Flatheaded Borer Workshop

Conference Proceedings

Tennessee State University, Otis L. Floyd Nursery Research Center, McMinnville, TN
July 1-2, 2019

Hosted and Sponsored by:

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Proceedings of the

Flatheaded Borer Workshop

July 1-2, 2019

McMinnville, TN

Tennessee State University
Local Arrangements Committee

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Dr. Karla Addesso, Co-Chair

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Disclaimers

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Acknowledgements

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We especially acknowledge the support of Dr. Thomas A. Bewick (USDA Specialty Crop Research Initiative Program Leader) and the USDA-NIFA Specialty Crop Research Initiative (SCRI) Planning Grant (Award No. 2018-51181-28385) that made the Flatheaded Borer Workshop possible. The grant allowed Workshop presenters and specialty crop industry stakeholders to travel, present, and make contributions to the planning process. The main objective of the Workshop, "to develop a comprehensive research and extension plan for tree crops (nursery, nut, and orchard) that addresses needs for improved, cost effective, and sustainable flatheaded borer management," would not have been achieved without the direct support and facilitation provided by USDA-NIFA-SCRI.

Special thanks are due to many on the committee. Dr. Nick Gawel (TSU-NRC Superintendent) made it possible to host the Workshop at the TSU-NRC, assisted with audio-visual, breaks, and meeting logistics. Holly Hodges (TSU-NRC Administrative Assistant) handled all of the travel arrangements for meeting participants, coordination of Workshop breaks, and facilitation of Workshop related items like notepads and pens. Amy Dismukes served as moderator for Day 1 of the workshop and set up information displays. Dr. Fulya Baysal-Gurel (TSU-NRC Assistant Professor of Pathology) established Zoom links for remote participants, assisted with presentation sharing, and Zoom operation. Dr. Karla Addesso (TSU-NRC Associate Professor of Chemical Ecology/Entomology) and Dr. Anthony Witcher (TSU-NRC Assistant Professor of Nursery Sustainability) both contributed extensively to the planning process and agenda organization. Dr. Addesso also assisted with Zoom. Bottled water, soft drinks, and additional snacks were provided by Nadeer Youssef (TSU-NRC Research Associate of Entomology), Dr. Jason Oliver (TSU-NRC Professor of Entomology), and Dr. Addesso at their own personal expense. Debbie Eskandarnia, Joshua Sizemore, and Amanda Miller assisted with name tag printing, room organization, handouts, and registration. A special thanks to Joshua Sizemore who made a trip to Nashville to pick up TSU meeting notepads and pens. We also want to thank many of the other workshop participants who provided advice, support, and contributions.

A final special thanks is given to High Rollers who furnished our workshop breaks and to Smooth Rapids Restaurant who hosted a Workshop participant evening social on Monday night (July 1). Smooth Rapids is normally closed on Mondays, but made a special opening for our group. A final thanks to Gary Clendenon (Tennessee Department of Agriculture Plant Inspector) who provided impromptu entertainment to our group at the evening social with his outstanding banjo playing and singing talents.

Workshop Agenda

Flatheaded Borer Workshop Program

Day 1 (July 1, 2019)

7:30 - 8:00 Arrive / Register / Load Talks / Interact (All times in Central Standard Time)

Workshop Moderator: Amy Dismukes (TSU Nursery Extension Specialist)

Time	Presenter	Affiliation	Title
8:00 - 8:15	Dr. Jason Oliver	Tenn. State Univ.	Welcome / Goals / Agenda
8:15 - 8:45	Dr. Jason Oliver	Tenn. State Univ.	Flatheaded appletree borer ecology and knowledge gaps
8:45 - 9:00	Dr. Anthony LeBude	North Carolina State Univ.	East coast: Shade tree production - factors affecting borers and management
9:00 - 9:15	Dr. Angelita Acebes-Doria Dr. Shimat Joseph Dr. Brett Blaauw	Univ. of Georgia	East coast: Factors affecting borers and management: Pecans, ornamentals, and fruit trees
9:15 - 9:45	Dr. Nik Wiman	Oregon State Univ.	Pacific flatheaded borer ecology and knowledge gaps
9:45 - 10:00	Dr. Nik Wiman	Oregon State Univ.	West coast: factors affecting borers and management in Oregon production horticulture
10:00 - 10:15	Dr. Jhalendra Rijal	Univ. of California	West coast: Walnut production and factors affecting borers and management
10:15 - 10:40		***Break***	
10:40 - 11:00	Dr. Cristi Palmer	IR-4 Program	General information on IR-4 program and update on borer and beetle sponsored research
11:00 - 11:15	Dr. Jill Calabro	AmericanHort and HRI	Horticultural Research Institute identified nursery industry stakeholder priorities for the next 5-10 years
11:15 - 11:45	Dr. David Shapiro-Ilan	USDA-ARS	Entomopathogens: Prior knowledge and potential for borer control
11:45 - 12:00	Dr. Diana Londoño	BASF	Entomopathogenic Nematodes from BASF: New tool for insect control
12:00 - 1:00		***Lunch***	
1:00 - 1:30	Other State Reports and Group Discussion	Multiple	Other state reports on flatheaded borers. Group discussion on morning workshop topics
1:30 - 1:45	Dr. Karla Addesso	Tenn. State Univ.	Management of flatheaded appletree borer in nursery production with cover crops
1:45 - 1:55	Dr. Kevin Chase	Bartlett Tree Research Lab	Bartlett protocols for flatheaded borers (and other wood-borers)
1:55 - 2:05	Dr. Frank Hale	Univ. Tenn.	Issues and management of flatheaded borers in landscapes
2:05 - 2:15	Dr. Bill Klingeman	Univ. Tenn.	Informal update on fungi associated with flatheaded borers in the genus *Chrysobothris*
2:15 - 2:30	Dr. Karla Addesso	Tenn. State Univ.	National Plant Diagnostic Network (NPDN) Reports: 2005-2019 state reports
2:30 - 2:45	SCRI Grant Group	Multiple	Summary of national industry survey results
2:45 - 3:00	SCRI Grant Group	Multiple	Summary of nursery industry town hall meeting results
3:00 - 3:20		***Break***	
3:20 - 4:00	Grower Roundtable	Multiple	Grower round-table discussion of their issues with flatheaded borers
4:00 - 5:00	Group Discussion	Multiple	Key grower and research priorities Knowledge gaps Other comments and brainstorming
5:00	Jason Oliver	Tenn. State Univ.	Closing remarks

6:00 - 8:00 Dinner (Dutch Treat) and Social at Smooth Rapids

Flatheaded Borer Workshop Program

Day 2 (July 2, 2019)

8:00 - 8:30 Breakfast (All times in Central Standard Time)

Time	Presenter	Affiliation	Title
8:30 - 8:45	Dr. Jason Oliver	Tenn. State Univ.	Recap and summary of priorities identified during Day 1 of workshop
8:45 - 9:15	Dr. Karla Addesso	Tenn. State Univ.	SCRI RFA 2019
9:15 - 10:00	Group Proposal Planning Session	Multiple	Project Objectives and Integration: - Prioritization ranking of proposal objectives & sub-objectives - identify obtainable goals - Timelines: Identify short, medium, & long-term research & extension goals - Identify additional expertise & cooperators - Identify group leaders for objectives - Assessment plan for outreach success
10:15 - 10:30		***Break***	
10:30 - 11:15	Content Outlines	Either Group Leader Breakouts or Group Activity	Development of content outlines for each priority objective
11:15 - 11:30	Dr. Karla Addesso	Tenn. State Univ.	Development of proposal writing timeline
11:30 - 11:45	Dr. Jason Oliver	Tenn. State Univ.	Closing remarks
11:45 - TBD	***Lunch, Additional Wrap-up (if needed), and Adjourn***		

Post-Meeting Activity Options:

If you are staying in town after the Workshop on Tuesday, we would be glad to arrange:

1) Tour of the Nursery Research Center
2) Tour of the local nursery area
3) Other group activities of interest

Workshop Sponsors:

USDA-NIFA Specialty Crop Research Initiative

Tennessee State University College of Agriculture

Flatheaded Borer Workshop Objectives and Goals

Main Objective: Develop a comprehensive research and extension plan for tree crops (nursery, nut, and orchard) that addresses stakeholder needs for improved, cost effective, and sustainable flatheaded borer management.

Goals:

1) Identify priorities and critical needs
2) Identify knowledge gaps
3) Determine how to address priorities, critical needs, and knowledge gaps

Index to Submitted Abstracts

NOTE: **NS** denotes Not Submitted. Speaker name in **bold**.

37 **IR-4 Environmental Horticulture Program: General Updates and Coleopteran Research. Cristi L. Palmer** (clpalmer@njaes.rutgers.edu). (IR-4 Environmental Horticulture Program Manager, 500 College Road East, Suite 201 W Princeton, NJ).

NS **Horticultural Research Institute – The American Foundation. Jill Calabro** (Jill@AmericanHort.org). (Horticultural Resarch Institute, 525 9th St. NW., Suite 800, Washington, DC 20004).

38 **Entomopathogens: Prior Knowledge and Potential for Borer Control. David Shapiro-Ilan** (David.Shapiro@ars.usda.gov). (USDA-ARS SE Fruit and Tree Nut Research Laboratory, 21 Dunbar Road, Byron, GA).

40 **Entomopathogenic Nematodes in BASF, a New Tool for Insect Control. Diana K. Londoño** (diana.londono@basf.com). (BASF Corporation, 26 Davis Drive, Research Triangle Park, NC 27709-3528.

41 **Flatheaded Appletree Borer: A Potential Pest of Blueberries in Florida. Krystal Ashman** (Krystal.Ashman@freshfromflorida.com) and Oscar Liburd.[2] (Division of Plant Industry, Florida Department of Agriculture and Consumer Services, 1911 SW 34th Street, Gainesville, FL. [2]University of Florida, Steinmetz Hall, Rm. 2102, 1881 Natural Area Drive, Gainesville, FL).

43 **Management of Flatheaded Appletree Borer in Nursery Production with Cover Crops. Karla M. Addesso** (kaddesso@tnstate.edu), Sujan Dawadi, Alex Gonzalez, Jason B. Oliver, and P.A. O'Neal. (Tennessee State University, College of Agriculture, Otis L. Floyd Nursery Research Center, McMinnville, TN).

47 **Tree Industry Buprestidae Management. Kevin Chase** (kchase@Bartlett.com) (Bartlett Tree Research Lab).

48 **Issues and Management of Flatheaded Borers in the Landscapes. Frank Hale** (fhale@utk.edu). (The University of Tennessee, Institute of Agriculture, UT Extension, Nashville, TN).

50 **Fungal Phoresy on Tennessee Beetles – *Pityophthorus juglandis*, Other Bark Beetles, and an Update on a Preliminary Survey in *Chrysobothris*. William Klingeman** (wklingem@utk.edu), Romina Gazis[2], Karandeep Chahal[3], Mark Windham[3], Grace Pietsch[1], and Denita Hadziabdic.[3] (The University of Tennessee Institute of Agriculture, Department of Plant Sciences, Knoxville, TN, [2]University of Florida, Department of Plant Pathology, Tropical Research and Education Center, Homestead, FL, [3]The University of Tennessee Institute of Agriculture, Entomology and Plant Pathology Department, Knoxville, TN).

Conference

Abstracts

and Papers

Flatheaded Appletree Borer Ecology and Knowledge Gaps

Jason Oliver,[1] Karla Addesso,[1] Donna Fare,[2] Fulya Baysal-Gurel,[1] Anthony Witcher,[1] Nadeer Youssef,[1] Joshua Basham,[3] Benjamin Moore,[4] and Paul O'Neal[1]

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[2] Retired: USDA-ARS National Arboretum, (NRC).
[3] Tennessee Department of Agriculture, (NRC).
[4] USDA-ARS National Arboretum, (NRC).

Flatheaded borers (Coleoptera: Buprestidae) are an important group of wood-boring beetles with over 700 described species in North America. The adult beetles often have bright metallic coloration and are flattened in lateral profile and bullet shaped from the dorsal view, while larvae have an enlarged prothorax that gives a "flatheaded" appearance. Because of the flattened lateral profile, adults leave d-shaped exit holes when emerging from host wood. The flatheaded appletree borer (*Chrysobothris femorata* Olivier) (FAB) is one of the most economically important species in nursery and landscape plantings. The FAB is reported to have a nationwide distribution that extends into Canada and a broad plant host range. Females are likely to lay up to 100 eggs and prefer bark cracks or wounds to oviposit (Brooks 1919, Fenton 1942). In most years, the FAB has one generation per year, but larvae may require more than one year if they are stressed or challenged by the host. The FAB common name is reported to be due to the timing of adult emergence coinciding with apple tree bloom, which would be about mid-April at the Tennessee latitude. In Kentucky, Potter et al. (1988) reported that FAB emerged at 742 growing degree days.

The current presentation examined some of the research performed at the Tennessee State University Otis L. Floyd Nursery Research Center, as well as by other researchers to identify some potential knowledge gaps in our understanding of FAB ecology and how this might relate to management. This paper will list the identified knowledge gaps presented at the flatheaded borer workshop and some details pertaining to each:

Knowledge Gap 1: What is FAB, how many species do we currently have, and how does this affect management? Based on Wellso and Manley (2007), there are 12 *Chrysobothris* species currently in the *C. femorata* species group, including: *C. adelpha* Harold, *C. caddo* Wellso & Manley, *C. comanche* Wellso & Manley, *C. femorata*, *C. Mescalero* Wellso & Manley, *C. quadriimpressa* Gory & Laporte, *C. rugosiceps* Melsheimer, *C. seminole* Wellso & Manley, *C. shawnee* Wellso & Manley, *C. sloicola* Manley & Wellso, *C. viridiceps* Melsheimer, and *C. wintu* Wellso & Manley. It is likely additional species will be added to this complex (Basham J., pers. comm.). A phylogenetic analysis performed by Hansen et al. (2015) using sequences from cytochrome oxidase I and arginine kinase supported *C. femorata* species group members of *C. adelpha*, *C. viridiceps*, and *C. wintu* as monophyletic, but produced paraphyletic renderings for *C. femorata*, *C. quadriimpressa*, *C. rugosiceps*, and *C. shawnee*. Hansen et al. conclude that imperfect taxonomic observations could be due to ancestral polymorphism, lineage sorting, or introgression among members of the *C. femorata* species group. If these species are still exchanging genetic material via introgressive hybridization, then management related decisions based on host susceptibility and borer phenology may be complicated by imperfect taxonomy. The host range of the 12 species recognized by Wellso and Manley (2007) is broad, but also overlaps among group members (especially with genera like *Carya* and *Quercus*) (Nelson et al. 2008). Because of the Wellso and Manley (2007) revisions to the FAB species group, any studies published before 2007 that did not keeping specimen vouchers could have been working with more than one species of *Chrysobothris*, which would reduce the value of the studies.

Among 1,483 *Chrysobothris* species trapped in 2001 to 2003 studies in Tennessee in a field adjacent to a mixed deciduous and coniferous forest, frequency of occurrence was *C. quadriimpressa* (43.70%), *C. azurea* LeConte (14.70%), *C. adelpha* (13.89%), *C. cribraria* Mannerheim (9.71%), *C. femorata* (7.82%), *C. rugosiceps* (3.30%), *C. viridiceps* (2.29%), *C. sexsignata* (Say) (1.89%), *C. shawnee* (1.21%), *C. harrisi* Hentz (0.74%), *C. pusilla* Gory & Laporte (0.47%), and *C. dentipes* (Horn) (0.27%). Among these trapped species, only *C. azurea*, *C. adelpha*, *C. femorata*, *C. rugosiceps*, *C. viridiceps*, and *C. sexsignata* have been reared from Tennessee nursery stock and one species that has never been trapped (*Chrysobothris chlorocephala* Gory) (Table 1). The number of new tree host genera records (Table 1) also may suggest cryptic species among the *Chrysobothris* members.

Table 1. Buprestidae species reared from Tennessee nursery stock (2001−2019 studies).

	Host Tree Genera[b]				
Buprestid Species[a]	***Acer***	***Cercis***	***Cornus***	***Quercus***	***Ulmus***
Acmaeodera pulchella (Herbst)	X(n)				
Acmaeodera tubulus (Fabricius)	X		X		
Actenodes acornis (Say)	X		X(n)		
Agrilus cephalicus LeConte			X		
Agrilus fallax Say	X				
Agrilus ferrisi Dury	X				
Agrilus obsoletoguttatus Gory	X(n)				
Agrilus putillus putillus Say	X				
Anthaxia quercata (Fabricius)					X(n)
Anthaxia viridifrons Gory					X
***Chrysobothris adelpha* Harold**	X(n)				
Chrysobothris azurea LeConte	X				
Chrysobothris chlorocephala Gory				X	
***Chrysobothris femorata* Olivier**	X		X(n)		
***Chrysobothris rugosiceps* Melsheimer**	X(n)				
Chrysobothris sexsignata (Say)		X		X	
***Chrysobothris viridiceps* Melsheimer**	X			X	
Ptosima gibbicollis (Say)		X			
Texania campestris (Say)	X				

[a] *Chrysobothris* species in bold are part of the *C. femorata* species group.
[b] X indicates specimen(s) were reared from host plant genus and X(n) indicates host plant genus is a new larval rearing record.

