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# Photographic Validation of Target Versus Nontarget Take of Brown Treesnake Baits

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## Tools and Technology

# Photographic Validation of Target Versus Nontarget Take of Brown Treesnake Baits

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**ABSTRACT** Use of toxic baits or other tools for managing nuisance species must ensure that the species of interest is adequately targeted while exposure to nontarget species is minimized. Nontarget takes of acetaminophen-laced baits for control of invasive brown treesnakes (*Boiga irregularis*) on Guam may put those animals at risk of lethal intoxication and render the bait unavailable to the intended target species. We used wildlife cameras to identify species removing toxic and nontoxic baits from brown treesnake bait stations designed to exclude nontarget taxa in 2015 and 2016. Throughout various sites and habitat types, and balanced by season (wet vs. dry), we monitored 512 bait stations. From those, 140 of the baits were taken and the species taking the bait was successfully identified. Brown treesnakes took 124 (88.6%) of the baits, 13 (9.3%) were taken by small coconut crabs (*Birgus latro*), and 3 (2.1%) were taken by monitor lizards (*Varanus indicus*). The greatest incidence of nontarget bait takes was by small coconut crabs at 2 adjacent sites atop the same cliff line during a single season; 96.9% of bait takes at all other sites were by brown treesnakes. Bait takes by brown treesnakes were particularly infrequent (2.3%) at sites associated with endangered swiftlet (*Aerodramus bartschi*) caves where intensive snake control was employed. Although the majority of baits in bait stations are taken by brown treesnakes, local and temporal pulses in nontarget species activity, particularly by crabs, may bias results, which would not be accounted for without supplemental validation by cameras. © 2019 The Authors. *Wildlife Society Bulletin* published by Wiley Periodicals, Inc. on behalf of The Wildlife Society. Published 2019. This article is a U.S. Government work and is in the public domain in the USA.

**KEY WORDS** bait station, *Boiga irregularis*, brown treesnake, camera, Guam, invasive species, nontarget effects, tool validation, toxic bait.

Tools for lethal or nonlethal control of problem wildlife (target species) may pose unintended risks to other species (nontargets). Further, nontargets interacting with control methods could render them ineffective. For example, traps

triggered by nontargets become nonfunctional for trapping the target species, and baits consumed by nontargets are no longer available for ingestion by targets. Nontarget consumption of baits often goes unmeasured, biasing estimates of bait delivery effectiveness for target species and underestimating exposure of nontarget species. Therefore, such baiting programs should be coupled with some form of validation of target versus nontarget bait interactions.

The brown treesnake (*Boiga irregularis*) was accidentally introduced to Guam in the late 1940s or early 1950s from a single point of origin in the Admiralty Archipelago (Rodda and Savidge 2007, Richmond et al. 2015). Since then, the brown treesnake has become a threat to the ecology and economy of Guam. Predation by brown treesnakes has extirpated nearly all

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of Guam's forest avifauna (Savidge 1987, Wiles et al. 2003), which has had cascading ecological effects (e.g., Perry and Morton 1999, Rogers et al. 2017). This predation has negatively affected all of Guam's native vertebrates (Rodda and Fritts 1992, Fritts and Rodda 1998). Economic effects include substantial damage to Guam's power infrastructure (Fritts 2002) and the elimination of a local poultry industry (Fritts and McCoid 1991). Brown treesnakes are extremely abundant on Guam, with localized population density estimates reaching 50–100/ha, which are among the greatest ever recorded for a snake. Although densities have dropped since the collapse of large prey populations, they are still unusually high, generally estimated at approximately 25/ha (Rodda et al. 1999). This invasive predator is currently the subject of a multiagency control program to prevent spread of the species throughout the Pacific Rim (e.g., Shwiff et al. 2010, Hawaii Interagency Biosecurity Plan 2017).

Operational snake-removal efforts around key resources and potential points of accidental export, such as power infrastructure and cargo terminals, are primarily conducted by U.S. Department of Agriculture (USDA) Animal and Plant Health Inspection Service (APHIS) Wildlife Services personnel. Current efforts typically rely on 3 methods: traps baited with live mice (Vice et al. 2005); spotlighting and hand-removal along fence lines (Engeman and Vice 2001); and application of toxic baits in bait stations intended to exclude nontarget organisms such as crabs, rats, and monitor lizards (*Varanus indicus*; Savarie et al. 2001, Clark et al. 2012, Lardner et al. 2013). Each of these techniques has relative merits, which are reviewed in more detail in Clark et al. (2018).

