± 36 DD), KY, although that also showed unexpectedly large differences between North Carolina and Tennessee (Table 2), which may have been because of differences in elevation between the sites in each state. Data from New York orchards showed degree-day summations to first capture (769 ± 50 DD) that were similar to those reported from orchards in New York by Riedl et al. (1985) (973 ± 72 DD). The underlying reasons for the trend toward an increasing number of degree-days to first capture from northern through more southern states remain speculative but may be a function of heat unit accumulations in southern regions that did not influence larval development. The relationship between temperature and the developmental rate of dogwood borer larvae has not been studied but would likely offer important insights into its emergence, flight patterns, and voltinism.

In combination with the findings of Leskey and Bergh (2005), our data suggest that new apple orchards planted on size-controlling rootstocks are at greater risk of damaging levels of dogwood borer when they are in proximity to existing orchards than when near native woodlands. Many commercial apple growers in the eastern United States are seeking additional revenue streams through diversification into other agricultural and horticultural enterprises. Growers contemplating production of ornamental landscape plants in proximity to existing apple orchards should consider the potential risks and additional management requirements posed by dogwood borer populations.

Chlorpyrifos is currently recognized as the most effective product for managing clearwing borers in commercial orchards and nurseries, although it is no longer available to homeowners for landscape pest management. A supplemental label specifically for borers in apple permits drench sprays of chlorpyrifos to the lower trunk of trees but does not provide for control of borer populations feeding at sites higher in the tree. Beginning in 2009, its use in apple will be restricted to one application per season, regardless of formulation, timing, or pest(s) targeted and, although there are not immediate concerns about the loss of chlorpyrifos, its availability in the long term remains uncertain. The loss of chlorpyrifos would create a significant gap in the ability of apple growers to protect trees from dogwood borer (Kain et al. 2004), particularly orchards in the early years of establishment and growth (Leskey and Bergh 2005). Improved knowledge of the chemical ecology of dogwood borer, its temporal patterns of emergence, and its relative abundance among habitats and geographical regions will enhance our ability to develop pheromone-based management approaches for it (Leskey et al. 2009).

Acknowledgments

We thank J. Engelman, S. Wright, T. Hancock, S. Schoof, and J. Nie for excellent technical assistance. This research was supported primarily by Grant 2005-34103-15592 from the USDA–CSREES Southern Region IPM Grants Program.

References Cited

Baskerville, G. L., and P. Emin. 1969. Rapid estimation of heat unit accumulation from maximum and minimum temperatures. Ecology 50: 514–517.

Bergh, J. C., and T. C. Leskey. 2003. Biology, ecology, and management of dogwood borer in eastern apple orchards. Can. Entomol. 135: 615–635.

Bergh, J. C., T. C. Leskey, and A. Zhang. 2004. Discrimination by male dogwood borer, *Synanthedon scitula* (Lepidoptera: Sesiidae), among traps baited with commercially available pheromone lures. J. Econ. Entomol. 97: 344–352.

Bergh, J. C., T. C. Leskey, J. M. Sousa, and A. Zhang. 2006. Diel periodicity of emergence and premating reproductive behaviors of adult dogwood borer (Lepidoptera: Sesiidae). Environ. Entomol. 35: 435–442.

Dickler, V. E. 1976. Zur biologie und schadwirkung von *Synanthedon myopaeformis* Brkh. (Lepid., Aegeriidae), einem neuen Schädling in Apfeldichtpfanzungen. Z. Angew Entomol. 82: 259–266.

Eliason, E. A., and D. A. Potter. 2000. Dogwood borer (Lepidoptera: Sesiidae) infestation of horned oak galls. J. Econ. Entomol. 93: 757–762.

Engelhardt, G. P. 1932. Business proceedings of the eastern branch of the American Association of Economic Entomologists. J. Econ. Entomol. 25: 293–294.

Greenfield, M. D. 1978. Niche segregation of adult clearwing moths (Lepidoptera: Sesiidae) in Wisconsin. PhD dissertation, University of Wisconsin, Madison, WI.

Herrick, G. W. 1904. Insects injurious to pecans. Miss. Agric. Exp. Stn. Bull. 86: 11–15.

Johnson, W. T., and H. H. Lyon. 1991. Insects that feed on trees and shrubs, 2nd ed. Comstock, Ithaca, NY.

