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Abstract: Polyvinyl chloride (PVC) tubes are effective bait stations for delivering dead neonatal mice (DNM) treated with the oral toxicant, 80 mg acetaminophen, to brown treesnakes *(Boiga irregularis)* in accessible jungle forest on Guam. However, PVC tubes are not practical for delivery of baits to remote areas of jungle or the forest canopy. Further, it is important that baits entangle in the canopy and not fall to the ground where they can be scavenged by non-target animals such as crabs. Data from helicopter aerial deployment of untreated DNM with radio transmitters that landed on the ground in areas of high coconut crab *(Birgus latro)* and hermit crab *(Coenobita* spp.*)* abundance showed that 67% of DNM were taken by crabs and 11% by monitor lizards *(Varanus indicus)*. In contrast, in low crab abundance areas crabs took 24% of the DNM that landed on the ground. It is evident from these data that a flotation system that delivers DNM to the canopy is needed; otherwise non-target animals will remove DNM, making them unavailable for snakes. Seven aerial flotation devices were evaluated. Promising aerial devices are two types of commercial cardboard paper streamers that resulted in 75% - 85% of the DNM becoming entangled in the canopy.

Key Words: aerial delivery, bait, *Boiga irregularis,* brown treesnake, crabs, Guam, invasive species, parachute, radiotelemetry.

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INTRODUCTION

The brown treesnake *(Boiga irregularis)* is an invasive exotic nocturnal predator that was probably introduced on the snake-free island of Guam as a stowaway in cargo in the late 1940s (Fritts 1988, Rodda et al. 1992). In the absence of natural predators and an abundant food supply the snake colonized the entire island with population densities in some areas as high as 50-100 snakes per hectare (Rodda et al. 1992, Rodda et al. 1999). The brown tree snake is considered to be the primary factor responsible for the decline and extirpation of many native birds and lizards on Guam (Savidge 1987, Fritts 1988, Rodda and Fritts 1992, Drahos 2002) and the decline of fruit bats *(Pteropus mariannus)* (Wiles 1987). It is mildly venomous and poses a health risk to small children (Fritts et al. 1994), causes power outages by climbing on electrical transmission wires (Fritts et al. 1987), and preys on poultry and domesticated birds (Fritts and McCoid 1991). Guam is the focal point of air and ship cargo traffic in the northern western Pacific and there is a threat that snakes could be inadvertently introduced and establish breeding populations on other snake-free islands (e.g., Hawaii) in the Pacific region (Fritts et al. 1999). In 1993 the United States (US) Department of Agriculture (USDA), Wildlife Services, initiated an operational program to deter the spread of snakes from Guam using hand capture from fences during nighttime spotlight searches, trapping, and inspection of cargo with search dogs (Hall 1996, Engeman and Vice 2001, Vice and Vice 2004). However, these methods have limited use for reducing snakes in large inaccessible landscapes required for the reintroduction of endangered species (BTSCC 1996).

Dead neonatal mice (DNM) baits treated with 80 mg acetaminophen distributed in bait stations are effective for reducing brown treesnake populations in small 5-7 ha plots of accessible jungle forest on Guam (Savarie et al. 2001), but a practical system for broadcast of baits to inaccessible areas of jungle is not available. Since 2001, studies have been ongoing to develop aerial bait delivery techniques. Small plastic parachutes (Shivik et al. 2002) and paper corn starch devices (L. Clark, personal communication) hand dropped from a helicopter have been used as flotation devices for entangling dead mice in the forest canopy. Canopy entanglement was 92% for plastic parachutes and 42% for the corn starch paper. But both have negative aspects: plastic takes at least two years to degrade, and the corn starch paper dissolves in the rain (which can occur daily on Guam), dropping the bait to the ground. Savarie and Tope (2004) evaluated 5 biodegradable flotation devices; results were marginally successful with 62% canopy entanglement with a commercial food cup.

The primary reason for placing DNM baits in the canopy is to keep them from being taken by terrestrial scavengers such as feral pigs *(Sus scrofa)*, monitor lizards *(Varanus indicus)*, coconut crabs *(Birgus latro)*, land hermit crabs *(Coenobita* spp.*)*, and marine toads *(Bufo marinus)*. Baits taken by non-targets result in fewer baits available for snakes and, therefore, a proportionately higher number would have to be delivered to maximize snake control. Three aerial bait studies (Shivik et al. 2002, Savarie and Tope 2004, L. Clark, personal communication) conducted on Andersen Air Force Base (AAFB), Guam, in areas known to have low crab densities and high densities of feral pigs revealed no evidence that feral pigs took ground-placed baits; bait-take was negligible by monitor lizards (<1%); and 6-11% for crabs and toads. However, a study in an area of high crab abundance is needed to quantify the potential of this non-target to remove baits.

