Efficacy of Traps, Lures, and Repellents for *Xylosandrus compactus* (Coleoptera: Curculionidae) and Other Ambrosia Beetles on *Coffea arabica* Plantations and *Acacia koa* Nurseries in Hawaii

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ABSTRACT The black twig borer, *Xylosandrus compactus* (Eichhoff) (Coleoptera: Curculionidae: Scolytinae), is a pest of coffee and many endemic Hawaiian plants. Traps baited with chemical attractants commonly are used to capture ambrosia beetles for purposes of monitoring, studying population dynamics, predicting outbreaks, and mass trapping to reduce damage. The objectives of this research were to optimize trapping systems for *X. compactus* and other ambrosia beetles such as *Xylosandrus crassiusculus* (Motschulsky) and *Xyleborinus saxesenii* (Ratzeburg) by comparing efficacy of several attractants, repellents, and trap types. The ability of certain chemicals to act as beetle repellents and thus interfere with trap catch was tested for purposes of protecting host plants from attack. Potential attractants and application methods tested were as follows: ethyl alcohol pouch delivery system, ethyl alcohol vial delivery system, α-pinene in Eppendorf tubes, eugenol bubblecaps, ginger oil bubblecaps, manuka oil bubblecaps, phoebe oil bubblecaps, and an unbaited control. Potential repellents tested were limonene and verbenone. Ethyl alcohol vials were as attractive as ethyl alcohol sleeves, and were more effective than traps baited with eugenol and α-pinene. Japanese beetle traps were more effective for black twig borer trapping than Lindgren funnel traps, and were easier to deploy. Verbenone and limonene significantly reduced trap catch of *Xylosandrus compactus* and *X. crassiusculus*, suggesting that they may be effective for reducing attraction to host plants. These results show the importance of developing a combination of several monitoring techniques to enhance management procedures for the black twig borer.

KEY WORDS ambrosia beetles, semiochemicals, traps

The black twig borer, *Xylosandrus compactus* (Eichhoff) (Coleoptera: Curculionidae: Scolytinae), originally is from Asia and is one of the most serious pests in coffee plantations as well as a number of endemic forest trees in Hawaii (Hara and Beardsley 1979, Marsden 1979). *Xylosandrus compactus* attacks >200 plant species including agricultural crops such as cacao (*Theobroma cacao* L.), mango (*Mangifera indica* L.), avocado (*Persea americana* Mill), macadamia (*Macadamia integrifolia* Maiden and Betche), and native Hawaiian forest trees to Hawaii such as ohia (*Metrosideros polymorpha* Gaudich), koa (*Acacia koa* A. Gray), mamaki (*Pipterus* spp.), and the endangered Mehamehame (*Flueggea neowawraea* W. J. Hayden). The black twig borer is considered an ambrosia beetle. Female black twig borers construct an entry hole into the heartwood and make galleries that are inoculated with an ambrosia fungus (Daehler and Dudley 2002). Females transport the symbiotic fungus to their galleries in a cuticular invagination known as mycangium (Beaver 1989, Six 2003) and serve as source of nutrition for larval and adult beetles (Hara 1977). Consequently, damage is caused by the physical excavation and the inoculation of pathogens into the host plants (Hara and Beardsley 1979). This ambrosia beetle causes significant mortality in koa seedlings and small saplings (Daehler and Dudley 2002), so efforts to propagate this endemic species are hampered by black twig borer attack. Damage by the black twig borer to koa tree also is a significant concern because koa is a culturally important forest species used to make furniture, canoes, and musical instruments (Yanagida et al. 1993). Black twig borer also is a coffee pest in Hawaii (Trujillo et al. 1995, Jones and Johnson 1996, Bittenbender and Smith 1999). Coffee is an important crop for Hawaii, not only because Hawaii is the only state that grows coffee commercially, but also because of its heritage value as a traditional industry in the islands (Bittenbender and Smith 1999). In the Kona area, losses to *X. compactus* incurred by the typically small-scale coffee growers are a serious concern. This problem has prompted a search for pest management alternatives such as attractants for mass trapping and

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repellents that can be deployed on host plants to protect them from damage by the black twig borer.

