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Understanding emergence phenology and developing monitoring tools for Pacific flatheaded borer in walnut orchards in California

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Abstract

Flatheaded borer infestation (*Coleoptera: Buprestidae*) is a resurging problem of commercial walnuts, *Juglans regia*, in California's Central Valley. Reported as a problem of stressed weaker trees historically, the flatheaded borer problem has been increasingly reported in both young and mature, healthy walnut orchards for over five years. Since limited information is available regarding the biology and monitoring of this borer pest, we conducted studies to understand the extent of the problem, determine pest phenology, and explore potential monitoring tools. Our study showed that adult emergence occurs from May through July, with the peak activity in mid-June. None of the traps and lures evaluated over three years attracted the flatheaded borer effectively. In 2019, 79 adult *Chrysobothris* sp. were captured in different traps (purple funnel traps = 57, green sticky traps = 19, and purple sticky traps = 3). The majority of the *Chrysobothris* specimens we caught on the green prism traps were *Chrysobothris mali*. In contrast, purple funnel traps captured considerably higher numbers of *C. wintu*. The results of the study are discussed.

Keywords: flatheaded borer, *Chrysobothris* sp., walnut, trap monitoring

INTRODUCTION

At least four species of buprestid beetles, commonly known as flatheaded borer or jewel beetle, in the family *Buprestidae* are reported from the California walnut orchards (Grant et al., 2017). Of those four species, three are genus *Chrysobothris*, and one is *Dicerca*. *Chrysobothris mali* Horn, the Pacific flatheaded borer (PFB), is the most common flatheaded borer species native to western North America (Burke, 1929; Furniss and Carolin, 1977; Solomon, 1995). Described first in 1886 from specimens collected on apples in California's Central Valley (Burke 1929), *C. mali* has a wide host range of at least 70 tree and shrub species in 21 plant families.

Pacific flatheaded borer adults are about 1.5-2.0 cm long, bullet-shaped beetles with six metallic spots on their wings (Grant et al., 2017). Fully-grown larvae are pale-yellow and ~2 cm long and have characteristic broad prothorax that gives them a flattened "flatheaded" appearance. Pacific flatheaded borer emerges during the summer and has an annual life cycle. After mating, females lay eggs on walnut tree barks. Upon hatching, neonatal larvae bore and feed in the cambium first and then to the branch pith until they mature in the fall. Feeding in younger trees can completely encircle the trunk and may kill the trees, while in mature trees causes branch breakage and dieback, and yield loss.

Historically reported as an occasional pest of young and diseased or stressed walnut, *Juglans regia*, trees (Davis et al., 1968), flatheaded borer infestations are being increasingly reported in seemingly healthy orchards in California, particularly in San Joaquin Valley. The increased activities and economic damage caused by flatheaded borer in commercial walnut orchards, which occupy over 140,000 ha (i.e., >350,000 acres) of California's Central Valley, has become a severe concern to walnut producers (Rijal and Seybold, 2019). Understanding pest biology, such as emergence phenology, and identifying pest monitoring tools are crucial for developing integrated pest management (IPM).

Observational reports from a century ago suggest that the *C. mali* emergence in



California walnuts occurs as early as April and can last until July and August (Burke, 1929). However, information, such as peak emergence period, that could help optimize spray timing and overall IPM of these pests is not available to our knowledge. Moreover, though several studies in the past have explored the trap and lure preference of several species of buprestids to develop monitoring tools for other buprestid beetles (Lindgren, 1983; Francese et al., 2008; Coleman et al., 2014; Cavaletto et al., 2020), there is no information available for the trap color, type and lure preference for the buprestid beetles that is prevalent in the California walnuts. Considering the recent reemergence of the Pacific flatheaded borer, understanding emergence phenology and developing monitoring tools for this pest is warranted to develop integrated management practices. In this study, we studied the emergence phenology and evaluated various traps and lure combinations for their effectiveness in attracting flatheaded borers common in California walnuts.

