Brown Tree Snake

Control Plan

Prepared by:

The Brown Tree Snake Control Committee

Aquatic Nuisance Species Task Force

under the

Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990

As Approved by the Aquatic Nuisance Species Task Force

June 28, 1996

I. Executive Summary - A native of Indonesia, New Guinea, the Solomon Islands, and Australia, the brown tree snake (*Boiga irregularis*) has caused or been a major factor in a modern extinction episode beyond its native range that is unprecedented in its scope: the extirpation of most of Guam's native terrestrial vertebrates, including fruit bats, lizards, and virtually all of the island's forest birds. In addition, brown tree snakes in Guam have caused more than a thousand power outages, damaged agricultural interests by preying on poultry, killed many pets, and envenomated numerous children.

Several governmental agencies and private entities have been working to prevent similar ecological disasters on other Pacific islands, since the threat of the brown tree snake's dispersal to other islands and continents is significant. The brown tree snake is a major threat to the biodiversity of the Pacific region and other areas at risk. High densities of snakes occur in many urban areas on Guam where cargo is loaded for transport by air and sea to other Pacific islands, and dispersal has been documented by snakes discovered on islands in Hawaii and the Commonwealth of the Northern Mariana Islands, and even in the continental United States.

In recognition of this threat, the United States Congress included a section in the Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 that authorizes a cooperative program to control the brown tree snake outside of its historic range. Representatives of the Departments of Agriculture, Commerce, Defense, and the Interior; the Commonwealth of the Northern Mariana Islands; the Territory of Guam; and the State of Hawaii formed the Brown Tree Snake Control Committee in May 1993 to develop an integrated pest management approach that would:

• reduce existing brown tree snake populations over large geographic areas on Guam;

• prevent the spread of brown tree snakes to other Pacific islands and mainland areas;

• eradicate or contain new populations as soon as detected;

• develop more effective and environmentally sound control and/or eradication strategies and methods;

• protect endangered species and other wildlife from brown tree snake predation;

• assist organizations and individuals on Guam to manage and control brown tree snake infestations, and especially to reduce disruptions of electrical supplies and human-snake encounters resulting in emotional trauma and bites; and

• develop adequate information on the brown tree snake's biology, dispersal dynamics, and control to support Federal, State, Territorial, and Commonwealth needs.

To meet these objectives, the BTS Control Committee proposes the following tasks be undertaken:

• reduce brown tree snake populations over large geographic areas on Guam;

• eliminate brown tree snakes from the transportation network;

• eradicate snakes in recently established populations;

• control snakes to reduce predation on endangered species and other native animals;

• control snakes to reduce human contacts resulting in snakebites and emotional trauma;

• control snakes to reduce electrical outages and damage to equipment;

• provide information and educational materials to the public, government agencies, and commerce to reduce risks of ecological and economic damages due to the establishment of this exotic pest;

• provide for the prompt and continuous evaluation of the effectiveness and viability of control actions, including both operational and research facets of the program, as well as a periodic review and updating of the Brown Tree Snake Control Plan.

These tasks are frequently interrelated and, as such, are not necessarily listed in any priority order. However, all are essential parts of both a short- and long-term strategy needed to control brown tree snakes outside their native habitat.

Several techniques for brown tree snake control are already in use, but most need further development to enhance their effectiveness. The following tools and techniques to implement the above tasks are:

• **Interception of snakes using canine detection** - This technique is operationally active on Guam. Special training, verification of performance, and identification of limitations of dogs used for interception on Hawaii and islands other than Guam are warranted and would require 1-2 years to complete. This tool is a high priority, especially to islands other than Guam.

• **Hand capture of snakes -** This tool is operationally available and is in use on Guam. Training is needed for personnel lacking experience with brown tree snakes (search methods, snake behavior and habits, handling, snakebite risks, etc.). Further training is a high priority for designated personnel.

• **Trapping** - This tool is operationally available and ongoing at considerable expense. Moderate levels of research are needed to develop inanimate attractants. Effective traps are available, but evaluation continues and future refinements may occur. The development of an inanimate attractant would be a high priority for operational control.

• **Fumigation** - Research has demonstrated the ability of the fumigant methyl bromide to kill snakes hidden in cargo containers, thereby preventing their accidental transport from infested areas to new sites. The Environmental Protection Agency has approved a methyl bromide product label (Meth-O-Gas® Q) for regulatory use to control brown tree snakes. Other substances that have been tested and evaluated include sulfuryl flouride and magnesium phosphide. Identification and testing of additional potential fumigants are needed.

• **Barriers, including chemical repellents, to exclude snakes from critical areas, reduce movements between habitat patches, and contain snakes if they are introduced to new areas** - A prototype electrical/physical barrier is available and development is ongoing, but additional innovations are needed to design permanent barriers resistant to typhoons, rats, and vandals. Barriers should be further designed in a manner suitable for urban and commercial settings. Research will require 2+ years and is a high priority for excluding snakes from transportation areas, protecting critical areas and sites for endangered species recovery, and preventing colonization on other islands.

• **Lighting to repel snakes and to facilitate their detection** - At least 1 year of research at modest expense is needed to verify snake behavior in response to lighting. This is a secondary task, but important to the transportation and electrical facets of the problem.

• **Habitat modification to reduce daytime refugia & increase invading snake detection -** Careful monitoring of initial habitat modification programs is needed. The primary cost would be to the user. This is a secondary priority.

• **Habitat modification to discourage prey species that attract snakes and cause snakes to remain in or around transportation areas** - Minimal research and careful monitoring of initial programs are needed to refine this effort. The primary cost would be to the user.

• **Manipulation of elements of prey base (especially nonnative species) as appropriate** - This tool is currently in use, but needs operational assessment. The use of diphacinone in Eaton's Bait Stations has been effective in controlling rats in field situations in Hawaii and this technique or similar efforts may be useful on Guam. Prey base management to reduce brown tree snake populations is a high priority.

• **Toxicants and attractants** - A major 5+ year research effort is needed on both a toxicant and a delivery system, although some data are available from current trapping work. Registration of the toxicant with the Environmental Protection Agency could amplify time and cost estimates. This research is a high priority for both local and large scale control.

• **Parasites and disease** - A major research effort is needed over 5+ years to develop this tool, which depends on a better knowledge of snake biology and disease ecology. Biological, sociological, and technical problems abound, and the cost will be high. The research is a high priority as a long-term solution and as a large-scale control method.

• **Reproductive inhibition** - Research is needed on reproductive inhibitors, and immunological and chemical fertility control, as well as a delivery system. These tools offer similar environmental and technical problems but fewer sociological obstacles. The cost would be high, but the results may be highly effective.

• **Monitoring of snake populations and dispersal events to provide guidance to other control efforts** - This technique is available and in use but is labor intensive. Additional coordination and distribution of information is needed to enhance these efforts.

• **Production and dissemination of public educational materials** - Some materials are currently in use, but the need remains for increased volume and frequency to increase citizen involvement and awareness on other target islands. The cost is modest, and both quality and scope of effort are important.

• **Dissemination of technical information to all concerned governments and agencies in the form of publications, reports, bulletins, and synoptic overviews** - Such distribution currently occurs, but increased publication and dissemination of results are limited by costs and publication procedures, and increased implementation is hindered by lack of continuity in staff assignments within cooperating agencies. Costs for this activity are moderate, and the tool is a high priority.

Inherent in most of these tools and techniques is the need for additional research, both into control technology and basic brown tree snake biology. Ongoing research is important, but at current levels will not be sufficient to develop the new techniques that will be required to meet brown tree snake control objectives. Federal expenditures will need to be increased to more than $4 million per year (including $2 million for research) with a gradual shift of funding over a period of 5 or more years from research to operational control as tools and techniques are developed that allow effective control.

Existing control activities and research are funded through the Department of Defense, the Department of the Interior [through the Office of Insular Affairs (formerly the Office of Territorial and International Affairs), the National Biological Service, and the U.S. Fish and Wildlife Service], the Department of Agriculture, the State of Hawaii, the Government of Guam, and the Commonwealth of the Northern Mariana Islands. These initiatives must be coordinated to develop a comprehensive program reflecting current operational needs and adequate research to develop better brown tree snake control methods for the future. Although good working relationships currently exist between agencies and among research and operational personnel, clarification of jurisdictional responsibilities and solid partnerships would benefit future progress.

Current techniques offer no known method for ridding Guam of its well-established snake population. Research to develop control technologies that are applicable over broad geographic areas is needed; but the present focus on prevention of further dispersal and rapid eradication of new populations may also lead to new tools and techniques that can assist Guam in controlling its brown tree snakes. The importance of a long-term, coordinated effort toward brown tree snake control cannot be overstated; neither can the importance of beginning now.

II. Introduction - Shortly after World War II (before 1952), the brown tree snake was accidentally transported from its native range to Guam, probably as a stowaway in ship cargo (Rodda *et al* 1992a). In the absence of natural predators and other population controls on Guam, the brown tree snake has been responsible for the extirpation of most of the native forest vertebrate species; hundreds of power outages affecting private, commercial, and military activities; large-scale loss of domestic birds and pets; numerous potentially fatal envenomations of children; and considerable emotional trauma to residents and visitors alike. Since Guam is a major transportation hub in the Pacific, numerous opportunities exist for the brown tree snake to be introduced accidentally on other Pacific islands. Although numerous sightings of this species have been reported on other islands, the establishment of additional populations has not been documented to date.

The risk of the brown tree snake dispersing to other islands from Guam is heightened by a number of factors (Fritts 1987b). The snake is clearly a successful colonizer, based on its widespread occurrence in its native range on numerous islands with varying ecological conditions. It tolerates natural and second growth habitats and is successful in maintaining high population levels in close contact with humans. Its extreme abundance on Guam, even near urban and developed areas with partially depleted bird and mammal populations, causes it to enter transportation facilities in search of prey. Once in ports and cargo facilities, the need to hide during the day causes brown tree snakes to enter vehicles, crates, and other materials that are commonly moved by air and sea to other islands.

Guam is a major transportation center for both civilian and military traffic in the Central Pacific Region. Brown tree snakes have been discovered in association with sea and air traffic from Guam on numerous islands, and unconfirmed reports exist for other islands. The detection of snakes in bulky cargo shipments by visual inspection is difficult, and many incidents likely have occurred in the past without being noticed or reported. Most incidents in Hawaii have involved military aircraft, but sightings in the Northern Mariana Islands and the Federated States of Micronesia have been associated with civilian ships and seaport facilities. A variety of historical and ecological factors contribute to the likelihood of snakes dispersing in air and sea traffic, surviving such movements, colonizing new areas, and successfully exploiting the native animals endemic and unique to nearly all Pacific islands and other areas at risk such as the west coast and southern United States.

Several governments and agencies have implemented various programs of brown tree snake control. However, comprehensive and better coordinated programs using adequate technologies and tools will be needed if the spread of these snakes to other islands is to be prevented and the population of snakes on Guam is to be controlled. In recognition of the need to control brown tree snake populations, the United States Congress incorporated a section into the Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 authorizing such a program:

"The [Aquatic Nuisance Species] Task Force shall . . . undertake a comprehensive, environmentally sound program in coordination with regional, territorial, State and local entities to control the brown tree snake (Boiga irregularis) in Guam and other areas where the species is established outside of its historic range."

