Repellents to Prevent Ambrosia Beetle Infestations in Apples

Arthur Agnello
Department of Entomology, New York State Agricultural Experiment Station, Cornell University, Geneva, NY

Keywords: black stem borer, Xylosandrus germanus, apple decline, trunk sprays, verbenone

This research was supported by the New York Apple Research and Development Program

The black stem borer, *Xylosandrus germanus* (Blandford) (Coleoptera: Curculionidae: Scolytinae), is an ambrosia beetle that is a serious pest in ornamental tree nurseries and landscapes in North America (Oliver and Mannion 2001, Rabaglia et al. 2006, Ranger et al. 2016). Originally from Asia, it now occurs throughout Europe and the US, having been first documented in New York in greenhouse-grown grape stems (Felt 1932, Weber and McPherson 1983). Since then, it has become established in much of the United States (Wood 1982, Rabaglia et al. 2006). It has had longstanding pest status in ornamental nurseries, with a wide host range including oak, elm, maple, beech, redbud, hickory, chestnut, magnolia, dogwood, and black walnut (Hoffmann 1941, Weber and McPherson 1983, Ranger et al. 2010). Infestations in apple orchards were first reported in Ohio in 1982 (Hall et al. 1982).

"Because verbenone has demonstrated efficacy in related groups of bark boring beetles, as well as for this species, we proposed that it might offer a higher degree of prevention than using insecticide sprays alone, so we incorporated it into orchard trial treatments in an effort to improve their effectiveness at preventing black stem borer attacks of target trees."

The adult female (Figure 1), which is approximately 2 mm in length, attacks and bores 1-mm diam holes (Figure 2) to form galleries in the heartwood of trunks or limbs of stressed, dying or recently dead trees, including stressed trees that are apparently healthy. Galleries are excavated by the foundress, and are composed of entrance tunnels, brood chambers containing eggs and immatures, and branch tunnels where the young develop; this arrangement accommodates all life stages and developmental processes of the insect's life history (Figure 3). Larvae pass through three instars, and development from egg to the adult stage takes approximately 30 days. The species is bivoltine in New York and overwinters as adults, primarily females, in galleries of its host trees, frequently located at the base of the trunk, and which can contain dozens of beetles.

Ambrosia beetles derive nourishment during the larval and adult stages from *Ambrosiella grosmanniae*, a mutualistic fungus carried by the adult female in a specialized internal pouch structure located in the cuticle behind the insect's head. The beetles feed directly on this fungal growth, rather than the host plant tissue; however, their presence signals the tree that it is under attack, and as the tree walls off its vascular system in response, infestation symptoms develop that include wilting, dieback, tree decline and death (Weber and McPherson 1983, Oliver and Mannion 2001, Ranger et al. 2016) (Figure 4).

A number of stressors, including flooding, drought, and freezing exposure have been identified as potential causes of physiological stress that preferentially attract ambrosia beetles through the production of ethanol, which has been documented to be a strong attractant to the beetles. Ethanol-baited traps have been shown to be useful for monitoring the flight activity of ambrosia beetles in ornamental nurseries (Oliver and Mannion 2001,

Figure 1. Black stem borer, *Xylosandrus germanus*, adult female (photo: Steve Valley, Ore. Dept. Ag.).

Figure 2. Holes and ooze from black stem borer infestation in stressed tree (photo: J. Carroll, NYS IPM).

Figure 3. Black stem borer gallery with adults and brood (photo: USDA-ARS).

Figure 4. Apple tree infested by black stem borer showing signs of decline (photo: M. Biltonen, Apple Leaf).

Reding et al. 2010). Reding et al. (2013) detected no attack or flight activity for *X. germanus* unless temperatures reached at least 20°C for 1–2 d, with a mean occurrence of first capture in ethanol-baited bottle traps of 76 degree days (DD) (base 10°C) from 1 Jan. Ranger et al. (2013a) demonstrated that *X. germanus* preferentially lands on and attacks physiologically stressed hosts, and that ethanol plays a primary role in mediating this interaction.

Few studies have specifically addressed control of *X. germanus*, but successful control of a related species, *X. compactus* (Eichhoff), was achieved in flowering dogwood trees sprayed with chlorpyrifos early in the spring (Mangold et al. 1977). In vitro tests showed high toxicity of chlorpyrifos, bifenthrin, and permethrin against *X. crassiusculus* (Motschulsky) (Hale and Oliver 1999). However, Mizell and Riddle (2004) found chlorpyrifos to be less effective against *X. crassiusculus* in dipped hardwood bolts than either bifenthrin or cypermethrin, although no insecticide was completely effective in preventing attacks. Frank and Bambara (2009) describe chlorpyrifos as being largely ineffective against this species.

