Canine detection of free-ranging brown treesnakes on Guam

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Abstract: We investigated canine teams (dogs and their handlers) on Guam as a potential tool for finding invasive brown treesnakes (*Boiga irregularis*) in the wild. Canine teams searched a 40 × 40 m forested area for a snake that had consumed a dead mouse containing a radio-transmitter. To avoid tainting the target or target area with human scent, no snake was handled or closely approached prior to searches. Trials were conducted during the morning when these nocturnal snakes were usually hidden in refugia. A radiotracker knew the snake's location, but dog handlers and search navigators did not. Of 85 trials conducted over four months, the two canine teams had an average success rate of 35% of correctly defining an area ≤ 5 × 5 m that contained the transmittered snake; the team with more experience prior to the trials had a success rate of 44% compared with 26% for the less experienced team. Canine teams also found 11 shed skins from wild snakes. Although dogs alerted outside the vicinity of transmittered snakes, only one wild, non-transmittered snake was found during the trials, possibly reflecting the difficulty humans have in locating non-transmittered brown treesnakes in refugia. We evaluated success at finding snakes as a function of canine team, number of prior trials (i.e. experience gained during the trials), recent canine success at finding a target snake, various environmental conditions, snake perch height, and snake characteristics (snout-vent length and sex). Success rate increased over the course of the trials. Canine team success also increased with increasing average humidity and decreased with increasing average wind speed. Our results suggest dogs could be useful at detecting brown treesnakes in refugia, particularly when compared to daytime visual searches by humans, but techniques are needed to help humans find and extract snakes once a dog has alerted.

Keywords: *Boiga irregularis*; brown treesnake; canine detection; detector dogs; invasive species

Introduction

The introduced brown treesnake (*Boiga irregularis*) has decimated the avifauna, eliminated several species of lizards, and has severely impacted fruit bats (*Pteropus mariannus*) on the Pacific island of Guam (Savidge 1987; Rodda & Fritts 1992; Wiles et al. 1995). Additionally, there are substantial economic costs associated with this introduction, including snake-caused power outages, foregone tourism, and increased shipping costs (Fritts et al. 1987; Fritts 2002; Vice & Pitzler 2002). These impacts and the risk of further spread associated with Guam's status as the hub for commercial and military shipments in the western Pacific make detection, containment and eradication of brown treesnakes an important objective.

Detector dogs are increasingly being used to find a variety of wildlife, from insects to carnivores (examples reviewed in Browne et al. 2006; Hurt & Smith 2009). They are particularly useful in finding sign (often scat) or actual individuals of threatened or endangered species such as grizzly bears (*Ursus arctos*) (Wasser et al. 2004), little spotted kiwis (*Apteryx owenii*) (Colbourne 1992), and desert tortoises (*Gopherus agassizii*) (Cablk & Heaton 2006). The ability of dogs to find cryptic or rare species has utility in various aspects of invasive species management. Dogs have been used in conjunction with trapping and hunting programs for invasive vertebrates (Veitch & Clout 2002; Campbell & Donlan 2005). In a study of island biosecurity systems for invasive rats, dogs correctly indicated rat activity on two occasions when all other detection methods failed (Russell et al. 2008). Detector dogs are used to find invasive quagga mussels (*Dreissena bugensis*) in California (California Department of Fish & Game 2009), and are being investigated for use in finding invasive snails (*Euglandina rosea*) (Whitelaw et al. 2009) and various invasive plants such as knapweed (*Centaurea maculosa*) (Goodwin et al. 2005).

Since 1993, detector dogs have inspected high-risk cargo leaving Guam for brown treesnakes. Detection rates averaged 62% for snakes in escape-proof containers planted in cargo without the knowledge of the dog handlers (Engeman et al. 2002). We questioned if dogs could be used for finding brown treesnakes in the wild on Guam, e.g. to ascertain if eradication has been achieved in an area, or for detecting potential incipient populations on other islands. Brown treesnakes are primarily nocturnal and although humans can detect them at night when the snakes are active, detection probability by human searchers is relatively low, about 0.07 per search occasion (Christy et al. 2010). During the day, brown treesnakes are usually well hidden in refugia amongst rocks, within dead tree branches or stumps, or up in the forest canopy, making visual detection by humans exceptionally difficult. Trained dogs, because they rely on olfactory cues, may be able to overcome this detection difficulty. Detection of brown treesnakes in the wild presents additional challenges when compared to cargo inspections, such as the risk to dogs of being poisoned by toads, distraction by numerous non-targets such as rats and chickens, searching in a highly complex three-dimensional forest in which dogs often cannot work on-leash due to obstacles, and variable weather.

