Influence of Trap Type, Size, Color, and Trapping Location on Capture of *Rhabdoscelus obscurus* (Coleoptera: Curculionidae)

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ABSTRACT The New Guinea sugarcane weevil, *Rhabdoscelus obscurus*) (Boisduval) (Coleoptera: Curculionidae), is a pest of palm plantations, ornamental nurseries, and sugarcane (*Saccharum* L.). Field and laboratory studies have explored the effects of trap characteristics such as design, size, color, visual and olfactory cues, and location on capture of *R. obscurus* in date palm plantations and ornamental nurseries at five locations (Dededo, Mangilao, Malojloj, Inarajan, and Yigo) on Guam, USA. Ramp and ground traps captured similarly, and both captured significantly more adults than bucket and pitfall traps. For economy and ease of handling, the ground trap was used for all further experiments. Larger ground traps (≥40 by 25 cm) were more efficient than smaller traps (30 by 15 cm) in capturing adults in the field. Of the eight trap colors tested in the field, brown proved most effective, followed by, in order, yellow, red, gray, blue, black, white, and green; russet was more effective than other shades of brown. Mixing paint of the other colors with brown paint did not significantly improve its performance. In contrast, laboratory color-choice tests indicated *R. obscurus* preferred black traps over those of other colors and showed no preferences among different shades of black. Again, mixing paint of the other colors with black paint did not significantly improve their performance. Russet brown ground traps baited with pheromone lures caught significantly more adults than did identical traps without lures. Traps strapped to trees caught significantly more individuals than traps placed between trees or away from trees. Russet-brown ground traps 40 by 25 cm seemed to be the most effective at catching *R. obscurus* in the field, whereas otherwise identical black-colored traps were more efficient indoors.

KEY WORDS *Rhabdoscelus obscurus*, Coleoptera, Curculionidae, trap characteristics, trapping location

The New Guinea sugarcane weevil, *Rhabdoscelus obscurus* (Boisduval) (Coleoptera: Curculionidae), is a very serious pest of ornamental palms and coconut, *Cocos nucifera* L., plantations in the Mariana Islands and other Pacific islands (Muniappan et al. 2004). Its incidence is so high on ornamental nursery plants, betel nut (*Areca catechu* L.), and coconut that several growers have given up cultivation in frustration (Reddy et al. 2005a). Incidence is extremely high during the hot and dry season. Even small populations of this weevil can cause severe damage, and they are a year-round pest in warm climates (Sallam et al. 2004).

Adult female borers chew a 3-mm-deep cavity into the sugarcane (*Saccharum* L.) stalk or trunks of other host trees, usually in existing adult feeding scars or cracks and occasionally at internodes or near the base

of leaf sheaths (Napompeth et al. 1972). On palms, weevils lay their eggs in the petiole and on the stem. Larvae bore into the living tissue, producing frass-filled tunnels that weaken the affected parts of the host plant and permit invasion of fungal and bacterial pathogens. Mature larvae pupate in cocoons made of plant fibers close to the exit holes (Halfpapp and Storey 1991). Currently, this weevil poses a serious threat to ornamental palms in the nursery industry and to betel nut production in Guam. Withdrawal of the prohibition by the Food and Drug Administration on the entry of betel nuts into the U.S. mainland from Guam has encouraged commercial cultivation of the betel nut in Guam.

Because the weather in Micronesia is mostly humid and hot throughout the year, *R. obscurus* infestation has been very severe (Bianchi and Owen 1965). Guam and other Micronesian islands are therefore in the midst of a decline in nursery and ornamental plant production. According to feedback from local farmers and homeowners in the region, extension faculty of the University of Guam, and unpublished data by the

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senior author, thousands of ornamental nursery and betel-nut plants are dying as a result of *R. obscurus* infestation. Recently, *R. obscurus* has begun attacking coconut palms. Although some control methods exist, chemical application is both undesirable and expensive (Robertson and Webster 1995). In the absence of appropriate, effective control, these *R. obscurus* populations are likely to cause widespread or even complete loss of nursery and betel nut production in Micronesia. Although a parasitoid, *Lixophaga sphenophori* (Villeneuve) (Diptera: Tachinidae), from Maui (Hawaii) was introduced on Guam in 2005 for the control of *R. obscurus,* it seems not to be established yet. Farmers, homeowners, and commercial firms in this region apply insecticides (Dimethoate, Acephate, Carbaryl, Malathion, Naled, and λ-cyhalothrin) up to 20–30 times per cropping period, particularly in ornamental nurseries, these costly measures have been associated with ecological and toxicological hazards. Ecologically sound and cost-effective semiochemical (pheromone)-based trapping methods must therefore be developed, implemented, and adopted by growers.

Both male and female *R. obscurus* produce a pheromone only when fed on sugarcane (Chang and Curtis 1972). These authors further reported that virgin males 4–6-d-old fed on sugarcane produced a pheromone that attracted only females, but the same males at 12–16 d old attracted both sexes. Giblin-Davis et al. (2000) identified the pheromone of Hawaiian *R. obscurus* as 2-methyl-4-octanol and the equivalent pheromone compounds for Australian *R. obscurus* population as 2-methyl-4-octanol, (*E*)-6-methyl-2-hepten-4-ol (rhynchophorol), and 2-methyl-4-heptanol, but 2-methyl-4-heptanol was not included in their trapping method for *R. obscurus* because it elicited no behavioral effect.