We documented the occurrence and timing of black stem borer in over 50 orchards using ethanol-baited traps from 2014–2016 (Agnello et al. 2017). First captures ranged from 48–83 degree days (base 10°C) from 1 Jan. Captures were numerically higher at the orchard-woods interface than within the orchard interior, but differences were not significant in locations with lower populations. Control using insecticide trunk sprays was tested in potted, waterlogged apple trees placed in orchards and nurseries, and inside wooded areas adjacent to orchards. Overall, insecticide sprays were inconsistent and marginal in preventing new infestations. Chlorpyrifos significantly reduced infestations vs. lambda-cyhalothrin and untreated trees at one location in the 2015 orchard trials, but otherwise performed no better than other treatments (Agnello et al. 2017).

The repellent verbenone has been observed to discourage beetle attacks by related species of pine bark beetles. Ranger et al. (2013b) reported a higher density of attacks from several ambrosia beetle species including *X. germanus* on trap trees farthest away from a verbenone dispenser. This product, a natural terpene compound found in many plants such as pine trees, is used in the control of bark beetles such as mountain pine beetle and southern pine bark beetle. It is produced, probably as a defensive mechanism, when the number of insects in an infested tree approaches the maximum that the tree can support, and acts as repellent to other beetles. It was shown to inhibit the attraction of *X. germanus* to artificially damaged red pine trap trees and baited traps (Dodds and Miller 2010). It has been found to deter both *X. germanus* and *X. crassiusculus* from ethanol-baited traps, and to reduce ambrosia beetle attacks on ethanol-injected trap trees (Dodds and Miller 2010, Ranger et al. 2013b). Because verbenone has demonstrated efficacy in related groups of bark boring beetles, as well as for this species, we proposed that it might offer a higher degree of prevention than using insecticide sprays alone, so we incorporated it into orchard trial treatments in an effort to improve their effectiveness at preventing black stem borer attacks of target trees.

Methods

Trap Monitoring. In 2016, traps were placed in a total of 43 orchards to determine the occurrence and timing of BSB. Traps consisted of inverted 1.75-L plastic juice bottles, which had 6 x 10-cm rectangles cut out of each of the sides and were baited in the upper portion of the traps with pouch-style dispensers loaded with 10 ml of 95% ethanol; water with a small amount of dish detergent placed in the cap was used as a capture medium (Figure 5). The traps were suspended from 1.2-m tall metal garden hangers at a 1-m height; at each site, two traps were placed on an edge of the planting adjacent to a hedgerow, and two additional traps were located in the orchard interiors, ~20–30 m from the orchard edge and in proximity to previously attacked trees, to verify their attractiveness. Traps were checked 1–2 times per week starting in mid-April, before maximum temperatures of 20°C began to occur, and through the summer. Beetles trapped were collected, sorted and identified. In 2017, traps were placed in 30 orchards around the state, mostly in sites used the previous year; traps and monitoring procedures were the same as in 2016.

Figure 5. Ethanol bottle trap for black stem borer.

Control Trials 2016. In two Wayne Co. sites, Sodus and Wolcott, with known orchard infestations of black stem borer (BSB), trials were set up using potted 'Rome Beauty' nursery apple trees inside wooded areas directly adjacent to the orchard planting. The potted trees were flooded to stress them into producing ethanol, so as to attract beetles and promote new attacks. Additionally, individual ethanol lures were attached to each tree to increase their attractiveness to the beetles. On May 10, just as the adult flight was starting, trunks of the potted trees were sprayed with one of four candidate insecticides using a Solo backpack sprayer: Lorsban Advanced (chlorpyrifos, Dow AgroSciences), 1.5 qt/100 gal; Cobalt (chlorpyrifos+lambda-cyhalothrin, Dow AgroSciences), 1.3 qt/100 gal; Perm-Up (permethrin, UPI), 10 fl oz/100 gal; or Danitol (fenpropathrin, Valent), 16 fl oz/100 gal; plus a Check (unsprayed). Trees were arranged in circular 5-tree groupings in the wooded areas, which were replicated 10 times at each site. Another identical set of 10 replicate tree groupings was also deployed at each site, with a dispenser of a commercial repellent, BeetleBlock (verbenone, ChemTica) hung ~1 m high on a pole placed in the center of each of the 5-tree groupings (Figure 6). Half of the treated replicates were evaluated for infestations on July 6, after the end of the first adult flight of the season, and the remaining replicates were evaluated near the end of the season, on August 19. Infestations were quantified and assessed by destructive sampling and dissection in the lab, to determine the following classes of infestation in the test trees: number of attack sites (holes)/tree, number of trees containing empty galleries, number of trees containing live adults, dead adults, and brood.

