Human–Wildlife Interactions 17(2):Early Online, Fall 2023 • digitalcommons.usu.edu/hwi

Case Study

An automatic system to evaluate bait station visitation by brown treesnakes and mongooses

Robert T. Sugihara, U.S. Department of Agriculture, Wildlife Services, National Wildlife Research Center, Hawai‘i Field Station, P.O. Box 10880, Hilo, HI 96721, USA *Robert.T.Sugihara@usda.gov*
William C. Pitt, Smithsonian Conservation Biology Institute, 1500 Remount Rd., Front Royal, VA 22630, USA
Are R. Berentsen, U.S. Department of Agriculture, Wildlife Services, National Wildlife Research Center, 4101 LaPorte Ave., Fort Collins, CO 80521, USA
Francis L. Benevides Jr., FB Engineering, P.O. Box 5023, Hilo, HI 96720, USA

Abstract: Understanding the temporal, spatial, and behavioral patterns of the free-ranging target species in response to candidate baits and baiting strategies is important to ensure control success. This information can also assist in the development and deployment of feeding stations and can exclude non-target species while constituting effective bait delivery and control strategies for certain invasive animals, especially at environmentally sensitive sites. We used passive integrated transponder (PIT) tags in conjunction with very-high frequency radio-telemetry to remotely record bait station visitations and evaluate bait attractiveness in separate field research studies of brown treesnakes (*Boiga irregularis*) on Andersen Air Force Base, Guam, Northern Mariana Islands, between 1999 and 2000 and in 2007, for small Indian mongooses (*Urva auropunctata*: Syn. *Herpestes auropunctatus*) on Hilo, Hawai‘i Island, Hawai‘i. USA. This system allowed us to document visitation rates to bait stations by brown treesnakes and mongooses. In Guam, we determined that 75% of medium to large brown treesnakes (>850 mm snout-vent length [SVL]) attracted to the bait stations consumed toxic bait, while smaller snakes (<850 mm SVL) were not attracted to the bait stations. On Hawai‘i Island, we learned mongooses foraged over large areas (range = 6.0–70.2 ha), traveled up to 598 m to select baits, had restricted centers of activity, and displayed fidelity to newly discovered food sources. We recorded discrete group feeding activity not previously documented for mongooses. We found that anterior and posterior double-PIT tagging improved detectability of both target species. The complimentary monitoring system we used can be easily adapted for monitoring small mammals, birds, reptiles, or amphibian species and various activities of interest.

Key words: bait delivery stations, *Boiga irregularis*, brown treesnake, foraging behavior, Guam, Hawaii, Hawai‘i, *Herpestes auropunctatus*, passive integrated transponder, small Indian mongoose, *Urva auropunctata*

An understanding of spatial population dynamics, foraging patterns, and feeding behavior is fundamental to effective control or eradication strategies that incorporate baits to mitigate impacts of invasive animal species. When planning field studies to assess baiting success and to optimize techniques for capturing or delivering treated baits to control invasive brown treesnakes (*Boiga irregularis*) and small Indian mongooses (*Urva auropunctata* Syn. *Herpestes auropunctatus*), we recognized a need for a monitoring system that could be easily deployed in rugged remote areas to assess bait acceptance with minimal interference or disturbance to the behavior of the 2 target species. Requirements include the ability to: (1) mark a large proportion of the resident population, (2) verify bait take (missing bait) and the identity of marked individual(s) responsible, (3) record the station (bait type) visited, (4) determine the date and time of visits, (5) record the duration and frequency of visitations, and together with radiotelemetry, one could also determine the distance traveled and time to bait discovery and fate of target animals consuming toxic baits. Besides unique identity, documenting various temporal and foraging/feeding parameters would be invaluable in baiting studies of the 2 non-native invasive pest species studied. Direct observation or use of traditional devices (e.g., cameras, traps, tracking boards) to monitor bait uptake for free-ranging wildlife can be tedious, time-consuming, costly, and disruptive to the animal's normal behavior (Shepp 1967, O'Farrell 1974, Jones et al. 2004, Stanton-Jones 2018). These techniques may not allow for discrete animal identification, which is required to characterize individual differences in response to baits and delivery systems.

Passive integrated transponder (PIT) tags or microchips are routinely used in many ecological studies and offer a simpler, safer, longer-lasting, and more accurate technique of unique identification of captive and wild animals than traditional tagging methods such as appendage clips or external tags (Fagerstone and Johns 1987, Elbin and Burger 1994, Boarman et al. 1998, Gibbons and Andrews 2004). Miniature non-surgically implantable tags are routinely used for demographic research and ecological studies of various aquatic species (Prentice et al. 1990, Castro-Santos et al. 1996, Mahapatra et al. 2001), mammals (Bertolino et al. 2001, Jones et al. 2004, Newey et al. 2009, Konig et al. 2015), reptiles and amphibians (Camper and Dixon 1988, MacGregor and Reinert 2001, Stanton-Jones 2018), birds (Bonter and Bridge 2011, Mariette et al. 2011, Iserbyt et al. 2018, Testud et al. 2019), and insects (Gilbert 2000, Leskey and Hogmire 2005, Testud et al. 2019).

Most field applications using PIT tags require subsequent recapture of previously tagged animals and identification using portable handheld scanners. In a few autonomous systems, stationary readers are placed at strategic pathways, such as burrow entrances, nests, supplemental feeders, and other frequently traversed sites to monitor and log various activity patterns. Such systems have been used to monitor a variety of mammals (Harper and Batzli 1996, Dell'Omo et al. 1998, Kenward et al. 2005, Rehmeier et al. 2006, van Harten et al. 2019), birds (Creuwels et al. 2000, Freitag et al. 2001, Moller et al. 2003, Mariette et al. 2011), reptiles and amphibians (Gruber 2004, Charney et al. 2009, Testud et al. 2019), and aquatic animals (Lundqvist et al. 2000, Riley et al. 2003, Briggs et al. 2021).

Researchers at the U.S. Department of Agriculture (USDA), Wildlife Services (WS) National Wildlife Research Center (NWRC) experimented with an earlier PIT tag autonomous prototype system to monitor efficacy of traps and bait stations. That prototype system was limited by battery life and was often burdened by a large physical size, which may impact the target animal's normal foraging behavior (R. T. Sugihara and E. W. Campbell, NWRC, unpublished report). The recording unit consisted of the receiving antenna, a PIT tag reader or decoder, data storage unit (data logger), and laptop computer. The components were connected by various lengths (15–30 m) of coaxial/electronic cables and powered by a heavy-duty automotive or deep-cycle 12-volt marine battery lasting from 4–8 days before requiring recharging. The data loggers were limited to 1,000 events due to onboard memory constraints. Where multiple readers were deployed, an array of 4–8 separate units were combined via a multiplexer, expanding the number of units deployed and area covered.

For future studies, we determined that a stand-alone, remote, autonomous monitoring system that was easier to deploy in the field and with increased datalogging capabilities was needed to record discrete animal identification, visitation parameters, and bait consumption at stationary bait delivery stations and for other animal monitoring studies.

For the studies reported here, we utilized a custom-designed compact automatic monitoring system using PIT tags, in conjunction with radiotelemetry, to record spatial and temporal data on bait station visitations and attractiveness of baits in 2 separate case studies evaluating the demographics and fate of brown treesnakes visiting bait stations with acetaminophen-treated baits used to reduce invasive snake populations on Guam, and attractiveness of candidate food bait products to free-ranging small Indian mongooses on Hawai'i. Benefits gained from incorporating transmitters (radiotelemetry) include recording spatial behavior in response to baiting, locating refugia sites, and determining fate of animals consuming toxic bait.

Brown treesnake

The brown treesnake was introduced to Guam during shipping activities following World War II and devastated the island's avifauna and herpetofauna (Savidge 1987, Rodda and Fritts 1992). In addition, it is responsible for frequent electrical power outages, loss of domestic poultry and small farm animals, occasional envenomation of infants, and presents a continuing threat to recovery programs to reintroduce threatened native birds and lizards (Rodda and Savidge 2007). An equally serious concern is the potential of brown treesnakes being accidentally transported to destinations outside of Guam, such as Hawaiʻi, USA, where if established, they would likely constitute an even greater ecological and economic disaster (McCoid et al. 1994, Fritts et al. 1999, Savidge et al. 2007, Shwiff et al. 2010).