Ethanol, manuka oil, α-pinene, and other lures have been proven attractive to ambrosia beetles (Oliver and Mannion 2001, Hanula and Sullivan 2008, Miller and Rabaglia 2009). Repellents such as verbenone and limonene, which are effective repellents for other beetle species (Livingston et al. 1983, Phillips et al. 1988, Payne and Billings 1989, Paine and Hanlon 1991, Bertram and Paine 1994, Miller et al. 1995, Rappaport et al. 2001, Bentz et al. 2005, Progar 2005, Miller 2007) could be used in combination with attractants and act in a push–pull manner to deter the settling of dispersing beetles while the attractant might lure the repelled beetles to a trap placed some distance from the protected plants (Cooke et al. 2007).

Lindgren funnel traps generally are efficient for monitoring and surveys of invasive ambrosia and bark beetles in the United States (Lindgren 1983, Miller and Duerr 2008, Kendra et al. 2011). It has been shown that Japanese beetle traps also are very effective for a wide variety of Scolytinae in coastal California (N. E. Gillette 2010, personal communication). Because Japanese beetle traps have the potential for efficiently monitoring black twig borer populations and are less expensive and easier to use than Lindgren traps, we designed tests to compare the two trap types. Two other ambrosia beetles, *Xylosandrus crassiusculus* (Motschulsky) and *Xyleborinus saxesenii* (Ratzeburg), were included in this study because they can be serious pests, co-occur with black twig borer in Hawaii, and respond to many of the same trapping systems (Kovach and Gorsuch 1985, Coyle et al. 2005). *Xylosandrus crassiusculus* and *X. saxesenii* are of Asian origin and have become pests of fruit orchards, ornamental trees, and conifers throughout North America (Atkinson et al. 1988, Oliver and Mannion 2001, Coyle et al. 2005). Therefore, this study compared the effectiveness of known attractants, repellents, and two trapping systems for the black twig borer *X. compactus*, *X. crassiusculus*, and *X. saxesenii* on coffee plantations and *A. koa* trees.

Materials and Methods

Comparison of Trap Baits in Coffee Plantations

Study Location. This study was conducted in a 15-yr-old commercial Kona coffee plantation (*Coffea arabica* L.) of the variety Guatemalan (also known as 'Kona typica') located at 538 m elevation (19° 33.361′ N, 155° 55.730′ W) in the district of Kona, Island of Hawaii, United States. The coffee trees had a high level of black twig borer infestation (≈70% of the trees had one or more infested twigs at time of survey) and the surrounding vegetation of this farm, which included mango, eucalyptus (*Eucalyptus sideroxylon*), Christmasberry (*Schinus terebinthifolius*), avocado, koa, and macadamia, provided alternate hosts for the black twig borer.

Experimental Design. In March 2006, ten green Japanese beetle traps (JB/Expando$^{(T)}$ trap) (Trécé Company, Salinas, CA) were deployed on three plots that were chosen randomly, with 30-m buffer rows of coffee trees among plots. This Japanese beetle trap consisted of a green plastic funnel with four vertical blades and a collection cup at the bottom of the funnel. The diameter of the funnel was 15 cm and height trap was 23 cm. The container cup consisted of a wide-mouth 250-ml jar (NalgeneLabware, Thermo-Fisher Scientific, Waltham, MA) with a drain hole at the bottom covered with metal mesh. Traps were hung from tree branches in a regular grid throughout each plot at a height of 1.5 m, with a distance of 20 m between traps and 10 m away from the border of the field. Individual traps were baited with one of four different lures and unbaited traps served as controls. The treatments consisted of 1) ethanol sleeves (constructed of a thick PVC plastic charged with 3 ml of 95% ethanol and 27-ppm Bitrex as a denaturant, 2) ethanol lures deployed in 15-ml low-density polyethylene (LDPE) vials filled with 95% ethanol with a 1-mm-diameter hole in the lid, 3) α-pinene lures composed of 1.8-ml polyethylene tubes charged with 300 μl of α-pinene, 4) eugenol bubble cap dispensers constructed from a laminated 10-ml clear LDPE bubble with a 40-μm clear LDPE release membrane, charged with 320 mg of 99% eugenol, and 5) an unbaited control trap. The release rates of the compounds used were: 7 mg/d at 20°C for ethanol sleeves, 0.33 ml/ day at 20°C for ethanol vials, 1.2 mg/d at 20°C for α-pinene, and 1 mg/d at 20°C for eugenol.

