Operational Control Of The Brown Tree Snake On Guam

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ABSTRACT: An operational control program for brown tree snakes (*Boiga irregularis*) on Guam began in April 1993. The program focused on minimizing the dispersal of brown tree snakes to other Pacific islands and the U.S. mainland. During the first year of operation, more than 3,000 snakes were caught within a kilometer of high risk port facilities using traps, detector dogs, and spotlighting. Additionally, habitat modifications and prey-base removal were used to reduce the attractiveness of these facilities to brown tree snakes. Public awareness was also an important part of the program such as the education of cargo packers, shippers, and Customs inspectors who could further minimize brown tree snake dispersal off-island. Initial control efforts in the program became more efficient with the recognition of brown tree snake characteristics, i.e., it was discovered that perimeter trapping a 5 ha patch of jungle was sufficient to remove most snakes instead of saturating the area with traps.

KEY WORDS: brown tree snake, snake control

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INTRODUCTION

Brown tree snakes have caused significant environmental and economic impacts since their inadvertent introduction to the island of Guam in the late 1940s. Other islands in the Pacific and the U.S. mainland have been concerned about their potential introduction with their propensity to do damage. Hawaii was particularly concerned and assisted in obtaining funds for an operational brown tree snake program at commercial port facilities on Guam to reduce the risk of them being transported on air and surface carriers or in their cargo to Hawaii.

In April 1993, the U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Animal Damage Control Program (ADC) started an operational control program involving containment activities at commercial air and seaports to minimize the dispersal of brown tree snakes. The ADC program was expanded to include military bases on Guam in August 1993 with funds provided by the Department of Defense. Control has been primarily focused at the highest risk areas on Guam including Anderson Air Force Base (AAFB), Apra Harbors (AH) Naval Station and commercial port, and Naval Air Station (recently changed to Tiyan Reuse Authority after base closure), and Won Pat International Airport (NAS) where cargo and craft depart. High risk cargo packing sites were also incorporated in the program as time allowed including sites where military personnel's household goods were being packed for shipment. Thus far, containment activities have appeared to be successful in minimizing brown tree snake dispersal and have provided additional insight into resolving the problem.

BACKGROUND

Since it was discovered that brown tree snakes were responsible for the decline of native bird populations (Savidge 1987), extensive research was conducted, and is ongoing, on the brown tree snake in hopes of eliminating them and their continued threat; research was conducted on Guam, in its native range, and elsewhere to provide information on the natural history of the species, determine the extent of the problem, and develop potential methods for resolving the problem. Background information is given here so that the complexity of this problem can be understood.

Identification

The brown tree snake, kulepbla to the native people of Guam, is a member of the colubrid family. It is characterized by a light to dark brown coloration typically marked with indistinct narrow dorsal bands, a light yellow belly which becomes increasingly gray with age, an extremely narrow, long body, and a distinctly wide head with large eyes. Most brown tree snakes are about 1 m long with some reaching lengths to over 3 m. These snakes are primarily nocturnal, seeking refuge from bright light and high temperatures during the day. Unlike most colubrids, the brown tree snake is mildly venomous; toxin is contained in the Duvernoy's glands behind the eyes. It envenomates its victims with two upper rear teeth on each side; in contrast to the hypodermic fangs of vipers, the venom is channeled into the victim through grooves in the teeth as they chew. Also, unlike the vipers, it uses its flexible body to constrict its prey while it injects the toxin into it; the venom helps immobilize prey and facilitate ingestion with digestive enzymes. The brown tree snake is arboreal and has a prehensile tail which allows it to climb remarkably well.

Range

Brown tree snakes range from western Indonesia through Papua New Guinea to the Solomon Islands, and the northern and eastern coasts of Australia. The introduced brown tree snake on Guam has characteristics that match those from Manus, an island in the admiralties. It was, therefore, assumed that they arrived on Guam when military bases on Manus were closed at the end of World War II and materials associated with these were shipped to Guam (Rodda et al. 1992). They spread relatively fast after their appearance in the late 1940s and by the early 1980s, they were found island-wide (Fritts 1987, 1988). They have since been found on several other Pacific islands including Oahu, Saipan, Tinian, Rota, Pohnpei, and Kwajilein and Diego Garcia

(Fritts 1987, 1988) and the U.S. mainland in Texas; these have all been associated with cargo or carriers from Guam. Saipan is of particular concern because it has had several reported sightings over the past ten years and a live snake was found along a fence line at their airport in 1994 indicating that they may currently have a breeding population; no snakes, though, have been trapped in extensive efforts by biologists in the Commonwealth of the Northern Marianas where sightings have occurred.