Control Trials 2017. In three Wayne Co. sites with known orchard infestations of BSB – Sodus, Huron, and Lyons – trials were set up using potted 'Harrison.G-935' nursery apple trees inside or alongside of wooded areas directly adjacent to the orchard plantings. The potted trees were flooded to stress them into producing ethanol and individual ethanol lures were attached to each tree, as above. On May 11, just as the adult flight was starting, trunks of the potted trees were treated with one of eight candidate preventive trunk treatments:

1 - Lorsban Advanced (chlorpyrifos, Dow AgroSciences), 1.5 qt/100 gal, applied using a Solo AccuPower 416 battery-powered backpack sprayer with a TeeJet 8004 LP flat fan nozzle

2 - SPLAT Verb (verbenone repellent, ISCA Technologies, EPA Reg. No. 80266-20), 35.0 g/tree, applied in a vertical line up the trunk starting just above the graft union (Figure 7A) using a pre-calibrated caulking gun

3 - Lorsban Advanced followed by SPLAT Verb

4 - SPLAT "A" experimental verbenone-based formulation, 35 g/tree

5 - SPLAT "B" experimental verbenone-based formulation, 35 g/tree

6 - SPLAT "C" experimental verbenone-based formulation, 35 g/tree

7 - Disrupt Micro-Flake VBN (verbenone repellent, Hercon Environmental, EPA Reg. No. 8730-68) 4.0 g/tree, applied by hand

Figure 6. Group of potted trees showing individual ethanol lures plus a central verbenone dispenser.

Figure 7. Potted apple trees showing trunk applications of SPLAT Verb (A) or Disrupt Micro-Flake VBN (B).

with brushed-on Micro-Tac adhesive to the trunk up to 12-15" above the graft union (Figure 7B)

8 - Lorsban Advanced followed by Disrupt Micro-Flake VBN

9 - Blank flakes

10 - Untreated Check

Each treatment was replicated on 6 trees, which were arranged in 6-tree groupings at each of the sites, with groups of trees separated by a distance of 30 m (one group per treatment per site).

Results

Trap Monitoring. In 2016, beetle activity began at a continuous but low level on 19 Apr statewide, although sustained captures did not occur until 15–17 May (corresponding to 50–65 and 48–109 $DD_{10°C}$ among trap sites in the Lake Ontario and Eastern NY regions, respectively). The first flight, which peaked in the Lake Ontario counties on 31 May and 1 Jun in ENY, subsided by 13–15 Jun statewide. In 2017, beetle activity began in most locations on 3-4 May statewide (corresponding to 96–109 and 102–157 $DD_{10°C}$ among trap sites in the Lake Ontario and Easterm NY regions, respectively). The first peak flight was May 17 in Wayne Co., with over 300 average beetles per edge trap (Figure 8A), and 22-24 May in the other locations around the state. The second summer flight proceeded at much lower levels statewide through August, as has been observed previously, with very few beetles captured after Sep 1. In the western NY trapping sites, higher numbers of beetles were routinely captured at the orchard edge than in the interior, although appreciable numbers were taken inside the blocks at some of the most heavily populated sites (Fig. 8B).

Control Trials 2016. Results on both evaluation dates at Wolcott (Table 1) showed no statistical differences between the insecticide-alone or insecticide+verbenone treatments in any of the infestation categories. There was a significant effect of evaluation date for the number of attack sites and the number of sites containing empty galleries (both higher on Aug 19, $P = 0.02$) and brood (higher on 6 July, $P < 0.001$). At Sodus (Table 2), results on July 6 showed no statistical differences between the insecticide-alone or insecticide+verbenone treatments in any of the infestation categories. However, on the Aug 19 evaluation date, the addition of verbenone to either the check or permethrin treatments resulted in significantly fewer attack sites containing brood ($P = 0.012$).

Control Trials 2017. The preliminary evaluation revealed no infestations or injury whatsoever at the Huron or Lyons sites, and only marginal damage in two of the treatments at Sodus – one damaged tree in the SPLAT Verb treatment, and one in the untreated Check. On the date of the final evaluation, only the Sodus site showed measurable levels of damage in the different treatments (Table 3); once again, the Huron site was without damage, and at the Lyons site there were only 2 infested trees, both in the untreated Check.