The ethanol vials were provided as an inexpensive alternative that small-scale farmers easily could duplicate. The choice of the attractants was based on commercial availability as well as published evidence of attractiveness to other ambrosia beetle species, so that an appropriate trapping method could be developed quickly for field implementation. Two traps per treatment were installed in each plot. This study was conducted for 4 mo (March to July) and each 2-wk trap collection, lures were rotated in each plot and the 15-ml ethanol vials were refilled. Rotation of lures was conducted to minimize bias from potential location effects. To maintain a consistent release rate throughout the study, all lures were replaced in the field every 2 mo as recommended by Contech, Inc. (Delta, BC). To kill the captured beetles and minimize predation by trapped predatory insects, a 2-cm strip of Hercon VaporTape II (10% 2,2 dichlorvos) (Hercon Environmental, Emigsville, PA) was placed in the trap collection containers. All the captured insects were refrigerated in the collection container until examination. Beetles collected from each treatment were separated by species, plot, treatment, and sample date. Voucher specimens were identified by Al Samuelson (Bishop Museum, HI), Anthony Cognato (Michigan State University), Robert J. Rabaglia (USDA Forest Service), and Donald Bright (Colorado State University). Voucher specimens of these insects were deposited in the University of Hawaii at Manoa Insect Museum (UHIM). Statistical methods for this and the other three experiments are described at the end of the methods section.

Evaluation of Trap Designs, Attractants, and Repellents in Koa Stands

Study Location. Studies were carried out in a 9-yr-old koa forest restoration stand in the Maunawili Valley on the windward side of the island of Oahu, HI (21° 21′3.7″ N, 157° 46′00.6″ W). Populations of black twig borer were causing severe damage to all koa trees there before commencement of the experiments.

Trap Preference Test. From 13 June to 11 July 2006, 12 trap locations were set up in a grid in the plantation, with 15-m spacing between trap locations. Six green Japanese beetle traps and six black Lindgren funnel traps (Contech, Inc.) were suspended from trees at 1.5-m heights at the gridpoints, with trap type for each location determined by random choice. The Lindgren funnel trap consisted of 12 black interconnected vertical funnels that allowed beetles to fall through a collecting cup located on the bottom funnel (Lindgren 1983). A 2-cm Hercon Vaportape II pesticide strip was placed in the collecting cup to kill the captured beetles. The diameter of funnel was 19.05 cm, height of trap top with 12 funnels was 110.49 cm, diameter of collection cup was 10.16 cm, and height of collection cup was 12.7 cm. Traps were then baited with vials of 95% ethanol, as described for the coffee trials. Traps were organized in a complete randomized design with rotated repeated measurements. Every 2 wk, each trap was moved up one position; when the last trap was reached, it was moved to the first position in the grid. Rotation of traps was conducted to minimize location effects. Samples from the traps were collected weekly for 4 wk and separated by species, treatment, and sample date.

Comparison of Attractants. From November 2008 to January 2009, 20 Japanese beetle traps were placed in a grid at 15-m intervals in a randomly selected area of the koa plantation. Traps were organized in a completely randomized design with rotated repeated measurements. The traps were placed in four rows with five traps per row, and each trap was allocated one of the five treatments. Japanese beetle traps baited with 95% ethanol were used as positive controls. Lure combinations for the four baited trap treatments consisted of ethanol-baited controls, ethanol plus manuka oil, ethanol plus ginger oil, ethanol plus α-pinene, and ethanol plus phoebe oil. Ethanol lures consisted of 15-ml polyethylene vials filled with ethanol and sealed with cotton. The attractant chemicals were released from polyethylene bubble caps (Alpha Scents, Inc., Portland, OR). The release rate of manuka oil was 50 mg/d at 21°C. Enhanced ginger oil contained 8% alpha-copaene, a daily release rate of 8 mg of total mix at 21°C. The release rate of α -pinene was $\approx$150 mg/d at 21°C. The release rate of phoebe oil was $\approx$7 mg/d at 21°C. Beetles were collected weekly and entire traps, including the attractant, were moved forward one position at each 1-wk collection interval. Thus, each trap had the same attractant throughout the trial, but the trap positions were rotated weekly to minimize potential location effects. This study was conducted for 8 wk and insects were separated and identified by species, treatment, and sample date every 2 wk.