We, along with other researchers on Guam, have used PIT tags in mark-recapture procedures, as well as visual detection and hand-capture, to study the population ecology and responses of brown treesnakes to various control strategies (e.g., trapping, barriers, toxicants) (Brooks et al. 1998, Engeman and Linnell 1998, Rodda et al. 1999, Tyrrell et al. 2009). Savarie et al. (2001) and Lardner et al. (2013) reported the development of an effective and safe toxicant delivery system utilizing PVC tube bait stations baited with dead neonatal mice (DNM) treated with acetaminophen, a registered brown treesnake pesticide in the United States. Unique identification provided by PIT tags affords collection of discrete foraging and bait interaction information in the evaluation of bait stations and other control programs to reduce populations of brown treesnakes on Guam.

Small Indian mongoose

Small Indian mongooses, originally introduced to Hawaiʻi for rat control in sugarcane fields in 1893, are serious predators of native upland forest and wetland birds in the Hawaiian Islands (Baldwin et al. 1952, Keith et al. 1987, U.S. Fish and Wildlife Service 1999, Hays and Conant 2007) and other introduction sites worldwide (Tvrtkovic and Krystufek 1990, Roy et al. 2002, Yamada and Sugimura 2004, Berentsen et al. 2017). In Hawaiʻi, the eggs and nestlings of ground-nesting birds are especially vulnerable to mongooses, which occupy diverse habitats on all but one of the major Hawaiian Islands. On the island of Kauaʻi where earlier introductions were not successful, a roadkill gravid female mongoose was discovered in 1976. More recent sightings and follow-up trappings during 2016 to 2023 by Kauaʻi Invasive Species Committee (KISC) and Hawaiʻi Department of Agriculture staff resulted in 7 new captures near ports of entries and cargo staging areas (https://www.kauaiisc.org/kiscpests/mongoose/).

Trapping and use of toxic baits in bait stations have been employed in attempts to reduce mongoose populations near and around native bird nesting habitats (Keith et al. 1990, Stone et al. 1994, Smith et al. 2000). However, these methods have been less successful in areas with low mongoose or high alternative prey densities. Management of wildlife damage caused by invasive mongooses and the potential for spread to other islands in the Pacific and Caribbean highlight the need for improved indexing and capture techniques (e.g., use of traps, scented visitation stations, baits, lures, or attractants) to quickly respond to reported sightings or incipient mongoose populations. Development and optimization of such tools can be aided by use of PIT tag marked animals in locations already colonized by these invasive predators.

Study area

Guam

We conducted this study in a 9-ha tract of mixed primary and secondary forest on the western edge of the Conventional Weapons Storage Area on Anderson Air Force Base, Guam (Figure 1). The habitat consists of overstory trees dominated by molave (*Vitex parviflora),* fadang (*Cycas circinalis*), screw pine (*Pandanus* spp.), and fagot (*Neisosperma oppositifolia*). Subcanopy species includes paipai (*Guamia mariannae*), beach hibiscus (*Hibiscus tiliaceus*), and limeberry (*Triphasia trifolia*) with assorted patches of ferns, vines, and small herbs growing on well-drained porous limestone rocks and soil.

Hawaiʻi

We obtained the mongoose case study data from October to December 2007 during a concurrent ecological study at the Keaukaha Military Reservation (KMR) near the Hilo International Airport, Hilo, Hawaiʻi Island, Hawaiʻi (Pitt et al. 2015; Figure 2). The study site consists of an 80-ha parcel of rocky lava substrate covered with a thin layer of mostly organic compost. The area was previously cleared for military use and left unused for >40 years, allowing propagation of mostly volunteer exotic vegetation dominated by molasses grass

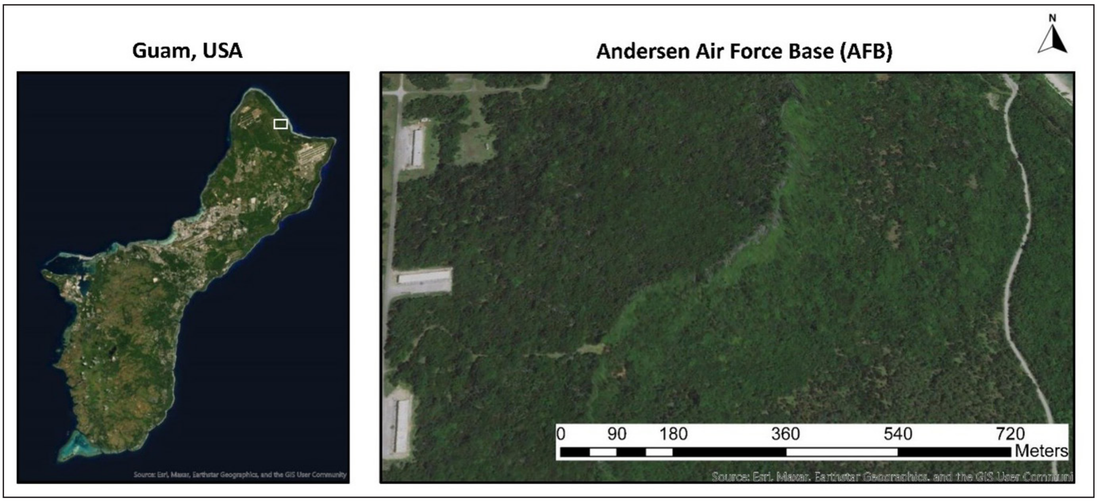

Figure 1. Brown treesnake (*Boiga irregularis*) study area, 1999–2000, Andersen Air Force Base, Guam, USA.

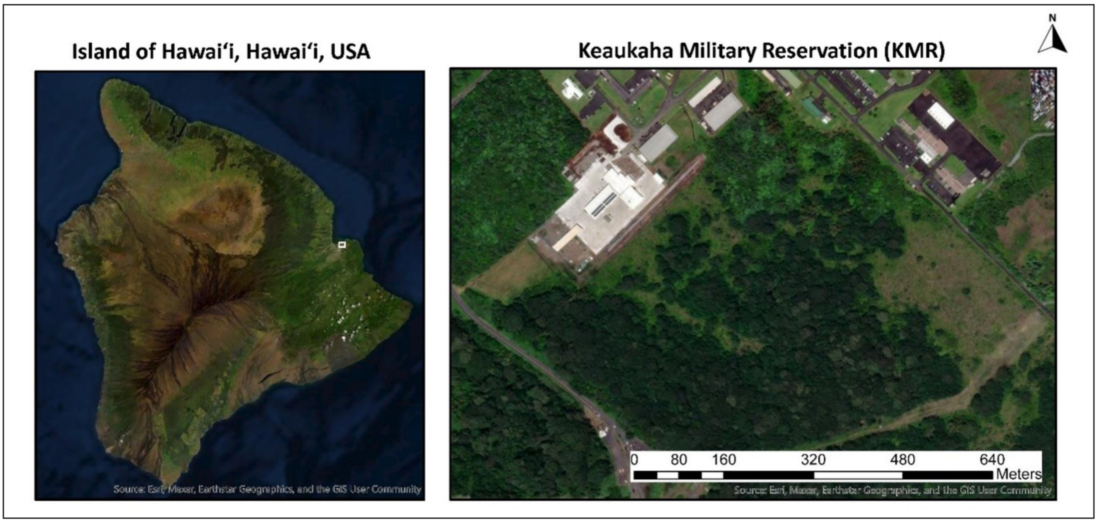

Figure 2. Mongoose (*Urva auropunctata*: Syn. *Herpestes auropunctatus*) study area, 2007, Hawai‘i Island, Hawai‘i, USA.

(*Melinis minutiflora*), bamboo orchid (*Arundina graminifolia*), ground ferns (*Nephrolepis* spp.), and strawberry guava (*Psidium cattleianum*). Scattered stands of albizia (*Falcataria moluccana*), gunpowder tree (*Trema orientalis*), ‘ōhi‘a (*Metrosideros polymorpha*), and screw pine (*Pandanus tectorius*) are also common alongside limited access perimeter roads.