Data from 3 aerial bait delivery studies conducted on Guam using untreated thawed DNM are reported in this paper: (1) comparative bait-take by BTS and non-target animals for baits delivered in areas of low and high crab abundance, (2) efficacy of paper towel and biodegradable plastic-like parachutes for entangling in the canopy, and (3) efficacy of four commercial biodegradable paper products for entangling in the canopy. The sole purpose of studies 2 and 3 was to determine the ability of the parachutes to entangle in the forest canopy and bait-take was not recorded.

METHODS

Bait-take in Low and High Crab Abundance Areas

Four 50 x 200 m aerial drop sites adjacent to roads were selected, 2 on AAFB, Tarague Beach Road, and 2 on US Naval Base, Orote Peninsula. Both sites are secondary growth forests. Vegetation and trees on the Tarague site have been described (Shivik et al. 2002). Tangantangan *(Leucaena leucocephala)* is the predominant tree on Orote. To assess crab abundance on these sites, 3 lure stations were established at 72-107 m intervals along the midline of each of the 4 drop sites. Stations were baited with a fermented attractant mixture of boiled rice, shaved coconut, and water (USFWS 2001) with pieces of raw coconut in a 2 m diameter circle on the ground. Attractant mixture was replenished at least once daily for 3 days, depending on rainfall. Lure stations were checked prior to the aerial drops for 3 consecutive nights between 2000-2400 hr and numbers and species of crabs counted.

Unattached DNM (5-7 g, Essex Co., Blum, Texas) and DNM attached to biodegradable jute netting (20.3 x 20.3 cm, 5.7 cm thick mesh) by a 30.5 cm long cotton thread to a rear leg were deployed by hand from a US Navy Knighthawk MH-60S helicopter from about 30 m above ground level (AGL). Twenty (20) DNM baits (10 unattached and 10 attached to netting) were deployed per drop on each of the 4 drop sites during August-September 2004. A radio transmitter (Model F1620, 1.9 g, Advanced Telemetry Systems [ATS], Isanti, Minnesota) was attached to the abdomen of each mouse with polyurthane adhesive (Gorilla Glue Co., Cincinnati, Ohio) and the 10.2 cm external whip antenna extended along the tail of the mouse.

Immediately after each bait drop, baits were tracked by radio receiver and visually located on the ground or in the forest canopy and height (m) in the canopy estimated. Status of the baits was checked daily for 1-7 days and radios were recovered from baits not consumed. Snakes that consumed baits were captured, euthanized, and its distance (m) from the initial bait drop point was estimated. Body mass (g), snout-vent length (SVL, mm), and sex were recorded and radio transmitters recovered.

Biodegradable Parachutes

In September-October 2005, 2 aerial bait drops were conducted on 50 x 200 m drop zones; 1 each on AAFB, Tarague Beach Road, and US Naval Computer and Telecommunications Station Guam (NCTS, Haputo Beach Road). Vegetation on NCTS is similar to Tarague. Two types of biodegradable parachutes were evaluated: paper towel, 23.8 x 27.3 cm, A-A-696 Type 1 Singlefold, Lighthouse for the Blind, New Orleans, Louisiana; and a plastic-like material, 20.3 x 20.3 cm, EcoFilm®, Cortec Corp., St. Paul, Minnesota. Four pieces of cotton thread (3-30.5 cm long and 1-35.6 cm long) were individually tied to the corners of each parachute type. The threads were knotted and the longer thread was tied to a rear leg of a DNM.

A radio transmitter (ATS Model F1620) was glued to each DNM bait. Twenty parachutes (10 of each type of parachute with DNM) were delivered by hand from a Knighthawk MH-60S helicopter from about 60 m AGL on Tarague and from a Hughes 500 helicopter from about 30 m AGL on NCTS. Immediately after each drop, bait locations were determined by radiotelemetry and height in canopy estimated.