Comparison of Repellents. During the course of the study of lures, it was shown (see results section) that Japanese beetle traps baited with 95% ethanol attracted significantly larger numbers of black twig borer than other trap and attractant combinations, and therefore this trap and lure combination were used as a positive control in assessing efficacy of the repellents. Ethanol lures consisted of 15-ml LDPE vials filled with ethanol and plugged with cotton wicks. The limonene treatment was constructed with LDPE vials filled with 15-ml R-(+)-limonene. Verbenone treatments consisted of LDPE vials filled with 84% (-)-verbenone. Lure and repellant combinations for the three baited trap treatments consisted of ethanol-baited controls, ethanol plus limonene, and ethanol plus verbenone. The release rate of limonene was 0.6 gm/d at 20°C and the release rate of verbenone was 2 mg/d at 20°C (Contech, Inc.).

Each treatment was replicated six times, and treatments were assigned randomly to the traps. Eighteen Japanese beetle traps were placed in a grid at 15-m intervals, at a height of 1.5 m above the ground on koa trees, in a completely randomized design. From 5 September to 3 October of 2007, samples were collected weekly for 4 wk, rotating the lures at each sampling occasion. Beetles collected from each treatment were separated by species, treatment, and sample date.

Sampling Design and Statistical Analyses for the Four Studies

The comparison of trap baits in coffee plantations was a randomized complete block design with repeated measurements, and the trap preference test, comparison of attractants, and comparison of repellents in koa stands were a completely randomized designs with rotated, repeated measurements.

Because in all four studies the response to be examined was beetle counts, the over-dispersed Poisson distribution was assumed for all the responses (Onsager 1981). The log of the expected counts (number of beetles per trap) conditioned to the location of the trap was modeled with a Mixed Poisson regression from the family of mixed generalized linear models (McCullagh and Nelder 1989, McCulloch and Searle 2001) (a mixed Poisson regression). The log of the expected trap catch was modeled as a function of the treatment effect and other explanatory variables as fixed effects and trap location, and other interactions, including location, as random effects. In other words: the true mean count is equal to the exponential of a linear combination of fixed and random effects (see supplementary materials for full statistical models). The inclusion of these random effects in the models accounts for the pseudo-replication caused by the repeated sampling at each location. Multiple comparisons between treatments were made based on the maximum likelihood ratio test with the Bonferroni approach (experiment-wise error rate = 0.05). The

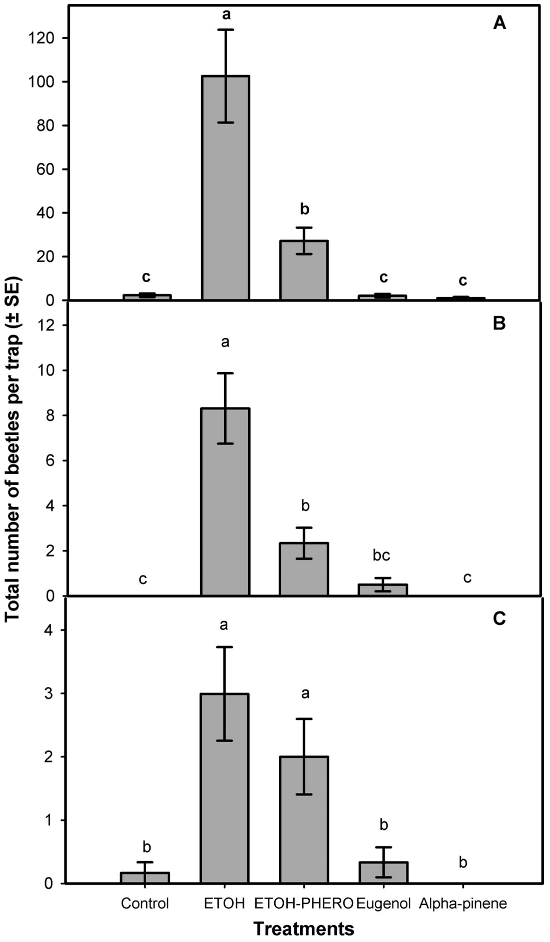

Fig. 1. Total number (±SE) of *X. compactus* (A), *X. crassiusculus* (B), and *X. saxesenii* (C) captured in Japanese beetle traps baited with three lures on coffee plants (means with the same letter are not significantly different from one another at a experiment wise error rate = 0.05).