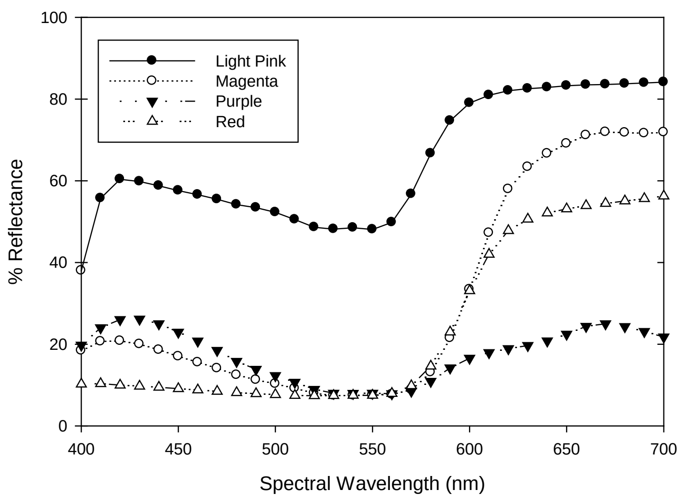
<u>Knowledge Gap 2:</u> Why are most adult buprestids beetles attracted to colors in the violet range of the electromagnetic spectrum? It is well known that buprestids and other wood borers are attracted to dark silhouettes like wooden posts (Brooks 1919, Fenton 1942). During the past two decades, it also has been determined that many species of adult buprestids respond to colors in the visible violet (and potentially the ultra-violet) range of the electromagnetic spectrum (Petrice et al. 2013, 2015; Francese et al. 2008). More buprestids were captured on red colored traps in 2001 and 2002 studies than blue, green, grey, white, or yellow colors (Table 2) (Oliver et al. 2003). Additional unpublished 2002 and 2003 trap studies by Oliver et al. indicated more attraction to purple, magenta, and pink colors (Table 2). The most attractive *Chrysobothris* and other buprestid colors appear to be colors with reflectance in both the violet and red range of the visible light spectrum (Fig. 1). The reason for this attraction is unknown. However, many insects have a peak spectral efficiency in the 350 to 365 nm and 490 to 500 nm range (Pope and Hinton 1977). The spectral sensitivity curves of emerald ash borer, (*Agrilus planipennis* Fairmaire) (EAB), peaked in ultraviolet (340 nm), violet (420−430 nm), blue (460 nm), and green (540−560 nm), with females also sensitive to red wavelengths (640−670 nm) (Crook et al. 2009). In addition, red, green, or purple traps caught significantly more EAB than blue traps (Crook et al. 2009), which would match the results of our studies for red and purple response in *Chrysobothris*. Interestingly, most beetles lack opsin proteins that are sensitive to short-wavelengths in the blue light range (Lord et al. 2016). However, Lord et al. also demonstrated that some buprestids express duplicate copies of opsins in the ultra-violet (i.e., near violet) and long-wavelength (i.e., near red) range and that these duplications, combined with amino acid variations in the opsins permitted sensitivity to short-wavelengths. One unanswered question from these studies is why buprestids in general appear to exhibit a reduced response to blue traps in one study and yellow and orange traps in our study. Hypothetically, blue wavelengths are adjacent to violet on the visible light scale and yellow and orange to red, so could it be possible the buprestid eye is finely tuned to colors starting at violet and red and not blue and yellow/orange. Color opponent theory states two colors cannot be red and green or blue and yellow at the same time, which is the basis for the red-green (a*) and blue-yellow (b*) color space (Minolta undated). Thus, it is possible buprestids in general are not attuned to the blue-yellow color space, but exceptions could be species looking for mate specific colors like blue (e.g., *Agrilus cyanescens* Ratzeburg) (Lelito et al. 2008). The metallic coloration in buprestid cuticles also is affected by layering and air gaps in the chitin, which can result in variation in reflected light wavelength depending on the angle of the viewer (Vigneron et al. 2006). Thus, beetles may appear one color from one angle and a different color from another angle. Finally, some buprestids are known to produce secretions on the pronotum and elytra that reflect ultraviolet light, which could serve in species and sex differentiation or as aposematic warnings to other invertebrate predators (Pope and Hinton 1977). Because violet and ultraviolet are adjacent in the light spectrum, there may be a connection in buprestid response to both of these spectral ranges. Because many buprestids prefer to rest in on the sunny-side of trees (Brooks 1919, Fenton 1942), this might also facilitate visual signaling of reflected light to potential mates. Studies suggest male buprestids utilize light reflectance to locate potential mates (Lelito et al. 2007, 2008). All of these observations on response to ultraviolet and violet reflectance could be the basis of new trapping systems. Overall, the *Chrysobothris* group appears to have good visual acuity and flight orientation ability based on higher captures on preferred trap colors that were randomized in blocks of other less preferred colors (Table 2 and unpubl. data).

Table 2. Total Buprestidae trap captures on colored trap studies.

Test[a]	Color Des.[b]	Color Space[c]					Total Buprestids[d]		
		L*	a*	b*	C*	h*	*Chrysobothris*	Other Genera	Total
2001 - 2002	Red	44.7	22.4	4.5	22.9	11.3	158	42	200
	Blue	56.0	-0.7	-19.2	19.3	267.9	57	21	78
	Green	48.6	-11.3	-0.2	11.3	181.0	46	30	76
	Grey						36	32	68
	White	93.1	1.1	-0.2	1.1	288.8	53	7	60
	Yellow	84.3	6.0	33.7	34.2	79.8	29	15	44
2002 - 2003	Purple	41.0	23.7	-21.8	32.2	317.5	122	153	275
	Magenta	48.3	48.2	1.2	48.2	1.4	124	61	185
	L. Pink	81.1	18.9	1.6	18.9	4.8	56	93	149
	White	90.7	-0.6	0.5	0.8	140.3	59	75	134
	Red	44.9	22.3	4.2	22.7	10.7	49	83	132
	M. Pink	69.2	32.6	0.2	32.6	144.3	73	57	130
	D. Red						59	68	127
	D. Pink	54.9	52.4	17.3	55.1	18.3	74	30	104
	L. Red						60	28	88
	Orange	54.1	45.3	44.6	63.6	44.6	36	23	59

[a] Total buprestids trapped on colored sticky trap combined for both years.
[b] Des. = color description. L.=light, M.=medium, D.=dark.
[c] Color space represents the average of 10 readings for each colored trap. L* (lightness: + = lighter; − = darker), a* (red to green scale: + = redder; − = greener), b* (yellow to blue scale: + = yellower; − = bluer), C* (chroma: + = brighter; − = duller), and h* (hue).
[d] Other genera included multiple species of *Agrilus*, *Acmaeodera*, *Actenodes*, *Anthaxia*, *Brachys*, *Buprestis*, *Dicerca*, *Phaenops*, *Ptosima*, and *Taphrocerus*.

Fig. 1. Percentage reflectance of top buprestid attracting colors versus spectral wavelength (nm).



<u>Knowledge Gap 3:</u> Is vision the primary method buprestids use to find hosts and orient in the environment or are other senses like olfaction also important? Although functional importance and relative size may not be directly proportional, it is obvious that most buprestids have relatively small serrate antennae, but compound eyes that are large in proportion to the head. Based on response to various colored traps (see Knowledge Gap 2), it is likely vision is an important component of buprestid biology. We have frequently observed *Chrysobothris* adults on cut stumps or damage tree branches, which would suggest response to some type of volatile. Ash trees damaged with girdling stress treatments produced elevated levels of six sesquiterpenes that were attractive to EAB (Crook et al. 2008). Several studies have been performed by our group to determine if volatile compounds also may be important in *Chrysobothris* biology. In a 2005 preliminary study, slow release bubble packs containing green leaf volatiles or an ultra high ethanol release lure were paired with purple colored sticky traps and compared to a non-baited trap. Total *Chrysobothris* captures on these traps were 32 (control), 66 (ethanol UHR), 50 (benzaldehyde), 18 (benzyl alcohol), 7 (hexanol), 7 (benzyl alcohol + benzaldehyde), 4 (benzyl alcohol + hexanol), and 3 (benzaldehyde + hexanol). Lures with benzyl alcohol or hexanol alone or in combination with other lures appeared to perform poorly in attracting *Chrysobothris* adults. The blank trap was less than ethanol or benzaldehyde baited traps, but still performed well. In another study by our group, three *Chrysobothris* species were captured on non-baited purple panel traps at rates equal to or better than traps baited with several commercially-available lures (Fig. 3). In a final study by our group, trunk sections of oak, maple, or pine were injected with ethanol, which served as a solvent to improve the release of other compounds that might be present in the wood. These bolts were arranged in clusters of six in various combinations of all oak, all maple, all pine, or mixtures of the three tree species. Traps were operated for multiple weeks and total *Chyrsobothris* collections are provided in Fig. 4. None of the tree combinations improved captures over just a standard blank trap or ethanol-baited control (Fig. 4). Likewise, species with known larval hosts of oak, maple or pine did not exhibit a greater affinity for traps containing the respective larval host (Fig. 4). All of these findings would suggest some buprestids (especially specialists like EAB), do respond to host volatiles. However, either *Chrysobothris* has little attraction to host volatiles, or we have not found the correct lure or release rate for species in this genus.

Fig. 2. Dorsal view of the eyes and antennae on the head of a *Chrysobothris* buprestid (image courtesy of Joshua Basham).

Fig. 3. Trap captures of three *Chrysobothris* species on purple panel traps near a deciduous forest baited with several commercially-available lures or no lure.

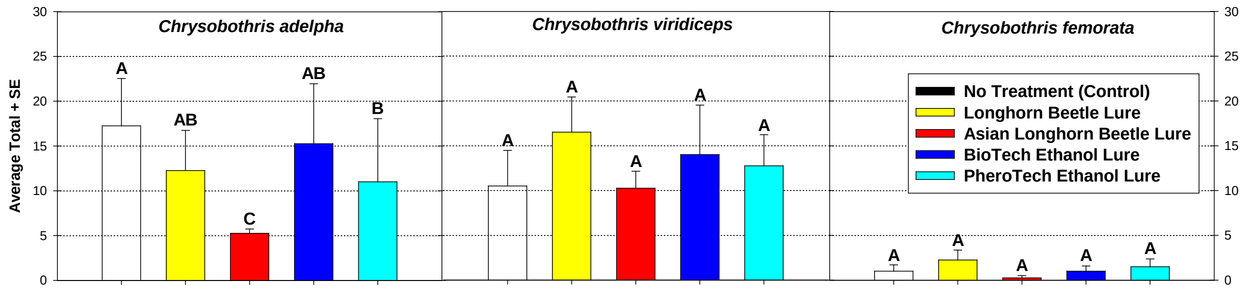


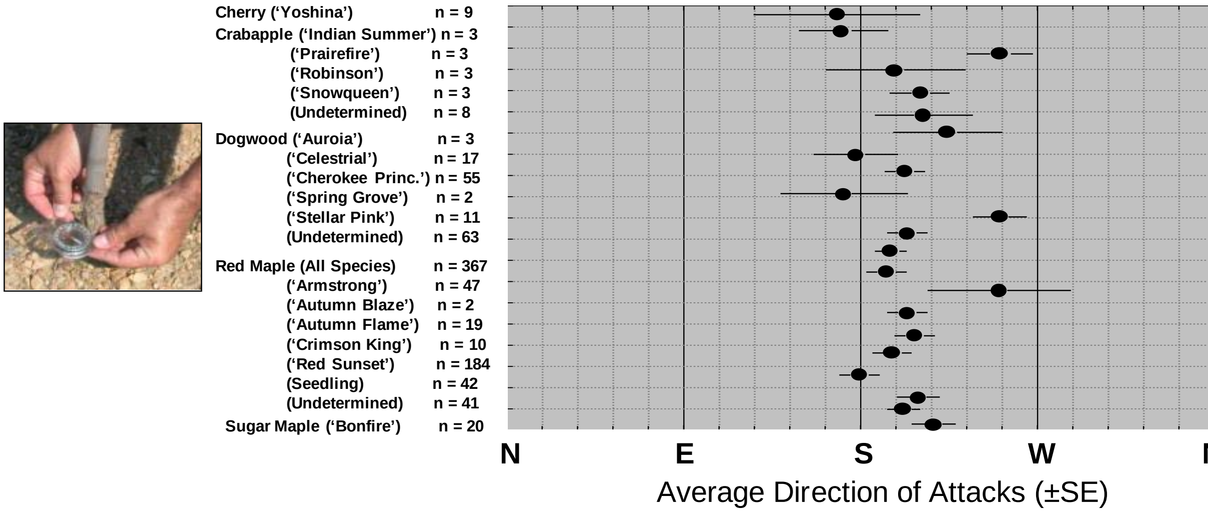
Fig. 4. Total numbers of *Chrysobothris* species captured on sticky prism traps that contained various combinations of maple, oak, or pine trunk pieces injected with ethanol.

	Tree Species							Ethanol	
Species	M-M-M-M-M-M	M-O-P-M-O-P	M-P-M-P-M-P	O-O-O-O-O-O	O-P-O-P-O-P	P-P-P-P-P-P	M-O-M-O-M-O	Lure	Blank
C. adelpha	10	11	4	7	5	6	6	11	7
C. cribraria	0	0	1	0	0	0	0	1	2
C. femorata complex	1	1	2	2	0	1	2	2	1
C. quadriimpressa	3	4	1	1	2	0	1	2	2
C. rugosiceps	5	0	0	0	0	0	1	1	0
C. sexsignata	0	0	0	1	1	0	0	0	1
C. shawnee	2	1	0	1	0	0	0	0	1

	Maple
	Oak
	Pine
	Maple, Oak
	Maple, Oak, Pine

Knowledge Gap 4: Why are buprestid attacks more common on the southwestern side of the tree and why are adults more commonly seen on this side of the tree? Buprestid attacks most frequently occur on the southwestern side of trees (Seagraves et al. 2013). Brooks (1919) reported attacks most frequently occurred on the south side of the tree and that adults spend most of their time on the sunny side of the tree where mating most often occurs. Our survey of nurseries also shows average attack location was most prominent in the southwestern quadrant (Fig. 5). Possible reasons for the preponderance of southwestern attacks might include a) prevalence of southwestern injury from the freeze and thaw cycle that can occur on the southwestern side during winter and spring opening cracks for flatheaded borer oviposition, b) faster larval development on the warmer side of the tree and improved ability to overcome host defenses, and c) adult behavioral preference for the sunny-side of the trunk leading to higher oviposition events. Adults also may favor the sunny side of the tree trunk if it improves mate detection and reproductive success (see knowledge gap 2 section on color preferences). Traps placed in open sunny areas also are more effective at capturing buprestids like EAB than low light forested areas (Francese et al. 2008), presumably because of greater light reflectance and adult detection ability in sunlight. LeBude and Adkins (2014) found that *C. femorata* only attack maple trees at the stub area of the budding union and that attacks could be reduced by orienting the stub area to the north or northeast during planting. LeBude and Adkins findings would suggest that *C. femorata* does exploit weakened areas of the trunk for larval entry (i.e., southwestern injury could also be a point of exploitation) and that the affinity for adult oviposition on the southwestern trunk side provides possibilities for management strategies like planting orientation or focus areas for trunk sprays.

Fig. 5. Average compass bearing (± SE) of flatheaded borer damage on various tree species and cultivars in middle Tennessee nursery surveys.



Knowledge Gap 5: **Why is flatheaded borer damage more common lower on the tree trunk?** Nursery surveys in middle Tennessee found most of the flatheaded borer trunk damage at heights below 30 cm (Figs. 6 and 7). The reason for a low attack site preference remains a knowledge gap, but possible reasons could include a) more favorable larval resources near the tree base, b) greater trunk damage area for borer entry, c) possible more bark splits at the trunk flare zone for borer entry exploitation, d) higher moisture content, e) adult landing preference or f) easier location for adult to oviposit (e.g., rougher bark to facilitate clinging during the oviposition process).

Fig. 6. Frequency plots of the height of flatheaded borer visible damage on various nursery tree species.