Biodegradable Paper Products

Four biodegradable commercial paper products were evaluated in August 2006: (1) single white flag, 3 m long x 10.2 cm wide paper streamer attached to cardboard on one end, (2) double white flag, 4.9 m long x 10.2 cm wide paper streamer attached to cardboard on both ends (single and double white flags from R-S Sales/Automatic Flagman®, Lewiston, Idaho), (3) paper plate, 22.9 cm diameter with daisy-like cutout pattern with intact outer edge, Wal-Mart, Bentonville, Arkansas, and (4) paper cup, 237 ml, Marfred Industries, Sun Valley, California. ATS Model R1645 radio transmitters (0.9 g) were glued to the abdomen of DNM. A rear leg of a DNM was secured to the cardboard on the single and double white flags with hot glue. Four lengths of cotton thread as described above were attached to the paper plates and cups tied to a DNM. The paper products were dropped by hand from a Hughes 500 helicopter from about 30 m AGL on a 50 x 200 m drop zone on NCTS, Haputo Beach Road. Five each of the 4 types of paper products were delivered on each of 3 drops, and 5 each of single white and double ender flags were delivered on 1 drop. Locations of baits was determined by radiotelemetry.

In each of the three studies, DNM were thawed and prepared the day before aerial delivery. They were then re-frozen overnight and thawed the next day before aerial deployment. In addition to the radio that was glued to each DNM, a 13 x 30 mm strip of pink flagging was also glued to each DNM to aid in visual identification.

As appropriate, descriptive statistics and chi-square analysis were used to analyze the data. A chi-square test was used to compare observed and predicted frequencies of bait-take in areas of low and high crab abundance. Proportions were in some cases, further examined using the chi-square subdivision method (Zar 1984). Subdivision was performed only when the initial test was declared significant ($P \leq 0.05$), and to minimize Type I error when evaluating a subdivision, significance was declared at $P \leq 0.01$.

RESULTS

Bait-take in Low and High Crab Abundance Areas

After observing crab lure stations for 3 nights, no crabs were recorded on the 2 sites on Tarague, whereas on the 2 Orote sites 44 coconut crabs and 9 land hermit crabs were recorded: 22 coconut crabs and 4 hermit crabs from one site, and 22 coconut crabs and 5 hermit crabs from the second site. Based on these numbers, Tarague was classified the "low" abundance crab site and Orote the "high" abundance site.

Bait-take and fate of baits on the ground at the low and high abundance crab sites are shown in Table 1. Frequencies of bait-take differed among bait-take categories ($\chi^2 = 26.0$, $df = 3$, $P < 0.0001$). Bait-take by crabs showed the largest deviation from its expected value, indicating take by crabs contributed most to the observed significance. Therefore, the chi-square was subdivided by removing bait-take by crabs from the analysis, which again, differed among categories ($\chi^2 = 14.6$, $df = 2$, $P < 0.0007$). Here, the category "other" (combined take by monitor lizards, toads, ants, and unknown) showed the largest deviation between observed and expected.

One of the 20 baits attached to jute netting dropped on Tarague, the low crab abundance site, could not be visually located. Of the remaining 19 baits, 5 (26%) landed in the canopy at a mean height of 4 m. Four of these 5 baits detached from the jute netting and fell to the ground, 3 after 1 day and 1 after 2 days. The bait remaining in the canopy was consumed by ants after 3 days. Seven of 14 baits that landed on the ground were detached from the jute netting. All of the 20 baits without jute netting landed on the ground.

On Orote, the high crab abundance site, 15% (3 of 20) of the baits attached to jute netting entangled in the canopy at a mean height of 3 m. One of the 3 baits was taken by a crab; 1 bait remained in the canopy for 3 days, and the fate of 1 bait could not be determined. The radio transmitter detached from one of the 20 baits attached to jute netting and was immediately recovered. One bait was consumed by a monitor lizard before it could be visually inspected and 11 of the 15 baits on the ground were detached from the jute netting. All of the 20 baits without jute netting landed on the ground.

Snakes consumed baits only at the low crab abundance site. Eight snakes consumed 9 baits from the ground and 7 of the 9 baits were taken on day 2 after the drop. The 8 snakes traveled a mean overnight distance of 29 m (range 6-95 m). Three of the 8 snakes that consumed bait were captured (2 females: 68.2 g, 826 mm SVL and 118.4 g, 990 mm SVL, and 1 male: 127.7 g, 1065 mm SVL). The other 5 snakes remained elusive, but their radios were expelled and recovered 2-7 days post-consumption. Two of the 9 baits (22%) consumed by crabs on the low crab abundance site were taken on night 1 and the remaining 7 baits on nights 2 and 3. On the high crab abundance site, crabs took 22 of 24 baits (92%) on night 1 and the remaining 2 baits on night 2.