Giblin-Davis et al. (1996) reported that baits of ≈3 mg/d synthetic pheromone in combination with insecticide-treated plant tissue were highly attractive to palm weevils, including *R. obscurus.* In our previous study, traps baited with lures from the Australian geographical population caught significantly more weevils than traps baited with lures from the Hawaiian *R. obscurus* population, suggesting that the Guam population is reacting similarly to the Australian population lures (Muniappan et al. 2004). Moreover, this population is predominantly present in the north because the majority of the commercial nurseries are located there. We also observed in that study that addition of ethyl acetate to the pheromone lures as a synergist significantly increased trap catches of *R. obscurus* but that the pheromone-based trapping method we previously developed resulted in poor catches and did not help in controlling *R. obscurus* (Reddy et al. 2005a).

Few data are available on the monitoring of *R. obscurus* with pheromone traps, so improving trap performance and making traps more reliable tools for integrated control programs will require characterizing the factors that affect trap capture efficiency. The purpose of the study reported here was to determine the effects of trap design, size, color, and location so

as to develop an efficient pheromone-based trapping method for controlling *R. obscurus* on Guam and in other parts of world.

Materials and Methods

Experimental Field Sites. The experiments were carried out on the island of Guam at five locations: Bob's Nursery, Dededo (13.52° N, 144.84° E); Landscape Management Systems, Mangilao (13.43° N, 144.80° E); The Green Thumb Plant Nursery, Malojloj (13.39° N, 144.45° E); and the University of Guam's Agricultural Experiment Stations (AES), Inarajan (13.15° N, 144.30° E) and Yigo (13.54° N, 144.89° E). The prevailing temperature, relative humidity, and wind velocity were recorded during the experimental period. A large part of the land area of these locations is covered entirely by ornamental nurseries and plantation palms (predominantly date palms) that were used for our experiments.

Trap Designs. A commercially available ramp trap and three other locally fabricated trap types (ground, bucket, and pitfall) were evaluated (Fig. 1).

The ramp trap used was commercially available from ChemTica Internacional S.A. (San José, Costa Rica). It was made of durable yellow Perspex and consisted of two box-shaped components, each 14 cm wide by 4 cm high (inside dimensions); one open side up, forming the floor of the trap and the other open side down, forming its roof and supported on short pillars at the corners (Reddy 2007). Wide Perspex ramps on all four sides led up to the rim of the lower box, which rested on the ground. The pheromone lure and ethyl acetate were attached to the ceiling of the trap with a piece of vinyl-clad steel wire (the same type of wire used in all trap types), and two cut pieces of sugarcane were placed inside the trap. The floor of the trap was treated with a 5-ml spray of malathion.

The ground trap was constructed in our laboratory from a 120- by 60- by 0.5-cm piece of white corrugated plastic board, with a 50- by 8-cm slitted baffle fitted at the top to prevent borers from escaping (Reddy et al. 2005b). The lower outer edges of the ground traps were shielded with soil to prevent weevils from crawling under the traps. The pheromone and ethyl acetate (*Rhynchophorus palmarum* lure) lures were suspended inside the traps on wires hung from the top. Two cut pieces of sugarcane (12 cm in length) were placed directly in the ground trap and replaced with fresh canes weekly. The inside bottom of the trap was treated with a 5-ml spray of malathion (2.0 ml/liter) to kill the attracted *R. obscurus.* Lures were changed at 4-mo intervals (Reddy et al. 2005a).

Pitfall traps were cylindrical, translucent white plastic cups (10 cm in diameter, 1.5-liter capacity) (Reddy et al. 2009). Four 24-mm drainage holes were drilled at 90° intervals in the sides of the cup, at least 5 cm above the bottom. The pheromone and ethyl acetate lures was suspended from the top of the cup on a wire (12 cm in length) threaded through a 3-mm hole. The floor of the trap was treated with a 5-ml spray of malathion, and two fresh sugarcane sections were
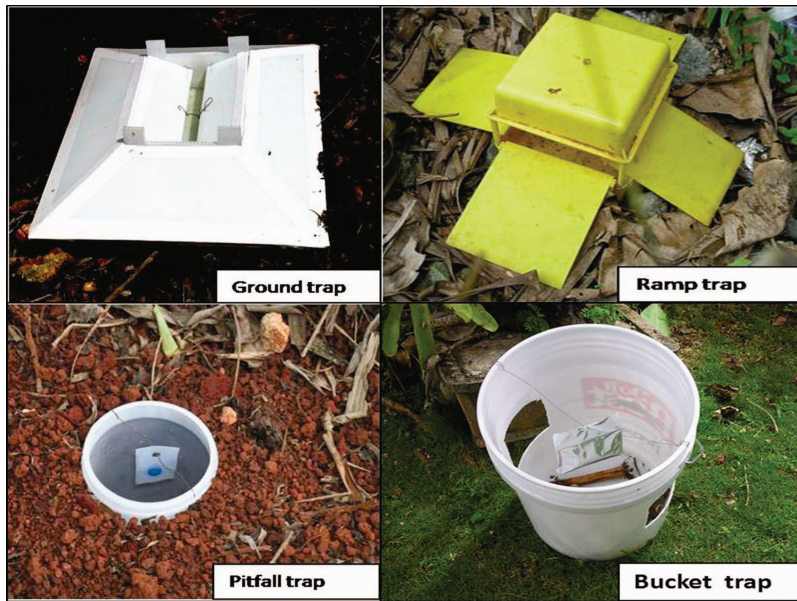
Fig. 1. Four trap designs used in the current study. (Online figure in color.)

placed in the trap. The traps were placed in 10-cm-deep holes into the ground, so that the upper edge of the cup was at the level of the soil surface.