Geography

Guam is the southernmost island in the Marianas archipelago. It is approximately 212 square miles with mountains reaching 300 m. The temperature rarely goes below 75°F or above 95°F and it has an average annual rainfall of nearly 100 inches. The native people of Guam, Chammorros, have inhabited the island for more than a thousand years. The current population including military personnel is about 140,000 people with more than a million annual visitors. Guam has several surface shipping ports, airports, and marinas. Apra harbor, located on the west, central side, has a commercial shipping facility and military harbor. The commercial airport and recently closed Naval Air Station is in central Guam. Anderson Air Force Base is located on the northeast side of Guam and currently services most military aircraft. These facilities all transport cargo via surface or air to many of the other Pacific Islands as well as the U.S. mainland and the Orient. Cargo is packed island-wide prior to staging at the port facilities, making control of the brown tree snake a daunting task. Guam also has three marinas where boats from them travel regularly to other islands, especially Rota, Tinian, and Saipan in the Northern Marianas.

Habitat

Most of northern Guam consisted of limestone forests; currently, the only large tracts remaining are found near the rugged cliff line on military lands. The remainder of the north has been developed. The southern half of Guam consists primarily of savannahs, wetlands, and mountains with scattered stands of limestone forests and urban areas. Much of the native forests in the central part of the island have been replaced by introduced tangentangen scrub (*Leucaena leucocephala*) and urban developments. The climatic conditions on Guam and its habitats are ideal for brown tree snakes, but the greatest densities occur in large contiguous limestone forests and tangentangen stands; these habitats offer ideal hunting grounds for the remaining birds, commensal rodents, and lizards, and provide escape cover for them.

Brown tree snakes are typically reclusive during the day, retreating from the hot temperatures and sunlight; they are found in dark, cool, damp areas such as in *Pandanus* roots, rotting coconut trunks, or under air-conditioners. However, it is difficult to ever find them in their daytime retreats. Because of their nocturnal and reclusive habits, most visitors, and even some residents, never see brown tree snakes.

Food Habits

Brown tree snakes are opportunistic feeders, eating anything from lizards, birds, and rodents to bones, dog food, and eggs. The primary diet of brown tree snakes less than 60 cm usually consists of ectothermic prey such as lizards—geckoes, skinks, and anoles; warm-blooded prey such as rodents and birds are included thereafter; and at lengths greater than 110 cm, their diets are shifted almost exclusively to endothermic prey (Fritts 1988).

General Biology, Reproduction and Behavior

Brown tree snakes have been uninhibited on Guam and have reached densities of up to 58 snakes/ha (about 15,000 snakes per square mile) in unfragmented jungle areas during the early 1990s (Rodda et al. 1992). These densities are much greater than any other snake in the world. Recent density data in 1995 found a significant drop in the population to 11-20 snakes/ha (about 3,000-5,000/mi^2) (G. Rodda, pers. comm.). In urban habitats with fragmented stands of tangentangen or other forest plants near port facilities, ADC personnel trapped approximately 7 snakes/ha (1800/mi^2) during 1993-1994.

Brown tree snakes reach sexual maturity when they are about 1 m in length. Hatchlings are about 35 cm, females rarely exceed 2 m, and males reach the greatest length at over 3 m. Males are distinguished from females only by their hemipenes located just below the vent on both sides and those of large size.

Brown tree snakes are oviparous (egg-laying). Little is known about their eggs and hatchling development even with the densities found on Guam. Few clutches of eggs have ever been found and documented. ADC personnel have recently found and hatched two clutches of eggs, and are gathering data about the eggs and hatchlings (M. Linnell, pers. comm.). Gravid females and clutches that are found are typically 5 to 8 and do not exceed 12. It is believed that females can store sperm for several years after copulation, giving them the most potential for colonizing other islands.

Brown tree snakes are aggressive and display threats if cornered. They often strike continuously at intruders when cornered or grabbed, more often than most other snakes. However, most threats are harmless and typically only serve to warn the intruder; they usually quit when the intruder retreats or lets go.

