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Short Communication

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Use of Digital Video Cameras to Determine the Efficacy of Two Trap Types for Capturing *Rhynchophorus palmarum* (Coleoptera: Curculionidae)

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Abstract

The efficacies of two trap types, bucket and Picusan traps, for capturing and retaining *Rhynchophorus palmarum* (L.), an invasive palm pest responsible for killing thousands of ornamental Canary Islands date palms (*Phoenix canariensis* Chabaud [Arecales: Arecaceae]) in San Diego County, CA, were compared. Digital video data were analyzed to determine how *R. palmarum* behavior toward each trap type affected capture and retention rates. Videography was conducted 24 h/d, 7 d/wk, for more than 7 mo resulting in 20,211 h of digital data for analysis. Weevil attraction to traps was observed only during daylight hours and no patterns in diel activity were found. Neither trap type tested captured 100% of weevils attracted to traps. Bucket traps suspended 1.5 m above the ground attracted 30% more weevils than ground deployed Picusan traps. Of those weevils attracted to bucket traps, 89% entered, 82% escaped, and 18% that entered traps were retained. Weevils that were not retained spent an average of 19 min 20 s entering and exiting entry holes and walking and flying around the bucket trap. By contrast, Picusan traps captured 89% of weevils that entered the trap. The time between weevils arriving (via walking or flight) on the sides of the Picusan trap and retention in the trap ranged between 90 and 376 s. These visual observations suggest that Picusan traps are more efficient than bucket traps for *R. palmarum* capture.

Key words: capture efficiency, invasive species, palm weevil, pheromone trap, videography

Rhynchophorus palmarum (L.) is a destructive palm pest native to parts of Mexico, Central and South America, and the Caribbean (Löhr et al. 2015). This weevil established in San Diego County, CA, around 2014 and has subsequently killed thousands of Canary Islands date palms, *Phoenix canariensis* Chabaud (Hoddle and Hoddle 2017). Palm mortality results from larval feeding damage to the apical meristem (Giblin-Davis 2001). Adult weevils are strong fliers and may have the capacity to disperse naturally over long distances (Hoddle et al. 2020). Semiochemically baited traps to which adult palm weevils are attracted are routinely used for monitoring incursions (Soroker et al. 2017), spread within infested areas (Goldshtein et al. 2020), population phenology (Oehlschlager 2005), and mass trapping can provide varying levels of control (Oehlschlager et al. 1995, 2002).

Adult *R. palmarum* are attracted to traps loaded with commercially available aggregation pheromone, ethyl acetate synergist, and baited with fermenting food (e.g., dates; Milosavljević et al. 2019, 2020). Two types of trap, the bucket trap (USDA-APHIS 2010) and the cone-shaped Picusan trap (ISCA Technologies, Riverside, CA), are used for trapping *R. palmarum*. The bucket trap is widely used to trap *R. palmarum*, but they may not reliably capture *R. palmarum* (Oehlschlager et al. 1993). With respect to red palm weevil, *R. ferrugineus* Olivier, the Picusan trap has proven to be as effective or superior to bucket traps for capturing weevils (Vacas et al. 2013). However, Picusan traps have not been field evaluated for *R. palmarum* capture efficacy.

No studies evaluating trap capture efficacy for palm weevils have examined the behavior of weevils attracted to traps or evaluated traps for capture efficiency, i.e., the proportion of the weevils encountering traps that are captured and retained. To address these shortcomings, we employed infrared digital video recorders (DVRs) to 1) compare the capture efficiencies of bucket versus Picusan traps for *R. palmarum* and 2) evaluate trap capture efficiencies by using behavioral observations resulting from interactions with traps. The aim of this work was to determine the number of weevils attracted to each trap type and the percentage of weevils that enter and leave traps, and of those entering traps the percentage that are captured and retained.

Materials and Methods

Experimental Site

This experiment was conducted over 15 September–13 November 2018 and 9 June–5 November 2019 at a Sweetwater Reserve in Bonita, CA. This riparian study area has hundreds of naturalized *P. canariensis*, many of which are infested with *R. palmarum*. The site was characterized by a semiarid subtropical climate with an annual rainfall of 280 mm (https://www.weather-us.com/en/california-usa/san-diego-climate).