In response to this statute, the Aquatic Nuisance Species Task Force established a Brown Tree Snake Control Committee (see Appendix A for a list of members). The Committee held an organizational meeting on May 20, 1993, to review the status of brown tree snake control efforts by various governmental agencies and to establish objectives for an integrated pest management approach. Committee members agreed to draft various sections of a Brown Tree Snake Control Plan to provide a more coordinated and enhanced level of control throughout the Pacific.

During a formal meeting of the Brown Tree Snake Control Committee in Honolulu, Hawaii, on December 13-14, 1994, a preliminary draft plan was reviewed, updated, and revised. Committee members developed summary tables outlining operational and research funding needs for an integrated pest management approach over a 5-year period. The draft plan was released for public review and comment in April 1995. A third Committee meeting was held in Honolulu, Hawaii, on April 30-May 1, 1996, to review the final draft and approve a final Brown Tree Snake Control Plan. The plan was finalized and approved by the Aquatic Nuisance Species Task Force on June 28, 1996, with the hope that funding will be made available as soon as possible for implementation of both the operational and research activities outlined within its pages.

III. Background and Current Situation

A. Biology of the Brown Tree Snake - The brown tree snake, *Boiga irregularis*, like other members of its genus, is an arboreal, nocturnal, and slender snake with grooved venom-conducting teeth at the rear of the maxilla. The species can attain relatively large size, facilitating predation on a broad range of vertebrates. Its natural distribution extends from Wallace’s Line in Indonesia east through New Guinea to the Solomon Islands and south along the northern and eastern rim of Australia (Fritts 1988).

The sexes differ only in maximum length (to about 2.3 meters total length in females, 3.0 meters in males). Color pattern and scutellation are variable across the snake's range, but are relatively uniform at any locality. The species is in need of taxonomic revision.

The behavior of the brown tree snake is characterized by its adaptability. This snake is not limited to specific habitats, forest strata, altitudes, or seasons, though extreme dryness, bright sunlight, high daytime temperatures, or freezing conditions will influence its activity. Home ranges are extremely large on Guam; adults may range over more than a dozen hectares. Both active (e.g., geckos) and inactive (e.g., eggs) prey are eaten opportunist-ically, including almost all vertebrates and carrion of a suitable size. Meals up to 70 percent of the snake's body mass have been observed in the wild.

Little is known about the reproductive habits of the brown tree snake because gravid females and eggs are infrequently found. In Australia, reproduction is highly seasonal. The seasonality of reproduction in Guam is not clearly known, though some evidence suggests reproduction occurs throughout the year. Clutches of 4 to 12 eggs are probably deposited underground and occasionally above ground in cavities within trees, requiring about 90 days for incubation. Nests have been reported on Guam in axillae of coconut fronds, in termite nests, and in a solution hole in a limestone cliff. Hatchlings vary from 275-400 millimeters in snout-vent length (SVL). The average snake on Guam matures at 900-1050 millimeters SVL, substantially larger than the minimal adult size (625-850 millimeters) reported for the native range. Newly maturing male snakes on Guam grow faster (about 20 millimeters/month) than their female counterparts (about 13 millimeters/month). In the last several years, populations on Guam have regularly reached densities in excess of 50 snakes/hectare.

There are no obvious natural predators for the brown tree snake in parts of its native range or on Guam, although ophiophagous (snake-eating) snakes such as the king cobra and birds and mammals with relatively broad diets undoubtedly eat them opportunistically in some localities. Although slow-moving when initially approached, the brown tree snake coils and strikes repeatedly when threatened. Its bite and venom are weak but effective deterrents to predators. Little is known about the parasites and diseases of the brown tree snake in its native range, and they have not been studied on Guam.

Populations of the brown tree snake and its predators, competitors, and prey on Guam have been documented by visual censuses, trap censuses, and mark-recapture population estimation since 1985, but few data are available prior to that time (Rodda *et al* 1992b). The brown tree snake population apparently grew slowly from its establishment around 1950, until by 1985, the initial irruption (peak densities of 50-100/hectare) had swept over the entire island, extirpating most indigenous vertebrates (Rodda *et al* 1992a). Snake population levels are now highly variable, apparently due to residual historical factors and prey availability. Sex ratios, population densities, and size distributions vary over short distances and through time. Introduced prey species continue to support large populations of snakes in areas lacking native vertebrates. In the snake's native range, and on Guam, the major factor limiting the abundance of the snake seems to be the availability of prey; there is no evidence to suggest that populations are significantly limited by habitat structure or predation on the snake. Food appears to be an important factor controlling survivorship and reproductive output of newly mature females. Larger mature females are rarely found, suggesting high adult female mortality. These demographic weak links may offer opportunities in developing control measures.

B. Population Development and Status - To date, the brown tree snake has been reported from 11 islands on which it is not native (Fritts 1987; McCoid and Stinson 1991). These islands include a large geographic area: Commonwealth of the Northern Mariana Islands (Saipan, Tinian, and Rota); Guam and Cocos Island; Okinawa; Diego Garcia; Republic of the Marshall Islands (Kwajalein); Hawaii (Oahu); Wake Island; and the Federated States of Micronesia (Pohnpei). One report exists from southern Texas in the continental United States (Fritts *et al* 1994a). No systematic search has been made for records of snakes on islands in the western and central Pacific regions, but heightened awareness of the problems caused by the brown tree snake and opportunistic contacts with officials on various islands have resulted in a large number of reports and incidents.

1. Guam - Since the post World War II introduction of the brown tree snake to Guam, the snake has attained unusually high population levels (perhaps as much as ten times higher (G. Rodda, pers. com.) compared with its native range of Papua New Guinea and the Northern Australian Coast. The high densities of snakes on Guam may partly be a result of an abundant and diverse prey base especially suited for high survivorship and growth of juvenile snakes, and the apparent absence of predators and diseases to the snake on Guam. As a result of high population densities of snakes, there have been frequent human encounters with snakes resulting in bites and hospitalization of children (at least 50 per year or 1 in 1,200 emergency room visits are a result of snake bites) (Fritts *et al* 1990; Fritts *et al* 1994b). Many other problems have cost millions of dollars, including frequent power outages (Fritts *et al* 1987) and loss of domesticated animals (Fritts and McCoid 1991). As a result of the snake infestation, biodiversity has declined precipitously on Guam. Nearly all of the native forest birds and other native vertebrate species have been extirpated, and other bird, mammal, and reptile populations have declined as a result of brown tree snake predation. At present, the dense snake populations in Guam are a threat to other islands because snakes inhabiting warehouses, crates, automobiles, and machinery are carried accidentally in air and ship cargo leaving Guam.

2. Commonwealth of the Northern Mariana Islands - Snake sightings in the Northern Mariana Islands have increased alarmingly in recent years, and each additional sighting increases the probability that this harmful pest snake has become established on the island of Saipan in the Northern Marianas (Fritts *et al* in press). Since 1986, more than 35 snake sightings have been reported on Saipan. Six snakes were recovered from these sightings.

Several snake sightings on Saipan are clustered near the commercial airport or the seaport, whereas others are centered around a small village two miles north of the port (Figure 1). These snakes likely arrived through individual cargo containers that were transported to the respective locations, and the snakes escaped when the containers were opened and cleared by Customs. No mechanism or developed protocol for detecting exotic reptiles in cargo from foreign lands currently exists, although such a plan is now being developed. Once a snake has dispersed from the point of initial introduction, the chances of capture are astronomically reduced. Therefore, it is crucial that snakes be captured at the point of initial introduction.

The frequency of sightings indicates a brown tree snake population is established on Saipan. Although several sightings could not be verified, all reports were investigated including interviews with observers, site visits, etc., to assess the legitimacy of each case and to document it accordingly. In addition to the brown tree snake sightings on Saipan, five unconfirmed snake sightings have been reported on Tinian, and two dead brown tree snakes have been found in cargo arriving on Rota.

3. Republic of the Marshall Islands - One brown tree snake has been found on the Island of Kwajalein in the Republic of the Marshall Islands. It crawled out of the landing gear of a military cargo plane at the Kwajalein Atoll Army installation associated with the Kwajalein Missile Test Range in 1979.

4. Federated States of Micronesia - Previous reports of snake sightings on Pohnpei, Chuuk, and Kosrae have been received and investigated, but none could be confirmed to be brown tree snakes. However, on November 3, 1994, a brown tree snake was discovered in a seaport at Kolonia in Pohnpei in association with containerized cargo.

5. Hawaii - Since 1981, seven brown tree snakes have been found on the island of Oahu in Hawaii arriving through commercial and military aircraft from Guam. Five of the snakes were found at the Honolulu International Airport and Hickam Air Force Base; one was found near an aircraft hangar at Barbers Point Naval Air Station in southwestern Oahu; and the most recent was found in a U.S. Army Schofield Barracks warehouse in central Oahu. Four of the seven snakes found were discovered within the past 4 years, consistent with the current high populations recorded on Guam. Snakes have been transported to Hawaii either as stowaways in aircraft or cargo, or on aircraft in the wheelwells. Snakes could also be inadvertently transported to Hawaii on commercial or military ships. Even containers of U.S. mail from Guam are potential sources of brown tree snakes, not just in Hawaii but in many other subtropical locations as well.

C. Current and Potential Impacts on the Environment and the Economy- Brown tree snakes have caused major ecological, economic, and social problems, directly impacting the biodiversity, island ecology, and human population of Guam. The best documented of these are the loss of the native bird fauna and the frequent power outages caused by snakes. Other effects include predation on agricultural animals and pets, increased vulnerability of agricultural crops and native vegetation to insect pests and increased risk of insect-borne diseases affecting humans and other animals due to the loss of avian and reptilian insectivores, and the fear or revulsion experienced by most residents and visitors when they encounter snakes in natural and urban settings. Several of these problems are less easily quantified than others. The cumulative negative impacts of the brown tree snake on commerce, the tourism industry, the military, and the civilian population of Guam have not been estimated but are undoubtedly significant.

1. Impacts on the Vertebrates of Guam - During the 1960's, most native birds disappeared from southern and central Guam. By 1963, several formerly abundant species of native birds had disappeared from the central part of the island where snakes were most populous. By the late 1960's, birds had begun to decline in the central and southern parts of the island and remained abundant only in isolated patches of forest on the northern end of the island (Engbring and Fritts 1988). Snakes began affecting the birds in the north-central and extreme northern parts of the island in the 1970's, and most native forest species were virtually extinct when they were listed as threatened or endangered by the U.S. Fish and Wildlife Service in 1984.

The large numbers of brown tree snakes were able to subsist on other vertebrates (small mammals and lizards) as bird populations declined and continued to take birds when encountered even after the birds were relatively rare. The bird populations remaining on Guam after 1984 were extremely patchy in distribution, occurring only in special habitats where some protection existed from snakes. By 1986, nine species of native forest birds were extirpated from Guam, and several other native birds not limited to forests were severely affected. Four other species, including three seabirds formerly present, are now absent or extremely scarce (Engbring and Fritts 1988).

The birds remaining on Guam since 1987 are either introduced birds with some defense against snake predators (black drongos (*Dicrurus macrocercus*) and black francolins (*Francolinus francolinus*)) or are among the largest of the native birds (Mariana crow (*Corvus kubaryi*)). Two species (yellow bittern (*Ixobrychus sinensis*) and Pacific reef heron (*Egretta sacra*)) may be best equipped to defend themselves with their long bills and fighting manner.