Bonferroni adjusted α-level = 0.05/#2*tests for two-sided tests. The fitting of the models and comparisons were conducted using the SAS (v.9.2) GLIMMIX or NLMIXED procedures (SAS Institute, 2002).

Results

Comparison of Attractants on Coffee Plants. Significantly more *X. compactus* were captured in traps baited with 95% ethanol vials than ethanol sleeves ($F_{4,102} = 35{,}9$; $P < 0.0001$) and there were no significant differences between the eugenol, α-pinene, and the control (Fig. 1.A). Although no significant differences between eugenol, α-pinene, and control treatments were observed, there were significant differences in captures for the nontarget organisms, *X. crassiusculus* and *X. saxesenii* collected in traps baited with the different semiochemicals. *X. crassiusculus* was significantly more attracted to ethanol vials than ethanol sleeves ($F_{4,\,102} = 28.5$; $P < 0.0001$, Fig. 1.B). There were no significant differences between ethanol sleeves and eugenol. Eugenol was not statistically different from the control and α-pinene. *X. saxesenii* was significantly attracted to both 95% vials and ethanol sleeves ($F_{4,\,102} = 17.9$; $P < 0.0001$) (Fig. 1.C) and there were no significant differences among eugenol, α-pinene, and the control for that species.

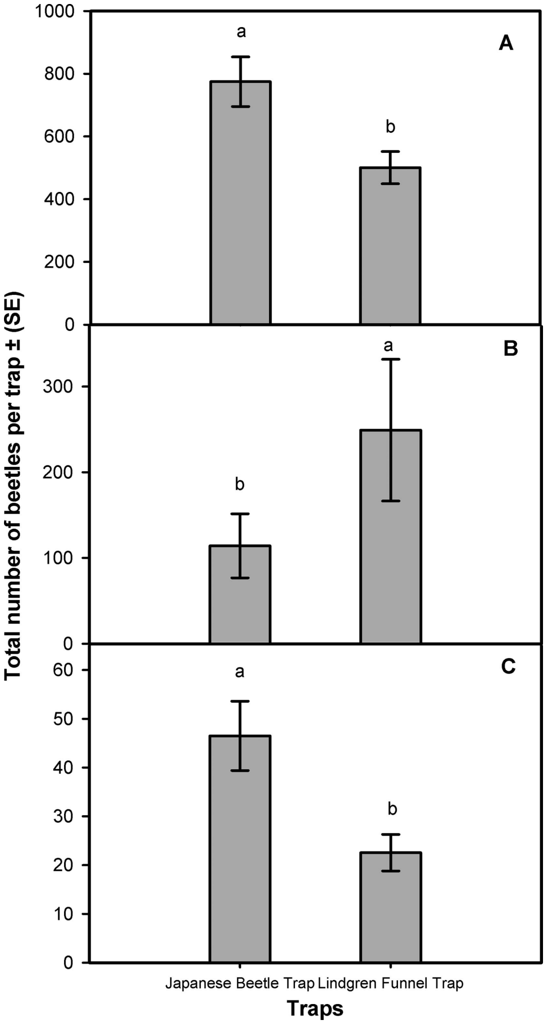

Fig. 2. Total number (±SE) of *X. compactus* (A), *X. crassiusculus* (B), and *Xyleborinus saxesenii* (C) captured in Japanese beetle traps or Lindgren multiple funnel traps in a 6-yr-old koa forest restoration stand in the Maunawili Valley on the windward side of the island of Oahu. Means followed by the same letter are not significantly different from one another at an experiment wise error rate = 0.05.

Trap Preference Test and Comparison of Attractants and Repellents on Koa Trees

Trap Preference Test. The green Japanese beetle trap baited with 95% ethanol caught significantly more black twig borers than the Lindgren funnel trap ($F_{1,18} = 16.9$; $P = 0.0007$) (Fig. 2.A). During the 4 wk

Table 1. Mean (± SE) of *X. compactus*, *X. crassiusculus*, and *X. saxesenii* attracted to five lures in Koa plantation in November 2008 to January 2009

