Aerial delivery of baits to brown treesnakes

John A. Shivik, Peter J. Savarie, and Larry Clark

Abstract The exotic brown treesnake (*Boiga irregularis*) has been implicated in the extermination of endemic species from Guam, and fears that it will be transported elsewhere have resulted in an intensive trapping and containment program. Current management methods do not depopulate large areas, a presumed prerequisite for the effective reintroduction of endangered native species, and logistically tenable techniques for removing snakes from remote forests are needed. Bait stations containing dead neonatal mice (*Mus musculus*) implanted with acetaminophen have been effective for depopulating areas of brown treesnakes, but a bait delivery system for effective use of toxicants on a large scale and in remote areas has yet to be developed, and the selectivity of air-dropped baits requires assessment. We developed and tested aerial delivery methods of distributing baits in forest canopy on Guam by implanting baits with radiotransmitters. We recorded bait uptake by snakes and other species and measured morphology and movements of snakes that consumed baits. Bait take by snakes was high (63%) using parachuted baits designed to entangle in forest canopy, and snakes moved 1–70 m after consuming baits. Snakes that consumed baits were of similar size, weight, and body condition to snakes captured in traps on the drop areas. Implanting transmitters in carcass baits was a useful method for monitoring brown treesnake movement for 5–11 days post-consumption.

Key words bait, *Boiga irregularis*, brown treesnake, Guam, movement, radiotelemetry, snake

The brown treesnake (*Boiga irregularis*) is a nocturnal Australasian colubrid predator and scavenger with a wide and ontogenetically shifting diet (Savidge 1988, Chiszar 1990, Rodda 1992, Shivik and Clark 1999). After arriving on Guam in the late 1940s or early 1950s (presumably as a stowaway in cargo), the population irrupted and expanded across the island (Rodda et al. 1992). The snake caused the decline and extinction of avifauna and herpetofauna, numerous power outages and loss of domestic animals, and is likely to be transported elsewhere (Fritts et al. 1987, Savidge 1987, Fritts and McCoid 1991, McCoid 1991). Therefore, the United States Department of Agriculture (USDA) has implemented a containment and monitoring program in areas (i.e., commercial and military cargo shipping facilities) where snakes have some likelihood of being transported from Guam (USDA 1996).

Traps are the most intensively used management tool (D. S. Vice, USDA, Animal and Plant Health Inspection Service, Wildlife Services, Guam, personal communication), but maintenance of live mice (*Mus musculus*) used as attractants requires animal care that is labor-intensive and expensive. Although trapping is an effective technique for snake removal (Engeman and Linnell 1998; Engeman et al. 1998*a*,*b*), evidence indicates that some snakes have reduced susceptibility to traps, thus limiting their effectiveness (Rodda et al. 1999*a*).

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Furthermore, a simple inanimate trap-lure has been difficult to find due to environmental factors and behavioral proclivities of brown treesnakes on Guam (Shivik and Clark 1997; Shivik 1998; Shivik et al. 2000*a,b*).

A containment program has been instituted based largely on the logistically intensive technique of trapping. However, a containment program is not the optimal management scheme because it does not clear snakes from large areas of Guam, which is presumably a prerequisite for effective reintroduction and growth of native endangered species populations. Acetaminophen can be used to control populations of brown treesnakes (Savarie et al. 2001); compared to traps, toxic baits are logistically and economically preferable for clearing snakes from large tracts of land (L. Clark, National Wildlife Research Center, unpublished data). The inaccessibility of many areas of Guam and the immense snake population, which in some areas has achieved densities of 100/ha on the 541-km^2 island (Rodda et al. 1992) make toxic baits especially practical. Acetaminophen baits, as they are currently used (80-mg tablets inserted into dead neonatal mice and distributed in bait stations, Savarie et al. 2001), are limited, however, because they require accessibility to an area for the establishment of bait stations, and a broadcast method is required for treatment of large, remote areas.

