Invasive Shot Hole Borer Trials Lakewood

James Komen, Donald R. Hodel, Ph.D., Cris Falco, and Camille Pawlak

The subject London plane trees in the study were part of a relatively uniform planting of street trees in Lakewood, California. *Photo by Donald R. Hodel*.

Abstract

Invasive Shot Hole Borers (ISHBs) are small ambrosia beetles that construct galleries in woody plants and vector a complex of fungi causing the disease *Fusarium* dieback (FD). ISHB and FD, which can cause severe tree damage and mortality, have been attacking southern California's urban forests for close to two decades. This study evaluated several insecticides and application methods (trunk spray, trunk injection, and soil injection) for control of ISHB on *Platanus* × *hispanica* (London plane tree), one of the most susceptible reproductive hosts and severely impacted landscape trees in southern California. We treated 50 trees and assessed ISHB activity over a two-year period. We found that pest activity was highly cyclical, with higher activity in the spring. More activity occurred on the north than south sides of the trees, perhaps due to more even temperatures not subject to daily fluctuations. None of the treatments consistently reduced the amount of pest activity, which differed from other studies showing effectiveness of similar materials and application methods.

Introduction

Invasive Shot Hole Borer is a collective term that includes two small Asian ambrosia beetles, the polyphagous shot hole borer (PSHB, *Euwallacea fornicates*) and the Kuroshio shot hole borer (KSHB, *Euwallacea kuroshio*). The two beetles are nearly indistinguishable morphologically, making DNA data necessary for positive identification. PSHB was first detected in Los Angeles County in 2003 (Eskalen et al., 2013, 2016; Stouthamer et al., 2016). For several years PSHB and FD were uncommon, but by 2010 they were more widespread and responsible for a devastating and well-publicized attack on *Acer negundo* (box elder) street trees in a multi-block stretch of northeastern Long Beach (Hodel 2012a; Hodel et al., 2012). FD and PSHB have now spread to Orange, Riverside, San Bernardino, and Ventura counties. KSHB was first detected in San Diego County in 2013 and is now in Orange and Santa Barbara counties (Eskalen, 2016; Eskalen et al., 2016).

ISHBs bore into trees, constructing galleries that they then inoculate with a complex of symbiotic fungi that they have vectored, including *Fusarium euwallaceae, Graphium euwallaceae*, and P*aracremonium pembeum* (Eskalen, 2016; Eskalen et al., 2013; Lynch et al., 2016). The fungi are a nutritional source for ISHB adults and larvae. Unfortunately, the fungi are also often plant pathogens, inhibiting movement of water and nutrients from the roots up into the trunk, branches, and leaves, causing the disease FD, which can severely damage and kill trees.

The ISHB/FD association has been attacking a wide variety of trees in southern California for about 17 years, including native and introduced landscape trees, some palms, and avocado groves in urban and wildland settings (Eskalen, 2016; Eskalen et al., 2013, 2016; Hodel, 2017; Stouthamer et al., 2016). More than 300 species of trees have been attacked, of which more than 100 are susceptible to the pathogenic fungal complex (Eskalen, 2012; Eskalen et al., 2013). However, only 64 species are designated as reproductive hosts, meaning they support both beetle reproduction and associated fungal growth that causes FD (Eskalen, 2018).

The ISHB/FD association causes slight to severe tree damage and death across southern California, affecting landscape trees in residential areas, parks, along streets, commercial establishments, agriculture, and even natural areas and trees in production nurseries, which has led to significant economic and ecological impacts; thus, effective management tools are of paramount importance (Grosman et al., 2019).

Management practices for the ISHB/FD association have appropriately and primarily focused on proper cultivation practices, including

- the selection of resistant species;
- optimal water, nutrition, mulch, root zone health, and pruning (Hodel, 2012b; 2017; Stouthamer et al., 2016);
- early detection and sanitation, including prompt removal and disposal of affected trees (Eskalen, 2016; Eskalen at al., 2016; Faber, 2016), including solarization and chipping of infested wood (Eatough Jones and Paine, 2017; Faber, 2016).

The use of insecticides has also been investigated. Contact sprays of permethrin and bifenthrin reduced ISHB attacks on trees for four and eight weeks, respectively (Eatough Jones and Paine, 2017; Reding et al., 2013). Systemic insecticides, which are touted as safer alternatives to contact sprays, have been evaluated recently for control of ISHB. Eatough Jones et al. (2017) and Mayorquin et al. (2018) showed that emamectin benzoate effectively reduced ISHB attacks on *Platanus racemosa* (California sycamore), an extremely susceptible reproductive host and one of the most severely impacted landscape trees in southern California, but the trials were not long-term, running for 6 and 12 months, respectively.

Because ISHBs depend on their symbiotic fungi for food and survival, targeting these fungi to reduce or eliminate the food source is a viable control strategy. Freeman et al. (2012) showed that propiconazole, a systemic triazole fungicide, was effective in inhibiting *Fusarium* sp. growth in laboratory bioassays. Although trunk-injected propiconazole was effective against several beetle-vectored fungal diseases (Appel and Kurdyla, 1992; Eggers et al., 2005; Mayfield et al., 2008; Stipes, 1994), no studies showed any materials were effective inhibitors of symbiotic fungal growth to stop beetle reproduction sufficiently for more than 90 days (Grosman et al., 2019).

