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Objectives and integrated approaches for the control of brown tree snakes

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Abstract

The inadvertent introduction of the brown tree snake (*Boiga irregularis*) to Guam has resulted in the extirpation of most of the island's native terrestrial vertebrates, has presented a health hazard to small children, and also has produced an economic problem. Management of brown tree snakes is aimed at a number of objectives, the foremost of which has been to deter its dispersal through Guam's cargo traffic to other locations. Another objective is to reclaim areas on Guam for reintroduction of native wildlife. A related objective is the protection of small sensitive sites on Guam from brown tree snake intrusion, such as power stations or nesting trees and caves. A fourth objective is to contain and capture incoming brown tree snakes at destinations vulnerable to their introduction. A final objective is to control incipient populations in other areas beyond their native range. A number of control tools have been developed, or are being developed. The efficacy of each control method depends on the situation to which it is to be applied. The control methods are described individually and the suites of methods most suited to each management objective are discussed.

Introduction

The brown tree snake (*Boiga irregularis*) on Guam is a severe example of the effects that an introduced predator can have on insular populations of native fauna. This snake, native to the northern and eastern coasts of Australia, eastern Indonesia, New Guinea and the Solomon Islands, most likely was brought to Guam accidentally through post World War II shipments of war materials from New Guinea (Rodda *et al*. 1992). By the 1970s, native bird populations were absent from all but the northern third of Guam. Disease and pesticides were first speculated to be responsible for the loss of avifauna (Grue 1985; Savidge 1987; Savidge *et al*. 1992), but predation by the arboreal and nocturnal brown tree snake ultimately was identified as the cause of the disappearances of birds (Savidge 1987). Guam's wildlife had evolved a resilience to dramatic changes in habitat regularly inflicted by typhoons (and also by World War II, Engbring & Pratt 1985), but the native birds and other potential prey species on Guam had not evolved in the presence of a predator such as the brown tree snake. In this environment, brown tree snake populations have achieved extraordinary densities on Guam (Rodda *et al*. 1992) and have decimated the native fauna.

Currently, of the 12 native species of forest birds on Guam, only the Mariana crow (*Corvus kubaryi*), the Mariana grey swiftlet (*Aerodramu vanikorensis bartschi*) and the Micronesian starling (*Aplonis opaca*) survive in the wild, with the crow population on the verge of elimination on Guam (National Research Council 1997). Two species, the Guam rail (*Gallirallus owstoni*) and the Micronesian kingfisher (*Halycon cinnamomina cinnamomina*), have been taken into captive breeding programs. Reintroductions of Guam rails have begun (Anderson *et al*. 1998; Vice *et al*. 2001).

The bat populations on Guam declined along with the bird populations. The Mariana fruit bat (*Pteropus mariannus*), already impacted by hunting, has had its

Guam populations further decimated by brown tree snake predation (Wiles 1987a,b; Wiles *et al*. 1995). Two other native bat species disappeared from Guam by the early 1970s (Wiles *et al*. 1995), but the cause of their demise was not determined at the time. Similarly, several indigenous or endemic species of lizards have become extinct or endangered (Rodda & Fritts 1992a), again primarily due to brown tree snake predation. In fact, only one of the 12 native lizard species appears in similar density on Guam as on nearby snake-free islands (Rodda & Fritts 1992a).

Guam has suffered more than ecological consequences from the brown tree snake introduction. Brown tree snakes have become agricultural pests through depredations on chickens, pigeons, caged song birds, newborn pigs, kittens and puppies (Fritts & McCoid 1991). These arboreal snakes are also economic pests as they climb utility poles and wires and cause frequent electrical power failures when their bodies connect live and grounded wires. This results in millions of dollars of losses from damaged power equipment and electrical appliances and machines, repair costs, and loss of productivity (Fritts *et al*. 1987). Furthermore, the brown tree snake is mildly venomous. It readily enters dwellings at night when it is active, and many victims have been bitten in their sleep. The brown tree snake is rear-fanged and must chew to envenomate its victims. Its threat as a health hazard is primarily to infants and small children, who are less able to defend themselves from its bite and from its constriction, which it also uses to subdue prey. There have been a number of life-threatening snake bite incidents with children on Guam (Fritts *et al*. 1990, 1994).

The brown tree snake may impact other islands in the future, as it is well-suited for transport to, and establishment at other locations (e.g. Fritts *et al*. 1999). The range of the brown tree snake on Guam encompasses the entire island, urban and rural areas alike. The very high snake densities found on Guam include the small forested patches in developed areas, landscaped areas adjacent to habitations and other buildings, and the military and commercial port areas. Brown tree snakes are highly mobile, agile climbers that seek refuge from heat and light during the daylight. Many types of cargo, shipping containers and air and sea transport vessels may offer ready daytime refugia. They are also opportunistic feeders that have been observed to consume a highly varied diet (Greene 1989; Savidge 1988; Rodda *et al*. 1999b; Shine 1991; Shivik & Clark 1999a; Linnell et al. 1997; Engeman *et al*. 1996). These elements, coupled with Guam's position as a focal point for commercial and military shipments of cargo and passengers throughout the Pacific, present an acute and chronic threat for the further dispersal of brown tree snakes to other islands (Vice *et al*. 2002). Indeed, sightings have been documented on Oahu in Hawaii, Kwajalein in the Marshall Islands, Pohnpei in the Federated States of Micronesia, Diego Garcia in the Indian Ocean, Okinawa in the Ryukyu Islands of Japan, and in Saipan, Tinian and Rota of the Commonwealth of the Northern Mariana Islands (CNMI), as well as the North American mainland (McCoid *et al*. 1994; Fritts *et al*. 1999). An incipient population is speculated to now exist on Saipan (McCoid *et al*. 1994).

Control Objectives

Multiple objectives motivate the management of brown tree snakes. In the remainder of the paper, these objectives are explicitly categorized, the available and potential control methods are described, and integrations of methods for addressing each objective are suggested. The arsenal of control methods for meeting the objectives has greatly expanded in the years since Campbell *et al*. (1999) described a plan for the integration of the control methods available in 1994. At that time large scale snake control had only been carried out for a much different snake, the habu (*Trimeresurus flavoviridis*), in the Ryuku Islands, Japan (e.g. Katsuren *et al*. 1999; Shiroma & Akamine 1999). However, brown tree snake control on Guam has since received considerable attention. Concerted research to develop control tools and experience from a federal program implemented in 1993 to control brown tree snakes on Guam have led to the development, definition, and refinement of brown tree snake control procedures. Many of the control tools are applicable to more than one of the objectives, but the optimal suite of integrated control methods varies according to the objectives.

Deterring brown tree snake dispersal from Guam. The management objective which has received the most effort and attention to date is to deter the further dispersal of brown tree snakes beyond Guam. Federal control efforts were implemented in 1993 to address this objective (Hall 1996; Ohashi & Oldenburg 1992), where the primary areas on Guam targeted for snake control have included the commercial and naval wharves and the associated warehouses and outdoor cargo staging sites around Apra Harbor, the area surrounding Won Pat International Airport and its cargo staging facilities, the flight line, warehouses and outdoor cargo staging facilities at Andersen Air Force Base (AAFB), commercial packers and shippers (located generally in the Harmon industrial area of Agaña), and military housing areas (high turnover of personnel at military bases daily presents a large amount of cargo associated with household moves). The areas subjected to control have evolved along with a greater definition of the cargo traffic flows within and from Guam (Vice *et al*. 2002).