We devised methods to broadcast dead neonatal mouse baits for brown treesnakes and tested them on Guam. We used streamer and parachute designs to promote entanglement in the canopy for maximal bait exposure to snakes and minimal exposure to terrestrial species. To study the effectiveness of bait delivery, we inserted miniature radiotransmitters into aerially dropped baits and monitored their fates. Our objectives were to monitor deployment of baits in the canopy, record snake consumption, and determine the distances snakes traveled after consumption. Furthermore, we gathered data on morphology of bait-consuming snakes relative to trap-captured snakes and identified nonsnake species that consumed baits. Corollary information included description of the application of miniature telemetry equipment inserted into baits as a means of gathering movement data on snakes. This information is necessary to design a scientifically based aerial drop program for eradicating brown treesnakes from large tracts on Guam, with a goal of enhancing areas for reintroduction of endangered species previously extirpated by the snake.

Study area

We identified 2 aerial bait-drop zones on Andersen Air Force Base, Guam. Drop area 1 was a 400 × 50-m zone of forest proximal to Tarague Beach and adjacent to an access road that bordered its long dimension. We dropped 20 baits on area 1 on 20 August 2001. Drop area 2 was a 300 × 50-m zone of forest immediately adjacent to drop area 1. We dropped 24 baits on area 2 on 22 August 2001. The areas contained a scattered canopy and dense subcanopy and understory vegetation on limestone-derived soils. Overstory plants included lagundi (*Vitex negundo*), cycad (*Cycas circinalis*), screw pine (*Pandanus dubius*), and kafu (*Pandanus fragrans*), and understory species included fagot (*Neisosperma oppositifolia*), lemondichina (*Triphasia trifolia*), paipai (*Guamia mariannae*), and pago (*Hibiscus tiliaceus*) and other species (Raulerson and Rinehart 1991). Animal species other than brown treesnakes known to inhabit the area included skinks (*Carlia fusca*, *Emoia caeruleocauda*) geckos (*Lepidodactylus lugubris*, *Hemidactylus frenatus*), marine toads (*Bufo marinus*), rats (*Rattus*

Helicopter dropping bait with streamer over Guam forest canopy.

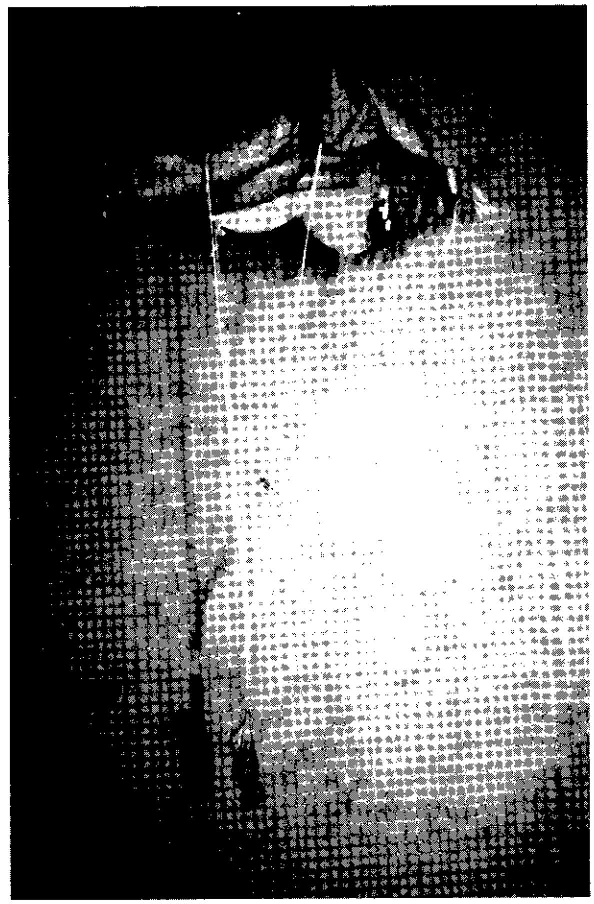
spp.), Philippine sambar (*Cervus mariannus*), feral pigs (*Sus scrofa*), and feral cats.