Methods

Surveillance system

The major components of the monitoring system consisted of an AVID® commercial NEMA PIT tag reader (AVID ID Systems, Norco, California, USA) and an Onset Tattletale® Data Logger/Controller Engine (Onset Computer Corporation, Bourne, Maryland, USA). The PIT tag reader automatically senses valid tags implanted on target animals that pass through a 15-cm-diameter hoop antenna tethered to the reader via a 2.5-m-long cable. We positioned and adjusted the sensitivity of the antennas so that PIT tags were only detected in proximity to (5–6 cm) and within the inner plane of the hoop antenna. The unique 9-digit identification (ID) number from each PIT tag was read, decoded, and transmitted as an RS-232 signal (9600 baud rate) on a digital output line to the connected data logger, which stored the tag ID along with tag acquisition date and time, AVID

Figure 3. Automatic monitoring system components enclosed in weather-proof container—12 volts direct current compact sealed lead acid battery (A), data logger (B), AVID PIT tag reader (C), and trailing PIT tag hoop antenna (D used for monitoring bait station visitation by brown treesnakes (*Boiga irregularis*) on Andersen Air Force Base, Guam, Northern Mariana Islands (1999–2000) and mongooses (*Urva auropunctata*: Syn. *Herpestes auropunctatus*) on Hawai'i Island, Hawai'i, USA (2007). Note: label (10) on plastic container cover denotes device identification number.

reader and data logger serial number, and various programmable user-defined data record fields and equipment diagnostic information. We determined and programmed the type and format of data to be stored into the data logger prior to activating the units in the field.

An external 12-volt direct current (VDC), 7-ampere hour, sealed lead acid battery (18 x 11 x 8 cm) weighing 2.3 kg provided power to both the PIT tag reader and data logger for approximately 5–7 days before battery replacement was needed. An internal 9 VDC battery provided data logger backup power to facilitate routine swap out of the main battery without losing the logging application software and data stored in volatile memory. We programmed the data logger to monitor and record the output capacity of the primary and memory backup batteries hourly. At the time, onboard memory capacity allowed for storage of up to 5,000 individual events.

The PIT tag reader unit was factory-sealed in a waterproof hard plastic NEMA-rated case. The hoop antenna and 2.5-m-long attachment cable were shielded in a hard vinyl coating. The single board electronic circuitry of the data logger was protected in a compact plastic case. All components fit into a small 27 x 27 x 11-cm (length, width, height) watertight plastic container; total package weighed 1,280 g (3,900 g with battery; Figure 3). The compact and lightweight unit allowed for easy handling and transport and added protection in harsh weather environments. When deployed, the bait delivery device and attached hoop antenna could be located up to 2.2 m from the control unit, minimizing the footprint of the monitoring system at the target location. We concealed the control unit container under vegetation, logs, or placed it above ground in trees to provide camouflage and reduce environmental impacts.

Prior to field deployment, we used a handheld or standard laptop computer to initially set up and control the data logger collection parameters. Current date, time, PIT tag reader, and data logger serial numbers, and maximum delay (1–30 seconds) were typical input selections programmed prior to field deployment of the system. Maximum delay referred to the time interval following initial acquisition of a unique PIT tag in which the data logger controller disregarded further inputs of the same tag. We used a 30-second delay where the same PIT tag repetitively detected within 30 seconds was recorded only once. The pre-programmed detection delay allowed us to quantify loitering (rapid entry/exit) activity at a station and record multiple visits to the same station within a short period of time. This feature conserved onboard memory storage capacity and facilitated ease of off-line data recognition and analysis. Data retrieval was accomplished using a handheld or laptop computer. An external light-emitting-diode plug (jack) inserted into the side port of the data logger provided an indication that at least 1 data record was available for download, indicative that a PIT-tagged animal visited the station. We used a standard computer terminal communication program to reset memory in the data logger and download and save recorded data onto a laptop computer.

Brown treesnake study

We used the automatic monitoring system described in a field study to determine the demographics, bait attractiveness, and fate of a population of brown treesnakes exposed to an oral toxicant during a baiting program conducted in northern Guam, Mariana Islands, in summer of 2000.

We delineated a 150 x 150-m section (2.8 ha) of an 8-ha forest block consisting of 49 trapping stations spaced 25 m apart in a 7 x 7 rectangular grid array to capture and mark brown treesnakes for the study. We used wire-mesh funnel snake traps baited with a live mouse (housed in separate protective chamber) to live-capture brown treesnakes (e.g., Linnell et al. 1998). We checked and maintained traps daily over a 20-day trapping period prior to activation of the toxic bait delivery stations. We removed captured snakes from traps, manually restrained them, and inserted uniquely numbered AVID PIT tags (12 x 2.1 mm) in muscle tissue under ventral scales proximal to the vent (MacGregor and Reinert 2001) and under dorsal scales in the neck posterior to the pivot point of the lower jaw before releasing the snakes at the capture location. Monitoring objectives, anatomy, and physiological differences of the target species approaching and entering passive bait delivery devices are important considerations in selecting appropriate PIT tag implantation sites (Biggins et al. 2006). Thus, we double-tagged snakes to optimize detection probability at bait stations.

Studies have documented low live-trap capture success of smaller size class of snakes (Savidge 1988, Rodda et al. 1999, Savarie et al. 2001). A secondary objective was to evaluate bait delivery station utilization and acceptance of treated DNM bait by smaller snakes. We grouped snakes <850 mm snout-vent length (SVL) to the smaller class and snakes ≥850 mm SVL to the larger class. We hand-captured small snakes along fence lines and other off-site locations during normal snake interdiction operations by USDA Guam WS personnel and similarly PIT-tagged and relocated them into the study site.

We surgically implanted miniature (1.4 g) radio transmitters (Holohil Systems, Ontario, Canada) into a subset of the PIT-tagged larger snakes following procedures described by Tobin et al. (1999). None of the off-site captured smaller snakes released into the study area were implanted with radio-transmitters due to the snakes' small girth relative to the transmitter package size. We tracked each radio-implanted snake with hand-held radio receivers (Advanced Telemetry Systems, Isanti, Minnesota, USA) and portable 3-element Yagi antennas (Wildlife Materials, Murphysboro, Illinois, USA) and located (visually whenever possible) each snake at least once daily to determine its daytime refuge location during the 20-day trapping period. We located all radio-implanted snakes once daily in the morning (0800–1000 hours).

Bait stations

We constructed bait stations from a pair of thick-walled white poly vinyl chloride (PVC) sewer pipes sized 20 cm long by 15 cm in diameter. We sandwiched the hoop antenna vertically between the 2 horizontal lengths of pipe and secured them with plastic ties. The bait station measured 42 cm long by 15 cm in diameter and

Figure 4. Brown treesnake (*Boiga irregularis*) bait delivery station hung from a tree (left) used on Guam, Northern Mariana Islands (1999–2000) and ground-placed mongoose (*Urva auropunctata*: Syn. *Herpestes auropunctatus*) bait delivery station (right) with PIT tag hoop antenna mounted in the center of the stations, Hawai‘i Island, Hawai‘i, USA (2007).

was open at both ends with a raised plastic mesh platform glued to the inside walls in the center of the station to hold a single bait (Figure 4).

We placed a baited PVC bait station at each of the inner 5 x 5 grid location (25 PIT tag monitoring stations) within the 7 x7 trapping grid 7 days after the last snake was captured, tagged, and released. We hung the bait stations horizontally from branches with nylon cords at each station (Global Positioning System [GPS] location recorded) approximately 1.5–2.0 m off the ground to maximize bait exposure to the arboreal target species and reduce disturbance by ground predators. We secured the control units under logs, boulders, or in the crotches of adjacent branches approximately 2.2 m from the receiving hoop antenna (bait delivery device). Each station was baited with a single DNM bait treated with an 80-mg acetaminophen tablet. In laboratory and field trials, Savarie et al. (2000, 2001) found the 80-mg dosage to be 100% lethal to both size classes of snakes as used in our study.

Bait station visitation monitoring

We tracked, located, and recorded the location (GPS) of each radio-implanted snake once daily for 21 consecutive bait exposure days and checked for recorded PIT tag detections at bait stations to determine the snake's eventual fate (e.g., time to death, location of carcass). We also monitored bait status (e.g., condition and disappearance) and PIT tag detections at each station daily and replenished stations with fresh bait as needed; uneaten baits were replaced after 2–3 days. We used each snake's prior day's location (GPS) and records of station visitations to determine the Euclidean distance traveled to the visited station and assess the attractiveness of the bait delivery system for brown treesnakes. We recorded snake locations using hand-held GPS receivers (Trimble Navigation, Sunnyvale, California). Additional daily searches were performed to physically locate and confirm the status of all snakes logged by monitoring stations with missing toxic bait. Subsequent searches were conducted the following day if necessary.

While PIT tag detections at bait stations and missing bait are not conclusive evidence that a visiting brown treesnake consumed the toxic bait, previous studies, in similar habitat as ours, using video data identified very few non-target visitors to suspended PVC bait stations baited with dead neonate mice (Siers et al. 2019; P. J. Savarie [retired], USDA, WS, NWRC, unpublished data).