The birds that declined first in the face of snake predation were those with small body sizes allowing most snakes to feed on eggs, nestlings, and adults whenever they were encountered. Examples of small birds that once were abundant on Guam but are now gone include the Guam flycatcher (*Myiagra freycineti*), the rufous fantail (*Rhipidura rufifrons uraniae*), the bridled white-eye (*Zosterops c. conspicillatus*), and the Micronesian honeyeater (*Myzomela rubrata saffordi*).

The Guam population of the Mariana crow has shown continuous decline in recent years and is now believed to number less than 50 individuals, with little or no successful recruitment into the adult population since 1986. Intensive efforts to protect nests in trees from snakes and monitor lizards are underway on Andersen Air Force Base at this time. The Micronesian kingfisher was once found throughout most of Guam's forests, but its population declined rapidly, and it is extirpated from the wild today. This species exists only in captive populations at several mainland zoos. The Guam rail, a small flightless bird endemic to Guam, disappeared from southern Guam in the early 1970's and from the rest of the island by the late 1980's. This species is now being bred in captivity by Guam's Department of Agriculture and at some mainland zoos for reintroduction into the wild. Approximately 60 rails were introduced on the island of Rota in the Commonwealth of the Northern Mariana Islands during 1995, and at least one chick has resulted from these efforts thus far.

At present, even small mammals are extremely rare in most forested habitats of Guam. Predation by the brown tree snake may be the primary factor preventing recruitment to the single population of native Mariana fruit bats (*Pteropus mariannus*) remaining on Guam (Wiles 1987). Despite protection from illegal hunting and human disturbance, the bat population has not expanded in recent years.

Although less information is available about lizard populations, brown tree snake predation appears to be one of several causes for the loss of lizard diversity on Guam. Of the species that have suffered declines, the brown tree snake probably had a major role in the apparent extirpation of the Micronesian gecko (*Perochirus ateles*), the virtual disappearance of the oceanic gecko (*Gehyra oceanica*), and the substantial reduction in numbers of the mutilating gecko (*Gehyra mutilata*). Brown tree snake predation also may have had a role in the disappearance of three other species, but insufficient data exist to verify that conclusion (Rodda and Fritts 1992a).

2. Electrical Problems - Brown tree snakes are commonly encountered climbing on manmade structures. Snakes climb guy wires leading to power poles supporting transformers, distribution lines, and high-voltage transmission lines. When the snakes simultaneously touch live and grounded conductors, they create faults, short circuits, and electrical damages. This has resulted in frequent losses of power to parts of the island and even islandwide blackouts. Such power failures, brownouts, and electrical surges in turn damage electrical appliances and interrupt all activities dependent on electrical power, including commerce, banking, air transportation, and medical services. Power outages caused by snakes have been a serious problem on Guam for several years, and the incidence of snake-caused outages increased fivefold from 1978 to 1982, a period of rapid snake population growth. In 1982, snakes caused a total of 84 major faults accounting for 252 hours of power outages to the electrical system operated by the U.S. Navy. Additional outages occurred on lines maintained by the Guam Power Authority, but a complete record of the outages experienced by the two agencies producing electricity on the island has not been assembled. However, records show more than 1,200 outages caused by snakes in the period of 1978-May 1994 (Fritts and Chiszar in press). Although precise cost figures are unavailable, it is conservatively estimated that power outages on Guam caused by brown tree snakes have cost millions of dollars a year, and the problem has been conspicuous since 1978.

Guam has 23 major power distribution circuits, and this compartmentalization of the electrical system reduces the chances of outages affecting the entire island or major geographic areas. However, major outages still occur. Many smaller Pacific islands have far fewer generating facilities and circuits, and if the snake becomes abundant on these islands, the damages to their electrical systems are more likely to affect the entire island or major municipal areas. Even Oahu, with a population of about 1 million, is subject to islandwide outages. One such outage caused by an electrical fire in an underground substation cost the island an estimated $20-60 million. Many Pacific islands suffer power supply problems, but the frequency and severity of the snakes on power lines in Guam would be devastating to an island with fewer alternate distribution lines and with less ability to shift to other generating facilities.

3. Snake Bite Risk and Human Fear - The brown tree snake is technically a mildly venomous snake. On several occasions in Guam, snakes have been found biting and/or coiled around infants and small children in their beds. From 1989 through 1991, 94 snakebites were reported. By June 1994 the total number of snake bites had reached 206, including dozens of cases in small children and 11 serious cases involving children under 1 year old. A high percentage (82 percent) of these victims were bitten while sleeping in their homes at night. Of these victims, 52 percent were children under the age of 5 years old. Although additional data are needed, the tendency to attack sleeping people and small children, apparently without provocation, may be related to exaggerated feeding behavior caused by reduced prey availability (Fritts *et al* 1994b).

The abundance of snakes in close proximity to people in Guam does have an effect on perceptions of the quality of life on the island. Snakes have been found in houses and commercial buildings and disrupt island residents and tourists not accustomed to living with snakes. Many people have a deep-seated fear of snakes, and the vast majority of people resent snakes inside homes, stores, and other human environments. Only the U.S. military and government expenditures surpass tourism in economic importance to Guam. Snakes startle people, and power outages frequently cut short their enjoyment of Guam's nightlife and shopping centers.

4. Other Ecological Damages Related to Brown Tree Snakes - Other long-term damages caused by the brown tree snake in Guam remain to be adequately investigated and defined. The loss of most insectivorous birds and many lizards from the island may leave Guam vulnerable to a variety of insect pests. Insects arriving on Guam in ship or air traffic are much more likely to become established and threaten agricultural crops, public health, and the island's ecology. Examples of such problems caused by insect pests include an outbreak of dengue fever carried by mosquitoes, the defoliation of extensive stands of tangantangan by an insect arriving from Hawaii, and the host of insects that reduce yields of fruits and vegetables grown by Guam's truck farmers and rural residents.

Birds and fruit bats are important in tropical forests because they naturally disperse seeds of shrubs and trees and thereby help maintain forest diversity and contribute to recovery after typhoons and other catastrophic events. Whether some trees particularly dependent on seed dispersal by birds or fruit bats will decline in abundance or disappear is unknown at present. The distribution of at least one introduced plant has changed as a result of the disappearance of birds that previously dispersed its seeds.

5. Beyond Guam - Many Pacific island ecosystems have much in common with Guam's environment. The introduction and establishment of brown tree snake populations on other islands would likely have consequences similar to those on Guam. This is particularly relevant to other islands that support unique species, have smaller power supply systems, and whose economies are largely based on tourism. Accidental transport of brown tree snakes to subtropical areas of the continental United States may result in unwanted colonizations that impact native species already at risk due to other factors, as well as affect tourism and local technical services such as electrical distribution. Recent brown tree snake feature stories in major newspapers and network television programs demonstrate the growing concern in the United States regarding the potential introduction and establishment of this snake.

IV. Objectives - As identified by the Brown Tree Snake Control Committee, the objectives of the integrated pest management strategy outlined in this Brown Tree Snake Control Plan are:

• To reduce existing brown tree snake population levels over large geographic areas on Guam.

• To prevent the spread of brown tree snakes to other Pacific islands and mainland areas.

• To eradicate or contain new populations as soon as detected.

• To develop more effective and environmentally sound control and/or eradication strategies and methods.

• To protect endangered species and other wildlife from brown tree snake predation.

• To assist organizations and individuals on Guam to manage and control brown tree snake infestations, and especially to reduce disruptions of electrical supplies and human-snake encounters resulting in emotional trauma and bites.

• To develop adequate information on the brown tree snake’s biology, dispersal dynamics, and control to support Federal, State, Territorial, and Commonwealth needs.

V. Current Brown Tree Snake Control Measures

A. Introduction - Adequate brown tree snake control measures for large areas do not currently exist. Brown tree snake control in high risk (e.g., transportation areas) and selected areas (e.g., military training grounds) is being conducted through hand capture, trap capture, dog-assisted capture, and physical barriers in buildings, around nesting trees, and on electrical equipment. Control around port areas is underway on Saipan and Guam. Implementation of control measures by government agencies, the general public, and businesses has been encouraged through public education, technical assistance, and demonstration projects. Physical and electrical barriers and modifications to discourage snake movements on electrical transmission structures have been developed but are not widely implemented. Existing techniques have achieved some success in reducing snake dispersal to new islands, reducing power outages, and protecting humans, domestic animals, and endangered species (Table 1). However, the efficacy of these tools and their benefits relative to their costs remain to be documented.

Electrical/physical barriers have been constructed around small areas of forested habitat on Guam to prevent entry of snakes and have proven to be effective in creating snakefree areas. Detector dogs are trained and used to find snakes dispersing to other islands from Guam. Toxicants, biological controls, attractants for baiting, and other technical approaches will require substantially more development; but it is these techniques that have the potential for providing long-term and cost-effective control over large areas. Efforts to protect indigenous wildlife need to be augmented as soon as possible to reduce risks of extinctions. Techniques presently under development may make it possible to contain or eradicate new (i.e., small) populations should they be discovered on other islands, but no techniques are available or foreseeable in the near future for the island-wide eradication of a well-established brown tree snake population such as occurs on Guam.

A variety of techniques is needed to implement an effective integrated pest management strategy and avoid over-reliance on any one technique. Alone, even highly effective animal control techniques are not adequate to accomplish control in all situations. A multi-technique approach for each control situation should be evaluated, while other new techniques are being explored. Several snake control techniques that could be cost effective should be investigated in various combinations with the hope that control will be achieved by using several techniques in the proper sequence and relative intensity. This will require expanding and modifying present control efforts as well as initiating new research programs to discover the appropriate combination of techniques.

An additional reason for using diverse tactics is that a given approach may impact only one segment of the snake population or only be practical under certain conditions. For example, considerable evidence from both habu (*Trimeresurus flavoviridis*, a poisonous Okinawan snake) and brown tree snake research on snake traps indicates that they are less effective for small snakes. As long as reproduction is occurring, removal of adults may only increase juvenile survivorship and create a constant supply of new adults to control. These factors appear to have hampered efforts to control the habu in Okinawa.

The risk of brown tree snakes being exported can be considered a function of the origin of the flight or shipment, the type and history of the cargo and craft, and inspection or treatment of cargo and craft immediately before loading and leaving. A wide array of under-utilized techniques are available now or will soon be available for eliminating the brown tree snake from traffic leaving Guam. To date, the main obstacles to the implementation of these techniques have been a lack of clear jurisdictional responsibility among governments and agencies, a misgauging of the complexity and magnitude of the problem by the public and government, and the difficulty for governments to commit the large amount of funds over the time necessary to deal with current control demands and with additional problems in the future (i.e., new infestations).