Natural resources of particular concern are roosting and nesting caves of endangered Mariana swiftlets (*Aerodramus bartschi*). Mariana swiftlets and Micronesian starlings (*Aplonis opaca*) are the only species of native forest birds to persist following the brown treesnake invasion, though predation on swiftlets by brown treesnakes is common (Klug et al. 2015). Wildlife Services, U.S. Geological Survey (USGS), and U.S. Navy resource conservation personnel have conducted monitoring and operational suppression of brown treesnakes in and around swiftlet caves, including visual searches and hand-captures inside caves and maintaining rings of traps and toxic bait stations around known swiftlet cave entrances (Klug et al. 2015, Sugihara et al. 2015).

The use of dead newborn mouse baits laced with 80-mg acetaminophen tablets and applied in bait stations to exclude nontarget species (lengths of plastic tube, hereafter referred to as bait tubes) is a cost-effective alternative to trapping and poses little risk of nontarget mortality (Johnston et al. 2002, Mathies et al. 2011, Clark et al. 2012). In addition to providing lethal control, the proportion of toxic or nontoxic baits removed, or take rates, have also become a standard metric of brown treesnake foraging activity, interpreted as an index of relative snake abundance for monitoring efforts (Savarie et al. 2001, Clark et al. 2012, Dorr et al. 2016). Savarie et al. (2001) cited unpublished video documentation establishing that dead newborn mouse baits were readily consumed by brown treesnakes and <1% of baits were removed from bait tubes by other species. However, as currently implemented

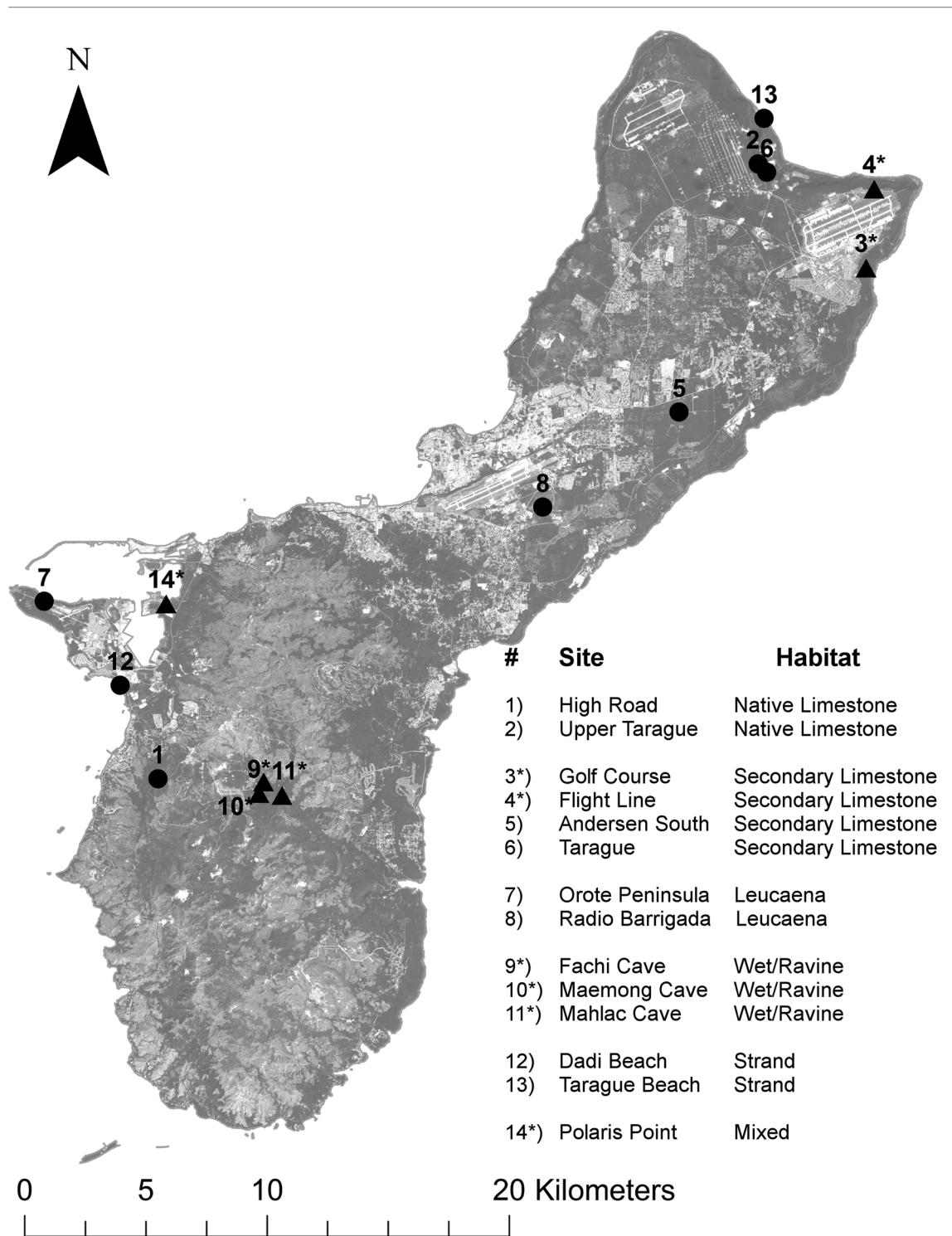
under operational snake suppression scenarios, there has been no systematic evaluation across habitat types and seasons of the rates at which baits are taken by nontarget organisms. This creates uncertainty in assumptions about snake control success and nontarget exposure. In areas where long-term snake-removal activities have been occurring, it is also questioned whether continued bait disappearance indicates that snakes remain present, despite persistent control efforts, or whether nontargets are taking the few baits that are removed. We used cameras triggered by removal of baits to document the proportion of baits taken from bait tubes by nontarget species and identify which nontarget species take baits.