Our initial work with canine teams (dogs and their handlers) on Guam demonstrated that they could find free-ranging brown treesnakes, but we had no idea of detection rates. Understanding the effectiveness of a detection technique is critical for management of an invasive species, but relatively few studies have quantified accuracy of detector dogs (i.e. the number of targets found divided by total available; Cablk & Heaton 2006). Accuracy has been determined under natural conditions for a known target population of endangered black-footed ferrets (*Mustela nigripes*) in prairie dog (*Cynomys ludovicianus*) colonies (Reindl-Thompson et al. 2006) and desert tortoise burrows (Cablk & Heaton 2006). In other situations researchers have resorted to using tethered target animals (tortoises; Cablk & Heaton 2006) or container-bound animals to quantify accuracy (e.g. brown treesnakes, Engeman et al. 2002; termites, Brooks et al. 2003). Confined targets offer logistical advantages, particularly in the case of invasive species that could present considerable risk if not recaptured. However, brown treesnakes are already established on Guam. We wanted to know if dogs could find wild brown treesnakes in locations chosen by snakes rather than by humans. Furthermore, during our initial dog evaluations using snakes in containers, our dogs appeared to use scent cues from containers and/or from humans placing the containers to help locate targets; thus we judged that container-bound snakes alone could not be used to assess accuracy of canine detection for brown treesnakes in the wild. Indeed, Nussear et al. (2008) attached transmitters on desert tortoises and found a 20% lower detection rate for dogs than that reported by Cablk & Heaton (2006) using tethered animals.

Our goal was to quantify canine team success at finding free-ranging brown treesnakes during the day in forest habitat on Guam. We also assessed the importance of several factors that might promote or inhibit detection by dogs including search team, number of prior trials (we predicted that success of canine teams would improve over the course of the trials due to experience), recent canine success (we predicted that dogs that had been recently rewarded might be more motivated and thus successful), environmental conditions, snake perch height, and snake attributes (size and sex). This is the first reported research on the ability of detector dogs to find known, free-ranging animals in the wild that could be located anywhere from below ground level to the top of the forest canopy.

Methods

Study area

We conducted trials in secondary forest in northern Guam dominated by exotic species including the tree *Leucaena leucocephala* and various vines and shrubs. Tree canopy averaged 4 m with some taller emergents. Discarded items such as appliances and cars, as well as several trash piles, were present. Various non-targets, such as domestic poultry, rats, and cane toads, *Bufo marinus*, were in our study area along with an unknown number of wild, non-transmittered brown treesnakes. The latter could have overlapping scent plumes with the target snake, potentially making it difficult for dogs to pinpoint a target. However, snake-free locations were not available on Guam, and it was considered too risky to conduct studies with free-ranging snakes on nearby snake-free islands. We did not determine wild brown treesnake densities in our study area, but a nearby habitat with similar vegetation had a population density estimated at 23 snakes/ha (Christy et al. 2010). Thus, we might expect 0–4 non-transmittered snakes within each of our search blocks (described below). The climate of Guam is tropical with little diurnal or seasonal variation in temperature. Our trials were conducted during the dry season and average monthly temperature and precipitation were 28° C and 100 mm, respectively (National Weather Service 2009).

Canine teams

We had two canine teams, each consisting of a dog (black Labrador retriever-mix) and its handler. Working Dogs for Conservation (Bozeman, MT, USA) in collaboration with Dogwerks All Breed Training (Missoula, MT, USA) selected the dogs and conducted the initial training of the canine teams. Training protocol was based on modified narcotic, forensic, and search and rescue techniques and included extensive use of box work (where a dog was encouraged to identify a box with a target brown treesnake in it amongst several boxes), handler-blind searches for snakes secured in tubes or mesh bags, and searches for wild snakes. Dogs signaled that they had found a brown treesnake either through their trained alert (sit, bark/sit or bark) or through on-scent behaviour, characteristic body language displayed by the dog when it encountered brown treesnake scent (as recognized by the handler). After successful finds the dogs were rewarded with a favorite play-toy. Dogs received 3–4 months of initial training in Montana, after which they were sent to Guam. At the time of our experimental trials, one dog (Canine Team 1) had been on Guam for 36 months and was considered competent to locate brown treesnakes in a variety of habitats. The same handler was with the dog for 24 months prior to the trials. The second dog (Canine Team 2) trained with his handler on Guam for 6 months prior to our trials. As with the first team, this team had demonstrated the ability to locate brown treesnakes in forested habitat.