MATERIALS AND METHODS

Determining flatheaded borer emergence phenology in California walnuts

Flatheaded borer emergence phenology was studied using adult emergence cages in semi-field and field conditions. In the semi-field study, we collected flatheaded borer-infested walnut branches during the winter from three walnut orchards in 2019 and two walnut orchards in 2021. The branches were stored in ventilated plastic containers simulating orchard conditions for adult emergence. Adult emergence from the infested branches was inspected at 7-15 days intervals. Additionally, in 2021 a field study was conducted to examine *C. mali* adult emergence in the field by caging infested branches and recording the adults that emerged from the caged branches using emergence cages.

Evaluating potential traps and lures for flatheaded borer monitoring

1. Effect of trap color and type on flatheaded borer adult capture.

In mid-April 2019, traps were deployed in six walnut orchards with a set of three traps, including one purple and one green sticky prism trap (referred to as purple or green sticky traps, respectively hereafter) 35×61 cm in size (Synergy Semiochemicals, Canada), and one purple multifunnel trap (referred to as multifunnel trap hereafter) (Synergy Semiochemicals, Canada) in six walnut orchards in the northern San Joaquin Valley. All these traps were hung on ~3 m tall stainless-steel conduit poles in orchard rows. A flexible metal wire was folded in the middle and inserted into the conduit pole top. The two ends of the wire were used to tie the triangular prism trap to the pole by inserting it into the punched holes of the trap corner. Similarly, two wire ends were used to hang the multifunnel traps. At the bottom of the multifunnel trap, a plastic jar with antifreeze liquid filled about 1/3 of the jar was attached to collect trapped specimen. For both trap types, green or purple color served as an attractant for the flatheaded borer adults. Traps were checked biweekly and serviced as needed. All the buprestid beetles trapped were removed from the prism trap and collected in vials with xylene. Xylene was used to remove the sticky material from the insect collected in a sticky trap. The trapped contents from the multifunnel trap jar were collected in vials until identification the insects. Average number of flatheaded borers per trap for the whole season was calculated. Effects of trap type and color on the two most common flatheaded borer species were analyzed using one-way analysis for variance.

2. Efficacy of lures on flatheaded beetle catch.

The study was conducted in a 5-year-old English walnut (cultivar: 'Tulare') orchard in Jack Tone Road, San Joaquin County, California, in 2019. Nine purple multifunnel traps consisting of three green leaf volatiles (GLV) (AgBio, Inc., Colorado), three ethanol (AgBio, Inc., Colorado), and three combos (i.e., a combination of GLV and ethanol lures) were installed in each of the three walnut rows separated by ~30 m (4 rows apart). The multifunnel trap was deployed using 3 m tall conduit poles as described in the previous sub-section. A plastic pouch carrying the lure was hung inside the funnel at about the mid-length of the multifunnel trap

using twist ties. All traps were installed at the interior of the orchard, a minimum of 30.4 m from the edges, to avoid potential edge effects. Traps were installed in mid-April and sampled biweekly, and the species of beetles caught in the trap were identified in the laboratory. The average number of flatheaded borers per trap for the whole season was calculated for each lure type. Effects of lure type on the flatheaded borer species, *C. wintu*, were analyzed using a chi-square test.

In 2021, we evaluated purple traps as a part of a USDA SCRI-funded multi-state project. Purple traps (23×30 cm) with sticky liners outside with each of the two lure types (benzaldehyde, ethanol, or no lure) were deployed along the borders, covering each of the four sides of the orchard (each lure type replicated four times). The traps were checked weekly, and the beetles caught in the trap were identified in the laboratory.

RESULT AND DISCUSSION

In the flatheaded borer emergence phenology study in 2019, adult emergence in a semi-field study began in May and continued through June. We recovered a total of 152 adults during the entire season. The highest proportion (~70%) of adults was recorded on June 12 (Figure 1). In 2021, 75 adults were captured in the semi-field survey, and their emergence pattern was like that of 2019 (Figure 2). In the field study, 2021, we captured 17 adults from 65 caged branches. Beetle emergence began in the second week of May, with peak emergence between May 28 and June 11 (Figure 2). This finding will help develop effective spray timing for controlling this pest.