The final evaluation results at Sodus did show some statistical differences among the treatments. For the number of attack sites (holes) per tree, neither of the plain verbenone treatments (SPLAT Verb or Disrupt Micro-Flake VBN) were significantly different from the Check or the Blank Flakes treatments, and two of the experimental SPLAT formulations, "B" and "C", were the only treatments showing zero damage. Lorsban Advanced, with a low level of attack sites, was statistically comparable to SPLAT "B" and "C"; however, Lorsban in combination with

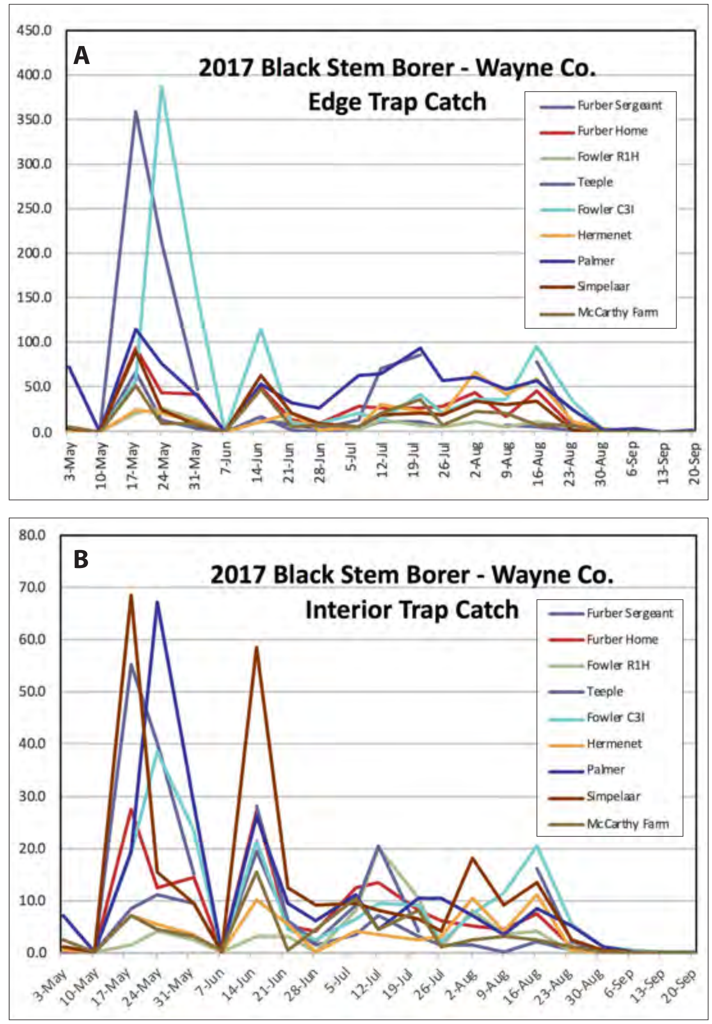

Figure 8. Trap captures of black stem borer in the Lake Ontario region, 2017 (A, captures at the orchard edge; B, captures in the orchard interior).

either of the verbenone formulations was no better than any of the other treatments. Lorsban plus the micro-flakes actually had the highest incidence of attack sites.

Results were comparable for the number of sites with empty (aborted) galleries; only SPLAT "B" and "C" had zero incidence for this category of damage. In the category of number of sites containing adults, results were zero for the Lorsban and all of the SPLAT formulations, with some statistical separation among treatments. There were no statistical differences among any of the treatments for number of attack sites containing brood. Many of the infestation category readings had a high level of variability, so results showing statistical differences were not always the lowest mean values. For the entire evaluation, only the SPLAT "B" and SPLAT "C" treatments had zero across all infestation categories.

Discussion

Although combining verbenone dispensers with insecticide sprays in 2016 resulted in some numerical reduction of infestation numbers and categories in our trials, effects were significant only at the Sodus location, and only for numbers of sites containing brood in the permethrin and check treatments (Table 5). It is possible that verbenone volatilizing from a pouch dispenser in proximity to the trees was insufficiently active against the beetles searching for a host to colonize. Gillette et al. (2006) reported that lodgepole pines sprayed directly with verbenone-releasing flakes had significantly lower attack density by *Dendroctonus ponderosae* than untreated control trees for up to 8 wk after application, and none of the treated trees were attacked by red turpentine beetle *D. valens*, whereas control trees averaged nearly two attacks per tree. Ten months after application, treated trees showed significantly lower mortality than control trees. For this reason, we decided to test topically applied verbenone formulations in 2017.

