8-1-2007

SPOTTING CRYPTIC ANIMALS IN THE DARK: WHAT LIGHT PROPERTIES SHOULD A GOOD HEADLAMP HAVE?

Bjorn Lardner
Colorado State University, Department of Fish, Wildlife, and Conservation Biology, Fort Collins, Colorado, USA

Julie A. Savidge
Colorado State University, Department of Fish, Wildlife, and Conservation Biology, Fort Collins, Colorado, USA

Gordon H. Rodda
USGS-BRD, Fort Collins Science Center, Fort Collins, Colorado, USA

SPOTTING CRYPTIC ANIMALS IN THE DARK: WHAT LIGHT PROPERTIES SHOULD A GOOD HEADLAMP HAVE?

BJORN LARDNER AND JULIE A. SAVIDGE, Colorado State University, Department of Fish, Wildlife, and Conservation Biology, Fort Collins, Colorado, USA
GORDON H. RODDA, USGS-BRD, Fort Collins Science Center, Fort Collins, Colorado, USA

Abstract: Relying on headlamp illumination for visual detection of cryptic nocturnal animals may present a challenge. To test how search light properties affect brown treesnake (*Boiga irregularis*) detection rate, we assigned eight biologists to search for dead snakes placed in roadside vegetation. Each person conducted 4 searches using lamps with varying properties: weak versus strong light, crossed by narrow versus wide beam. On each occasion, 100 snakes were placed randomly along the roadside transect. The mean number spotted per transect search was 13.5. Using an information theoretic approach, sequential order of transect runs was the only confounding variable included in the model with the highest support: 1.5 fewer snakes (95% CI = -0.4 to -2.5) were found for every sequential transect search a person conducted. A narrow beam spotlight rendered almost seven fewer snakes per search than a broad beam floodlight (95% CI = -4.5 to -9.2). A weak light rendered 4.5 fewer snakes than a strong light (95% CI = -2.1 to -6.9). We suspect that the benefit of using a lamp with a floodlight beam is particularly pronounced when a complex, 3-dimensional forested habitat is surveyed and when the traveling speed is relatively high.

Key Words**:** *Boiga irregularis*, brown treesnake, floodlight, headlamp, invasive species, light source, power, search efficacy, spotlight, visual search.

Managing Vertebrate Invasive Species: Proceedings of an International Symposium (G. W. Witmer, W. C. Pitt, K. A. Fagerstone, Eds). USDA/APHIS/WS, National Wildlife Research Center, Fort Collins, CO. 2007.

INTRODUCTION

Animal surveys often use visual searches as a detection tool. For nocturnal animals, this may present a challenge. In some taxa, the *tapetum lucidum* layer of the retina reflects light. Using a light source held close to the observer's own eyes, the observer may, therefore, be able to locate a distant animal by its 'eye shine' (Ribi 1981). This is the case for many, though not all, nocturnal animals in a wide range of taxa, including invertebrates, fishes, amphibians, crocodiles, and certain birds and mammals (e.g., Stavenga et al. 1977, Somiya 1980, Bearder et al. 2006). In snakes, however, the eyes normally do not reflect much light (although see Henderson 2002). Therefore, detecting a snake in the dark typically relies on spotting the characteristic shape or the somewhat different sheen of the animal compared to the surrounding habitat.

Most field workers studying nocturnal snakes use headlamps to free their hands for capturing and handling snakes or to take notes. The physical light properties of headlamps used by field herpetologists vary substantially. Many use spotlights with a narrow beam angle, while others use floodlights with a broader beam angle; some use light weight, low power lamps, while others rely on rechargeable cells that allow for more powerful lamps to be used. While many herpetologists have a favored headlamp type (sometimes advocated with great emphasis), rarely are the effects of these headlamp differences on animal detection rates addressed.

We work on a nocturnal, arboreal snake – the brown treesnake (*Boiga irregularis*) – on the Pacific island of Guam. This species (henceforth referred to as BTS) has caused the demise of many of Guam's native vertebrate species (Savidge 1987a, Rodda and Fritts 1992), and now threatens to colonize other Pacific islands (Fritts 1987, Savidge 1987b, McCoid and Stinson 1991, Kraus and Cravalho 2001). Much of our field work occurs at night, and visual searches are an important research and management tool, instrumental in ongoing BTS control efforts on Guam (e.g., Engeman et al. 1998). The multi-agency 'Rapid Response Team,' tasked with traveling throughout the Pacific region to respond to credible BTS sightings, also relies on nocturnal visual searches as an important tool for snake intervention (alongside trapping and detector dog searches).

To date, the BTS project has used two main types of headlamps. The first, used only on Guam due to restrictions on air transport of wet cell batteries, is a powerful spotlight lamp. The Rapid Response Team also uses a lightweight headlamp that runs on 4 C-size batteries. When searching for snakes, the latter is normally set to the halogen spot mode, rather than the less powerful LED flood mode. Both these headlamps have a very narrow light beam (about 7^o and 9^o, respectively, when set to spot mode) and can, thus, be characterized as true spotlights. We suspected, however, that it might be beneficial to use a wider floodlight beam when searching for snakes in dense vegetation. We decided to estimate the effect of beam width and light intensity on snake detection rate. To our knowledge, no formal test of this kind has previously been conducted, at least not focusing on amphibian or reptile surveys. We also investigated whether lamp properties interacted with detectability in reference to target perch height and distance from the searcher.