Most recently, a four-year study (Grosman et al., 2019) evaluated emamectin benzoate alone and in combination with propiconazole as therapeutic and prophylactic treatments for ISHB and its symbiotic fungal complex on *Platanus racemosa*. They found that all emamectin benzoate treatments reduced ISHB activity and emamectin benzoate and propiconazole alone or combined protected trees for 45 months.

Our objective was to evaluate several insecticide materials and application methods (trunk spray, trunk injection, and soil injection) for control of ISHB on *Platanus* × *hispanica*, one of the most susceptible reproductive hosts and severely impacted landscape trees in southern California.

Methods

Field observations

In a residential neighborhood of Lakewood, California, we identified two 1.8 meter-wide parkways as our study site. These parkways, located between the curb and sidewalk, run along both sides of the road and are planted with *Platanus* × *hispanica*. In January 2018, 50 of these trees, ranging from 30.5 to 94 cm DSH, were selected for monitoring for signs of ISHB activity. A history of ISHB activity was documented in the trees along this street, but no resulting tree mortality had been recorded prior to this study. The trees all had moderate *Anthracnose* symptoms that are typical of *Platanus* × *hispanica*, but otherwise they were all in fair to good health.

Authors Donald Hodel and Cris Falco count the hits on one of the trees in the study. *Photo by James Komen.*

From January 2018 through January 2020, trees were inspected every three months for a total of nine data collection dates. During each monitoring period, a cylindrical section of the trunk was inspected for ISHB activity between 0.9 meters and 1.8 meters above the ground. The boundaries of the inspected area were to ensure accessibility from the ground and that the trunk was not distorted by the root crown flare. ISHB activity was quantified as individual "hits," which were defined as entry/exit boreholes in the trunk that had either frass or active sap exudation.

Each newly observed, active hit was marked with an all-weather paint pen. A different color was used in each period to indicate when each hit was first observed. Active hits in each observation period were counted separately if they were "new" or "old." Inactive hits were not counted. If an overwintering hit was reactivated in the spring, it was counted as old. Hits on the northern half and southern half of the trunk were counted separately.

On June 4, 2020, each of the trees was observed and its condition consensus-rated from 1 to 5, where 1 is very poor and 5 is optimal.

Treatments

The trees received insecticide treatments and a non-treatment control. Trees were divided into 10 blocks of five trees. Each of the five trees in each block received one of five treatments through random assignment:

1. Dinotefuran (Mitsui Chemicals, Tokyo) as Transtect® (Rainbow Ecoscience, Minnetonka, MN) and bifenthrin (Sino Agro-Chemical Industry, LTD., Shenzhen, Guangdong, China) as Baseline® (FMC, Philadelphia, PA) basal trunk spray. Pentra-Bark® (alkylphenol ethoxylate, a bark penetrant, Quest Products Corp., Westminister, CO) was added to the dinotefuran formulations.
2. Bifenthrin trunk spray.
3. Emamectin benzoate (Hebei Xingbai Agrochem Group Co., Ltd., Shijiazhuang,

Entry/exit holes were marked with a different color in each period they were observed. The hole adjacent to the purple mark was first observed in January of 2019. The holes adjacent to the orange marks were first observed in July of 2019. *Photo by Donald R. Hodel.*

Group	Product	Application Method	Application Frequency	Treatment Dates
1	Transtect®, Pentra-Bark®, and Baseline®	trunk spray	twice per year	January 11, 2018 July 12, 2018 January 18, 2019 July 3, 2019
2	Baseline®	trunk spray	twice per year	January 11, 2018 July 12, 2018 January 18, 2019 July 3, 2019
3	Tree-age G4® and Propizol	trunk injection	once every two years	January 11, 2018
4	Imidacloprid 2F® and Baseline®	soil injection and trunk spray	twice per year	January 11, 2018 July 12, 2018 January 18, 2019 July 3, 2019
5	Control - No Product	N/A	N/A	N/A

Figure 1: Trees in the study received one of five treatments.

Active Ingredient (AI)	Brand Name	EPA Reg. No.	Pesticide Type	Application Method	Application Rate
dinotefuran	Transtect®	59639-170-74779	systemic insecticide	trunk spray	7.2 Oz per Gal
bifenthrin	Baseline®	279-3177	contact insecticide	trunk spray	32 Oz per 100 Gals
alkylphenol ethoxylate	Pentra-Bark®	83416	bark penetrating surfactant	trunk spray	2.5% of solution
emamectin benzoate	Tree-age G4®	74578-10	systemic insecticide	trunk injection	15.25 ml per cm DBH
propiconazole	Propizol®	74578-8	systemic fungicide	trunk injection	15.25 ml per cm DBH
imidacloprid	Imidacloprid 2F®	66222-203	systemic insecticide	soil injection	30 ml per cm DBH

Figure 2: **Specifications for the treatment products applied to the trees in the study.**

Hebei, China) as Tree-äge G4® (Arborjet, Inc., Woburn, MA) and propicanazole (Syngenta AG, Basel, Switzerland) as Propicol® (Arborjet, Inc., Woburn, MA) trunk injection.