Reclamation of areas on Guam. A related objective is to return areas on Guam to pre-brown tree snake condition by removing brown tree snakes and maintaining the population reduction. Accomplishing this benefits existing native wildlife and provides a more secure habitat in which captive-bred species can be reintroduced to the wild. A 24 ha site in northern Guam was the first reclamation effort (Anderson *et al*. 1998; Vice *et al*. 2001) and other large sites are underway or in planning (Lynch *et al*. 2001).

Protection of small sensitive sites on Guam. A similar objective, but on a much smaller scale is the removal and exclusion of brown tree snakes from very small, but especially sensitive sites on Guam. Primary examples of this objective include prevention of brown tree snake intrusion into power stations, or nesting trees and caves used by endangered birds (Aguon *et al*. 1998, 1999; Clark & Vice 2001; Vice *et al*. 2001).

Intercepting inbound snakes dispersing from Guam. Another primary management objective is to intercept inbound brown tree snakes arriving from Guam at other locations. When considering the long-term environmental impacts and economic costs, prevention is the best medicine for brown tree snake infections. Because brown tree snakes have occasionally arrived alive from Guam at a variety of destinations (McCoid *et al*. 1994), preventing the escape of new arrivals beyond port areas is especially crucial, particularly when considering that mitochondrial DNA evidence suggests the Guam population may have resulted from the introduction of very few individuals (Rawlings *et al*. 1998). The most active programs to contain and control inbound brown tree snakes are in the state of Hawaii and within the CNMI. While it often is politically difficult to spend significant amounts of money for a problem that is not full-blown, the cost of containment would be far less than to later attempt to control an incipient population (Campbell *et al*. 1999; B. Kaiser unpublished economic analysis).

Detect and control incipient populations outside Guam. A final objective is to detect and then control incipient populations outside of Guam before they grow into a problem similar to the situation on Guam. Detecting an incipient population will be difficult. Because of this species' nocturnal habits and secretive behavior during the day, many people on Guam have never seen a brown tree snake despite the high snake population densities. Densities of an incipient population probably would be infinitesimally small compared to those on Guam and detection probabilities would be correspondingly small. Detection and control would require intense application of methods to overcome the small contact probabilities. Furthermore, information is not available on whether control methods that rely on a food-related bait or attractant would be attractive to well-fed brown tree snakes in a prey-rich environment where many foraging options are presented.

Control methods currently available. A variety of control methods have been developed and implemented, and the operational efficacy of some methods has been well-documented. Simultaneously, considerable research attention has been directed towards developing new control methods or more efficient applications of existing methods. These control methods complement each other, with different combinations providing optimal integrations for different objectives.

Trapping. Trapping is central to the control activities carried out on Guam and it is the control method for which the most extensive information is available. Trapping takes place around forested plots, as well as along fences, buildings and other sites where control is needed. Funnel trap designs were first applied for snake control to protect waterfowl nests from bullsnakes (*Pituophis melanoleucas*) on a wildlife refuge in Nebraska (Imler 1945). Brown tree snakes also are captured using a basic funnel trap design, similar to that of commercial minnow or crayfish traps, but with one-way door flaps installed at entrances on both ends (Linnell *et al*. 1998). A live mouse, protected in an interior cage, serves as the attractant. The trap design currently used in federal and territorial operational control efforts (Vice *et al*. in review) has evolved considerably from those used in early ecological research efforts (Rodda & Fritts 1992b; Fritts *et al*. 1989; Rodda *et al*. 1999a). Trap designs are continuing to change in an effort to improve efficacy while reducing costs and labor for their maintenance. The continued evaluation of trap innovations has led to the establishment of optimal protocols for assessing new design features in the face of limited resources (Engeman & Vice 2001b).

For operational snake control, modified two-piece, crayfish traps have been replaced by a one-piece, custom-designed snake trap. The mouse cage in this trap is integrated into the wall of the trap so that care for the mouse can be done without opening the trap body. Procedures and conditions are excellent for survival of the mice used as lures in the traps, with life expectancies similar to that in other captivity settings (Vice *et al.* in review). This new design dramatically reduced trap maintenance times while equaling or exceeding previous levels of capture efficacy (Vice *et al.* in review). Multiple and large snakes readily enter the traps; a single trap has simultaneously captured snakes 1.5, 2.1, and 2.2 m in length (D. Vice, unpublished data).

The one-way flaps at the entrances to the traps are essential components for capturing snakes and preventing subsequent escapes. Designs that prevent lateral movement of the flap hinge pin provide the best capture rates because they swing shut even when the trap is rotated 75–80° along its horizontal axis, resulting in very low probabilities of jammed flaps (Linnell *et al.* 1998). Entrance rates appear highest when a snake at an entrance is provided maximum visibility through the flaps to the live mouse (Vice *et al.* in review), which corresponds to observations that brown tree snakes show a lesser attraction to a live mouse when the mouse is visually obscured (Shivik 1998). Door flaps must be resistant to opening by wind, but must be strong enough to withstand gnawing by rats (*Rattus* spp.) and tearing by coconut crabs (*Birgus latro*), which are often nontarget catches in snake traps. Flaps constructed from heavy gauge one-quarter inch (6.4 mm) wire mesh, while maintaining the immovable hinge pin, best withstand the nontarget animals captured and maintain the highest brown tree snake capture rates.

Video camera observations of snake behavior at wire mesh traps have demonstrated that brown tree snakes are highly attracted to the mouse in the trap, but often have difficulty locating the entrance (Clark 2001). A recent study using a one-piece trap with an exterior constructed of PVC to reduce damage from by nontarget captures demonstrated a substantial increase in brown tree snake capture rates (Vice, Engeman & Vice, unpublished data). While this trap design is not logistically suitable for all trapping circumstances, these results suggest that having the mouse only visible to the snakes from the trap entrance improves entry over traps where the mouse is continually visible to the snake without it being at an access point (door).

Several trap placement strategies have been applied to forested plots. Perimeter trapping encloses the plot with a trap line on the forest edge (Engeman & Linnell 1998; Engeman *et al.* 1998c). Interior trapping places traps along trails cut through the interior of the plot. Boundary trapping places the traps along one edge of a plot, often where a plot cannot be easily enclosed by physical features such as roads, or it used to maintain low snake populations after a more thorough trapping regimen has been applied to it. In plots where both perimeter and interior trapping were applied, the perimeter traps have exhibited up to 3 times the capture rate as interior traps (Engeman & Linnell 1998), perhaps because snakes in fragmented forested plots frequently encounter the forest edge and then tend to stay along the forest perimeter (Engeman & Linnell 1998). Perimeter trapping is a less labor-intensive method to implement and maintain on a plot-wise basis because it does not require cutting and traveling trails through the forest and it also permits access to traps with vehicles. Thus, perimeter trapping allows control personnel to potentially apply more traps and cover greater areas by providing easy access for high quality care of the traps. A further advantage of perimeter trapping is that it has minimal impact on native vegetation. Once snake populations have been reduced or extirpated, maintaining some strategically placed traps around the plot helps deter population recovery (Engeman & Linnell 1998). Snake removal by trapping has been well-modeled by exponential decay functions (Engeman & Linnell 1998; in press; Engeman *et al.* 2000). A general model has been developed to provide managers with guidelines of expected catch rates or the time needed to reduce the catch to a certain level (Engeman *et al.* in review).