Study design

We divided the study area into 36 search blocks, each 40 x 40 m, the borders of which were flagged to aid navigation during trials. We experimented with larger search blocks prior to our trials but determined that 40 x 40 m allowed teams to thoroughly search the area in the time allotted. Participants in each trial included a radio-tracker, the canine team, and a search navigator. The general approach was for a canine team to search a block housing a free-ranging, transmittered brown treesnake. Only the tracker knew the location of the target snake, and during a trial, the tracker remained behind the canine team to avoid influencing the search. The navigator helped ensure complete coverage of the area, recorded data (dog alerts, on-scent behaviour, break times, environmental data, etc.) and helped search for the target brown treesnake when requested by the handler. We conducted field trials from 27 December 2007 through 2 May 2008 at 0700–0900 hours, when snakes were expected to be in their daytime refugia. Although suboptimal from the standpoint of snake visibility, daytime searching facilitated communication between dog and handler and eliminated snake flight as a confounding variable in tests. A canine team participated in one trial per day and generally 3–4 trials per week, with a break from snake searching every third week.

We trapped snakes for the trials using standard brown treesnake traps baited with a live, protected mouse (Rodda et al. 1999; Engeman & Vice 2002). We placed traps outside the study area, and when a snake was caught, we put a dead mouse with a transmitter inside its body cavity within the trap as a food item for the snake. We used three different transmitters in the trials: BD-2HX, 1.92 g, Holohil Systems Ltd., Ontario, Canada; R1655, 1.2 g, and F1040, 2.6 g, Advanced Telemetry Systems, Isanti MN, USA). Previous work showed that snakes that consume mice with transmitters generally pass them within 5–8 days (Shivik et al. 2002).

If the snake consumed the mouse by the next morning, we moved the trap with the snake to the study area and opened the trap, allowing the snake to passively exit. We attempted to release snakes randomly throughout the study area. However, we avoided release in search blocks located on the edge of the study area, to reduce the potential for snakes leaving, and we also avoided releasing snakes in or adjacent to search blocks that had been recently searched. Humans never handled the snakes, thus minimizing or eliminating any human scent cues associated with the trial snake.

Each morning, prior to trial initiation, one or two trackers triangulated the location of transmittered snakes, avoiding approach within 10 m and never walking within 5 m of the snake. The tracker then walked throughout the search block to evenly distribute human scent. We aimed to use different snakes in each trial; however, since we did not always have enough available targets, some snakes were used in multiple trials (21 snakes were used twice and two snakes were used three times). Several factors influenced target selection for a given trial. First, to allow the snake to settle into the area, it could not be used on the day it was released. Second, a search block could not be searched two mornings in a row (to minimize any potential for residual dog scent). Third, if a snake had been used in a previous trial, at least 24 hours must have elapsed before it was used in a subsequent trial. Fourth, a canine team could search for a previously used snake only if the snake had moved to a different search block and had never been handled by humans (if a snake was captured after a trial, it was removed from the study area). Lastly, if both canine teams searched on the same morning, we separated the search blocks as far as possible; no searches were conducted in adjacent blocks to prevent the dogs from being distracted by the other team.

After a target snake was chosen, the canine team arrived with a navigator and was told which block to search. The team had up to one hour of actual search time. The handler could take breaks as needed during the trial, which were not considered part of the overall search time. Handlers independently decided their search strategy based on wind direction and terrain and whether to work their dog on- or off-leash during a trial (usually dogs were worked off-leash during the trials). Dog detection of a brown treesnake was determined by the handler and was based on the dog's alert or on-scent behaviour. When this determination was made, the handler designated an area $\leq 5 \times 5$ m to be searched. Generally, the handler and navigator would do a quick search for a visible snake. However, since snakes are rarely visible during the day, usually the handler and navigator left the area and remained out of view of the tracker while the tracker checked the location of the target snake. If the snake was within the designated area this was considered a success, and the handler gave the dog the opportunity to perform a second alert and be rewarded. We then attempted to capture the snake, aided by radio-telemetry, and whether captured or not the trial was terminated. If the snake was not present, the search continued. At the end of a trial, we measured the distance from all dog alerts to the transmittered snake.