Methods

Baits

The objective of our research was the fate of baits, not toxic effects of acetaminophen; therefore, no toxic baits were deployed in this study. Instead, we defrosted 5-g neonatal mice, implanted them with radiotransmitters (Model F1620, Advanced Telemetry Systems, Isanti, Minn.), and deployed the transmittered mice baits. Transmitters weighed 1.9 g and measured 1.9 × 0.7 mm with a 10.2-mm whip antenna (<0.1-mm wire). We secured transmitters inside the mouse body cavity using cyanoacrylate adhesive (area 1) or thread (area 2) and extended antennas out of the body and along the tail of the mouse.

On area 1, we secured baits to a 60-mm loop of plastic flagging and counterweighted them with a 5-g wooden dowel to increase the probability of entanglement in the canopy. On area 2 we secured baits to 20-mm-diameter light-plastic (toy) parachutes for deployment. We secured baits to streamers or parachutes using a single strand of cotton thread knotted to one hind leg of the defrosted neonatal mouse. We dropped baits from approximately 30 m above the ground in straight-line passes over the drop areas using H-46D Sea Knight helicopters.



Mouse bait on parachute.

Data collection and analysis

Immediately after bait drop, we visually determined the location (including height in canopy) of baits with radiotelemetry. We monitored baits daily and recorded their fates (e.g., hung in canopy, eaten by a snake). When a snake consumed the bait, it was located the next day and captured. Movement in the first 24 hrs was the metric of concern because snakes that consume acetaminophen baits die within 12–36 hrs (P. J. Savarie, unpublished data), and we tried to determine the effective area where snakes were likely to disperse the toxicant beyond the point of consumption. We measured captured snakes' snout-vent lengths (SVL) and weighed and held them in individual cages to record the date at which transmitters passed through their digestive tract and were expelled.

To address the question of differential susceptibility of snakes to traps and aerially delivered baits, we also used traps to collect reference snakes from the 2 plots. We compared morphology of trap-captured snakes to morphology of telemetered and subsequently hand-captured snakes. We captured reference snakes using 10 (5 on each area) standard 50-mm-length × 21-mm-diameter wire mesh USDA, Animal and Plant Health Inspection Service, Wildlife Services-designed brown treesnake traps. Each trap had one-way flap doors on each end and contained a live mouse lure. From 25–29 August 2001, we collected reference snakes in an effort to obtain a sample collection similar in number to that obtained using the bait and telemetry method. Upon termination of field work on 31 August 2001, all captured snakes were euthanized, frozen, and transported to the National Wildlife Research Center (NWRC, Fort Collins, Colorado) for analysis of body condition using an index of dissected fat-body weight/total body weight. Where appropriate, we made statistical comparisons of morphology between hand-collected and trapped snakes using *t*-tests, and received approval of study protocol from the NWRC Institutional Animal Care and Committee.

Results

Drop area 1

We dropped 20 baits on area 1 on 20 August, 2001. Eleven of the baits landed on the ground, 8 were suspended in the canopy, and 1 transmitter fell out of the bait and was immediately recovered. We observed 5 of the 8 baits in the canopy at a mean height of 6 m (we were not able to visually identify the point of entanglement for the 3 other baits). Of the 19 baits dropped and out the first night, 1 was eaten by ants, 3 by snakes (2 from the canopy, 1 on the ground), and 5 transmitters were found on the ground and no longer associated with the bait. Of the 10 remaining baits on night 2, 2 more were eaten by 1 snake, 1 was consumed by a toad, and 4 disassociated transmitters were retrieved. For one of these, the bait remained suspended in the canopy, and it was apparent that the transmitter had fallen out of the body cavity through the insertion point (evidently a failure of the cyanoacrylate adhesive to hold rotting tissues together). Of the 3 transmitters remaining on night 3, 2 baits were rotted away and the transmitters recovered, and the third bait was consumed by a snake. In summary, of the 5 snakes that ate 6 transmitters (32% of those successfully dropped), 3 transmitters were consumed from 8 canopy baits (38%) and 3 from 11 (27%) ground-placed baits.