4. Imidacloprid (Bayer, Leverkusen, North Rhine-Westphalia, Germany) as Quali-Pro Imidacloprid T&O 2F® (Control Solutions, Inc., Pasadena, TX)soil injection and bifenthrin trunk spray.
5. Non-treated control

Treatment began in January of 2018, shortly after the first observation date. Details of these applications are shown in Figures 1 and 2.

The treatments were applied by the Plant Health Care department of West Coast Arborists, Inc. (Anaheim, CA). All applicators held a Qualified Applicator License and were supervised by a Pest Control Adviser. The trunk injections were performed using the Q Connect system manufactured by Rainbow Ecoscience (Minnetonka, MN). Trunk spraying was performed using Birchmeier four-gallon backpack sprayers (Stetten, Switzerland). Soil treatments were administered using a soil injector attached to a trunk-mounted spray rig. Soil injection solution was measured with a flow meter manufactured by GPI (Sparta, NJ).

Trunk spray treatment application. ***Photo by Donald R. Hodel.***

Soil injection treatment application. ***Photo by Donald R. Hodel.***

Treatment misapplication

Two treatment misapplications were identified during the study. One tree received an additional erroneous treatment, and one missed one of its four scheduled treatments. Trees with treatment misapplications were removed from the analysis.

Statistical analysis

To test the relationship between total number of hits and tree end-of-study condition we used an ordinary least squares (OLS) model. The correlation between the two variables was also calculated. Total number of hits were aggregated for each tree for each season. For each season, we assessed the correlation between the number of hits on the north and south sides of each tree. To determine if there was a significant difference between the number of hits for each treatment and the control, we conducted a paired T-test for each treatment type and the control group. We also assessed the correlation between tree size and total number of hits. To test the relationship between season and number of seasonally adjusted hits, we created a linear regression for each treatment type comparing season or date of study to the total number of seasonally adjusted hits. We ran the same regression for each treatment comparing season to number of seasonally adjusted hits with hits split into new and old hits. All analyses were done in Microsoft Excel using the "Regression" and "CORREL" functions.

Results

Tree condition

There was no tree mortality over the course of the study. All trees initially chosen for observation in 2018 were alive and present at the conclusion of the study in 2020. Although there was some measured amount of ISHB activity, it was not sufficiently significant to cause any substantial decline in the health of any trees.

No significant relationship or strong correlation existed between the total number of hits recorded on a given tree and that same tree's end-of-study condition rating ($p > 0.1$; $r = 0.21$) (Figure 3). The tree with the greatest number of total hits had the highest end-of-study condition rating (3.5 out of 5) in the study. If that single tree was excluded as an outlier, the correlation between the number of hits on a tree and the tree's end-of-study condition rating would have been even lower ($r = 0.11$).

ISHB activity

The total number of hits for all the trees in the study was aggregated for each season to track the overall pest population activity. A clear cyclical pattern of seasonality was present with more total activity in July and October and less in January and April (Figure 4). The season with the highest activity was July, with 74 total hits in 2018. In 2019, July and October both had 52 hits. In January of 2018, 2019, and 2020, activity was at a minimum, with 2, 10, and 5 active hits, respectively.

Hits remained active for an average of 186 days (σ = 45 days). Nine holes were marked as active in October

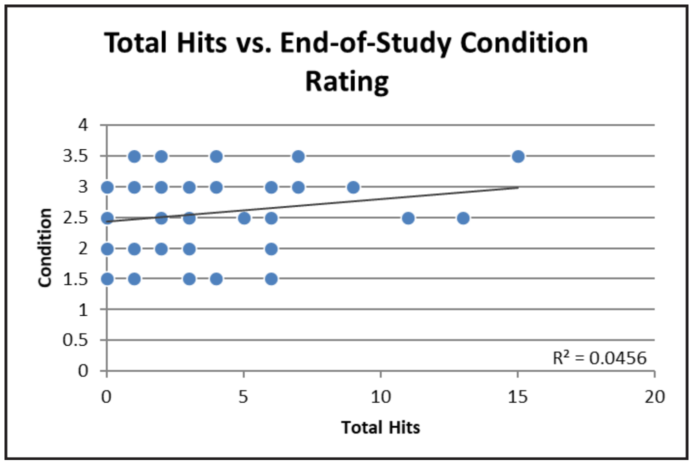

Figure 3: Scatterplot comparing the relationship of the total number of hits recorded during the study on each tree to its end-of-study condition rating. There was no significant correlation.

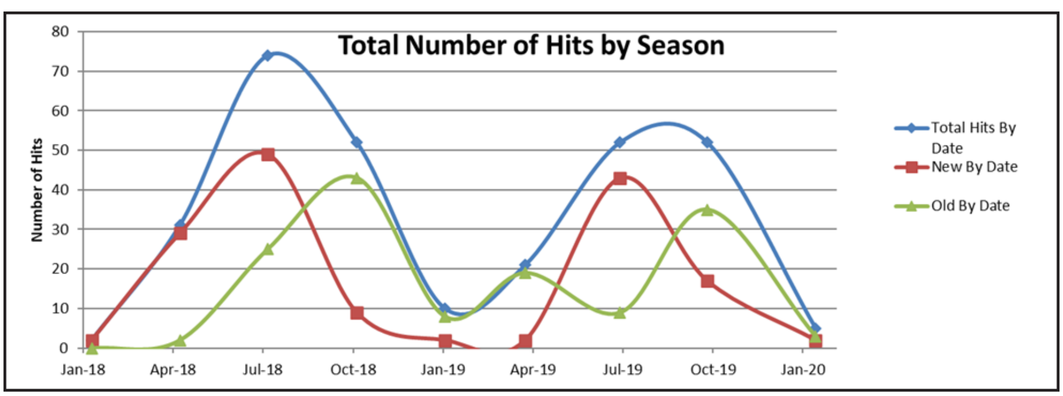

Figure 4: Total population of active hits in the study area (blue), new hits (red), and old active hits (green) form a cyclical seasonal pattern.

