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NEW DEVELOPMENTS IN SNAKE BARRIER TECHNOLOGY: FLY-ASH COVERED WALL OFFERS A FEASIBLE ALTERNATIVE FOR PERMANENT BARRIERS TO BROWN TREESNAKES (*BOIGA IRREGULARIS*)

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***Abstract.*—Barriers to Brown Treesnake (*Boiga irregularis*) movement are a useful tool for reducing the risk of this invasive species' dispersal from Guam to unoccupied areas and to prevent re-colonization of areas subjected to snake control. We investigated the feasibility of a fly-ash covered wall design as a Brown Treesnake barrier. We tested a mock-up of the wall design with two surface types (rough and smooth) by providing Brown Treesnakes access to the wall as the only potential escape route from a test chamber. All of the 100 snakes tested on the smooth finish were contained by the wall, and one out of 153 snakes tested on the rough finish was able to breach the wall. Extremely large snake size appeared to be the only factor contributing to the successful scaling attempt. We conclude that this new wall design may provide a feasible and cost-effective alternative to existing wall designs, provided it meets criteria for structural integrity and longevity under environmental conditions present on Guam and other Pacific islands.**

Key Words.—*Boiga irregularis*; Brown Treesnake; conservation; Guam; invasive species; Mariana Islands; snake barrier

INTRODUCTION

The accidental introduction of the Brown Treesnake (*Boiga irregularis*) to Guam in the late 1940's has had devastating effects both ecologically and economically (Savidge 1987; Rodda et al. 1997; Fritts and Rodda 1998; Perry et al 1998). The Brown Treesnake (BTS) is thought to be responsible for the extirpation or decline of most of the island's native vertebrate species, has cost millions of dollars in damage due to power outages (Fritts 2002), and presents a human health risk for infants (Rodda et al. 1998; Fritts and McCoid 1999). Solutions to solving the BTS problem focus on two specific management needs. Firstly, preventing the dispersal of snakes off of Guam; and secondly, finding long term solutions on Guam with regard to environmental, economic, and safety concerns (Perry et al. 1998).

Since tools for successful large-scale eradication of BTS from Guam are not yet available, blocking snakes from entering critical areas (e.g., transportation areas, cargo facilities, and protected sites for endangered species recovery) seems the best approach to achieving some management goals (Perry et al. 1998). Major research efforts have been devoted to developing effective barriers to the dispersal of BTS. Barriers are currently being used to reduce the risk of snake dispersal during one-time military exercises, to exclude snakes from major transportation and cargo facilities, and to intercept snakes at off-island ports and airports receiving traffic from Guam. Barriers are used in concert with trapping and visual search efforts, a multi-agency rapid response team, and detector dog teams.

During the 1990's, USGS scientists tested various barrier options under controlled conditions both in the laboratory and in the field and succeeded in developing three different physical barrier designs to accommodate varying permanence and cost requirements. A full description and the advantages and disadvantages of each of these barriers can be found in Perry et al. (1998). The major objective of further barrier testing is to investigate, develop, and test effective barriers to better serve the full range of management needs, while simultaneously searching for low cost and/or low maintenance options.

Wondertec™ International (Loxahatchee, Florida, USA; www.wondertecinternational.com) manufactures walls that could potentially be used for snake barriers. Wondertec walls are composed of a durable fly ash material that is plastered onto a wooden frame, and are proposed to be roughly 20% less expensive to fabricate and install than the pre-stressed concrete designs that have been tested to date by the USGS. In laboratory tests, an eight foot tall Wondertec wall withstood pressures exceeding those generated by winds at 300 kilometers per hour (Wondertec International 2005), which is in excess of the sustained wind speed of a Class 5 hurricane or typhoon. Our objective in this project was to determine whether the Wondertec wall is sufficiently snake resistant (> 99% retention rate) to warrant consideration for permanent BTS barriers. Given that the pre-stressed concrete design currently in use has shown to be very effective at repelling BTS breaching attempts (Perry et al. 2001), the main motivation for testing the Wondertec design is the lower fabrication cost when compared with the pre-stressed concrete design.