Bait consumption criteria

Records of bait removal have been the standard metric used to evaluate brown treesnake foraging activity (e.g., abundance) in monitoring the efficacy of various ecological and control related studies (Savarie et al. 2001, Clark et al. 2012). We used the same criteria to confirm bait take of the acetaminophen-laced DNM bait in our study. Bait status (present or absent) was recorded each morning during the bait exposure period. For each night's PIT tag detection of snakes visiting bait stations, the following fate status was assigned: (1) if only 1 snake was detected at a bait station and the bait was missing the following morning, we assumed that individual consumed the bait, (2) if multiple snakes were detected at a bait station during the night and the bait was missing in the morning, the first detected snake was recorded as consuming the bait and, (3) if a PIT-tagged snake was detected at a bait station and the bait was intact in the morning, the snake did not consume the bait.

We used the monitoring system to collect the following information: (1) individual identity of snakes visiting bait stations, (2) distance from the last telemetry locations to the bait stations, (3) bait take success, (4) time of visitation, (5) location and fate of bait consumers, and (6) daytime refugia locations. Capture and handling procedures were approved by the USDA WS NWRC Institutional Animal Care and Use Committee under protocol QA-817.

Small Indian mongoose

We evaluated the monitoring system during a study to determine the effectiveness of selected food baits in attracting mongooses to bait delivery stations (Pitt et al. 2015).

We live-captured mongooses in Tomahawk® (Tomahawk Live Trap Co., Tomahawk, Wisconsin, USA) wire cage traps baited with 6.5-cm^2 chunks of fresh coconut endosperm. We placed traps in 4 parallel transects 100–150 m apart with 6–7 trapping stations at 100-m intervals. We anesthetized captured mongooses via inhalation of isoflurane gas as described by Pitt et al. (2015). Similar to the brown treesnake case study, we used dual AVID PIT tags (12 x 2.1 mm each): 1 tag implanted subcutaneously between the shoulder blades and a second tag inserted in the dorsal rump area. In addition, a subset of captured and PIT-tagged mongooses was fitted with 6.5-g neck collar radio-transmitters (Advanced Telemetry Systems, Isanti, Minnesota). We used this subset of PIT-tagged and radio-collared mongooses to determine baseline foraging boundaries and subsequent daily travel distances as well as identify individual responses to selected food baits via the monitoring system and validate the system's performance. We tracked radio-collared mongooses at least once daily, except weekends and holidays.

Bait stations

The monitoring/bait delivery device used for mongooses consisted of an open-ended 12.5 x 12.5 x 37.5-cm (height, width, length) tunnel with a flat floor and arched roof constructed from thick, waxed, white signboard paper (Pitt et al. 2015; Figure 4). We secured the receiving hoop antenna perpendicularly on the outside center of the station with plastic ties and attached wooden support legs to the bottom of the station to position it level to the ground. We used 4 fresh, non-toxic food baits: (1) beef scraps, (2) previously frozen fish (mackerel), (3) whole chicken eggs, and (4) fresh coconut (endosperm). We placed approximately 50 g of each bait type or 1 egg in a 7 x 12-cm (width, length) pouch constructed from 12-mm mesh plastic hardware cloth. We secured the pouch to the inner middle bottom floor of the bait station to prevent displacement or complete removal of bait to optimize PIT tag detections and documentation of visitation parameters (i.e., lingering activity, time at station, etc.). Each bait type was evaluated separately during 2 3-day exposure trials/bait type (trial 1 and 2). Trials were conducted 7–14 days apart with 21–28 days between trials of each bait type.

Bait station visitation monitoring

To evaluate distance traveled to the baits, we located mongooses each morning by triangulation. Subsequently (within 1 hour), we placed 12 bait stations with the predetermined test food (3 of each bait type) at 50 to 100-m intervals along linear transects. Stations were typically placed >500 m away from that morning's mongoose locations. The following morning, we first determined the location of each radio-collared mongoose, then visually checked each bait station, queried the data logger, and downloaded mongoose visitation records. We replaced missing, disturbed, or partially eaten baits with fresh bait that had been stored under ambient field conditions.

We recorded the following information: (1) fresh food type at bait station, (2) individual identity of mongooses visiting bait stations, (3) distance from the last telemetry locations to the bait stations, (4) bait take success, and (5) time of visitation. Mongoose capture, handling, and anesthesia were approved by the USDA WS NWRC Institutional Animal Care and Use Committee under protocol QA-1255.

Results

Brown treesnake

We captured, PIT-tagged, and released 101 brown treesnakes (e.g., larger size class, mean SVL = 1,044 mm, range = 856–1,268 mm) during the 20-day pre-toxic bait exposure trapping period, of which we implanted 25 snakes with miniature very high frequency (VHF) transmitters. We translocated an additional 27 smaller snakes (mean SVL = 721 mm, range = 465–833 mm) and 3 large (SVL = 856, 866, and 894 mm) brown treesnakes (PIT tag only) into the study site. During the 21-day toxic bait exposure period (525 station-days), the monitoring system automatically recorded 1,067 episodes (PIT tag detections) of 32 individual brown treesnakes at the bait stations. Each episode consisted of 8–45 detection records with 2–5 repeated visits at the same station within a 14-day period. All visitation episodes (time spent at bait station) were <2 minutes. Of snake identifications, 62% were exclusively via neck-implanted PIT tags, 28% were by tail-implanted tags only, and 10% included both neck and tail tags detected of the same snake.

We found that 32 of 101 large snakes tagged and released (31.7%) visited bait stations. Of these, 24 snakes apparently consumed bait, and 8 snakes visited a bait station but did not consume bait. We affirmed 8 snakes with VHF transmitters as mortalities and 8 sole snake detections (no other PIT-tagged snakes detected at the bait stations during the night) with subsequent missing bait the next morning as also assumed mortalities. The other snakes (8) were the first ones detected among multiple snakes at the bait station with subsequent missing baits. One snake apparently consumed baits from 2 different stations within a 2-hour period.

We found the exposed carcasses of 7 radio-tagged snakes that consumed bait. The carcasses were found exposed on the ground. We found the transmitter from the eighth snake on the ground in the decomposed fecal pellet of a monitor lizard (*Varanus indicus*), which presumably found and consumed the dead or dying snake. The average discovery time between presumed consumption of treated bait to discovery of dead snakes was 32 hours (range = 10–48 hours). Fifty percent of mortalities occurred within 24 hours of a tagged snake being recorded at a bait station. Snakes may have perished earlier since nighttime (12-hour period) searches were not conducted due to logistics and observer safety concerns. Snakes that consumed toxic bait that lived longer than 24 hours ($n = 4$) were initially located in normal refugia on the first morning of telemetry monitoring and were subsequently found dead. Carcasses were found an average of 30.3 m (range = 10–54 m) away from the bait delivery station visited. Despite daytime ground searches, no carcasses of the remaining PIT-tagged only snakes (without transmitters) that presumably consumed toxic bait ($n = 16$) were discovered.

We detected 2 small (SVL = 682 and 769 mm) and 1 large (SVL = 894 mm) PIT-tagged supplemental snakes we had released into the study plot at bait stations. The baits at the stations visited by the smaller snakes were intact. The relocated large snake detected at a bait station apparently consumed the toxic bait and is assumed to have died.

Snake visits to bait stations occurred throughout the hours of darkness from 1900–0600 hours with peak visits at 2100–0000 hours. We also recorded 126 daytime refugia (90% visually confirmed) for the 25 radio-tagged brown treesnakes. We found live snakes most frequently on the ground under dead vegetation or wedged in rocky crevices (62 locations), coiled in tree branches or crotches ($n = 48$), and in a hollowed cavity of a dead log ($n = 1$).

Small Indian mongoose

We focus on reporting the performance and capabilities of the monitoring system in collecting discrete individual mongoose responses to bait delivery devices. Details on the attractiveness of candidate food baits to mongooses, bait preference, and related biological and ecological findings are reported in Pitt et al. (2015).

We captured, PIT-tagged, and released 41 mongooses (8 male, 33 female), 21 of which were also collared with radio-transmitters (8 male, 13 female). The monitoring system recorded 6,268 mongoose visitation episodes (PIT tag detections), including same-day or consecutive-day visitations by the same mongoose to preferred baits during 336 station-exposure days. This includes 129 visitations by 29 individual mongooses to selected food bait stations during 2 separate trials of each of 4 bait types. Most mongoose detections were via both shoulder and rump-implanted PIT tags; sole tag identifications accounted for <10% of all detections and was 53.9% and 46.1% for anterior (shoulder) and posterior (rump) PIT tags, respectively.