Biodegradable Parachutes

There was no difference in canopy entanglement of baits between the Tarague and NCTS drop zones for the Ecofilm® and paper towel parachutes (χ^2 = 3.8, *df* = 3, *P* = 0.28). Fifteen of 20 (75%) of the Ecofilm® parachutes (7 of 10 on Tarague and 8 of 10 on NCTS) and 17 of 20 of the paper towel parachutes (7 of 10 on Tarague and 10 of 10 on NCTS) were entangled in the canopy. Mean height in the canopy ranged from 3-5 m for each type of parachute at each of the drop zones. No baits detached from these parachutes.

Biodegradable Paper Products

Canopy landings for the single white flags, double white flags, paper plates, and paper cups were 85%, 95%, 67%, and 80%, respectively, and there was no difference among these four paper products for entanglement in vegetation (χ^2 = 5.0, *df* = 3, *P* = 0.17). Mean height in canopy ranged from 2-4 m for each of the four paper products. Of the baits that landed in the canopy, 1 of 17 (6%) detached from single white flags and 2 of 19 (11%) detached from double white flags. No baits detached from either the paper cups or paper plates.

DISCUSSION

Based on results from the crab lure stations, there is a dramatic difference in numbers of crabs between Tarague and Orote. Anecdotal information indicates that high feral pig numbers limit crab populations (USFWS 2001). Signs of pigs, including visual sightings and ground rootings, were prevalent on Tarague, but no signs of pigs were observed on Orote.

Although no crabs were recorded on Tarague from the crab lure stations, a hermit crab was observed with 1 of the 9 baits designated as being taken by crabs (Table 1). A hermit crab was also observed with 1 of the 24 baits taken by crabs on Orote. Evidence that crabs took baits included damage to the radio antenna or battery. And radios with or without the dead mouse bait, or a partially shredded mouse bait, were often located in a protected crab refugium under logs, stumps, or rocks. Characteristically, crabs would consume the flesh of the mouse leaving the radio attached to the glue.

Table 1. Bait-take and fate of baits on ground at low (Tarague) and high (Orote) crab abundance sites.

Bait-take/ fate of bait	Low crab abundance (Tarague)		High crab abundance (Orote)	
Snake	9*/38	23.7%	0/36	0.0%
Crab	9/38	23.7%	24/36	66.7%
Monitor lizard**	0/38	0.0%	4/36	11.1%
Marine toad**	1/38	2.6%	0/36	0.0%
Ants**	8/38	21.1%	5/36	13.9%
Unknown**	1/38	2.6%	3/36	8.3%
No take	10/38	26.3%	0/36	0.0%
Totals	38/38	100%	36/36	100%

* 8 snakes consumed 9 baits.

** For purposes of chi-square analysis, these 4 entities were grouped in the “other” category.

The impact of crabs as major scavengers of baits for snakes is indisputable and not surprising (Table 1). Three times more baits were taken by crabs on Orote (67%) as compared to Tarague (24%). And the rapid disappearance of baits by crabs on Orote (92% of baits taken on night 1) indicates that baits would not be available during night 2 when they are most attractive to snakes (Jojola-Elverum et al. 2001). Second to crabs for taking baits was the combined take by monitor lizards, toads, unknown, and ants, the latter being omnipresent on both Tarague and Orote.

Including the 7 materials tested in the present study, a total of 15 materials have been evaluated since 2001 as parachute/flotation materials for broadcast application of baits for brown treesnakes (Shivik et al. 2002, Savarie and Tope 2004). With an overall canopy entanglement of only 21% (8/39) the jute netting is the worst of the 15 materials. The 2 biodegradable parachutes, Ecofilm® and paper towel, and the 4 commercial paper products (single and double white flags, paper cup, paper plate) were good for hanging-up in the canopy. However, a problem with the 2 parachutes and the paper plate and paper cup is that threads have to be secured to them for attaching the dead mice. This is a time consuming effort and with authorized broadcast application rates of 36 baits/hr (3,600 baits/100 hr), resources are not adequate to prepare the thousands of baits needed for large-scale control of snakes.

From an operational management perspective, the single and double white flags, also called streamers, appear to have the best potential as materials for delivering baits to the canopy. They are commercially available and dead mouse baits can be glued to them without the tedious effort of attaching threads. In addition to hand broadcast, they can be deployed by an electro-mechanical dispenser from
helicopters and fixed-winged aircraft. An automatic dispenser is not available for any of the other types of flotation materials. The flags are also biodegradable, however, a negative aspect of this is that water (rain) destroys the paper streamer within seconds, allowing the cardboard with attached bait to fall to the ground (P. Savarie, personal observation). Additional testing with a more water resistant paper will be conducted. streamers, even with the inherent advantages of the paper automated systems for treating dead mice with acetaminophen and for attaching the dead mouse to the cardboard are needed to help make the aerial baiting system as efficient as possible.

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