## STUDY AREA

We conducted this study on Department of Defense lands on the island of Guam, a territory of the United States in Micronesia (13°27'51"N, 144°47'50"E). Site selection was guided by U.S. Navy natural resources personnel wishing to validate that baits in brown treesnake suppression areas were being taken by snakes rather than nontarget species. Suppression activities at these sites consisted of trapping, toxic baiting, and spotlighting and hand-capture. We also selected additional sites on Department of Defense lands to assess nontarget bait takes where snake suppression was not being conducted. Sites were distributed among multiple habitat types in order to be representative of the variability in nontarget communities. We conducted trials at sites on Andersen Air Force Base, U.S. Naval Computer and Telecommunications Station Barrigada, and Naval Base Guam (Fig. 1) in 2015 and 2016.

Our study included 15 different locations, each of which was designated by a descriptive name (Table 1). Native limestone forest was characterized by moist, broad-leaved evergreen forest on elevated limestone plateaus. Secondary limestone forest ("scrub forest") was primarily composed of nonnative species resulting from a long history of human disturbance. *Leucaena* forest was artificially reforested habitat dominated by *Leucaena leucocephala* (tangantangan), a tree species introduced as land cover. Cave sites were within "wet forest" or "ravine forest"; these were low-lying, moist, green forests surrounding flowing and ephemeral watercourses, characterized by greater proportions of palms, bamboos, and *Pandanus* spp. Strand forest occurred along beaches and coastlines within the immediate vicinity of the Pacific Ocean. More complete habitat descriptions are detailed by Mueller-Dombois and Fosberg (1998); land cover distributions on Guam are provided in Liu and Fischer (2005).

The Fachi Cave, Maemong Cave, and Mahlac Cave sites in the Naval Base Guam Munitions Area comprised the majority of known nesting caves of Mariana swiftlets. An estimated >171 birds used Fachi Cave, >326 used Maemong Cave, and >1,418 used Mahlac Cave in 2015 (maximum of quarterly counts; S. Vogt, U.S. Navy, unpublished data). At the largest cave (Mahlac), we recorded takes from bait tubes around the exterior (Mahlac Cave Exterior) and within the interior of the cave (Mahlac Cave Interior).