Each plastic bucket trap consisted of a 19.0-liter white plastic tapered container (37.0 cm in height by 30.0 cm i.d. base; Reddy et al. 2005a). Two holes (17.5 cm in height and 7.5 cm in width) were cut in opposite sides of the container (14.75 cm above the soil surface) to allow weevil entry into the trap. Twenty drainage holes (each 3 mm in diameter) were made in the floor. A pheromone and ethyl acetate lure was suspended in the trap from wires attached to opposite sides of the rim. Two fresh sugarcane sections were placed directly in the bucket trap, and the floor of the trap was treated with a 5-ml spray of malathion.

Semiochemical Lures. The pheromone and ethyl acetate lures were stored in a refrigerator until use. The pheromone lures—(E2)-6-methyl-2-hepten-4-ol and 2-methyl-4-octanol—were sealed in polymer membrane release devices optimized for the Australian population of *R. obscurus.* The release rates and method of use of these lures were as described previously (Reddy et al. 2005a).

Effect of Trap Design on Captures of Adult *R. obscurus*. Ground, ramp, pitfall, and bucket traps of white color with pheromone and ethyl acetate lures were placed at the five locations ≈10 m apart on the ground in ornamental nurseries (four of each trap type were deployed and separated by 10 m at each location). Trapped *R. obscurus* were counted and removed weekly. The traps were washed and rinsed, and new fresh cut sugarcane was added. The traps were randomized across each field to preclude any possible local location effect. Concurrently, traps without lures and sugarcane were used as controls. The experiment was carried out from June to September 2008.

Effect of Trap Size on Captures of Adult *R. obscurus*. The effectiveness of four different sizes of ground traps (60 by 40, 50 by 30, 40 by 25, and 30 by 15 cm) was compared. In each field site, one trap of each size was set up, and their locations were rotated every week to preclude any local location effect. The experiment was conducted from October to December 2008.

Effect of Trap Color on Captures of Adult *R. obscurus*. Trap-color characteristics were determined using a Konica Minolta CR-410 chromometer (Minolta Instrument Systems, Ramsey, NJ). L* indicates a measure of "lightness" that runs through the median of the color-scale chart, where 100 (at the top) represents white, and 0 (at the bottom) represents black. The a* axis, which runs from left to right on the color chart, indicates a red shade when greater than zero (positive) and a green shade when lower than zero (negative). Similarly, the b* axis runs vertically through the color chart indicates a yellow shade when positive and a blue shade when negative (Wrolstad et al. 2005). The hue angle is expressed on a 360° grid on which 0° is red, 90° is yellow, 180° is green, and 270° is blue. Trap color measurement values are given in Tables 1–5.

Because *R. obscurus* attacks plants both indoors and outdoors, we carried out four field and two laboratory experiments. Paint of eight commercially available colors (BEHR Process Corporation, Santa Ana, CA) was purchased locally from Home Depot. Four traps of each color were grouped together at each of the five locations listed under Experimental Field Sites.

For the first field experiment, ground traps (40 by 25 cm) were painted blue (Sailboat: S-H-590), yellow (Sunny Summer: S-G-380), gray (Beluga: 770 F-7), green (Pine Grove: 460B-7), brown (Bear Rug: S-G-

Table 1. Color measurements of traps

Trap color	L*	a*	b*	Chroma (C)	Hue angle (h°)
Black	30.44 ± 0.06	0.42 ± 0.03	−1.08 ± 0.04	1.16 ± 0.05	
Brown	35.26 ± 0.18	3.98 ± 0.03	3.94 ± 0.02	5.60 ± 0.03	44.66 ± 0.11
Gray	39.83 ± 0.11	−0.17 ± 0.02	−2.23 ± 0.01	2.24 ± 0.01	85.64 ± 0.47
Yellow	82.57 ± 0.02	−2.92 ± 0.03	84.02 ± 0.27	84.07 ± 0.27	91.99 ± 0.02
Red	42.84 ± 0.11	49.88 ± 0.28	19.44 ± 0.20	53.54 ± 0.34	21.29 ± 0.09
White	92.29 ± 0.03	1.34 ± 0.01	−2.59 ± 0.04	2.91 ± 0.03	
Green	43.50 ± 0.08	−27.32 ± 0.03	1.72 ± 0.09	27.37 ± 0.03	176.39 ± 0.19
Blue	36.02 ± 0.10	15.19 ± 0.10	−35.82 ± 0.12	38.91 ± 0.14	292.98 ± 0.08

Means ± SD were generated from three observations. L* indicates a measure of "lightness" that runs through the center of the color chart, where 100 at the top represents white and zero at the bottom represents black. The a* axis, which runs left to right on the color chart, indicates a red shade when greater than zero (positive) and a green shade when lower than zero (negative). Similarly, the b* axis, which runs vertically through the color chart, indicates a yellow shade when positive and a blue shade when negative.

790), red (Pure Red: 2-8610), white (Ultra-Pure White: 2-9-850), or black (Pure Black: 2-8620) (Table 1). The experiment was carried out from January to March 2009.

For the second field experiment, ground traps of the same size were painted with (1:1) mixtures of brown with each of the other colors. Traps colored with unmixed brown paint served as controls. Color measurements for the mixed color traps are given in Table 2. The experiment was carried out from April to June 2009.