Table 1. Techniques for brown tree snake control

Technique	In Use	Requires Expansion	Available Soon	Requires Further R&D

Public Education	**x**	**x**		**x**
Physical/Electrical Barriers				
For Bldg Interiors	x	x		
For Trees	x	x		x
For Power Poles	x	x		x
For Forested Areas	x	x		x
For Urban Areas			x	x
Capture				
Hand/Visual	x	x		
Traps & Bait	x	x		x
Dog Assisted	x	x		x
Habitat Alterations				
Illumination			x	x
Prey Reduction	x		x	x
Structural Habitat Alteration	x	x		x
Chemical Control				
Fumigants	x	x	x	x
Toxicants				x
Phermone/Attractant Assisted				x
Repellents				x
Biological Control				
Pathogens/Parasites				x
Fertility Control				x

No one has ever eradicated an incipient snake colony. Actions now being taken to eradicate the brown tree snake on Saipan and prevent its establishment are unprecedented. Even if it is not possible to eradicate the snake, it may be practical to depress the snake population to a level where native wildlife are not extirpated, or to slow any outbreak to gain time to develop strategic techniques applicable to islandwide control. New tools and technologies are needed to enhance the chances of successful eradication.

To assist in tracking an infestation and estimating brown tree snake population size, public education may be used to enlist a large number of observers for snake detection. Snake traps are among the most effective detection tools, but visual searches and an alert citizenry may be needed to focus efforts. Dogs have been used to locate many vertebrates and to capture some arboreal reptiles, but to date dogs have been trained to locate brown tree snakes only in and around buildings and other man-made structures and in cargo. The utility and efficacy of dogs in detecting snakes in the transportation system should be verified and expanded as necessary to adequately reduce dispersal to islands where the scope of damages would be enormous.

The task of eradicating a newly established brown tree snake population is a daunting one, probably requiring large expenditures of funds, vast numbers of traps, many snake searchers, and specific chemical tools such as toxicants. Although eradication of the well-established brown tree snake population on Guam is not likely, significant population reduction and control through technologies not currently available, such as biological control with pathogens or fertility control, may be possible. It is clear that the cost of preventing dispersal of brown tree snakes will be far less than comparable costs for controlling any well-established infestation on other islands. Early detection and effective response to new infestations are critical to the potential eradication of new infestations.

B. Past and Current Control Operations

1. Department of the Interior - Office of Insular Affairs (formerly the Office of Territorial and International Affairs) - On the basis of preliminary data and assessments by U.S. Fish and Wildlife Service research biologists of the damages caused by the brown tree snake on Guam, the Office of Territorial and International Affairs provided technical assistance funding to the Fish and Wildlife Service research program to conduct biological studies of the snake and to develop methods to control snakes and reduce damages caused by them. Studies in Fiscal Year 1987 on ways to protect Guam's electrical system from snakes were expanded during Fiscal Years 1988 and 1989 to include assessment of population levels of snakes, design of traps, and assembly of relevant biological data. A 5-year plan prepared in cooperation with the Department of the Interior, Fish and Wildlife Service, Department of Defense, and Government of Guam resulted in Congressional appropriations of $1 million in Fiscal Year 1990 to fund work during Fiscal Years 1990 and 1991. Funding facilitated preliminary snake control work by Guam's Department of Agriculture and research on trapping, attractants, snakebite risks, climbing behavior, and the biology of the brown tree snake by Fish and Wildlife Service/National Biological Service researchers.

From Fiscal Years 1992 through 1995, Territorial and International Affairs received $596,000 annually for brown tree snake control work and divided it equally between the State of Hawaii for detector dogs; the Government of Guam for preliminary snake control; and the Fish and Wildlife Service/National Biological Service for research on control techniques and biology.

The Office of Territorial and International Affairs became the Office of Insular Affairs during Fiscal Year 1996. The Department of the Interior's Fiscal Year 1996 appropriations bill (approved as part of the Omnibus Appropriations bill on April 26, 1996) also included $596,000 for brown tree snake control work.

2. Legacy Program - The Department of Defense's Legacy Program has provided funding for projects to enhance the stewardship of the Department's air, land, and water resources and to protect biological systems, species biodiversity, and cultural resources. This Department of Defense funding has supported research by the U.S. Fish and Wildlife Service and the National Biological Service to develop baiting, trapping, and exclusion technologies for the brown tree snake. Major goals of the research were to demonstrate the feasibility of snake-free plots in forested areas on Guam to restore suitable habitat for native birds, and to reestablish breeding bird populations destroyed by the brown tree snake.

A key element in establishing control of brown tree snake populations involves the use of barriers to prevent snakes from reinvading areas from which they have been removed. Areas made snakefree by a combination of hand capture and trapping can be maintained snakefree by using barriers that prevent snakes from entering the management plots. Efficiency and size of the plots can be increased substantially by taking advantage of natural emigration over a special barrier fence (allowing snakes to leave but not return to the area).

Research results from the efforts of the National Biological Service work to date are encouraging; snakefree areas were produced using available technology one re-entry was prevented by using a suitable electrified snake barrier. A need exists to increase the size of demonstration plots from 2 hectare to 5-10 hectare demonstration plots, and finally to larger areas suitable for maintaining endangered species or applicable to protecting generating facilities, electrical substations, and transportation facilities (ports, airports, and cargo-handling areas). Concerted tests have been completed to demonstrate the efficiency and efficacy of new types of permanent barriers (resistant to wildlife, typhoons, and industrial applications) using both active and passive removal strategies.

A variety of barrier designs and applications are envisioned to allow retrofit of existing perimeter fences, construction of special refuges for endangered birds and protection of other high priority areas, and use of temporary barriers for military exercises and other special situations where risk is for a temporary period only. Although this work is still in progress, the techniques being used are directly applicable for efficiently creating and maintaining snakefree zones in other areas besides forested areas, such as ports and airports. The results suggest that the problems encountered in maintaining snakefree exclosures change with the size of the area; that is, maintaining the leakproof boundary becomes more difficult for larger areas. More than 50 percent of all research activities on the brown tree snake by the National Biological Service have been funded through the Legacy Program, but demonstration and initial application of barrier technologies to management situations will undoubtedly depend upon financial support from other Defense branches as well as a variety of other governmental and user organizations. This work also provides valuable data on snake population dynamics, movements, trapping technology, and the status of the animal populations on which the snakes prey.

The Legacy Program also funded preliminary laboratory investigations in Fiscal Years 1992 and 1993 by the National Zoological Park on the potential of selected viruses to control the brown tree snake. During Fiscal Year 1994, the Legacy Program provided funding to the U.S. Department of Agriculture, Animal Damage Control's Denver Wildlife Research Center to begin development of chemical methods for brown tree snake control. During Fiscal Year 1995, the Denver Wildlife Research Center completed evaluations of three fumigants currently registered for other uses with the Environmental Protection Agency, screened twelve potential toxicants, and developed and validated methods to analyze them relative to eventual field evaluations. Department of Defense-funded research in Fiscal Year 1996 will continue developing chemical methods for brown tree snake control management, primarily through conducting field evaluations of attractants, oral and dermal toxicants, and artificial baits and potential delivery systems; and activity patterns using radio telemetry relative to implementing a baiting strategy. In addition, Center chemists will begin development of analytical techniques necessary for eventual toxicant use.

After Fiscal Year 1996, it appears the Legacy Program will no longer exist, and other programs may need to substitute for the services and funding delivered by this program.

3. Military Brown Tree Snake Control Program - The Military Brown Tree Snake Control Program was initiated in 1988 in concert with the U.S. Fish and Wildlife Service and Guam Department of Agriculture to provide technical training to reduce the risks of snakes leaving Guam in military traffic. Since 1993, the Department of Defense joined forces with the U.S. Department of Agriculture's Animal Damage Control to combat exportation of brown tree snakes from Guam.

The Department of Defense provides funding and the infrastructure from which Animal Damage Control personnel carry out inspections, training, brown tree snake trapping, habitat modification, prey reduction, detector dog handling, and barrier construction. All brown tree snake control activities are now performed by Animal Damage Control personnel and Andersen Air Force Base Traffic Management Office Quality Control Inspectors.

The purpose of inspections is to detect snakes in military traffic prior to leaving Guam. Normal military inspections involve passengers, accompanied luggage, personal property (household goods, privately owned vehicles, and unaccompanied baggage), Department of Defense owned and leased ships, aircraft and crews, and Department of Defense cargo shipped from or transitting through Guam. Inspectors are given training on snake behavior and are directed to search for the snake while clearing outbound cargo containers, pallets, vehicles, and aircraft. Particular emphasis is placed on inspection of confined spaces favored by the snake as day hiding refugia (e.g., aircraft wheelwells, undercarriages of vehicles, and compartments). Snakes that are encountered in cargo areas and on perimeter fences are removed and killed.

The Military Brown Tree Snake Control Program for Guam covers various military installations on Guam, including the major installations. Five of seven brown tree snakes found in Oahu to date were associated with military aircraft or on military facilities; one was found on a taxiway shared by military and civilian aircraft and one was in the

Customs Area of Honolulu International Airport. A live brown tree snake arrived in Texas in a military household goods shipment from Guam.

Components of the U.S. Pacific Command are constantly reminded of the seriousness of Guam's brown tree snake problems, and inspectors are advised to closely scrutinize conveyances and cargoes arriving from Guam. Cargo handlers and aircraft ground crews in Hawaii have been sensitized to the requirement for an intensive post- operational check of Guam-arriving vessels and aircraft and routinely conduct visual examination of these conveyances, with particular attention to wheelwells or confined spaces.

4. Animal Damage Control Brown Tree Snake Control Program - The Animal Damage Control Program, a unit of the Animal and Plant Health Inspection Service within the U.S. Department of Agriculture, began a brown tree snake control program in April 1993 under a cooperative agreement with the Government of Guam’s Department of Agriculture. The objective of the control program is to focus on reducing the risk of snake dispersal via commercial shipments from Guam’s Won Pat International Airport and Apra Commercial Harbor.

In Fiscal Years 1993 through 1996, the Department of Defense received $1 million annually in appropriations from Congress to establish a model brown tree snake control program that had the potential for use by other state, territorial, and local governments. The Department of Defense has used the services of the U.S. Department of Agriculture’s Animal Damage Control for animal control programs through an established Memorandum of Understanding.

The Department of Defense developed an integrated brown tree snake program with Animal Damage Control. The overall goals of the control program are:

• To manage and implement an operational control program on Guam to prevent the dispersal of brown tree snakes via military material, aircraft, and vessels to Pacific islands and the U.S. mainland. Operations are being implemented at Department of Defense transportation sites and Department of Defense/civilian joint-use transportation sites on Guam;

• To provide training and snake control supplies to Emergency Snake Control Teams in Hawaii and the Commonwealth of the Northern Mariana Islands (CNMI);

• To provide personnel upon request to monitor Department of Defense training sites on Saipan and Tinian during Department of Defense exercises; and

• To assist military inspectors in searching vehicles, equipment, and supplies for brown tree snakes prior to shipment to CNMI during Department of Defense training exercises.

The Animal Damage Control work plan recommends expanding the brown tree snake cooperative control program on Guam to include high risk dispersal areas within military and military/civilian joint use transportation sites. These sites include the military and civilian airports and seaports. To accomplish this, Animal Damage Control has established a District Office on Guam to aggressively pursue control of the brown tree snake. Assistance will also be provided to the following locations in Hawaii: Hickam Air Force Base, Naval Air Station Barbers Point, Naval Station Pearl Harbor, and the Pacific Missile Range Facility.

Animal Damage Control will also provide material and training assistance to the Hawaii Department of Agriculture and the Hawaii Department of Land and Natural Resources to implement a brown tree snake contingency plan on and adjacent to military installations in Hawaii. Both state agencies currently provide brown tree snake detection and control assistance to the military in Hawaii.