Traps and Lures

Bucket traps were constructed from white 7.5-liter buckets wrapped in burlap (to enable weevils attracted to traps to reach entry holes by walking) with four evenly spaced 5-cm-diameter holes cut into the sides of the bucket (Hoddle 2020). Weevils attracted to bucket traps enter through these holes and are killed by drowning in propylene glycol. White buckets were used because they were readily available, and trap color (i.e., white vs yellow vs black) does not influence *R. palmarum* captures (Oehlschlager et al. 1993). Buckets were suspended on metal stakes approximately 1.5 m above the ground (Fig. 1A). In contrast, Picusan traps are designed to be placed on the ground. Picusan traps consist of a 4-liter collection base and a corrugated conical cover with a vertical entrance funnel in the top of the trap (Fig. 1C). To be captured, a weevil needs to descend 10 cm down the funnel and enter the trap via a 3-cm-diameter exit port. The pheromone lure was held in a plastic receptacle (4 cm high and 2 cm diameter) above the funnel. In all cases, traps were loaded with a commercially available *R. palmarum* aggregation pheromone (ISCA Lure IT192) and baited with 200 g of bait. Bait consisted of 100 g of Medjool dates and 7 g of baker's yeast *Saccharomyces cerevisiae* Meyen *ex* E.C. Hansen (Saccharomycetales: Saccharomycetaceae) (Kroger, Cincinnati, OH) mixed with 200 ml of water. In addition, 20 ml of ethyl acetate, a synergist, in a 25-ml plastic vial (27D × 120 70H mm; Thermo Fisher Scientific, Waltham, MA) with a 1-mm perforation in the lid was used to increase the combined attractiveness of the pheromone and bait (Vacas et al. 2014, 2017). Both trap types were filled with 700 ml of 50/50 propylene glycol–water solution to kill and preserve captured insects.

DVR System

DVRs consisted of 1) Raspberry Pi Model B computer, 2) Raspberry Pi NoIR camera, 3) two LED infrared bulbs, 4) a Raspiban operating system SD card (Raspberry Pi Foundation, Caldecote, United Kingdom), 5) a digital clock for determining date and time of observations (AB Electronics UK, Swanage, United Kingdom), and 6) a USB flash drive for data recording. The 256-Gb USB flash drive could store up to 250 h of digital recordings. DVRs were housed in a waterproof 21.6L × 14H × 6.4W cm polypropylene case (Pelican Products, Torrance, CA). DVRs were powered with four 12 V, 200 Ah rechargeable SLA AGM batteries (Universal Power Group Inc., Coppell, TX) housed in 46L × 31.1H × 29.2W cm waterproof plastic bin. The batteries were charged with 100-Watt, 12-V solar panels interconnected with Wanderer Li 30A PWM charge controllers and 1000-Watt grid-tie inverter (Renogy, Ontario, CA).