MATERIALS AND METHODS

Experimental Design

To test the effects of different headlamp properties on snake detection rate we designed an experiment that allowed us to investigate the separate effects of beam width (spot or flood) and light output (strong or weak). To reduce the confounding effect of different reflector properties we used one single headlamp model (Mila® 3-light Digital; manufactured by Mila Design & Tillverkning AB, Haninge, Sweden; www.mila.se/english/) and manipulated the two light characteristics independently. By using either a 5W or a 20W halogen bulb (i.e., not by dimming the lamp by the electronic circuit this lamp model features) we altered the light intensity. By shielding off the beam with a 220 mm long tube-like extension mounted in front of the reflector, and attaching a 22 mm wide iris at the end of the tube, we created a narrow spot light treatment (about 16^o) that differed from the non-manipulated wide flood light state (about 94^o). While shielding off the beam caused some drop in light intensity in the center of the beam, this effect was considerably smaller than the difference between the strong and weak power states (Figure 1). The lamp treatments obtained by our manipulations were classified as weak spot, weak flood, strong spot, and strong flood. We anticipated that different lamp types may suit different persons. We, therefore, let eight experienced snake searchers on our staff test all 4lamp types once each, allowing us to model searchers as randomized blocks. Each such test meant walking a 1 km roadside transect, looking for snakes in the scrub forest vegetation along the roadside. Since live snakes come and go, and since we wanted a reasonable spotting rate on which to base the analysis, we chose to ignore any live snakes and had the searchers look for dead snakes that we had placed in the vegetation along the transect. The snakes used were BTS that we obtained (dead and frozen) from the USDA Wildlife Services BTS control program. On the day preceding a transect search, we thawed 100 snakes and arranged them according to a stratified randomized snake placement protocol that was unique for each of the eight transects. Snakes were stratified in placement from the transect line (defined by red paint dots sprayed on leaves at eye-height along the edge of the vegetation lining the road side) to as far into the vegetation as 5 m, and from ground level to as high as 4 m above ground. This 20 m^2 cross section area perpendicular to the transect formed 20 'cells' (of 1 m^2 each). Five of the 100 snakes were allocated for placement in each cell. The exact location within a distance-by-height cell was chosen based on availability of suitable vegetation for snake attachment (using thin, black cable ties). Snakes allocated to the lowest level could also be placed on the ground.

The order with which the cell allocations appeared along the transect was randomized. If a gap in the vegetation prevented placement of a snake in its assigned cell at a certain transect meter mark, we chose the first available position in a random direction parallel to the transect line (i.e., distance-by-height cell assignments were maintained even if the randomized position along the transect was adjusted). Prior to mounting a snake we measured its snout-vent length (SVL) by stretching it along a tape measure. Once mounted, its mid-body position was measured with a precision of ca 0.1 m relative to the transect line and to the ground.

The searchers were familiar with the experimental design, but had no access to the snake placement protocols, and thus no knowledge on where a snake might be. The same roadside was used for all eight transect searches. The vegetation was a secondary forest with plant genera such as *Hibiscus*, *Leucaena*, *Premna*, *Guamia*, *Triphasia*,

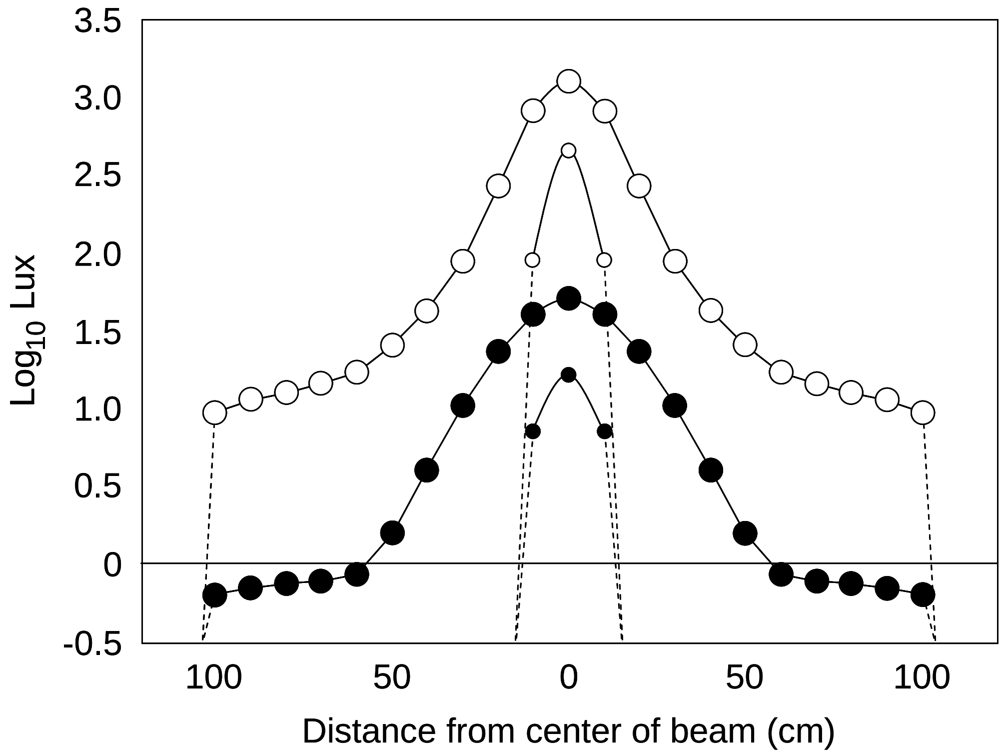

Figure 1. Light pattern and intensity of the four lamp treatments used in the experiment. The light intensity was measured with a Lux meter sensor positioned on a flat surface 1 m from the front glass of the lamp. Each symbol is the mean of 8 replicate measures taken in radiating directions from the center of the beam. Filled symbols indicate weak power treatments, empty symbols strong power, large symbols indicate floodlight treatments, and small symbols spotlight treatments. The edges of what the human eye perceives as the distinct beam(s) are indicated by dashed lines.

Eugenia, *Morinda*, *Artocarpus*, *Vitex*, *Pandanus*, and various other trees and shrubs.