Trap spacing may affect trapping efficacy and efficiency. The traps applied for brown tree snake control situations typically have about 20 m inter-trap spacing. One trial has been conducted to examine larger inter-trap spacings in an operational control setting (Engeman & Linnell in press). That study found no differences in capture rates when traps were spaced at 20, 30 and 40 m on the forest perimeter. However, the plots used in that study were narrow (high perimeter to area ratio), thus increasing the likelihood that snakes would be on the forest perimeter where they would contact a trap. This could have reduced the sensitivity for discriminating among trap spacings. There is not a clear definition of the distance from which a trap will attract a snake, but if it is greater than the currently applied spacing, then increased distances between traps could extend applications or increase efficiency of trapping.

Plot dimensions can affect the trap placement strategy for effectively reducing a population. As plot dimensions increase, boundary trapping on only a portion of the perimeter could not be expected to reduce snake populations as effectively as placement strategies that more completely encompass a plot. For example, a plot having a boundary trap line was later intensively trapped throughout, and the only snakes captured were from the side opposite the boundary trap line (Engeman & Linnell 1998). Similarly, as plot dimensions increase, the likelihood diminishes that perimeter trapping would effectively capture the snakes in the central-most portion of the plot. Although the maximal plot size for which perimeter trapping is effective has yet to be defined precisely, we know from a 7.5-mo study that perimeter trapping effectively removed the trappable snakes from a 17.8-ha trapezoidal-shaped plot (Engeman *et al*. 2000). The results to date indicate that as the perimeter to area ratio for a plot increases, so does the efficacy of perimeter trapping. A thin plot of great area would be more effectively trapped on the perimeter than a circular plot of same area.

The efficacy of control trapping for reducing brown tree snake populations and snake population recovery was examined by subjecting plots to intense trapping, which only was terminated after at least 4 weeks without a capture (Engeman *et al*. 1998a; Engeman & Linnell 1998). Only 2 snakes were captured in a 4.2-ha plot and 4 were captured in a 6.5-ha plot, and trapping was concluded to be highly effective at reducing snake populations in plots of fragmented forest. After snake population reduction, the population recovery rates in those particular plots were relatively slow, only 0.24 and 0.75 snakes/ha/mo, respectively (Engeman & Linnell 1998). These slow recovery rates could have reflected the level of isolation of those plots from larger forested areas, because other studies using plots closer to pools of large snake populations found a high degree of snake movement among plots (Tobin *et al*. 1999), and quicker population recoveries (Savarie *et al*. 2001c).

An important issue is the current difficulty in capturing (by any method) hatchling-sized brown tree snakes (e.g. Sachtleben & Qualls 2001). Information is needed on the proportion of the wild population they comprise, their survival, and how long it takes them to reach a trappable size. This information will permit assessment of the risk level this segment of the population poses for emigration off-island and for repopulation of snake-reduced areas. It will also better define trapping strategies and timing to account for this component of the population in a control program.

The utility of trapping for large-scale brown tree snake population reduction has met mixed reviews. Rodda *et al*. (1998) labeled trapping on a large scale as a ‘seductive loser’ and based that opinion on the economics of simultaneously trapping very large areas of Guam (up to the entire island). They are logical in suggesting that trapping, or any other single control method, could not be biologically or economically effective on that scale. However, the label applied to trapping is inappropriate, and the fallacy in their treatment was that it did not consider trapping as a component in an integrated control program that simultaneously uses multiple control methods, and employs a sequential, strategic approach for snake removal over large areas. Maximization of efficacy of snake removal efforts within economic practicalities requires a program integrating all appropriate control tools in a judicious geographic progression.

Spotlight searches of fence lines. Capturing brown tree snakes from fence lines during spotlight searches has been an efficient way to remove large numbers of snakes (USDA/APHIS Wildlife Services unpublished data 1994–2001). In some areas snake traps are heavily vandalized, or damaged by feral dogs (*Canis familiaris*) and/or feral swine (*Sus scrofa*), sometimes producing enough trap losses that a trapping program is impractical to maintain. In these situations spotlighting fences may be the best control tool available for removing brown tree snakes.

Most port areas, other cargo staging locations, and many other areas where brown tree snakes are to be controlled are surrounded by extensive fence lines. Habitat adjacent to the fences is highly variable, ranging from manicured lawns and landscaping to contiguous forest. Typically, the fences searched on Guam are 2.4-m chain-link fences with 3 parallel strands of barbed wire on 45° outriggers above the chain link portion. In most areas, a horizontal bar supports the top of the chain link, although many fences are constructed with steel wire or braided cable woven through the top of the chain link to provide support. Searches typically are conducted by illuminating fences with 250,000 candlepower spotlights from slowly moving (8–16 kph) vehicles between 8 pm and 4 am. Fences usually have suitable topography and cleared vegetation on one, and usually both, of the sides to permit vehicle access.

Because they are arboreal, brown tree snakes readily ascend fences where they are easily detected in a spotlight beam. Rodda (1991) found that snakes released near a fence with low vegetation on both sides would exhibit a high likelihood (77%) that they would climb the fence and two-thirds of the snakes captured from the fences in that study were concentrated near the fence top or on the wires above it. In contrast to searching fences, spotlighting forest edges for capturing snakes has been found to be much more difficult (Rodda & Fritts 1992b), and is not practical as a routine control tool.

More recently, brown tree snake usage of fences was characterized from over 600 captures during spotlight searches (Engeman *et al*. 1999). Fences with the horizontal support bar on top had 75% of snakes captured on either the top bar or on the parallel strands of barbed wire above it, and inclusion of the top third of the chain link with the top bar and barbed wires accounted for 92% of the captures. Fences without the top bar also concentrated brown tree snakes at the top of the chain link and on the wires above, but to a lesser extent than when the top bar was present (82%). Snakes found on the fences were usually in a horizontal position (resting or traveling), leading to the speculation that brown tree snakes were using fences as travel pathways (Engeman *et al*. 1999), possibly as part of foraging for geckos (Rodda 1991).

Brown tree snake usage of fences as travel pathways suggests spotlight searches as a useful means for detecting and controlling incipient brown tree snake populations (Engeman *et al*. 1999). Also, snakes in recipient locations have often been associated with cargo facilities, where vegetation is sparse and a perimeter fence invariably is present. Thus, a fence may be the first structure that a snake could climb, and as such, fences may be critical locations to search following a snake report.

Assuming, in the short term at least, that not all brown tree snakes are immediately trappable, then spotlight searches of fences complements trapping as a means of snake removal. While captures by trapping decrease exponentially over time, captures by spotlighting fences tend to consistently produce brown tree snake captures at low levels (Engeman & Vice 2001a). In areas of extensive fence lines, spotlight searches may produce significant population reductions over time.