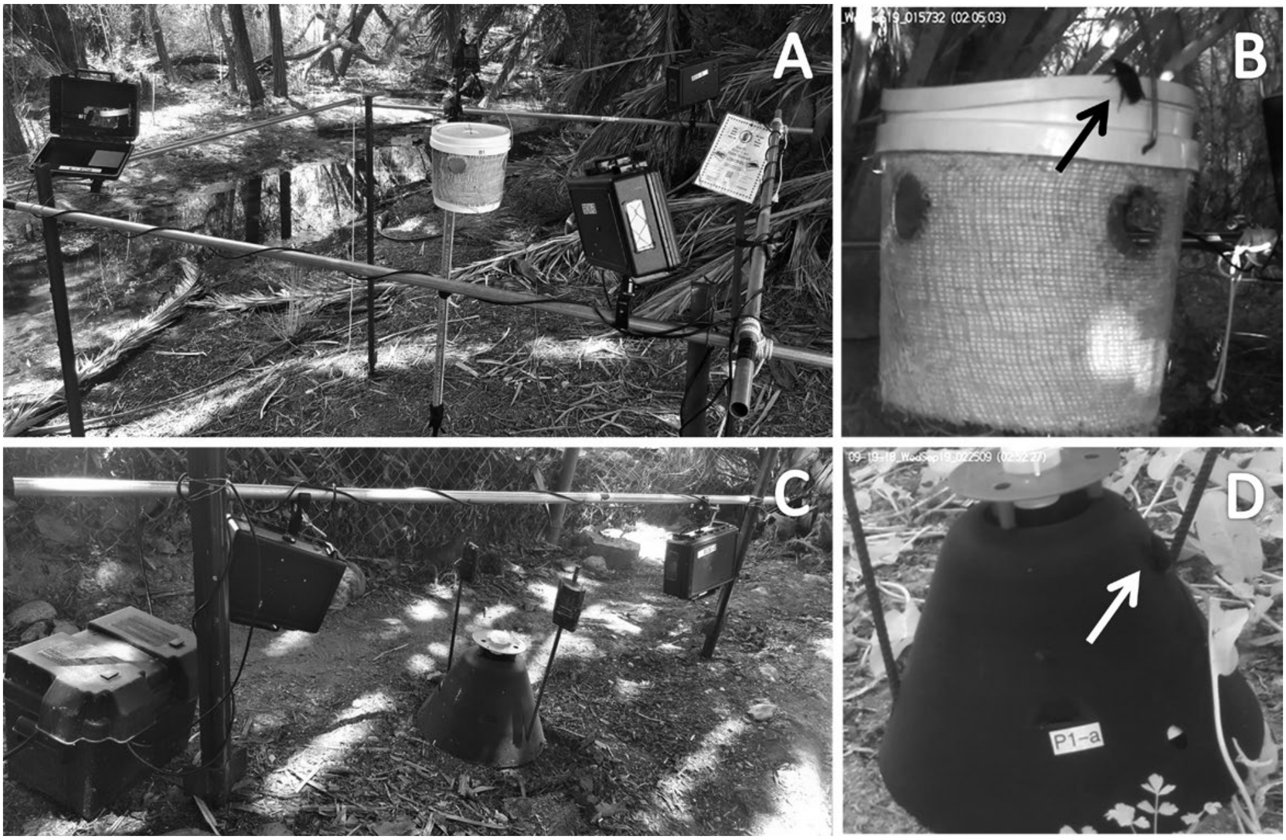

Fig. 1. Video system set up for monitoring *Rhynchophorus palmarum* attracted to bucket and Picusan traps. (A, C) Digital video arrays to record weevil activity around bucket and Picusan traps. (B, D) A single frame from a digital video recorder time lapse video with the time and date in the upper left of the images. Weevils are visible on the traps (arrows).

Trap Observations

The experiment included two blocks of two treatments: 1) bucket traps or 2) Picusan traps, for a total of four traps (i.e., one bucket and one Picusan trap in each block). Traps within a block were separated by at least 20 m and blocks were separated by at least 50 m. Bucket traps were monitored with three DVRs arranged in a triangular configuration around the trap to provide 100% coverage of all sides and entry holes. DVRs were attached to a 100-by-100 cm metal frame 1.5 m above the ground facing the trap positioned ~40 cm away (Fig. 1). Picusan traps were observed with two DVRs spaced 90 cm apart. DVRs were placed on a metal pole 0.6 m above the ground with traps set centrally between them on the ground (Fig. 1). DVRs were synchronized so that the corresponding date and time stamps from each of the recording angles corresponded to the same video frame. In total, 10 DVRs were used with this set up. Each month, lures and baits were replaced; ethyl acetate and propylene glycol were replenished. DVRs were inspected every 15 d, at which point USB flash drives were exchanged. Video data from flash drives were copied onto an external hard drive for viewing on a computer screen in the laboratory.