Due to staff constraints we divided the study in two parts: a first phase in which 4 persons searched on 4 nights (each person conducting a transect search with a different lamp type on each of 4 nights) and a second phase for another 4 persons to conduct their 4 searches. We anticipated that searchers might get increased experience of the search method as the study progressed, so within each group of 4 searchers we let the order with which they tested the different lamps be determined by a randomized Latin square design. The searches took place in darkness (starting >50 minutes after sunset; no searches were scheduled during a full moon).

A searcher was sent out on a transect search accompanied by a note taker who had two roles in addition to data collection. First, the note taker made sure the searcher's walking speed during the search was kept at a constant 0.5 km/hr, a task aided by meter mark signs every 5 m on the transect and data sheets indicating times that certain meter marks should be passed to maintain the correct pace. Brief pauses for taking notes were not part of the 2-hr search. Secondly, the note taker associated each snake spotted by the observer with any nearby snakes' previously measured locations to determine which snake was found. This was possible since the data sheets stated the positions (distance perpendicular to the transect, height, and meter mark) of all snakes. Needless to say, this information was not disclosed to the searcher. The matching was made even easier for the note taker since the data sheet also said whether a snake had a stretched-out pose (85% of the snakes) or if it was coiled (15%). In case two nearby snakes were at obvious risk of being confused with one another, we normally placed one in a stretched position while the other was coiled.

Measuring Snake Visibility Through Vegetation

We expected reduced detection at greater viewing distances. This is a universal pattern used, for example, in distance analysis to estimate population densities (Buckland et al. 1993).

However, in our experiment, we did not use the information for density estimation but to discern if such a decline over distance was due primarily to the greater probability of vegetation obscuring a snake with increasing distance or for other reasons (e.g., a snake appearing smaller and less-well lit and therefore harder to see at greater distance). To describe the vegetation effect at different distances from the transect we pooled the vertical layers. Snakes were thus classified and grouped only in horizontal 1-m intervals from the transect line. A searcher walking a transect line does not look only perpendicularly into the vegetation, he/she also looks at some angle ahead, and, occasionally, somewhat backwards. To quantify the value of these oblique viewing angles, we prepared a 14-meter long rope by attaching tags every 1 m, the tags marked from -7 m to +7 m. During daytime we pulled this rope along the transect line and stopped when the 0-m tag was perpendicular to a focal snake. Our surveyor (who had good eye sight) located the snake and memorized its position. He then tried to spot the snake when standing on top of each of the fifteen tags on the rope. If the snake could be spotted from a meter mark tag, it scored as 1 for that situation; if not, 0. For each snake subjected to this procedure, we got 15 such scores. We deemed it unlikely that anyone would spot a snake from a more oblique view point.

We performed this test for 25 snakes on each of the 8 transects. On transect 1 and 5, visibility of snakes #1-25 were scored; on transect 2 and 6, snakes #26-50 were scored, and so on. We then grouped snakes placed in the five 1-m intervals perpendicular to the transect line (the horizontal snake placement aspect) and calculated the mean spotting success (based on 0/1 data) for each meter step along the survey rope. In this way, the detection rate from the points perpendicular to the snakes, and for every meter mark away from those points (up to ±7 m), was expressed as a percentage. For example, focusing on snakes placed 1-2 m from the transect line, we might find that 90% could be spotted from the transect point perpendicular to the snake; 85% could be spotted at points 1 m on either side of it; 78% could be spotted from points ±2 m away, and so on. Because this was merely an aid to better appreciate the influence of vegetative structure, our analyses were limited to graphical and verbal summarization of the results.

Statistical Analysis

Our main question was simply "Do the number of snakes spotted depend on any of the lamp variables?" The counts obtained were far enough from the end points of the distribution (0, 100) to allow use of non-transformed data in the analysis.

We assumed that the eight observers would differ in their ability to spot snakes. To control for this confounding effect we included the random effect variable Observer in the model. It soon became obvious, however, that the snake spotting rate also differed substantially between the eight transects. We, therefore, adjusted for the random effect variable Transect in the analysis. Even though our experimental design cancelled out any systematic bias of treatment order (i.e., searcher experience of the set-up) there could still be an order effect that added unexplained variation to the data. Hence, we included the covariate Sequential order modeled as a linear trend. We tested for an interaction effect between Beam and Power while the other variables were modeled without interactions (partially due to lack of replication). The full model can thus be written as:

y = intercept + Transect + Observer + Sequential order + Power + Beam + Power x Beam

where y is the predicted number of snakes spotted during a transect search. The analysis treats both Power and Beam as factorial variables. As pointed out above, shielding off the beam caused an undesired drop in central beam intensity. While it was therefore tempting to treat Power as a continuous variable (taking four values), there were two reasons we did not do so. First, the light intensity in the center of the beam was not representative of the entire beam. In the flood light treatments, the majority of the beam had a light intensity much lower than the corresponding spot treatments. Second, it was not evident which measurement scale to use for the light intensity measure, as this is an issue of questionable linearity in light perception. We chose the most easily interpreted analysis method: treating Power as a category variable, taking only two states (strong, weak).

We used an information theoretic approach to evaluate the relative evidence for alternative candidate models (i.e., when successively dropping one or more independent variables). We first tested the full model to see if the confounding variables (Transect, Observer, and Sequential order) and the interaction between Power and Beam had any effect and would be relevant to include in subsequent models. Variables with little or no explanatory value were dropped before we defined and estimated four plausible models: two models with mixed effects and two with only fixed effects (PROC MIXED, SAS Institute 2003). To obtain correct parameter counts used for calculation of Akaike's Information Criterion (AIC), we used maximum likelihood (ML) as the estimator instead of the default restricted maximum likelihood (REML) [see also Gurka 2006 for a discussion on ML and REML in linear mixed models]. Hand calculation of the AIC_c statistics [the subscript 'c' indicating a small sample adjustment of the AIC value (Burnham and Anderson 2002)] verified that AIC_c values produced using maximum likelihood in PROC MIXED were correct. Random effect variables should not be subjected to statistical tests, and are here merely treated as confounding nuisance variables. Therefore, we do not report on these effect sizes but instead emphasize the lamp-design variables.