The population of brown tree snakes on Guam has mostly been uninhibited. Competition with other species for food and space is minimal, with the exception of rats for some prey. The only predators of adult brown tree snakes on Guam outside of people are feral cats, dogs, pigs, and monitors and the population appears to have been relatively disease-free, making for relatively low mortality rates. Thus far, the greatest limiting factor appears to have been themselves because their population expanded beyond the available food supply.

Damage

Brown tree snakes have severely impacted and extirpated many of the native avifauna (Savidge 1987), bats and lizards (Rodda and Fritts 1992), caused power outages, threatened human health and safety, primarily infants (Fritts et al. 1990), and predated pets, poultry and eggs (Fritts and McCoid 1991). They have also had an impact on tourism and cultural heritage.

The introduction of exotic species is one of the leading causes of extinction and endangerment of native

species in the world. No where else has this been illustrated more graphically than on Guam with the introduction of the brown tree snake. Nine of 11 forest species on Guam were extirpated or became extinct as a result of the brown tree snake: the Guam flycatcher (*Myiagra freycineti*) and Guam subspecies of the rufous fantail (*Rhipidura rufifrons*) and bridled white-eye (*Zosterops conspicillatus*) are extinct; the Guam rail (*Rallus owstoni*) and the Guam subspecies of the Micronesian kingfisher (*Halcyon cinnamomina*) are now found only in captivity; the Micronesian honeyeater (*Myzomela rubrata*), white-throated ground-dove (*Gallicolumba xanthonura*), Marianas fruit-dove (*Ptilinopus roseicapilla*), and nightingale reed-warbler (*Acrocephalus luscinia*) have been extirpated, but still exist on northern islands in the Marianas (Savidge 1987). Only a few hundred Micronesian starlings (*Aplonis opaca*) and about 50 Marianas crows (*Corvus kubaryi*) remain of the native forest avifauna, along with a few hundred island swiftlets. Much of Guam's current avian wildlife consists of a few species of resident seabirds, migratory birds, and introduced species.

The only mammals native to Guam were three species of bats. The little Marianas fruit bat (*Pteropus tokudae*) and the Pacific sheath-tailed bat (*Emballonura semicaudata*) are extinct. An endangered colony of about 500 Marianas fruit bats (*Pteropus mariannus*), though, still exists on Guam and Rota. Brown tree snakes have partially been implicated in their decline, but their disappearence was complex and probably included factors such as hunting and habitat destruction. Currently, the juveniles of the population are threatened by the brown tree snake and the adults from poaching (G.Wiles, Div. Aquatics & Wildl., Guam, pers. comm.)

Several of the native geckos (i.e., rock gecko, *Nactus pelagicus*, and island gecko, *Gehyra oceanica*) and skinks (i.e., Snake-eyed skink, *Cryptoblepharis poecilopleurus*) have also declined. Some may have declined because of competition with introduced lizards, but brown tree snakes were also implicated in their demise (Rodda and Fritts 1992).

Brown tree snakes have caused considerable damage to the island's power supply. They cause an average of over 50 outages per year with damages estimated in the millions. Power outages and associated damages were especially a problem before Guam Power Authority switched from an island-wide power system to substations. It could take two days to find where the system was shorted before substations were installed, while it only takes an average of 45 minutes now. Typhoon Omar in 1992 helped reduce the problem because downed wooden poles were replaced with cement, "typhoon-proof" poles that do not allow snakes to climb. They still gain access to the electrical wires, though, from the guy wires.

Human health and safety is also a concern (Fritts et al. 1990). The island's hospitals treat numerous snake bite victims each year. Adults are rarely ever at risk of toxic poisoning from being bitten. The greatest threat is to infants under two years of age. Several infants have had their entire arm engulfed before parents are aware of a snake's presence. Fortunately in the most severe cases, the infants bitten have been taken to hospitals quickly enough to stabilize them; a few children have suffered respiratory failure and cardiac arrest, but were revived. Brown tree snake bites, though, do have the potential for causing death to infants if treatment is not obtained.

Brown tree snakes have also affected poultry and pets (Fritts and McCoid 1991). Pigeons and chickens along with their eggs are commonly taken by the snakes. Greatest damage dollarwise occurs to racing pigeon and gamecock breeders. Pets as large as a Labrador puppy have also been preyed upon by the snakes.