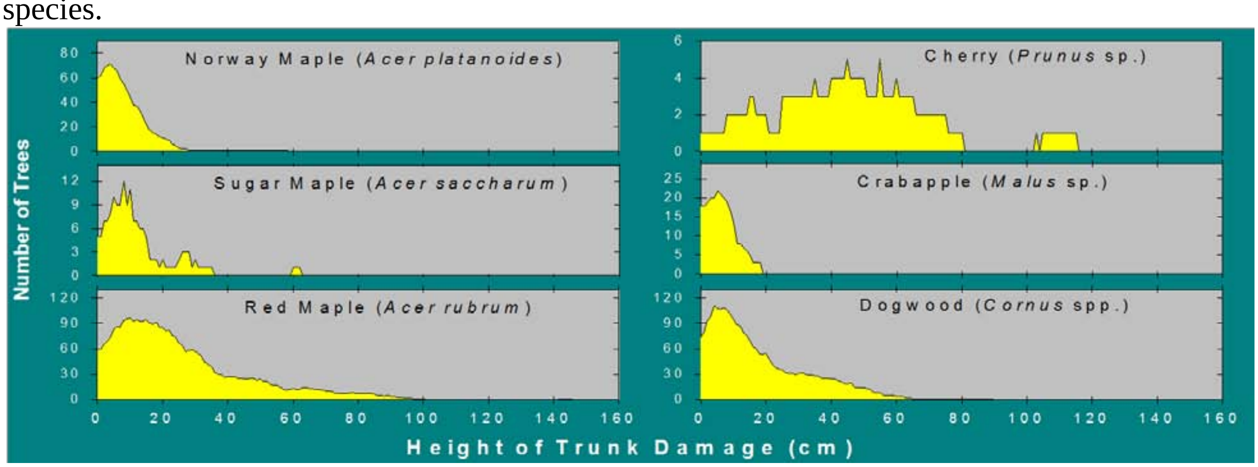
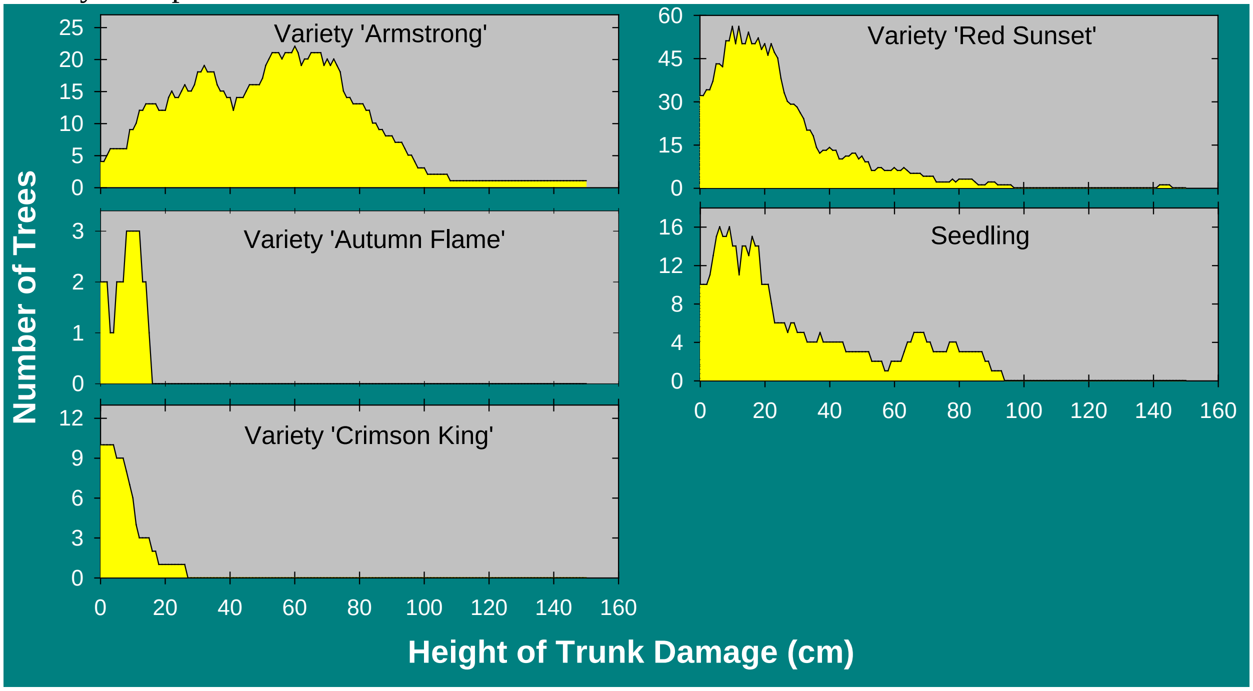
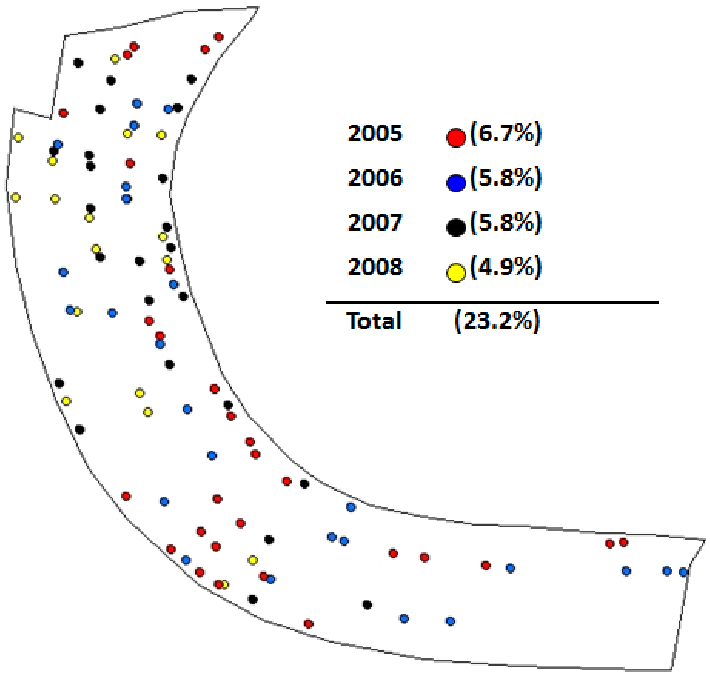


Fig. 7. Frequency plots of the height of flatheaded borer visible damage on various maple (*Acer*) nursery tree species.



<u>Knowledge Gap 6:</u> How many adult beetles are involved in attacks observed in a given field and what is the source of those beetles? Field observations in maple fields indicate flatheaded borers continue to attack new trees at a rate of about 5% of the crop per year and that attacks occur throughout the field in a somewhat random pattern (Oliver et al. 2010; Fig. 8). There are several knowledge gaps with respect to flatheaded borer attacks in fields, including a) how many different individual beetles are involved with attacks, b) what is the source of those beetles (local trees already in the field or from field exteriors, c) how do females select trees within the field to attack (e.g., is oviposition directed or random), and d) do females make multiple trips in and out of field sites to oviposit or do females remain in the field and perform multiple oviposition bouts in the same area. Females that venture in and out of field sites might be more vulnerable to trapping programs. Likewise, if the source of beetles infesting trees each year is localized from within field sites, then removal and destruction of trees that are already infested could have management benefits. It is known that females can fly long distances to locate trees to attack based on observations of flatheaded borer damage on isolated parking lot trees. It is likely some type of molecular technique may be needed to address questions like numbers of different females involved with oviposition. Tracking of female flight behavior (e.g., Rice et al. 2015) also might improve our understanding of the biology involved with field attacks.

Fig. 8. Global positioning system map locations of annual flatheaded borer attacks in a red maple (variety 'Autumn Flame') field over four years (2005 – 2008). (annual changes for this map also can be viewed in Oliver et al. 2010).



<u>Knowledge Gap 7:</u> **Because there is a long interval between egg laying/larval tree entry and onset of damage symptoms, a) does scouting have any value, b) how do you predict damage earlier and manage, and c) how do you avoid preventative or calendar sprays and utilize IPM principles?** It is believe that flatheaded borers principally oviposit from about mid-May through June (Fenton 1942). Larvae are reported to enter trees after about a 15–20 day egg development period and attacks may not be successful if the tree is vigorous and there is sufficient sap to reduce larval viability (Brooks 1919). Evidence of larval infestation may not be present for several months, until the larvae become large enough for the damage to be visible on the trunk exterior. We normally do not detect flatheaded borer attacks until the fall, and damage ratings are even more effective if postponed until spring. Once damage is sufficient for growers to detect, the market quality of the tree is usually compromised. Unfortunately, a producer has no way of knowing if their trees are under flatheaded borer attack early in the attack phase following oviposition. Likewise, producers also have no way of knowing if oviposition events that may have occurred will be successful or if the tree vigor will be sufficient to prevent attacks. Due to these factors, there is little value for producers to scout for flatheaded borers near the time of adult flight activity and late season scouting after the larval damage has been done also affords little benefit. Better methods are needed to predict timing and actuality of tree attacks and the need for sprays. For example, does the presence of a certain number of adults on traps indicate trees should be sprayed and does the absence of adults mean trees do not need protection?

<u>Knowledge Gap 8:</u> **What factors contribute to greater susceptibility of different tree species or cultivars?** Field surveys for flatheaded borer damage on the main tree trunk revealed that maples have some of the highest flatheaded borer attack rates among tree species, followed by dogwood, crabapple, and redbud. Some trees like oak and golden raintree had little to no

flatheaded borer damage. During insecticide trials, we also observed that some cultivars of maple varied in their flatheaded borer attack rates and typically the slowest growing trees were more likely to be attacked. Slow growth and greater flatheaded borer susceptibility would support Brooks (1919) statement that tree vigor can affect attack success. In one of our tests, 'Autumn Blaze' maple (a very fast growing hybrid of red and silver maple) had no flatheaded borer attacks, while the slowest growing 'New World' red maple cultivar had the most attacks. It is likely cultivar adaptation to the growing zone would be one factor that could lead to tree stress and greater susceptibility. Likewise, planting tree species or cultivars in the wrong growing sites (e.g., too wet or too dry) might also favor borer attacks. Cultivar and species specific factors also may increase borer attack success, like bark thickness, color, volatiles, defensive compounds, bark roughness, etc. Tree size at planting also probably can affect attacks, as we have often seen damage on large caliper tree liners following transplanting. Seagraves et al. (2012) observed variation in flatheaded borer attack rates on red maple cultivars with 'Burgundy Belle' having the highest attack rate, and the authors concluded that stress volatile differences might have been a factor in flatheaded borer cultivar preferences.

Knowledge Gap 9: Why do weedy fields have less flatheaded borer attacks? During insecticide trials that are presently unpublished evaluating herbicide and systemic imidacloprid interactions, we observed that herbicide-treated plots had higher flatheaded borer attack rates than non-treated plots that had more weeds. When borer attacks did occur, the often were not on the southwestern side of the tree or were higher on the trunk than typical (see knowledge gaps 4 and 5). In follow-up studies, cover crops were determined to provide the same beneficial reduction in flatheaded borer attacks (Dawadi et al. 2019). The reason for lower flatheaded borer attack preference when weeds or cover crops are present is unknown, but possible explanations could include trunk camouflage, reduced suitability for larval development (e.g., cooler trunk temperatures), adult beetle unwillingness to enter vegetation to oviposit (e.g., greater predation hazard from other invertebrates), or modifications of preferred adult behavior like resting on the sunny side of the tree trunk before mating.

Knowledge Gap 10: Does plant stress increase flatheaded borer attacks? It is generally recognized that most borers have greater success in attacking trees that are stressed. Many authors have indicated transplant stress can increase attack rates (Brooks 1919, Potter et al. 1988, Seagraves et al. 2012). We have observed flatheaded borer attack rates of about 5% per year for four years following transplanting (Fig. 8), which would suggest that transplant stress is not necessarily required for successful flatheaded borer attacks. More work is needed to identify specific stress factors that can increase attack rates. Likewise, additional work is need to determine what chemical cues *Chrysobothris* borers might utilize to detect host stress.

Knowledge Gap 11: Alternative systemic insecticide options and timing of trunk sprays. Insecticide research has found some neonicotinoid insecticides like imidacloprid provide long residual activity against *Chrysobothris* borers (Oliver et al. 2010). At the same time, trunk spray treatments like chlorpyrifos or bifenthrin were less effective. Follow-up research indicates half the labeled rate of imidacloprid is equivalent to current label recommendations (unpubl. data). The lower imidacloprid rate is needed since current active ingredient restrictions per acre limit the number of trees that can be treated. However, even at half the labeled imidacloprid rate, active ingredient restrictions are still too low for the numbers of trees typically grown in nurseries. Because many producers are utilizing imidacloprid for flatheaded borer management, it is possible some of these growers may be exceeding the labeled activity ingredient limits. In addition, overreliance on one insecticide strategy increases the risk of flatheaded borer insecticide resistance. Finally, recent concerns in the public with possible neonicotinoid effects on pollinators could become an issue with the utilization of borer effective neonicotinoids like imidacloprid and dinotefuran. One possible alternative group needing more research testing are the anthranilic diamides. Trunk sprays that have been less than efficacious in past testing also might be more effective with better information on timing. At the present time, it is unknown what is the best time to apply trunk sprays, when is the peak egg deposition period, are more than one species of flatheaded borer involved with tree attacks and if so, do different species have different attack phonologies, and finally, what exactly is the target stage of trunk sprays (i.e., the adult requiring chemicals to be on the tree before egg-laying is initiated, the egg requiring chemicals to either be on the tree before egg-laying or else sprayed on the egg after egg-laying, or the larva requiring chemicals to be on the trunk before the larva attempts to enter the tree). It is also unknown what the effective concentration is to kill the target flatheaded borer stage and/or what the residual of this effective concentration is with time and weathering. Data from one preliminary study in middle Tennessee suggests egg-laying by *Chrysobothris* spp. may be occurring in early June, which would indicate the current trunk spray timing recommended by extension may be incorrect.

Knowledge Gap 12: Does biological control of flatheaded borers have any value and/or can it be improved? When flatheaded borer damaged nursery trees are held in plastic rearing containers, we often rear braconid and ichneumonid parasitoids from the wood rather than adult buprestids. The buprestid infested tree materials that are put into rearing containers are always severely damaged by the borers, which is the reason they are being held for borer rearing. Because the trees are already damaged, it also means the parasitoid attack on the buprestid most likely occurred after the nursery tree was already devalued by the borer. Consequently, although the parasitoids may be reducing future buprestid populations, they are not necessarily preventing trunk attacks before the damage exceeds grower thresholds. More research is needed on the timing of parasitoid attacks, species involved, whether they can be augmented or enhanced, etc. Since weedy fields also reduce flatheaded borer attacks (see Knowledge gap 9), cover crops and other diverse vegetation might also afford and opportunity to augment natural enemies in the cropping system. Other natural enemies in the system like pathogens or predators that can be exploited also need to be studied.

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East Coast: Shade Tree Production – Factors Affecting Borers and Management

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North Carolina ranks in the top 10 states for specialty crops revenue generated in the U.S. Both the number of operations and the total acreage have been decreasing since a high of 2002, according to 2017 Census of Agriculture (Anon. 2019), however, sales remained between $5-7 billion between 2007 and present.

Shade trees planted in the eastern part of the U.S. are produced primarily by vegetative propagation using budding, grafting, stem cuttings, or micropropagation. These methods increase growth and decrease production time. Budding is the primary method of vegetative propagation for most shade trees. One- to three-year-old understock is field planted in spring or early summer in nurseries to obtain an established root system. In late summer, buds of desired cultivars are placed within an incision just under the bark of the understock using various budding techniques. The following winter, just as the new bud is beginning growth, the understock is pruned off and its resources are channeled through the single cultivar bud, thus producing tremendous growth of the desired cultivar in one year. When plants reach the desired height for liner production, they are dug dormant and field planted elsewhere. During the budding process, stubbing-off the understock leaves a scar at the plant base that is essentially a wound until it calluses completely in two to three years prior to final sale. The practice of budding is not detrimental to plant growth, and has been used successfully with many cultivars and hundreds of thousands of plants transplanted into the landscape.

The stubbed bud union produced during budding or grafting or even stubbing at ground level for maples can increase the incidence of flatheaded appletree borer (*Chrysobothris femorata* Olivier) (FAB) infestation (LeBude and Adkins 2014). Planting trees with this stubbed portion of the bud union facing a northerly direction is a simple cultural practice that can be used by nurseries to decrease the probability of FAB infestation by as much as 40%.

Complete control of FAB (100% of trees not infested) was recorded over four years in three cultivars of red maple when newly field-planted liners were drenched with cyfluthrin plus imidacloprid (Oliver et al. 2010). The trunk-applied contact insecticides chlorpyrifos and bifenthrin, however, were less effective in preventing damage to the same maple cultivars (Oliver et al. 2010). Permethrin, another trunk-applied contact insecticide, has also been recommended for use on maples (*Acer* spp.) (Frank et al. 2013). Drenches, however, have higher initial costs than trunk-applied contact insecticides, which may encourage growers instead to monitor beetle emergence in May or June and to better time lower costing trunk-applied sprays during that time. This requires use of purple panel traps (Oliver et al. 2004) and some experience identifying the *Chrysobothris femorata* complex (Hansen et al. 2009). Very few producers of ornamental crops, however, use any passive traps or lures to monitor emergence of wood boring pests (LeBude et al. 2012). Since these trunk applied sprays are required yearly and multiple times per year, missed or poorly timed applications increase the likelihood of attack during the 24 to 60 month production cycle of shade trees in the eastern U.S.

Producers of shade trees need more reliable, precise detection and subsequent identification of adult emergence for these wood boring pests. Additionally, summer field scouting protocols should now include inspection of the stubbed area of cultivars that were budded or grafted to determine if FAB is present. Focusing solely on this area, especially when it is facing a southerly direction, might increase the chances of detecting the presence of FAB while decreasing the actual time spent scouting for the pest.