Drop area 2

Nearly all (92%) baits dropped on area 2 ($n=22$) were entangled in the canopy at a mean height of 5.5 m. After night 1, snakes consumed 14 baits and we recovered 3 transmitters disassociated from the bait. After night 2, of the 7 remaining baits, we found 5 disassociated on the ground, 1 was collected from a rotted bait, and 1 was eaten by a snake. In summary, 15 snakes ate baits and transmitters (63% of those dropped), with 13 (59%, $n=22$) taking them from canopy baits and 2 (100%, $n=2$) from ground baits.

Snake movements and morphology

Of the 19 snakes that consumed baits, the mean overnight movement was 21 m (range 1-70 m). We captured 18 (7 M, 11 F) transmittered snakes by hand and 21 nontransmittered snakes (8 M, 13 F) in traps. Length, weight, and fat content of snakes captured by trapping or hand did not differ ($P>0.70$, Table 1).

Thirteen snakes (74%) expelled their transmitters while held in captivity, but we did not observe the process and were unable to determine whether transmitters were regurgitated or defecated. Snakes were remarkably consistent in expelling transmitters; 10 expelled them 5 days after consumption ($\bar{x}=5.5$, SE$=0.3$, range$=5$-8 days). Field work ended on 31 August 2001, and we euthanized the remaining 5 snakes before they passed their transmitters; how long transmitters would have remained in their gastrointestinal tracts under natural conditions was unknown, but 4 snakes had consumed the transmitter 8 days earlier and 1 11 days earlier. As determined from the necropsies of these 5 snakes, only 1 consumed the mouse back to front, thus folding the antenna back over itself and possibly causing it to lodge; most (4) snakes showed no evidence of transmitters being bound in the digestive tract. We found all transmitters in the stomachs of the euthanized snakes. Hypothesizing that smaller snakes had more difficulty passing transmitters, we compared sizes of snakes that expelled transmitters versus those that had not and found a clear trend, but opposite to our prediction. Snakes that did not expel transmitters were 16% longer (SVL range$=919$-1027 mm, $\bar{x}=973.6$, SE$=18.29$) than those that expelled them (SVL range$=591$-1104 mm, $\bar{x}=822.1$, SE$=35.3$; $t_{16}=2.6$, $P=0.02$).

Discussion

We demonstrated that baits could be dropped and entangled in the canopy using a relatively simple system. These baits were effective for selectively delivering radiotransmitters and, inferentially, toxicants to brown treesnakes. We found only 1 instance of a nontarget vertebrate species consuming the bait (an exotic toad), but found many transmitters disassociated from their baits. We

Table 1. Mean morphometric differences between snakes that consumed transmitters and then were hand-captured versus those captured in traps 21–29 August 2001 proximal to Tarague Beach, Guam.

	Hand-captured			Trapped					
	n	$\bar{x}$	SE	n	$\bar{x}$	SE	t	df	P
Snout-vent length (mm)	18	864.2	30.5	21	871.8	26.0	0.19	37	0.85
Weight (g)	18	73.6	8.0	21	77.4	7.2	0.36	37	0.72
Percent fat	18	4.0	0.5	21	4.0	0.4	0.12	37	0.90