For the third field experiment, 40- by 25-cm ground traps were painted with different shades of brown— dark brown, mahogany brown, russet brown, saddle brown, and light brown—were evaluated. Color measurement values for the different shades of brown are given in Table 3. The shades were tested individually (five traps per shade; one trap per location) at the same five field sites. The experiment was conducted from September to November 2009.

The three indoor experiments on trap color were conducted in a laboratory (10 m in length by 6 m in width by 3.5 m in height. Because *R. obscurus* is known to be nocturnal (Napompeth et al. 1972), the field-collected adults were fed and reared under a reverse photoperiod for 2 wk before starting the experiment in the laboratory. This was to facilitate experiments during the daytime. The tests were run in a dimly lighted laboratory between 1200 and 1730 hours with 40- by 25-cm ground traps of different colors, baited with pheromone and ethyl acetate lures. The trap to be tested was placed on the floor of the laboratory 2 h before the release of the adults, so that pheromone and

ethyl acetate vapors could spread throughout the laboratory. Forty adults were then released into the laboratory, ≈3 m from the trap. The number of adults trapped during the succeeding 3 h was recorded. Trapped beetles were removed after capture and discarded. Uncaptured insects were removed before the next trial, and we used fresh adults for each replicate to avoid pseudoreplication.

For the first indoor experiment, brown, black, gray, yellow, red, white, green, and blue trap colors (Table 1) were tested individually (eight replicates, 40 insects per color). The experiment was carried out from June to July 2009. For the second indoor experiment, the traps were painted with (1:1) mixtures of black with each of the other colors. Measurement values for the colors blended with black are given in Table 4. Pure black traps served as controls (10 replicates, 40 insects per color). The experiment was carried out in July 2009. For the reason that black traps caught significantly ($P < 0.05$) more adults than other-colored traps indoors, different shades of black (100% black, mixed black, black medium, black thick) were evaluated in the third indoor experiment. Here, 40- by 25-cm ground traps were painted with four different shades of black. Color measurement values for different shades of black are given in Table 5. The shades were tested individually (four replicates, 40 insects per shade). The method of adult releases and capture was followed as described in the previous experiment. The experiment was conducted in July–August 2009.

Relative Effects of Visual and Olfactory Cues. To determine the comparative importance of the visual and olfactory components of attraction, we com-

Table 2. Color measurements of paint colors mixed with brown (1:1) used on ground traps

Trap color	L*	a*	b*	Chroma (C)	Hue angle (h°)
Gray/brown	53.01 ± 0.02	8.59 ± 0.20	5.44 ± 0.06	10.16 ± 0.20	32.36 ± 0.32
Yellow/brown	45.90 ± 0.46	4.17 ± 0.34	19.81 ± 0.26	20.25 ± 0.32	78.12 ± 0.80
Red/brown	39.11 ± 0.11	22.40 ± 0.25	11.19 ± 0.07	25.04 ± 0.25	26.55 ± 0.12
White/brown	67.07 ± 0.07	10.22 ± 0.02	5.95 ± 0.03	11.83 ± 0.03	30.21 ± 0.07
Green/brown	36.23 ± 2.69	−7.12 ± 0.05	4.83 ± 0.04	8.61 ± 0.06	
Blue/brown	34.11 ± 0.06	−1.09 ± 0.03	−1.45 ± 0.01	1.81 ± 0.01	53.07 ± 0.82

Means ± SD were generated from three observations. L* indicates a measure of "lightness" that runs through the center of the color chart, where 100 at the top represents white and zero at the bottom represents black. The a* axis, which runs left to right on the color chart, indicates a red shade when greater than zero (positive) and a green shade when lower than zero (negative). Similarly, the b* axis, which runs vertically through the color chart, indicates a yellow shade when positive and a blue shade when negative.

Table 3. Color measurements of the different shades of brown

Trap color	L*	a*	b*	Chroma (C)	Hue angle (h°)
Dark brown	35.26 ± 0.18	3.98 ± 0.03	3.94 ± 0.02	5.60 ± 0.03	44.66 ± 0.06
Mahogany brown	35.91 ± 0.01	5.44 ± 0.02	4.35 ± 0.03	6.97 ± 0.03	38.65 ± 0.13
Russet brown	38.99 ± 0.03	11.37 ± 0.05	9.00 ± 0.01	14.51 ± 0.03	38.37 ± 0.07
Saddle brown	48.37 ± 0.01	9.25 ± 0.06	20.62 ± 0.02	22.60 ± 0.03	65.83 ± 0.10
Light brown	61.13 ± 0.03	4.50 ± 0.02	21.87 ± 0.02	22.33 ± 0.01	78.38 ± 0.03

Means ± SD were generated from three observations. L* indicates a measure of "lightness" that runs through the center of the color chart, where 100 at the top represents white and zero at the bottom represents black. The a* axis, which runs left to right on the color chart, indicates a red shade when greater than zero (positive) and a green shade when lower than zero (negative). Similarly, the b* axis, which runs vertically through the color chart, indicates a yellow shade when positive and a blue shade when negative.

pared the efficacy of russet brown 40- by 25-cm ground traps either baited with pheromone lures or unbaited. Four traps of each treatment were deployed at each of the same five field sites, and the experiment was carried out from December 2009 to February 2010.

Effect of Trap Location on Captures of Adult *R. obscurus*. Russet brown 40- by 25-cm ground traps baited with pheromone and ethyl acetate lures were placed on the ground but were either strapped (with wire) to betel nut trees, placed on the ground between trees, or placed on the ground 10 m from the nearest tree. Each treatment was replicated four times at each field site, and the experiment was conducted from March to May 2010.