Fences can be designed and maintained to effectively assist in brown tree snake capture and control (Engeman *et al*. 1999; Hall 1996; Rodda 1991). The chain link fences constructed with a bar on top and parallel strands of wire above appear to best concentrate snakes at the top of the fence, increasing the efficiency of spotlight searches. Fences subject to spotlight searches should be maintained free of vegetation and have a buffer of mowed vegetation between them and surrounding forest. Vegetation on the fence makes it difficult to observe snakes, while a mowed buffer between the fence and the forest facilitates searches from vehicles and promotes brown tree snake fence climbing behavior.

Detector dog inspections of cargo. Trapping and spotlight searches are effective toward snakes naturally occurring in an area, but snakes stowed-away in outbound cargo that is trucked into a controlled area circumvent the trap lines and the fenceline searches. Therefore, trained dogs (Jack Russell terriers) are used to locate and remove brown tree snakes from outbound cargo on Guam. Outbound cargo, cargo staging areas, and transport vessels identified as posing a risk for accidental introduction of a brown tree snake to a vulnerable location may be inspected by detector-dog teams. Each team is comprised of a handler and the unique detector-dog assigned to that handler. A variety of commercial and military locations are inspected, with handlers and their dogs available 24 h for conducting inspections. Examination of the records for brown tree snakes detected during dog inspections revealed that 80% of the snakes found by the dogs had been at high risk for export, with Hawaii, followed by Micronesian islands, the most frequently identified potential destinations (Engeman et al. 1998b). Natural disasters, such as the typhoons that frequently strike Guam can: alter snake habitat, result in increased cargo flow for the recovery process, and damage the traps and fences used in control efforts. This combination of impacts increases the likelihood for brown tree snakes to enter the cargo flow, and therefore increases the importance of detector dog inspections (Vice & Engeman 2000).

The efficacy of the teams of handlers and their dogs for locating stowed brown tree snakes was investigated by planting live brown tree snakes (in escape-proof containers) in cargo without the knowledge of the handlers responsible for inspecting the cargo (Engeman *et al*. 1998d; Engeman *et al*. 2002). When an observer attended the inspection to watch procedures, 80% of the planted snakes were located. Otherwise, 70% of the planted snakes were discovered, but only after such plantings had become a routine procedure. Prior to that, efficacy was nearly 50% less. The reasons dog teams missed some planted snakes were split between an insufficient search pattern by the handler, or the handler not detecting an indication from the dog that a snake was present. The interaction between a dog and a handler is complex and it is impossible to precisely determine in the latter situation whether: (1) the dog did not detect the snake, (2) the dog detected the snake but did not respond, or (3) the handler did not recognize a response by the dog. Continued testing has found efficacy to remain around two-thirds for finding brown tree snakes planted in cargo, but fewer missed snakes were due to insufficient search patterns (Engeman *et al.* 2002).

These studies indicate that discontinuation of the random trials of the dog teams with planted snakes likely would lead to decreased attentiveness to inspection procedures and a subsequent decrease in efficacy. Beyond that, finding planted snakes instills confidence in the dogs from their handlers. Similarly, facility workers and managers where inspections occurred have expressed greater confidence and interest in the abilities of the handlers and dogs, leading to more proactive snake control efforts by employees at regularly inspected facilities (Engeman *et al.* 1998d).

The use of the dog teams for cargo is the result of cooperative arrangements and coordination with agencies, organizations, and companies transporting cargo from Guam. Thus, a thorough understanding of cargo transport from Guam is necessary to effectively apply the dogs (and other control methods) as a deterrent to dispersal. Cargo inspections on Guam are prioritized according to risk, because it is logistically impossible to search all cargo. This has led Hawaii to conduct detector dog inspections of inbound cargo from Guam using trained beagles. The dogs are available for commercial flights from Guam and they are cross-trained to also detect agricultural products (Kaichi 1998). Searches of inbound cargo from Guam with trained detector dogs have been conducted for several years on Saipan in the CNMI, with the program expanding to Tinian and Rota (Vogt 1998; Arriola & Igisomar 2001). No live brown tree snakes have been located by detector dogs on either Hawaii and Saipan. Consideration is being given to also cross-training the CNMI dogs to search for agricultural products to maintain higher levels of attention (Vogt 1998). Information is not available about whether cross-training dogs to other cues affects their ability to detect brown tree snakes.

The use of dogs to inspect cargo leads to a number of policy issues (Immamura 1999). These include training issues such as standards for methods and efficacy, and the maintenance of vigilance in the face of task monotony. Economic issues relating to vessel delays due to inspection times, search times following a positive dog response, as well as protocol for handling cargo where a positive response was exhibited but no snake was found must be resolved in an acceptable manner. Resolution of such policy issues will insure the efficacy and harmonious coordination of detector dog programs with cargo facilities.

Cargo/transport risk assessment. Addressing the threat of brown tree snake dispersal from Guam requires identification of the transportation means by which snakes could successfully leave Guam to vulnerable locations. The ideal scenario for preventing brown tree snakes from leaving Guam would be to search all outbound cargo (both military and commercial) and transport vessels, and yet this would still require the maintenance of 'snake-reduced' buffer zones around port areas to deter snake entrance into already-inspected cargo and/or transport vessels.

Only a portion of the cargo leaving Guam is subject to protection. The type, amount, frequency (seasonal and daily), and primary destinations of the cargo leaving Guam are continually monitored as a means for identifying changes in cargo handling processes and procedures. Other factors used to prioritize risk include type of packing, storage (cross contamination potential), location and environment of storage facilities, transportation method, origination points and time in transit (Vice *et al.* 2002).

Data is currently being evaluated concerning the environmental conditions in airplane wheel wells, transport vessels, and cargo containers over various lengths of trips by various modes of transport (Perry & Vice 1998; Perry 2001). The collection and analyses of sufficient data will provide a much more detailed picture of the risks for live transport of brown tree snakes to off-island destinations under various transportation scenarios, with control strategies adjusted and applied accordingly.

Oral toxicants. A large variety of chemicals and commercially available products have been examined for oral toxicity to brown tree snakes (Brooks *et al.* 1998a,b). Rotenone, propoxur, natural pyrethrins, allethrin, resmethrin, diphacinone, warfarin and aspirin were found to be orally toxic to brown tree snakes (Brooks *et al.* 1998b). Other compounds since have been tested, with acetaminophen showing the most promise (Savarie *et al.* 2000, 2001c). Three non-narcotic analgesic drugs have been tested for efficacy when delivered in dead neonate mice (DNM) as a matrix (Savarie *et al.* 2000). Acetaminophen was highly effective, whereas aspirin was only moderately effective, and ibuprofen was ineffective. Recent field tests have revealed that caffeine may be about as effective as acetaminophen (P. Savarie, pers. comm. on unpublished data).