RESULTS

How Many Snakes were Spotted?

Of the 100 snakes that were mounted along each transect, observers spotted an average of 13.5. While mean number of snakes spotted by each observer during his/her 4 transect searches varied between 12.0 and 16.8, the effect size of the random factor Observer was estimated as zero. Obviously, the variance within observers was greater than between observers, thus the lack of a between-subject effect. Also the interaction between Power and Beam failed to show an effect (95% CI = +2.0 to -6.5). Transect, however, did have some explanatory value in the full model (the 8 transect nights had mean snake sighting values ranging from 10 to 18.5, resulting in a parameter estimate >0), as did the covariate Sequential order (95% CI = -0.2 to -2.8).

We ended up with 4 plausible models with all containing the main effects of Power and Beam, in the 4 possible combinations with (or without) Transect and Sequential order (neither of them modeled with any interactions). When ranking the 4 models by ΔAIC_c (Table 1), both of the top models contained the covariate Sequential order. The effect was in the opposite direction than expected: the Observers saw, on average, 1.5 fewer snakes for each consecutive transect search (for the top model, 95% CI = -0.4 to -2.5). The intercept of the top model was 22.9 (95% CI = 19.5 to 26.2). To better appreciate the lamp trait effects, setting Sequential order to 2.5 (i.e., after an observer had conducted half of his/her transect searches) in the top model renders an 'experience adjusted' intercept of 19.2. Given the effect coding it means that approximately 19 snakes should be sighted when a strong floodlight is used.

Table 1. Summary of Akaike's Information Criterion (AIC_c) statistics for modeling snake sighting rates with different lamp types. Variables are coded as follows: T = Transect; O = Observer; S = Sequential order; P = Power; B = Beam; PB = interaction Power × Beam. Transect and Observer were treated as random variables. All variables but Sequential order were coded as factorial. Models with a ΔAIC_c <2 have considerable support (Burnham & Anderson 2002). *K* is the number of parameters and includes an intercept; w_i is the Akaike weight.

Models	**-2LogLikelihood**	***K***	**AIC_c**	**ΔAIC_c**	**w_i**
S + P + B	169.73	5	182.04	0.00	0.51
T + S + P + B	168.52	6[1]	183.88	1.84	0.20
T + P + B	172.32	5[1]	184.63	2.59	0.14
P + B	176.38	4	185.86	3.82	0.08
T + O + S + P + B + PB	167.46	7[1, 2]	186.13	4.09	0.07

[1] PROC MIXED (SAS Institute 2003) adjusts for the trace of the matrix of random effect variables in linear models and estimates *K* = 1 for random effects with parameter estimates >0.
[2] The AIC_c value of the full model does not include any penalization for factor Observer since the effect size was estimated as zero.

Both factors Beam and Power affected the snake spotting rate. The effect size of factor Beam in the top model was -6.9 (95% CI = -4.5 to -9.2), meaning that a strong spotlight search should result in 12 snake sightings. The effect of Power was somewhat weaker (-4.5; 95% CI = -2.1 to -6.9), translating to 15 snake sightings during a search with a weak floodlight. Combining the main effects, the model prediction for a search with a weak spotlight was 8 snake sightings.

If we consider spotting 19.2 snakes with a strong floodlight as a baseline value, the decline in predicted snake sightings using other lamp types can be given as a percentage for better data transparency. When swapping to a weak floodlight, the search efficacy drops by 23%, while a strong spotlight results in a 36% decline. Choosing a weak spotlight constitutes a 59% drop in snake sightings relative to a search using a strong floodlight.

Which Snakes were Spotted?

Snake detection rate fell off rapidly with distance from the transect line (Figure 2). Also, few of the snakes placed on, or close to, the ground were detected (Figure 3). The grand mean positions of snakes spotted across the four lamp treatments and by the 8 observers were nearer to the observers and slightly higher than the mean positions of the target snakes (Figure 4).

Using the data on the 2800 snake spotting opportunities for which we have SVL data (7 Transects × 4 Observers × 100 snakes; SVL data for snakes on one transect were unfortunately lost), the mean detected snake (N = 375) had an SVL of 941 mm (SD = 349 mm) whereas snakes not spotted (N = 2425) averaged 915 mm (SD = 330 mm). However, the snakes used for setting up the different transects varied somewhat in size (SVL means ranging from 868 to 982 mm). The mean