Statistical Analysis. The data were analyzed with the generalized linear mixed model procedure of SAS version 9.13 (SAS Institute 2009). Because all the response variables used in the experiments were counts, a two-way analysis of variance (ANOVA) was done to see whether there was any effect of trap design, lure, or both, and a one-way Poisson ANOVA model was fitted by The GLIMMIX Procedure to analyze the data from all other experiments. For the comparisons of the means, the least square means test was used to make multiple comparisons for significant differences between treatments at $P = 0.05$.

Results

Effect of Trap Design on Captures of Adult *R. obscurus*. Traps of all the designs tested, baited with pheromone lures, captured *R. obscurus*, but designs differed in capture rate. Ramp and ground traps captured significantly more *R. obscurus* than bucket and pitfall traps ($F = 37.4$; df = 2, 33; $P < 0.005$) (Fig. 2), and bucket traps caught significantly more than did pitfall traps. Traps without lures captured no adults. During the experimental period, the average temperature was 27.0°C, the average relative humidity 65–80%, and the average wind velocity 5.6 m/s. Although ground and ramp traps were equally effective, the ground trap was selected for all further experiments because it is less expensive and more easily fabricated.

Effect of Trap Size on Captures of Adult *R. obscurus*. Ground traps (30 by 15 cm) caught significantly fewer adult *R. obscurus* (6.6 ± 0.8 adults per trap) than did the three larger sizes (mean of 10.1 ± 0.4, 11.2 ± 1.2, and 10.4 ± 0.7 adults per trap for 60 by 14, 50 by 30, and 40 by 25 cm, respectively), and values did not differ significantly from one another ($F = 4.3$; df = 3, 44; $P < 0.05$) (Fig. 3). During the experimental period, the average temperature was 28.4°C, relative humidity 65–80%, and wind velocity 4.3 m/s. For economy and ease of handling, 40- by 25-cm traps were chosen for further study.

Effect of Trap Color on Captures of Adult *R. obscurus*. In the field experiments, brown ground traps were most attractive to *R. obscurus* ($F = 4.4$; df = 7, 88, $P < 0.01$) (Fig. 4), catching, on average, 11.4 ± 1.3 adults per trap, significatchly more than traps of any of the other colors tested. No significant differences were observed among the other colors. During the experimental period, the average temperature was 27.8°C, the relative humidity 65–80%, and the wind velocity 2.6 m/s.

Table 4. Color measurements of paint colors mixed with pure black (1:1) used on ground traps

Trap color	L*	a*	b*	Chroma (C)	Hue angle (h°)
Red/black	33.80 ± 0.02	1.75 ± 0.01	2.45 ± 0.02	3.01 ± 0.01	54.42 ± 0.40
White/black	49.21 ± 0.05	−1.04 ± 0.01	−1.82 ± 0.01	2.10 ± 0.01	60.38 ± 0.12
Yellow/black	34.60 ± 0.10	−2.61 ± 0.02	3.19 ± 0.05	4.12 ± 0.04	
Blue/black	31.67 ± 0.48	−0.19 ± 0.02	0.66 ± 0.03	0.68 ± 0.02	
Gray/black	38.67 ± 0.12	−0.49 ± 0.02	−1.02 ± 0.03	1.13 ± 0.02	64.48 ± 1.24
Green/black	33.09 ± 0.13	−0.92 ± 0.01	0.77 ± 0.04	1.20 ± 0.03	
Mix black/black	32.48 ± 0.05	−0.16 ± 0.02	0.81 ± 0.04	0.82 ± 0.04	
Brown/black	33.41 ± 0.14	−0.36 ± 0.02	1.10 ± 0.02	1.15 ± 0.02	
Pure black	32.75 ± 0.24	−0.18 ± 0.03	0.72 ± 0.03	0.74 ± 0.02	
Mix black	31.89 ± 0.03	−0.12 ± 0.02	0.95 ± 0.02	0.96 ± 0.02	

Means ± SD were generated from three observations. L* indicates a measure of "lightness" that runs through the center of the color chart, where 100 at the top represents white and zero at the bottom represents black. The a* axis, which runs left to right on the color chart, indicates a red shade when greater than zero (positive) and a green shade when lower than zero (negative). Similarly, the b* axis, which runs vertically through the color chart, indicates a yellow shade when positive and a blue shade when negative.

Table 5.　Color measurements of the different shades of black

Trap color	L*	a*	b*	Chroma (C)	Hue angle (h°)
Pure black	32.75 ± 0.24	−0.18 ± 0.03	0.72 ± 0.03	0.74 ± 0.02	
Mix black	31.89 ± 0.03	−0.12 ± 0.02	0.95 ± 0.02	0.96 ± 0.02	
Black medium	30.44 ± 0.06	0.42 ± 0.03	−1.08 ± 0.04	1.16 ± 0.05	
Black thick	33.8 ± 0.1	7.6 ± 0.2	−5.4 ± 0.1	9.28 ± 0.1	

Means ± SD were generated from three observations. L* indicates a measure of "lightness" that runs through the center of the color chart, where 100 at the top represents white and zero at the bottom represents black. The a* axis, which runs left to right on the color chart, indicates a red shade when greater than zero (positive) and a green shade when lower than zero (negative). Similarly, the b* axis, which runs vertically through the color chart, indicates a yellow shade when positive and a blue shade when negative.