It is not known why the overall infestation levels in 2017 were

Table 1. Mean (± SE) infestation levels by *X. germanus* in potted apple trees on two evaluation dates, after a trunk application of a preventive insecticide, with and without a verbenone repellent, Wolcott. 2016.

	no. attack	no. sites/tree containing			
Evaluation date[a]/treatment	**sites/tree**	**empty galleries**	**brood**	**live adults**	**dead adults**
6 Jul					
Check, no verbenone	6.2 ± 2.1	1.8 ± 0.9	0.4 ± 0.4	1.0 ± 0.4	0.4 ± 0.2
Check+verbenone	4.6 ± 2.7	1.2 ± 0.6	1.0 ± 0.8	0.8 ± 0.8	0.6 ± 0.6
Chlorpyrifos/lambda-cyhalothrin, no verbenone	6.2 ± 2.7	0.2 ± 0.2	1.2 ± 0.8	1.0 ± 0.5	1.8 ± 1.1
Chlorpyrifos/lambda-cyhalothrin+verbenone	6.6 ± 2.9	1.6 ± 1.0	1.4 ± 0.7	1.0 ± 0.8	0.8 ± 0.5
Fenpropathrin, no verbenone	9.6 ± 2.9	3.0 ± 2.3	2.0 ± 1.3	1.0 ± 0.4	1.2 ± 0.7
Fenpropathrin+verbenone	5.4 ± 1.4	1.4 ± 0.9	0.6 ± 0.4	0.2 ± 0.2	1.2 ± 0.6
Chlorpyrifos, no verbenone	9.6 ± 5.8	0.4 ± 0.4	1.6 ± 1.1	0.8 ± 0.6	2.2 ± 1.4
Chlorpyrifos+verbenone	11.6 ± 4.1	1.0 ± 1.0	2.4 ± 1.0	1.2 ± 1.2	2.8 ± 0.6
Permethrin, no verbenone	10.8 ± 3.9	2.0 ± 2.0	2.4 ± 1.1	1.4 ± 1.0	1.8 ± 0.9
Permethrin+verbenone	11.8 ± 4.8	0.0	1.4 ± 0.5	2.6 ± 1.0	1.2 ± 0.7
19 Aug					
Check, no verbenone	18.0 ± 4.9	2.4 ± 0.8	1.2 ± 0.6	4.4 ± 2.1	2.6 ± 0.9
Check+verbenone	11.4 ± 5.4	2.2 ± 1.0	0.0	0.2 ± 0.2	2.6 ± 1.4
Chlorpyrifos/lambda-cyhalothrin, no verbenone	10.8 ± 1.9	4.2 ± 0.9	0.4 ± 0.2	0.4 ± 0.2	2.0 ± 0.8
Chlorpyrifos/lambda-cyhalothrin+verbenone	6.4 ± 3.2	2.0 ± 0.8	0.4 ± 0.2	1.0 ± 0.6	0.8 ± 0.5
Fenpropathrin, no verbenone	14.8 ± 5.0	3.4 ± 1.7	1.0 ± 0.6	1.6 ± 0.7	1.4 ± 0.5
Fenpropathrin+verbenone	11.8 ± 4.5	3.6 ± 1.0	0.2 ± 0.2	1.4 ± 1.2	1.0 ± 0.4
Chlorpyrifos, no verbenone	17.0 ± 6.5	6.0 ± 1.9	0.4 ± 0.4	1.6 ± 1.4	3.4 ± 1.9
Chlorpyrifos+verbenone	7.2 ± 4.7	2.0 ± 0.8	0.4 ± 0.4	1.4 ± 1.2	0.2 ± 0.2
Permethrin, no verbenone	7.2 ± 4.3	3.0 ± 2.8	0.2 ± 0.2	0.8 ± 0.6	1.0 ± 0.6
Permethrin+verbenone	17.0 ± 3.6	4.8 ± 1.6	0.6 ± 0.2	1.2 ± 0.4	3.2 ± 0.6

[a] Significant main effect of evaluation date (Chi-square, $P < 0.05$): higher on 6 Jul for no. sites containing brood, and higher on 19 Aug for no. attack sites and no. sites containing empty galleries.

Table 2. Mean (± SE) infestation levels by *X. germanus* in potted apple trees on two evaluation dates, after a trunk application of a preventive insecticide, with and without a verbenone repellent, Sodus. 2016.