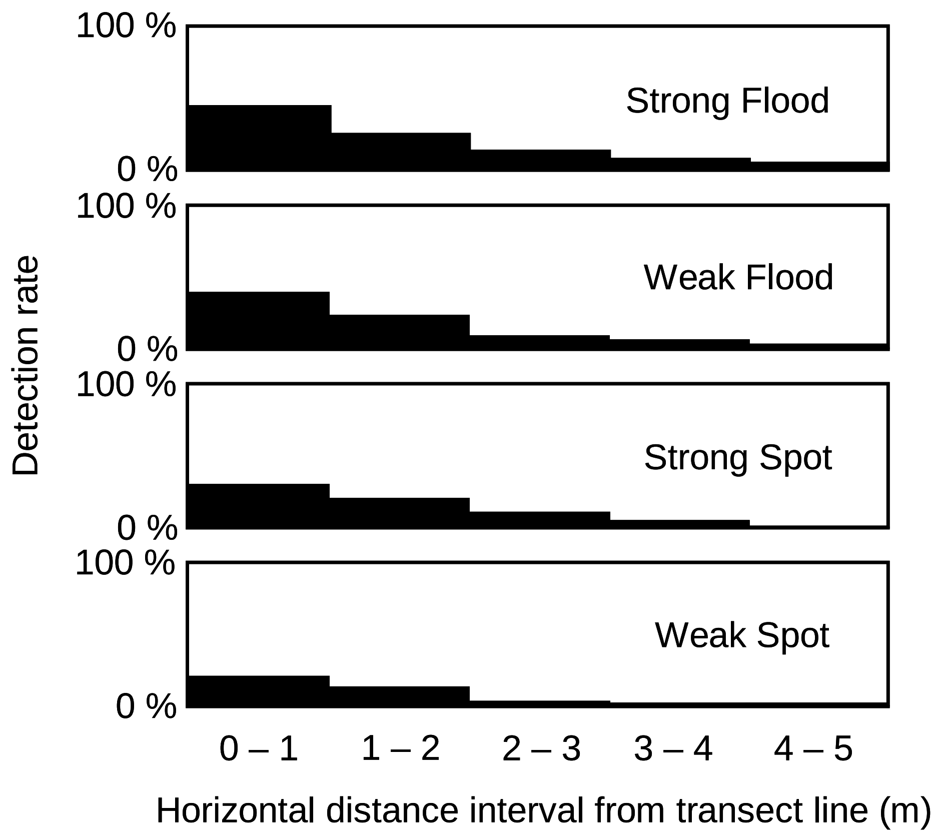

Figure 2. Detection rate of BTS by distance from the transect line for the four lamp types tested.

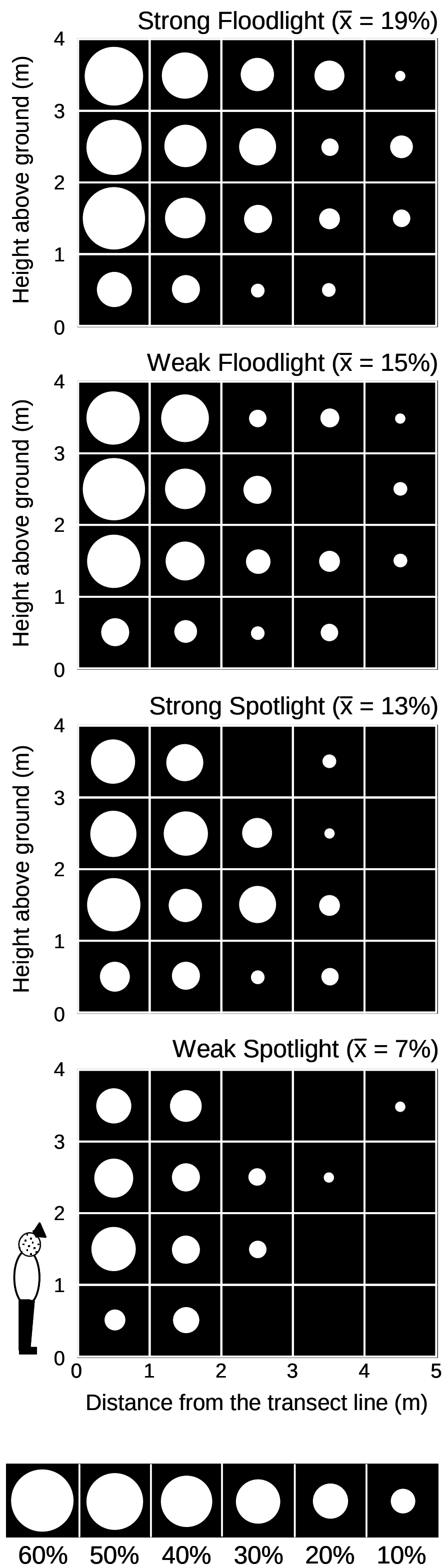

Figure 3. Detection rate of BTS per cell for the four lamp types tested. The area of each circular symbol relative to the area of the square 1×1 m cell it sits in correspond to the percentage of BTS spotted in that cell. While the legend below the four panels show 10% increments the size of the symbols are accurate to 1%. Percentages shown are the actual ones; not model predictions.