Mongooses were attracted to all the food baits (i.e., fish, beef, egg, coconut) evaluated in the case study (Pitt et al. 2015). A small proportion (29.1%) of tagged mongooses did not visit any baited food stations, although some radio-collared mongooses were regularly located foraging near bait stations. Mongooses foraged over large areas (range = 6.0–70.2 ha) throughout the daylight hours (0600–1800 hours) with reduced activity shortly after sunrise and before sunset. Male mongooses generally were attracted to the food baits from greater distances than females, with baits being discovered within 24–30 hours from distances up to 598 m and 483 m by males and females, respectively. Mongooses displayed apparent habituation to novel food stations as evidenced by repeat and prolonged visitations within the same day and over the 3-day bait exposure period. Concurrent detections of multiple mongooses ($n = 2–6$) at the same station within a short (<5 minutes) period provides evidence of greater cohort interactions and group feeding activity not previously documented in mongooses in Hawai‘i.

Discussion

We successfully deployed the automatic PIT tag monitoring system in separate toxic and non-toxic baiting studies of an arboreal nocturnal snake and a terrestrial diurnal carnivore, respectively. We used the same system for both field studies with simple modifications to bait station design and strategic placement of the receiving hoop antenna to accommodate target species differences in body size and foraging behavior. Deployment of this custom-designed automatic monitoring system in the case studies of the brown treesnake and small Indian mongoose provided valuable chrono-ecological data on individual animal behavior that has the potential to optimize the success of bait station delivery systems in controlling these non-native invasive predators.

Brown treesnake

Recorded system data showed that visitation rates to the toxic bait stations by brown treesnakes in this case study were low (32% of all PIT-tagged snakes). In a follow-up large-scale study evaluating extended (12 weeks) baiting using similar toxic (acetaminophen) bait stations in combination with operational trapping, researchers recorded bait take ranging from 21–40% per week (R. T. Sugihara and E. W. Campbell, NWRC, unpublished report). Bait takes by non-PIT-tagged snakes or non-target visitors were minimal in both studies based on only a few instances of stations with missing bait without valid PIT-tagged snake detections, validating that bait was readily available for foraging brown treesnakes.

Some snakes visited multiple stations within a period of 2–3 days with or without taking the bait; 1 snake presumably consumed 2 treated baits from 2 different bait stations within a 2-hour period. We assigned bait take to the first snake detected at the bait station on a particular night, but the lingering bait odor plume could still be attractive to subsequent snakes visiting and detected at the bait station (Sugihara et al. 2015, Siers et al. 2018). Bait take was consistent over the first 15 days and decreased slightly thereafter during the 21-day bait exposure period of this study. Savarie et al. (2001) and Siers et al. (2018) also found a consistent bait take rate over time.

We found the carcass of 7 of 8 radio-tagged snakes that consumed bait fully exposed on the ground. Only the transmitter of the other snake was found imbedded in the fecal dropping of a monitor lizard. In a similar study by Smith et al. (2016), 92% of the carcasses of captured brown treesnakes fed acetaminophen-laced mice and then released in the forest were found on the ground. These results suggest that snake carcasses may be accessible to a wide range of potential scavengers (Smith et al. 2016). Despite daily searches, we were not able to locate dead PIT-tagged only or non-PIT-tagged snakes that consumed bait. The inability to find dead snakes is consistent with other studies evaluating efficacy of brown treesnake control programs (Goetz et al. 2020, Siers et al. 2020).

Only 2 of the 27 translocated small snakes were detected at the bait stations, and none of them appeared to have consumed the treated bait. Reliable data on smaller size class brown treesnake movements is lacking, and we are unsure if the introduced small snakes dispersed out of the unfamiliar relocated site during the bait exposure period. All on-site PIT-tagged snakes were of the larger size class, precluding valid comparisons of age class differences in bait station usage between on-site and supplementally relocated snakes. Thus, with the monitoring system used, we were not able to adequately determine bait station utilization and acceptance of treated bait by small snakes in this study. Researchers have suggested that this PVC tube delivery device, placement, and/or bait type (DNM) are ineffective for smaller size class snakes (Savarie et al. 2001, Lardner et al. 2013). It was reported that small brown treesnakes almost exclusively feed on small lizards (Savidge 1988, Lardner et al. 2009).

Small Indian mongoose

The monitoring system provided valuable insight and information on mongoose foraging ecology and individual responses to baits used to attract mongooses to traps and other bait delivery devices. Through its use in the case study, researchers documented prolonged and repeated visits to a particular bait station, indicating that mongooses were spending more time at a familiar "food-rich" location than they normally would have and suggesting learned fidelity at a known food source site. This is evident in urban habitats in Hawaiʻi where scores of mongooses are attracted to a variety of anthropogenic foods discarded along roadways, waste disposal sites, residences, commercial areas, and parks (Tomich 1969, Hays and Conant 2007). A high proportion (70%) of PIT-tagged mongooses found selected baits; however, some individuals were not attracted to bait stations placed within their normal home range. Baits with strong olfactory cues and persistent latent odors such as fish may be more attractive to mongooses than other fresh or processed food baits and may be the bait of choice in areas of low mongoose densities or newly established sites.

This study found that mongooses foraged throughout the daylight hours, supporting evidence that this species is a strict diurnal forager in Hawaiʻi. The disproportionate capture rate of female mongooses (0.80) has been recorded in past trapping at the study area (R. T. Sugihara, unpublished data) and other locations and may reflect post-reproduction dispersal of female mongooses (Hays and Conant 2007). Discrete recorded information on spatial and temporal responses by mongooses to selected baits provide valuable insight toward optimizing control strategies using bait stations (Pitt et al. 2015).

System capabilities and limitations

Operationally, system portability allowed easy transport, deployment, and deactivation of multiple individual monitoring units in the 2 rugged and remote study sites, especially in the limestone forests of northern Guam. System components (e.g., PIT tag reader, data logger, battery) were interchangeable between individual stand-alone units; this allowed for easy maintenance and diagnostics in the field. The compact all-in-one housing of the entire system (<4 kg total package weight) is a significant advantage over other autonomous systems plagued by bulky (22 kg) batteries and large space requirement of the separate and often hard-wired hardware components (Kenward et al. 2005, Rehmeier et al. 2006; R. T. Sugihara, NWRC, unpublished data).

The programmed 30-second delay was a compromise between reducing same animal detections (i.e., loitering activity) and ensuring identification of new individuals visiting the same station concurrently or within a short period of each other. For mongooses especially, this short time delay resulted in multiple records of the same individual at a particular station. In the case of brown treesnakes with toxic baits, repeat visits to bait stations by the same snake were much less. For studies with extended service periods, depending on study objectives, increasing the delay period would be a solution to conserve data storage capacity. We do not suspect that a lingering mongoose significantly excluded other cohorts from the station since visits by 2–6 different mongooses at a station within a short period of time (<5 minutes) were frequently recorded. We only examined an individual mongoose's first visit to the respective food bait station in assessing the attractiveness of the candidate food to eliminate learned responses and habituation to particular food baits.

The system did have some initial drawbacks and limitations (though they were resolvable with minor modifications), and a few equipment operational outages were experienced during the monitoring periods. Some equipment failures, resulting in monitoring outages, were experienced with the automatic PIT tag monitoring system; most technical problems (e.g., blown fuses, PIT tag reader failure, disconnected cables) were caused during pre-field activation/transport of units, during component and battery exchanges, or other operator interventions. The few PIT tag misreads (<0.5%) recorded (missing data fields, garbled PIT identification) were related to the power and battery malfunctions. Power surge and battery polarity protection incorporated into the reader unit and power cables resolved subsequent related problems.

Feral pigs (*Sus scrofa*) attracted to selected food baits (i.e., fish, coconut) prematurely deactivated 6 mongoose bait delivery stations, resulting in disturbance (protective cover displaced) and displacement of the separate electronic components 1–2 m from their original locations. However, the units were successfully put back in service after overnight drying. The easy-disconnect battery cable likely prevented permanent damage to the system. Placement of the electronic component cases above ground in trees or away from pig-disturbed areas and pathways eliminated the problem during subsequent trials.