	no. attack	no. sites/tree containing			
Evaluation date[a]/treatment	**sites/tree**	**empty galleries**	**brood[b]**	**live adults**	**dead adults**
6 Jul					
Check, no verbenone	13.0 ± 4.9	1.6 ± 0.8	2.4 ± 1.3	0.0	4.0 ± 1.4
Check+verbenone	11.6 ± 6.3	0.6 ± 0.6	2.0 ± 1.1	0.4 ± 0.2	4.4 ± 2.8
Chlorpyrifos/lambda-cyhalothrin, no verbenone	7.0 ± 3.4	1.0 ± 0.5	1.2 ± 0.6	0.2 ± 0.2	1.6 ± 0.7
Chlorpyrifos/lambda-cyhalothrin+verbenone	7.6 ± 2.7	1.4 ± 0.7	2.4 ± 1.2	0.0	2.8 ± 1.4
Fenpropathrin, no verbenone	9.0 ± 2.7	0.0	1.2 ± 0.6	0.0	3.6 ± 1.2
Fenpropathrin+verbenone	5.4 ± 1.2	0.0	0.6 ± 0.2	0.4 ± 0.2	1.0 ± 0.8
Chlorpyrifos, no verbenone	8.6 ± 4.1	0.6 ± 0.6	1.2 ± 0.7	0.6 ± 0.6	3.4 ± 2.1
Chlorpyrifos+verbenone	11.4 ± 3.5	0.4 ± 0.4	4.6 ± 2.0	0.0	4.2 ± 2.0
Permethrin, no verbenone	14.4 ± 5.0	1.6 ± 0.7	1.8 ± 0.5	0.2 ± 0.2	3.4 ± 1.4
Permethrin+verbenone	11.0 ± 1.9	0.8 ± 0.4	2.2 ± 0.2	0.4 ± 0.4	2.4 ± 1.3
19 Aug					
Check, no verbenone	17.0 ± 7.5	4.4 ± 1.7	1.4 ± 1.4	2.6 ± 1.5	1.8 ± 1.1
Check+verbenone	11.0 ± 3.9	3.8 ± 7.2	1.2 ± 0.5*	1.8 ± 0.9	1.2 ± 0.4
Chlorpyrifos/lambda-cyhalothrin, no verbenone	13.4 ± 2.2	4.8 ± 1.9	1.0 ± 0.8	1.8 ± 0.5	1.6 ± 0.2
Chlorpyrifos/lambda-cyhalothrin+verbenone	8.6 ± 2.6	2.4 ± 0.9	0.6 ± 0.6	1.0 ± 0.8	0.6 ± 0.4
Fenpropathrin, no verbenone	5.8 ± 1.7	1.0 ± 0.6	0.2 ± 0.2	1.0 ± 0.6	2.2 ± 1.0
Fenpropathrin+verbenone	17.4 ± 1.1	6.0 ± 1.5	1.4 ± 0.6	2.8 ± 1.2	1.4 ± 0.5
Chlorpyrifos, no verbenone	13.6 ± 6.6	2.4 ± 1.7	1.6 ± 0.8	2.8 ± 1.4	4.6 ± 2.3
Chlorpyrifos+verbenone	10.6 ± 4.6	3.8 ± 1.8	0.2 ± 0.2	1.6 ± 0.9	0.8 ± 0.5
Permethrin, no verbenone	17.2 ± 9.0	3.4 ± 1.7	2.4 ± 1.5	1.6 ± 1.1	3.0 ± 1.7
Permethrin+verbenone	22.8 ± 5.6	7.2 ± 3.4	0.6 ± 0.2*	3.0 ± 0.9	3.8 ± 1.0

[a] Significant main effect of evaluation date (Chi-square, $p < 0.05$): on 6 Jul, higher no. sites containing brood; on 19 Aug, higher no. attack sites and sites containing empty galleries and live adults.
[b] Asterisks denote treatments with significantly fewer sites containing brood from addition of verbenone (Tukey's test, $P < 0.05$).

Table 3. Mean (± SE) infestation levels by *X. germanus* in potted apple trees on 29 Aug after a preventive trunk application on 11 May. Sodus, 2017.

Treatment[a]	no. attack sites/tree	no. sites/tree containing empty galleries	brood	adults
Check	1.3 ± 0.9ab	1.3 ± 0.9ab	0.0	0.7 ± 0.7ab
SPLAT Verb	1.0 ± 0.6ab	0.3 ± 0.3ab	0.3 ± 0.3	0.3 ± 0.3ab
Lorsban Advanced	0.3 ± 0.3b	0.3 ± 0.3ab	0.0	0.0b
SPLAT Verb+Lorsban Advanced	2.7 ± 2.2ab	2.3 ± 1.9ab	0.3 ± 0.3	0.0b
SPLAT "A" (XF+V10)	3.7 ± 2.0ab	1.7 ± 1.7ab	0.7 ± 0.7	0.0b
SPLAT "B" (XF+V10M10)	0.0b	0.0b	0.0	0.0b
SPLAT "C" (XF–V10M10)	0.0b	0.0b	0.0	0.0b
Verbenone Disrupt Micro-Flake	5.0 ± 4.5ab	5.0 ± 4.5ab	0.7 ± 0.3	1.3 ± 0.9ab
Verbenone Disrupt Micro-Flake+Lorsban Advanced	5.7 ± 0.9a	4.3 ± 1.5a	0.7 ± 0.7	1.7 ± 0.7a
Blank flakes	2.5 ± 2.5ab	2.5 ± 2.5ab	0.0	2.0 ± 2.0ab