**Figure 1.** Map of study sites on the island of Guam, USA, within the Pacific Ocean. Triangular symbols and labels with an asterisk denote sites undergoing snake suppression activities during 2015 and 2016.

## METHODS

### Camera, Trigger, and Bait Tube System

We offered dead newborn mouse baits in 30-cm lengths of 5.1-cm-inner-diameter polyvinyl chloride (PVC) tube with steel bolts bisecting the openings at each end to limit access by nontarget species, as used for operational snake control by

Wildlife Services. We suspended tubes horizontally from woody vegetation, such as tree or shrub limbs, by nylon cord approximately 1.5–2.0 m above ground level. At sites without sufficient vegetation (i.e., Polaris Point, Golf Course, and Flight Line), we hung tubes from existing structures such as fences or poles. Following Sugihara et al. (2015), we monitored bait tubes with a modified infrared camera system.

**Table 1.** Locations, each designated by a descriptive name, where we used wildlife cameras to identify species removing toxic and nontoxic baits from brown treesnake bait stations designed to exclude nontarget taxa in Guam, USA, during 2015 and 2016. Locations are depicted in Figure 1.

Site name	Habitat	Control <sup>a</sup>	Tr × Cam <sup>b</sup>	Baits <sup>c</sup>
High Road	Limestone forest	No	4 × 10	39
Upper Tarague	Limestone forest	No	4 × 10	40
Golf Course	Secondary forest	Yes	4 × 10	39
Flight Line	Secondary forest	Yes	4 × 10	38
Andersen South	Secondary forest	No	2 × 15 <sup>d</sup>	27
Tarague	Secondary forest	No	2 × 11	20
Orote Peninsula	<i>Leucaena</i> forest	No	4 × 10	40
Radio Barrigada	<i>Leucaena</i> forest	No	4 × 10	38
Fachi Cave	Wet/ravine forest	Yes	4 × 10	40
Maemong Cave	Wet/ravine forest	Yes	4 × 10	40
Mahlac Cave	Wet/ravine forest	Yes	2 × 6	12
Interior				
Mahlac Cave	Wet/ravine forest	Yes	4 × 10	40
Exterior				
Dadi Beach	Strand forest	No	4 × 10	39
Tarague Beach	Strand forest	No	4 × 10	39
Polaris Point	Mixed grass/ <i>Leucaena</i>	Yes	4 × 10	20

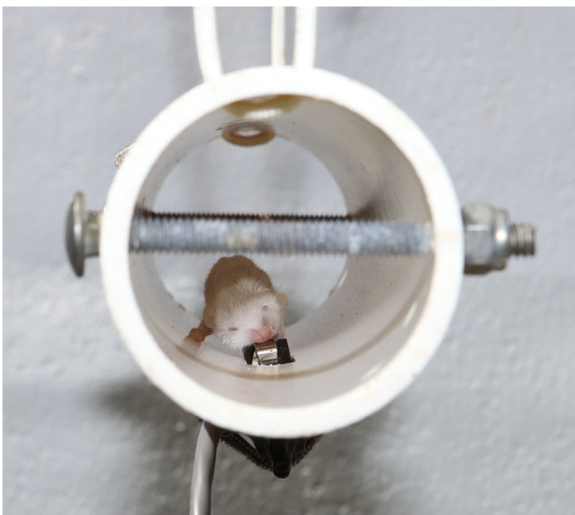
<sup>a</sup> Recent or concurrent brown treesnake removal operations at the site.

<sup>b</sup> No. of transects and cameras per transect.

<sup>c</sup> No. of baits successfully monitored by camera.

<sup>d</sup> Although 15 cameras were set, 4 were stolen during the second transect at Andersen South.