Mixing brown paint with the other colors did not improve the catch rates ($P < 0.05$). Traps of unmixed brown captured significantly more weevils than the traps with mixed colors ($F = 11.2$; df = 7, 88; $P < 0.05$) (Fig. 5). During the experimental period, the average temperature was 30.4°C, relative humidity 65–80%, and wind velocity 6.8 m/s.

Effect of Shades of Brown. The shade of brown significantly affected adult catches in ground traps ($F = 11.2$; df = 4, 46; $P < 0.01$) (Fig. 6) in the field. Russet brown traps caught significantly more adult weevils (10.6 ± 0.6 adults per trap) than did other shades. Mahogany and light brown did not differ significantly in the numbers caught, whereas dark brown and saddle brown traps caught significantly fewer than the other shades (2.6 ± 0.3 and 2.5 ± 0.6 adults per trap, respectively). During the experimental period, the average temperature was 27.7°C, relative humidity 80–85%, and wind velocity 5.2 m/s.

In the indoor experiments, black ground traps were more attractive to *R. obscurus* than traps of any other color tested ($F = 8.7$; df = 7, 98; $P < 0.001$) (Fig. 7), catching, on average, 13.5 ± 1.8 adults per trap, significantly more than brown traps (8.8 ± 0.7 adults per trap), the second most preferred. Brown traps differed significantly ($P < 0.001$) from red traps; red, gray, blue,

white, yellow, and green traps did not differ significantly.

Mixing black paint with paint of other colors did not significantly improve ($P > 0.05$) those colors' trapping effectiveness. Traps painted with pure black, mix black, or mix black mixed with pure black captured significantly higher numbers of adults than those painted with the other mixtures ($F = 13.4$; df = 3, 46; $P < 0.01$) (Fig. 8).

Effect of Shades of Black. In the indoor experiment, no significant difference in catches was observed between traps of different shades of black ($P > 0.05$; data not shown). During all the indoor experimental periods, the average temperature was 25.8°C, relative humidity was 80–85%, and wind velocity was 0.5 m/s.

Effects of Visual and Olfactory Cues. Russet brown ground traps baited with pheromone lures caught significantly more adults (10.5 ± 0.4 adults per trap) than did identical traps without such lures (3.5 ± 0.1 adults per trap) ($F = 42.3$; df = 1, 22; $P < 0.05$) (Fig. 9). During the experimental period, the average temperature was 27.3°C, relative humidity was 80–85%, and wind velocity was 3.7 m/s.

Effect of Trap Location on Captures of Adult *R. obscurus*. Russet brown ground traps baited with pheromone lures strapped to trees caught significantly more adult weevils than identical traps placed between trees or away from trees ($F = 7.4$; df = 1,20; $P <$
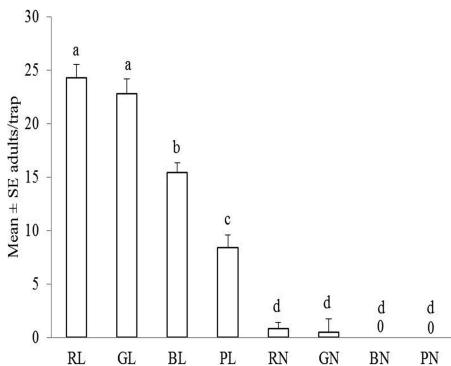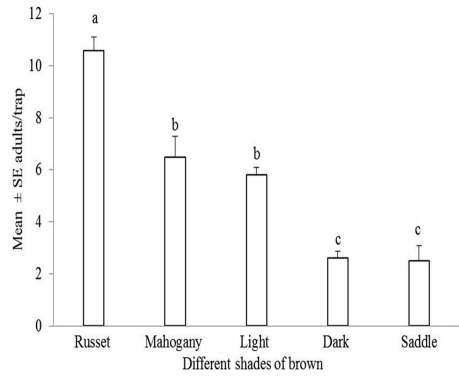