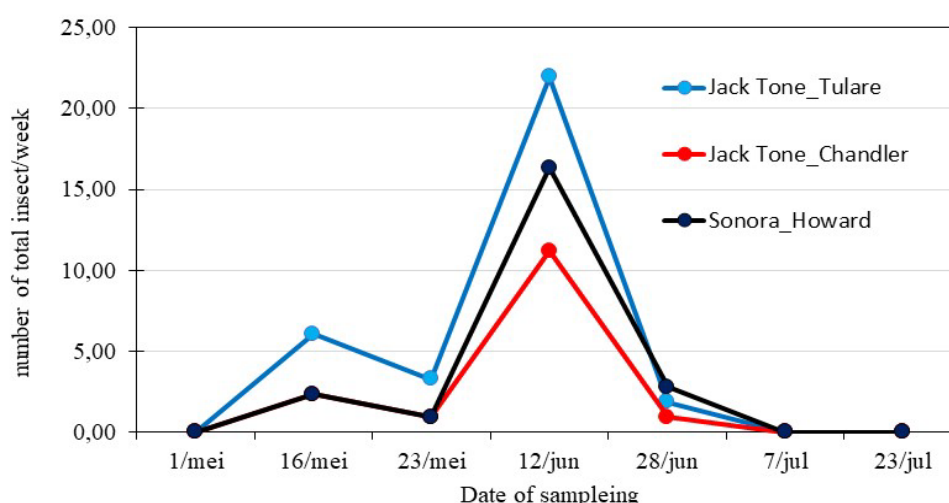


Figure 1. Numbers of *Chrysobothris mali* adults emerged per week in plastic emergence cages in the laboratory from the infested branches collected from 3 locations in 2019.

In the beetle emergence phenology study, all the reared-out specimens from the infested walnut branches in the laboratory in 2019 and 2021 were *Chrysobothris mali*. Moreover, all the beetle specimens collected from infested branches in the field were also *C. mali*. This indicates that *C. mali* is the primary species causing damage in walnut orchards. Our finding confirms the previous reports (Burke, 1929; Grant et al., 2017) that the primary flatheaded borer in California walnut is *C. mali*.

In the trap and lure evaluation studies conducted in 2019, 1761 wood boring and bark beetles were caught in the study. Beetle species and numbers caught in different studies are presented in Tables 1 and 2.

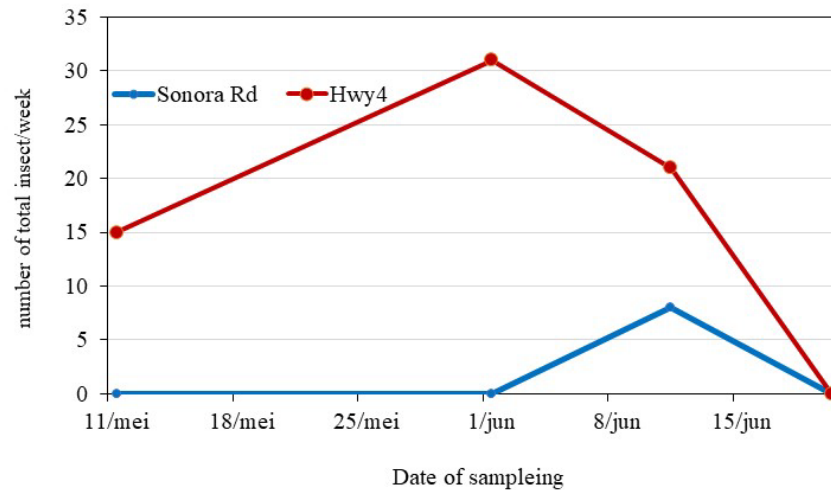


Figure 2. Numbers of *Chrysobothris mali* adults emerged per week in plastic emergence cages in the laboratory from the infested branches collected from two locations in 2021.

Table 1. Seasonal total of insects capture in different trap color/types in 2019 in California walnut orchards.