Tourism has been affected because of the presence of the snake on the island and its publicity. Articles that described Guam as having "snakes like spaghetti in trees" have an obvious effect. Some tourists that read about such densities are likely to vacation elsewhere.

Finally, some of the cultural heritage of Guam has been lost. The native Chammorros revered the local wildlife and many legends involved these species. The rufous fantail, or chicharika locally, was said to help keep families together. Its loss has been blamed for the breakdown of family unity by some Chammorros and is said to have negative implications for future generations. The Marianas fruit bat, or Finihi locally, was commonly hunted and eaten at fiestas. The Chammorros relished the bats, but they no longer can be hunted because of their endangered status. Poaching, though, is common to obtain the delicacy and further endangers the bat.

OPERATIONAL CONTROL

In April 1993, an operational control program to control and contain brown tree snakes on Guam was initiated by ADC. After reviewing the available literature on control methods for brown tree snakes and discussing options with people involved in different facets of the brown tree snake problem, several strategies were determined to be viable approaches for containing and controlling the snake near port facilities—trapping, spotlighting, detector dogs, prey-base removal, habitat management, barriers, and modifications of cultural practices. Once the techniques were selected and administrative duties were in place, personnel were hired to begin operational control in July 1993. By September, ten personnel were conducting brown tree snake control at port facilities. Following are some of the results from the first few years of trapping and methods used to reduce the chance of the snake dispersing elsewhere.

Trapping

Traps have long been used to trap ground dwelling snakes. The U.S. Fish and Wildlife Service developed a trap for the brown tree snake using a modified Gee's® crayfish trap (Rodda et al. 1992). The funnels on each side are fitted with flaps to allow snakes to enter, but not get back out. The traps are baited with live mice inside a chamber placed into the trap. Since house mice are difficult to obtain on Guam, a breeding colony was established in cooperation with the Guam Division of Aquatics and Wildlife. The breeding colony produced an average of 500 mice/month. Mice were climatized prior to being put out in the field. Once put in the field, they were fed grain and half-sliced potatoes for their water.

The primary method used by the ADC snake control program has been the modified crayfish traps and each

ADC employee could monitor about 150 of them. The traps have been very successful at capturing snakes and making trapped areas relatively "snake-free." Traps are placed in appropriate habitat, typically fragmented forest stands, at high densities; initially traps were placed at 20 m intervals around the perimeter of selected areas and at 30 m apart on trails cut at 30 m intervals inside these areas. Research conducted with the traps determined that optimal trap density was about 25 m apart to trap all snakes in an area (Rodda et al. 1992). Areas were considered "snake-free" only after snakes had not been captured in a plot for at least a week. Research conducted for 15 days at Orote Point, an expansive area of tangentangen, found that brown tree snakes, being highly mobile, would recolonize areas quickly (Rodda et al. 1992).

Port facilities were initially mapped, distinguishing between areas of good or poor snake habitat, to determine the most appropriate route to take with traps such that a "snake-free" zone could be established. Traps were initially placed in an area that could not easily be reinvaded at least on three sides. Once they were declared "snake-free," all traps were removed except those along the perimeter adjacent to the next stand to be trapped and adjacent to any area that had not been trapped to reduce reinvasion. Traps were placed into the next adjacent area until it was declared snake-free. Then traps from the first plot's perimeter and all but the appropriate perimeter trap would be moved to the next stand. This cycle was repeated until all areas were trapped. Paved roads and extensive urban areas with few plants, brush piles, and debris were considered relative barriers for snakes and did not threaten reinvasion of trapped areas significantly. If an area was not conducive to trapping (i.e., high-visibility) or it was developed, it was searched with spotlights to catch snakes and determine if a significant number of snakes were present warranting trapping.

During the first year of operational control (July 1, 1993 to June 30, 1994), 2,546 brown tree snakes were removed from areas within a kilometer of port facilities with traps (during the first quarter, 100 hagfish traps were used until the crayfish traps came and were assembled in September 1993 and only 156 snakes were taken with traps during the first quarter). This combined with other methods represented a take of about 7 snakes/ha from the overall habitat including urban areas. Since the first year, numbers of snakes taken per year with traps have increased to over 5,000 with additional employees hired and modifications in trapping techniques.