On Guam, controlling brown tree snakes within high risk transportation sites will be an ongoing activity unless the island-wide population of brown tree snakes is lowered sufficiently to make the probability of dispersal close to nil. Differential rates of snake removal from within high risk areas and areas adjacent to such sites will determine the efficacy of any control program. Training of Emergency Snake Control Teams and developing an awareness among personnel throughout the Pacific and at Department of Defense installations worldwide is an important component in a broad program to monitor and assure the success of the containment program.

5. Military Exercises and Snake Control - Military exercises involve the use of fixed-wing aircraft and helicopters for transport to airfields or tactical landing zones, parachuting into drop zones, boats to beaches or swimming to beaches across the reef, and amphibious assault vehicles or air cushion landing craft to beaches. Regular military training occurs on Tinian Island in the Commonwealth of the Northern Mariana Islands (CNMI), 100 miles north-northeast of Guam. The U.S. military leases approximately 18,000 acres of Tinian for training purposes. Supplies and equipment to support exercises are shipped from Andersen Air Force Base and/or port facilities on Guam.

The potential for brown tree snake introduction is a concern for CNMI governmental agencies, the Commander of U.S. Naval Forces Marianas, and to exercise planners. The CNMI Division of Fish and Wildlife, Department of Lands and Natural Resources, and the CNMI Coastal Zone Manager require brown tree snake surveillance using baited snake traps as established by Coastal Zone Consistency Determination requirements. Military inspectors and Animal Damage Control personnel search for brown tree snakes on transportation, equipment, and supplies used during exercises. Exercise planners include, within operational plans, procedures to be followed for brown tree snake inspection and control.

The limitations of snake exclusion efforts must be acknowledged. In some cases, personnel are routed from the U.S. mainland to Tinian before going to Guam to reduce risks of snakes being transported in equipment, supplies, and vehicles.

6. Snake Control Associated with Other Wildlife Programs on Guam - The Natural Resource program at Andersen Air Force Base purchased electrical and solar powered barrier equipment used for brown tree snake control in support of Guam Department of Agriculture efforts to protect active Mariana crow nests. The objective of the effort is to prevent snakes from climbing tree trunks during nesting seasons using electric barriers wrapped around tree trunks. Despite these efforts, snakes have continued to gain access to these trees, nests have been lost, and crow populations are at precariously low levels. Since the early 1980s, only four young are known to have fledged successfully, and the crow population is now composed of mostly older adults. However, it is believed that these devices have helped to protect some Mariana crow nests from snake predation.

Guam's Department of Agriculture monitors bird and bat populations including but not restricted to: Mariana crows, island swiftlets, common moorhens, Micronesian starlings, various introduced bird species, and Mariana fruit bats. Snake control is attempted with tree barriers, habitat modification, and removal of snakes by hand when practical. The Department has also provided logistic support for snake control through access to laboratories, cages, storage facilities, and a mouse colony for trap baits. Department staff participate in various control planning and projects through cooperative involvement.

A wild game exclosure constructed by Andersen Air Force Base at Northwest Field to keep out pigs and deer may be suitable for a pilot project to exclude snakes from 60 acres of forested habitat. Test projects are planned to meet the goals and objectives of the U.S. Fish and Wildlife Service’s Native Forest Birds and Endangered Mariana Fruit Bat Recovery Plans.

Natural resource management plans exist for each Naval installation on Guam. Comparable planning exists for Air Force installations. The plans are comprehensive and support not only the natural resources program but also the pest management and the military’s brown tree snake control programs. Pest management control efforts have been limited to responses to complaints to remove snakes from homes, yard areas, and industrial sites.

The Guam National Wildlife Refuge was established in 1993 to protect Guam’s threatened and endangered species and their habitat, as well as its native forests and cultural resources. The Refuge hosts much of the brown tree snake field work being conducted by the National Biological Service and offers an excellent field worksite for brown tree snake control efforts.

7. Commonwealth of the Northern Mariana Islands Control Activities - In May 1991, CNMI launched a concerted attack against the brown tree snake through the establishment of the Brown Tree Snake Control and Interdiction Program. Funding for the program came from the Department of the Interior's Office of Territorial and International Affairs.

The purposes of the program are to prevent any further introductions of snakes into CNMI and to eradicate brown tree snakes that have already been introduced to prevent their establishment as residents of the islands. The specific objectives include:

• To prevent brown tree snakes from becoming established on Mariana Islands;

• To eradicate or contain new brown tree snake populations already established before numbers are too high to control;

• To protect endangered species and other wildlife from brown tree snake predation; and

• To develop more effective and environmentally sound control strategies and methods.

By placing snake detection devices (traps) around cargo and commercial port facilities (areas considered high risk for snake introduction), snakes passing through these areas may be lured into the detection devices. Trapping efforts and visual searches at night are conducted at all sites where snake sightings occur. To date, sightings and control efforts have centered around areas of the seaport, airport, and village of Tanapag. Other sites have had less consistent sightings and consequently have received less attention due to limitations of personnel and materials. Major problems have been maintaining an adequate number of traps and a constant source of bait, trap vandalism and theft, and personnel limitations to monitor traps, conduct nocturnal searches, and interview residents reporting snakes.

Once introduced on an island, the snakes disperse in search of food and adequate habitat. Traps are positioned in areas within the vicinity of where snakes have been sighted or near high-risk areas of suitable brown tree snake habitat. The snake trapping program is not a foolproof method against snake introductions, but when carried out in conjunction with night searches, it presents the best available means of intercepting a snake.

Although living snakes have been documented by hand capture and dead snakes have been found, no snakes have been captured by traps in CNMI. This does not, however, demonstrate that there are no snakes present, but instead reflects (1) modest levels of trapping effort relative to the size of the island; (2) problems of fabricating and deploying traps that function properly and are consistently baited; (3) the need for protecting traps from rats, vandalism, and theft; and (4) relative probabilities of trapping individual invaders and detecting very low population density through trapping. Snake traps can work in prey-rich environments, but the levels of control over every aspect of the trapping program must be increased to overcome problems of catching snakes from a small, well fed population scattered over large, heavily vegetated areas.

An effective education tool for members of the CNMI snake control team is to make frequent visits to Guam for establishing and reinforcing visual images of the brown tree snake, improving abilities to capture and handle snakes, and to communicate with research and operational personnel on details of search and trapping techniques. Periodic visits to CNMI by snake experts also facilitate communication of new strategies, identification of problems, and transfer of equipment.

The Division also is developing an enhanced brown tree snake control plan for Saipan, including such potential activities as quarantining and/or fumigating high-risk cargo, intensifying inspections, and erecting snake barriers at cargo ports. The eventual establishment of the snake on Saipan presents a greater peril to birds that are already threatened, and enhanced control efforts are necessary to ensure the continued survival of certain species.

8. Quarantine Activities (State of Hawaii and U.S. Department of Agriculture) - At this time, methods to assure the absence of brown tree snakes on aircraft or cargo do not exist. The best potential screening/inspection method identified to date is the use of well-trained snake-detection dogs and handlers.

The Hawaii Department of Agriculture's Brown Tree Snake Inspection Program has been entirely funded by the U.S. Department of the Interior's Office of Territorial and International Affairs (now Office of Insular Affairs). The program uses trained dog teams to inspect for hitchhiking brown tree snakes in incoming military and civilian aircraft and ships arriving from Guam. The program started with four dog teams, each comprised of one dog and one plant quarantine inspector/handler. Due to the medical retirement of two dogs, two dog teams currently operate, using beagles cross-trained to detect plants and animals. Two replacement dog teams are presently undergoing training.

Currently, daily commercial flights arrive from Guam at Honolulu International Airport. The teams inspect the wheelwells and gear assembly after the plane has docked and the engines are shutdown. Unloaded cargo is inspected as it is broken down. Aircraft cargo holds are not inspected because of insufficient time between unloading and loading operations. Military flights do not follow a set schedule, but typically arrive in Hawaii at a rate of two to eight flights per week. In one year, 389 military flights arrived in Hawaii from Guam, resulting in 1,400 tons of cargo being offloaded at Hickam Air Force Base. The dog teams inspect the undercarriage of the aircraft and cargo as they do for civilian flights. After cargo is unloaded, the team may inspect the interior of the aircraft and any unloaded cargo, but the potential hazards of such inspections limit their frequency.

No routine, direct commercial maritime shipping occurs from Guam to Hawaii, though it may on a contractual basis. Such shipments are difficult to monitor and inspections of cargo is intermittent. Military maritime vessels are not inspected, but their cargo is examined occasionally.

Five to eight dogs selected and trained through cooperation between Plant Protection and Quarantine and Animal Damage Control under contract with the U.S. Department of Defense and Guam are being used in Guam in transportation situations. Currently, limited inspection of civilian cargo, aircraft, or ships leaving Guam occurs. Additional dogs could be trained for detection to reduce risk posed by brown tree snakes at other ports. Special needs exist in CNMI where the risk is high and snakes may already be present in small numbers. The elimination of other future dispersal could be critical to preventing a major infestation throughout CNMI.

A potential problem exists in maintaining the training of dogs and verification of performance on Oahu, the CNMI, and other islands where no brown tree snakes are available as training aids. Use of surrogate snake species, use of snakes that have been recently handled by humans, and limitation of training to atypical search situations are potential weaknesses of dog programs that lack access to brown tree snakes for training. A need exists for training and certification exercises using live snakes or odor extracts from the brown tree snake.

The Plant Protection and Quarantine unit of the U.S. Department of Agriculture's Animal and Plant Health Inspection Service inspects international flights into the United States to reduce the risk of introduction of exotic animal or plant pests and diseases. Plant Protection and Quarantine personnel inspect foreign flights into Hawaii, though not all flights on a routine basis and not necessarily for snakes. If passengers declare that they are carrying any plant or animal products, Plant Protection and Quarantine inspects those products on flights from Hawaii to the mainland United States. Inspections of all high-risk flights from Guam to Hawaii would substantially increase the inspection workload. Plant Protection and Quarantine inspectors in Hawaii have viewed videotapes on brown tree snakes and are aware of the risk that brown tree snakes pose to Hawaii. If any snakes are found during their inspections, the snakes would be contained.

A Hawaii brown tree snake response protocol has been developed that provides graphic information assigning responsibilities to agencies and providing telephone numbers to contact in the case of a snake sighting within the State. The protocol has been distributed to many interested governmental agencies and private entities throughout the State for reference and implementation.

9. Multi-Agency Memorandum of Agreement - Under a 1993 Memorandum of Agreement, the Department of the Interior, Department of Defense, Department of Agriculture, State of Hawaii, and Territory of Guam agreed to coordinate brown tree snake programs, funding, and control research. The Commonwealth of the Northern Mariana Islands also became a signatory on the Agreement on May 24, 1996. The Memorandum of Agreement provides ongoing coordination and an annual meeting of participating agencies. As the purposes of the Brown Tree Snake Control Committee formed under the Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 and the Memorandum of Agreement working group are similar, the meetings of the groups are often held concurrently.