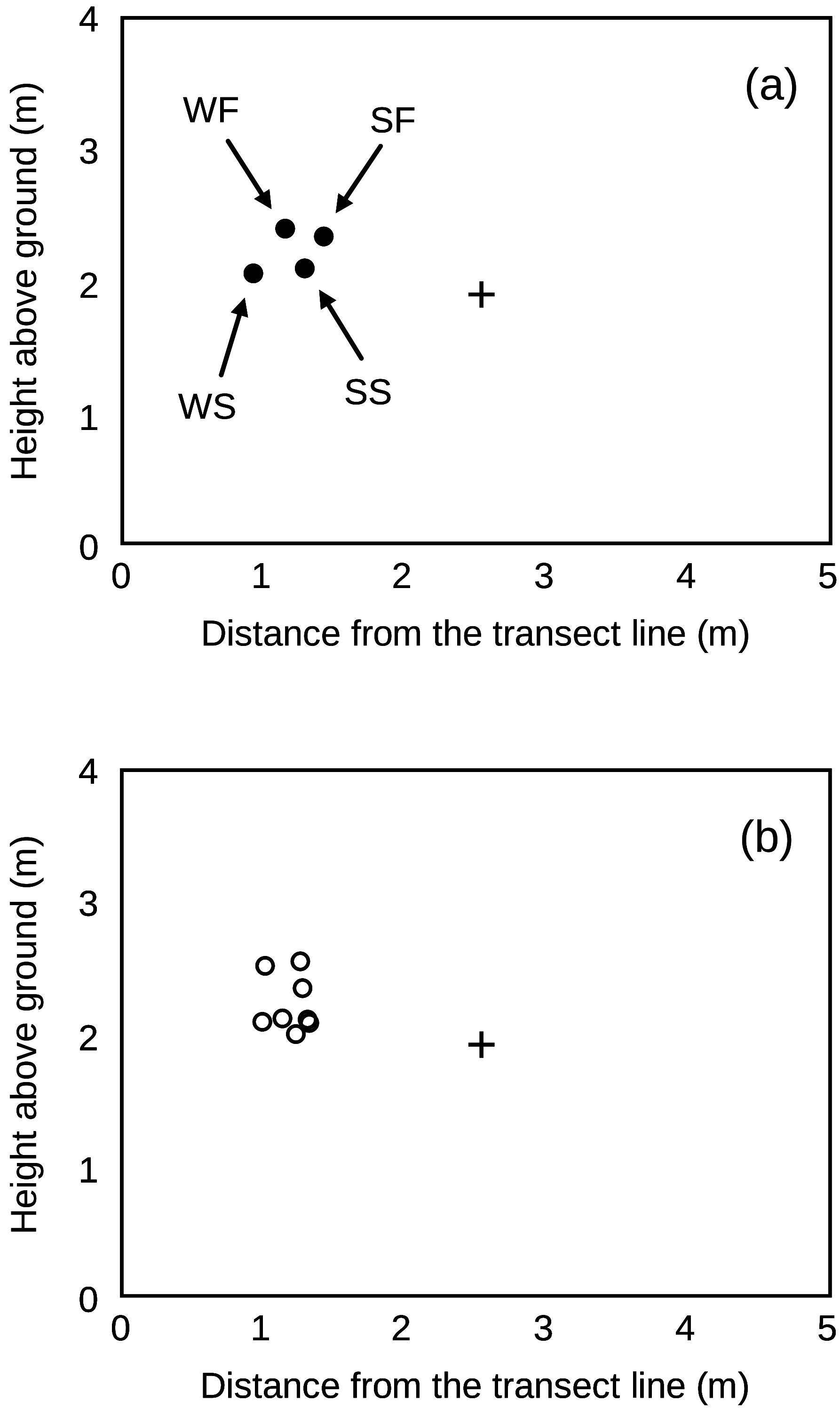

Figure 4. Mean positions of (a) BTS spotted with the different lamp types, and (b) by the eight searchers. The + sign indicates the grand mean position of BTS present; SF = Strong Floodlight, WF = Weak Floodlight, SS = Strong Spotlight, and WS = Weak Spotlight.

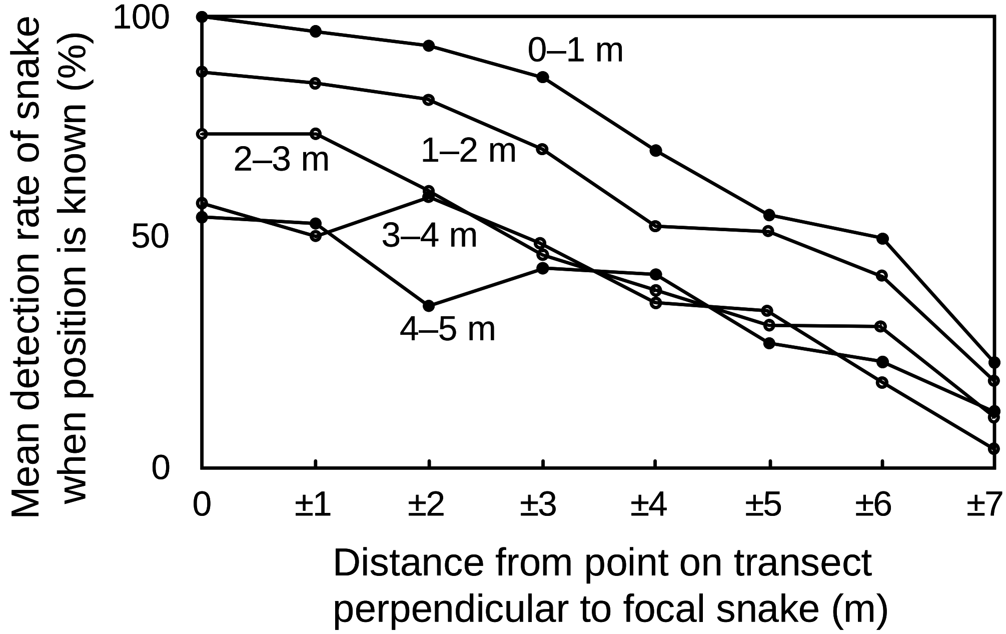

Figure 5. The effect of intervening vegetation on BTS visibility: detection rate of BTS known by the surveyor for five meter-wide distance intervals parallel to the transect line (indicated by figures next to curves) as seen from points perpendicular to the focal BTS (x = 0) and progressively more oblique viewing angles up to ±7 m from the perpendicular point. See the text for further explanation.

difference in SVL of snakes spotted versus not spotted on a given transect was 23 mm, with a bias in the direction of larger than average snakes being spotted.

Measuring Snake Visibility Through Vegetation

Snakes perched within 1 m of transects had average visibility rates >90% from any sampled point over a distance of 4 m along the transect (i.e., ±2 m from the point perpendicular to a focal snake, Figure 5). The farther one moves away from the point on the transect that is perpendicular to the snake, the longer the distance to the snake and the more vegetation likely to be obscuring it. This is illustrated by the curves in Figure 5 sloping off to the right. While the visibility dropped with a snake's distance from the transect, it must be realized that a lower visibility score – for example, 56% of the snakes 4-5 meters from the transect are visible when viewed from the 0-m mark – does not mean that the complementary figure (in this example 44%) of the snakes equally far into the vegetation cannot be seen from the transect. Even if a snake could not be spotted from one point it might have been visible from some other nearby point. For example, in our sample of 199 snakes (one datum excluded due to uncertainty of the snake's identity and thus its 'true' position) only 5% (N=10) could not be spotted from any of the 15 points we sampled. These "invisible" snakes were situated on average 3.8 m from the transect line and half of them were placed on the ground.