[a] Values within a column followed by the same letter not significantly different at $p < 0.05$ (Student's t test; data transformed using arc-sine sqrt before analysis)

so low during the season and among the trial sites, particularly since we were collecting fairly high numbers of adults in our traps set out around the region, including all of the potted tree trial sites (Figure 8). It can only be speculated that the inordinately long and heavy periods of rainy weather experienced during June and July that year may have somehow interfered with the normal infestation behavior of the local BSB populations. Only the Sodus site, where the potted trees were placed in the woods (rather than adjacent to them and along the fence lines, as at the other two sites), showed levels of infestation high enough to generate measurable results among the different treatments.

Our 2017 results indicate that the SPLAT "B" and "C" formulations definitely had a measurable effect on preventing infestations of black stem borers in the test trees. The composition of these formulations is not currently being disclosed by the manufacturer for proprietary reasons, but in tests of repellents for the redbay ambrosia beetle, *Xyleborus glabratus* Eichhoff, dollops of SPLAT (ISCA Technologies) wax-based matrix containing verbenone alone and combined with methyl salicylate directly applied to bolts of redbay, *Persea borbonia* (L.), significantly reduced beetle captures and boring holes compared with untreated bolts (Hughes et al. 2017); treatment effects persisted over a 10-wk period. The experimental SPLAT "B" and "C" formulations may have included an additional active ingredient such as methyl salicylate, which contributed to the repellent capabilities of the verbenone to result in lower attacks. It is clear that follow-up trials on these products will be warranted in subsequent seasons.

Preventive trunk sprays of insecticides are not necessarily practical, or even effective enough to be economically warranted in all cases. Current recommendations generally advise removal and burning of infested trees, but with the suggestion to leave them in place for some time after attacks are initiated, where they can act as attractants for other adults, before being removed (Mizell and Riddle 2004, Ranger et al. 2016). In our observations, infested trees tend to occur in batches, with dozens in one part of the orchard showing die-off or decline, while adjacent and presumably healthy trees are unaffected. Inspections of infested orchards in western New York show a tree loss of up to 30% in some cases; however, not all trees that are attacked die, and the occurrence of callus tissue underneath old attack sites in some trees provides an indication that a certain proportion can apparently recover. The results of these studies support the utility of using ethanol-baited traps for detecting adult flight activity in the spring, and timing trunk sprays of insecticides that may offer some control of colonizing beetles; however, there are still many questions needing to be addressed before effective solutions and recommendations are available. It is clear that maintenance of tree health and avoidance of potential sources of stress will be an important component of any effective management program of this pest in commercial apple orchards.

Acknowledgements

We wish to thank Todd Furber, J.D. Fowler, Wayne Hermenet, and Ken Simpelaar for allowing us to conduct these trials on their farms; Wafler Nursery for providing the trees and facilities for potting them; John Vandenberg, Louela Castrillo, Michael Griggs and Rebecca Howes for their advice and assistance in potting trees, setting up the trials, and providing technical supplies and support for conducting the research, and for technical support from David Combs, Steve Gordner, Alex Walbridge, Forrest English-Loeb, Joshua Neal, Mikhail Fischer, and Amy Sparer. This work was supported by the donation of products for testing from ISCA Technologies (Jesse Saroli, Agenor Mafra-Neto), Hercon Environmental (Katie Ellis), and funds from NY Apple Research & Development Program, the USDA Hatch Program, Dow AgroSciences (Alejandro Calixto), Valent Biosciences (Gary Kirfman), and UPI (United Phosphorus) (Tony Estes).

References

Agnello, A. M, Breth, D. I., Tee, E. M., Cox, K. D., Villani, S. M., Ayer, K. M., Wallis, A. E., Donahue, D. J., Combs, D. B., Davis, A. E., Neal, J. A., and English-Loeb, F. M. 2017. *Xylosandrus germanus* (Coleoptera: Curculionidae: Scolytinae) occurrence, fungal associations, and management trials in New York apple orchards. J. Econ. Entomol. 110: 2149–2164.

Dodds, K. J. and Miller, D. R. 2010. Test of nonhost angiosperm volatiles and verbenone to protect trap trees for *Sirex noctilio* (Hymenoptera: Siricidae) from attacks by bark beetles (Coleoptera: Scolytidae) in the northeastern United States. J. Econ. Entomol. 103: 2094–2099.

Felt, E. P. 1932. A new pest in greenhouse grown grape stems. J. Econ. Entomol. 25: 418.