Fig. 2. Mean ± SE numbers of adult *R. obscurus* caught by ramp (R), bucket (B), ground (G), and pitfall (P) traps with (L) and without (N) pheromone lures. Different lowercase letters indicate significant differences between treatments (two-way ANOVA using Poisson model; least square means, $P < 0.005$). Means were generated from five replications. Traps with lures outperformed traps without lures, and ramp and ground traps outperformed others.
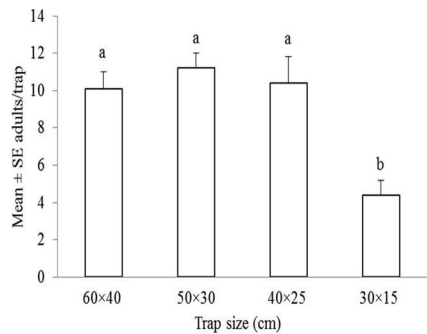
Fig. 3. Mean ± SE numbers of adult *R. obscurus* caught in pheromone-baited ground traps of different sizes. Different lowercase letters indicate significant differences between treatments (one-way ANOVA using Poisson model; least square means, $P < 0.05$). Bars represent means of five replicates. The smallest traps were least effective.
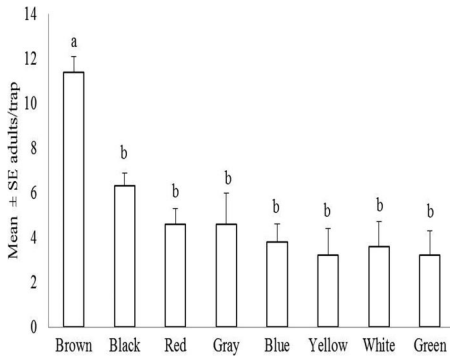
Fig. 4. Mean ± SE numbers of adult *R. obscurus* caught in pheromone-baited ground traps of different colors in the field. Different lowercase letters indicate significant differences between treatments (one-way ANOVA using Poisson model; least square means, $P < 0.01$). Brown traps outperformed all others. Bars represent means of five replicates.
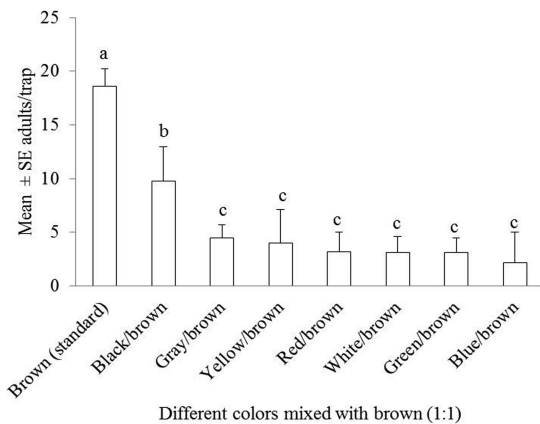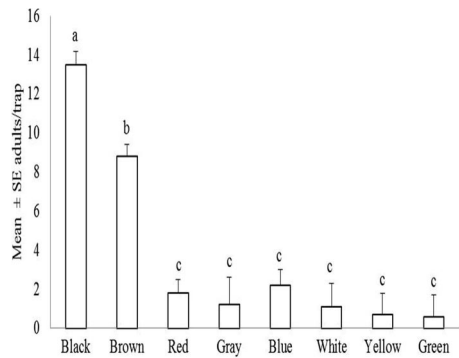

Fig. 6. Mean ± SE numbers of adult *R. obscurus* caught in pheromone-baited ground traps of different shades of brown in the field. Different lowercase letters indicate significant differences between treatments (one-way ANOVA using Poisson model; least square means, $P < 0.01$). Russet outperformed other shades of brown. Bars represent means of five replicates.

0.05) (Fig. 10). During the experimental period, the average temperature was 26.9°C, relative humidity 80–85%, and wind velocity 8.6 m/s.

Discussion

Semiochemical-based trapping methods can provide a useful, viable, and environmentally sound control approach for many insects, particularly wood borers, where application of insecticides is not feasible (Reddy and Guerrero 2004, 2010). Existing pheromone-based trapping methods—the routine use of bucket traps baited with pheromone lures—have helped in the monitoring of *R. obscurus* (Muniappan et al. 2004, Reddy et al. 2005a), but they have resulted in only low capture rates and did not help to control *R. obscurus* on Guam and other Pacific islands. Re-

cently, *R. obscurus* has been attacking coconut trees and might become uncontrollable and kill all ornamental nursery plants and palms. Moreover, little work has been done to determine the impact of trap design on capture of *R. obscurus.* Although Sallam et al. (2007) recommended water traps for this purpose, this method proved effectual only in dry areas. Because high rainfall occurs throughout the pacific, the water trap is not practical there. Optimization of trap characteristics for *R. obscurus* is therefore timely, and the optimized methods can be used in other parts of the world where this widespread pest is a problem. In our study, ramp and ground traps were more efficient in capturing *R. obscurus* than were bucket or pitfall traps. Although ramp and ground traps were equally effective, ground traps are easily made by hand from corrugated plastic and are convenient and inexpensive. Moreover, captured adults can be seen easily and

Fig. 5. Mean ± SE numbers of adult *R. obscurus* caught in pheromone-baited ground traps of different colors mixed 1:1 with brown in the field. Different lowercase letters indicate significant differences between treatments (one-way ANOVA using Poisson model; least square means, $P < 0.05$). Adding brown to the other colors did not improve their performance. Bars represent means of five replicates.
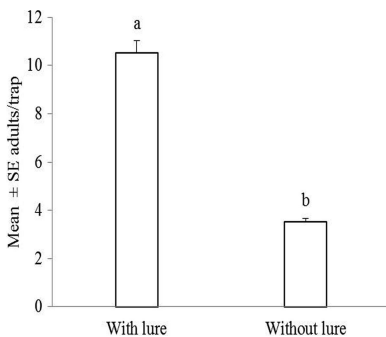

Fig. 7. Mean ± SE numbers of adult *R. obscurus* caught in pheromone-baited ground traps of different colors indoors. Different lowercase letters indicate significant differences between treatments (one-way ANOVA using Poisson model; least square means, $P < 0.001$). The means were generated from eight tests each using 40 insects. Black traps outperformed all others.
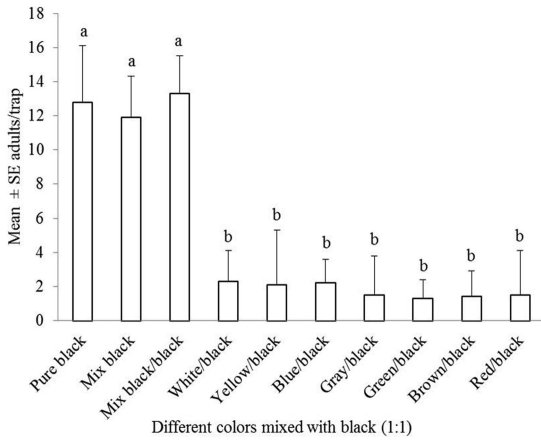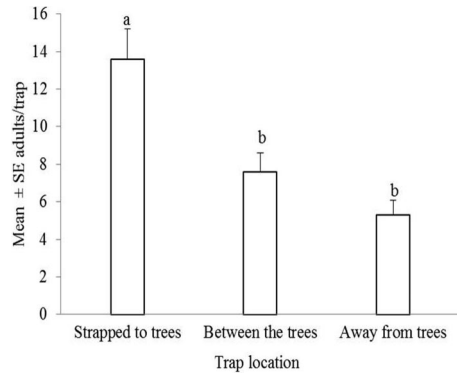
Fig. 8. Mean ± SE numbers of adult *R. obscurus* caught in pheromone-baited ground traps of different colors mixed 1:1 with black indoors. Different lower-case letters indicate significant differences between treatments (one-way ANOVA using Poisson model; least square means, $P < 0.01$). Adding black to the other colors did not improve their performance. The means were generated from ten tests each using 40 insects.