10. Public/Private Partnerships for Brown Tree Snake Control - Not only governmental agencies are working to prevent the spread of the brown tree snake beyond Guam. Two public/private partnerships have been very active in Hawaii for several years. The Brown Tree Snake Control Group was founded in 1990 by former Honolulu Zoo Director Paul Breese to help prevent the establishment of this snake in Hawaii. The group has worked effectively in helping with the development of programs and securing funds for brown tree snake control measures through the Hawaii Congressional delegation. Supported by a grant from the Hawaiian Electric Company, the Brown Tree Snake Control Group met with officials on Guam and developed recommendations for improving inspections and control procedures and for initiating additional techniques for detecting these snakes.

In 1994, more than 80 professionals from government, nonprofit, and private agencies, organizations, and businesses collaborated to produce the Alien Species Action Plan, a strategy to strengthen Hawaii’s protection against nonnative pests. A 1992 report prepared by The Nature Conservancy of Hawaii and the Natural Resources Defense Council, *The Alien Pest Species Invasion in Hawaii: Background Study and Recommendations for Interagency Planning*, provided a starting point for plan development. The plan called for the establishment of a Coordinating Group on Alien Pest Species (CGAPS) to implement the action plan. Although not focused specifically on brown tree snake control, the group has incorporated significant information about this species into its activities. A major public awareness campaign is being developed and is scheduled to be launched during August 1996.

VI. Proposed Integrated Brown Tree Snake Control Plan - The complexity of problems posed by the brown tree snake in Guam together with the significant history of dispersal from Guam to other destinations in military and civilian traffic justifies a focused integrated control effort comprised of six major task areas. This integrated approach includes ongoing operational programs, applied research, and public outreach. These tasks will entail use of a wide range of tools and strategies, most of which will require development, enhancement, and verification to meet the needs of this program. A comprehensive research program will be necessary to develop and refine the tools and techniques upon which the individual program tasks and operational strategies will be based. The program outlined below enumerates the primary tasks, tools and techniques, and the research elements inherent in implementation of the control program for this insidious pest species.

A. Synopses of Tasks - In the following compilation, the basic tasks of the Brown Tree Snake Control Program are described and annotated with related tools and techniques, as well as research needs. Numbers and letters are from the following sections of the Control Plan (pages 30-31), and agency acronyms are defined on page 29.

1. Reduce brown tree snake populations over large geographic areas on Guam - Reducing brown tree snake populations throughout Guam is a primary task that contributes to lowering the risk of its dispersal to other islands and countries, protecting endangered and other native species, and reducing electrical power outages and negative snake-human encounters. Existing control techniques are not applicable over broad landscapes or geographic areas. While this task is ambitious, new and innovative techniques are needed for broadscale population reduction across the island of Guam, as well as on other islands where populations become established. Biological control strategies such as toxicants, parasites and diseases, reproductive inhibition, and manipulation of prey bases offer potential for development to address such large-scale population control.

Operational Groups: GDA; Cooperators, Tools and Techniques: 9-12, Research Support: NBS; Cooperators, Research Needs: a-w

2. Eliminate snakes from the transportation network - An ongoing effort to control dispersal from Guam is under way. This is the highest operational priority and must be continued even as better techniques are being sought. The basic premise of this task is to reduce the dispersal of snakes in ship and air traffic from Guam to other geographic areas where the snake could become established. It involves a major commitment from a number of territorial and federal military and civilian agencies and may be the single most costly objective to carry out. Inherent in the task are: (a) delineating the high risk sites and activities within civilian and military transportation terminals; (b) eliminating brown tree snakes within high risk sites and from high risk activities; (c) reducing the attractiveness of high risk sites to snakes by eliminating the snake's prey and habitat; (d) preventing the immigration or slowing the movement of snakes into high risk sites by erecting barriers; (e) inspecting all materiel entering high risk sites from other parts of Guam; (f) inspecting aircraft, ships, and materiel leaving Guam; and (g) intercepting all snakes that elude the above efforts prior to their escape into new geographic areas. All potential avenues for snake dispersal should be identified and evaluated, including mail shipments, household freight, inter-island tours, post-typhoon clean up and assistance efforts, etc. Technologies are available to implement snake and prey control at transportation terminals and to perform the inspections of carriers and cargo.

Operational Groups: ADC; DOD; GDA; HI-AG; CNMI-DFW, Tools and Techniques: 1-15, Research Support: NBS; ADC-DWRC; Cooperators, Research Needs: a-w

3. Eradicate snakes in recently established populations - Acknowledging that much evidence points to an incipient population already on Saipan in the Northern Marianas and the possibility that past and future dispersal of snakes to other islands and mainland situations may result in the establishment of new brown tree snake populations, a comprehensive strategy and appropriate tools are needed to immediately eradicate such populations before they become immutably established as has occurred in Guam. Early detection and response with adequate technological capabilities will be critical to the success of any eradication efforts in new areas.

Operational Groups: ADC; HI-AG; HI-DLNR; CNMI-DFW, Tools and Techniques: 1-15, Research Support: NBS; ADC-DWRC; Cooperators, Research Needs: a-w

4. Control snakes to reduce predation on endangered species and other native animals - The reduction of snake populations in habitats occupied now or in the future by endangered species and other native fauna is desirable, but must be attempted on a scale appropriate to the technology available. Removal of snakes from forested habitats is possible if repeated invasions are prevented with barriers. Preliminary barriers have been effective, but increasing resistance to typhoon and rat damage and lowering construction and maintenance costs to allow construction of barriers of suitable size are important goals. Development of new technologies applicable to snake population control over large areas are an important need to effectively accomplish this task.

Operational Groups: FWS; ADC; DOD; GDA, Tools and Techniques: 1-5, 7, 9-15, Research Support: NBS; ADC-DWRC; GDA; Cooperators, Research Needs: a-f, i-j, l-w

5. Control snakes to reduce human contacts resulting in snakebites and emotional trauma - The high densities of snakes in many areas of Guam with extremely limited prey resources have resulted in frequent invasions of homes and workplaces by snakes in search of food and hiding places. In addition to lowering densities of snakes on Guam islandwide, control of human-snake encounters will involve focused trapping efforts in urban and suburban settings, removal of stimuli prompting snakes to enter or live near homes, and concerted efforts to snake-proof houses.

Operational Groups: GDA; ADC, Tools and Techniques: 1-8, 10-14, Research Support: NBS; ADC-DWRC; GDA; Cooperators, Research Needs: a-j, l-w

6. Control snakes to reduce electrical outages and damage to equipment - The use of barriers deployed on guy wires and around electrical substations vulnerable to snake-caused power outages is a primary technique for preventing snakes from coming in contact with electrical conductors. Electrical links of 220V in guy wires, concave barriers on guy wires, and snake-fences around substations have all proven beneficial, but have not been used on a systemwide basis due to cost and maintenance considerations. The redesign and location of electrical lines and facilities to habitats less attractive and suitable to snakes should be considered in future modifications of the electrical system in Guam. Other techniques for controlling snakes to reduce electrical outages should be investigated

Operational Groups: GPA; GTA; GDA; ADC, Tools and Techniques: 3-7, 13-15, Research Support: NBS; ADC-DWRC; Cooperators, Research Needs: a, b, f, h, j, l-w

7. Provide information and educational materials to the public, government agencies, and commerce to reduce risks of ecological and economic damages due to the establishment of brown tree snakes - The efforts of agencies involved in snake control and exclusion can be greatly augmented through involved vigilance and active participation of residents of the geographic areas threatened. Similarly, cooperating agencies can increase their efficacy and avoid unnecessary duplication of efforts through the sharing of information and coordination of activities. These agencies also recognize and support the efforts of public/private entities involved in alien species control and public awareness, such as the Brown Tree Snake Control Group and the Coordinating Group on Alien Pest Species. Comprehensive education and information transfer programs are important to the success of the complex array of tasks inherent in dealing with brown tree snakes in all regions.

Operational Groups: FWS; NBS; OIA; ADC ; GDA; HI-DLNR & AG; CNMI-DFW, Tools and Techniques: 13-15 , Research Support: to be determined, Research Needs: to be determined

8. Provide for the prompt and continuous evaluation of the effectiveness and viability of control actions, including both operational and research facets of the program, as well as a periodic review and updating of the Brown Tree Snake Control Plan - Due to the importance of brown tree snake control to a number of island governments and even to the continental United States, and to the costs involved in implementing the program, the effectiveness of ongoing control actions must be continuously evaluated. Such evaluations may occur through a variety of venues, including through project implementers and agencies, the annual meeting of participating agencies in the brown tree snake Memorandum of Agreement, and through continuing meetings of the Brown Tree Snake Control Committee. The latter committee is responsible for reviewing and, if necessary, updating this Brown Tree Snake Control Plan on an annual basis in calendar years 1997 and 1998, and at least on a biennial basis thereafter.

Operational Groups: ADC; ADC-DWRC; CNMI-DFW; DOD; FWS; GDA; HI-DLNR & AG; NBS; OIA

Agency Acronyms:

ADC Animal Damage Control, Animal/Plant Health Inspection Service (APHIS), U.S. Dept of Ag.

ADC-DWRC Denver Wildlife Research Center, ADC, APHIS, U.S. Dept of Ag.

CNMI-DFW Commonwealth of Northern Marianas, Division of Fish and Wildlife

DOD Department of Defense

FWS U.S. Fish and Wildlife Service, U.S. Department of the Interior

GPA Guam Power Authority

GTA Guam Telephone Authority

GDA Guam Department of Agriculture

HI-AG Hawaii Department of Agriculture

HI-DLNR Hawaii Department of Land and Natural Resources

NBS National Biological Service

OIA Office of Insular Affairs, U.S. Department of the Interior

B. Existing and Proposed Snake Control Tools and Techniques

<u>Control of Individual Snakes and Localized Snake Populations</u>

1. Interception of snakes using canine detection

2. Hand capture of snakes

3. Trapping

4. Fumigation

5. Barriers, including chemical repellents, to exclude snakes from critical areas, reduce movements between habitat patches, and contain snakes if they are introduced to new areas

6. Lighting to repel snakes and to facilitate their detection

7. Habitat modification to reduce daytime refugia and increase detection of invading snakes

8. Habitat modification to discourage prey species that attract snakes and cause snakes to remain in or around transportation areas

9. Manipulations of the prey base (especially nonnative species) as appropriate

10. Toxicants and attractants

<u>Control Over Large Areas</u>[5]

11. Parasites and diseases (biological control)

12. Reproductive inhibition/genetic control/fertility control

13. Monitoring of snake populations and dispersal events to provide guidance to other control efforts

<u>Public Outreach</u>

14. Production and dissemination of public educational materials for general audiences, including radio, television, and printed media and for front-line entities

15. Dissemination of technical information to all concerned governments and agencies in the form of publications, reports, bulletins, and synoptic overviews

C. Research Needs - (See Appendix B for descriptions of each research activity)

1. <u>Basic Control Technology</u>

a. Trap enhancement

b. Attractant identification/verification

c. Bait for toxicant delivery

d. Toxic bait delivery station

e. Toxicant screening/testing/registration

f. Repellent identification/verification

g. Fumigants development/registration

h. Lighting as a repellent

i. Detection/eradication of low-density populations

j. Barrier development

k. Canine detection verification/training aids

l. Integrated control plan development

2. Basic Snake Biology in Support of Control

m. Population dynamics/monitoring

n. Behavior

o. Reproduction — ecology/seasonality

p. Sensory perception/visual acuity

q. Genetic variation/founding population

r. Diet/foraging/movements

s. Climatic variation - survival/recruitment

t. Habitat use

u. Human health/safety

3. Biological Control Technology

v. Parasites, disease, and other infectious agents

w. Reproductive inhibition/genetic control/fertility control

VII. Integrated Brown Tree Snake Control Funding Needs - The funding for brown tree snake research and control measures that was available in past years may not be an accurate reflection of what will be needed for funding in the future. Also clear is the fact that the millions of dollars in costs attributed to the brown tree snake infestation (power loss and damages/claims, military training and readiness impacts, medical costs, direct and indirect agricultural industry losses, loss of pets, wildlife losses, ecotourism opportunity losses, and costs to commerce) greatly exceed the estimated cost per year of carrying out this plan.