Temperature, relative humidity, rain, and wind speed were recorded in the search block at the beginning and end of a trial. Additionally, wind direction was recorded during strong on-scent behaviour and all alerts. If a snake was captured at the end of a trial, we measured total length and snout-vent length (SVL) by gently stretching it along a tape measure, weighing it with a spring scale, and sexing it by either everting hemipenes or by probing. We also estimated perch height of the snake and recorded substrate where it was located (plant species, human-made object, etc.).

Occasionally, before, after, or as a break during a trial, a canine team searched for a snake in an escape-proof container (either a ventilated tube or dark-colored mesh bag). The tracker hid these snakes before the search, at least 40 m outside of the designated search block and in the prevailing downwind direction. The dog handler determined if and when they wanted to search for the captive snake; since the dogs were frequently successful at finding these targets, searches were generally implemented for dog motivation. Snakes used for this purpose came from a captive colony, and although the tracker used gloves when handling the tube/bag and an extension pole for placement, these targets probably had some associated human and/or container scent.

Analysis

We used logistic regression modeling (GENMOD procedure; SAS Institute, Inc. 2001) in program SAS to predict the success of canine teams in detecting free-ranging brown treesnakes. The independent variables were canine team, recent canine success (a binary variable defined as either finding a snake in an escape-proof container prior to the trial or finding a telemetered snake at the previous trial), number of prior trials, environmental covariates (percent cloud cover, rain [during trial or within the past six hours], average wind speed [km/h], average temperature [°C], and average percent humidity), and individual covariates of the snake (perch height, sex, and SVL).

We initiated modeling by defining 12 models that contained all five environmental covariates along with various combinations of canine team, recent canine success, number of prior trials (hereafter referred to as trial; modeled as a linear trend), and two interactions (canine team by trial and canine team by recent canine success). We quantified two metrics for rain but used only one metric in a given model; we retained the strongest predictor for rain in all subsequent modeling efforts. Non-environmental variables with support were used to build the balanced model set (n = 31 models) to fully evaluate the environmental covariates; each environmental covariate appeared in 16 of the 31 models. We then used the top two models from the balanced model set to evaluate the importance of individual snake covariates. We were able to evaluate perch height of the snake with data from all 85 trials, but because of missing data (not all snakes were captured as some defecated the transmitters and several transmitter signals quit before the snakes could be recovered), the remaining individual covariates of sex and SVL were evaluated with a subset of the data (65 trials).

Model selection was based on Akaike's Information Criterion corrected for small sample size (AIC_c; Burnham &

Anderson 2002). Models were considered competitive with the top-ranked model when ΔAIC_c was ≤ 2.0 (Burnham & Anderson 2002). We calculated a relative importance value of each environmental covariate by summing Akaike weights over every model in the balanced model set in which that covariate appeared (Burnham & Anderson 2002). An importance value of ≥ 0.5 indicates that a variable is important to the process being investigated (Barbieri & Berger 2004). All estimates are presented as means. We assessed covariate importance by evaluating slope estimates (β) and 95% confidence intervals, for which covariates with 95% confidence intervals not overlapping zero were considered influential.

Results

We conducted 85 trials: 43 for Canine Team 1 and 42 for Canine Team 2. Trials were conducted in 31 of the 36 search blocks. Using the criteria that snakes needed to reside in an area ≤ 5 × 5 m that had been designated by the handler, both teams combined found 30 of the 85 transmittered snakes for a 35% success rate (Table 1). Canine Team 1, which had been together longer as a team, had a success rate of 44% (19 snakes found) compared with 26% (11 snakes found) for Canine Team 2. There were nine additional trials that on examination of wind direction and distance of alert or on-scent behaviour to the snake might also qualify as successes. In these cases, the dog was relatively close to the target (1.0–6.2 m), but the handler did not correctly define the search area to include the snake (i.e. handler error). It took from 4–60 minutes of search time to find each of the 30 snakes. The teams also found 11 shed skins from brown treesnakes during the trials and one wild, non-transmittered snake. Of the 29 successes where distance was recorded, the alert or on-scent behaviour ranged from 0–12 m from the target snake, with 38% of alerts/on-scent behaviours within 1 m of the snake. There was no detectable wind when the dog alerted in 13 of the successful trials. In the other 17 successful trials, the dog was down-wind of the target snake (n = 12), upwind of the snake (n = 2), or wind was recorded as a crosswind (n = 2) or swirling (n = 1).