Commercially available frozen DNM have been demonstrated as a very effective means for delivering acetaminophen to brown tree snakes in the field (Savarie 2001c). In addition, tests have shown that this method of baiting poses minimal risks to crows (Avery & Tillman 2001). Similarly, no evidence of primary or secondary hazards to coconut crabs or land hermit crabs (*Coenobita brevimanus*) was found (Savarie *et al.* 2001a). Thousands of hours of video monitoring of DNM baits and snake carcasses in the wild indicated that risks to nontarget species were negligible (Savarie *et al.* 2000, 2001b). In Guam's climate the baits deteriorate very rapidly (in 2–3 days) and monitor lizards (*Varanus indicus*), an exotic species, were the only nontarget species observed (on only two occasions) to consume the baits (Savarie *et al.* 2000, 2001b). As a result of its efficacy and safety, acetaminophen has been registered with the US Environmental Protection Agency (EPA) for use in a DNM matrix under a Section 18 Emergency Use Permit allowing up to 2000 units to be distributed each night (Fagerstone & Eisemann 2001).

One aspect requiring consideration relative to endangered species reintroductions is that interactions of Guam's native forest birds with baits or bait stations could not have been observed, because those birds have been virtually eliminated by the snakes. However, if toxicants are to be used concomitantly or post-reintroduction of endangered species, then further investigation will first be needed to insure that bait delivery poses no risk to the species being recovered.

Acetaminophen baits appear to have great potential for economic and efficient wide-scale reduction of brown tree snake populations on Guam, with negligible potential for adverse environmental impacts. Similar to trapping, establishment of bait stations on the perimeters of defined plots appears to be an efficient and effective strategy for removing the snakes within (Savarie *et al.* 2001c). Toxic baits also offer the prospect for wide-scale broadcast, including by aircraft, for the treatment of the interiors of large or inaccessible areas (Savarie *et al.* 2001c).

Barriers. Brown tree snakes are remarkable climbers. Nevertheless, suitably effective barriers potentially could prevent intrusion by brown tree snakes. Barrier applications include protecting port and cargo staging areas for outbound cargo on Guam from snake entry, containing snakes arriving from Guam at ports of entry, and protecting sites such as endangered species habitats, power stations, and poultry production areas. Lastly, barriers could be used to direct snakes to traps or to toxicant delivery devices.

The variety of applications for which barriers could be useful in blocking brown tree snake movement calls for a variety of barrier materials and designs. Perry *et al.* (1998) described three passive characteristics useful in effective barrier design; smooth materials, height and overhang. Electrification is an active addition that can be used to increase barrier efficacy. If a brown tree snake should manage to breach a barrier, the barrier design should be such that the snake can return without difficulty. Guam and other islands where barriers would have the greatest applicability are frequently subjected to cyclonic weather. Therefore, the ability of a barrier to resist or deflect wind is highly desirable.

When selecting the materials and design for a particular barrier application, a variety of factors needs to be considered, the foremost of which is duration of time that the barrier will be required. Very short-term needs such as one-time military exercises or some construction sites may require only temporary barriers, which are easily transportable, quickly assembled, and relatively inexpensive. These barriers, however, tend to be less effective and less durable than permanently installed barriers (Perry *et al.* 1998). The question of duration also affects the construction design for permanent barriers, as areas such as ports or military bases may be redesigned frequently, requiring 'permanent' barriers to be repeatedly reconstructed. Other important criteria for selecting construction design for permanent barriers include the existence of structures such as fences to which a barrier might be attached, difficulty of terrain, the need for visibility through a barrier, and cost.

Development and testing of barrier designs for brown tree snakes have been carried out for over a decade. Campbell (1996, 1999) experimented in the early 90s with various designs for electrical barriers and found a five-wire design with nylon netting fence to be most effective. Exclosure tests with this design suggested that, with refinements, barriers could be a practical brown tree snake control method.

Recent testing has identified a variety of effective temporary barrier designs and has brought definition to barrier construction design for application to various situations (Perry *et al.* 1998). A temporary barrier, 115-cm high, constructed of shade cloth angled at 60° to produce an overhang was found to be highly effective. Use of longitudinally slit PVC pipe to attach and connect panels largely eliminated the potential for furrows that could permit snakes to climb over.

Besides the temporary barriers, several designs for permanent barriers were effective (Perry *et al.* 1998, 2001). A design very effective in laboratory and outdoor tests was a wire mesh barrier made of 1/4″ galvanized hardware cloth developed for attachment to existing chain link fences. A 1.2-m flat panel is placed against the lower fence with a 15-cm radius bulge attached above to create an overhang. While this barrier is not as long-lasting as some constructed of more durable materials, it facilitates erection of barriers in areas with fences, and it provides visibility through the barrier in areas where security is important, such as at airports and military bases.

Perry *et al.* (1998, 2001) also reported on more durable barriers constructed of masonry and vinyl seawall materials. The masonry barrier was 115-cm high with a 20-cm ledge to form an overhang. This passive shape blocked 90% of breach attempts and the addition of electrification raised efficacy to 100%. Vinyl seawall material was identified as a potential barrier material (M. Linnell, pers. comm.) and subsequently tested for efficacy (Perry *et al.* 1998). The seawall barrier was constructed from interlocking sectional pieces of vinyl seawall at heights of 115 and 152 cm. The initial costs for masonry and seawall barriers will be greater than for the wire mesh barrier, but could be considered in locations where long-term durability is essential (where breaches by snakes are least tolerable), and visibility is not an issue. The modular nature of the seawall material may be preferable for difficult terrain as it is more easily carried, manipulated, modified, and assembled.

The use of barriers is challenged not only by the climbing abilities of brown tree snakes, but also with the difficulties of maintenance in the field. Damage by typhoons, damage by large animals (pigs, dogs and deer), rat damage, and overgrowth of tropical vegetation all can provide frequent and easy breaches for brown tree snakes. Thus, barriers on tropical islands will require a concomitant inspection and maintenance program.

Barriers have begun to be applied in practice to control brown tree snake movements. The temporary barrier has been used in conjunction with US military exercises originating from Guam (M. Pitzler, pers. comm.; Perry *et al.* 1998). Individual nests of the Mariana crow have been protected by ringing nest trees with electric barriers, placing hardware cloth perpendicular to the trunk, and separating the canopies from neighboring trees by pruning (Aguon *et al.* 1998, 1999). The wire mesh barrier attached to chain link fences has been placed around the port on Rota, CNMI and along the flight line at AAFB, Guam. A similar barrier, but with a larger bulge, was placed on a fence around a large (24 ha) forested plot on Guam being prepared for reintroduction of endangered native species by removing or reducing the brown tree snake population (Anderson *et al.* 1998). A masonry barrier was constructed on Tinian, CNMI to quarantine construction materials from Guam (Perry *et al.* 1998), and others are under construction on Guam and Saipan. For large areas on Guam, costs might prevent installation of barriers highly secure to snake breaches. However, less efficacious barriers integrated with other control methods might be cost-effective, while providing the necessary protection.

With the variety of existing materials and designs available for barrier construction, clear protocols are needed on the implementation and maintenance of barriers. Criteria for selecting the most appropriate from among the existing barrier models are needed, along with rigid design specifications for construction. Without such guidelines considerable money and labor could be spent to erect ineffectual or inappropriate barriers.