This integrated pest management plan must include both operational programs and applied research and development. The purpose of this section is to display those high priority tasks needed for the integrated brown tree snake control program, along with funding requirements over a 5-year period. Some tasks defined in this plan will be implemented immediately upon approval of the plan or are already underway. However, many tasks cannot be implemented until new funding is made available.

A. Operational Program Needs

Element	**Cost/Year (In Thousands)**				
	Year 1	Year 2	Year 3	Year 4	Year 5
Task 1: Reduce BTS populations over large geographic areas [Funding reflects existing efforts only; new estimates will be developed as technology improves]	$175	$175	$175	$175	$175
Task 2: Eliminate snakes from transportation network • Inspections • Origin (Guam) • Destinations (Hawaii, CNMI)	$1,600	$1,600	$1,600	$1,600	$1,600
Task 3: Eradicate snakes in recently established populations • Establish surveillance system • Establish office to receive calls • Develop standby response capabilities	$200	$200	$200	$200	$200
Task 4: Control snakes to reduce predation on T&E species • Establish snake-free areas	$250	$300	$350	$350	$350
Task 5: Reduce human contacts to prevent snake bites/emotional trauma • Education • Technical assistance	$60	$50	$50	$50	$50

Task 6: Reduce electrical outages & equipment damages • Responsibility of Guam Power Authority	--	--	--	--	--
Task 7: Education and Outreach • Support Hawaii's Coordinating Group on Alien Pest Species in its public awareness campaign • Support other information and education efforts in the western Pacific, perhaps through SPREP	$100	$100	$100	$100	$100
Task 8: Evaluation of the effectiveness and viability of control actions • Conduct annual/biennial reviews of Brown Tree Snake Control Plan implementation; status and effectiveness of ongoing control activities	$50	$55	$55	$60	$60
Totals for Operational Control	$2,435	$2,480	$2,530	$2,535	$2,535

B. Brown Tree Snake Research Needs - Significant progress has been made on the research and development of several control tools and technologies applicable to addressing control of the BTS, but additional work is needed on some elements for broadscale application in operational programs, and work must be initiated for development of other control tools. Thus, research funding needs for some categories decline rapidly as techniques become available, and funding needs increase for other categories after 1-3 years at modest levels.

Basic Control Technology	**Cost/Year (In Thousands)**				
	Year 1	Year 2	Year 3	Year 4	Year 5
• Trap development	$150	$150	--	--	--
• Attractant identification/verification	$100	$200	$100	--	--
• Bait for toxicant delivery	$200	$200	$200	--	--
• Toxic bait delivery station	$30	$30	--	--	--
• Toxicant screening/testing/registration	$130	$239	$273	$257	$400
• Repellent identification/verification	--	$20	$20	$20	$20
• Fumigants development/registration	--	$20	$20	--	--
• Lighting as a repellent	$75	$75	--	--	--
• Detection/eradication of low-density populations	$125	$125	--	--	--
• Barrier development	$150	$150	$150	--	--
• Canine detection verification/training aids	$75	$75	--	--	--
• Integrated control plan development	$80	$80	--	--	--
Subtotals	**$1,115**	**$1,364**	**$763**	**$277**	**$420**

Basic Snake Biology in Support of Control	**Cost/Year (In Thousands)**

	Year 1	Year 2	Year 3	Year 4	Year 5
• Population dynamics & monitoring	$50	$50	$50	$100	$100
• Behavior	$25	$25	$25	--	--
• Reproduction — ecology/seasonality	$50	$50	$50	--	--
• Sensory perception/visual acuity	$35	$35	$35	--	--
• Genetic variation/founding population	$30	--	--	--	--
• Repellent identification/verification	--	$20	$20	$20	$20
• Diet/foraging/movements	$20	$20	--	--	--
• Climatic tolerance — survival/recruitment	$25	--	--	--	--
• Habitat use	$55	$55	--	--	--
• Human health/safety	$40	--	--	--	--
Subtotals	**$330**	**$235**	**$160**	**$100**	**$100**

Biological Control Technology (Feasibility & Development)	**Cost/Year (In Thousands)**				
	Year 1	Year 2	Year 3	Year 4	Year 5
• Parasites, disease, and other infectious agents	$200	$200	$350	$350	$350
• Reproductive inhibition/genetic control/ fertility control	$400	$400	$700	$700	$700
Subtotals	**$600**	**$600**	**$1050**	**$1050**	**$1050**

C. Summary of Integrated Brown Tree Snake Funding Needs

Element	**Cost/Year (In Thousands)**				
	Year 1	Year 2	Year 3	Year 4	Year 5
Operational Needs	$2,435	$2,480	$2,530	$2,535	$2,5350
Research Needs					
• Basic control technology development	$1,115	$1,364	$763	$277	$420
• Biological control technology	$600	$600	$1,050	$1,050	$1,050
• Basic snake biology	$330	$235	$160	$100	$100
Total Funding Needs	$600	$600	$1050	$1050	$1050

Appendices

Appendix A

Brown Tree Snake Control Committee Membership

Mr. Robert P. Smith, Chair U.S. Department of the Interior,U.S. Fish and Wildlife Service, Pacific Islands Ecoregion, Honolulu, Hawaii

Capt. H. T. Bolton, U.S. Department of Defense, Armed Services Pest Management Board, Washington, DC

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Dr. Richard Bruggers, U.S. Department of Agriculture, Animal Plant Health Inspection Service, Animal Damage Control, DWRC, Denver, Colorado

Mr. Arthur Buckman, U.S. Department of Defense, U.S. Air Force, Pacific Headquarters, Hickam Air Force Base, Hawaii

Dr. Thomas Fritts, U.S. Department of the Interior, National Biological Service, Washington, DC

Mr. Ernie Kosaka, U.S. Department of the Interior, U.S. Fish and Wildlife Service, Honolulu, Hawaii

Mr. Michael W. Kuhlmann, Government of Guam, Department of Agriculture, Mangilao, Guam

Mr. Larry Nakahara, Hawaii Department of Agriculture, Plant Quarantine Office, Honolulu, Hawaii

Mr. Tim Ohashi, U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Animal Damage Control, Honolulu, Hawaii

Mr. Gary Oldenburg, U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Animal Damage Control, Olympia, Washington

Mr. Arnold Palacios, Commonwealth of the Northern Mariana Islands, Department of Land and Natural Resources, Division of Fish and Wildlife, Saipan, CNMI

Mr. Barry D. Smith, University of Guam Marine Laboratory, Mangilao, Guam

Mr. Scott Vogt, Commonwealth of the Northern Mariana Islands, Department of Land and Natural Resources, Division of Fish and Wildlife, Saipan, CNMI

Dr. Lyle Wong, Hawaii Department of Agriculture, Plant Industry Administrator, Honolulu, Hawaii

Dr. Alice Wywialowski, U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Policy and Program Development, Riverdale, Maryland

Mrs. Barbara A. Maxfield, Executive Secretary, U.S. Department of the Interior, U.S. Fish and Wildlife Service, Pacific Islands Ecoregion, Honolulu, Hawaii

Appendix B

Description of Brown Tree Snake Research Needs

I. Basic Control Technology

A. Trap Enhancement

Objective: To continue to evaluate and enhance traps and trapping methods so that they are more effective and less prone to failure in the hands of the public, control personnel, and cooperating agencies; to reduce costs of fabrication, deployment, and monitoring of traps; to develop alternative traps appropriate to special situations such as buildings, shipping containers, and electrical substations.

Synopsis: Effective traps have been developed but further work is needed to define the specific attributes that make it effective to facilitate widespread use by various cooperating agencies and citizens. The critical variables of an effective trap design need to be determined and incorporated into a uniform trap design, which would be mass produced to specifications to ensure quality control, smooth operation, and greater effectiveness. Additional work is needed to reduce personnel costs associated with trapping programs and to develop alternative traps appropriate to special situations such as buildings, shipping containers, and electrical substations. Traps are applicable to actual control efforts and to monitoring population levels, detection of snakes in new areas, and investigations related to development of other control technologies. The inability to deploy traps as a primary control technique over large areas must be realized, but in relatively small areas traps can be effective in catching and facilitating removal of snakes.

B. Attractant Identification/Verification

Objective: To develop artificial (nonliving) attractants that will bring snakes to traps, bait stations, or regions where most detectable; to develop attractants that have practical characteristics in terms of availability, cost, duration in field situations, and efficacy in attracting snakes from maximal distance (*viz.*, scent trails).

Synopsis: A critical need exists to develop artificial (nonliving) attractants to reduce the dependency on live baits and eliminate handicaps associated with live bait. Attractants are needed that will bring snakes to traps to be caught, to bait stations to be poisoned, or to specific habitat situations where snakes would be most detectable for control or monitoring purposes.

C. Bait for Toxicant Delivery

Objective: To develop inanimate (nonliving) baits capable of delivering chemical toxicants or biological control organisms. Important considerations are durability in field situations, low appeal to nontarget organisms, and ability to mask taste or smell of toxicants or control substances.

Synopsis: In contrast to an attractant, a bait for the brown tree snake program would be a substance that would be ingested as a means of delivering a toxicant or control substance (*e.g.*, disease agent, biological marker, or sterilizant). Important considerations are durability in field situations, lack of appeal to nontarget organisms, and ability to mask taste or smell of toxicant or control substances. Brown tree snakes are known to eat a variety of nonliving substances, and evidence shows that they will respond to specific odor cues and attempt to eat substances with appropriate characteristics. A combination of laboratory and field tests will be needed to adequately assess suitability of baits (and the attractants that could increase bait efficacy).

D. Toxic Bait Delivery Station

Objective: To present baits to snakes while minimizing exposure to weather, nontarget organisms, and contamination of environment.

Synopsis: The ideal toxic bait formulation would not entail presentations in special bait stations, but in practice such a station may be needed to minimize exposure to weather, reduce or eliminate contact by nontarget organisms, and avoid contamination of the environment. The elongate body form of snakes will contribute to the probability that such a station can be designed that will be small, inexpensive, and appropriate to reduce contact by other vertebrates and man.

E. Toxicant Screening/Testing/Registration

Objective: To scan candidate toxicants, evaluate applicability, determine toxicity, define delivery and dosages, assess environmental risks, and register effective toxicants for brown tree snake control use.