The dogs alerted from 0–6 times per trial and showed strong on-scent behaviour (behaviour that convinced the handler that a snake was present) from 0–3 times per trial in locations other than where the transmittered snake was located, with an average of 1.9 alerts/on-scent behaviours per trial. During the successful trials, dogs signaled using either their alert (sit, bark/sit, or bark; n = 19) or on-scent behaviour (n = 11).

Ambient temperature ranged from 23–34° C and humidity ranged from 68–100% during our trials. Wind speed ranged from 0–2 on the Beaufort scale with a mode <1 km/h (i.e. calm conditions). We used a total of 60 different snakes in the 85 trials (mean SVL = 988 mm, range: 729–1120 mm). The average and range of SVL's of snakes found by the canine teams were similar to SVL's of snakes used in the trials (Table 1). The sex ratio of snakes used in trials was slightly skewed towards males (37 males, 28 females), while dogs found close to an equal ratio (10 males, 11 females, Table 1). Target snakes ranged from 0.2 m below ground (a snake located in a buried appliance) to 6.5 m above ground in a coconut tree (*Cocos nucifera*). The majority of snakes were in refugia in trees at an average height of 2.7 m. Mean height of detected snakes was similar among canine teams and ranged from ground level to 5 m high (Table 1).

Of the variables (canine team, trial, recent canine success) and interactions (canine team by trial and canine team by recent canine success) initially evaluated, only canine team and/or trial were present in the top three models (ΔAIC_c values ≤ 2.0). We retained these two variables together in the balanced model set for fully evaluating environmental covariates. The top model from the balanced model set (table results for this modeling step are not shown) contained canine team, trial, wind, and humidity (model weight = 0.375). The very weak canine team effect (β_{team} = -0.970, 95% CI = -2.044, 0.044) was in the expected direction; the team with more experience had greater success (Fig. 1). The only other competitive model in the balanced set (model weight = 0.167) mirrored the top model with the addition of average temperature. However, average temperature had a beta estimate that was almost centered on zero (β_{temp} = -0.227, 95% CI = -0.812, 0.269). Importance values for the environmental covariates indicated strong support for relative humidity (0.901) and wind speed (0.837) and lacked support for average temperature (0.362), clouds (0.259) and rain in the past 6 hours (0.097).

We then used the two top models from the balanced model set and their various permutations (e.g. without canine team because the effect was marginal) to evaluate perch height (Table 2). The top model from this analysis contained only trial, wind, and humidity. Canine team success rate increased

Table 1. Results of two canine teams (one dog and handler per team) in finding free-ranging brown treesnakes in forested habitat on Guam. Target snakes had consumed a dead mouse with a radio-transmitter. Trials were conducted at 0700–0900 hours, when brown treesnakes are normally in refugia. To be counted a success, snakes had to be within a handler-designated area ≤ 5 × 5 m. Range is presented in parentheses.

	Team 1	Team 2
No. trials	43	42
Successful trials	19	11
Mean time (min) to find snake	28 (6–60)	24 (4–42)
Male:female ratio[1]	6:8	4:3
Mean SVL (mm) of snakes[1]	995 (729–1110)	1009 (870–1120)
Mean perch height (m)	2.8 (0.1–4.0)	2.9 (0–5.0)
Wild snake sheds found	7	4
Wild snakes found[2]	0	1
Time as dog team	24 months	6 months

[1]Sex and snout-vent length (SVL) of trial snakes were determined in 21 of 30 successful trials.
[2]Wild snakes other than those used in the trials.