Cargo fumigation. Another potential means for deterring the dispersal of brown tree snakes from Guam is to apply a toxic fumigant to outbound cargo that is effective against brown tree snakes. Products already registered with EPA for cargo fumigation against other pests that also demonstrate high efficacy against brown tree snakes would be ideal candidates, as the registration process would be simplified.

Savarie *et al.* (in press) found methyl bromide, a fumigant treatment for pests used world-wide, to be effective against brown tree snakes in cargo containers. Brown tree snakes have been added to the product label registered with the EPA (Brooks *et al.* 1998a). Two other registered fumigation products, sulfuryl fluoride and phosphine, have since been tested and found effective within EPA registered application rates (Savarie *et al.* 2000). Brooks *et al.* (1998c) tested several pyrethrin/pyrethroid insecticide foggers as cargo fumigants, but found that they were not effective for killing brown tree snakes in cargo containers, although snakes directly exposed to fog droplets from products containing pyrethrin were killed (Brooks *et al.* 1998c).

Other chemicals effectively kill brown tree snakes within cargo containers, but as with methyl bromide there is little current demand for their use, as they also are highly toxic, expensive, and time consuming to apply. Until an inexpensive, easy-to-apply fumigant/fogger that is highly effective for brown tree snakes in packed cargo containers is developed, or a legal requirement for fumigation mandated, there likely will be only limited potential for application of cargo fumigants.

Prey base reductions. Introduced species of birds and rats are removed from civilian and military ports on Guam to decrease the attractiveness of the area to brown tree snakes. Cage traps and air rifles are used to reduce the populations of Eurasian tree sparrows (*Passer montanus*) and feral pigeons (*Columba livia*) using port areas for loafing or nesting. EPA registered toxic baits in tamper-proof containers are used against rats in the same areas.

Removal of brown tree snakes from an area might be expected to be followed by an increase in rodent populations. Engeman *et al.* (2000) noted an increase in incidental rat captures in snake traps over time as brown tree snakes were removed from plots of forested land. Increased rodent populations would enhance the habitat quality for brown tree snakes and also serve as an attractant back into the area. Thus, prey base reductions can be viewed as potentially extending the longevity and efficacy of brown tree snake removal. Also, because rats can pose substantial hazards to endangered birds (e.g. Buckle & Fenn 1992; Witmer *et al.* 1998), their population reduction likely would be a component for reclaiming land for endangered species reintroductions, and may further serve to decrease the attractiveness of the area to brown tree snakes. Reductions in nonnative prey items in potential recipient locations for brown tree snakes may enhance the attractiveness of a mouse in a trap in these environments.

Public awareness. Education and enlistment of the public and military on Guam, and at transport destinations from Guam provide vital support for meeting management objectives. Besides the multitude of scientific reports on the brown tree snake situation, many reports also have been made through the popular media. These efforts not only generate public support for brown tree snake control efforts, but they facilitate control efforts through the public detecting snakes and alerting authorities, or directly controlling the snake. Informative and training videos describing the brown tree snake problem and appropriate responses to snakes (e.g. Hawaii Dept. Agriculture & USDA 1996; USDA 1997), posters (e.g. USDA & USDOD 1997), flyers, brochures (e.g. USDA 1998; Gov. Guam Department of Agriculture 1990), educational television commercials (e.g. Arriola & Igisomar 2001), workshops, seminars, and live demonstrations with detector dogs all have been useful educational tools for promoting public involvement in the control of brown tree snakes on Guam and beyond. For large exercises originating on Guam, the military has produced pocket brochures describing the responsibilities of all personnel towards the environment, with an emphasis on preventing the spread of brown tree snakes (e.g. USDOD 1999). Also to enlist public involvement, the Government of Guam Department of Agriculture has provided snake traps to the public.

Control Methods Nearing Availability

Recent research has developed and tested a number of additional approaches for controlling brown tree snakes. Some of these methods need some fine-tuning, some need additional field testing, and others may require registration through the appropriate agency. Enough data has been collected for each method to indicate a solid potential that each could be added to the armamentarium of applied control methods.

Dermal toxicants. Besides oral toxicity testing, a variety of chemicals and commercially available products also have been examined for dermal toxicity to brown tree snakes (Brooks *et al.* 1998a,b). For dermal toxicity, rotenone, nicotine, propoxur, natural pyrethrins, allethrin, and resmethrin killed brown tree snakes (Brooks et al. 1998b). Some commercial household insecticide sprays also produced toxicity (Brooks *et al.* 1998a; Savarie *et al.* 2000).

Large-scale toxicant applications for brown tree snakes require effective, safe and brown tree snake-specific delivery systems. A passive aerosol dispenser for delivering pyrethrins to brown tree snakes when an infrared sensor is triggered has been developed (National Wildlife Research Center 2000, Savarie *et al.* 2000). An effective, long-lasting attractant to lure snakes into contact with a toxicant must be produced for practical application of dermal toxicants.

Attractants. The identification of substances attractive to brown tree snakes could greatly advance their control, and a variety of substances have been tested. A nonliving attractant that produces a 7-day, or more, effect would immediately increase efficiency of trapping because the preponderance of the associated labor involves maintaining a live mouse as an attractant. Mice require maintenance in the traps on a weekly basis and considerable additional effort is expended to prepare food blocks and to maintain a reserve supply of mice. Artificial attractants could greatly improve the costs and logistics for delivering toxicants to brown tree snakes, either by enticing snakes to consume toxic baits or by contacting a dermal toxicant. Similarly, attractants could be used to deliver a contraceptive substance to brown tree snakes, once one is developed.

A number of studies have examined the sensory cues for attracting brown tree snakes. Chiszar *et al.* (1988) observed that visual cues by themselves would induce attack behavior. The effectiveness of chemical cues often were lost if the container for an odor source was visibly empty (Chiszar 1990). Even so, Fritts *et al.* (1989) found that brown tree snakes would enter traps baited only with bird odors. Clark (1997) reported that potential prey odors lost their attractiveness when fractioned, implying that the overall odor profile is important for attractiveness. Brown tree snakes appear able to switch between sensory modalities when foraging (Chiszar 1990). Odor and movement have been demonstrated as important components for inducing predatory behavior (Shivik *et al.* 2000a). Odor and visual cues are both important components for the attractiveness of live mice to brown tree snakes and together produce a synergistic effect (Shivik 1998; Shivik *et al.* 2000b). These results have indicated that the chemical cues involved in brown tree snake behavior are complex and not easily discernable. Moreover, Chiszar *et al.* (1997) reported that chemical cues eliciting strong responses in the laboratory often have diminished effects in the field, although Shivik (1998) later defined behavioral metrics for laboratory observations of chemical attractiveness that corresponded very well with field test results.