	Xylosandrus compactus	*Xylosandrus crassiusculus*	*Xyleborinus saxesenii*
ETOH	19.50 (4.2)a	132.86 (19.13)b	23.64 (4.5)c
ETOH + Ginger Oil	21.27 (4.5)a	160.98 (22.99)b	24.01 (4.6)c
ETOH + α-Pinene	26.95 (5.5)a	118.15 (17.15)b	39.35 (7.1)c
ETOH + Phoebe Oil	14.94 (3.3)a	98.09 (14.40)b	38.16 (6.8)c
ETOH + Manuka Oil	19.89 (4.2)a	125.66 (18.14)b	36.95 (6.7)c

Means within columns followed by the same letter were not significantly different ($P < 0.0.5$).

of the study, the mean number of black twig borer females per Japanese beetle trap was ≈800 compared with 500 per Lindgren funnel trap. The Lindgren funnel trap caught more *X. crassiusculus* ($F_{1,18} = 6.5$ $P = 0.021$) (Fig. 2.B), whereas the Japanese beetle trap caught more *X. saxesenii* ($F_{1,18} = 12.5$; $P = 0.0024$) (Fig. 2.C).

Because of the relatively small absolute differences between the two traps in terms of beetle catches, the Japanese beetle traps were preferred for further work, because of their compact size, durability, and lower price.

Comparison of Attractants on Koa Plants. There were no significant differences among the five treatments ($F_{4,54} = 1.6$; $P = 0.184$) (Table 1). However, the combination of ethanol plus α-pinene and ethanol plus ginger oil tended to capture more *X. compactus* than the other attractant combinations. Ethanol and ethanol plus ginger oil were the most attractive for *X. crassiusculus.* However, phoebe oil may have promise as an interruptant for *X. crassiusculus.* α-Pinene, phoebe oil, and manuka oil, as well as the combination of each with ethanol, had promise as attractants for *X. saxesenii.*

Comparison of Repellents on Koa Plants. The total number of *X. compactus* was significantly reduced in the Japanese beetle traps treated with verbenone and limonene compared with Japanese beetle traps baited with 95% ethanol alone ($F_{2,49} = 1046.2$; $P < 0.0001$) (Fig. 3.A). Verbenone, even in the relatively slow releasing bubblecap dispenser (>10 mg/d), was an effective inhibitor of the black twig borer attraction to ethanol, reducing the trap catch by almost 50%. *X. crassiusculus* was significantly reduced in traps baited with verbenone or limonene compared with traps baited only with ethanol ($F_{2,\ 49} = 91.9$; $P < 0.0001$) (Fig. 3.B). Japanese beetle traps baited with limonene reduced the number of beetles for all three species ($F_{2,49} = 79{,}5$; $P < 0.0001$) (Fig, 3.A and Fig. 3.B), but this reduction was not significant for *X. saxesenii* (Fig. 3.C).

Discussion

This study reports the first attempt to attract *X. compactus,* as well as other ambrosia beetles such as *X. crassiusculus* and *X. saxeseni,* to baited traps in coffee and koa plantations in Hawaii. Ethanol has been identified in extracts of wood and bark as the primary attractant of several ambrosia beetles and is responsible for increasing their attack rate (Moeck 1970, Bhagwandin 1992, Shore and Lindgren 1996). Our findings therefore are consistent with the general pattern showing attraction of ambrosia beetles to this by-product of injury to plant tissues. Eugenol and α-pinene and their synergistic effect with ethanol have been widely studied as attractants of ambrosia and bark beetles (Nakayama and Terra 1986, Schroeder and Lindelöw 1989, Czokajlo and Teale 1999). In this study *X. compactus* was significantly more attracted to ethanol than either eugenol or α-pinene, and more *X. compactus* were captured in traps baited with ethanol vials than sleeves. Several studies have