Trap success varied from plot to plot, 0 to 25 snakes/ha with an average of about 16 from plots greater than 1 ha. Typical removal rates from all urban areas with fragmented forest stands were approximately 6 snakes/ha during the first year of operation. The number of snakes trapped during the first 2 to 3 weeks in plots less than 30 ha was constant, but dropped off dramatically to zero at normally 4 to 6 weeks. These areas appeared to remain relatively snake-free after being trapped. A 14 ha plot at Naval Station had ten traps placed randomly after it had been trapped three months prior. No new snakes were trapped for two weeks, but eight rats were. During the initial trapping, only one rat was caught in nine weeks with 140 traps placed; rats frequently are caught in the snake traps and an obvious inverse relationship is exhibited with the number of rats and snakes caught in a plot. Therefore, it was assumed that trapping efforts were mostly successful at removing snakes from an area and that roads and other urban features provided barriers for snakes to recolonize areas. Recent research determined that the authors' assumptions were correct in that areas did remain relatively snake-free for an extended period of time after removal where barriers such as roads surrounded the area (Engeman et al. 1996). Soon after the first few months of trapping, it was determined that the interior trails could be widened to 50 m apart without having an effect on the number of snakes taken thereby reducing effort needed to make an area snake-free. This was illustrated further in April 1994 when ADC personnel had placed perimeter traps around a 5 ha forested area (approximately 175 x 300 m) at NAS. ADC personnel were unable to cut interior trails for four weeks, but the perimeter traps caught over 100 snakes. After interior trails were cut, only 1 snake was caught in three weeks with the 45 new traps placed, indicating that perimeter trapping was highly effective at removing snakes from at least small fragmented forest stands. This had a profound effect on the trapping program as fewer traps and significantly less effort cutting trails was required to remove snakes from plots as little as 5 ha. Recent research corroborated this and determined that areas up to 8 ha were effectively trapped using only perimeter traps (Engeman et al. 1996); however, mixed results were obtained for areas over 20 ha. Brown tree snakes are highly mobile and probably hunt edges for a short period when they come to them where they eventually encounter a trap. Removal of snakes with this method enabled a much larger area to be trapped since fewer traps were required to make an area "snake-free."

The greatest number of snakes taken during the first year was from the edge of contiguous habitat surrounding the air operating area at AAFB that could not be completely trapped because of its expansiveness. Snakes were trapped along a cliff line to the north and east of the airfield in 75 perimeter traps. Native limestone forests lined the top and bottom of the cliffs and extended for up to a few kilometers beyond. Over 500 snakes were removed from the area in four months of trapping. Capture rates remained relatively high for a few months in the perimeter traps, but dropped to zero after four months. Snakes apparently reinvaded the area relatively quickly, though.

The crayfish traps were very effective, but needed minor improvements. The entrance doors or flaps often got stuck open, allowing snakes to escape. Several door designs were made and monitored for their success. Recently, a new door was made that had encouraging success (Linnell et al. 1996). Another problem is that the trap was time consuming to maintain. Several styles of traps were monitored to determine if one could be made that allowed easier access to the mice, yet maintained similar trap success rates. Unfortunately, the trap designs monitored required similar or a little less time for maintenance, but were much more costly to produce. Finally, an inanimate bait that attracts snakes nearly as

well as live mice would be significantly more efficient because maintenance of traps, and mouse colony, would be reduced considerably. Thus far, the most favorable inanimate baits tested such as chicken manure and commercial predator baits attract snakes only at a rate of 5 to 20% as well as live mice. The National Wildlife Research Center is currently researching baits and chemical attractants for an effective bait.

Spotlighting

Since brown tree snakes are nocturnal and found in dense numbers, one would expect that spotlighting would be an efficient method of capture. However, this is not completely true; snakes in optimal jungle habitats can be collected at only about 1 snake/hour, making this a less than acceptable method of capture (E. Campbell, pers. comm.). However, it has been found that when tree snakes encounter fencelines, they readily climb it (90% + of the time), but only if vegetation and debris are maintained or mowed on both sides. This makes fencelines ideal collecting surfaces and capture rates can often be as high as 10 snakes/hour.

Fencelines surround the airfields on Guam and many of the shipping port's facilities. Since fencelines offer ideal collecting surfaces close to high-risk cargo and carriers, they were monitored frequently for snakes. During the first year, 407 snakes were caught on fencelines surrounding port facilities. Most of these snakes were taken during the first quarter (over 50% July to September 1993) when few traps had been placed in the field. Once areas near fencelines had been trapped, capture rates dropped off significantly, often to less than 1 snake/hour; in addition, snake movements were less from October to May which decreased success rates for spotlighting.