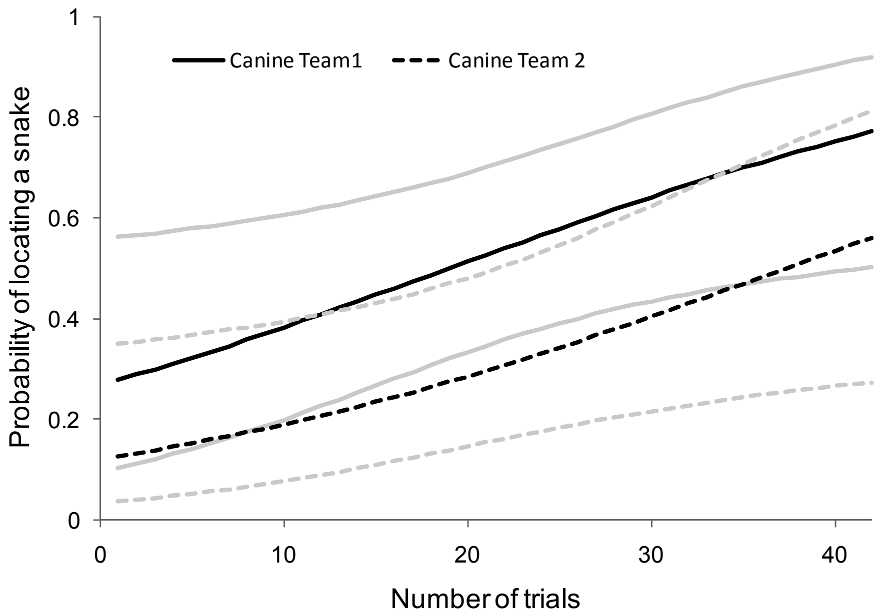

Figure 1. Logistic predictions generated from the top model in our balanced model set of the probability of locating a brown treesnake as a function of number of trials and canine team (Canine Team 1 = more experienced team, and Canine Team 2 = less experienced team). Corresponding 95% lower and upper limits provided in grey. Average humidity was held constant at its mean (88.9%) and wind speed was held constant at its mode (calm conditions: < 1 km/h).

Table 2. Model selection results for logistic regression used to predict the probability of finding a brown treesnake in a forested environment on Guam by canine teams. Results include the number of model parameters (*K*), relative Akaike's Information Criterion corrected for small sample size (ΔAIC_c), and Akaike weight (w_i). We used the two top models from the balanced model set and their various permutations to evaluate perch height (12 models total). See text for descriptions of variable names used in the models.

Models	*K*	AIC_c	ΔAIC_c	w_i
Trial + wind + humidity	4	100.5	0.00	0.295
Canine team + trial + wind + humidity	6	101.6	1.06	0.173
Trial + wind + humidity + temperature	5	102.1	1.55	0.136
Trial + wind + humidity + perch height	5	102.7	2.20	0.098
Canine team + trial + wind + humidity + temperature	7	103.2	2.69	0.077
Canine team + trial + wind + humidity + perch height	7	103.8	3.32	0.056
Wind + humidity	3	103.9	3.35	0.055
Trial + wind + humidity + temperature + perch height	6	104.4	3.84	0.043
Canine team + trial + wind + humidity + temperature + perch height	8	105.6	5.08	0.023
Wind + humidity + perch height	4	106.1	5.52	0.019
Wind + humidity + temperature	4	106.1	5.54	0.019
Wind + humidity + temperature + perch height	5	108.3	7.77	0.006