The loss of PIT tags from implanted sites can have major implications on the results of mark-recapture or detection studies (Schooley et al. 1993, Harper and Batzli 1996, Roark and Dorcas 2000). Most reported losses occurred within 2–4 days after tag implantation. We recorded 4 instances of single tag loss (3 anterior, 1 posterior) in recaptured brown treesnakes and 3 instances of single tag loss (3 anterior) in recaptured mongooses during the early stages of trapping prior to bait exposure. Closing the PIT tag needle puncture sites with cyanoacrylate adhesive resulted in 100% tag retention in subsequently recaptured snakes. Implantation of dual PIT tags in brown treesnakes and mongooses served as backup identification and optimized detection probability. Most detections of brown treesnakes were via anterior placed tags, characteristic of their anatomy and bait seeking pattern and entry into the PVC bait delivery station, whereas dual tag detections of mongooses were more common. Dual PIT tag implants also contributed to the oversampling of the same individuals.

A basic disadvantage of PIT tag systems is that only tagged individuals are detected, limiting its use to animal species with high initial trappability or requiring prolonged trapping efforts to ensure that a high percentage of the population is marked (Sutherland and Singleton 2003). We were able to trap and mark most of the animals in the core study sites of the 2 predator species in this study within a short 3–4 week trapping period to satisfy the focus of the study to evaluate the monitoring system. Untagged cohorts accounted for <1% and <2% of bait-take by brown treesnakes and small Indian mongooses, respectively, as evidenced by missing bait with no PIT tag detections.

High initial equipment cost is probably the main reason preventing wider use of automatic PIT tag monitoring systems (Schooley et al. 1993, Harper and Batzli 1996, Rehmeier et al. 2006). However, once cost-prohibitive and limited to a few units deployed in a small area, recent technological advancements have made the system affordable for more users. Designed, procured, and deployed in 2000, the system we described cost approximately $1,500 USD per unit, not including initial engineering, design, and prototype development costs. Stand-alone PIT tag readers with built-in data storage capacity are now available for <$500 USD with built-in data storage capabilities; however, we are not aware of any current autonomous monitoring system with similar capabilities and the programmable features that we describe. Recent advancements in electronics, controllers, and programming (e.g., Arduino, SerialGhost PCI boards) can greatly reduce the footprint and improve the capabilities of the earlier system used (Bridge et al. 2019). The SerialGhost Timekeeper is a compact RS232 logger and serial bus datalogger with 16 GB of memory and a time-stamping module that can directly plug into the existing AVID PIT tag reader that is being considered as an economical upgrade of the existing system. Considering the advantages of autonomous systems in collecting discrete spatial and temporal data not possible with other techniques and often on hard-to-study cryptic animal species, an investment in this technology to complement radiotelemetry or other monitoring systems is a labor-saving and feasible alternative.

Management implications

Deployment of the automatic PIT tag monitoring system can allow wildlife managers and researchers to collect important information on foraging behavior and attractiveness of selected baits and document individual visitations to bait delivery systems for the 2 case invasive species, not easily obtainable by other field techniques. Easily deployable in various habitats, the system can be an effective technique to supplement other methods (radio-telemetry and camera traps) to optimize collection of discrete animal identification and behavioral activities of interest of small mammals, birds, reptiles, or amphibians with minimal disturbance to the target species. The PIT tag monitoring system, when used in conjunction with radiotelemetry and camera traps, allows for comprehensive documentation of individual and species removing and consuming bait, providing further validation of operational control programs utilizing toxic baits. The system received interest from researchers to record nest attentiveness of endangered native Hawaiian forest birds (P. C. Banko, U.S. Geological Survey, personal communication).

Acknowledgments

Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government. We are grateful to E. Campbell, former Hawaiʻi Field Station project leader, who seeded the autonomous concept of monitoring snakes, supported, and assisted in evaluating the earlier prototypes of the system during many deployments on various brown treesnake research projects on Guam. We especially thank L. Oberhofer and P. Dunlevy for field assistance with capturing and tracking brown treesnakes and D. Vice (deceased) for facilitating access to study sites and additional support on Guam; and L. Pitt, R. Doratt, M. Higashi, R. Swift, J. Curl, and C. Deringer for their help with the mongoose field studies in Hawaiʻi. M. Cruz of AVID ID Systems provided engineering support of earlier prototype designs. M. Fall, C. Antaky, S. Hess, and I. Leinbach critically reviewed earlier drafts of this manuscript. Funding was provided to the National Wildlife Research Center by the U.S. Department of Defense under their Legacy Program for studies on Guam and by the U.S. Fish and Wildlife Service's Ecological Services Pacific Islands Office for the mongoose project in Hawaiʻi. Comments provided by HWI Associate Editor S. Siers and 2 anonymous reviewers improved our manuscript.

Literature cited

Baldwin, P. H., C. W. Schwartz, and E. R. Schwartz. 1952. Life history and economic status of the mongoose in Hawaii. Journal of Mammalogy 33:335–356.

Berentsen, A. R., W. C. Pitt, and R. T. Sugihara. 2017. Ecology of the small Indian mongoose (*Herpestes auropunctatus*) in North America. Pages 251–267 *in* W. C. Pitt, J. C. Beasley, and G. W. Witmer, editors. Ecology and management of terrestrial vertebrate invasive species in the United States. CRC Press, Boca Raton, Florida, USA.

Bertolino, S., C. Viano, and I. Currado. 2001. Population dynamics, breeding patterns and spatial use of the garden dormouse (*Eliomys quercinus*) in an alpine habitat. Journal of Zoology 53:513–521.

Biggins, D. E., J. L. Godbrey, M. R. Matchett, L. R. Hanebury, T. M. Livieri, and P. E. Marinari. 2006. Monitoring of black-footed ferrets during reestablishment of free-ranging populations: discussion of alternative methods and prescription of minimum standards. Pages 155–174 *in* J. E. Roelle, B. J. Miller, J. L. Godbey, and D. E. Biggins, editors. Recovery of the black-footed ferret—progress and continuing challenges. U.S. Geological Survey Scientific Investigations Report 2005-5293.

Boarman, W. I., M. L. Beigel, G. C. Goodlett, and M. Sazaki. 1998. A passive integrated transponder system for tracking animal movements. Wildlife Society Bulletin 26:886–891.

Bonter, D. N., and E. S. Bridge. 2011. Application of radio frequency identification (RFID) in ornithological research: a review. Journal of Field Ornithology 82:1–10.

Bridge, E. S., J. Wilhelm, M. M. Pandit, A. Moreno, C. M. Curry, T. D. Perarson, D. S. Proppe, C. Holwerda, J. M. Eadie, T. F. Stair, A. C. Olson, B. E. Lyon, C. L. Branch, A. M. Pitera, D. Kozlovsky, B. R. Sonnenberg, V. V. Pravosudov, and J. E. Ruyle. 2019. An Ardiuino-based RFID platform for animal research. Frontiers in Ecology and Evolution **7**:257.

Briggs, A. J. A., C. A. Robstad, and F. Rosell. 2021. Using radio-frequency identification technology to monitor Eurasian beavers. Wildlife Society Bulletin 45:154–161.

Brooks, J. E., P. J. Savarie, and J. J. Johnson. 1998. The oral and dermal toxicity of selected chemicals to brown treesnakes (*Boiga irregularis*). Wildlife Research 25:427–435.

Camper, J. D., and J. R. Dixon. 1988. Evaluation of a microchip marking system for amphibians and reptiles. Texas Parks and Wildlife Department Research Publication 7100-159, Austin, Texas, USA.

Castro-Santos, T., A. Haro, and S. Walk. 1996. A passive integrated transponder (PIT) tag system for monitoring fishways. Fisheries Research 28:253–261.

Charney, N. D., B. H. Letcher, A. Haro, and P. S. Warren. 2009. Terrestrial passive integrated transponder antennae for tracking small animal movements. Journal of Wildlife Management 73:1245–1250.

Clark, L., P. J. Savarie, J. A. Shivik, S. W. Breck, and B. S. Dorr. 2012. Efficacy, effort and cost comparisons of trapping and acetaminophen-baiting for control of brown treesnakes on Guam. Human–Wildlife Interactions 6:222–236.

Creuwels, J. C. S., W. Van der Veer, and J. A. Van Franeker. 2000. AWIN, an automatic weigh and identification nest-system to study petrels in Antarctica. Poster presented at "Measuring Behavior 2000." Third International Conference on Methods and Techniques in Behavior Research, Nigmegen, The Netherlands.

Dell'Omo, G., R. F. Shore, and H. Lipp. 1998. An automated system, based on microchips, for monitoring individual activity in wild small mammals. Journal of Experimental Zoology 280:97–99.