The tubes were fitted with a pressure-sensitive lever switch (FB Engineering LLC, Hilo, HI, USA) positioned at the bottom interior and midway along the length of the tube, upon which we placed a dead newborn mouse bait by inserting the trigger lever into the dead newborn mouse via the oral cavity (Fig. 2). We wired each switch to a custom external triggering port on a Reconyx<sup>®</sup> PC900 camera (Holmen, WI, USA) that we mounted in the vegetation <1.5 m from the bait tube and positioned to view down the interior length of the tube (Fig. 3). This same trigger system



**Figure 2.** Dead newborn mouse bait on bait-tube camera trigger. Removal of the mouse triggers image capture by the camera. Cross-bolts at each end of the tube further exclude nontargets without impeding access by brown treesnakes.

was employed by Abernethy et al. (2016) to monitor carcass scavenging. We programmed cameras to take multiple pictures upon triggering. Standard trail-camera motion sensors have not proven reliable for capturing images of slow-moving ectothermic brown treesnakes. Bait tubes were open at both ends, and images would be captured regardless of which end the bait was taken from.

We purchased frozen dead newborn mouse carcasses from a commercial supplier (Noble Supply and Logistics, Rockland, MA, USA). Following standard Wildlife Service operational methods for brown treesnake control, we treated each carcass with one 80-mg acetaminophen tablet inserted into the dead newborn mouse body cavity through the mouth. Baits at the Andersen South and Tarague sites did not contain acetaminophen because we did not have prior permission to apply toxic baits at these supplemental locations. Previous and subsequent unpublished USDA observations using treated and untreated dead newborn mouse baits do not suggest that the presence of acetaminophen within the bait changes target or nontarget response. All animal use was conducted in accordance with protocols reviewed and approved by the USDA APHIS National Wildlife Research Center Institutional Animal Care and Use Committee (QA-2399).

### Experimental design

In total, the experimental design comprised 52 transects among 15 sites, and we deployed 522 baits for monitoring by cameras. We baited and monitored each transect 4 times: twice during Guam's wet season (Jul to Nov), and twice during the dry season (Dec to Jun). Dry season monitoring occurred from 2 March to 17 June 2015, and wet season monitoring occurred from 29 July to 28 October 2015. Transects were 200 m in length with 10 camera-monitored bait tubes spaced 20 m apart within continuous habitat tracts. We set these  $\geq 10$  m interior to the forest edge and a minimum of 50 m from any transect location used during previous sampling occasions, to avoid testing in a given location twice during the duration of the study. In areas that were already being treated with dead newborn mouse baits, including swiftlet caves, we placed cameras on randomly selected existing bait tube locations; snake removal at these sites had gone on for  $\geq 1$  year prior to this study. Previous unpublished studies have demonstrated that it is possible for snakes to take more than one bait from within the same transect during the same set period; we did not attempt to make alterations to avoid this possibility because this study was intended as a validation of control methods. We spaced contemporaneous transects  $\geq 500$  m apart. Brown treesnake mean daily relocation distances average around 50 m within small short-term activity areas, with longer movements rarely exceeding 200 m (Santana-Bendix 1984, Tobin et al. 1999, Anderson 2002, Lardner et al. 2014). The majority of brown treesnakes taking acetaminophen baits die within 24–48 hours of ingestion (Savarie et al. 2000). Therefore, we consider it unlikely that an individual would take multiple baits from different transects in the same week.

We monitored baits for 7 days without replacing taken or decomposed baits. Mid-week bait checks allowed for



**Figure 3.** Bait station setup, with tube, trigger, cable, and camera assembly installed within vegetation on the island of Guam, USA, during 2015 and 2016.