Insect species/family	Trap types			Seasonal total
	Purple funnel	Green sticky	Purple sticky	
<i>Chrysobothris mali</i> (Buprestidae)	18	17	2	37
<i>C. wintu</i> (Buprestidae)	37	2	1	40
<i>Polystoma californica</i> (Buprestidae)	2	0	0	2
<i>Pityophthorus juglandis</i> (Curculionidae)	11	0	0	11
<i>Xyleborinus saxeseni</i> (Curculionidae)	1324	0	0	1324
<i>Nathrius brevipennis</i> (Cerambycidae)	11	0	0	11

Table 2. Seasonal total of insects captured in Lindgren style multifunnel purple traps baited with different lure types in 2019 in California walnut orchards.

Lure types	Insect species/family			
	<i>Chrysobothris mali</i> (Buprestidae)	<i>Xyleborinus saxeseni</i> (Curculionidae)	<i>Hypothenemus eruditus</i> (Curculionidae)	<i>Nathrius brevipennis</i> (Cerambycidae)
Green leaf volatiles	5	63	1	1
Ethanol	3	174	12	1
Combo (green volatiles + ethanol)	3	70	2	1
Seasonal total	11	307	15	3

In the trap type and color evaluation study in 2019, the highest number of beetles were caught in the purple funnel trap. Of the total beetles caught, ~93% were *Xyleborinus saxeseni* (Coleoptera: Curculionidae). Among the flatheaded borer beetle, we caught 37 *C. mali* and 40 *C. wintu* during the entire season. Slightly higher numbers of both beetle species were caught on multifunnel trap followed by the green sticky trap. The lowest number of beetles were caught in a green sticky trap (Table 1). However, there was no significant effects of trap types on the number *C. mali* ($F=1.57$, d.f.=2,21, $p=0.23$) (Figure 3) and *C. wintu* ($F=1.79$, d.f.=2,21, $p=0.19$) (Figure 4).

In the lure evaluation study in 2019, the ethanol lure caught the highest number of beetles, followed by combo volatile (Table 2). The lowest numbers of beetles were caught on green volatile. Of the total beetles caught, the highest number caught was *Xyleborinus saxeseni*.

Only 11 specimens of Pacific flatheaded borer, *C. mali*, were caught in the traps, and the lure type did not significantly affect the number of *C. mali* caught in the trap ($\chi^2=0.72$, d.f.=2, $p=0.70$).

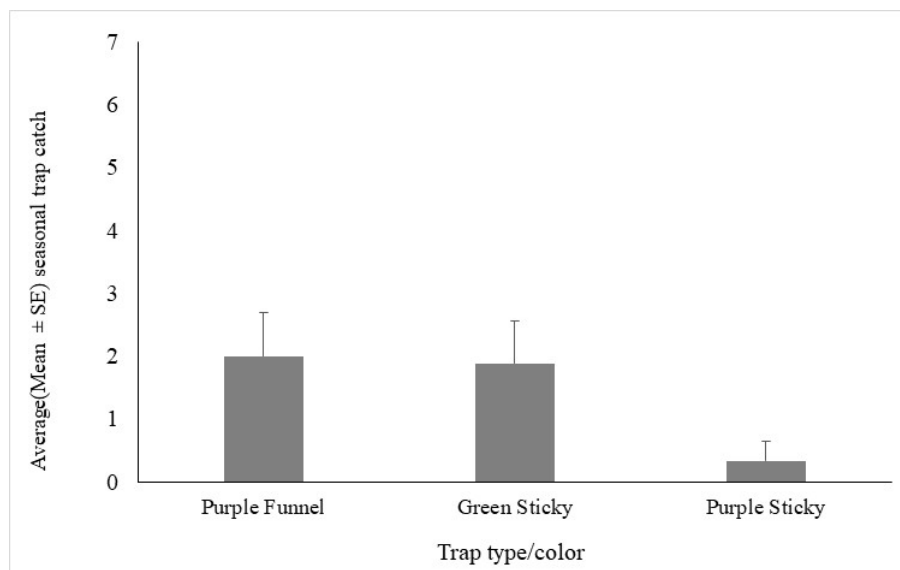


Figure 3. Effects of trap type/color on average seasonal *Chrysobothris mali* catch, 2019 ($P>0.05$, one way analysis of variance).