2018, inactive in January 2019, and active again in April 2019. These "reactivated" holes accounted for the higher standard deviation (Figure 5).

In every season, more hits occurred on the north side of the trees than on the south side (Figure 6). This relationship held when the total hits were separately analyzed as new hits (r = 0.91) and old hits (r = 0.93). The same pattern of seasonality was observed on both sides of the trees. The mean percentage of total hits on the north side of the trees was 77% (σ=14%), and the relative percentage remained the same for new hits and old hits (σ=20% and σ=15%, respectively). All nine of the holes that overwintered and reactivated from January 2019 to April 2019 were on the north side of the tree (Figure 7).

No strong correlation existed between the size of a tree (DSH) and the total number of hits observed on it (r = 0.29). Similarly, no significant correlation was present between the size of a tree and the total number of hits per unit of trunk diameter (r = 0.02).

Treatment

In all periods except October of 2018, October 2019 and January 2020, the control trees had fewer

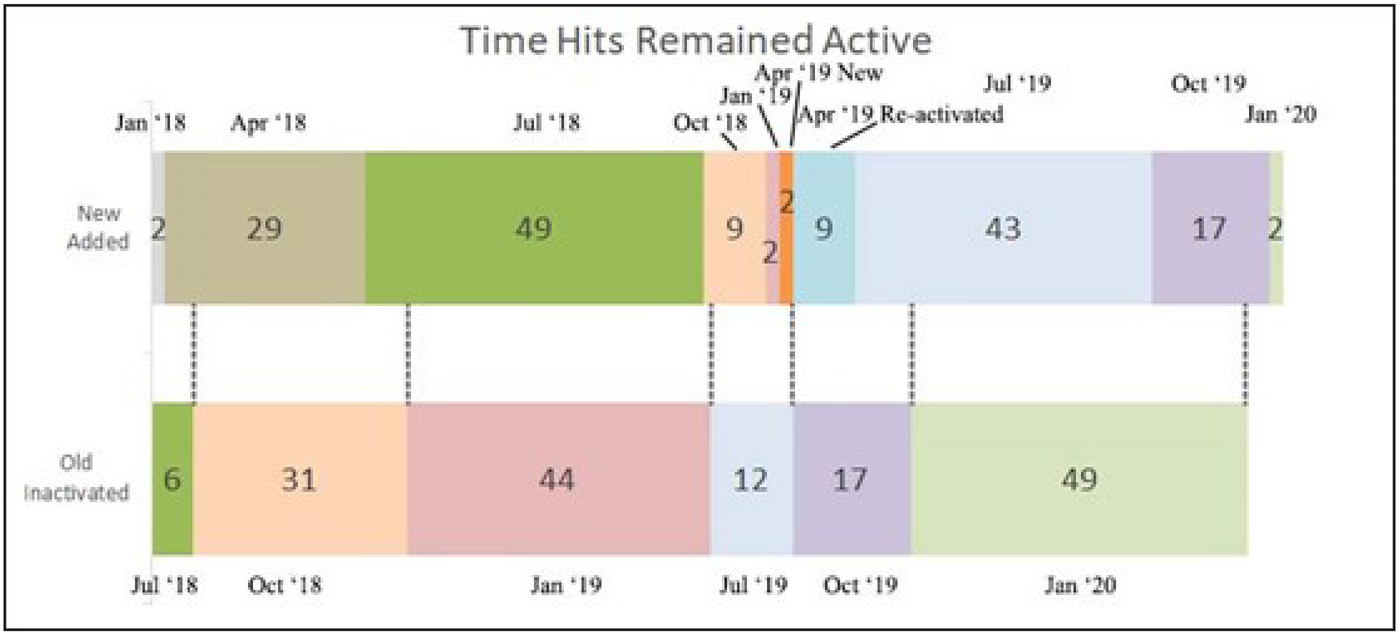

Figure 5: **Cumulative population of active hits and inactivation of old hits illustrating the average time each hit remained active. The top bar represents the period in which hits first became active. The lower bar represents the period in which those hits became inactive permanently. Hits remained active for an average of 186 days (σ = 45 days). Nine old hits that were inactive in January 2019 reactivated in April 2019.**

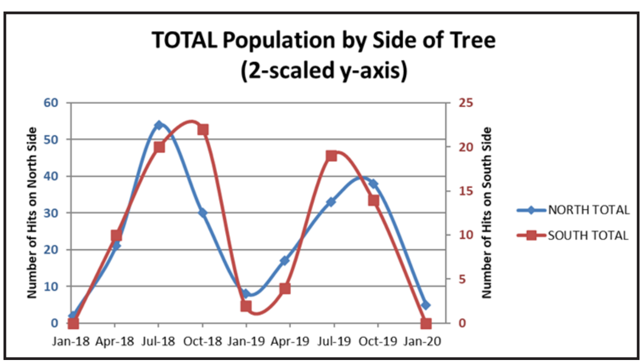

Figure 6: **Population of active hits segmented by side of the tree on which they were observed. A 2-scaled y-axis was used to emphasize the strong correlation between the number of active hits on the north side of the trees and the south side. 79% of the total hits were observed on the north sides of the trees.**