Detector Dogs

Dogs can be trained effectively in locating pests because of their keen sense of smell. Detector dogs, as they are often referred to, have been used extensively in pest and wildlife management. Dogs have been used by USDA's Plant Protection and Quarantine at ports of entry to detect pests and products such as plants that may have undesirable organisms in them. Dogs have been used by ADC to detect problem wildlife species such as bears and mountain lions. Detector dogs have also been used to locate contraband including snakes by the Hawaii Department of Agriculture and have proven to be effective.

Breeds were selected for snake control after evaluating specific criteria: their tenacity with snakes (i.e., Beagles can become afraid of snakes if bitten whereas Jack Russell terriers become more aggressive), maintenance requirements, size (smaller dogs can get into more places), and ability to work in hot conditions. The selection of detector dogs was made after discussion with several Oregon ADC personnel, ADC guard dog specialists, Portland veterinarians and assistants, and APHIS employees from Plant Protection and Quarantine. The final consensus was that the best suggestions were short coat Jack Russell (K. Wells, pers. comm.) or Cairns terriers (J. Green, pers. comm.).

Jack Russell terriers were relatively easy to obtain and two were trained in California and brought to Guam in October 1993. Handlers for the two terriers were hired prior to their arrival and the dogs were put to work shortly thereafter. The dogs were used to inspect outgoing cargo and carriers, especially cargo heading for other Pacific islands and the U.S. mainland, at all port facilities. Since brown tree snakes are nocturnal and evening temperatures allowed the dogs to work longer, the dogs were primarily used during late evenings. During the first eight months of operation, the dogs found 15 snakes in or around outgoing cargo including two that were taken from cargo headed for Hawaii and Farralon Island just prior to loading. Currently, ADC is using eight Jack Russell terriers for control operations at port facilities and packing sites.

The primary problem noted with the terriers for snake detection was that they became very visual and relied less on their nose for detection, and therefore, required constant and consistent training. Another problem was that they got hot relatively quickly and were unable to use their nose effectively because of panting (panting basically cuts off the ability of the nose to detect). Another breed may be able to detect the snakes scent better and for longer periods in the high temperatures. A different breed that uses its nose effectively and withstands hot temperatures for longer periods of time could be teamed up with Jack Russell terriers to be more effective. The efficacy of these dogs will be researched by the National Wildlife Research Center.

Habitat Modification

Urban areas with fragmented jungle, brush piles, and other debris support moderate populations of snakes; these areas often attract commensal rodents which in turn attract brown tree snakes. Removal of this habitat, especially adjacent to port and cargo facilities, reduces the brown tree snake population and reduces the risk of snakes entering cargo or carriers.

Several of the port facilities were immediately adjacent to fragmented forests (primarily tangentangen), brush piles, and debris. These areas were identified and port directors or commanding officers were encouraged to have these removed. Several heeded the requests, especially the removal of brush and debris. For example, NAS had brush and tangentangen stands within 50 feet of a helicopter hangar where several brown tree snakes were caught, including in the hangar; the Commanding Officer had maintenance clear the area. Another sight near the flightline where snakes were commonly found had fragmented forests and debris; these were removed and no more snakes were caught there. Guam Airport Authority cleared a tangentangen stand adjacent to the commercial cargo shipping facilities where several brown tree snakes had been trapped. Naval Station at AH kept grass fields mowed more often after being notified that they were growing to heights of over three feet in areas that would support brown tree snakes. All of these modifications helped reduce the population of snakes as well as prey.

Brown tree snakes are attracted to areas with abundant prey. They can detect prey at long distances, especially if prevailing winds carry the scent and/or

dander any distances. Guam has several introduced species that are prey for the brown tree snake including the house mouse (*Mus musculus*), roof rat (*Rattus rattus*), Norway rat (*R. norvegicus*), musk shrew (*Suncus murinus*), feral pigeon (*Columba livia*), Eurasian tree sparrow (*Passer montanus*), and black drongo (*Dicrurus macrocercus*). Therefore, control of these species at port facilities and cargo packing and staging locations would reduce the number of brown tree snakes attracted to these areas.