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East Coast: Factors Affecting Borers and Management: Pecans, Ornamentals and Fruit Trees

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Flatheaded appletree borer (FAB) is only a sporadic and minor pest in Georgia pecan, ornamental and tree fruit systems. There have been anecdotal reports of pecan trees and ornamental trees being attacked by these borers. In the case of peaches in Georgia, management for peach tree borers may also indirectly control for FAB. It is possible that lack of awareness on the injury caused by these borers is a factor for infestations to be under-reported in the state. Thus far, no formal studies on monitoring and management in the state have been conducted. Preliminary studies on species survey and identification and grower assessment on FAB injury encompassing the three production systems may be warranted moving forward.

Pacific Flatheaded Borer Ecology and Knowledge Gaps in Western Oregon Orchard crops

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The Oregon hazelnut industry produces 99% of the US hazelnut (*Coryllus avellana* L.) crop, primarily in the Willamette Valley. Recent introduction of hazelnut cultivars with genetic resistance to the devastating disease of European hazelnut, eastern filbert blight, has stimulated extensive growth in the industry. Currently, more than half of the total hazelnut acreage (>80,000 Ac) is comprised of immature young trees (<11 years old). Pacific flatheaded borer (PFB; *Chrysobothris mali* Horn) has been causing serious problems for growers establishing new orchards in recent years. The pest attacks trunks of the young trees, often girdling and killing the aboveground parts of the tree. Most new orchards have lost trees to PFB, some experiencing up to 35% loss. In old orchards with eastern filbert blight, PFB can also infest diseased or sunburned scaffold limbs. Expansion of the hazelnut industry has provided new opportunities for the pest as many of the new orchards are planted on suboptimal hazelnut soils leading to irrigation challenges and plant stress, and orchards are appearing more and more in the foothills of both the Coast Range and Cascade mountains where there are presumably abundant alternate host plants and some of the biggest impacts of PFB occur. Besides hazelnut, other orchard crops attacked in the Willamette Valley include apples and cherries, though these are relatively minor crops for the region.

Although both flatheaded apple tree borer, *Chrysobothris femorata* (Oliver) and PFB are native pests in the western U.S., PFB is the more economically important species in the region (Burke 1919). PFB has long been recognized as a problematic pest for new orchards, shade trees and certain forest species (Burke 1917, 1919, Burke and Boving 1929). However, there has been little recent research on PFB in orchard systems, and there may be some indication that economic impacts from the pest are cyclical. In the late 1960's, PFB was considered a major pest for orchardists in California's Central Valley (Davis et al. 1968, Mcnelly et al. 1969). However, since that time there has been little published on PFB as a pest of orchards and no research on management of PFB in hazelnut orchards in Oregon.

Working closely with hazelnut growers and field consultants and supported by the Oregon Hazelnut Commission, we have identified key knowledge gaps for management of PFB in hazelnut and other orchard crops in the Willamette Valley. These include: 1) phenology, to improve understanding of when the trees are attacked so that management can be appropriately timed, 2) crop protection, where the objective is to recommend chemical, cultural and potentially biological management tactics that prevent borer attack, 3) monitoring, so that we might determine whether the pest is present or absent in orchards and ultimately use trap thresholds to guide management, 4) life history and biology, because we have a poor understanding of landscape risk factors, dispersal capacity, voltinism, and plant stress factors that are important for attracting borers. To date, we have made the most progress on crop protection and phenology.

In 2017, we began a campaign to collect PFB-infested stems of hazelnut trees from growers to begin investigating PFB phenology. We collect several hundred stems from commercial growers each year. Our tactic has been to keep borers alive in the stems in field cages to track them as they naturally emerge from the wood. After collection, we cap the pruned stems with paraffin wax at each end to seal in moisture and place the infested stems in small emergence cages within field cages located in Aurora, OR. During the spring, we dissect some stems every week to monitor the life stages of PFB and provide growers notice about the anticipated emergence date. Once borers begin to emerge, the emergence cages are checked frequently for adult PFB. This has allowed us to produce an emergence curve for borers in 2017, 2018, with 2019 in progress. This data indicated that PFB emerge starting in early June and emergence continues through the month of July (Fig. 1). We know little about adult lifespan, but these data suggest that the flight period of PFB likely extends into the first two weeks of August and the period of plant protection is likely to be roughly 10-12 weeks.

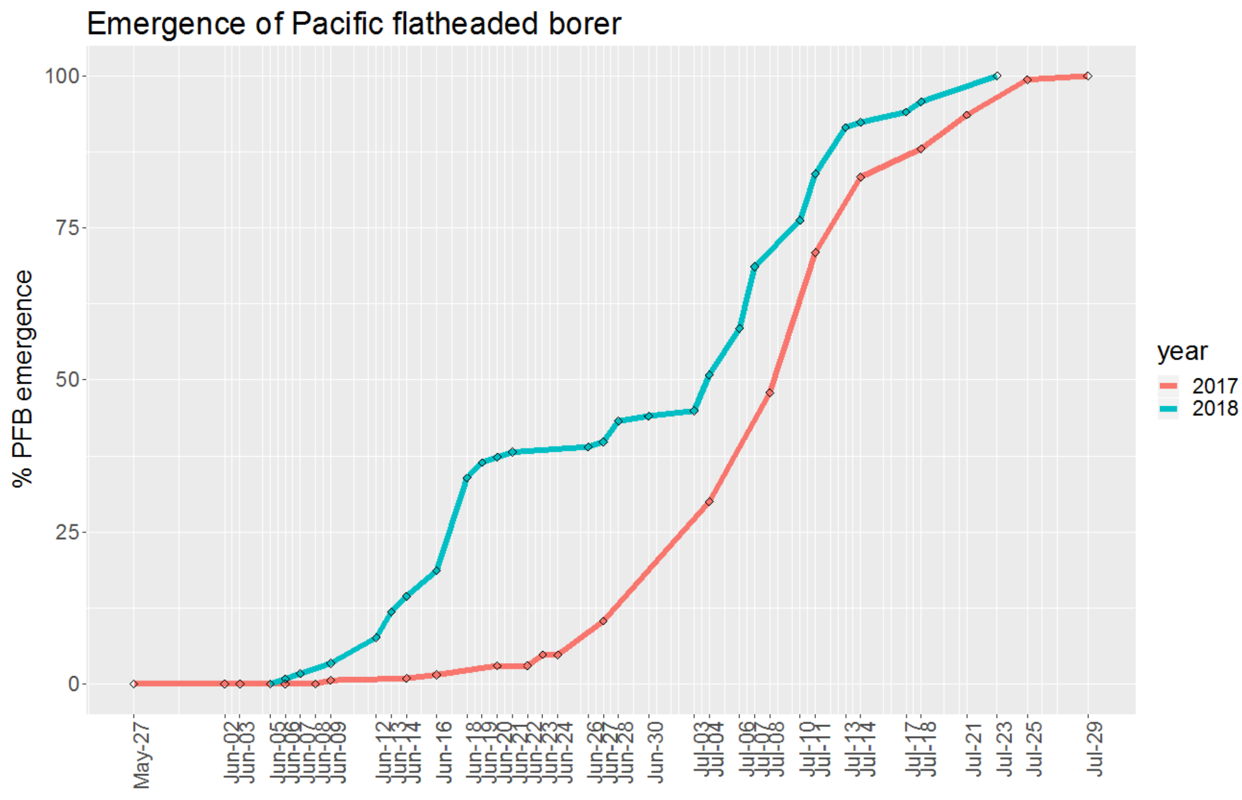

Fig. 1. Emergence timing of Pacific flatheaded borer from infested hazelnut stems. Borers emerged in field cages at the Oregon State University North Willamette Research and Extension Center in Aurora, OR.

To evaluate plant protection tactics we began investigating methods to induce PFB attack of trees. We found that planting bare root hazelnut trees late in the growing season was an excellent way to induce attack. Typically bare root hazelnuts are planted during the dormant season, but allowing trees to break bud and initiate root development prior to planting in the field in May can create conditions that lead to PFB attack. Plant protectants can be applied to trees under these conditions, then stems harvested in fall, capped in wax and borer damage and emergence assessed by allowing emergence in field cages for different treatments. Unfortunately, it takes over a year to determine emergence of PFB from treated trees. For the interim period, we have successfully evaluated plant protectant treatments with a qualitative indication of infestation by borer. By rating swell and bulging of the hazelnut trunks and by rating the canopy color in the fall (infested trees tend to show chlorotic foliage), we have been able to approximately rate efficacy for different treatments. Promising treatments include imidacloprid drench, chemigation, and cover sprays. Other IRAC Group 4 materials also show efficacy. Like other researchers, we have also demonstrated that simply painting trunks with white latex to prevent sunburn is a simple preventative cultural management solution (Mcnelly et al. 1969). We are also seeing encouraging results that Group 28 ryanodine receptor modulators (diamides) may provide some systemic protection from PFB.

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Important Flatheaded Borer Species Impacting Ornamental Trees and Shrubs in Oregon

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There are several flatheaded borer species of economic importance in Oregon's nursery industry or are destructive in ornamental plantings, including:

Flatheaded cedar borer, *Chrysobothris nixa* Horn is a native species that can be very destructive in plantings of arborvitae (*Thuja occidentalis*), juniper (*Juniperus* spp.) and western red cedar (*Thuja plicata*). Similar to other flatheaded borers, the flatheaded cedar borer is opportunistic and may be attracted to trees after summer pruning or accidental mechanical injury. Most specimens have been collected from early June to mid-July; avoidance of summer pruning while maintaining tree vigor are considered best management recommendations. Very little research exists for this pest.

Pacific flatheaded borer, *Chrysobothris mali* Horn can be an issue in shade tree production blocks, particularly grafted species, where the attack often occurs near the graft union. Sunburn, drought stress, or overwatering are often the cause for attack. Growers typically burn infested trees.

Rose stem girdler, *Agrilus cuprescens* Ménétriés is an increasing invasive pest issue in the Pacific Northwest. Originally from Europe, it was first observed from Washington State in 2014, Eastern Oregon in 1994, and Western Oregon (Willamette Valley) in 2015. This pest affects commercial caneberry production and may affect roses. On caneberries (*Rubus* spp.), the pest feeds just below the bark causing spiral tunnels and a gall-like swelling where the bark may become discolored and cracked and breaks easily. Foliage above infested stems tends to flag. Mature larvae move to the pith of stems where they overwinter and form the pupal cell the following spring before emerging. Management of this pest includes sanitation through pruning of infested canes and insecticides targeting ovipositing adults.

English Walnut Production and Factors Affecting Flatheaded Borers and Their Management in California

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Background

Walnut production in California. California produces more than 95% of the total production of English walnut, *Juglans regia* L., in the United States. The total bearing acres of walnuts in California has been increased drastically in the recent two decades from ~200,000 acres in 1999 to ~350,000 in 2018 (NASS 2018). The rapid increase of walnuts and other nut crop acreage, drought conditions in recent years, excessive heat in the valley during the summer in some parts of the Central Valley and other various factors can contribute to new challenges in production and pest management. The recent example is the sudden increase in flatheaded borer damage in commercial walnut orchards in several walnut growing areas in the Central Valley.

Flatheaded borer-pest status. During late August 2018, several growers and Pest Control Advisers (PCAs) from San Joaquin and Stanislaus counties reported unusually high borer infestations in walnut orchards. Research and extension professionals from the University of California and the US Department of Agriculture (USDA) visited several walnut orchards with this borer problem in the valley, particularly in two northern San Joaquin Valley counties - San Joaquin and Stanislaus. The insect was identified as a flatheaded borer belonging to the family Buprestidae. The larval stage of the flatheaded borer beetle has a greatly enlarged and flattened anterior part of the body (technically the thorax; hence a flat “head”).

In several orchards, we observed borer infestations on a range of orchard tree ages [young (2 years) to mature (15-20 years)] and a range of English walnut cultivars such as Howard, Chandler, and Tulare. High-density feeding galleries by the larvae were leading to breakage of nut-bearing branches. Although Pacific flatheaded borer (*Chrysobothris mail* Horn [PFB]) has been reported as an occasional pest in a limited number of orchards (i.e., walnuts, almonds, cherries, and plums) on trees with compromised health (Davis et al. 1968), this infestation appeared to be much more severe and widespread with reports throughout the walnut growing regions of California. Flatheaded borers are known to cause damage to weaker, wounded, and sunburn-susceptible parts of trees. However, in our observations, the feeding damage was not limited to wounded and sunburn-damaged branches, and this behavior as a primary pest is a concern for walnut growers. The damage observed was distributed randomly throughout the tree, including twigs (pencil-sized), branches (2-4 in. diameter), limbs, and trunks. The flatheaded borer-infested orchards that we visited did not all manifest obvious nutritional deficiency. More interestingly, the damage we observed did not occur in other places or on other tree species, and the PFB is not considered as the pest of mature trees.

Biology of Pacific flatheaded borer. Pacific flatheaded borer belongs to the Buprestidae beetle family, the members of which are wood borers. Adults are ½ to ¾ inch long small-sized, with brown and gray markings on the wing covers, and have an oval head with the wedge-shaped body. Female beetles deposit ~100 eggs singly in the potentially weaker portion of the wood (i.e., sunburnt, freshly pruned, etc.) on in bark crevices or depressions. Larvae bore through the bark and feed on the cambium layer of the wood initially, but can reach to the xylem eventually. The larvae are cream-colored and legless. They construct pupal chambers and molt into the final instar (i.e., prepupae stage) for overwintering. Pupation occurs in the spring and early summer followed by adult emergence. Pacific flatheaded borer has one generation per year, but the life cycle may be longer (1-3 years). Although there has been some old reports and literature mentioned the PFB infestation in fruit trees in California (Davis et al. 1968, McNelly et al. 1969), there is a significant lack of basic information on this pest such as seasonal phenology, life history, extent of damage to walnuts and other crops in general in California. Pacific flatheaded borer has a wide host range that includes at least 70 forest and other tree species of 21 plant families. A few examples are alder, birch, ash, ceanothus, oak, boxelder, mahogany, maple, poplar, sycamore, willow, apple, pear, beech, elm, cotoneaster, peach, plum, avocado, loquat, cherry, currant, fig, apricot, walnuts.

Knowledge gaps, initial steps in advancing the research, and future needs

Based on several formal and informal meetings and conversations with local walnut growers and pest control advisors in the northern San Joaquin Valley, we realized that there was a clear need to study the biology of the pest and develop monitoring and management tools to minimize the impact. There has not been any research conducted in recent memory on this insect in walnuts in California. Understanding the basic information such as seasonal phenology of adult emergence, documenting damage symptoms, population abundance, and potential factors associated with host susceptibility to attack will provide essential background for developing and implementing management targeting this borer in walnuts. Preliminary research activities started since the Fall of 2018 are as follows:

1. Documenting damage symptoms. Based on our initial assessment of several infested orchards, we documented the following visual symptoms (Fig. 1) as the indicator of the flatheaded borer in walnut orchards:

- Brown colored sap oozing from under the bark on the trunk, limbs, and lower branches
- Presence of visual wounds on the tree branches and limbs that are prone to sunburn
- Feeding channels packed with frass (sawdust-like insect waste) and cream-colored larva underneath the bark after peeling of branches with suspected infestations
- D-shaped exit holes from adult beetle emergence on the bark

Fig. 1. Various injury symptoms caused by Pacific flatheaded borer in walnuts

2. Study of the phenology of adult emergence.

During the winter of 2019, we collected walnut branches from the walnut orchards infested by flatheaded borers in the previous season for an adult emergence study. Three walnut orchards representing three commonly grown varieties-Tulare, Chandler, and Howard, were selected for this purpose. Collected branches (0.5-1.0 inch diameter) were cut into 24-34 inches long pieces, put into plastic storage containers, and kept outdoors to facilitate adult emergence. Based on the preliminary results, we found that flatheaded borer adult emergence started in mid-May and continued through June. The highest number of adults were recorded on June 12 (Fig. 2).