Video Analysis

Digital video files were watched using a VLC Media Player (version 2.2.2., Video LAN Org., Paris, France), which permitted viewing of four frames simultaneously at eight times the real speed. In total, 20,211 h of digital data were used to make counts of weevils engaging in the following behaviors: 1) approach, weevils encountering a trap. To address the independence of weevil encounters, we mandated that 30 min had to pass between observations for weevils to be considered a unique trap approach; 2) leave, weevils approached the trap but left without entering the trap; 3) enter, weevils entered trap; 4) escape, weevils leave trap through an entrance; and 5) capture, weevils entering traps that were retained. These observational data were used to construct ethograms. Additionally, time spent interacting with the trap were quantified for all weevils.

Statistical Analysis

To compare the escape and capture frequencies between bucket and Picusan traps, Fisher's exact tests with two (i.e., escape or capture) by two (i.e., trap types) contingency tables were used. Only visits from weevils that entered traps were included in analyses. Total numbers of observed captures and escapes from each trap type were summed over the entire duration of the study. Nonparametric Mann–Whitney U test Wilcoxon rank-sum tests were employed to compare the duration of weevil encounters with the two trap designs. Incomplete recordings were excluded from analyses as there were some cases of camera malfunctions over the course of the study. Weevil visits were only observed during daylight (i.e., from 0600 to 1900 h), but the visits were too infrequent to statistically analyze patterns in diel activity. All statistical analyses were performed in SAS 9.4 (SAS Institute 2013).

Results and Discussion

Picusan traps were more efficacious than bucket traps at capturing *R. palmarum* (Supp Table 1 [online only]). Studies on *R. ferrugineus* in Spain indicate that Picusan traps are 45% more effective than bucket traps for capturing this weevil (Vacas et al. 2013). The difference in the number of weevils captured in the two trap designs was related to the proportion of weevils interacting with traps that subsequently were captured and retained (Fisher's exact test: $P < 0.001$; Supp Table 1 [online only]). With bucket traps, the disparity between *R. palmarum* visits and retention was significant (Supp Table 1 [online only]; Fig. 2). Of 25 weevils that approached bucket traps, 22 (89%) entered, 18 (82%) escaped, and 4 (18%) were retained and killed (Fig. 2). These results support findings by Oehlschlager et al. (1993) and Gonzalez et al. (2019) who demonstrated that 30% of *R. palmarum* escape from bucket traps. In contrast, of the 19 weevils that approached Picusan traps, 18 (95%) entered and 16 (89%) were retained, with just two weevils (11%) escaping (Fig. 2). Previous studies indicate that cone-shaped traps, like Picusan traps, retain over 90% of weevils that enter (Gonzalez et al. 2019).

The observed differences in trap type capture efficacy of *R. palmarum* are also likely due to differences in the physical characteristics of the two trap designs (Milosavljević et al. 2020). Bucket traps have four openings that facilitate weevil ingress and egress. Data recorded here indicated that *R. palmarum* attracted to bucket traps were often not retained. Moreover, weevils frequently passed over trap entrances without entering, and if they entered, many would exit again. Videography data indicated that weevils passed over holes 96% of the time, entered 92% of the time, and then exited 75% of the time. Once inside the trap, weevils were observed through entrance holes walking on the smooth interior walls of the trap which facilitated egress following entry. Consequently, these factors combined resulted in low retention rates of weevils (Fig. 2). Additionally, weevils spent significant amounts of time (from 12 up to 27 min) moving inside and around the outside of bucket traps (Supp Table 1 [online only]). In contrast, the Picusan trap has one funnel-shaped entrance that allows ingress and this funnel design significantly reduces the probability of weevils escaping the trap (Hallett et al. 1999). In this study, Picusan traps retained 89% of weevils that entered. Weevils spent significantly less time moving around Picusan traps when compared with bucket traps (Mann–Whitney U test Wilcoxon rank-sum test: $P < 0.001$). The time between arriving at a Picusan trap and capture or escape from the trap ranged between 90 and 376 s (Supp Table 1 [online only]).