Materials and Methods

We conducted testing in the USGS Brown Treesnake laboratory, Guam National Wildlife Refuge, Ritidian Point, Guam. Wondertec International provided a short segment of a Wondertec wall mock-up to serve as the test barrier. The mock-up was 1.82 m long by 1.46 m high with a horizontal overhang starting at 1.2 meters. The overhang protruded out perpendicular from the wall for 0.2 m on each side (Fig. 1). These dimensions were matched to that of the pre-stressed concrete design described by Perry et al. (1998). The Wondertec mock-up had two finishes; one side had a smooth finish similar in texture to the pre-stressed concrete design, while the other side had a rough finish comparable to medium grade sandpaper. The rough finish was tested from 10 Jan 2005 to 5 May 2005 and the smooth finish was tested from 3 August 2005 to 22 November 2005.

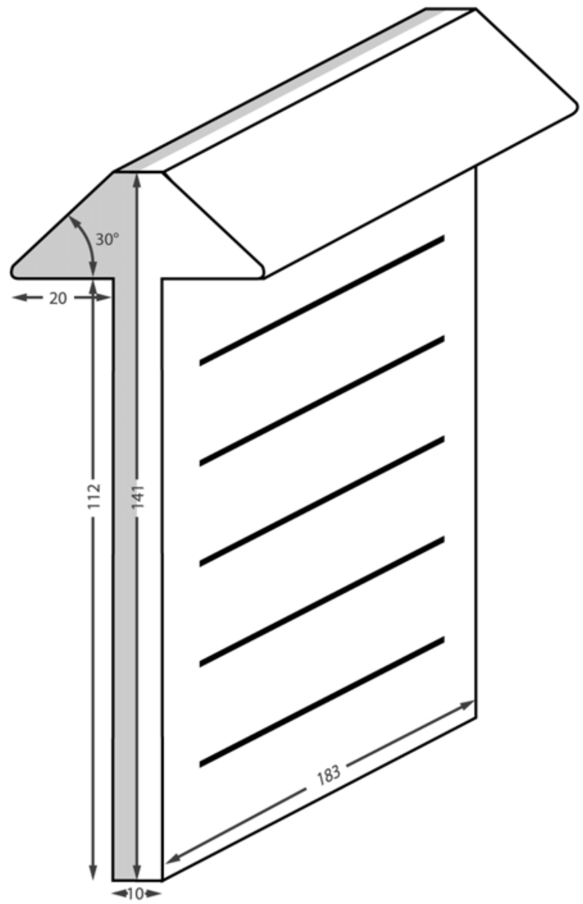

Figure 1. Schematic of the Wondertec sample barrier used in all trials, including measurements in centimeters. Shading on one side indicates that surface textures varied between sides. Horizontal black lines were drawn on the wall at 0.2 m intervals for use in analyzing video recorded scaling attempts by Brown Treesnakes (*Boiga irregularis*).

We constructed a snake proof chamber that could be attached to the Wondertec mock-up and which incorporated three important features: (1) the chamber permitted videotaping of the wall; (2) encouraged snakes to focus climbing efforts on the wall; and (3) contained snakes even if they succeeded in scaling the barrier wall. The walls of the barrier chamber were composed of sheets of smooth, black Formica® laminate (1.8 m high) backed by a wooden frame. Brown Treesnakes are able to use corners of 90 degrees or less to scale barrier walls (Perry et al. 1998), so the chamber was attached to the Wondertec wall at 110 degree angles. We used a mesh roof with a zippered flap door for access to enclose the chamber and seal any exit points from the roof and the top of the Wondertec mock-up. The test chamber provided approximately 8 m³ of space, with 4.5 m² of floor area. Small rocks (20-30 mm) glued to the floor at the base of the wall served to motivate BTS to concentrate their escape efforts on the Wondertec portion of the chamber. We placed a PVC pipe segment (36 cm long, 11 cm diameter) on the floor near the center of the chamber to serve as a refugium.