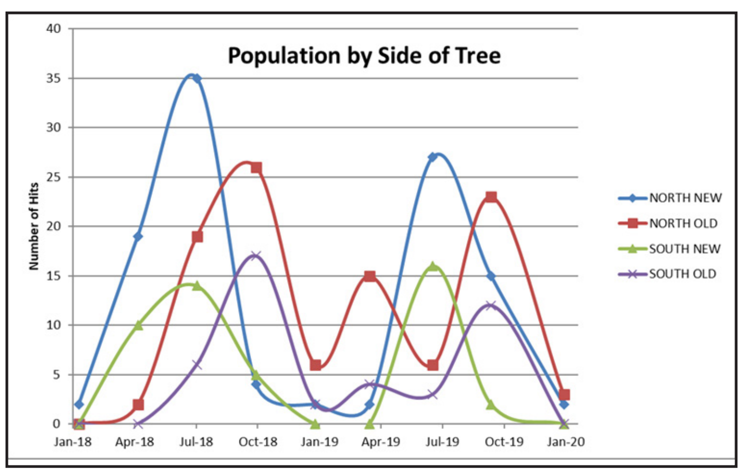

Figure 7: **Population of active hits segmented by age and side of the tree. All 10 of the overwintering hits that reactivated in April of 2019 were on the north side of the tree.**

active hits than any of the trees that received treatments. Trees treated with dinotefuran and bifenthrin (in combination) trunk spray and bifenthrin (alone) trunk spray had significantly more active hits compared to the control trees at $p < 0.05$ and $p<0.1$, respectively. Trees treated with emamectin benzoate had more hits except in October of 2019 (five hits on the treated trees, six on the control), but the relationship was inconsistent across the dates in the study. Trees treated with bifenthrin trunk spray had fewer hits than the control in January 2020 and October 2018, but it did not have consistently fewer hits across the dates in the study (Figure 8).

Total active hits for each period were divided by a seasonal adjustment factor to assess the effectiveness of each treatment over time without the distortion of cyclical seasonality of pest pressure (Figure 9). The seasonal adjustment factor for each season was calculated by dividing the total quantity of active hits in each period of observation by the average number of hits for all observation periods. The linear trend between season and number of seasonally adjusted hits explained a moderate amount of variation for imidacloprid-injected soil ($R^2 = 0.64$). None of the other treatments had strong variation explained with their trendlines ($R^2 < 0.10$).

Counts of active hits were segmented into new hits and old hits, and the data were seasonally adjusted as described above. A strong variance was not explained by the linear regression trendlines for the seasonally adjusted new hits for bifenthrin spray or imidacloprid soil injection and bifenthrin trunk spray ($R^2 < 0.006$). A small amount of variance was explained by the linear regression trendlines for the seasonally adjusted new hits for dinotefuran and difenthrin trunk spray ($R^2 = 0.26$) and emamectin benzoate and propiconazole trunk injection ($R^2 = 0.39$). The linear regression line for season and seasonally adjusted upward trend for the number of old hits explained a moderate amount of variance for the bifenthrin spray treatment and emamectin benzoate and propiconazole trunk injection ($R^2 = 0.63$ and $R^2 = 0.62$ respectively), but little variance was explained by the model for the other treatments.

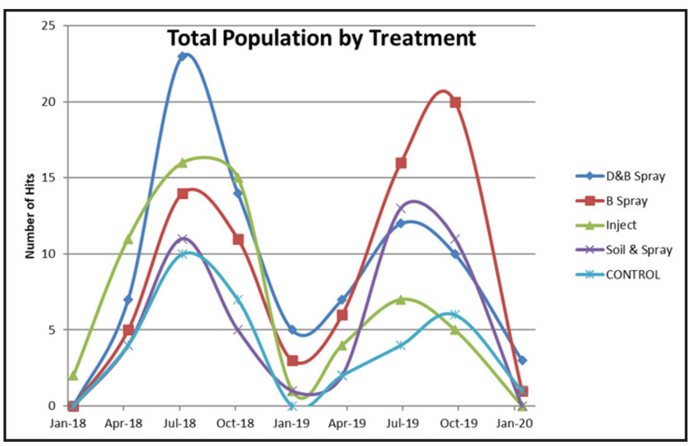

Figure 8: **Total number of active hits, segmented by treatment. In all periods except October of 2018, October 2019 and January 2020, the control trees had fewer active hits than any of the trees that received treatments. Treatment curves shown are: (1) Dinotefuran ("D&B Spray"), (2) Bifenthrin ("B spray"), (3) Emamectin benzoate injection ("Inject"), (4) Imidacloprid soil injection and bifenthrin trunk spray ("Soil & Spray"), and (5) Control.**

Discussion

Seasonality

Generally, activity for new hits was highest in the spring. Little new activity occurred in the other seasons. Hits tended to remain active into the fall, but activity substantially dropped by winter. While active hits were observed in the fall, most of the new site activity was complete by the late summer. This cyclical pattern in seasonality could help inform the time when risk is the highest for the spread of ISHB and identify when efforts can be most effective for treatment of trees.