Carrion in the form of a dead mouse has demonstrated the same level of attraction to brown tree snakes as the live mouse used for trapping, except during wet seasons (Shivik & Clark 1997; Shivik *et al.* 2000b). Also, when used in brown tree snake traps, mouse carrion, potentially may broaden the size range of brown tree snakes vulnerable to trapping (Shivik & Clark 1999a). Unfortunately, in Guam's climate dead mice are attractive only for 2–3 days before decomposition becomes too severe to attract snakes. The attraction of carrion to brown tree snakes led to the highly successful testing of DNM (frozen, commercially available) as a bait substrate for toxicant delivery (Savarie *et al.* 2001c). Nevertheless, if the correct chemical cues can be defined, there appears to be a reasonable potential for developing an inanimate attractant. Based on observed brown tree snake attraction to carrion, Shivik & Clark (1999b) tested a variety of artificial odiferous compounds associated with decomposition, but none showed a useful level of attraction to the snakes. In addition to testing DNM as potential toxic bait substrates, a mechanical mouse treated with mouse odors was found in laboratory tests to be as attractive to brown tree snakes as live mice (Shivik 1999) and also was found to elicit responses in the field (Lindberg *et al.* 2000). An economical and practical mechanical mouse expressing appropriate odors and able to withstand Guam's climate would probably require considerable development.

Repellents and irritants. Repellents and irritants to deter brown tree snake entry into a location or to force brown tree snakes from a specific location would have great application for insuring cargo, cargo staging areas and transport vessels are free of brown tree snakes. McCoid *et al.* (1993) tested a commercially available product (Dr. T.'s Snake-Away) for repellency to brown tree snakes, but found it to be ineffective. More recently, research has focused on chemical vapors that would induce escape behavior in brown tree snakes. Such a product would be a valuable asset for driving snakes from cargo. Cargo where detector dogs exhibit a response could be treated, and any snakes present removed. Moreover, if the irritant/repellent compound was suitably economical and easy to apply to cargo, and if efficacy at causing the snake to escape was at or near 100%, then it could be widely applied to the cargo leaving Guam.

Repellent testing has been aimed at natural products that would minimize concerns about human health and safety (most have been FDA approved for human consumption), and also require minimal support data for registration by the US EPA. Additionally, candidate compounds must not leave lasting odors or degrade the materials they contact. Laboratory tests have yielded promising results for some of these compounds (Clark & Shivik 1998). Some of the compounds tested seem to uniquely affect snakes and do not appear to affect mammals or birds (Clark & Shivik 1998). Field testing and development of delivery mechanisms are required. Cold buoyant fogs and vapor buoyant forms are being tested as delivery mechanisms because they penetrate well and should not destroy repellency of compounds as has been the case with thermal fogs (L. Clark, pers. comm.). Aerosols worked well in tests where the snake was directly in line of sight.

Potential Control Methods Requiring Considerable Development

Research in other potential areas for brown tree snake control probably will require some time to produce practical results, and possibly even longer to have a registered product for in-field use. These topics merit discussion as they eventually could impact brown tree snake control.

Contraception. The use of contraception as a method to manage wildlife populations is relatively recent (Miller *et al.* 1998). Research into reptilian contraception is in its infancy. Success with a variety of species of mammals and birds suggests that success might also be achieved with brown tree snakes. Studies using chemical contraceptive agents for brown tree snakes are underway (T. Felix & T. Mathies pers. comm.). Contraceptive control, like the use of toxicants, will require a mechanism for delivering a contraceptive agent to brown tree snakes, orally most likely. Again, an effective bait (attractant) is needed for delivery. In theory then, any snake that could be sterilized also could be poisoned using an oral bait. Thus, applications of contraceptive methods most likely would be directed towards situations where toxic control could not be applied safely.

Biological control. Using living organisms to control pest species has been applied most commonly to insect, plant, and plant pathogen species, but successful applications to vertebrate pests has been limited. Selecting the appropriate organisms to implement biological control on brown tree snakes will be difficult. Rodda *et al.* (1999c) concluded that neither habitat structure nor predation are primary limiting factors for brown tree snakes. On Guam, brown tree snakes have been observed as prey for monitor lizards (e.g. Rodda *et al.* 1999c) and other brown tree snakes (Engeman *et al.* 1996), but with no apparent affects on snake populations. Introduction of a brown tree snake predator to Guam could easily inflict further environmental harm to the island without reducing the problem.

Most interest for biological control research has centered on the use of viruses and parasites. Paramyxovirus is a reptilian virus that appears to be relatively easily transmitted among snakes without requiring direct contact, and some strains have demonstrated over 50% lethality (Nichols & Lamirande 1998, 2001). Although parasites rarely are important regulatory factors for vertebrate populations, Haemogregarin parasites (blood protozoans transmitted by vectors) have also been considered as potential control agents (Telford 1998; Whittier *et al.* 1998). Substantial long-term development, including genetic engineering, would be required to produce a practical tool for use on brown tree snakes that would not affect nontarget reptiles.

The efficacy of a biological control agent depends on its ability to reproduce, disperse, locate and impact a target species, preferably without additional human assistance (Howarth 1999). Unfortunately, these are the same characteristics of noxious invasive species. Thus, biological control is fraught with risks, requiring extensive testing and prior implementation of safeguards before application of the method.

Meeting Management Objectives

Deterring brown tree snake spread from Guam. The snake removal methods of trapping, spotlight searches of fences, and detector dog inspections have been found to be highly effective control tools on Guam. As effective as the methods might be individually, they must be carefully applied using the available information on their application, or their efficacy will suffer. Also, their use must be integrated to maximize efficiency of the methods and to insure that the scenarios by which a brown tree snake could evade the controls and depart the island would be minimized. Augmentation with passive deterrence measures, such as barriers when cost-effective, plus continued refinements and optimization of application strategies should allow steady improvement in effectiveness. A better understanding of snake survivability in transit from Guam, an in-depth understanding of cargo flows from Guam, and a public awareness to cooperate with snake control efforts, should allow more precise control strategies and more efficient application of control methods. Implementation and continued improvements to the control methods have greatly reduced chances that a brown tree snake could access and successfully stow away in a human means of transportation from Guam to a vulnerable destination. For example, no live brown tree snakes have been verified in Hawaii since 1994, just after the federal control program was implemented on Guam (M. Pitzler pers. comm.).

Although effective, the methods currently in place can be labor intensive. Means by which the existing methods can be made more efficient and/or more effective would greatly enhance the application of the control efforts. Acetaminophen delivered in DNM has recently become available as a control tool, and it is the most promising new control method. This toxicant delivery system should open doors for wider scale snake control on Guam. Additional methods that are practical to apply that also would complement the existing tools in an integrated program could offer quantum increases in the ability to prevent brown tree snakes from dispersing from Guam. Fortunately, a number of control tools are on the horizon that could become available for use in the field within the next couple years. Of particular importance is finding a replacement attractant for live mice in traps and DNM as a bait matrix. This would greatly reduce labor and allow many more traps and baits to be placed in the field. Repellents to deter entry into cargo and irritants to drive snakes from cargo would be major assets to cargo inspections with dogs and would provide more powerful assurances that cargo is snake-free. Assuming no decreases in the control efforts on Guam, and assuming wider use of acetaminophen, and other new methods come on-line soon, the likelihood for brown tree snake spread from Guam should continue to diminish.