The BTS used in this study were wild-caught by USDA Wildlife Services on Guam using live traps and spot-light searches during regular control activities, and were tested within two weeks of capture. Prior to testing, we housed snakes in commercially-produced snake cages (Neodesha Plastics, Neodesha, Kansas, USA), placed under 12 L: 12 D lighting and offered water *ad libitum*. We selected snakes of a given size range randomly for nightly tests. We tested the widest possible range of BTS sizes that were available, but avoided mixing very large and very small animals during any given run. We placed a maximum of five BTS in the chamber at one time. Each BTS was assigned a unique ID and labeled with pairs of small squares (~2 x 2 mm, Fig. 2) of blue reflective tape (Identi-tape Inc., Golden, Colorado, USA) applied to the skin on either side of the vertebral column with non-toxic surgical glue (Skin-bond® Cement, Smith & Nephew plc, London,

FIGURE 2. Brown Treesnake (*Boiga irregularis*) with patches of blue reflective tape attached with surgical glue. The patches were used to identify individual snakes when reviewing video images recorded with the IR camera and time-lapse video system.

UK). The number of pairs of reflective tape ranged from one to five and allowed identification of individual snakes during the videotaped trials. We recorded snout-vent length (SVL), total length, mass, and sex for each BTS prior to placement in the chamber (Fig. 3).

Given the simplicity of the Wondertec design, its similarity to the pre-stressed concrete design already proven successful, and urgency of this study for planned applications on Guam, we used the smallest sample size that would suffice for comparing its performance to that of the pre-stressed concrete design (Perry et al. 2001). We decided in advance to test each finish of the Wondertec mock-up until either: (1) at least 100 snakes had been tested without an escape; or (2) at least 150 snakes had been tested with only one escape; or (3) two or more snakes had escaped. Conditions "1" or "2" were judged *a priori* to indicate comparability to the pre-stressed concrete design, whereas condition "3" was indicative of a less successful barrier. Each trial consisted of two consecutive nights during which up to five snakes were kept within the barrier test chamber with access to the Wondertec mock-up. On day one of each trial, we placed the snakes in the chamber 1-3 hours before the start of the trial, and then they remained undisturbed in the chamber from 1800 on day 1 until 0600 on day 3 (after 36 hours had elapsed). We recorded behavior for both nights during a twelve hour period of darkness (1800-0600) using an infra-red camera (model TIR-301, TeviCom, Seoul, Korea) and time-lapse videocassette recorder (model SVT-D224, Sony Corporation, Tokyo, Japan). We placed the infra-red camera at the bottom/center of the chamber opposite the Wondertec wall. Black horizontal lines painted on the wall at 0.2, 0.4, 0.6, 0.8, and 1 meter were used to score individual BTS attempts at climbing the wall (Fig. 1). Upon completion of a trial (2 snake nights) we reviewed the videotape and counted the total number of scaling attempts by each BTS. We recorded an "attempt" if a snake reached or exceeded the 0.6 m mark using only the Wondertec portion of the chamber (thus, we did not include attempts to scale the wall at the