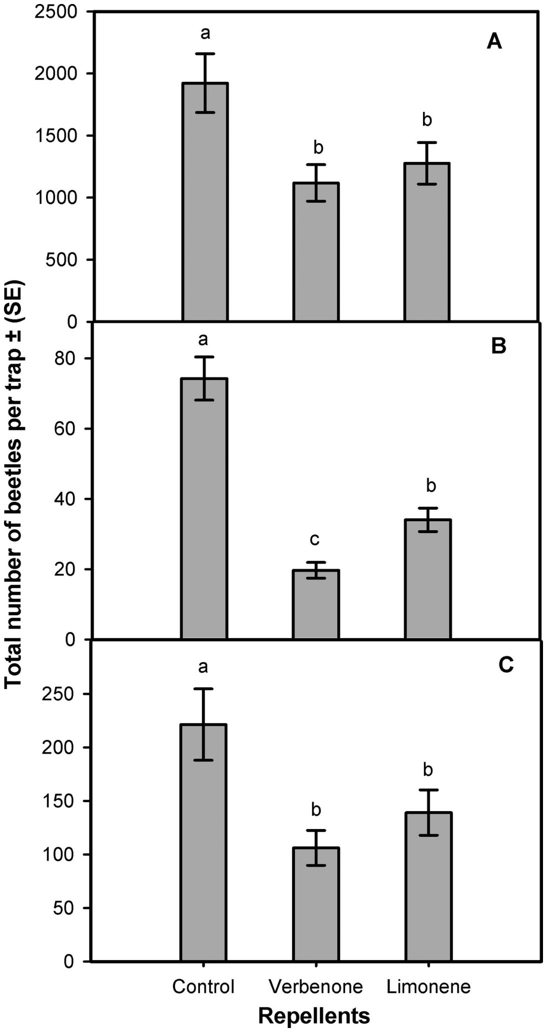

Fig. 3. Comparison of two compounds, verbenone and limonene, as repellants for *X. compactus* (A), *X. crassiusculus* (B), and *X. saxesenii* (C) in a 6-yr-old koa forest restoration stand in the Maunawili Valley on the windward side of the island of Oahu. Means followed by the same letter are not significantly different from one another at an experiment wise error rate = 0.05.

reported the attraction of scolytid species to ethanol at different concentrations and release rates (Moeck 1970, Oliver and Mannion 2001, Hoagland and Schultz 2006, Miller and Rabaglia 2009), both factors that may have affected black twig borer attraction. In our study ethanol vials were refilled during each trap clearing, and ethanol sleeves were replaced every 2 mo as recommended by the manufacturer. It is possible that ethanol vial concentrations were relatively constant throughout the experiment, while ethanol pouch concentrations degraded after a number of weeks of use, and reduced black twig borer captures resulted. Several studies have shown that increasing the release rate of ethanol increases the number of scolytines species trapped (Schroeder 1988, Joseph et al. 2001). Black twig borer has been reported to be more attracted to trees that are under stress, such as recent transplanting or drought (Hara and Beardsley 1979). However, apparently healthy coffee trees also have been observed to sustain black twig borer attack (Burbano 2010). To increase the attraction of black twig borer to traps, a high release rate of ethanol may be appropriate to simulate recently damaged branches, but a range of release rates should be tested to confirm this supposition.

Ethanol has been reported to synergize attraction with α-pinene and other attractants for some scolytine species (Czokajlo and Teale 1999, Miller and Rabaglia 2009). Although there was no significant difference among the attractants that we tested on koa plants, there was a trend toward higher numbers of beetles in traps baited with ethanol plus α-pinene and ethanol plus manuka oil. The use of these attractants combined with effective sanitation of infested trees possibly could be used to reduce ambrosia beetle populations or as bait for early detection of new pest introduction (Hanula and Sullivan 2008). Studies should be conducted to determine the optimum release rate of ethanol and the synergistic effect of these volatiles with other attractants to increase black twig borer captures. These results allow the development of an operative lure for the effective monitoring of black twig borer, although further study should be conducted to optimize release rates.