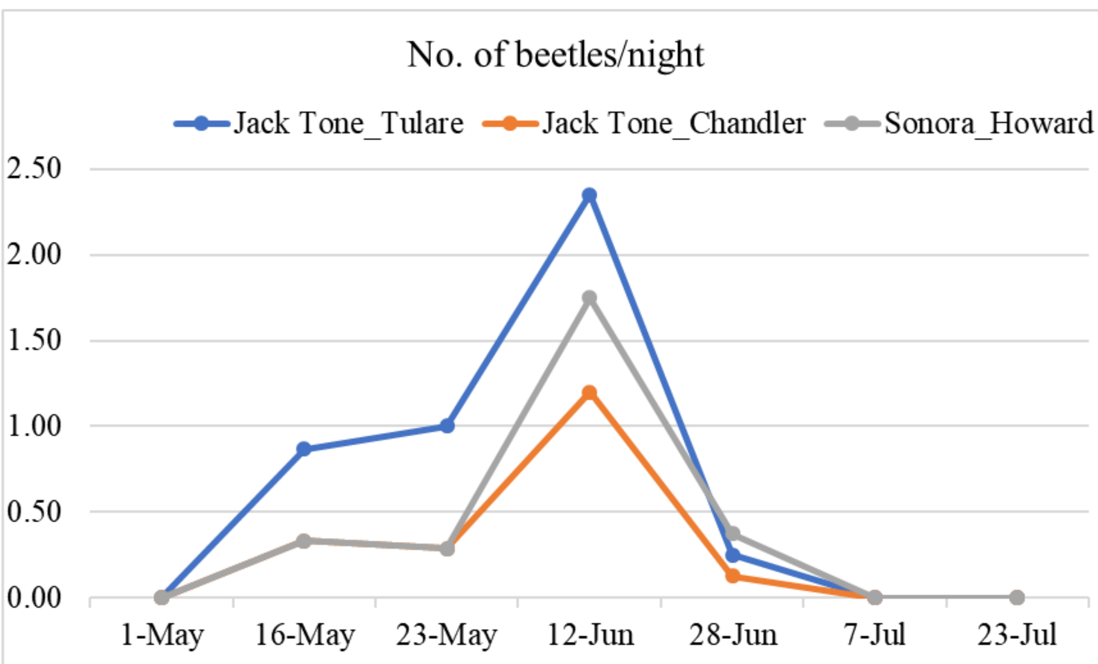

Fig. 2. Seasonal trend of Pacific flatheaded borer emergence from the winter-collected walnut branches

3. Exploring monitoring tools.

Previous studies reported that green or purple colored sticky prism trap (35.6 × 59.7 cm) and purple multifunnel trap (also called Lindgren funnel traps) play a significant role in attracting several buprestids such as emerald ash borers (Francese et al. 2008) and goldspotted oak borer (Coleman et al. 2014). The multifunnel traps are recyclable for repeat uses and more user-friendly for buprestid beetle trapping as the user does not have to deal with the sticky materials that characterize the prism trap (Francese et al. 2011).

In 2019, we deployed traps in six walnut orchards with a set of three traps -one purple and one green sticky prism traps and one purple multifunnel traps. All these traps were hanged on ~10-ft tall poles in orchard rows. Traps were checked bi-weekly and serviced as needed. All buprestid beetles captured in prism and funnel traps were counted and later identified (Westcott et al. 2015). The preliminary results showed that these all traps captured buprestid beetles, including PFB. Purple funnel traps captured the highest number of beetles compared to the sticky purple or green prism traps (Fig. 3).

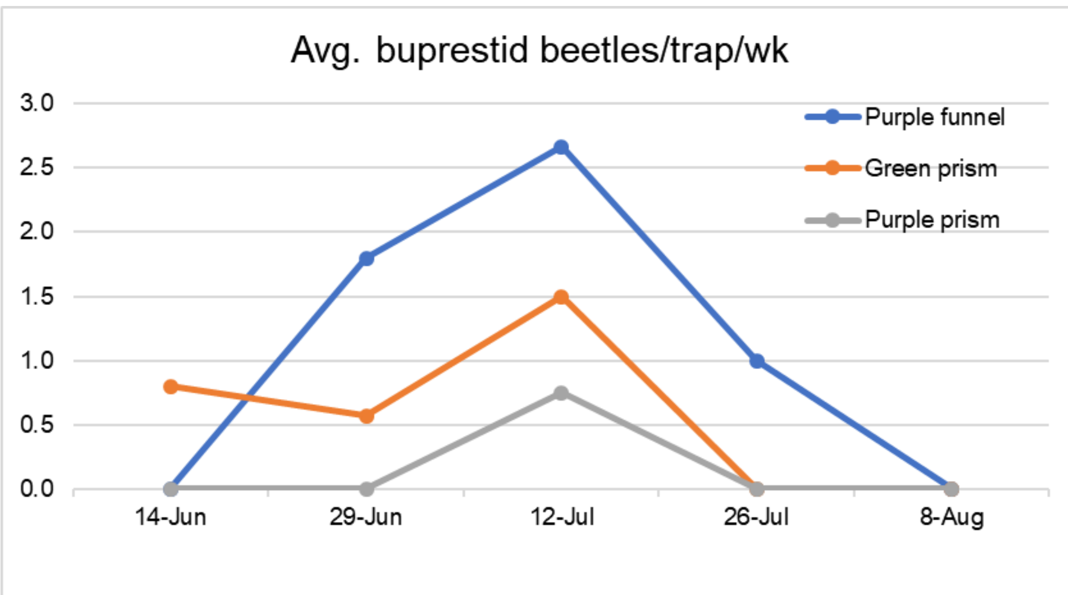

Fig. 3. Season buprestid beetles captured in various trap types in walnut orchards

4. Lack of preventative and other control measures. Flatheaded borer infestations may be reduced by adopting cultural practices that encourage vigorous, healthy plants, although the PFB seems to also attack healthy trees (UCIPM Guidelines 2017). Young trees may be protected from the sunburn by applying white latex paint or using mechanical covers over the trunk (e.g., trunk guard), although the systematic evaluation of these practices is needed. One of the general practices for these kinds of borers is orchard sanitation, which includes the removal of the weakened, injured, dead, and flagged branches, but its effectiveness and timing need to be investigated. To our knowledge, there is no insecticide registered for this pest in walnuts in California, and therefore, it is critical to explore various preventative and curative control measures to minimize the impact of this pest in walnut production.

Acknowledgements. California Walnut Board provided funding support to initiate flatheaded borer research and extension activities in California.

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IR-4 Environmental Horticulture Program: General Updates and Coleopteran Research

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The mission of the IR-4 Project is to facilitate the registration of sustainable pest management technology for specialty crops to enhance human health and wellbeing. The Environmental Horticulture (EHC) Program focuses on non-edible crops such as flowers, shrubs and trees (annuals, herbaceous perennials, woody perennials), while the Food Crop Program focuses on edibles such as fruits, nuts and vegetables. There are three main areas of the EHC program: Registration Support, Invasive Species, and Special Projects (currently Pollinator Protection).

Since 2003, the EHC Program has sponsored more than $4 million for research into tools to manage pathogens, pests and weeds in woody perennial crops, with close to $1.5 million on azaleas and rhododendrons primarily for Phytophthora efficacy and crop safety. Outcomes of this research - project summaries and product registrations - are posted on the IR-4 website (https://www.ir4project.org/ehc/) . Since the EHC program began, more than 840 products and numbered compounds have been screened for performance with the result that more than 44,000 crop uses have become registered and available to growers and landscape managers.

The EHC Program sponsored research for managing borers during 2006 through 2009 and 2018 and 2019. Two flatheaded borer species were studied: bronze birch borer (Agrilus anxius) and flatheaded appletree borer (Chrysobothris femorata). Unfortunately, in all three experiments, there were very low infestation levels, so it was not possible to determine product performance. The research in 2018 and 2019 focused on Ambrosia beetles, but it might be possible to glean potential tools for managing flatheaded borers from this protocol.

The biennial workshop to determine IR-4 EHC Program research priorities will be occurring Sept 25-26, 2019 outside Baltimore, MD as part of a week of workshops to establish research priorities across the IR-4 Project. Part of the process to select EHC priorities involves summarizing grower and extension personnel responses to a survey (https://www.ir4project.org/ehc/ehc-registration-support-research/env-hort-grower-needs/#Survey) about management tool needs. If flatheaded borers are a critical impediment to growing good quality crops, it was encouraged that audience members participate in this survey and disperse it to colleagues.

In summary, the EHC Program assists growers in obtaining the tools needed to grow their crops and has successfully done so by collaborating with growers, researchers, extension personnel and members of the crop protection industry to identify research priorities and screen new tools.

Entomopathogens: Prior Knowledge and Potential for Borer Control

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Entomopathogenic nematodes (EPNs) used in biological control consist of two genera (*Steinernema* & *Heterorhabditis*). They are safe biocontrol agents; commercially produced and applied against a wide variety of insect pests (Shapiro-Ilan et al. 2018). There are currently > 110 species described (> 80% steinernematids), with about 12 of these commercialized. The nematodes kill the host with the aid of symbiotic bacteria (*Xenorhabdus* bacteria spp. are associated with steinernematids and *Photorhabdus* spp. are associated with heterorhabditids) (Shapiro-Ilan et al. 2018).

Entomopathogenic nematodes have been applied extensively for control of various borer pests (Shapiro-Ilan et al. 2018). For example, successful targets include the peachtree borer, *Synanthedon exitiosa*, and lesser peachtree borer, *Synanthedon pictipes*; in both cases levels of control were equal or superior to chemical insecticide standards (Shapiro-Ilan et al. 2009, 2010, 2016). For peachtree borer, high levels of control (88−100%) have been observed when applying the nematodes in a preventative or curative manner (Shapiro-Ilan et al. 2010). For lesser peachtree borer, issues of aboveground application presented a challenge, yet a gel formulation (Barricade firegel) facilitated use of the nematodes while protecting them from harmful UV and desiccation (Shapiro-Ilan et al. 2010, 2016). The gel formulation may be useful in other aboveground borer applications.

Some preliminary efficacy has also been demonstrated against flat-headed borers such as the flatheaded root borer, *Capnodis tenebrionis*. However, challenges exist to improve EPN control against flat-headed borers and to make the approach feasible. Challenges include cost of the product, and environmental barriers (such as UV and desiccation). These barriers can be addressed through 1) Using improved EPN strains, and 2) Improved formulation and application technology.

Strain improvement can be achieved via direct selection or hybridization of nematode populations. This has been accomplished for *S. carpocapsae* to improve virulence and environmental tolerance for pecan weevil control (Shapiro-Ilan et al. 2005). Once an improved strain is obtained it should be genetically stabilized through establishment of purebred homozygous lines (Shapiro-Ilan et al. 2018). Formulation technology can be improved as indicated above via protective materials such as gels (Shapiro-Ilan et al. 2016). Improved application can be achieved via the novel technology of adding “boosters” to the EPN mixture. For example, Oliveira-Hofman et al. (2019) recently demonstrated that EPN pheromones can greatly enhance efficacy when mixed with the nematodes during biocontrol applications. These approaches can be applied to other systems. Therefore, in summary, improved biocontrol of various borer pests can be achieved by improving and stabilizing EPN strains and by enhancing formulation and application methods.

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Entomopathogenic Nematodes in BASF, a New Tool for Insect Control

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Steinernema feltiae (Nemasys), *Steinernema carpocapsae* (Nemasys C/Millenium), *Steinernema kraussei* (Nemasys L), *Steinernema riobrave* (Nemasys L) *and Heterorhabditis bacteriophora* (Nemasys G) are produced in industrial scale by BASF are natural soil-dwelling nematode. Infective juveniles chase susceptible larvae/pupae depending of the insect in the soil/trunk and foliar, using cues such as carbon dioxide to detect insect hosts and enter their bodies through their natural openings. Once inside the host, the nematodes reproduce and release bacteria that the nematodes carry in their guts, causing the death of the insect by septicemia, normally 3-5 days after nematode application. EPNs could be a new addition to the resistance management programs already utilized by farmers or as complement to other management strategies in both conventional and organic farms.

Flatheaded Appletree Borer: A Potential Pest of Blueberries in Florida

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Introduction

The flatheaded borer is a new pest in Southern Highbush blueberries. It was discovered approximately three years ago when growers realized that bushes were exhibiting typical symptoms of borer infestation including girdling and tunneling on blueberry stems. In addition, some growers observed frass exiting from the stems of bushes. The grower reports were followed by immediate sampling of selected bushes where growers claimed to be seeing symptoms. After careful examination, we found evidence of the borer's presence.

Methodology

Subsequently, larval sampling was conducted monthly from April 2018 to October 2018 in all of the primary blueberry growing regions in Florida. Sampling consisted of inspecting the canes of 20 randomly selected blueberry bushes within each sampling area. Plants were inspected visually and by removing or scraping bark. Several canes with active tunnels were collected from each survey site (with grower permission). The ends of each cane were sealed with paraffin wax and stored in 18-gal plastic containers for rearing borers. We subjected the collected infested branches to controlled conditions in our laboratory and extracted larvae from blueberry canes exhibiting borer damage. These specimens were sent to a molecular lab for identification and confirmation. In addition, we reared other woodboring insects that were collected from various blueberry plantings around the state including cerambycids and other *Chrysobothris* spp. Containers were checked at least once every two weeks for any emerged beetles. In addition to larval sampling, we also established 3 purple panel sticky traps at every farm surveyed for monitoring adult borers.

Results

We collected a few *Chrysobothris* adults off purple panel traps placed on blueberry farms from 2018. These were identified using morphological and molecular techniques as mostly belonging to the *Chrysobothris femorata* complex. Several woodboring beetles also were reared or extracted from branches for identification.

Data from the molecular lab and from morphological identification revealed several *Chrysobothris* species, including *Chrysobothris femorata*, *Chrysobothris viridiceps*, *Chrysobothris shawnee*, *Chrysobothris cribraria*, and *Chrysobothris crysoela*. There were also other cerambycid woodboring beetles identified, including *Anelaphus inermis and Elaphidion mucronatum*. The species found on sticky traps included *Chrysobothris crysoela*, *Chrysobothris shawnee*, *Chrysobothris cribraria*, and *Chrysobothris viridiceps*. The species removed from infested branches include *Chrysobothris femorata* and *Chrysobothris crysoela*. Successfully reared species include *Chrysobothris crysoela* and *Anelaphus inermis*.

Approximately 8% of the blueberry bushes sampled had injury that appeared to be associated with *Chrysobothris* species or other woodboring beetles.

Discussion

Our 2018 data revealed the presence of woodboring beetles that caused injury to blueberry bushes in Florida. The identities of these beetles were confirmed with our morphological and molecular techniques. We will continue our monitoring activities with the hope of identifying woodboring species causing economic damage to blueberry growers.

This year we are conducting on-farm demonstrations to compare various types of baited and unbaited traps for monitoring the flatheaded borer. These include purple panel traps, cross vane panel traps, and Lindgren funnel traps. The results from this study will be important in terms of giving growers a tool that they can use to monitor flatheaded borers in their blueberry plantings.

Management of Flatheaded Appletree Borer in Nursery Production with Cover Crops

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Current best management practices for flatheaded borers in nursery production include the application of a systemic neonicotinoid in the spring following transplant. The application of imidacloprid confers up to three years of protection while annual applications of shorter-lived neonicotinoids, such as dinotefuran, are also effective. Alternative treatment options for growers are needed in order to address some concerns raised by the exclusive use of neonicotinoids. The first concern is that region-wide use of the same products could cause resistance development in some flatheaded borer populations. Secondly, the acreage limits for imidacloprid application can result in label violations if too many trees are treated in the same acre in one year. Additionally, concerns have been raised by consumer and industry groups regarding the application of systemic neonicotinoids to flowering trees and shrubs which may serve as pollen and nectar sources for bees.

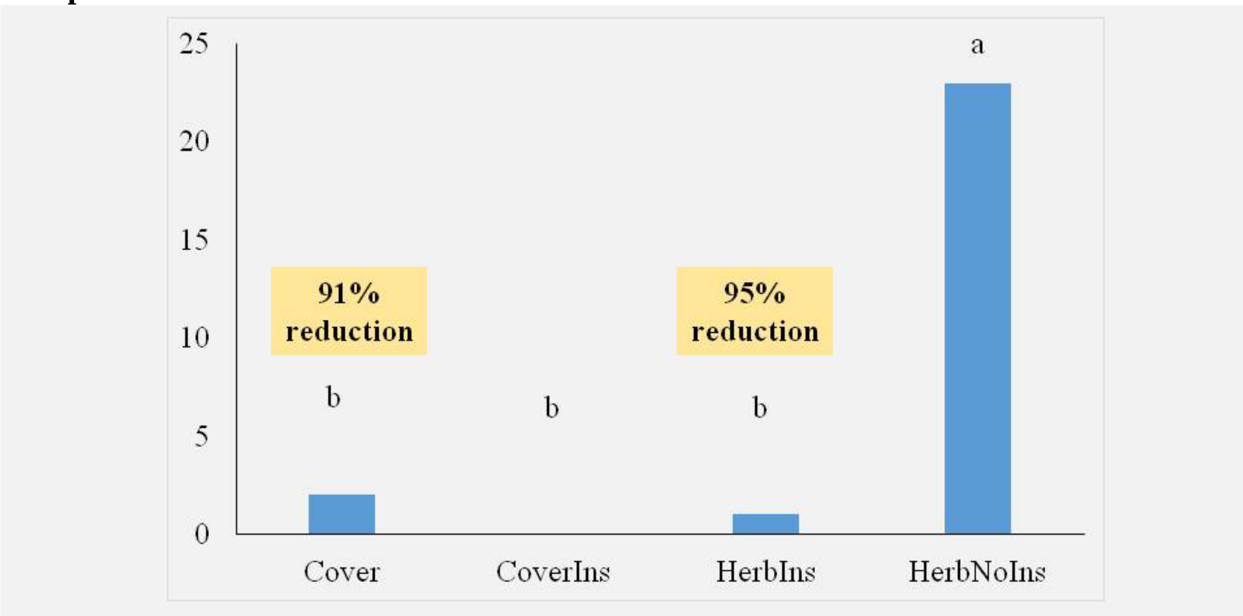
One alternative method for flatheaded borer management investigated here is the use of cover crops to camouflage or otherwise make the tree crop an undesirable host for borer eggs. This work was initiated based on previous observations of weedy plots having fewer borer attacks than herbicided plots with bare tree rows. The objective of this study was to determine if the presence of cover crops at the base of trees could prevent flatheaded borer attacks. The cover crops were selected based on the estimated height of the crop by May 1st. Previous work on flatheaded borers had demonstrated a preference for the beetles laying eggs on the southwest side of the trunks in the first 20 cm from the ground. Cover crops needed to be at least 60 cm tall by May 1st, prior to the known first flights of local borer populations. For the first year of this study, a mixture of winter wheat and crimson clover were used. The cover crop was initiated in the late summer of 2015 and trees were transplanted into the crop in late fall. In the second year, annual ryegrass and crimson clover were broadcast in the fields. While it is possible to use any cover crop mixture in the first year of cover cropping, in subsequent years, seeds that germinate on contact with ground are necessary since it is not possible to disturb the soil at the base of the trees. For this reason, any seed that must be drilled or disked into the soil is not appropriate for subsequent years. The crimson clover was added to the blend in order to supply additional nitrogen to the cover crop since it is most common for growers to topdress their trees with nitrogen, rather than broadcast across the entire field. Four treatments were evaluated in this experiment in a 2x2 factorial design: cover crop, cover crop + insecticide, hebicided rows (untreated control), herbicided rows + insecticide (standard practice). The insecticide applied to the trees was an imidacloprid drench at 11 ml/in diameter (Discus® N/G) in April 2016 following transplant. Trees were arranged in four replicated blocks of 25 trees per block (Fig. 1). Herbicided rows were maintained bare using pre and post-emergent herbicides (Finale, Sureguard). Middles were mowed periodically to keep foliage low and middles passable.