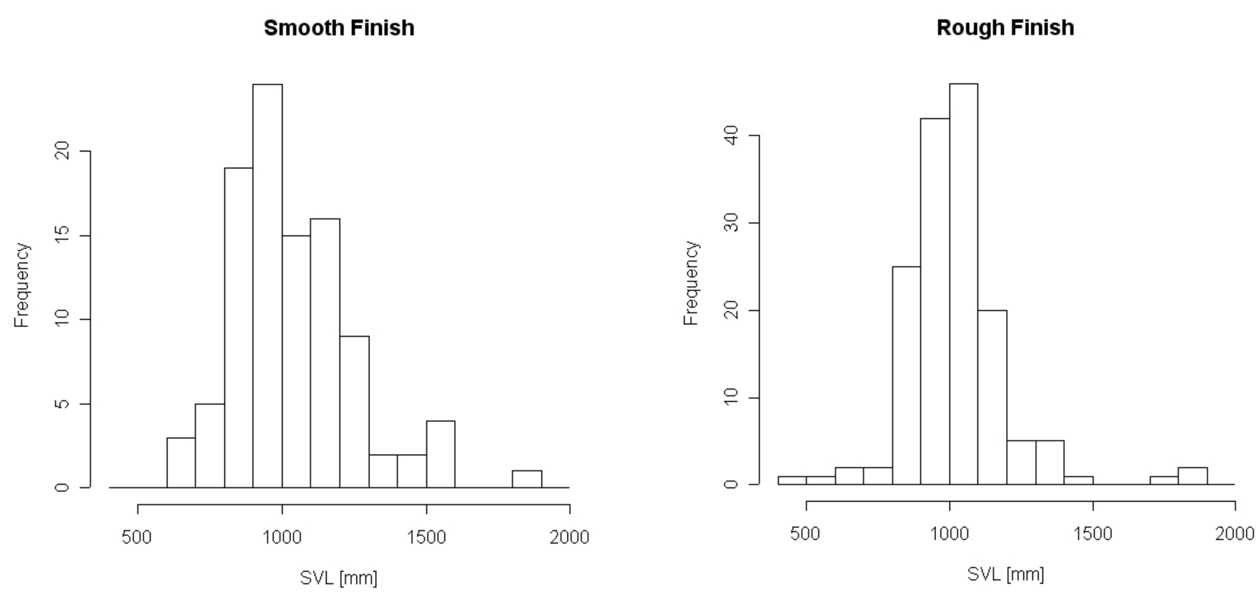

FIGURE 3. Size distribution of Brown Treesnakes (*Boiga irregularis*) used in trials on the rough and the smooth Wondertec finish type. SVL = snout-vent length of snake. Only one individual in the largest size class succeeded in breaching the rough side of the barrier. There were no breaches of the smooth side of the barrier.

corners where the Formica® laminate was attached to the mock-up wall). We recorded time, snake ID, and maximum height attained for each attempt. We analyzed data using the statistical programming languages R (Version 2.0.1, The R Foundation for Statistical Computing, http://www.r-project.org) and SAS (Version 8.02, SAS Institute Inc., Cary, North Carolina, U.S.A.). We added one (1) to each animal's total number of attempts before determining its natural logarithm, in order to be able to incorporate animals with zero attempts in the analysis.

Results

Snakes generally emerged from refugia in the test arena within minutes of the lights going out and spent some time, usually less than an hour, moving around at the base of the barrier. Most BTS then attempted to climb the Wondertec wall. A few BTS did not emerge from refugia during the first night of the trials, but that was uncommon. Among BTS with SVL $<$ 900 mm (n = 57), 43.9% (rough finish: 36.1% of 36, smooth finish: 57.1% of 21) did not reach 0.6 m during the entire trial, while only 13.8% of BTS with SVLs $\geq$ 900mm (n = 196) failed to reach the 0.6 m mark (rough finish: 12.8%, of 117; smooth finish: 15.2%, of 79). BTS activity (number of attempts) was generally high on the first night of the trial in the chamber and declined substantially on the second night; on average 80% (SD = 26.9, n = 201) of the total number of attempts made by a BTS occurred during the first night of the trial. Inside corners and visual discontinuities, such as the small rocks glued to the floor at the base of the wall and the camera attachment on the back of the chamber attracted some attention; however, the test BTS appeared to focus the majority of their efforts on the Wondertec wall. These observations are consistent with snake behavior in previous barrier tests (Perry et al. 1998). Only the Wondertec mockup, a small portion of the floor, and the edges of the surrounding Formica were within the camera's field of vision, therefore, the time spent attempting to climb the Formica laminate is unknown.