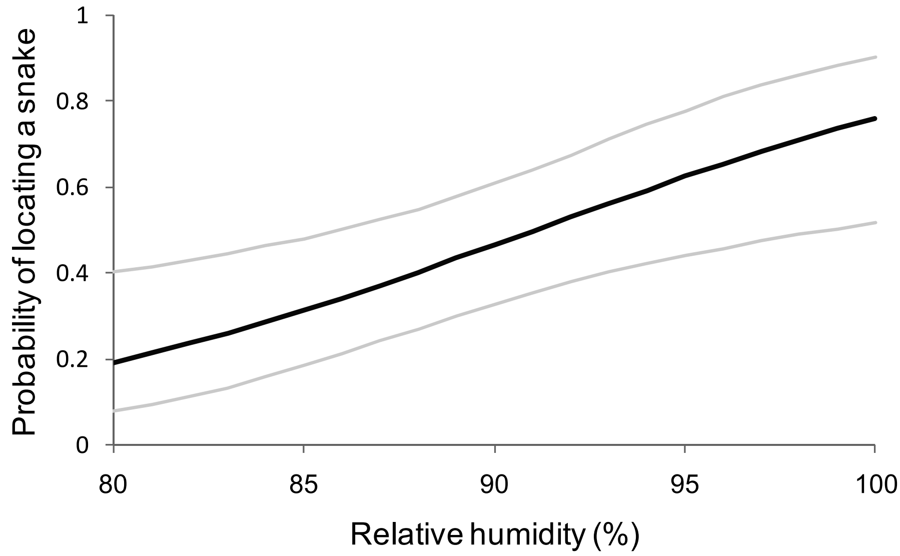

Figure 2. Logistic predictions (black line) and 95% confidence intervals (grey lines) generated from the top model in our final model set (see Table 2) of the probability of locating a brown treesnake as a function of average humidity (range based on the lower and upper fifth percentiles) on Guam. Average wind speed was held constant at its mode (calm conditions < 1 km/h) and trial was defined as the middle of the trial period (trial 22).

over the course of the trials (β_{trial} = 0.053, 95% CI = 0.009, 0.101) and with increasing average humidity ($\beta_{humidity}$ = 0.129, 95% CI = 0.045, 0.224; Fig. 2), but decreased with increasing average wind speed (β_{wind} = -0.902, 95% CI = -1.747, -0.187). At wind speeds of 0.5 and 3.0 km/h, the predicted probability of locating a snake declined from 0.43 (95% CI: 0.30-0.57) to 0.07 (95% CI: 0.01-0.31), respectively. Models containing perch height had no support; the best model containing this variable had a beta value that was almost centered on zero ($\beta_{perch\ ht}$ = -0.050, 95% CI = -0.468, 0.377). Similarly, models containing sex and SVL indicated no support for these variables (β_{sex} = -0.854, 95% CI = -2.194, 0.403 and β_{SVL} = 3.916, 95% CI = -3.050, 11.671).

Discussion

Our study suggests that dogs have utility in finding brown treesnakes during the day in a forested environment. However, inference from our results is limited due to small sample size (two canine teams) and use of one study area. Canine teams had an average success rate of 35% for correctly defining an area ≤ 5 × 5 m that contained a transmittered snake. The success rate is 46% if we include the additional nine trials for which the dogs may have detected the snake, but the handler incorrectly designated the search area. The more experienced canine team was about 1.7 times more successful than the less experienced team. However, the rising success rate over the course of our trials implies that experience from frequent searching could yield even higher success rates for both teams. Cablk & Heaton (2006) reported that dogs missed fewer tethered tortoises as their trials progressed and attributed this, in part, to learning by dogs and their handlers.

Our success rates were lower than that reported in other canine studies (e.g. 57–100% for black-footed ferrets, Reindl-Thompson et al. 2006; average of 91% and 93% for tethered tortoises and tortoise burrows, respectively, Cablk & Heaton 2006; 70% for transmittered desert tortoises, Nussear et al. 2008). Gsell et al. (2010) released radio-tagged, laboratory rats (*Rattus norvegicus*) and mice (*Mus musculus*) into a rodent-free forest sanctuary. These targets were closely followed by humans and then caught and either placed in hidden cages at the end of the scent trail or removed before dogs were tested. Dogs found an average of 84% of the rats or mice and/or their scent trails. Our dogs searched for a largely arboreal target in a spatially complex forest as compared to the relatively one-dimensional desert or grassland environment in which many dogs were tested. In the study by Gsell et al. (2010) in forest habitat, targets primarily left trails on the ground. Additionally, several studies listed above used animals (or scent trails) that may have had associated human scent; based on our experience, this may elevate canine success rates.

Trials were conducted at 0700–0900 hours, and we estimate most snakes had been in refugia for > 2 hours. Only one wild, non-transmittered snake was found during our trials, which is not surprising as it is very difficult for humans to find non-transmittered brown treesnakes in refugia. Dogs alerted or showed strong on-scent behaviour on average 1.9 times per trial, which is consistent with possible wild snake densities.