DISCUSSION

A floodlight beam was important for success in spotting snakes. It appears this effect was stronger than the power aspect; sighting rates dropped only moderately when shifting from a 20W floodlight to a 5W floodlight beam. The latter is good news for field workers that survey remote areas where access to electricity (and the option to re-charge batteries) is limited, since batteries will last four times longer with a 5W bulb than a 20W bulb. What eventually counts, however, is not the wattage as such, but the brightness of the emitted light. Different types of bulbs – and particularly when comparing regular bulbs with diodes – have different energy conversion efficacies, and thus emit more or less light for a given wattage. Given a certain bulb (or diode) type and wattage, there will also be a reflector dependent trade-off between light intensity and beam width; one may opt for either a brighter spot or a weaker flood illumination. What is the optimal trade-off in this situation may be dependent on several factors, including the habitat structure, how fast the searcher travels, and the study organism itself.

We believe that vegetation structure may have a significant effect on the relative merits of the beam types. When searching less complex vegetation structures – in the extreme, two-dimensional surfaces such as sandy desert, mowed lawns, water surfaces, or fences – a spotlight may be just as good (or better) than a floodlight. For such habitats or structures, vegetation does not obscure the view and a spotlight beam can be held close to the ground (water surface, fence) and the narrow beam used to scan the surface. Since the light is concentrated by a spotlight reflector, the light intensity of the beam, and thus the potential spotting range, increases. This is a good feature in open habitats, but of limited value in densely vegetated habitats. In the latter, a beam that allows a wider peripheral visual field is probably of more importance than the power of the light.

We also anticipate that the speed of walking may have an effect on the relative merits of spotlight versus floodlight lamps. The faster one walks the harder it is to search the entire vegetation of a complex, three-dimensional habitat. That effect is likely to be most evident when a spotlight is used, causing a Beam-by-Pace interaction. Adding the habitat complexity aspect, we may expect a Beam-by-Pace-by-Habitat interaction. It is notable that the headlamp we used (and several similar lamps, all of which feature floodlight reflectors) are designed for night orienteering. This sport is normally conducted in forests where it is important to detect branches, tree stumps, and other obstacles while running as fast as possible between control stations – a situation not dissimilar to searching for animals in a complex habitat under a severe time constraint.

The optimal walking pace will presumably differ not only with the lamp properties and the habitat structure, but also with the focal animals. The harder they are to spot (the smaller or the more cryptic) the slower the walking pace necessary to be to detect a certain proportion of the population within a given distance from the observer. We would thus predict that given a complex habitat, someone surveying small, cryptic animals would benefit more by swapping from a spotlight to a floodlight than would a searcher looking for large animals that stand out from the background.

With the level of replication used, there are issues that we could not resolve. For example, do observers differ in what is a suitable (or not so suitable) headlamp for them personally? This would be manifested as an Observer-by-Lamp interaction. Since each observer tested each lamp type (i.e., each of the four Power by Beam combinations) only once, we cannot test if there is such an effect. It is striking, however, that searchers using the least productive lamp showed a rather remarkable difference in success: the number of snakes spotted varied from 3 to 16 with the weak spotlight. These figures are however confounded by effects of Transect, Observer, and Sequential order with which the lamps were tested, so caution is warranted to not over-emphasize the differences.

Which Snakes were Found and Why?

While it may seem self-evident that smaller animals are harder to spot than larger ones, the size bias was actually very modest: snakes spotted were, on average, merely 23 mm larger than those missed. This corroborates previous results showing that visually searching for brown treesnakes is a method far less prone to size bias than trapping (Rodda et al. 2007). Had we searched a habitat where the visibility was greater, allowing animals to be spotted from farther away, the size bias might have been more pronounced. This is simply because the smaller an object, the more difficult to spot it from a long distance.

As expected, the snake detection rate declined rapidly with distance from the transect. However, vegetation density seems not to be the sole reason for this: recall that 95% of the snakes were visible from at least some point along the transect and almost all snakes within 1 m from the transect were visible from multiple transect points. Spotting snakes perched far into the vegetation is likely more difficult at night than during broad daylight (when our data on visibility was collected). This is because the illumination level of objects close to the searcher relative to that of distant objects differs substantially at night (but not during daytime), and spotting a weakly illuminated, distant animal through a layer of nearby, brightly illuminated leaves might be difficult.

Floodlight beams allowed us to detect snakes at a somewhat wider vertical range compared to searchers using spotlights, who detected a greater concentration around eye height (Figure 3). Most striking, however, is the low detection rates of snakes on or close to the ground, regardless of lamp type. This could in part be explained by the presence of herbaceous plants along part of the transect line, obscuring snakes at ground level. However, when watching the observers search for snakes, we also noted that they tended to spend only a small proportion of time scanning the ground. We saw searchers almost stepping on snakes sitting on the ground immediately by the transect line without noticing them. It appeared that observers were biased in directing their search efforts towards higher strata. Despite their common name, we know that brown treesnakes often move on the ground (Rodda 1989). This biased search pattern may, therefore, lead us to miss snakes that would be easy to detect, should we just look for them in the appropriate stratum. Judging from the mean perch height of snakes detected by our eight observers, they seemed to have reasonably similar search patterns (Figure 4).