The number of new active hits may be used as a proxy measurement for the amount of pest pressure at any given time. Overall, pest pressure generally was lower in 2019 than in 2018. But in 2018, there were three trees that accounted for the difference in total activity between 2018 and 2019. If the counts from these three trees were excluded, then the total activity in 2018 and 2019 would have been approximately equal.

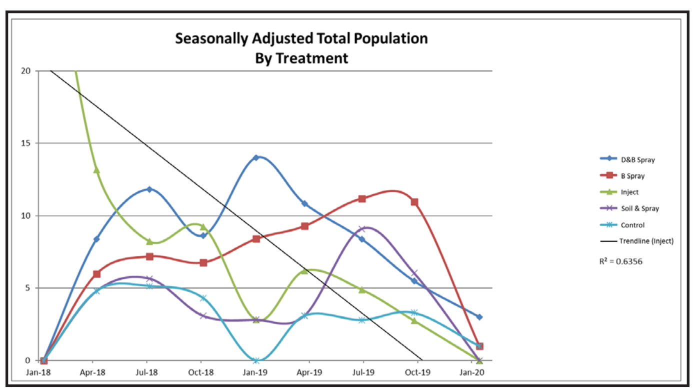

Figure 9: **Seasonally adjusted number of hits, segmented by treatment. Treatment curves shown are: (1) Dinotefuran ("D&B Spray"), (2) Bifenthrin ("B spray"), (3) Emamectin benzoate injection ("Inject"), (4) Imidacloprid soil injection and bifenthrin trunk spray ("Soil & Spray"), and (5) Control. The trunk injection treatment had a moderately significant correlation with its linear regression trendline ($R^2 = 0.6$).**

North- vs. south-facing trunks

Consistently throughout the study, 77% of the hits were found on the north side of the tree (σ=14%). This is a useful observation for studies that track pest populations because it helps inform where on the tree most of the activity might be found.

The study was conducted in the northern hemisphere, so the north sides of the trees receive less sunlight throughout the year than the south sides of the trees. Daytime temperatures are higher on the southern sides of the trees due to higher solar exposure. However, the ratio of hits on the north side to hits on the south side did not change with the seasons, suggesting that the peak daytime temperature of the bark might not be the primary reason for the preference of the north side. If peak daytime temperatures were the sole reason for the preference, then the number of northern-side hits would have been higher in the hotter months and lower in the cooler months when the temperature of the southern sides of the trees dropped below the peak summertime temperatures of the northern sides.

Age of active holes

Once a hit was observed as active, it lasted for a mean of 186 days (σ = 45 days). This pattern held generally for the new hits that appeared in the spring and summer. But hits that appeared in the fall went inactive for the winter months, and some re-activated in the spring. This subset of hits lasted 266 days from the date when they first appeared until the date they went inactive the following summer.

Tree size

No statistically significant correlation between the size of a tree and the total number of hits was observed. Large trees were equally as likely to be attacked as small trees in this study, and each unit of exposed trunk ssurface area on either the north side or the south side was equally likely to be attacked as any other.

Effectiveness of treatment

The most striking result of this study across all observation periods and all treatments, was that the control trees most often had fewer active hits than any of the treated trees. Although ememectin benzoate and bifenthrin trunk spray had some dates with fewer hits than the control trees, these results were inconsistent across all the dates in the study, and when the number of hits was fewer, it was only by one or two hits. If the number of hits is used as the metric of treatment effectiveness, then data show that all the treatments were similar or ineffective when compared to the control trees. However, if tree mortality rate is used as the metric of effectiveness, then this study did not have sufficient data to show effectiveness of any treatment because none of the study trees died.

Higher numbers of hits can damage and kill trees (Lynch et al., 2021), so the quantity of hits may be inferred to be a proxy for tree mortality in the absence of any tree death. But it is also possible that the trees with more hits in this study have the same ability to respond to insect attacks and have the same likelihood of dying as trees with fewer hits in this study. This study does not have sufficient data to conclude when a "critical mass" of hits would lead to tree death.

The seasonally adjusted number of hits segmented by treatment shows a significant correlation with the linear regression downward trendline for trunk injection treatments. One potential explanation for this observed trend is that immediately after application, the trees reallocated resources to respond to the wound sites created by the injection ports. It may be possible that the reallocation of resources left the trees more vulnerable to attack in the season immediately following treatment. Then later in the study, the injection product's effectiveness increased, reducing the number of seasonally adjusted hits down to the level as the control trees. The moderate correlation with the trunk injection treatment's seasonally-adjusted linear regression trendline (r = 0.8) shows that the effectiveness of the product may have changed over time.

Condition rating

No significant correlation was observed between the total number of hits on a tree and that tree's end-of-study condition rating (r = 0.21). Inferences that may be drawn from this conclusion are limited for several reasons.

First, the condition of each tree was not rated throughout the study; it was only rated one time at its conclusion. It is possible that the condition of each tree varied throughout the study and there may have been a higher correlation between tree condition and the number of hits during a particular study period.