We modeled variables that could influence canine team success at finding brown treesnakes. Neither a recent reward nor measured characteristics of the target snakes influenced success. We also found no relation between perch height of the target and canine team success, but we hypothesize that detection of snakes would be more difficult in a higher canopy forest. Canine team success in our trials increased with increasing average humidity, an environmental variable thought to enhance scent (Syrotuck 1972). However, with Guam's tropical climate, humidity is high and ranged from 68–100% during our trials. Indeed, we predicted that canine teams might become less effective with increasing humidity on Guam due to increased fatigue. Even though we had relatively little wind during our trials, canine team success increased with decreasing average wind speed. If searching a relatively small area, as in our study design, decreased wind speeds may allow scent pooling, or accumulation, helping dogs localize targets. Greater wind speeds disperse scent over a larger area, and may result in greater detection distances (Cablk et al. 2008). Thus, we would expect that if a team was searching a larger area, such as might occur in a deployment to another island, some air movement to transport odor molecules to the dog might be desirable; however, excessive wind might overly disperse scent, making detection difficult.

Relatively few studies have quantified canine success in relation to environmental variables and those that have were in temperate climates. Of the environmental variables analyzed by Shivik (2002), which included temperature and humidity, only highly variable wind was found to influence the time for a dog to find a hidden person; increased wind variability negatively affected a dog's ability to find the person. Climatic variables did not influence the ability of dogs to find free-ranging desert tortoises (Nussear et al. 2008) or scat of forest carnivores (Long et al. 2007).

Proper evaluation of canine team accuracy can be challenging. In our study area, odors were likely coming from multiple snakes, potentially overlapping, and confounding target detection. Additionally, cryptic species such as brown treesnakes in refugia are very difficult for human searchers to find. Our handlers gave a verbal reinforcement but did not reward their dogs when they signaled and a snake was not visually detected. Many of these alerts probably were on non-transmittered snakes, and we do not know if the inconsistency with rewards reduced dog motivation. Trials in a low-density snake environment would be desirable and would more accurately mimic detection of an incipient population on another island. Under such conditions, snake scent would be less ubiquitous and should allow dogs to more readily pinpoint the source. Our use of ingested radio-transmitters overcame the challenge of locating target snakes, allowed us to minimize human scent associated with the target, and have a quantified test of the efficacy of our dog teams. When possible, we recommend other studies evaluating canine teams employ free-ranging, transmittered targets. However, it may be necessary to contain invasives. Since brown treesnakes were already established on Guam, there was no potential of accidentally introducing this species to a new environment.

A key question is how do dogs compare with other techniques for finding brown treesnakes, including visual searches by humans? Scat-detecting dogs found up to four times as many kit fox (*Vulpes macrotis mutica*) scats along transects than an experienced person (Smith et al. 2001). Dogs found twice as many avian carcasses amongst dense vegetation when compared to humans (Homan et al. 2001). However, canine teams and humans had the same detection rates for desert tortoises (Nussear et al. 2008). Dogs may be particularly useful in finding brown treesnakes during the day, when they are otherwise largely undetectable by humans. Although detection, in and of itself, is important for management programs, subsequent capture is obviously desirable. Daytime capture rates for snakes would be much lower than our detection rates; we were successful at finding our target snakes only because they had transmitters. Techniques for finding and extracting snakes from refugia are needed.

It remains to be determined how good dogs are at finding brown treesnakes at night. Visual searches by humans at night have been an important control tool for brown treesnakes and are considered effective for detecting all size classes of snakes (Rodda et al. 2007), but visual detection probability for humans is only 7% per search occasion (Christy et al. 2010). In an experiment where dead brown treesnakes were placed at various heights in vegetation and distances from a transect, human detection of snakes at night fell off rapidly beyond 2 m of the transect line and few snakes placed on or close to the ground were found (Lardner et al. 2007). Although we have no data on maximum detection distances of snakes by dogs, it is reasonable to assume they can detect snakes in thickly vegetated forest habitat on Guam over a greater distance by olfaction than can humans by sight.

A large, multi-agency response team with early detection and rapid response capabilities for assisting Pacific islands with invasive snake concerns was established in 2002 (Stanford & Rodda 2007). Trained human searchers respond to nonnative snake sightings on other islands and depend heavily on visual searching and snake traps. Where time is of the essence and/or when brown treesnakes occur at very low densities, such as when trying to ascertain if a population of snakes has established or if snakes remain after an eradication effort, detector dogs may be particularly useful in supplementing human search efforts.

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