Elbin, S. B., and J. Burger. 1994. Implantable microchips for individual identification in wild and captive populations. Wildlife Society Bulletin 22:677–683.

Engeman, R. M., and M. A. Linnell. 1998. Trapping strategies for deterring the spread of brown treesnakes from Guam. Pacific Conservation Biology 4:348–353.

Fagerstone, K. A., and B. E. Johns. 1987. Transponders as permanent identification markers for domestic ferrets, black-footed ferrets, and other wildlife. Journal of Wildlife Management 51:294–297.

Freitag, A., A. Martinoli, and J. Urzelai. 2001. Monitoring the feeding activity of nesting birds with an autonomous system: case study of the endangered wryneck (*Jynx torquilla*). Bird Study 48:102–109.

Fritts, T. H., M. J. McCoid, and D. M. Gomez. 1999. Dispersal of snakes to extralimital islands: incidents of the brown treesnake (*Boiga irregularis*) dispersing to islands in ships and aircraft. Pages 209–223 *in* G. H. Rodda, Y. Sawai, D. Chiszar, and H. Tanaka, editors. Problem snake management: the habu and the brown treesnake. Cornell University Press, Ithaca, New York, USA.

Gibbons, J. W., and K. M. Andrews. 2004. PIT tagging: simple technology at its best. Bioscience 54:447–454.

Gilbert, R. 2000. Using PIT tags for tracking honeybees. Proceedings of PIT Tag Workshop 2000. Pacific States Marine Fisheries Commission, Stevenson, Washington, USA.

Goetz, S. M., A. A. Yackel-Adams, and S. R. Siers. 2020. Validating deployment of aerial delivered toxic bait cartridges for control of invasive brown treesnakes. Wildlife Society Bulletin 44:617–622.

Gruber, G. 2004. Measuring activity of geckos with an automatic movement monitoring system. Herpetological Review 35:245–247.

Harper, S. J., and G. O. Batzli. 1996. Monitoring use of runways by voles with passive integrated transponders. Journal of Mammalogy 77:364–369.

Hays, W. S. T., and S. Conant. 2007. Biology and impacts of Pacific Island invasive species. 1. A worldwide review of effects of the small Indian mongoose, *Herpestes javanicus* (Carnivora: Herpestidae). Pacific Science 61:3–16.

Iserbyt, A., M. Griffion, B. Borremans, M. Eens, and W. Muller. 2018. How to quantify animal activity from radio-frequency identification (RFID) recordings. Ecology and Evolution 8: 10166–10174.

Jones, C., H. Moller, and W. Hamilton. 2004. A review of potential techniques for identifying individual stoats (*Mustela ermine*) visiting control or monitoring stations. New Zealand Journal of Zoology 31:193–203.

Keith, J. O., D. N. Hirata, and D. L. Espy. 1987. Control of mongoose predation on endangered Hawaiian birds. Progress report 1986. U.S. Department of Agriculture, Denver Wildlife Research Center, Denver, Colorado, USA.

Keith, J. O., D. N. Hirata, D. L. Espy, S. Greiner, and D. Griffin. 1990. Field evaluation of 0.00025% diphacinone bait for mongoose control in Hawaii. Progress report. U.S. Department of Agriculture, Denver Wildlife Research Center, Denver, Colorado, USA.

Kenward, B., R. E. Kenward, and A. Kacelnik. 2005. An automatic technique for selective feeding and logging of individual wild squirrels. Ethology, Ecology, and Evolution 17:271–277.

Konig, B., A. K. Lindholm, P. C. Lopes, A. Dobay, S. Steinert, and F. J. Bushmann. 2015. A system for automatic recording of social behavior in a free-living wild house mouse population. Animal Biotelemetry 3:1–15.

Lardner, B., J. A. Savidge, G. H. Rodda, and R. N. Reed. 2009. Prey preferences and prey acceptance in juvenile brown treesnakes (*Boiga irregularis*). Herpetological Conservation and Biology 4:313–323.

Lardner, B., A. A. Yackel Adams, J. A. Savidge, G. H. Rodda, R. N. Reed, and C. S. Clark. 2013. Effectiveness of bait tubes for brown treesnake control on Guam. Wildlife Society Bulletin 27:664–673.

Leskey, T. C., and H. W. Hogmire. 2005. Monitoring stink bugs (Hemiptera: Pentatomidae) in Mid-Atlantic apple and peach orchards. Journal of Economic Entomology 98:143–153.

Linnell, M. A., R. M. Engeman, M. E. Pitzler, M. O. Watiton, G. F. Whitehead, and R. C. Miller. 1998. An evaluation of two designs of stamped metal trap flaps for use in operational trapping of brown treesnakes (*Boiga irregularis*). Snake 28:14–18.

Lundqvist, H., F. Arnason, and I. Berglund. 2000. An automatic battery-operated PIT monitoring system for use in field traps helps to study runtiming of wild smolts of *Salmo salar*. Proceedings of PIT Tag Workshop 2000. Pacific States Marine Fisheries Commission, Stevenson, Washington, USA.

MacGregor, G. A., and H. K. Reinert. 2001. The use of passive integrated transponders (PIT tags) in snake foraging study. Herpetological Review 32:170–172.

Mahapatra, K., G. Gjerde, P. V. G. Reddy, M. Sahoo, R. K. Jana, J. N. Saha, and M. Rye. 2001. Tagging: on the use of passive integrated transponder (PIT) tags for the identification of fish. Aquaculture Research 32:47–50.

Mariette, M. M., E. C. Pariser, A. J. Gilby, M. J. L. Magrath, S. R. Pyrke, and S. C. Griffith. 2011. Using an electronic monitoring system to link offspring provisioning and foraging behavior of a wild passerine. Auk 128:26–35.

McCoid, M. J., T. H. Fritts, and E. W. Campbell, III. 1994. A brown treesnake (Colubridae: *Boiga irregularis*) sighting in Texas. Texas Journal of Science 46:365–368.

Moller, H., C. Hunter, M. Howard, P. McSweeney, P. Scofield, D. Scottm, and S. Uren. 2003. Automated system for measuring breeding burrows entry and exit by sooty shearwaters (*Puffinus griseus*). Department of Conservation Science Internal Series 129, Wellington, New Zealand.

Newey, S., P. Allison, S. J. Thirgood, A. A. Smith, and I. M. Graham. 2009. Using PIT-tag technology to target supplementary feeding studies. Wildlife Biology 15:405–411.

O'Farrell, M. J. 1974. Seasonal activity patterns of rodents in a sagebrush community. Journal of Mammalogy 55:809–823.

Pitt, W. C., R. T. Sugihara, and A. R. Berentsen. 2015. Effect of travel distance, home range, and bait on the management of small Indian mongooses, *Herpestes auropunctatus*. Biological Invasions 17:1743–1759.

Prentice, E. F., T. A. Flagg, C. S. McCutcheion, D. F. Brastow, and D. C. Cross. 1990. Equipment, methods, and an automated data-entry station for PIT tagging. American Fisheries Society Symposium 7:335–340.

Rehmeier, R. L., G. A. Kaufman, and D. W. Kaufman. 2006. An automatic activity-monitoring system for small mammals under natural conditions. Journal of Mammalogy 87:628–634.

Riley, W. D., M. O. Eagle, and M. J. Ives. 2003. A portable passive integrated transponder multipoint decoder system for monitoring habitat use and behavior of freshwater fish in small streams. Fisheries Management and Ecology 10:265–268.

Roark, A.W., and M. E. Dorcas. 2000. Regional body temperature variation in corn snakes measured using temperature-sensitive passive integrated transponders. Journal of Herpetology 34:481–485.

Rodda, G. H., and T. H. Fritts. 1992. Sampling techniques for an arboreal snake, *Boiga irregularis*. Micronesica 25: 23–40.

Rodda, G. H., T. H. Fritts, and E. W. Campbell, III**.** 1999. The feasibility of controlling the brown treesnake in small plots. Pages 469–477 *in* G. H. Rodda, Y. Sawai, D. Chiszar, and H. Tanaka, editors. Problem snake management: the habu and the brown treesnake. Cornell University Press, Ithaca, New York, USA.

Rodda, G. H., and J. A. Savidge 2007. Biology and impacts of Pacific Island invasive species. 2. *Boiga irregularis*, the brown tree snake (Reptilia: Colubridae). Pacific Science 61:307–324.