Frank, S., and Bambara, S. 2009. The Granulate [Asian] Ambrosia Beetle. North Carolina Ext. Serv. https://www.ces.ncsu.edu/depts/ent/notes/O&T/trees/note111/note111.html

Gillette, N. E., Stein, J. D., Owen, D. R., Webster, J. N., Fiddler, G. O., Mori, S. R., and Wood, D. L. 2006. Verbenone-releasing flakes protect individual *Pinus contorta* trees from attack by *Dendroctonus ponderosae* and *Dendroctonus valens* (Coleoptera: Curculionidae, Scolytinae). Agric. Forest. Entomol. 8: 243–251.

Hale, F. A., and Oliver, J. 1999. Insecticide evaluation for control of the Asian ambrosia beetle, *Xylosandrus crassiusculus*, in vitro. pp. 160–162 In: James, B. L., ed. Proc. 44th Annu. South. Nursery Assoc. Res. Conf., Marietta, GA.

Hall, F. R., Ellis, M. A., and Ferree, D. C. 1982. Influence of fireblight and ambrosia beetle in several apple cultivars on M9 and M9 interstems. Ohio State Univ. Res. Circ. 272: 20–24.

Hoffmann, C. H. 1941. Biological observations on *Xylosandrus germanus* (Bldfd.). J. Econ. Entomol. 34: 38-42.

Mangold, J. R., Wilkinson, R. C., and Short, D. E. 1977. Chlorpyrifos sprays for control of *Xylosandrus compactus* in flowering dogwood. J. Econ. Entomol. 70: 789–790.

Mizell, R. F., and Riddle, T. C. 2004. Evaluation of insecticides to control Asian ambrosia beetle, *Xylosandrus crassiusculus*. Proc. South. Nursery Assoc. 49: 152–155.

Oliver, J. and Mannion, C. M. 2001. Ambrosia beetle (Coleoptera: Scolytidae) species attacking chestnut and captured in ethanol-baited traps in middle Tennessee. J. Econ. Entomol. 30: 909–918.

Rabaglia, R. J., Dole, S. A., and Cognato, A. I. 2006. Review of American *Xyleborina* (Coleoptera: Curculionidae: Scolytinae) occurring north of Mexico, with an illustrated key. Ann. Entomol. Soc. Am. 99: 1034–1056

Ranger, C. M., Reding, M. E., Persad, A. B., and Herms, D. A. 2010. Ability of stress-related volatiles to attract and induce attacks by *Xylosandrus germanus* and other ambrosia beetles Agric. For. Entomol. 12: 177–185.

Ranger, C. M., Reding, M. E., Schultz, P. B., and Oliver, J. B. 2013a. Influence of flood-stress on ambrosia beetle host-selection and implications for their management in a changing climate. Agric. For. Entomol. 15: 56–64.

Ranger, C. M., Tobin, P. C., Reding, M. E., Bray, A. M., Oliver, J. B., Schultz, P. B., Frank, S. D., and Persad, A. B. 2013b. Interruption of the semiochemical-based attraction of ambrosia beetles to ethanol-baited traps and ethanol-injected trap trees by verbenone.

Ranger, C. M., Reding, M. E., Schultz, P. B., Oliver, J. B., Frank, S. D., Addesso, K. M., Chong, J. H., Sampson, B., Werle, C., and Krause, C. 2016. Biology, ecology, and management of nonnative ambrosia beetles (Coleoptera: Curculionidae: Scolytinae) in ornamental plant nurseries. J. Integr. Pest Manag. 7: 1–23.

Reding, M., Oliver, J., Schultz, P., and Ranger, C. 2010. Monitoring flight activity of ambrosia beetles in ornamental nurseries with ethanol-baited traps: influence of trap height on captures. J. Environ. Hort. 28: 85–90.

Reding, M. E., Ranger, C. M., Oliver, J. B., and Schultz, P. B. 2013. Monitoring attack and flight activity of *Xylosandrus* spp. (Coleoptera: Curculionidae: Scolytinae): The influence of temperature on activity. J. Econ. Entomol. 106: 1780–1787.

Weber, B. C., and McPherson, J. E. 1983. Life history of the ambrosia beetle *Xylosandrus germanus* (Coleoptera: Scolytidae). Ann. Entomol. Soc. Am. 76: 455–462.

Wood, S. L. 1982. The bark and ambrosia beetles of North and Central America: A taxonomic monograph. Great Basin Nat. Mem. No. 6. Brigham Young Univ., Provo, Utah. 1376 pp.

Arthur Agnello is a research and extension professor in the Department of Entomology at Geneva who leads Cornell's extension program in tree fruit entomology.