Despite the data collected, it is possible that tree condition could still be correlated with pest activity. The total pest pressure during the study was relatively low, so sufficient data to establish a correlation through an observable decline in tree condition were lacking. We observed no tree mortality. The active hits did not girdle any significant fraction of a tree's stem circumference, even on the trees that had the highest numbers of hits. If this study was repeated under conditions of higher pest pressure, it is possible the data might show a correlation.

Other observations

Beginning in July of 2018, small triangular-shaped wounds appeared on the trunks of the trees that were injected. These wounds persisted for the remainder of the study. Wounds were widest at the injection ports. It is possible these wounds were related to the trunk injection techniques employed. Injections were performed in the winter months when sap flow was at the lowest. Applicators may have increased injection pressure to compensate for the slow rate of product uptake. If the pressure used by the applicators was too high, the injected product may have damaged the xylem tissue underneath the bark, resulting in the observed wound patterns.

Conclusions

ISHB activity in Southern California has caused tree damage and mortality across the urban forest. This damage can be expensive for cities to manage in terms of treatment and tree removal, and if the outcome of ISHB activity is tree mortality, residents lose amenities and benefits that the urban forest and trees provide.

This study examined where and when ISHB activity is the highest. ISHB activity was highest in the spring and exhibited a cyclical nature, which could help inform when to apply treatments most effectively and studies could be conducted comparing different application times of year for each of the treatments. ISHB activity was the highest on the north side of the tree, where daily sunlight is the lowest and temperatures more moderate with less fluctuation, which did not change across seasons, indicating that daily maximum temperature might not be the factor controlling this behavior. Additional studies investigating pathogenic fungal growth and ISHB feeding and temperature might be revealing.

We hoped to assess which treatment method was most effective for *Platanus* × *hispanica* in Southern California so that city managers could choose the best treatment for their cities. However, this study indicated a lack of efficacy across the two-year study when comparing each treatment to the untreated trees. Emamectin benzoate and bifenthrin trunk spray had some dates with fewer hits than the control trees, but the number of hits reduced was small, and the treated trees having fewer hits was inconsistent across the entire study, indicating that spending the time and resources treating trees may not bring the desired benefits and outcomes. Health outcomes measured at the end of the study, and number of active hits on each tree did not appear to be significantly improved with any of the treatments. Furthermore, because a variety of tree species can survive with minimal levels of ISHB activity for many years, a wait-and-see approach with judicious pest monitoring might be the best strategy rather than immediately applying pesticides. Indeed, abundant observational evidence exists that a variety of untreated tree species heavily infested as early as 2010 are today healthy and vigorous with little or no ISHB activity.

Small triangular-shaped wounds appeared on the trunks of trees that were injected. It is possible these wounds were the result of increased injection pressure at the time of application. ***Photo by James Komen*****.**

Special Thanks

The authors would like to thank Grant Pickering and the City of Lakewood for providing the sample trees used in the study. Special thanks to West Coast Arborists, Inc. for providing the treatments for the trees in the study.

James Komen
BCMA and Registered Consulting Arborist
classonearboriculture@gmail.com

Donald R. Hodel, Ph.D.
UC Cooperative Extension (emeritus)
drhodel@ucanr.edu

Cris Falco
BCMA and PCA
cfalco@treepath.com

Camille Pawlak
Graduate Student - Cal Poly, San Luis Obispo
cpawlak@calpoly.edu

REFERENCES

Appel, D.M., and T. Kurdyla. 1992. Intravascular injection with propiconazole in live oak for oak wilt control. *Plant Disease* 76: 1120–1124.

Eatough Jones, M., J. Kabashima, A. Eskalen, M. Dimson, J.S. Mayorquin, J.D. Carrillo, C.C. Hanlon, and T.D. Paine. 2017. Evaluations of insecticides and fungicides for reducing attack rates of a new invasive ambrosia beetle (*Euwallacea* sp., Coleoptera: Curculionidae: Scolytinae) in infested landscape trees in California. *Journal of Economic Entomology* 110: 1611–1618.

Eatough Jones, M., and T.D. Paine. 2017. Potential pesticides for control of a recently introduced ambrosia beetle (*Euwallacea* sp.) in southern California. *Journal of Pest Science* 110: 1611-1618. DOI:10.1007/s10340-017-0866-8

Eggers, J., J. Juzwik, S. Bernick, and L. Mordaunt. 2005. Evaluation of propiconazole operational treatments of oaks for oak wilt control. *Research Note NC-390*. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station. https://www.nrs.fs.usda.gov/pubs/rn/rn_nc390.pdf Accessed June 12, 2023.

Eskalen, A. 2012. Polyphagous shot hole borer. UC Riverside Center for Invasive Species Research. http://cisr.ucr.edu/polyphagous_shot_hole_borer.html Accessed June 12, 2023.

Eskalen, A. 2016. Polyphagous shot hole borer/*Fusarium* dieback. https://ucanr.edu/sites/eskalenlab/ Accessed June 12, 2023.

Eskalen, A. 2018. Known suitable reproductive hosts of shot hole borer-*Fusarium* dieback in California. https://ucanr.edu/sites/pshb/pest-overview/about-the-beetles/ Accessed June 12, 2023.

Eskalen, A., J.S. Mayorquin, J.D. Carrillo, S.C. Lynch, J. Kabashima, T. Paine, R. Stouthamer, F. Byrne, and J. Morse. 2016. Invasive shot hole borers threatening trees in southern California. *UC IPM Green Bulletin* 6(3): 1-3. https://ucanr.edu/blogs/blogcore/postdetail.cfm?postnum=22807 Accessed June 12, 2023.