Kain, D. P., R. W. Straub, and A. M. Agnello. 2004. Incidence and control of dogwood borer (Lepidoptera: Sesiidae) and American plum borer (Lepidoptera: Pyralidae) infesting burrknots on clonal apple rootstocks in New York. J. Econ. Entomol. 97: 545–552.

Leskey, T. C., and J. C. Bergh. 2005. Factors promoting infestation of newly planted, non-bearing apple orchards by dogwood borer, *Synanthedon scitula* Harris (Lepidoptera: Sesiidae). J. Econ. Entomol. 98: 2121–2132.

Leskey, T. C., J. C. Bergh, J. F. Walgenbach, and A. Zhang. 2006. Attractiveness and specificity of pheromone-baited traps for male dogwood borer, *Synanthedon scitula* Harris (Lepidoptera: Sesiidae). Environ. Entomol. 35: 268–275.

Leskey, T. C., J. C. Bergh, J. F. Walgenbach, and A. Zhang. 2009. Evaluation of pheromone-based management strategies for the dogwood borer (Lepidoptera: Sesiidae) in commercial apple orchards. J. Econ. Entomol. 102: 1085–1093.

Marini, R. P., M. L. Parker, J. A. Barden, and C. R. Unrath. 2003. The effect of eight dwarf rootstocks on burrknot development on 'Gala' apple trees at two locations. J. Am. Pomol. Soc. 57: 93–96.

Pfeiffer, D. G., and J. C. Killian. 1999. Dogwood borer (Lepidoptera: Sesiidae) flight activity and an attempt to control damage in 'Gala' apples using mating disruption. J. Entomol. Sci. 34: 210–218.

Pless, C. D., and W. W. Stanley. 1967. Life history and habits of the dogwood borer, *Thamnosphecia scitula* (Lepidoptera: Aegeriidae) in Tennessee. Tenn. Agr. Exp. Stn. 42: 117–123.

Potter, D. A., and G. M. Timmons. 1981. Factors affecting predisposition of flowering dogwood trees to attack by the dogwood borer. HortScience 16: 677–679.

Potter, D. A., and G. M. Timmons. 1983. Flight phenology of the dogwood borer (*Lepidoptera:Sesiidae*) and implications for control in *Cornus florida* L. J. Econ. Entomol. 76: 1069–1074.

Riedl, H., R. W. Weires, A. Seaman, and S. A. Hoying. 1985. Seasonal biology and control of the dogwood borer, *Synanthedon scitula* (Lepidoptera: Sesiidae) on clonal apple rootstocks in New York. Can. Entomol. 117: 1367–1377.

Rogers, L. E., and, J. F. Grant. 1990. Infestation levels of dogwood borer (Lepidoptera: Sesiidae) larvae on dogwood trees in selected habitats in Tennessee. J. Entomol. Sci. 25: 481–485.

Rogers, L. E., and J. F. Grant. 1991. Seasonal incidence of male dogwood borer (Lepidoptera:Sesiidae) and other species of clearwing moths in selected habitats in Tennessee. Environ. Entomol. 20: 520–525.

Rom, R. C. 1970. Burr knot observations on clonal apple rootstocks in Arkansas. Fruit Var. Hortic. Dig. 24: 66–68.

Rom, R. C. 1973. Burr knot characteristics of six clonal apple rootstocks. Fruit Var. J. 27: 84–86.

Underhill, G. W. 1935. The pecan tree borer in dogwood. J. Econ. Entomol. 28: 393–396.

Wallace, P. P. 1945. Biology and control of the dogwood borer, *Synanthedon scitula* Harris. Conn. Exp. Stn. Bull. 488: 373–395.

Warner, J., and S. Hay. 1985. Observations, monitoring, and control of clearwing borers (Lepidoptera: Sesiidae) on apple in central Ontario. Can. Entomol. 117: 1471–1478.

Weires, R. 1986. Five years research and experience with control of dogwood borer and related burr knot problems. Compact Fruit Tree 19: 86–89.

Zhang, A., T. C. Leskey, J. C. Bergh, and J. F. Walgenbach. 2005. Sex pheromone of the dogwood borer (DWB), *Synanthedon scitula.* J. Chem. Ecol. 31: 2463–2479.

Received 2 May 2008; accepted 23 January 2009.