Searchers' ability to find snakes declined over time. This drop in detection rate was large enough to be relevant in an operational context. While we have no certain answer to why this pattern was seen, we suspect the searchers were more observant when faced with a novel set-up coupled with the perception that the trials might be seen as a test of their ability to find as many snakes as their fellow searchers. Over time, they realized that they would not be able to find more than a small fraction of the snakes (and that being true also for the other searchers); thus they may have become more relaxed and less observant to the extent that the detection rate was negatively affected. This indicates some level of positive competition among searchers or perhaps a reward for finding snakes (Henke 1998) may be needed to maintain the highest possible detection rate during extended search efforts.

How Good Can we Afford to Get?

In the best of worlds, we would not have to trade one good lamp trait for another. Given ample power supply we might opt for a lamp that has both a wide beam and a high light intensity. The 20W floodlight used in this study match those criteria. With a 9Ah NiMH battery pack, weighing about 600 g, it lasts for about 2 hr 15 min in the 20W mode. Two battery packs (costing approximately US $125 each) are thus appropriate for an evening's field work. Those aiming for the best possible detection rates might aim for an even more powerful metal halide or LED headlamp. Marketed for orienteering and mountain biking, these come with re-chargeable lithium-ion batteries. While their wattages are typically similar to or somewhat lower than the halogen lamp we used, the amount of light emitted per watt is considerably higher – as is, unfortunately, the price tag. Even though the price of high-power floodlight headlamps might seem daunting, it is small compared to the cost of labor for extended search efforts. When used regularly, the price paid per snake detected is probably lower for high-end headlamps than cheaper models. Considering the possibility that high snake detection rate may be the difference between BTS succeeding in or failing to colonize another island, the economic benefits of using the best possible lamp increases even more.

ACKNOWLEDGMENTS

This research was conducted under Colorado State University animal care and use committee permit 06-193A-01. Funding came from the U.S. Department of the Interior's Office of Insular Affairs. The USDA Wildlife Services of Guam kindly supplied us with dead snakes from their invasive species control program. The US Navy permitted us to conduct the study on Navy property. We are grateful to R. Bischof, E. Fidler, G. Haddock, A. Hambrick, T. Hinkle, P. Reynolds, R. Stafford, A. Tuggle and K. Winford for help with the field work. N. X. Hinkle kindly donated soft drinks to thirsty field workers. M. Christy and J. Stanford gave comments on the experimental design and set-up. A. Yackel Adams, K. Burnham, P. Chapman, and T. Stanley provided valuable insight and help on statistical issues. A. Yackel Adams and A. Wiewel commented on the manuscript. Brand names are mentioned for information only, and are not known by the authors or their institutions to be better or worse than other products.

LITERATURE CITED

BEARDER, S. K., K. A. NEKARIS, AND D. J. CURTIS. 2006. A re-evaluation of the role of vision in the activity and communication of nocturnal primates. Folia Primatologica 77:50-71.

BUCKLAND, S. T., D. R. ANDERSON, K. P. BURNHAM, AND J. L. LAAKE. 1993. Distance sampling: estimating abundance of biological populations. Chapman and Hall, London.

BURNHAM, K. P., AND D. R. ANDERSON. 2002. Model selection and multimodel inference: a practical information-theoretic approach. 2nd edition. Springer-Verlag, New York, USA.

ENGEMAN, R. M., M. A. LINNELL, D. S. VICE, AND M. E. PITZLER. 1998. Efficacy of the methods used in an integrated program to deter the dispersal of BTS from Guam. Pages 435-440 *in* G. Pickles, editor. 11th Australian Vertebrate Pest Conference, Bunbury, Western Australia, 3-8 May 1998. Programme and Proceedings.

FRITTS, T. H. 1987. Movements of snakes via cargo in the Pacific region. 'Elepaio 47:17-18.

GURKA, M. J. 2006. Selecting the best linear mixed model under REML. The American Statistician 60:19-26.

HENDERSON, R. W. 2002. Neotropical treeboas - natural history of the *Corallus hortulanus* complex. Krieger, Malabar, Florida, USA.

HENKE, S. E. 1998. The effect of multiple search items and abundance on the efficiency of human searchers. Journal of Herpetology 32:112-115.

KRAUS, F., AND D. CRAVALHO. 2001. The risk to Hawai'i from snakes. Pacific Science 55:409-417.

MCCOID, M. J., AND D. W. STINSON. 1991. Recent snake sightings in the Mariana Islands. 'Elepaio 51:6.

RIBI, W. A. 1981. The phenomenon of eye glow. Endeavour 5:2-8.

RODDA, G. H. 1989. Foraging behaviour of the brown treesnake, *Boiga irregularis*. Herpetological Journal 2:110-114.

RODDA, G. H., AND T. H. FRITTS. 1992. The impact of the introduction of the Colubrid snake *Boiga irregularis* on Guam's lizards. Journal of Herpetology 26:166-174.

RODDA, G. H., J. A. SAVIDGE, C. L. TYRRELL, M. T. CHRISTY, AND A. R. ELLINGSON. 2007. Size bias in visual searcher and trapping of brown treesnakes on Guam. Journal of Wildlife Management 71:656-661.

SAS INSTITUTE. 2003. SAS/STAT software version 9.1, SAS Institute, Inc., Cary, North Carolina, USA.

SAVIDGE, J. A. 1987a. Extinction of an island forest avifauna by an introduced snake. Ecology 68:660-668.

SAVIDGE, J. A. 1987b. The ecological and economic impacts of an introduced snake on Guam and its threat to other Pacific islands. Ples 3:29-34.

SOMIYA, H. 1980. Fishes with eye shine – functional morphology of guanine type *tapetum lucidum*. Marine Ecology Progress Series 2:9-26.

STAVENGA, D. G., J. A. J. NUMAN, J. TINBERGEN, AND J. W. KUIPER. 1977. Insect pupil mechanisms. Pigment migration in retinula cells of butterflies. Journal of Comparative Physiology 113:73-93.