Effect of Silhouette Color on Trap Catches of *Dendroctonus frontalis* (Coleoptera: Scolytidae)

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**ABSTRACT** With the exception of responses to semiochemicals, host selection behaviors of *D. frontalis* are largely unstudied. To better understand the host-finding behavior of *D. frontalis*, and to identify potential visual disruptants, we evaluated the response of *D. frontalis* to multiple-funnel traps of eight different colors. Multiple-funnel traps provide an attractive vertical silhouette, similar to a host stem, that aids in capturing bark beetles and allows for controlled evaluation of visual cues. Evaluation of mean trap catch of each color by analysis of variance (ANOVA) produced two separate groups: white and yellow traps caught significantly fewer *D. frontalis* than the other six colors tested (black, blue, brown, gray, green, red). Examination of spectral reflectance curves showed that the eight colors could be naturally placed into two groups, those with high peak reflectance (white and yellow) and those with low peak reflectance (black, blue, brown, gray, green, red). When high and low peak reflectance were substituted for color in a separate ANOVA, reflectance group was as good as color at explaining the variability in trap catch ($r^2 = 0.88$ versus 0.92). Therefore, hue (dominant wavelength) was unimportant in affecting *D. frontalis* host-finding behavior at the reflectance levels we tested and, thus, we found no strong evidence that differential wavelength sensitivity affected the response of *D. frontalis*. These results show that dark colored silhouettes (those with low reflectance values), regardless of hue, are best for capturing *D. frontalis*, while white or yellow are the best candidate colors for disrupting host finding.

**KEY WORDS** bark beetles, southern pine beetle, Scolytidae, host finding, insect vision

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**Materials and Methods**

This study was conducted in Florida during May and July 1997 and consisted of seven replicates, one at each of seven sites. All sites were plantation pine (12–20 yr old), six loblolly, *Pinus taeda* L., and one slash, *P. elliottii* Engelm., each with an active *D. frontalis* infestation. Multiple-funnel traps were used, because they provide physical stimuli that are similar to tree boles, making them reasonable host mimics and good models for host finding. At the same time, they reduce spatial and temporal variations that are inherent in pine hosts, allowing treatments to be compared more directly. Eight traps, one of each color, were assigned initial positions at random, 5–10 m apart, then rotated each day either systematically (three sites) or reassigned positions randomly (four sites), depending upon the length of time a site was available before harvesting (i.e., sites cut in fewer than 8 d were sampled using the latter method). Mean trap catch of each color at each site was used as the dependent variable in all analyses.

Visual treatments consisted of multiple-funnel traps (16-funnel: Phero Tech, Delta, BC, Canada) painted with various colors of Krylon spray paints (Krylon, Division of Sherwin-Williams, Solon, OH) (Fig. 1). The colors used were: gloss black (Krylon product number 1601), true blue (no. 1910), leather brown (no. 2501), dove gray (no. 1605), moss green (no. 2004), cherry red (no. 2101), gloss white (no. 1501), and sun yellow (no. 1806). Other than color pigments,
the different colors of Krylon paints do not use different ingredients (Krylon, Inc.), thus controlling for potential semiochemical effects among paint colors. Reflectance spectra (Fig. 1) were generated for each color by comparing it to a white standard (Spectralon SRS-99-010 calibrated reflectance standard; Labsphere, North Sutton, NH) using a Labsphere RSA-SP-84 integrating sphere attachment on a Hewlett-Packard HP 8452A diode array (UV-VIS) spectrophotometer. All traps were baited with the attractive semiochemical blend frontaline (2 parts alpha-pinene to one part frontaline) (~2.5 ml) eluted from transfer pipettes (4 ml; Corning Samco Corporation, San Fernando, CA) (Strom et al. 1999).

Field elution rates were determined previously to be 46–58 mg/d, depending on light environment (lower values in the shade, higher in full sun) but independent of trap color (black or white) (Strom et al. 1999).

Data were analyzed by mixed-model (sites considered random) ANOVA (Proc Mixed) (SAS Institute 1997), with the mean daily catch for each color at each site, transformed by its natural log, serving as the dependent variable. Mean separations were accomplished using Tukey’s studentized range test (SAS Institute 1997). Histograms of raw data (Proc Univariate) (SAS Institute 1997) and visual inspection of residuals demonstrated that transformed values better met the assumptions of parametric statistics. The effect of color on catch of D. frontalis was evaluated using the ANOVA model: catch = site, color. Because a plot of peak reflectance suggested that there were two distinct groups in our treatments, one with relatively low peak reflectance (six colors) and one with high peak reflectance (white and yellow) (Fig. 1), a second ANOVA was used to evaluate this parameter. The effect of peak reflectance group (high or low) was evaluated using the model: catch = site, peak reflectance group. This model was more parsimonious because it used only 1 degree of freedom for treatment effects (compared with seven for color) and eliminated the effects of hue (at the reflectance levels of our colors).

Results

Each color had a unique reflectance spectrum, showing the effects of hue (the wavelength at which a peak occurs), intensity or peak reflectance (how high the peak reflectance was), and saturation (unsaturated colors are those without a distinct hue, i.e., black, gray, and white) (Fig. 1). The peak reflectance of white and yellow traps was >70%, and, above >500 nm, their spectra were similar. Other colors differed in hue but had similar peak reflectances, all being <30%.