During the first year, the pigeons at NAS and AAFB and most at AH were removed with air rifles. Over 100 pigeons were removed from Won Pat International during the first year and after their removal, additional pigeons did not try to reestablish there for several months. Drongos and tree sparrows were controlled to a lesser extent, but those that seemed to be significant attractions near port facilities were removed. Commensal rodents were controlled at the commercial facilities with snap traps and registered rodenticides (zinc phosphide and brodifacoum products). After populations were reduced, they were monitored periodically to determine if control was necessary again.

Cultural Practices

Shipments from Guam are packed island-wide and the containers are then transported to port facilities. Educational programs for shippers, cargo handlers, and Customs inspectors (military and civilian) that describe the brown tree snake problem and appropriate methods of handling cargo could significantly reduce dispersal. Packers should inspect cargo prior to packing and shipment to port facilities, especially items stored outdoors such as household goods like outdoor washing machines, lawn mowers, and barbecues. Cargo should be packed in sealed containers that do not allow access to brown tree snakes. Once packed, containers should be staged in open areas on concrete or asphalt surfaces to reduce the likelihood of snakes seeking refuge in them. Cargo considered the highest-risk for brown tree snakes are uncontainerized such as open wooden crates, vehicles, machinery, outdoor washers and dryers, and construction materials. High risk items should be visually inspected thoroughly by packers and they should call for inspection by detector dogs where possible.

The Commonwealth of the Northern Marianas had developed the first educational poster on brown tree snakes. It was developed primarily to alert the public of the problem on Guam and the authorities to notify should a brown tree snake be found; it was posted at port facilities. Hawaii Audubon Society produced a video that graphically outlined the brown tree snake problem and focused attention on shipments from Guam. Quarterly training programs were given to Military Customs by National Biological Survey personnel and later by ADC to increase their awareness of the problem and where they could assist in minimizing the risks. The Hawaii Department of Agriculture in conjunction with ADC recently developed a training video for shippers and cargo handlers that outlines the problem and shows appropriate shipping techniques that minimize dispersal. ADC also developed a poster for Guam and elsewhere that has been used extensively to educate the public of the problem. These types of educational programs and displays help reduce the threat of dispersal because more eyes are watching.

Exclusion

Non-electric barriers are fairly effective against ground snakes, but minimally for tree snakes. However, electric barriers have proven to be effective against entrance by brown tree snakes. Temporary mesh barriers at least 1 m high and angled slightly outwards do help keep brown tree snakes from particular areas or cargo staging areas. A one-way electric fence that allows brown tree snakes to exit fenced areas, but not to enter, kept hectare plots snake-free for extended periods of time (E. Campbell, Ohio State Univ., pers. comm.). The biggest problem with the design was that rats would gnaw holes through the fence, subsequently allowing brown tree snakes access into protected areas. These barriers are permanent and somewhat costly, making temporary control of small areas difficult. Barriers have great applicability for protecting cargo and ships from brown tree snakes, but only temporary mesh barriers have thus far been used.

Toxicants

Research is ongoing to provide an effective toxicant for the brown tree snake. An effective, safe toxicant(s) could provide island-wide control of the snake. Recently, the Great Lakes Chemical Company added brown tree snakes to their methyl bromide label, a fumigant proven very effective for brown tree snakes. Currently, no other toxicants are registered for the brown tree snake. The Denver Wildlife Research Center has tested several oral candidates that have been effective including rotenone, pyrethrins, propoxur, diphacinone, and aspirin. One of these will be selected for registration after the development of a suitable drug delivery system. Four commercially available insecticide aerosol products killed snakes when applied dermally and are candidates as a dermal toxicant (USDA 1996).

Continuing Research

Research is continuing on several other potential control methods for the brown tree snake. Researchers from the National Zoo and Oregon State University are looking into pathogens that potentially would infect only the brown tree snakes and not native reptiles. A few pathogens are known from zoo collections that infect snakes and another from the brown tree snakes native range. These could have significant impacts on the population if they were suitable to introduce into the population and would not infect the native fauna. The Denver Wildlife Research Center is currently looking into inanimate attractants for toxicant delivery systems and snake traps. If these research efforts find new tools, they will be incorporated into the brown tree snake control program and could have significant impacts on the control program, possibly eradicating the brown tree snake from Guam.

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