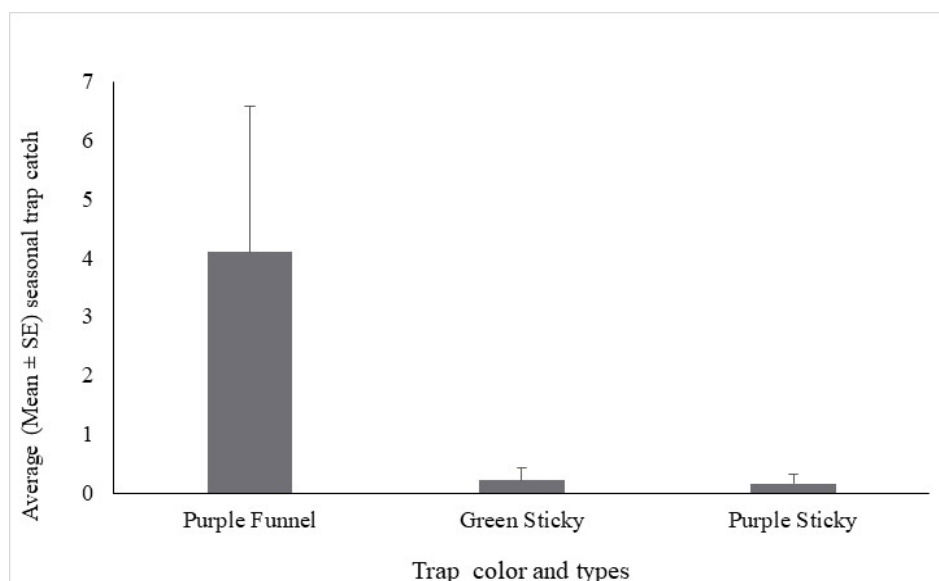


Figure 4. Effects of trap type/color on average seasonal *Chrysobothris wintu* catch, 2019 ($P>0.05$, one way analysis of variance).

In the 2021 lure evaluation field study, only five adults were captured in the traps. Overall, none of the trap and lure combinations highly attracted any flatheaded borer species suggesting none of the volatiles and traps used in our study can be effectively used for flatheaded borer monitoring.

Though not the objective of this study, multifunnel traps were highly attractive to ambrosia beetles *Xyleborinus saxeseni* and attracted many ambrosia beetles. Multifunnel traps are historically proven to be very attractive and are commonly used for trapping these groups

of beetles (Lindgren, 1983). We also caught some longhorn beetles (family: *Cerambycidae*), notably in the purple trap (with or without a lure). Cavaletto et al. (2021) reported that purple trap is attractive to cerambycids though it is not the most attractive color to them.

Buprestid beetles are colorful and primarily diurnal insects. The color or visual cues play a crucial role in their feeding and oviposition host-finding and mate-finding behavior (Evans et al., 2004; Lelito et al., 2011). Various trap colors and lures used in our current study were based on the findings of previous studies on other Buprestid beetles and their preference for color, types, or lures. For example, green- or purple-colored sticky prism traps and purple multiple funnel traps (also called Lindgren funnel traps) play a significant role in capturing several buprestid beetles such as emerald ash borers and others (Lindgren, 1983; Francese et al., 2008; Cavaletto et al., 2020) and goldspotted oak borer (Coleman et al., 2014). Fürstenau et al. (2015) found that purple prism traps, when lured with green leaf volatiles (GLVs), were the most effective traps for flathead oak borer, *Coroebus undatus*. Similarly, among the lures, the benzaldehyde commercially available lure was previously found to be attractive to other species of *Chrysobothris* (JO, unpublished data). Ethanol was used because it is common tree stress volatile and is found to attract other wood boring (cerambycids) and bark beetle (curculionids) (Montgomery and Wargo, 1983).

While our study showed that the common Buprestid found in our study, *C. wintu*, was attracted to green and purple colors, the insects were not caught in high numbers, given the fact that the orchards where the traps were deployed were severely infested by this beetle. The addition of different lures, such as ethanol, benzaldehyde, and green volatiles, with various trap colors and types also did not improve the trap catch considerably, suggesting that the lures used were not the right blend of volatiles for these species. Future studies should investigate a wide range of color and lure combinations that these beetles are attracted to develop a monitoring trap for this pest.

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