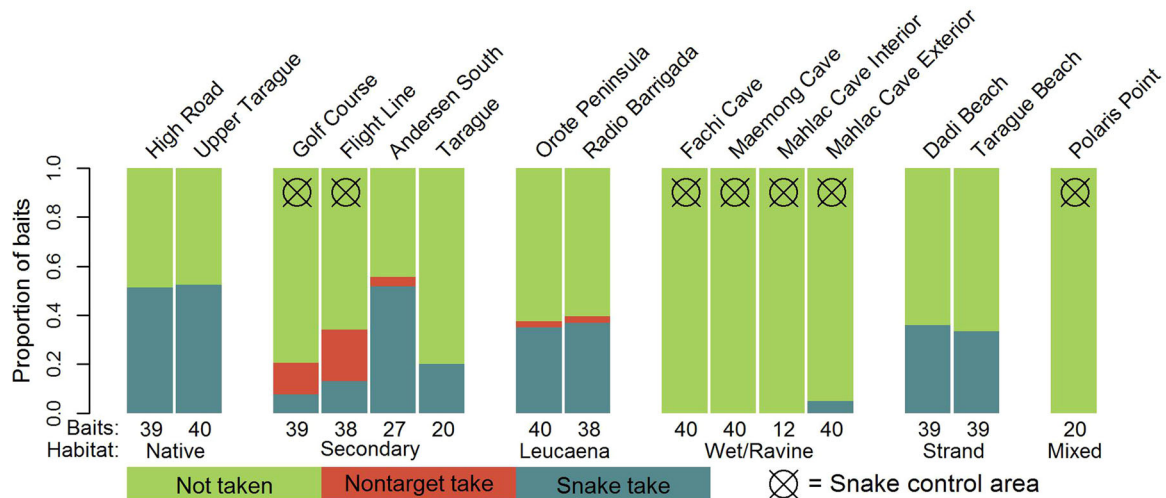
adjusting cameras as needed and documentation of bait consumption by ants or flies that might prematurely trigger the camera as a result of loss of dead newborn mouse body mass. At the end of each monitoring period, we downloaded and reviewed photo data to determine the species responsible for removing baits and the time and date the bait was removed. On 3 occasions, images clearly depicted a snake vigorously but unsuccessfully attempting to remove a bait that was apparently stuck on the trigger mechanism. We classified these instances as bait takes by snakes; under operational circumstances the absence of a trigger would have allowed bait removal. There were minor modifications to our study design at sites that had either spatial or temporal restrictions. The Polaris Point and Mahlac Cave Interior sites were sampled only twice, once during each season. The Mahlac Cave Interior transects consisted of only 6 cameras, rather than 10, owing to space limitations. We later conducted supplemental sampling at the Andersen South and Tarague sites during only the dry season (25 Feb to 21 Mar 2016); 2 transects at each site included 15 cameras each,

though theft of 4 cameras resulted in loss of data from 3 baits at the Andersen South site and left only 11 cameras/transect at the Tarague secondary forest site.

Site selection was driven by the operational objectives of the study sponsors and overall bait take at many sites was very low to zero (particularly sites undergoing operational snake control); therefore, our data were not amenable to proper modeling to evaluate influence of land cover type, season, or control status on relative incidence of nontarget versus target bait take rates. Instead, our stratification of sampling sites and times served to ensure that results were representative of a range of conditions on Guam.

## RESULTS

We successfully monitored 511 baits. We removed 10 baits from our analysis owing to trigger malfunctions. Overall, 140 (27.4%) successfully monitored baits were taken, of which 124 (88.6%) were taken by brown treesnakes (Fig. 4). Bait takes by nontarget organisms were rare (11.4%). Of the 16 baits taken by nontarget species, 13 (81.3%) were



**Figure 4.** Comparison of proportions of monitored baits not taken, taken by nontargets, or taken by brown treesnakes among sites and habitats, as determined by wildlife cameras during 2015 and 2016 on the island of Guam, USA. “Baits” is the sample size of baits successfully monitored. “Habitat” describes the dominant land-cover condition of each site. Names of individual sites correspond to the sites in Figure 1. Crossed circles indicate sites at which snake control was being conducted.

removed by small coconut crabs (*Birgus latro*) and 3 (18.7%) were removed by monitor lizards. Of the 16 nontarget bait takes, 13 (81.3%) occurred in areas undergoing snake control; however, 9 of these takes were by small coconut crabs at only 2 sites. Brown treesnakes took 115 (40.8%) of 282 baits placed in areas without snake control, while snakes took only 11 (4.8%) of 229 baits in areas with ongoing control. This comprises an 88.2% decrease in bait take rate by snakes in control areas. Of the baits taken by brown treesnakes, 53% were taken within 24 hours, 86% within 48 hours, 96% within 72 hours, and only 4% were taken beyond 72 hours after being offered.