removed from the trap bottom. Ground traps have proven more appropriate for use both in the field and indoors and are effective against other insects, such as *Hylotrupes bajulus* (L.) (Coleoptera: Cerambycidae) (Reddy et al. 2005b) and *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae) (Reddy et al. 2009). The influence of trap type on capture rates of other insects has been described in our previous publication (Reddy et al. 2009).

Trap size selection is important, as is the compromise among cost, ease of deployment, and trap performance (Miller and Crowe 2009). The trap size chosen as optimal in the current study was the same as that selected for *C. sordidus* (Reddy et al. 2009). Trap-size results are not always so clearcut, however.

Fig. 9. Mean ± SE numbers of adult *R. obscurus* caught in russet-brown ground traps with and without pheromone lures in the field. Different lowercase letters indicate significant differences between treatments (one-way ANOVA using Poisson model; least square means, $P < 0.05$). Traps with lures outperformed identical traps without lures. Bars represent means of 20 replicates (four replicates per location × 5 sites).

Fig. 10. Mean ± SE numbers of adult *R. obscurus* caught in pheromone-baited ground traps placed in different locations. Different lowercase letters indicate significant differences between treatments (one-way ANOVA using Poisson model; least square means, $P < 0.05$). Bars represent means of 20 replicates (four replicates per location × 5 sites).

Miller and Crowe (2009), using traps consisting of linear arrays of funnels, got mixed results. They found that more *Arhopalus rusticus nubilus* (LeConte) (Coleoptera: Cerambycidae) and *Xyleborus* spp. Eichhoff (Coleoptera: Scolytidae) were caught in 16-unit traps than in 8-unit traps, that catches of *Hylobius pales* (Herbst) (Coleoptera: Curculionidae) in 16-unit traps were 54% lower than those in 8-unit traps and that trap size had no effect on catches of *Xylotreches sagittatus* (Germar) (Coleoptera: Cerambycidae).

Trapping location is one of the important factors that affect the trap catches. That responses of insects vary to trap placement has been demonstrated in *Cydia pomonella* (L.) (Kehat et al. 1994), *Diaphania nitidalis* (Stoll) (Valles et al. 1991), *Palpita unionalis* Hübner (Athanassiou et al. 2004), and *C. sordidus* (Reddy et al. 2009). In the study reported here, the traps strapped to the trees caught more target insects than did traps placed between or away from trees, suggesting that *R. obscurus* preferred to walk or crawl from the trees to the trap. This kind of behavior was observed in *H. bajulus;* even though adults initially flew upwind in the pheromone plume, they generally walked the final distance (≈50 cm) to the source (Reddy et al. 2005b).

Nocturnal insect species have been reported to discriminate flower colors at starlight intensities, when humans and honey bees (*Apis mellifera* L.) are color blind (Kelber et al. 2003). For example, *Macroglossum stellatarum* (L.) (Lepidoptera: Sphingidae) can use achromatic, intensity-related cues if color cues are absent. Even in dim starlight, however, nocturnal insects can use chromatic rather than achromatic cues to recognize flowers (Kelber et al. 2003). The fast-flying nocturnal sweat bee *Megalopta genalis* Meade-Waldo (Hymenoptera: Halictidae) relies primarily on vision and can forage and home by using visually discriminated landmarks at starlight intensities (Warrant et al. 2004, Frederiksen et al. 2008). Most studies on color vision in nocturnal insects has been confined

to hawk moths and bees (Kelber et al. 2003, Warrant et al. 2004), but our results showed that trap color influenced the capture efficiency of nocturnal weevils (Curculionidae). Our previous results showed that *C. sordidus* not only clearly prefers brown to yellow, red, gray, blue, black, white, and green but prefers mahogany brown to four other shades of brown. From the results presented here, we argue that *R. obscurus* can also discriminate colors, but further research effort is necessary.

R. obscurus responded to baited ground traps of different colors differently in the field and indoors. In the field, *R. obscurus* preferred brown, and particularly russet brown, over the other colors, but indoors, black traps were favored. We have no explanation for the difference.

In conclusion, our study indicated that trap design, size, color, and trapping location are important factors affecting the response of *R. obscurus* to pheromone-baited traps. In particular, the 40- by 25-cm russet brown ground traps baited with pheromone lures and strapped to the trees are an efficient tool for catching *R. obscurus* in the field. Indoors, black, but otherwise identical, traps were most effective. These findings should be taken into consideration when mass trapping techniques are developed for this important borer pest.

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