A three-way ANCOVA with SVL, gender (categories: male, female), and finish type (categories: rough, smooth) as factors and the log-transformed number of recordable scaling attempts as the response showed a significant main effect of SVL (F = 37.13, df = 239, P < 0.0001, Fig. 4) on the number of scaling attempts, with larger snakes making more attempts. There was also a significant main effect of finish type (F = 11.89, df = 239, P = 0.0007), as snakes made fewer scaling attempts on the smooth side of the test wall. Although there was no main effect of gender (F = 0.081, df = 239, P = 0.776), we did detect an significant SVL:Sex interaction (F = 8.63, df = 239, P = 0.0036); the latter is due to the fact that the largest BTS are all males. There were no other significant interactions between factors (SVL:Finish, Sex:Finish, SVL:Sex:Finish; all P > 0.45).

Because we tested snakes in groups of up to five individuals, the assumption of data independence may have been violated. However, during reviews of the video recordings we observed very few interactions among snakes tested together.

Rough finish: We tested 153 BTS (74 female, 77 male, 2 unsexed juveniles) in trials on the rough finish of the Wondertec wall. Snout-vent lengths (SVL) of snakes ranged from 435 mm to 1865 mm SVL (mean = 1022, SD = 183.1, Fig. 4). During 306 snake-nights, we recorded 1533 total attempts by BTS to scale the Wondertec wall. Snakes averaged 10.02 recordable attempts (SD = 17.8,

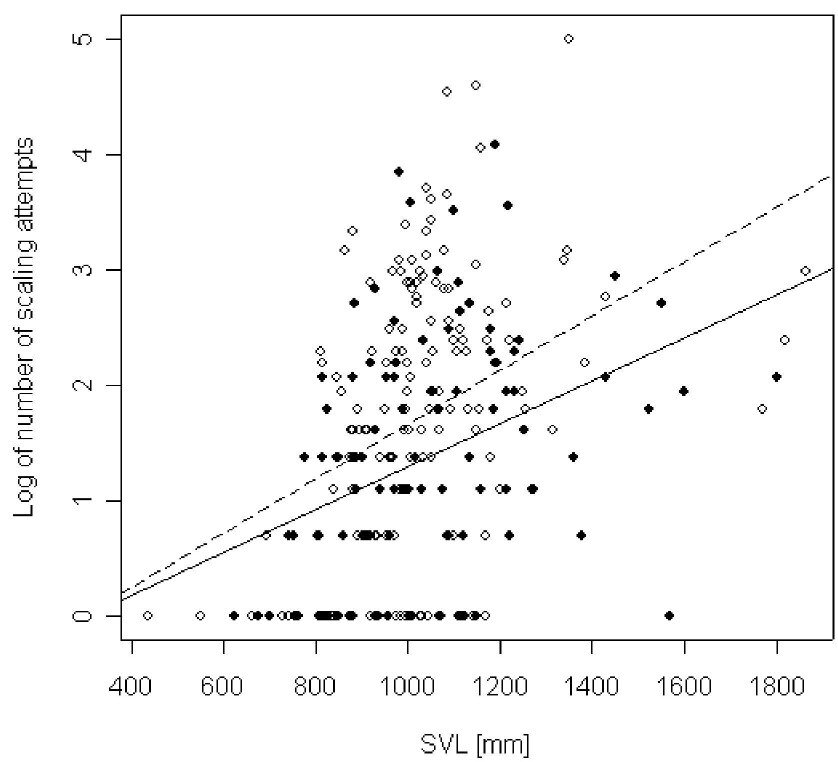

Figure 4. Number of scaling attempts (log transformed, 1.0 added to each observation prior to transformation to eliminate zeroes) per trial as a function of SVL of Brown Treesnakes (*Boiga irregularis*; hollow diamonds indicate attempts on rough finish; solid diamonds indicate attempts on smooth finish), including lines of best fit for trials on the rough (dotted line) and smooth (solid line) finishes.

min = 0, max = 149) to scale the rough surface type.

The rough finish repelled 99.4% of the snakes. Only the largest snake (♂#1164, SVL = 1865 mm, total length = 2340 mm, mass = 1054 g) was able to scale the entire height of the wall plus the overhang. None of the other snakes were able to lift their bodies completely off the ground while using only the Wondertec portion of the test chamber.