Reclamation of areas on Guam. Removal of brown tree snakes to reclaim land areas on Guam has been implemented in recent years. Most of the removal methods applied for deterring the spread of snakes from Guam are also applicable to reclamation of land areas on Guam. The exception is the use of detector dogs, because this objective does not call for cargo searches. Dogs have not been trained nor tested for searching natural environments, and it would be somewhat futile as brown tree snakes are primarily arboreal. A 24 ha site has already been largely reclaimed on Guam, primarily through perimeter trapping and containment using a wire mesh barrier attached to a fence to deter re-invasion (Anderson *et al.* 1998). Some traps always will be in place to catch remaining or re-invading brown tree snakes. The efforts have had some success, as reintroduced Guam rails have reproduced (Vice *et al.* 2001). Continued success in removing brown tree snakes likely will lead to more and larger land areas for reclamation on Guam. Reclamation will rely heavily on trapping and toxic baits, although areas with fences could have snake removal augmented with spotlight searches. As larger areas are targeted, perimeter trapping and baiting will be the primary removal methods. The potential for broadcasting baits would make snake removal from the interiors of large plots much more cost-effective and less labor-intensive than trap lines through plot interiors. For smaller plots, the same perimeter strategy can be applied to effectively deliver acetaminophen baits to brown tree snakes. For larger areas, aerial delivery might be considered. Where feasible, barriers could deter reoccupation by snakes and some traps should be left throughout the plot for the same purpose. A strategic sequential targeting of adjacent plots for snake removal could reclaim very large areas of land and has been implemented in the munitions storage area on AAFB (Lynch *et al.* 2001). The development of attractants would have similar quantum impacts as for deterring the spread of brown tree snakes and make snake removal much more efficient and effective.

Prey base reductions undoubtedly will be important because rodent populations can increase exponentially when controls, natural or otherwise, are not in place. A large rodent population would directly impact endangered birds as well as provide an attractive food base for brown tree snakes. This could promote rapid snake population increases by re-invasion, and reproduction in response to food-related increased fecundity.

Protection of small sensitive sites on Guam. There are a number of sites on Guam where it is essential that brown tree snakes do not intrude, including the many power stations, the few trees in which Mariana crows nest, and the few caves in which Mariana grey swiftlets nest. Barriers would be important for deterring entry into these sites. Because barriers are susceptible to the environmental conditions that promote breaches, the fewer the number of snakes available to test the barrier, the lower the probability of a breach. Thus, brown tree snake control in the vicinities of sensitive sites would complement deployment of barriers. Trapping and/or toxic baits would be universally applied. Because power station sites usually are fenced, spotlight searches complement the other snake removal methods. Although people working to protect endangered species on Guam are acutely aware of the issues surrounding brown tree snakes, awareness programs directed at employees and occupants at other affected locations to be protected would enlist valuable help towards control efforts. Even if direct control is not provided by the public, their vigilance in reducing vandalism of control materials would be helpful.

Intercepting inbound snakes dispersing from Guam. Over the years a number of live brown tree snakes have been discovered in many vulnerable locations, usually in the port areas. Although it appears that the federal control program has diminished the flow of snakes from Guam, probabilistic reasoning would suggest that the large volume of commercial and military cargo traffic through Guam would still result in snakes occasionally arriving alive at vulnerable destinations. This coupled with the genetic implication that very few, perhaps only one gravid female (Rawlings *et al*. 1998), can initiate a population demonstrates the importance of containing inbound snakes at port areas. Permanent barriers around air and sea port cargo and vessel handling areas could deter dispersal from port areas. Detector dogs could be applied more extensively to inbound cargo. Irritants, when fully developed, also would be useful for insuring that inbound cargo does not contain snakes. Public awareness, especially on the part of port employees and other cargo handlers, would be essential for locating and controlling inbound snakes.

Unfortunately, locations without an observable snake problem may not have the political incentive to generate the financial resources required to implement thorough preventative measures. Public awareness of the costs of a brown tree snake introduction could help assuage the authorities that preventative measures are much more cost-effective in the long term than attempting to detect and control an incipient population. This reality serves to emphasize the value of brown tree snake containment on Guam. By the time the wheel wells of an inbound aircraft open up over a distant island, containment potentially has been lost if not dealt with on Guam. Thus, redirecting financial resources to the detriment of snake control on Guam would be inappropriate.

Detect and control incipient populations. Fortunately, there are no other known large populations outside of Guam where brown tree snakes have become entrenched as an invasive species. However, a realistic prospect is the need to respond to a newly established breeding population. Two goals exist for application of control tools to an incipient population. The first issue is to identify at the earliest possible stage if brown tree snakes have been introduced and the extent of their range (dispersal). The next step would be to isolate them, if possible, and control them. Detection of a brown tree snake beachhead will probably include snake sightings by the public, as has been the case on Saipan. For this purpose, a campaign is needed to alert the public that snakes should be killed, or otherwise restrained, and the authorities notified. Spotlight searches and trapping would probably be the primary means attempted to detect and control incipient populations. A colonial population would be of low density, resulting in much lower probabilities of coming into contact with control methods such as traps or spotlight searches. Because the attraction to traps presumably would be reduced in a prey-rich environment, intensive spotlight searches of fences, or even forest edges, could be the best means for detecting pioneering populations, defining their range, and removing them. Even if the efficacy of traps is likely to be diminished in a new environment, intensive trapping should take place in areas suspected to hold brown tree snakes. If nontarget hazards are minimal, and environmental regulations permit, toxic baits could be applied simultaneously in high density. If a discrete site is identified as holding brown tree snakes, and it is small enough and environmental conditions allow, barriers could be erected to contain the infecting population and control methods applied within.

Conclusions

Five management objectives were defined for brown tree snake control, along with a number of available and potential control tools, which vary in their applicability among the management objectives. As an aid for defining an optimal integration of methods for addressing each objective, a matrix of the objectives crossed with the control methods is provided in Table 1. The table body contains a rating of the applicability of each method, or potential method, to each objective. Hopefully, managers can find this useful for optimizing resources for developing an effective control program.

Table 1. A cross-tabulation of brown tree snake control objectives by potential control methods. A rating value from 0 to 5 is presented as a subjective guideline as to the potential utility of individual control methods to each of the control objectives, where 0 indicates no or extremely low applicability and 5 represents highest applicability

	Objective				
	Deter spread from Guam	Reclamation on Guam	Protect small sensitive sites	Contain inbound snakes elsewhere	Incipient population
Current methods					
Trapping	5	5	5	5	4
Spotlight searches	5	4	5	5	5
Detector dogs	5	0	1	3	1
Cargo risk assessment	5	0	0	3	0
Oral toxicants	5	5	5	4[1]	4[1]
Barriers	4	5	5	5	3
Prey base reductions	4	4	4	2	2
Cargo fumigation	1	0	0	0	0
Public awareness	5	4	4	5	5
Potential methods with substantial data					
Dermal toxicants[1,2]	5	5	5	4	4
Repellents/irritants[1]	5	1	4	5	1
Potential methods with limited data	no ratings are given for these methods as development is too far in the future to assume that the method will become available				
Contraception	1	1	0	?	?
Biological control	?	?	?	0	?

[1]Assumes necessary registrations (EPA, FDA) have been completed.
[2]Assumes availability of a suitably effective attractant, a delivery device targeting only brown tree snakes.

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