At the end of two growing seasons, 23% of the trees in the herbicide plots had been attacked by flatheaded borers. Two percent of trees were attacked in the cover crop plots and 1% in the recommended treatment plots (herbicide + insecticide). No trees were attacked in the cover crop + insecticide plots (Fig. 2). While we do not know precisely why the cover crop reduced attacks, trunk temperature data indicated that tree trunks in the cover crop plots were as much as 4°C cooler than those in the herbicided plots (Fig. 3). Since previous research has indicated that females prefer to oviposit on the sunny side of trees, temperature could have impacted borer preference. In addition to microclimate, the cover crop may also act as a camouflage or physical barrier, reducing the likelihood of females locating the host plant. Finally, predation risk is likely higher in the cover crop plots which could have reduced borer success.

While the cover crop was as successful as the insecticide at protecting trees from flatheaded borer attacks, the cover crop treatment did negatively impact tree growth. In this study, the cover crop was allowed to senesce naturally throughout the summer and no additional irrigation was provided to the trees. Competition from the cover crop within the tree rows resulted in significant reductions in diameter and height growth (Table 1) as well as canopy size and new shoot development (data not shown). In year one, trees in the herbicided plots added an average of one additional centimeter in diameter and 50 cm in height more than the cover cropped trees. In the second year, cover cropped trees continued to grow more slowly, but not as slow as in the first year of establishment. The trees in this study will be followed until fall 2019 to determine whether cover cropped trees will recover some of their lost growth after an additional two years without cover crop and how much total loss in growth can be expected if adopting a minimally managed cover crop production method for borer control.

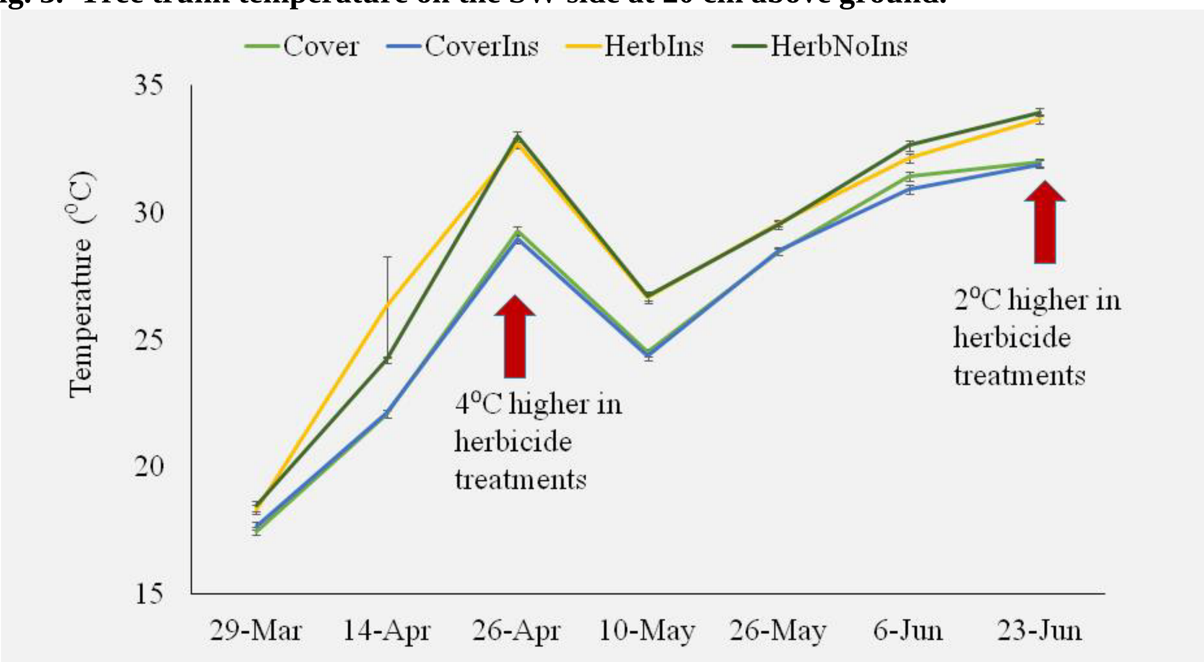
Fig. 1. Cover crop and bare row plots.

Fig. 2. Percent of trees attacked by flatheaded borers in each treatment first year post-transplant.



Cover = cover crop in tree row; CoverIns = Cover crop in tree row and trees drenched with imidacloprid; HerbIns = bare ground in tree row and trees drenched with imidacloprid (current recommended practice); HerbNoIns = bare ground in tree row (untreated control).

Fig. 3. Tree trunk temperature on the SW side at 20 cm above ground.



Cover = cover crop in tree row; CoverIns = Cover crop in tree row and trees drenched with imidacloprid; HerbIns = bare ground in tree row and trees drenched with imidacloprid (current recommended practice); HerbNoIns = bare ground in tree row (untreated control).

Table 1. Height and trunk diameter of trees in the first year following transplant.

Treatments	Height Growth (cm)	Trunk Diameter Growth (cm)
Cover	8.26 ± 1.18**c**	0.41 ± 0.10**c**
CoverIns	10.59 ± 1.45**c**	0.31 ± 0.01**c**
HerbIns	65.28 ± 1.84**a**	1.43 ± 0.03**a**
HerbNoIns	40.60 ± 2.92**b**	1.17 ± 0.03**b**

Cover = cover crop in tree row; CoverIns = Cover crop in tree row and trees drenched with imidacloprid; HerbIns = bare ground in tree row and trees drenched with imidacloprid (current recommended practice); HerbNoIns = bare ground in tree row (untreated control).

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Tree Industry Buprestidae Management

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Buprestidae (and other wood-boring insect) management tactics are discussed with highlights of cultural practices that reduce abiotic stress. A review of the pesticide industry standards are also discussed.

Highlights: Ensuring that newly planted trees are in the correct pH range, in aerated soil and watered in correctly can reduce the likelihood of early attack. A systemic replacement for imidacloprid and dinotefuran needs to be found.

Issues and Management of Flatheaded Borers in the Landscapes

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Flatheaded borers are some of the most damaging insect pests of woody ornamental trees. Newly planted trees in the landscape are particularly susceptible. Most of these trees are stressed by the process of digging the trees in the nursery or being grown in containers that are then shipped to retail centers for sale. The plants are then kept at these retail centers, exposed to the weather until they are purchased, transported again, and transplanted in the landscape. Most flatheaded borer species lay their eggs on stressed trees in the spring. Thus, transplanted trees can come under attack in the spring before the trees have had an opportunity to become established in the landscape and start to grow vigorously. The following year, the damaged trees can be attacked again by a new generation of flatheaded borers so the damage is cumulative.

A study was conducted in Middle Tennessee (Nashville and Franklin) to document borer damage to trees planted in the landscape over the last 4-7 years (Hale 2001). Damage from a flatheaded borers was attributed to the flatheaded appletree borer and that type damage was documented in pin oak, willow oak, crabapple, sweetgum, yellowwood, dogwood, hackberry, littleleaf linden, sugar maple and red maple although sweetgum, crabapple, and dogwood were not listed as host plants of this pest (Solomon 1995). Tree caliper was measured 6 inches above the ground (base caliper) and on the dominant leader (leader caliper) at breast height (4.5 feet) (Hale 2001). The trees were also ranked for tree health and borer damage. If no borer damage occurred, the trees were ranked for health only on a 1 to 5 scale with 1 being very healthy to 5 being in severe decline. Borer damaged trees were additionally ranked for damage on a 1 to 5 scale. The slightest signs of borer damage were rated 1.5 and the tree was generally healthy while a rating of 2 was still slight borer damage with generally good health. A rating of 3 was more noticeable borer damage but the tree canopy was still good. A rating of 4 showed considerable signs of borer damage to the trunk while the canopy may or may not show thinning or branch die-back. A rating of 5 was severe trunk damage, usually with bark peeling, some exposed wood with noticeable tunneling damage, and branch die-back. A tree with a rating of 4 or 5 will never again be a sound tree and is in serious decline. The poor appearance of such a tree is reason enough to replace it. A rating of 5 was given to dead trees (Hale 2001).

Seven willow oak trees at the Bicentennial Mall in Nashville (city park) had an average damage ranking of 1 while 2 willow oak trees at the commercial office park had an average damage ranking of 3.8 for a combined average of 1.6 (Hale 2001). At the same commercial office park, 23 pin oak trees and 10 sugar maple trees had an average damage ranking of 4.7 and 4.9, respectively. Red maple was rated in two locations with 39 trees in the city park having an average damage rating of 3.7 while 11 trees in a commercial office park had an average ranking of 5. At the office park, 1 crabapple tree had an average damage rating of 3. At the city park, 8 dogwood trees and 5 yellowwood trees had an average damage rating of 4.3 and 2.6, respectively. Also at the city park, 4 littleleaf linden and 12 hackberry trees had an average damage rating of 5 and 3.3, respectively (Hale 2001). The average damage ranking of all the trees of each species was 3.9.

Best management practices include timely irrigation, mulching and protective insecticide applications. The trees at the city park were irrigated on a regular basis during the first 2 years and as needed afterward (Hale 2001). Only the city park trees were known to have had any protective insecticide sprays. One chlorpyrifos spray was made in the third season only after considerable damage was detected by the manager (Hale 2001).

While insecticide sprays were the most common practice at the time of this survey, most landscape professionals are currently using imidacloprid or dinotefuran as a soil drench for flatheaded borer control. Tree injections of emamectin benzoate for emerald ash borer, an invasive flatheaded borer, are used extensively because of its high efficacy and long lasting protection.

Most residential properties do not use a landscape professional to apply highly effective systemic insecticide drenches or tree injections for flatheaded borers. The prevalence of systemic insecticide use by homeowners for flatheaded borer control is unknown. Since flatheaded borer damage is still one of the most significant tree problems, systemic insecticide use to protect trees from flatheaded borers appears to be highly underutilized.

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Fungal Phoresy on Tennessee Beetles – *Pityophthorus juglandis*, Other Bark Beetles, and an Update on a Preliminary Survey in *Chrysobothris*

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Between 2015 and 2017, insects active in walnut canopies were collected to assess candidate insect vector that contribute to spread or persistence of thousand cankers disease in Tennessee. More than 11 species of bark weevil, bark beetles, and ambrosia beetles, including *Cnestus mutilatus*, *Dryoxylon onoharense*, *Monarthrum fasciatum* and *M. mali*, *Xyleborinus saxesenii*, *Xylosandrus crassiusculus*, *Xylobiops basilaris*, and *Stenomimus pallidus,* can now be associated with *Geosmithia morbida*. Other *Geosmithia* species were recovered: *Geosmithia* sp. 2 from *X. saxesenii*, *C. mutilatus*, *X. basilaris*, and *S. pallidus*; *Geosmithia* sp. 3 from *X. crassiusculus* and *C. mutilatus*, and *Geosmithia* sp. 23 from *C. mutilatus*, *Xyle. saxesenii*, *Xylo. crassiusculus* and *X. basilaris*. *Geosmithia* sp. 41, which has caused foamy bark disease on *Quercus* species in California, was recovered in Tennessee from *C. mutilatus* and *Xyle. saxesenii*. Work to assess the pathogenicity of Tennessee-collected isolates of *G*. sp. 41 on oaks is ongoing.

The relationship of plant pathogenic fungi with flatheaded borers (FHB) has not been well documented for landscape or nursery systems. Consequently, the capability that FHB may contribute to plant pathogen dispersal (like *Neonectria*, *Botryosphaeria*, *Diplodia*, and other pathogenic fungi that can cause cankers and branch dieback) to established or transplanted landscape trees and trees grown for commercial nursery sale is speculative. Female beetles visit and oviposit on trees with mechanical (e.g., mower and string trimmer injury), cultural (e.g., pruning cuts and graft union wounds), and abiotic stress (e.g., freeze cracks and bark splits) damage. Female ovipositors or newly eclosed larvae may introduce plant pathogens to tissues upon contact and entry. Not all larvae reach maturity, and galleries excavated by failed larval FHB may provide additional entry points or serve as propagation sites for subsequent injury yielding new sites susceptible to pathogen invasion.

A current constraint to examining FHB and pathogen relationships is the lack of a reliable means to collect suitable adult FHB specimens that can be used for fungal isolation. Sticky panel traps and wet-trap collection receptacles (including for Lindgren funnel and soda bottle collection traps) confound fungal recovery. FHB are not reliably attracted to pheromone or plant volatile compounds. Populations of FHB in commercial nurseries may be cryptic, and flying adults are difficult to observe and more difficult to capture.

In a pilot study, adult *Chrysobothris* beetles were collected by hand at locations in Anderson Co. and Morgan Co. TN where mature *Quercus*, *Carya*, or *Acer* tree species had been recently knocked down (storm damage), or cut (tree removal). Gender and species of beetles were stereoscopically determined. Walk-on assays were conducted with 12 *C. quadriimpressa* and 30 *C. viridiceps* female beetles. In a biosafety cabinet, beetles were placed onto sterilized potato dextrose agar (PDA) media supplemented with antibiotics (+) in a 60 mm x 15 mm Petri dish and allowed to move around for 5 min. After exposure, PDA+ plates were sealed with Parafilm and then incubated at room temperature (~20 C) for 5-7 d. More than 20 fungal genera were recovered, following culture on ½ strength PDA plates, and photographed. In addition, many cultures of *Alternaria* sp., *Aspergillus* sp., *Cladosporium* sp., and *Penicillium* sp. were recovered, but these fungi, which are environmentally ubiquitous, were not evaluated further and were discarded. Axenic cultures were used for DNA extractions and barcode amplification (Internal Transcribed Spacer (ITS) region of the ribosomal RNA operon and elongation factor alpha (EF-1) gene) through conventional PCR, using the Phire Plant Direct PCR Kit or the GeneJet Genomic DNA Purification Kit (Thermo Fisher Scientific) per manufacturers directions. Amplicons were sent to MCLAB (www.mclab.com) for cleanup and sequencing. Briefly, fungal identification steps were undertaken as follows: sequences were cleaned using Sequencher 5.0 (Gene Codes Corporation) and contigs identified in GenBank using the Basic Local Alignment Search Tool (BLAST). Taxonomy was assigned using Internally Transcribed Spacer (ITS) region of the ribosomal RNA operon and elongation factor (EF) gene sequences based on BLAST results using a 98% identity threshold. Where more than one molecular identity was still possible, fungi were grown on V-8 agar for 3 wk after which a small portion of conidia and hyphae were slide mounted and examined microscopically for confirmation of fungal identities.

Walk-on agar assays from the 12 *C. quadriimpressa* individuals yielded cultures of fungal saprophytes (*Absidia* sp., *Epicoccum nigrum*, *Pithomyces chartarum*), plant pathogenic *Ophiostoma pluriannulatum*, and *Trichoderma atroviridae* and *T. harzianum*, which may be beneficial symbiont or endophytes with host plant tissues. More fungal species were recovered from the 30 assayed *C. viridiceps* females. Among them were foliar-associated fungi (*Aureobasidium pullulans* and *Monochaetia dimorphospora*), root-associated fungi (*Umbellopsis isabellina*), and known plant pathogens (*Coniella* (syn. *Phoma*) *granati*, *Coniochaeta* sp., *Curvularia soli*, *Neofusicoccum parvum* (syn. *Botryosphaeria parva*), *Pestalotiopsis cocculia* and *P. neglecta*, and *Quambularia cyanescens*. Saprophytic (decomposer) fungal species included *Nigrospora sphaerica*, *Pithomyces chartarum* and *Talaromyces pittii*. Symbiotic or endophytic *Trichoderma atroviridae*, *T. harzianum*, and *T. viridae* were recovered, as was *Paecilomyces formosus*, which may be entomopathogenic. Fungal culturing is in progress for whole-body wash extracts from these and other adult, female *Chrysobothris* species that were collected.