Weevil visits to traps were only observed from 0600 to 1900 h (Supp Table 1 [online only]), suggesting that *R. palmarum* flight activity might be restricted primarily to daylight hours. Flying weevils were recorded with similar frequency across all daylight hours that observations were made (Supp Table 1 [online only]). Field observations of flying *R. palmarum* in Venezuela similarly concluded that weevil flight was diurnal (Hagley 1965). Furthermore, flight mill studies with *R. palmarum* (Hoddle et al. 2020), *R. ferrugineus* (Hoddle et al. 2015), and *R. vulneratus* (Panzer) (Hoddle and

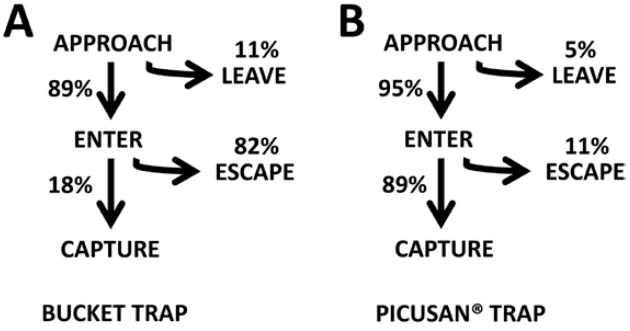

Fig. 2. Ethograms summarizing *Rhynchophorus palmarum* behaviors with respect to interactions with (A) bucket and (B) Picusan traps. Approach, leave, enter, escape, and capture and retention of *R. palmarum* were determined using digital data recorded by digital video recorders (Fig. 1). Observed approaches were unique individuals (see Supp Table 1 [online only]).

Hoddle 2016) reported that over 85% of tethered weevils flew between 0700 and 1900 h regardless of weevil species. For native and invasive populations of *R. palmarum*, visual inspections of flying weevils (Hagley 1965), activity on flight mills (Hoddle et al. 2020), and diurnal trap captures (this study) suggest a tendency for flight during daylight hours.

Overall, results presented here indicate that Picusan traps are more efficacious than bucket traps for capturing and retaining *R. palmarum*. Observations strongly suggest that trap design drives trapping efficacy. Consequently, trap-dependent programs (e.g., detection, monitoring, and population suppression) for *R. palmarum* should use Picusan traps instead of bucket traps when possible.

Supplementary Data

Supplementary data are available at *Journal of Economic Entomology* online.

Acknowledgments

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References Cited

Giblin-Davis, R. M. 2001. Borers of palms, pp. 267–304. *In* F. W. Howard, D. Moore, R. M. Giblin-Davis, and R. G. Abad (eds.), Insects on palms. Commonwealth Agricultural Bureau (CAB) International, Oxfordshire, United Kingdom.

Goldshtein, E., Y. Cohen, A. Hetzroni, Y. Cohen, and V. Soroker. 2020. The spatiotemporal dynamics and range expansion of the red palm weevil in Israel. J. Pest Sci. 93: 691–702.

Gonzalez, F., S. Kharrat, C. Rodríguez, C. Calvo, and A. C. Oehlschlager. 2019. Red palm weevil (*Rhynchophorus ferrugineus* Olivier): recent advances. Arab J. Plant Protect. 37: 178–187.

Hagley, E. A. C. 1965. On the life history and habits of the palm weevil, *Rhynchophorus palmarum*. Ann. Entomol. Soc. Am. 58: 22–28.

Hallett, R. H., A. C. Oehlschlager, and J. H. Borden. 1999. Pheromone trapping protocols for the Asian palm weevil, *Rhynchophorus ferrugineus* (Coleoptera: Curculionidae). Int. J. Pest Manage. 45: 231–237.

Hoddle, M. S. 2020. Biology and management of South American palm weevil, *Rhynchophorus palmarum* (L.) (Coleoptera: Curculionidae), in California. (https://cisr.ucr.edu/sites/g/files/rcwecm2631/files/2020-02/palm-weevil-bucket-trap.pdf) (accessed 10 May 2020).

Hoddle, M. S., and C. D. Hoddle. 2016. How far can the palm weevil, *Rhynchophorus vulneratus* (Coleoptera: Curculionidae), fly? J. Econ. Entomol. 109: 629–636.

Hoddle, M. S., and C. D. Hoddle. 2017. Palmageddon: the invasion of California by the South American palm weevil is underway. CAPCA Adviser 20: 40–44.