Roy, S. S., C. G. Jones, and S. Harris. 2002. An ecological basis for control of the mongoose *Herpestes javanicus* in Mauritius: is eradication possible? Pages 266–273 *in* C. R. Veitch and M. N. Clout, editors. Turning the tide: the eradication of invasive species. Proceedings of the International Conference on Eradication of Island Invasives, University of Aukland, Aukland, New Zealand.

Savarie, P. J., D. L. York, J. C. Hurley, S. Volz, and J. E. Brooks. 2000. Testing the dermal and oral toxicity of selected chemicals to brown treesnakes. Proceedings of the Vertebrate Pest Conference 19:139–145.

Savarie, P. J., J. A. Shivik, L. Clark, T. J. Linder, and D. L. York. 2001. Laboratory and field efficacy tests of acetaminophen in brown treesnakes (*Boiga irregularis*). Page 21 *in* Brown treesnake 2001: research & management. Andersen Air Force Base, Guam, USA.

Savidge, J. A. 1987. Extinction of an island forest avifauna by an introduced snake. Ecology 68:660–668.

Savidge, J. A. 1988. Food habits of *Boiga irregularis*, an introduced predator on Guam. Journal of Herpetology 22:275–282.

Savidge, J. A., F. J. Qualls, and G. H. Rodda. 2007. Reproductive biology of the brown tree snake, *Boiga irregularis* (Reptilia: Colubridae), during colonization of Guam and comparison with that in their native range. Pacific Science 61:191–199.

Schooley, R. L., B. Van Horne, and K. P. Burnham. 1993. Passive integrated transponders for marking free-ranging Townsend ground squirrels. Journal of Mammalogy 74:480–484.

Shepp, W. 1967. The effect of live-trapping on the movements of *Peromyscus*. American Midland Naturalist 78:471–481.

Shwiff, S. A., K. Gebhardt, K. N. Kirkpatrick, and S. S. Shwiff. 2010. Potential economic damage from introduction of brown tree snakes, *Boiga irregularis* (Reptilia: Colubridae), to the Islands of Hawaiʻi. Pacific Science 64:1–10.

Siers, S. R., A. B. Shiels, and P. D. Barnhart. 2020. Invasive snake activity before and after automated aerial baiting. Journal of Wildlife Management 84:256–257.

Siers, S. R., A. B. Shiels, C. G. Payne, F. M. Chlarson, C. S. Clark, and S. M. Mosher. 2018. Assessment of target and non-target bait take around swiftlet caves and additional habitats on Guam. Final report QA-2399. U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Wildlife Services, National Wildlife Research Center, Fort Collins, Colorado, USA.

Siers, S. R., A. B. Shiels, C. G. Payne, F. M. Chlarson, C. S. Clark, and S. M. Mosher. 2019. Photographic validation of target versus nontarget take of brown treesnake baits. Wildlife Society Bulletin 43:752–759.

Smith, J. B., K. L. Turner, J. C. Beasley, T. L. DeVault, W. C. Pitt, and O. E. Rhodes. 2016. Brown treesnake (*Boiga irregularis*) population density and carcass locations following exposure to acetaminophen. Ecotoxicology 25:1556–1562.

Smith, D. G., J. T. Polhemus, and E. A. VanderWerf. 2000. Efficacy of fish-flavored diphacinone bait blocks for controlling small Indian mongooses (*Herpestes auropunctatus*) populations in Hawaiʻi. ʻElepaio 60:47–51.

Stanton-Jones, W. 2018. The development and use of an automated cellular PIT tag reader system for assessing the activity patterns of the Sungazer (*Smaug giganteus*). Dissertation, University of the Witwatersrand, Johannesburg, South Africa.

Stone, C. P., M. Dusek, and M. Aedler. 1994. Use of an anticoagulant to control mongooses in nene breeding habitat. ʻElepaio 54:73–78.

Sugihara, R. T., A. B. Shiels, and T. M. Maple. 2015. Brown treesnake captures and treated bait take (PVC stations) at Mariana swiflet (*Aerodramus bartshi*) caves on Guam and evaluation of a prototype remote camera trap triggering system to identify target and non-target bait take from toxic

PVC bait stations. Final report QA-2283. U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Wildlife Services, National Wildlife Research Center, Hawai'i Field Station, Hilo, Hawai'i, USA.

Sutherland, D. R., and G. R. Singleton. 2003. Monitoring activity patterns and social interactions of small mammals with an automated event-recording system: wild house mice (*Mus domesticus*) as a case study. Australian Centre for International Agricultural Research Monograph Series 96:159–164.

Testud, G., A. Vergnes, P. Cordier, D. Labarraque, and C. Miaud. 2019. Automatic detection of small PIT-tagged animals using wildlife crossing. Animal Biotelemetry 7:21.

Tobin, M. E., R. T. Sugihara, P. A. Pochop, and M. A. Linnell. 1999. Nightly and seasonal movements of *Boiga irregularis* on Guam. Journal of Herpetology 33:281–291.

Tomich, P. Q. 1969. *Herpestes auropunctatus* (small Indian mongoose). Pages 93–101 *in* Mammals of Hawaii: a synopsis and notational bibliography. Bishop Museum Press, Honolulu, Hawai'i, USA.

Tvrtković, N., and B. Kryštufek. 1990. Small Indian mongoose, *Herpestes auropunctatus* (Hodgson 1836) on the Adriatic islands of Yugoslavia. Bonner Zoologische Beitrage 41:3–8.

Tyrrell, C. L., M. T. Christy, G. H. Rodda, A. A. Yackel Adams, A. R. Ellingson, J. A. Savidge, K. Dean-Bradley, and R. Bischof. 2009. Evaluation of trap capture in a geographically closed population of brown treesnakes on Guam. Journal of Applied Ecology 46:128–135.

U.S. Fish and Wildlife Service. 1999. Draft revised recovery plan for Hawaiian waterbirds, second revision. U.S. Fish and Wildlife Service, Portland, Oregon, USA.

van Harten, T. Reardon, L. F. Lumsden, N. Meyers, T. A. A. Prowse, J. Weyland, and R. Lawrence. 2019. High detectability with low impact: optimizing large PIT tracking systems for cave-dwelling bats. Ecology and Evolution 9:10918–10928.

Yamada, F., and K. Sugimura. 2004. Negative impact of an invasive small Indian mongoose, *Herpestes javanicus* on native wildlife species and evaluation of a control project in Amami-Ohshima and Okinawa Islands, Japan. Global Environmental Research 8:117–124.

Associate Editor: Shane Siers

ROBERT "BOB" T. SUGIHARA started his federal career studying rat ecology and reducing rat damage in sugarcane cane fields in Hawai'i as a wildlife technician with the former U.S. Department of Interior Animal Damage Control program. He also worked at the U.S. Geological Survey Pacific Ecological Research Station studying limiting factors of endangered native Hawaiian forest birds. Currently, at the U.S. Department of Agriculture, National Wildlife Research Center's Hawai'i Field Station, he continues research on ways to mitigate agricultural, conservation, and human health and safety impacts of various invasive vertebrate species in the Pacific region.

WILLIAM C. PITT is the deputy director of the Smithsonian Conservation Biology Institute and the associate director for conservation and science for the National Zoological Park. He leads research, conservation, and education as well as science administration and operations. The Smithsonian Conservation Biology Institute is headquartered at a 3,200-acre research facility in Front Royal with >250 staff and students working in >25 states and 40 countries around the world.

ARE R. BERENTSEN completed a B.S. degree in zoology from the University of California at Davis and an M.S. degree in wildlife biology from Utah State University. His previous work includes black rhinoceros reintroduction in Zimbabwe, antelope and carnivore studies in Zambia, California ground squirrel, and coyote research. He has conducted terrestrial wildlife rabies research in Ohio, Arizona, Hawai'i, Tennessee, Puerto Rico, Zambia, St. Kitts, and St. Croix. He has assisted with rodent eradication work on Palmyra Atoll, Diego Garcia, and Wake Island. His current research is on small Indian mongoose ecology and the development of an oral rabies vaccination program for mongooses.

FRANCIS L. BENEVIDES JR. holds bachelor's and master's degrees in electrical engineering and a doctoral degree in ocean engineering from the University of Hawai'i, where he is also an affiliate faculty member with the Tropical Conservation Biology and Environmental Science Program at the Hilo campus. He has provided engineering design, consultation, and technical support for government wildlife projects for >26 years. His latest work is a trilogy of papers on the acoustic characteristics of the *Eleutherodactylus coqui*.