Several factors challenge next steps in planned research. An efficient strategy for trapping live adult specimens is needed. In Tennessee, *Chrysobothris femorata* causes significant losses to nursery stock across the growing seasons required to achieve salable field grown deciduous trees. However, live adult beetles are difficult to observe and collect in nursery habitats. Success in hand-collection is unlikely due to lack of a working attractant or lure. A modified trap design will be needed to secure and maintain live beetles until collection can occur. Subsequent to capture, fungal culturing from beetle specimens should be initiated as soon as possible in order to obtain the greatest diversity of associated fungi. Regardless, data retrieved by these methods are restricted to those fungal species that can be cultured on agar media, and favors fungal species that rapidly grow. Slow-growing fungi may be outcompeted on agar plates, and underrepresented by isolation efforts. Host plant obligate fungi will not be detected. In addition, future work is also needed to assess the role of FHB in transporting bacterial plant pathogens in the landscape. Use of antibiotics in the agar media provides better recovery of fungal species, but restricts categorization of bacterial species that are associated with *Chrysobothris* adult beetles, including plant pathogenic bacteria like *Erwinia* sp., *Xylella* sp. and *Ceratocystis* sp. One solution to these challenges would be to pair the agar-based isolation procedures with a metagenomic characterization approach, which would greatly expand fungal and bacterial species detection and identification capability. In turn, genetic data would reveal considerably more information about the understudied interactions between host plants, *Chrysobothris* beetles, and plant pathogens. Finally, detection of phoretic plant pathogens does not necessarily signify capability of an identified fungal (or bacterial) species as a plant pathogenic agent. Subsequent work with beetles, plant pathogens, and host plants will be needed to demonstrate the practical significance of pest-pathogen correlations that are found.

National Plant Diagnostic Update on Buprestid Detections

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Chrysobothris spp. are a genus of native wood boring beetles found throughout the continental United States. The National Plant Diagnostic Database was accessed and reports of damage by species of *Chrysobothris* borers was collated from 2005-2019. A total of 171 reports were submitted during this time (Table 1). Of those reports, 45 specimens were identified to genus, only. Of the remaining specimens, 103 were identified as *C. femorata* (flatheaded appletree borer), 9 as *C. mali* (Pacific flatheaded borer), 7 as *C. sexsignata*, 3 as *C. dentipes*, 2 as *C. chrysoela* and 1 each of *C. caurina* and *C. rossi*. In total, 62.5% of contiguous United States reported an incident of *Chrysobothris* as a pest. Historically, the two species causing greatest damage in nursery, nut and fruit production systems have been *C. femorata* and *C. mali*. During the reporting period, *C. femorata* was reported in 29 states and *C. mali* in 5 states (Table 2). *Chrysobothris femorata* was reported from 22 genera of plants and *C. mali* from 3 genera (Tables 3 and 4). The most common hosts of *C. femorata* were maples (*Acer* spp.), apple (*Malus* spp.) pecan (*Carya* spp.) and oak (*Quercus* spp.). It is important to note, that identification to the species level of *C. femorata* and its close relatives is challenging. The NPDN Database reports its confidence in pest identification as 'confirmed', 'suspected' or 'undetermined'. Confirmed specimens were identified using available keys. Suspected identifications could not be confirmed at the species level, but are the closest match based on available information. Undetermined specimens are those that could not be confirmed with the available specimen. Given the uncertainty surrounding identifications of *C. femorata*, we conclude only that those specimens identified with this name are likely to be members of the *C. femorata* species group (Hansen et al. 2015, Wellso and Manley 2017).

Table 1. Reports of Chrysobothris spp. from 2005-2019 in the continental United States.

Chrysobothris spp.	45	AK, AR, CA, CO, DE, FL, MI, MN, Mt, NC, NE, NM, NY, OK, OR, RI, VT, WI, WV
C. caurina	1	OR
C. chrysoela	2	VA, FL
C. dentipes	3	RI
C. femorata	103	AL, AR, CA, CO, CT, DE, IA, IL, IN, KS, KY, LA, MD, MI, MN, MS, MT, NC, NE, NJ, NM, OH, OK, PA, RI, TN, UT, VA, WI, WV
C. mali	9	CA, IN, MT, OR, WA
C. rossi	1	NM
C. sexsignata	7	NE, NY, RI, WI
Total Reports	171	

Table 2. State-by-state reports of *Chrysobothris femorata* and *C. mali* from 2005-2019 in the continental United States.

State	# femorata	State	# *C. femorata*
CT	1	NE	2
DE	1	PA	2
IA	1	AL	3
KY	1	IL	3
LA	1	MD	3
MI	1	MT	3
MN	1	RI	3
MS	1	OH	5
NJ	1	IN	6
NM	1	TN	7
UT	1	AR	11
WV	1	OK	12
CA	2	VA	12
CO	2	WI	12
NC	2		

State	# *C. mali*
CA	4
IN	1
MT	1
OR	1
WA	2

62.5% of contiguous United States reported *Chrysobothris* as a pest

Table 3. Host plant reports for *Chrysobothris femorata* from 2005-2019 in the continental United States.

Flatheaded Appletree Borer			Confidence in Pest Identification		
Genus	Common Name	# Reports	Confirmed	Suspected	Undetermined
Acer	maple	21	9	12	
Carya	pecan/hickory	8	8		
Castanea	chestnut	1		1	
Celtis	hackberry	2		2	
Cornus	dogwood	5	4	1	
Crataegeus	hawthorn	1		1	
Fagus	beech	1	1		
Fothergilla	witch-alder	1		1	
Fraxinus	ash	4		2	
Itea	holly	1	1		
Juglans	walnut	2	1	1	
Malus	apple	19	6	13	
Parrotia	Persian ironwood	1		1	
Pinus	pine	1	1		
Populus	poplar	2	1	1	
Prunus	cherry/plum	2		2	
Pyrus	pear	2		2	
Quercus	oak	11	7	4	
Rosa	rose	1			1
Tilia	basswood	1		1	
Ulmus	elm	1	1		
Vaccinium	blueberry/blackberry	1	1		
Not reported		14	12	2	

Table 4. Host plant reports for *Chrysobothris mali* from 2005-2019 in the continental United States.

Pacific Flatheaded Borer			Confidence in Pest Identification		
Genus	**Common Name**	**# Reports**	**Confirmed**	**Suspected**	**Undetermined**
Acer	maple	1		1	
Corylus	hazelnut	1		1	
Prunus	cherry/plum	3		3	
Not reported		4	3		1

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Results of a Nursery, Orchard, and Nut Grower and Extension Flatheaded Borer Importance Survey Sponsored by SCRI

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Results of the nursery, orchard, and nut grower survey developed by Auburn University, North Carolina State University, Oregon State University, Tennessee State University, and University of Georgia are in a separate summary available on the Southern IPM Region website.

Tennessee Nursery Grower Town Hall Meeting Flatheaded Borer Results

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On 19 June 2019, a nursery grower town hall meeting on flatheaded borers was held at the Tennessee State University Otis L. Floyd Nursery Research Center (NRC), McMinnville, TN. Ten growers on the NRC Advisory Group were invited to the town hall meeting. In addition, other growers in the area with past flatheaded borer issues also were invited to the meeting. Seven growers representing seven different field and container nursery operations attended the meeting including Phil Herd, Matt Eller, Mary Roller, Frank Collier, Martin Scott, Alex Neubauer, and Rickey Magness. Growers were shown a series of PowerPoint slides with questions to facilitate group discussion. The authors moderated and recorded grower comments.

Grower Participant Perspectives on Flatheaded Borers and Their Management in TN

The following key points were identified from the town hall session in Tennessee:

1) **Pest importance:** Pest importance varies from year to year. Some pests are consistently problematic like mites, scales, and borers.
2) **Most vulnerable trees:** Research field surveys routinely found maples, dogwood, crabapple, redbud, and some cherry with flatheaded borer issues, but growers also indicated hornbeams (*Carpinus*) have issues with flatheaded borer attacks.
3) **Timing of attacks:** Growers indicated they felt most issues were in the first to second years after transplanting and trees in the 1 to 1.5 inch (2.5 to 3.8 cm) range were most susceptible, especially if stressed.
4) **Types of nursery plants with issues:** Growers present at this meeting had no opinions on whether containerized versus field-grown nursery plants were more vulnerable to flatheaded borers.
5) **Borer damage effect on tree marketability:** Growers had mixed opinions on this question. Some said tree damage ruined the quality of the tree and created an unmarketable tree, while others felt trees might heal sufficiently to allow eventual sale (possibly at a reduced price). The majority of the group felt borer damage ruined the tree.
6) **Difficulty in borer damage detection:** Most growers in the group felt they or their farm staff were capable of recognizing damage caused by flatheaded borers.
7) **Need for better borer detection tools:** The group consensus was that there seemed to be no need for better detection tools because, "Once you have a borer infestation, it is too late to treat". The following comment also pertains to this perspective.
8) **Preventative or curative treatments:** Grower consensus was preventative treatments are essential and that they cannot afford not to treat preventatively (the damage / loss is too severe without preventative treatments). Growers expressed heavy reliance on imidacloprid

as the most cost and time effective insecticide available for borer control. They also felt that, in essence, preventative treatments eliminate the need for scouting (see previous comment).

9) **Management methods (trunk sprays, soil drench, trunk wraps, plant type, planting depth, transplant factors [size, container, bare root], cultural factors, cover crops, other):** Growers indicated most have switched to using imidacloprid soil drenches (one said no flatheaded borer damage in 6 years since started using imidacloprid). All indicated no tree wraps are used. All said planting depth issues continue to be a problem because of the thousands of trees being transplanted in short periods of time. Training staff is critical for avoiding planting depth issues. One grower said planting location is also very important (in other words, finding the right location in their fields for planting a given tree species).
10) **Feasibility of applying trunk paint / guards or insecticide netting:** All agreed that any type of wrap would be unfeasible, time and cost-wise, given the high number of trees being produced.
11) **How critical is imidacloprid or other neonicotinoids?** Consensus was that imidacloprid is absolutely critical. One grower said that they would quit growing crabapples and dogwoods if imidacloprid was unavailable.
12) **Are other chemical control options needed?** Consensus was "Yes".
13) **Would you try to salvage a borer-damaged tree?** Response was mixed. Most said they only sell non-damaged trees to avoid liability issues with buyers. One said it depends on the extent of the damage and how long the grower is willing to hold trees to allow callus to heal over the damage (if customer demand is high and the buyers don't express a concern about presence of callus, they will sell the trees with the understanding they are lower grade trees).
14) **Do you or farm staff regularly scout for flatheaded borer damage?** All said that preventative treatments eliminate the value of scouting. One said that in new transplants, borer damage may not be seen and by the time damage is visible, scouting would do no good.
15) **Would you consider mass or targeted trapping to intercept adult borers?** Comments: It depends on factors like the value of the crop, number of traps needed, and trapping efficacy.
16) **Would it be feasible to transplant trees in a specific orientation (e.g., graft union facing north)?** All said this would be totally impractical because 2,000 to 3,000 trees are being planted at a time at a rapid rate. In addition, since trees are stored in bundles in cold packing houses and roots and bases are dirty, it would be difficult to see the graft union. Finally, seedling trees have no graft union to orient.
17) **How do you prevent planting too deep?** All said planting too deep is still a big issue. The only solution they had was adjusting the planter and educating the planting crew.
18) **Is root pruning to fit in containers or transplant chute a factor in borer attacks?** One grower said root pruning is required for some transplanters if roots are too big, but unknown if root pruning increases attack rates. Another said everyone root prunes, and so it probably is not an issue. Another said that they saw no difference in borer attack rates when they root pruned trees that were being transplanted into 3 gallon containers.
19) **Is damage from staking or tag girdling a flatheaded borer issue?** No one in the group thought that swelling or bark inclusions from staking or tags were issues with borer attacks.
20) **Is lack of irrigation a factor in borer attacks?** Everyone indicated the few in the Tennessee field-grown nursery industry irrigate because there is adequate rainfall in most years. However, there was uncertainty about whether attack rates were increased in years with drought.

21) **Cover crops to prevent borers:** There were not clear comments expressed about whether growers would consider vegetative cover use for borer management, but one said they thought weeds increased borer attacks. No one had any thoughts on how to integrate a cover crop program with other issues that require "plant-free ground" like fire ant and Japanese beetle quarantines.
22) **Estimated losses or expenses from flatheaded borers:** All said imidacloprid was their biggest annual cost. Growers did not have clear estimates of the other economic costs associated with flatheaded borers. Most felt prevention of damage with imidacloprid eliminated other economic concerns.
23) **Have you had issues with buyers wanting reimbursement for borer damaged trees?** One grower said they would not reimburse for "claimed borer damage" because there is no way to know if the borer is still in the plant.

University Participant Perspectives on Some Issues Raised in the Town Hall Meeting:

1) **General Statement:** Grower numbers at the town hall were limited (n=7), so a broader numeric perspective would provide a more robust picture of challenges that are effecting the entire industry. The regional grower survey administrated by North Carolina State University, in conjunction with the Flatheaded Borer Workshop, may broaden the input and perspectives of other growers.
2) **Timing of attacks:** Our experience with non-treated research test sites is that flatheaded borers continue to attack nursery crops during the entire production cycle (~5 years) with about 5% loss added during each year of production, which is in contrast to grower observations that attacks only occurred 1-2 years after transplanting. **The issue of actual tree losses across time is both an important area for extension education, and will highlight accuracy of economic assessments for salable crop production costs in response to this pest**.
3) **Borer damage effect on marketability:** One grower in the group did indicate that trees that had healed from borer attacks would still be sold at a lower grade if buyers were willing to purchase flatheaded borer-damaged trees. One issue with trees that have healed or callused injury inclusions would be restricted vasculature, diminished stress tolerance, and predisposition to wood rotting fungi and secondary plant pathogen activity. Across time when transplanted into the landscape, these trees could develop with a weak area that can translate to future issues including mature tree failure. **Post harvest and buyer perception issues associated with marketing trees with dead cambium tissues would be another valuable educational extension component.**
4) **Difficulty in borer damage detection and need for better borer detection tools:** We also were surprised that growers unanimously agreed that flatheaded borer damage was easy to recognize; that [their] farm staff did not need training in borer damage identification; and, that no scouting tools are needed. Working with farm labor in the past, we have observed that borer damage is often mis-attributed as resulting from other types of damage like sunscald, mechanical injury, winter damage, canker, etc. This information gap suggests that a persistent issue remains regarding field crew member capabilities in recognizing and properly attributing cause of damage. **Although the group of growers attending this meeting (and their field labor) may be proficient at detecting borer damage, our observations indicate this is still a problem for some nurseries and would be a good area**

for additional extension work. Regarding the lack of need by growers to scout for flatheaded borer damage, we agree with the growers that it can be difficult to detect new borer attacks. However, since research shows borer damage continues to accrue within a crop block across time, proactive grower scouting could identify blocks with developing issues earlier and possibly allow treatments to reduce damage in subsequent years. **The value of crop monitoring by proactive scouting would be another valuable area for extension education**. Regardless, a need still remains for researchers to be able to accurately identify the species of flatheaded borer involved with trunk attacks on different nursery and landscape tree species. In part, this will assist researchers to develop accurate growing degree day models that will be based on the phenologies of economically and environmentally important *Chrysobothris* species.

5) **Preventative or curative treatments, management methods, and imidacloprid / neonicotinoid importance:** Growers were unanimous that systemic neonicotinoid drenches (especially imidacloprid) were critical to their flatheaded borer management. Most were relying exclusively on this chemical class for their management and were satisfied with it, because they perceived that all flatheaded borer damage had ceased at their operations. Before the Town Hall, meeting organizers anticipated finding that growers were using a variety of flatheaded borer management methods. Although the meeting included a small sample size of growers, it is quite concerning to learn they are relying exclusively on an insecticide-based management approach that is dependent upon availability of a single insecticide active ingredient (imidacloprid). Concerns University personnel have regarding a single-chemical-based approach: a) insecticide resistance development across time is highly likely due to lack of rotation among active ingredients, particularly when paired with high selective pressure on the pest population, which also across time, may experience sublethal exposures to systemic pesticide and secondary metabolite residues and b) the industry is extremely vulnerable if they lose their primary management strategy (e.g., regulatory action removes the product over other issues like pollinator effects of neonicotinoids). A separate issue, depending on how many trees are being treated, is the per acre rate limits of current imidacloprid labels, which may not be suitable for the quantity of trees being produced. This in turn may lead to label violations in some cases. **Research to find new chemical and non-chemical alternatives to prevent resistance development and provide more options is needed. Likewise, extension education regarding proper rate limits may be warranted if imidacloprid is being used ubiquitously regardless of tree quantities. Apparent mis-attribution of the cause of crop damage (to biotic and abiotic agents other than flatheaded borer, described in Issue #4 above) are also likely to be confounding grower perception about the level of borer activity at their respective nurseries.**

6) **Feasibility of applying trunk paint / guards or insecticide netting, cover crops, or adult trapping:** Growers were unanimous that management options involving placing any type of object or coating on trunks like paint or guards would likely be too time consuming to be practical given the numbers of trees typically being grown. However, discussions did not examine whether these approaches would become feasible if such cultural or mechanical strategies were the only option or if the tree species or cultivars were particularly susceptible to flatheaded borer damage, or had very high values. We expect that other strategies, like cover crops or adult trapping, also would become cost effective and biologically advantageous for nursery crop producers under the right scenarios. **We think this is another**

area where economic assessments and social willingness to adopt new options could be valuable.