Smooth finish: We tested a total of 100 BTS (45 female, 42 male, 3 unsexed juveniles) in trials on the smooth finish of the Wondertec wall. Snout-vent lengths (SVL) of snakes ranged from 623 mm to 1803 mm SVL (mean = 1036.6, SD = 214.2, Fig. 4). During 202 snake-nights, we recorded 612 total attempts by BTS to scale the Wondertec wall. Snakes averaged 6.06 recordable attempts (SD = 9.6, min = 0, max = 59) to scale the smooth finish, significantly fewer than observed during trials on the rough surface (t-test assuming unequal variances, df = 244, $t = 2.299$, two-tailed $P = 0.022$). The smooth finish had a retention rate of 100%. None of the snakes was able to lift its body completely off the ground while using only the Wondertec portion of the test chamber.

We used a two-sample design; each snake was only tested on one side of the Wondertec mock-up, with the exception of ♂#1164. This animal was the only snake able to scale the Wondertec mock-up during trials on the rough finish, hence we decided to re-run the same individual (outside of the scope of our experimental design and excluded from the above analysis) on the smooth finish. During that trial (two nights), BTS #1164 made only two attempts over 0.6 meters (compared with 19 attempts during the rough finish trial) and was unable to breach the barrier.

DISCUSSION

Both surface types of the Wondertec fabrication were subjected to a substantial number of scaling attempts and showed retention rates > 99%. The smooth surface (with a retention rate of 100%) matched the retention rate of the pre-stressed concrete barrier design favored by Perry et al. (2001).

Extreme BTS size appears to be the only factor contributing to the single successful breach of the rough finish. BTS of this size are rare in the wild and are all male, based on our Guam sample of 10,404 BTS. Snakes in the larger size classes made more attempts exceeding the 0.6 m mark than did the smaller size classes. This result, in concert with the finding that only one very large snake could lift its body off the ground while using only the Wondertec portion of the chamber, suggests that large snake size presents the main challenge to the Wondertec wall system. Furthermore, neither the rough nor the smooth finish provided a climbable surface without support from the ground. In contrast, earlier designs of the bulge barrier type were challenged not only by extreme snake sizes but also by very small snakes that were able to climb on the barrier (presumably due to higher agility and low mass), using miniscule features on its surface as “climbing holds” (USGS, unpubl. data).

The only snake (♂#1164) that was able to scale the rough finish of the Wondertec wall did not breach the wall on the smooth finish side. We cannot infer whether this was a result of time spent in captivity between the first and second trial (seven months) and associated changes in escape behavior, agility, and muscle tone, or due to the differences between the rough and the smooth surface. However, the average snake made 65% more scaling attempts during trials on the rough side than on the smooth side.

As a solution to the problem of retaining extreme snake sizes, Perry et al. (1998) suggested increasing the height of the barrier, but added that simply increasing barrier height did not statistically improve the success rate per snake-night in their tests. Furthermore, higher barriers are more costly and vulnerable to wind damage, a major concern in the Mariana Islands.

Based on our findings, the Wondertec barrier system, specifically the smooth surface type, appears to be comparable to the pre-stressed concrete wall in its ability to repel scaling attempts by Brown Treesnakes.

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Jennifer Farley is currently the Education Coordinator for Tumon Aquarium, LLC in Guam. Previously she was a Marine Biology/Biology teacher and a Biologist for IAP World Services working with USGS on the control, containment, and interdiction of brown tree snakes on Guam and neighboring islands in the Pacific. She obtained her Master's degree in Wildlife Biology and Management from James Cook University in Townsville, Australia, and her B.S. in Marine Biology from University of New England in Biddeford, Maine. Jenn enjoys educating students about wildlife conservation and working with fellow biologists on conservation and rehabilitation projects. Her future career endeavors will unquestionably continue to keep her involved with both.

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