Eskalen, A., R. Stouthamer, S. Colleen Lynch, P.F. Rugman-Jones, M. Twizeyimana, A. Gonzalez, and T. Thibault. 2013. Host range of *Fusarium* dieback and its ambrosia beetle (Coleoptera: Scolytinae) vector in southern California. *Plant Disease* 97(7): 938-951. https://www.researchgate.net/publication/262107119_Host_Range_of_Fusarium_Dieback_and_Its_Ambrosia_Beetle_Coleoptera-_Scolytinae_Vector_in_Southern_California Accessed June 12, 2023.

Faber, B.A., J.S. Morse, and M.S. Hoddle. 2016. UC Pest Management Guidelines: Avocado. Polyphagous shot hole borer and Kuroshio shot hole borer. *UC ANR Publication* 3436. http://ipm.ucanr.edu/PMG/r8302011.html Accessed June 12, 2023.

Freeman, S., M. Sharon, N. Okon-Levy, A. Protasov, M. Eliyahu, and Z. Mendel. 2012. Fungicide screening for inhibition of the fungal symbiont *Fusarium* sp. nov. in Israel. In: *Proceedings of the Invasive Ambrosia Beetle Conference—The Situation in California,* Riverside, CA, August 12-14, 2012. http://www.avocadosource.com/Journals/IABC_2012/S5_04_Freeman.pdf Accessed June 12, 2023.

Grosman, D. M., A. Eskalen, and C. Brownie. 2019. Evaluation of emamectin benzoate and propiconazole for management of a new invasive shot hole borer (*Euwallacea nr. fornicates*, Coleoptera: Curculionidae) and symbiotic fungi in California sycamores. *Journal of Forest Entomology* 112(3): 1267-1273. DOI: 10.1093/jee/toy423

Hodel, D.R. 2012a. The new, ambrosia beetle-vectored Fusarium disease on landscape trees in Los Angeles. In: *Proceedings of the Invasive Ambrosia Beetle Conference—The Situation in California,* Riverside, CA, August 12-14, 2012.

Hodel, D.R. 2012b. *The Biology and Management of Landscape Palms*. The Britton Fund, Inc., Western Chapter, International Society of Arboriculture, Porterville, CA. 176 pp.

Hodel, D.R. 2017.Polyphagous shot hole borer and Fusarium dieback disease on palms. *PalmArbor* 1: 1–17. https://ucanr.edu/sites/HodelPalmsTrees/files/255716.pdf Accessed June 12, 2023.

Hodel, D.R., A. Liu, G. Arakelian, A. Eskalen, and R. Stouthamer. 2012. *Fusarium* dieback: a new and serious insect-vectored disease of landscape trees. *Western Arborist* 38(3): 54-59.

Lynch, S.C., A. Eskalen, and G.S. Gilbert. 2021. Host evolutionary relationships explain tree mortality caused by a generalist pest–pathogen complex. *Evolutionary Applications* 14(4): 1083-1094.

Lynch, S.C., M. Twizeyimana, J. Mayorquin, D. Wang, F. Na, M. Kayim, M. Kasson, P. Q. Thu, C. Bateman, P. Rugman-Jones, J. Hucr, R. Stouthamer, and A. Eskalen. 2016. Identification, pathogenicity, and abundance of *Paracremonium pembeum* sp. nov. and *Graphium euwallaceae* sp. nov. — two newly discovered mycangial associates of the polyphagous shot hole borer (*Euwallacea* sp.) in California. *Mycologia* 108(2): 313-329.

Mayfield, A.E. III, E.L. Barnard, J.A. Smith, S.C. Bernick, J.M. Eickwort, and T.J. Dreaden. 2008. Effect of propiconazole on laurel wilt disease development in redbay trees and on the pathogen in vitro. *Arboriculture and Urban Forestry* 34: 317–324.

Mayorquin, J.S., J.D. Carrillo, M. Twizeyimana, B.B. Peacock, K.Y. Sugino, F. Na, D.H. Wang, J.N. Kabashima, and A. Eskalen. 2018. Chemical management of invasive shot hole borer and Fusarium dieback in California sycamore (*Platanus racemosa*) in southern California. *Plant Science* 102: 1307–1315.

Reding, M.E., J. B. Oliver, P.B. Schultz, C.M. Ranger, and N.N. Youssef. 2013. Ethanol injection of ornamental trees facilitates testing insecticide efficacy against ambrosia beetles (Coleoptera: Curculionidae: Scolytinae). *Journal of Economic Entomology* 106: 289–298.

Stipes, R. J. 1994. Preventive and therapeutic management of Dutch elm disease with fenpropimorph and propiconazole fungicides. *Phytopathology* 84: 548 (Abstract).

Stouthamer, R., P. Rugman-Jones, A. Eskalen, J. Kabashima, M. Dimson, A. Gonzalez, G. Arakelian, D. R. Hodel, and S. Drill. 2016. Polyphagous shot hole borer. *UC ANR Publication* 3436. http://ucanr.edu/sites/socaloakpests/Polyphagous_Shot_Hole_Borer/ Accessed June 12, 2023.