7) **<u>Planting too deep</u>:** It was encouraging that all growers recognized that planting too deep is a serious issue for tree health. Unfortunately, most growers also said that the practice persists and continues to be a significant issue to the industry, in part due to, quantities of trees and shrubs being transplanted and the speed of the tree planting process to optimize labor inputs. The only solution they felt for preventing the detrimental practice is vigilant training and follow-up assessment of planting crews. **The planting depth topic may likewise be another area for an extension role, as well as research development of new strategies to assist producers with planting depth management.**
8) **<u>Root pruning and/or trunk damage from staking or tags</u>:** It was interesting to learn that most growers did not consider root pruning or trunk damage from stakes and tags to be an issue in predisposing crop specimens to borer attacks. Growers confirmed that root pruning is a widespread procedural practice resulting from need to fit some plants' root structures through narrow transplanter chutes, so this would hypothetically support their claim that the practice is not an issue. Still, no known research effort has tracked post-transplant (or post-harvest) effect of root pruning on tree incidence with flatheaded borer attack across time. We expect that under some circumstances like drought, flood stress, or excessive root pruning (in which the root to crown ratio is greatly altered), this practice could lead to crop losses from flatheaded borers. University attendees also have encountered trees that present damage from improper staking and use of plastic tagging, often left on or unadjusted too long, and that now girdle the trunk or branch. Despite the wound responses that have been observed in the field and in retail settings, it is possible these types of injury are seldom a point of attack leading to borer entry, because most growers felt it was not an issue. Post-transplant performance of these damage trees regarding flatheaded borer attacks has not been assessed. We also have observed that well-intentioned, or proactive, farm labor can be quite good at removing tags (i.e., frequently occurs in experimental research plots at grower sites), probably in an effort to reduce stem girdling injury.
9) **<u>Irrigation factor in borer attacks</u>:** Most growers did not feel that irrigation was needed in the Tennessee region due to adequate rainfall. At the same time, growers pointed out that most attacks occur early in the transplanting cycle (years 1 and 2) and are more prevalent when trees are stressed. **Given these conflicting concerns, determining tree physiology and borer response to tree physiology will be critical to enable production strategies that minimize tree stress and limit flatheaded borer attacks**. Sufficient and appropriate irrigation to crops will likely play a role in solutions, particularly if growers continue to utilize flatheaded borer-susceptible tree crop species and cultivars.
10) **<u>Estimate losses or expenses from flatheaded borers</u>:** It was somewhat surprising to our research group to learn that the growers believed that their primary flatheaded borer expense was for imidacloprid, which in turn, had eliminated all of the other costs associated with borer losses. The issue with this comment is again the overreliance on a single-strategy approach in management rather than a multi-pronged integrated pest management approach. We were not surprised that growers did not seem to have a clear estimates of other economic costs associated with flatheaded borers, as these costs are difficult to estimate and require multi-year calculations. **We believe better economic estimates of borer losses and costs are critical for producers to properly manage their operations in a profitable manner. Integrated approaches likewise are needed to ensure management remains effective.**

Pacific Flatheaded Borer Workshop and Town Hall for Orchard Crop Producers

Nik Wiman[1], Jhalendra Rijal[2], Heather Andrews[1], and Anthony Mugica[1]

[1]Oregon State University, North Willamette Research and Extension Center, Aurora OR.
[2] University of California Cooperative Extension, Modesto CA.

On August 20, 2019 we hosted a half-day Pacific flatheaded borer (PFB) workshop at the North Willamette Research and Extension Center in Aurora, OR. Over 40 growers and field consultants attended. The first presentation (Wiman) covered the current research and knowledge gaps for flatheaded borers generally, and PFB management in hazelnuts. The second presentation (Rijal) covered the recent issues of PFB attacking bearing walnut scaffold and nut bearing branches in the Central Valley of CA. We then opened the floor for questions and open discussion. Most of the issues raised by the growers pertained to hazelnut production and the questions are summarized in the following list:

- What are the long-term PFB population trends, cyclical and based on environment conditions?
- Irrigation and promoting tree vigor were suggested as preventative management tactics to avoid PFB attack. What can dryland farmers do to promote vigor and make their trees more resistant to PFB attack?
- Most treatments discussed were for protecting young trees. For mature trees, what are potential treatments to apply against PFB?
- The presentations discussed how PFB exploits wounds on the trunk to lay eggs. How much should we worry about pruning wounds?
- What is optimal timing to prune trunks for optimal would healing and avoiding risk from PFB?
- What application methods for systemic insecticides such as imidacloprid result in greatest uptake and concentration in young hazelnut trunks?
- How could soaking bare-root hazelnut trees in imidacloprid before planting reduce borer attacks?
- How does mulching trees affect uptake of drench or chemigation applications of imidacloprid?
- How do the life stage development timings affect management decisions? For example, how long before eggs hatch after being laid?
- Physical barriers that be used to strengthen trunk paint?
- Should infested wood be burned or is shredding sufficient?
- How do trunk guards affect PFB attack on young trees?
- Is there a susceptibility difference for trees from micropropagation (potted) vs. bare root trees?

After the discussion, we went out to look at the PFB flatheaded borer research plots where many plant protection strategies demonstrated. We also viewed the borer emergence cages. Anthony Mugica gave and overview of his PFB research that he is conducting for his MS thesis and we addressed further questions (Wiman, Rijal, Mugica, Andrews).

Flatheaded borer workshop for tree crops

Location:	North Willamette Research and Extension Center, 15210 NE Miley Rd, Aurora, OR
Date:	Tuesday, August 20, 2019
Time:	8:30-12:00 (optional field component)
Facilitators:	Nik Wiman, RSVP to Heather Andrews, Heather.Andrews@oregonstate.edu
Cost:	None

Agenda

8:00 – 8:15	Welcome and Introduction	Nik Wiman, OSU Extension Orchard Specialist
8:15 – 9:00	Biology and management of Pacific flatheaded borer in hazelnuts/tree fruits	Nik Wiman
9:00 – 9:45	Pacific flatheaded borer: an emerging issue in California walnut production	Jhalendra Rijal, Area IPM Advisor, University of California Cooperative Extension & Statewide IPM Program
9:45 – 10:15	Open discussion and research and Extension priority ranking for SCRI proposal	All
10:15 – End (12 pm latest)	Tour field trials and current borer research	Anthony Mugica, Heather Andrews Nik Wiman

Oregon State University

NC STATE UNIVERSITY

UNIVERSITY OF GEORGIA

AUBURN

TENNESSEE STATE UNIVERSITY

Priorities and Critical Needs in Flatheaded Borer Research and Extension Outreach Identified from Workshops and Town Hall Meetings

Multiple Workshop Participants

Workshop Group Discussion on Key Grower / Research Priorities, Knowledge Gaps, and Other Comments and Brainstorming:

I. Insecticides and Chemical Management:

1) Critical insecticides: Systemic insecticides (e.g., imidacloprid)
2) Resistance Issues:
    - Rotation alternatives for imidacloprid (e.g., anthranilic diamides)
    - Detection options and monitoring capability
    - Effects of long interval sub-lethal exposures on resistance
    - Are current susceptible refugia sufficient to prevent resistance development?
3) Chemical Efficacy Issues:
    - Detecting chemical concentrations in tree tissues and determining effective dosages
    - Optimizing application methods (trunk sprays, foliar, drench)
    - Residual activity of chemicals (bark or internal tissues)
4) Research: Methods to reliably induce attacks for chemical testing
5) Insecticide timing:
    - When is most effective spray or systemic treatment timing for key flatheaded borer species?
    - What stage is being killed by trunk spray treatments and how does this relate to timing (e.g., adults post-landing, eggs after oviposition, or larvae during tree entry).
6) Other: RNAi to knockout gut symbionts

II. Biological Control:

1) Entomopathogenic nematodes (EPN):
    - Identifying EPN strains that work best on flatheaded borers
    - Synergy of EPN with other borer treatments
    - Field deployment opportunities (inside trunk guards, gels, EPN pheromone)
    - Benefit to organic production
2) Parasitoids: Biology, species involved, benefits, and importance
3) Live traps for borer collection (needed for LD50 studies, pathogen symbionts, etc.)

III. Taxonomy:

1) Molecular work needed: a genomic approach with expansion of genes and SNPs (from mitochondrial, nuclear genes, and non-genecoding regions) to improve identification of non-diagnostic larvae, species differentiation, and separation/classification of *Chysobothris femorata* species-group members and cryptic species (Table 1).
2) Better morphological taxonomy that agrees with molecular taxonomy.
3) New taxonomic techniques:
    - Surface hydrocarbons for possible improved identification (are enough differences between species or male/female)
    - ELISA???

4) Pairing taxonomy with other important factors:
   - Host records to determine species involved with tree attacks across US
   - Emergence phenology of different species
   - Oviposition phenology of different species

IV. Phenology of Flatheaded Borers:
1) Oviposition timing and how it relates to chemical treatments
2) Phenology of different flatheaded borer species across regions

V. Biology Factors:
1) Life history studies:
   - Host effects on larval development time (why multi-year sometimes)
   - Why do adults prefer sunny side of tree (competitive advantage for larvae, mate attraction, etc.)? (Is it larval growth differences?)
   - Environmental factors on larval survival
2) Pathogen interaction with flatheaded borers:
   - Plant pathogen effects on attack success or attraction
   - Pathogen symbionts or associations (and their importance in borer biology)
3) Adult beetle field attack factors:
   - Number of beetles involved with attacks (molecular tools?)
   - Origin of these beetles (local trees or far sites)

VI. Trapping and Attraction:
1) Trapping tools are not uniformly effective across species. Some species are more reliably recovered from emerging adults from infested host plant materials (Table 1).
2) Better methods to attract:
   - Screening for attractive volatiles
   - Measuring volatiles on stressed plants, cut trunks, etc.
   - Producing region adapted cultivars in different regions to assess volatile production differences.
3) Stress detection technology and correlation with attacks:
   - Infrared or other remote sensing tools
   - GIS to identify landscape level risk factors in attacks (marginal sites, soil type, forest effects, etc.).
4) Can traps be used to prevent crop attacks (mass trapping):
   - Placement location near crop to effectively intercept females
   - Trap interval and type needed for successful mass trapping
5) Live trap needed for pathogen association studies.

V. Production Related Needs:
1) Comparison of production techniques on borer attacks:
   - Bare root
   - Container transplants
   - Grafting on root stock
   - Others - regional / origin effects on susceptibility?

2) Cultural control methods:
   - Cover crop type and planting timing
   - Cover crop planting method (isles, whole field
   - Barrier fences to shade or camouflage
   - Effective trunk guards without canker issues
   - Non-living trunk covers (e.g., pom-pom skirts, tiki grass)
3) Types of stress factors involved with attacks:
   - E.g., planting depth, drought, mechanical damage, root pruning, defoliation, heat, SW injury, herbicide, freeze
   - Why does one stress type cause attacks and another not?
4) Plant physiological factors related to attacks (quantification):
   - Bark thickness
   - Sap flow (sugar plugs)
   - Trunk color (sunscreen to block UV reflectance?)
5) Other production methods and their effects:
   - Tree wraps and their effects on tree response
   - Paint

VI. Outreach:

1) Comprehensive extension practices used to manage borers in each crop production system
2) Grower educational materials:
   - Damage recognition
   - Growing degree days for each key flatheaded borer species

VII. Economics:

1) Better estimates of true treatment costs:
   - Different methods and loss costs when don't work
   - Costs during different production phases (late in plant growth, early resulting in vacant field space, etc.)
   - Economics of key insecticide loss (e.g., imidacloprid)
   - Economics of new methods (e.g., cover crops, bud union orientation, etc.)

Table 1. Species of *Chrysobothris* flatheaded borers in need of advanced genetic characterization to facilitate future diagnostic and research efforts. Discussion during and following the **Flatheaded Borer Planning Workshop** identified this list of *Chrysobothris* species that will be targeted to facilitate future diagnostic and genetic profiling efforts. Outcomes will directly enhance Extension outreach and provide validity and accuracy for planned research including: insecticide efficacy trials, trapping studies, biological and behavioral studies, and economic impact assessments.

***Chrysobothris* Species**[A]	**Frequency of Encounter**[B]		**Status**[C]
	Traps	**Larval Host Plant**	
Chrysobothris adelpha	C	O	1
C. azurea	O	O	1,2
*C. caddo**	*n.d.*	*n.d.*	2,3
C. chlorocephala	I	O	2
C. chrysoela	*n.d.*	R	2,3,4[E]
*C. comanche**	*n.d.*	*n.d.*	3,4[E],5
C. cribraria	C	O	2
C. dentipes	O	O	2
*C. femorata**	O	C	1
C. harrisi	I	I	2
C. mali	C	C	1,4[W],5
*C. mescalero**	I	I	4[W],5
C. neopusilla	*n.d*	I	4[E],5
C. neotexana	*n.d*	I	4[E],5
C. nixa	I	C	1,4[W],5
C. orono	*n.d.*	I	4[E],5
C. pusilla	*n.d.*	I	4[E],5
*C. quadriimpressa**	C	C	1,3
C. rotundicollis	*n.d.*	I	2,3,5
*C. rugosiceps**	O	C	1,3
C. scabripennis	*n.d.*	I	3,5
C. scitula	*n.d.*	*n.d.*	3,5
*C. seminole**	*n.d.*	*n.d.*	3,4[E],5
C. sexsignata	C	C	1
*C. shawnee**	I	I	1,2,3
*C. sloicola**	R	R	3,6
C. trinervia	*n.d.*	I	2,4,5[E]
C. viridiceps	O	C	2,4[E],5
C. verdigripennis	*n.d.*	I	2,4[E],5
*C. wintu**	*n.d.*	I	2,3,4[W]

[A] Species and putative species marked with an asterisk represent members of the *Chrysobothris* species group after Wellso and Manley (2007).

[B] Traps=Frequency in monitoring traps. Larval Host Plant=Frequency via emergence from host plant tissues. Abbreviations: C= common; O= occasional; I= infrequent; R= rare; *n.d.*= no data.

[C] Status: 1= economically damaging to commercial nursery stock and landscape plants; 2= ecologically important (e.g., as decomposer; wildlife food resource, etc.); 3= taxonomically important (e.g., diagnostically ambiguous morphologically or genetically); 4= range distribution- ([W]= western US; [E]= eastern US) or host plant-restricted; 5= species is desirable within study (diagnostically, genetically, or morphologically), but species is uncommon and specimens not likely to be collected; 6= known only from a single specimen.

Last updated: 10/2019

Flatheaded Borer Workshop Attendees

Last Name	First Name	Affiliation
Abana	Uzoamaka	Tennessee State University
Acebes	Angelita	University of Georgia
Addesso	Karla	Tennessee State University
Amarasekare	Kaushalya	Tennessee State University
Ashman	Krystal	Florida Division of Plant Industry
Basham	Joshua	Tennessee Department of Agriculture
Baysal-Gurel	Fulya	Tennessee State University
Blaauw	Brett	University of Georgia
Burrows	Matthew	Hale & Hines Nursery
Calabro	Jill	AmericanHort / HRI
Chase	Kevin	Bartlett Tree Experts
Chong	Juang-Horng (JC)	Clemson University
Clendenon	Gary	Tennessee Department of Agriculture
Dismukes	Amy	Tennessee State University
Dyer	Pam	Tennessee Department of Agriculture
Fare	Donna	Horticulturist
Hale	Frank	University of Tennessee Extension
Held	David	Auburn University
Hines	James	Hale & Hines Nursery
Joseph	Shimat	University of Georgia
Klingeman	Bill	University of Tennessee Plant Science
Knight	Dusty	Plantation Tree Company
LeBude	Anthony	North Carolina State University
Liburd	Oscar	University of Florida
Londoño	Diana	BASF
Moore	Benjamin	USDA-ARS and Moore Nursery
Murillo	Axel	Tennessee State University
Oliver	Jason	Tennessee State University
Palmer	Cristi	IR-4
Prabodh	Illukpitiya	Tennessee State University
Puckett	Traci	Tennessee Department of Agriculture
Ranger	Christopher	USDA-ARS
Reding	Michael	USDA-ARS
Rijal	Jhalendra	University of California
Scott	Martin	Hidden Valley Nursery, LLC
Shapiro-Ilan	David	USDA-ARS
Vafaie	Erfan	Texas A&M University
Watkins	Jason	USDA-APHIS-PPQ
Williams	Kyle	Tennessee State University
Wiman	Nik	Oregon State University
Witcher	Anthony	Tennessee State University
Youssef	Nadeer	Tennessee State University

Workshop Images