More than 570 trap collections were made, resulting in a total catch of >101,000 D. frontalis during the 20 trapping days of this study. Mean catch of D. frontalis was significantly affected by trap color (F = 21.62; df = 7, 42; P < 0.0001). White and yellow traps caught significantly fewer D. frontalis than any other color (P < 0.05 in all cases) (Fig. 2). There were no significant differences in catch among the other six colors (~80%) demonstrates that both colors hold potential for successful disruption of host...
finding of this beetle and suggests that either would be a good choice for further evaluation and development as visual disruptants. The reduction in the number of D. frontalis caught in white traps compared with black in this experiment was very similar to that observed earlier with multiple-funnel traps (≈70%) and sticky panels (79%) (Strom et al. 1999). Thus, modification of visual silhouettes using bright (high reflectance) colors provides both consistent and significant reductions in the number of D. frontalis trapped.

The results also show that, in the visual range (400–700 nm), hue was unimportant for capturing D. frontalis at the reflectance levels tested. Among the six colors categorized as low reflectance (Fig. 3), none showed significant variability in the number of individuals caught (Fig. 2). Comparing white and yellow it is interesting to note that, although no significant differences in catch were observed, yellow traps caught the fewest D. frontalis at every site. Either white or yellow appears suitable for disruption of D. frontalis host finding, while any of the other colors could be used in monitoring or management schemes where the objective is to attract as many D. frontalis as possible.

The visual physiology of D. frontalis has not been studied; however, there are two bark beetle species, D. pseudotsugae and I. paraconfusus, whose electrophysiological responses to light have been evaluated using ERGs (Groberman and Borden 1982). The response of each of these species was similar, with two sensitivity maxima being observed in the visual range: one in the blue region (≈450 nm) and one in the green (510–530 nm). By comparison, we did not observe any effects that suggest D. frontalis had strong positive or negative responses at either of these wavelengths, i.e., neither blue nor green traps caught significantly different numbers of D. frontalis than the other colors in the low reflectance group (Figs. 1 and 2). It is possible, perhaps likely, that scolytids possess a third sensitivity maximum in the UV (UV) range, but experiments with UV light have not been conducted and neither attraction nor disruption of D. frontalis host finding seems to require it. The results of this experiment support the idea that UV reflectance is unnecessary to disrupt host finding of D. frontalis, as white and yellow traps, neither of which reflected much UV (Fig. 1), reduced trap catches by >70%. Apparently UV reflectance is not necessary for attraction of D. frontalis either, because boles of southern pines, their natural hosts, do not reflect much UV (Strom et al. 1999).

The reflectance spectrum of an object in situ is a function of its reflectance potential and the availability of light across the electromagnetic spectrum. Our laboratory results provide a high quality relative measure of reflectance, but our methods do not allow us to evaluate the actual reflectance of traps in the field. Published measures of light quality in southern pine forests are scant. Hailman (1979) observed that, under cloudy conditions, closed canopy loblolly pine forests reduce total light by about an order of magnitude but change light quality very little. Under sunny conditions, closed forest canopies (forest shade) reduce total light and cause a color change from whitish to yellow-green, with one peak of transmittance at 550 nm and another in the red range above 680 nm (Endler 1993).

Strom et al. (1999) hypothesize that D. frontalis is a ‘visual specialist’, which implies that it should be relatively easy to disrupt with visual treatments (sensu Prokopy and Owens 1978). Ease of disruption may be taken to mean that any variation from the visual stimulus provided by the natural host should disrupt host finding or, alternatively, that a disruptive stimulus, when it exists, should be more effective. Although this hypothesis was not directly addressed in this experiment, the results support the latter interpretation. No color other than white or yellow negatively affected host finding of D. frontalis. However, the results of this and other experiments suggest that some species of scolytids are not affected by visual stimuli (e.g., Conoplotherus resinosae, Cnaphalochira, spp.), while others are significantly deterred by white silhouettes (e.g., Dendroctonus and Ips species). Among the species of scolytids that have been tested, D. frontalis seems to exhibit the most dramatic difference between white and black traps. Modification of visual silhouettes using highly reflective (>70% of the standard) white or yellow paint consistently reduces successful host finding (landing) of D. frontalis by 70–90%. Therefore, D. frontalis is a likely candidate for which to evaluate strategies that include manipulation of the visual environment to more efficiently meet management objectives.

The utility of employing color, for either disruption or attraction, will not be known for certain until field
experiments are done to test management scenarios of interest. The levels of visual disruption observed with *D. frontalis* are, however, as great or greater than those achieved thus far from antigaugent semiochemicals (Salom et al. 1992, Hayes et al. 1994), some of which are now available to managers. In addition, visual and olfactory disruption appear additive in *D. frontalis* (Strom et al. 1999), suggesting that more effective protectants may be developed through disjunct combinations. Therefore, increasing our knowledge of the biology and ecology of scolytid host selection may be a fertile area for facilitating both the improvement of existing management strategies as well as the development of novel ones.

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