Hoddle, M. S., C. D. Hoddle, J. R. Faleiro, H. A. El-Shafie, D. R. Jeske, and A. A. Sallam. 2015. How far can the red palm weevil (Coleoptera: Curculionidae) fly? Computerized flight mill studies with field-captured weevils. J. Econ. Entomol. 108: 2599–2609.

Hoddle, M. S., C. D. Hoddle, and I. Milosavljević. 2020. How far can *Rhynchophorus palmarum* (Coleoptera: Curculionidae) fly? J. Econ. Entomol. 113: 1786–1795.

Löhr, B., A. A. Vásquez-Ordóñez, and L. A. Becerra Lopez-Lavalle. 2015. *Rhyncophorus palmarum* in disguise: undescribed polymorphism in the 'black' palm weevil. PLoS One 10: e0143210.

Milosavljević, I., H. A. F. El-Shafie, J. R. Faleiro, D. A. Hoddle, and M. S. Hoddle. 2019. Palmageddon: the wasting of ornamental palms by invasive palm weevils, *Rhynchophorus* spp. J. Pest Sci. 92: 143–156.

Milosavljević, I., C. D. Hoddle, A. Mafra-Neto, F. Gómez-Marco, and M. S. Hoddle. 2020. Effects of food bait and trap type on captures of *Rhynchophorus palmarum* (Coleoptera: Curculionidae) and trap bycatch in Southern California. J. Econ. Entomol. (in press). doi:10.1093/jee/toaa175

Oehlschlager, A. C. 2005. Current status of trapping palm weevils and beetles. Planter 81: 123–143.

Oehlschlager, A. C., C. M. Chinchilla, L. M. Gonzalez, L. F. Jiron, R. Mexzon, and B. Morgan. 1993. Development of a pheromone-based trapping system for *Rhynchophorus palmarum* (Coleoptera: Curculionidae). J. Econ. Entomol. 86: 1381–1392.

Oehlschlager, A. C., R. S. McDonald, C. M. Chinchilla, and S. N. Patschke. 1995. Influence of a pheromone-based mass-trapping system on the distribution of *Rhynchophorus palmarum* (Coleoptera: Curculionidae) in oil palm. Environ. Entomol. 24: 1005–1012.

Oehlschlager, A. C., C. Chinchilla, G. Castillo, and L. Gonzalez. 2002. Control of red ring disease by mass trapping of *Rhynchophorus palmarum* (Coleoptera: Curculionidae). Fla. Entomol. 85: 507–513.

SAS Institute. 2013. SAS/STAT user's guide 9.4, 2nd ed. SAS Institute, Cary, NC.

Soroker, V., P. Suma, A. La Pergola, V. N. Llopis, S. Vacas, Y. Cohen, Y. Cohen, V. Alchanatis, P. Milonas, O. Golomb, and E. Goldshtein. 2017. Surveillance techniques and detection methods for *Rhynchophorus ferrugineus* and *Paysandisia archon*, pp. 209–232. *In* V. Soroker and S. Colazza (eds.), Handbook of major palm pests: biology and management. Wiley-Blackwell, Chichester, United Kingdom.

Vacas, S., J. Primo, and V. Navarro-Llopis. 2013. Advances in the use of trapping systems for *Rhynchophorus ferrugineus* (Coleoptera: Curculionidae): traps and attractants. J. Econ. Entomol. 106: 1739–1746.

Vacas, S., M. Abad-Payá, J. Primo, and V. Navarro-Llopis. 2014. Identification of pheromone synergists for *Rhynchophorus ferrugineus* trapping systems from *Phoenix canariensis* palm volatiles. J. Agric. Food Chem. 62: 6053–6064.

Vacas, S., O. Melita, A. Michaelakis, P. Milonas, R. Minuz, P. Riolo, M. K. Abbass, P. Lo Bue, S. Colazza, E. Peri, *et al.* 2017. Lures for red palm weevil trapping systems: aggregation pheromone and synthetic kairomone. Pest Manag. Sci. 73: 223–231.