This study is the first attempt to monitor ambrosia beetles such as *X. compactus, X. crassiusculus,* and *X. saxesenii* in Hawaii and to compare two of the most common traps used in scolytine management. There was a difference in effectiveness of Japanese beetle traps and the Lindgren funnel trap in the attraction of *X. compactus, X. crassiusculus,* and *X. saxesenii.* Japanese beetle traps baited with 95% ethanol attracted more *X. compactus* and *X. crassiusculus* and the Lindgren funnel trap attracted more *X. saxesenii.* These results agree with those obtained by Flechtmann et al. (2000) for several scolytid species when evaluating ESALQ-84 trap, which is similar to the Japanese beetle trap but is black in color and has a small plate covering the trap top (Flechtmann et al. 2000). The majority of the ambrosia beetle species that we examined were captured in significantly larger numbers in Japanese beetle traps than in Lindgren funnel traps. One factor that might explain the higher trapping in the Japanese beetle trap in our study may be because the beetles that collide with the trap drop shorter distances into the collecting cup compared with the Lindgren funnel trap, where beetles have to pass through a series of funnels before reaching the collection cup. These multiple steps may allow them to spread their wings and escape (Flechtmann et al. 2000). It is also possible that visual cues may play a role, and the green color and smaller size of the Japanese beetle trap may more closely mimic the host plant than the large, black Lindgren trap. Trap efficacy also is related to lure release rate (Flechtmann et al. 2000), however in our study the ethanol vial was slightly more exposed in the Japanese beetle trap than the Lindgren funnel trap. In addition, the Lindgren funnel trap had a plate located at the top of the trap, which may have hindered the ethanol release. The results of this study confirm those obtained by Flechtmann et al. (2000) who ranked the ESALQ-84 trap as having a higher degree of exposure to ambient air with resulting higher release rates of attractants than the Lindgren trap. A lower lure diffusion of ethanol to the environment in the Lindgren trap also may explain the lower rate of capture (Flechtmann et al. 2000). Because of the relatively small differences in captures between the two traps used in our study, the Japanese beetle traps are preferred because of their compact size, durability, and low price.

Verbenone is an antiaggregation pheromone produced by several species of bark beetles (Bentz et al. 2005). Verbenone is released by colonizing beetles when the beetle population density exceeds the population that the host can support and thus these chemicals are presumed to reduce competition for resources (Lindgren and Miller 2002). Here we describe the effect of verbenone and limonene inhibiting response of three ambrosia beetles, *X. compactus, X. crassiusculus,* and *X. saxeseni,* to an attractant. Our data show that ethanol-baited Japanese beetle traps treated with verbenone significantly reduced the number of *X. compactus* and *X. crassiusculus* compared with the traps baited with ethanol. This result is consistent with the study of Bentz et al. (2005) who worked with different beetle species and demonstrated the efficacy and consistency of verbenone (84% (-)-enantiomer, 98% purity, 5.0-g pouch releasing 50 mg/d at 30°C) for protecting stands of lodge pole and whitebark pine from mountain pine beetle (*Dendroctonus ponderosae* Hopkins) attack. A dose of 40 verbenone pouches per 0.40 ha significantly reduced the number of mountain pine beetle attacked trees (Bentz et al. 2005).

Limonene was less effective than verbenone, but there was nevertheless a trend to reduce the number of beetles present in traps treated with limonene. A higher release rate of verbenone and limonene also may increase the efficacy of these repellents for *X. compactus, X. crassiusculus,* and *X. saxesenii,* but other factors may limit the effectiveness of verbenone. Surrounding landscapes may contain odors that affect verbenone's effectiveness, attracting beetles from surrounding suitable hosts (Bentz et al. 2005). This study was conducted in a koa field that was located close to potential alternate hosts for *X. compactus, X. crassiusculus,* and *Xyleborinus saxesenii.* These host plants provide breeding habitat for ambrosia beetles, and the semiochemical released from them may have interfered with the effect of verbenone and limonene. It is essential to understand that verbenone likely would not protect all trees within the treated area; some trees may still be attacked, based on the fact that only ≈50% of beetles were repelled form baited traps. Anti-attractant semiochemicals such as verbenone do not remove insects from the system; however they can be part of a management system that reduces entry by beetles into treated areas (Bentz et al. 2005). Because verbenone is presumed to be more effective in beetles that prefer fresh host tissue than aged host tissue (Lindgren and Miller 2002) it can be a potential management tool for reducing attack of beetles such as *X. compactus* that attack healthy trees. Additional studies on higher release rates of verbenone and limonene should be conducted to determine whether they can reduce the beetle population approaching *A. koa* nursery plants, and in coffee fields before the beetles reach their peak numbers.

Trap collections may indicate levels of risk for tree attack, and also may give useful data for timing of control measures. Such control measures for black twig borer in coffee trees include pruning or the use of insecticides (Mangold et al. 1977, Jones and Johnson 1996). Previous studies have shown that black twig borer occurs perennially in Kona, HI (Burbano 2010). Therefore, lures can be an important tool for monitoring adult insect populations as part of an integrated pest management (IPM) program; baited Japanese beetle traps also could serve as a physical control tactic for mass trapping.

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