believe that transmitters were often ejected from baits during the constriction associated with snakes swallowing the baits. Other transmitters fell out as baits rotted or were regurgitated by snakes that had eaten the baits. We cannot unequivocally demonstrate that all disassociated transmitters were not caused by another species consuming the bait piecemeal (e.g., coconut crabs, *Birgus latro*). In reference to a toxic baiting program, preliminary studies indicated that nonsnake species were not as susceptible to acetaminophen baits as are brown treesnakes; for example, coconut crabs did not consume acetaminophen pellets in neonatal mouse baits (P. J. Savaric, National Wildlife Research Center, unpublished data). Fish crows (*Corvus ossifragus*, a model species for the endangered Marianas crow, *Corvus kubaryi*) consumed carcasses piecemeal, rejecting the acetaminophen dose and also recovered after being force-fed an 80-mg dose used in a brown treesnake acetaminophen bait (M. L. Avery, National Wildlife Research Center, unpublished data). Furthermore, none of 20 captive rails (*Rallus owstoni*) on Guam consumed dead mouse baits (P. A. Dunlevy, National Wildlife Research Center, unpublished data); however, 4 zoo-raised Guam rails were enticed to consume neonatal mouse baits. Therefore, we cannot entirely preclude the possibility of a desirable species eating broadcast baits, even when they are designed to entangle in the canopy (e.g., 8% of baits in drop 2 landed on the ground, this study).

The use of a bait rather than a trap-and-attractant system remains appealing, however, because the logistical difficulties of trapping in remote areas makes wide-scale snake depopulation using traps unfeasible. Therefore, we believe that continued development of a broadcast baiting program for depopulating brown treesnakes from large areas on Guam is necessary. However, an aerially dropped brown treesnake bait still requires research and development before wide-scale use. Future work should focus on developing automated or simplified attachment of baits to biodegradable parachute systems as well as automated bait-delivery mechanisms for rapid ejection during fixed or rotary wing deployment.

Mass-delivery of baits using an aerial technique may also allow for rapid snake depopulation, thus readying areas for the re-introduction of endangered species, but not subject the ecosystem and other species to long-term presence of a toxicant. That is, a program of long-duration low-effort toxic baiting is less desirable than high-intensity short-duration baiting because long-term baiting could pose risks to reintroduced indigenous species, but aerial baits delivered antecedently impact snakes almost exclusively.

In the literature, the effect of snake size on susceptibility to management techniques remains equivocal. For example, Rodda et al. (1999*a*) concluded that current trap designs preferentially captured medium-sized and large snakes, but Rodda et al. (1999*b*) reported contrary results, indicating that juvenile snakes (<800 mm SVL) were relatively easy to capture (i.e., juveniles were 4 times as likely to be captured as adult males). In our study, however, we did not detect a bias in capture rate by size class using traps, based on comparison to snakes that were transmittered and then hand-captured. Although Shivik and Clark (1999) suggested that smaller brown treesnakes were more likely to be captured in traps baited with mouse carrion, our current data suggested that aerially dropped baits exposed all size classes of snakes to a toxicant. Similarly, based on fat-content analysis, there was no indication that snakes that ate carrion baits were less adept foragers or "hungrier" than those lured into traps using live mice.

We explored a new technique of distributing carcass baits implanted with radiotransmitters as a means of marking brown treesnakes for movement analyses. Use of transmitters in baits for studies of snake movements might be limited because brown treesnakes usually expelled the transmitters in 5 days. However, this technique was less invasive than surgical implantation of transmitters and can be performed on much smaller snakes (e.g., 591 mm SVL) than previously attempted (Tobin et al. 1999). Also, questions regarding transmitter fate within snakes should be a topic of research because of differential expulsion of transmitters by different-sized snakes. We hypothesize that smaller snakes did not pass the transmitters through their digestive tracts, but rather regurgitated them after passing the digestible components of the bait past the pylorus, and that larger snakes retained the transmitters in their stomachs, which could allow them to be tracked for the life of the transmitter (rated at >2 weeks, Advanced Telemetry Systems, Isanti, Minn).

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