## DISCUSSION

Bait take rates are sometimes used as a proxy for relative snake abundance (e.g., Savarie et al. 2001, Dorr et al. 2016). This method fails to give information on individual snakes or size classes that might not be attracted to carrion baits, particularly small snakes that exhibit a strong ontogenetic preference for small lizards (Shivik and Clark 1999; Lardner et al. 2009, 2013). We consider bait take rates indicative of foraging activity of snakes that are prone to taking rodent carrion. Although most of the baits removed from bait tubes were taken by brown treesnakes rather than nontargets in our study, the large number of nontarget takes by coconut crabs suggests that without cameras monitoring bait consumption, bait take rates used as an index of snake abundance may be unreliable owing to localized nontarget activity. Little is known about temporal patterns of coconut crab activity, aside from greater activity during periods of limited moonlight (C. Brunson, U.S. Fish and Wildlife Service, personal communication). Where bait removal by coconut crabs is anticipated, longer segments of PVC tube may defeat access by larger individuals. In areas with high crab takes that cannot be overcome by bait tube placement or design alterations, alternative snake control methods, such as spotlighting, may be more appropriate. Increasing the number of baits offered may also offset the loss to crabs. Our data collection method was unable to capture failed bait take attempts. Cameras recorded images only when bait take attempts were successful or the trigger was otherwise actuated. It is possible that the low rate of bait takes indicates low abundance of nontarget species inclined to take carrion baits. Photographs can verify baits are taken by brown treesnakes and justify use of an adjustment factor for nontarget takes for inferences about snake abundance.

Of the 511 baits observed during these trials, only 3 (0.59%) were taken by nonnative monitor lizards. Acetaminophen has been proven to be an effective toxicant for juvenile monitors (Mauldin and Savarie 2010), and mortality of monitor lizards by aerially delivered acetaminophen-laced brown treesnake baits has been documented (Dorr et al. 2016). Although lethal control of monitor lizards may be desirable in some cases, such as protection of reintroduced bird populations (Siers and Savidge 2017), acetaminophen is not registered with the U.S. Environmental Protection Agency for monitor lizard control. Effective techniques to exclude nontarget species from taking baits are important

from a regulatory perspective and help to ensure that baits remain available for the target snakes.

No baits were taken by rodents, likely owing to brown treesnake predation that has drastically suppressed rodent abundance within forest habitats on Guam (Wiewel et al. 2009). Despite theoretical and empirical observations that rodents will exhibit predator release and rebound in abundance upon suppression of brown treesnakes (A. Yackel Adams, U.S. Geological Survey, unpublished data; Siers et al. 2018), this pattern was not documented by our bait monitoring because no baits were taken by rodents at any of the sites where snake abundance was suppressed. Our camera system records observations of species when baits are taken, so we cannot be certain that there were no attempted takes by rodents. However, given what is known about the extraordinary jumping, climbing, and intrusion abilities of rats (*Rattus* spp.), it seems unlikely that there were many unrecorded unsuccessful attempts (e.g., Pitt et al. 2011a,b). Rats have been known to enter brown treesnake traps and kill the bait mice (S. Siers, personal observation). The utility of dead newborn mouse baits in plastic bait tubes in areas of high rodent abundance, such as neighboring snake-free islands, remains untested.

Dead newborn mouse baits were often swarmed by small black ants (probably nonnative *Monomorium* spp.; R. Miller, University of Guam, personal communication), which are abundant in Guam's vegetation. Our observations, and those of Sugihara et al. (2015), demonstrate that these ants do not deter consumption of baits by brown treesnakes. It is unknown whether other less common ant species, including ants known to deliver painful bites, deter bait consumption. Although ants and fly larvae cause degradation of the baits, potentially reducing attractiveness and palatability for brown treesnakes, we documented no evidence that any of the baits were completely removed by decomposition or consumed by insects. All dead newborn mouse baits began to decompose quickly. With only 4% of brown treesnake bait takes occurring >72 hours after baits were placed, it appears that this decomposition negatively affects attractiveness or palatability.

The majority of toxic baits removed from the bait tubes were taken by brown treesnakes. Brown treesnake control methods appear to be having a strong effect on snake activity, as indicated by low bait take rates in the snake control areas included in our study. Bait take rates provide an index of snake foraging activity or relative abundance. However, at least some bait tubes should be equipped with cameras to identify where and when nontarget species may interfere with snake control or bias inference from bait take data. When new baiting sites are established, cameras should be deployed in advance to evaluate potential interference by nontargets, so that modification to bait station design and location can minimize nontarget effects.

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