Synopsis: The need exists for a toxicant appropriate for snakes to allow control of snake populations over larger areas than presently possible with current trap and hand capture methods. Because the brown tree snake is the only snake on Guam that consumes vertebrates, the ideal toxicant would be one to which snakes were extremely sensitive and to which birds and mammals (including man) had negligible vulnerabilities. Primary emphases in toxicant research will be on determining efficacy, minimal dosages, delivery methods, reduction of risks to secondary targets, avoidance of environmental contamination, and selection of substances that will not build up in the natural ecosystem, the island's fresh water supply, or the adjacent marine environment. Research to date has resulted in pyrethrins and rotenone being identified as potential dermal toxicants and pyrethrins, propoxur, and acetylsalicylic acid in bait matrices being identified as oral toxicants. Additional toxicant screening will likely be needed. Analytical chemical residue methods are being developed for these potential toxicants for use in eventual registration with the Environmental Protection Agency.

F. Repellent Identification/Verification

Objective: To identify and test substances and stimuli that will reduce or eliminate movements of snakes into specific areas; to define circumstances in which repellents are most applicable.

Synopsis: The ability to cause snakes to avoid specific areas where they cause problems would be a useful tool in the control of off-island dispersal, reduction of electrical outages, and the protection of Guam residents from snake bite. Some candidate substances have been identified, but their utility, duration, and optimal means of use remain to be documented.

G. Fumigants Development/Registration

Objective: To identify, test, and register effective fumigants and application rates that could be used safely and successfully on cargo and in ships and planes to help reduce brown tree snake dispersal to other islands.

Synopsis: Methyl bromide was evaluated as a cargo fumigant because it has a long history of effective use worldwide as a quarantine and trade fumigant on a wide variety of food and nonfood cargo and vehicles. Research in 1991 and 1995 proved the effectiveness of methyl bromide against snakes inside loaded overseas containers in as little as 2 hours. Great Lakes Corporation of West Lafayette, Indiana, received approval from the Environmental Protection Agency on November 4, 1994, for Metho-O-Gas® Q, a methyl bromide product for use on brown tree snakes. Meth-O-Gas® Q has been registered in many states and can be used in Hawaii, Guam, and the Commonwealth of the Northern Mariana Islands. Because of environmental concerns associated with methyl bromide, further field evaluations of two fumigant alternatives were conducted in 1995. Sulfuryl fluoride and magnesium phosphide were effective, but not as practical as methyl bromide. Further research needs will be determined as the regulatory status of fumigants changes.

H. Lighting as a Repellent

Objective: To determine efficacy and practicality of using light to discourage snakes from invading specific situations; to investigate acclimation to stationary or moving lights; to determine if lights serve to attract prey species that in turn bring snakes to the area.

Synopsis: The use of bright lights to repel snakes or discourage them from sensitive areas warrants careful investigation. Snakes are known to avoid movements on the ground in bright lights, but determination of the actual intensities of light required, the degree of repulsion achieved, and the long-term efficacy of using lights will require behavioral studies under experimental conditions.

I. Detection/Eradication of Low-Density Populations

Objective: To develop optimum trapping strategies and protocol for detection and eradication of low-density brown tree snake populations.

Synopsis: The ability to deploy traps as an effective control measure in recently established populations (e.g., in Hawaii or the Northern Mariana Islands) where initial snake densities will be low and prey abundance will be high depends on understanding how snakes react to traps and specific baits/attractants in such conditions. Investigations of trap success in habitats with varying densities of small mammals, birds, and lizards could allow determination of the most effective trap densities, bait/attractant combinations, and development of specific programs useful in exterminating any incipient brown tree snake populations before they become well established.

J. Barrier Development

Objective: To devise and test practical barriers compatible with intended applications (i.e., perimeter of transportation centers, electrical substations, residential areas, endangered species habitats, electrical guy wires, cargo staging areas, and sites of military operations).

Synopsis: Until snakes can be eradicated from an entire island or area, barriers will be essential to achieving lasting reductions in smaller scale control areas where snakes can be removed and prevented from re-invasion. Barriers are also applicable to the perimeter of transportation centers, electrical substations, residential areas, endangered species habitats, electrical guy wires, cargo staging areas, and sites of military operations. Factors in need of resolution are permanence in typhoons, resistance to rat damage, and compatibility with fencing for security, esthetics, and privacy.

K. Canine Detection Verification/Training Aids

Objective: To develop techniques for determining efficacy of detection dogs, retraining dogs with surrogate training aids in lieu of live snakes, determining circumstances (distance, temperature, air movements, and degree of enclosure) appropriate for adequate levels of success in detecting snakes, and improving training of detection dog handlers.

Synopsis: The potential value of dogs in detecting snakes hidden from view in cargo and aircraft is great; however, the problems of maintaining the training of dogs in inspection situations where encounters with snakes are rare and of evaluating the limitations and circumstances that could prevent dogs from functioning effectively remain to be adequately explored. Qualifed dog handlers are a key ingredient to the success of canine interdiction.

L. Integrated Control Plan Development

Objective: To develop appropriate combinations of tools, strategies, and personnel needed to achieve the desired level of control in various situations (e.g., endangered species recovery in plots, elimination of snakes from transportation network, reduction of power outages, human snakebites, and incipient infestations when snakes appear in new situations).

Synopsis: Realizing that the brown tree snake is a complex problem of considerable magnitude, a coordinated multi-faceted control program will be needed to achieve adequate levels of control to meet the needs of federal, state, and territorial governments, private industry, and citizens in general. In order to achieve desirable levels of control in the most efficient and environmentally compatible form, different tools and strategies will be needed in combinations and in varying degrees of implementation depending on the individual situation where control is performed.

II. Biology of Brown Tree Snake

The ability to develop, test, and effectively deploy a multi-faceted control program to reduce the devastation caused by the brown tree snake depends to a great degree on a comprehensive understanding of the snake's biology. The following research tasks address known or potential weaknesses in biological characteristics of the brown tree snake that may provide points of vulnerability on which control efforts can be focused.

M. Population Dynamics/Monitoring

Objective: To anticipate outbreaks and windows of vulnerability; to estimate magnitude of efforts needed; to facilitate the ability to monitor control success; and to track changes in populations due to changes in weather, habitat characteristics, human intervention, and other factors.

N. Behavior

Objective: To understand stimuli causing specific reactions in feeding, predator avoidance, climatic variation, etc.; to maximize control efforts by taking advantage of innate behaviors of snakes in response to certain stimuli; and to understand variation in activity, movements, and responsiveness.

O. Reproduction

Objective: To illuminate resilience or vulnerability of snake populations to control efforts; to facilitate elimination of reproductive adults and their progeny; and to define seasonal patterns in snake distribution and abundance related to reproduction.

P. Sensory Perception

Objective: To guide development of attractants, baits, traps, repellents, and other control tools; to guide development of barriers to dispersal, climbing, and invasion of buildings; to define how prey are located and captured; to understand how snakes kill prey and prey defenses; and to promote safety by control program personnel and cooperators.

Q. Genetic Variation

Objective: To determine the minimal number of snakes likely to constitute a risk of founding new populations and the level of containment necessary to protect other areas, such as the Island of Rota and the State of Hawaii, from snakes being established; and to verify the hypothesized source population of snakes that colonized Guam.

R. Diet, Foraging, and Movements

Objective: To assist in guiding the design and scope of control efforts, to guide bait/ attractant formulation, to anticipate predatory pressure on endangered species, and to define probable impacts on other faunas that may be contacted in future.

S. Climatic Tolerance/Thermal Biology

Objective: To assess probability of survival in other geographic areas; and variation in activity, reproduction, and survival due to daily, seasonal, and annual climatic variation.

T. Habitat Use

Objective: To define areas where control is most needed and the controls appropriate for such areas; to identify most important refugia for recently established populations to facilitate control efforts; and to define habitats avoided by snakes to use as natural barriers or filters to snake movements.

U. Human Health/Safety

Objective: To assess and reduce risks to infants, small children, and adult populations; to guide treatment of snakebite cases.

III. Biological Control Technology

Biological control, the regulation of populations by the introduction or manipulation of natural enemies, offers potential to control or regulate brown tree snake populations on Guam and to prevent establishment or expansion of new populations on other Pacific islands. Biological control has most frequently been applied to insect and weed pests and plant pathogens, and to a limited extent to vertebrates. There have been few attempts at biological control of snakes. An unsuccessful attempt to control habu in certain Japanese islands by introducing mongoose and preliminary work with parasites and disease agents in the same area are exceptions.

Multiple control agents would be required in an effective biological control program to minimize the probability that resistance or behavioral modifications to individual agents will develop. Integration of successful biological control agents as components of a comprehensive integrated pest management program offers the greatest potential for success. It is theoretically possible that a biological control agent may eradicate a small, or founder, population on other islands such as Hawaii through stochastic processes, but biological controls would theoretically have the greatest potential in reducing dense and well-established populations.

No effective natural predators of snakes exist on Guam. Introduced feral cats, feral pigs, and monitor lizards prey on snakes, but their effect on brown tree snake populations on Guam apparently has been negligible. Predators of snakes in other ecosystems are generally catholic in their diet, and often opportunistic. Introduction of other predators to Guam could thus result in further impacts on native fauna. Any impact on brown tree snake populations would be buffered by the relative abundance and susceptibility of alternative prey species. Like feral cats and pigs, any other introduced predator could become a pest without effective population control. Previously introduced predators such as monitor lizards, cats, and pigs present on other Pacific islands could contribute to preventing the establishment of new brown tree snake populations on these islands.

Introduction of the mongoose to Guam has been proposed due to its largely unfounded reputation as a snake predator. However, they are in reality less efficient as snake predators than popularly believed. Previous introductions of mongooses to control the habu and rats in Pacific islands and the West Indies have been largely unsuccessful, and have resulted in additional ecological problems, including the extirpation of some native herpetofauna. In addition, mongooses are not nocturnal and do not climb well; thus they are poorly adapted as predators of the brown tree snake.

To date, no other potential snake predators have been identified that could effectively control the brown tree snake population on Guam and simultaneously pose no environmental or economic risk. Thus, no research needs related to predators have been identified at this time.

V. Parasites, Disease, and Other Infectious Agents

The introduction or enhancement of a pathogenic parasite or infectious disease offers potential in controlling brown tree snake populations on Guam, as has been suggested for mammals introduced to island ecosystems. A wide variety of viruses, bacteria, fungi, and parasites infect snakes; however, known disease agents that can inflict the epizootic mortality in nature or reproductive impairment that may be required to effectively control snake populations are few. Several diseases in snakes have caused epizootic mortality in captivity, including a paramyxovirus, retrovirus, and herpesvirus and a protozoan (*Entamoeba invadens*). Experimental challenge studies have shown that at least two strains of paramyxovirus isolated from disease outbreaks in captive snakes can also be fatal in brown tree snakes. As with many disease agents, these pathogens may affect a wide variety of snake species, and possibly other reptiles as well.

Surprisingly little is known about the natural infection of brown tree snakes with microbial or parasitic organisms, either on Guam or in their natural range. A single helminth species (a reptilian hookworm) is known from the brown tree snake in its native range, and haemogregarine parasites (vector transmitted blood protozoa) were found in 4 of 4 brown tree snakes collected in New Guinea. Few surveys of bacterial, viral, or fungal microbes in the brown tree snake have been conducted. A recent survey of 25 brown tree snakes captured on Guam disclosed a wide array of bacterial species from tracheal and pharyngeal swabs, probably representing "normal" flora.

The area of biological control of the brown tree snake with an infectious or parasitic disease deserves further investigation. The lack of species-specificity for known virulent diseases among snakes poses questions that must be addressed about the probability and environmental risk of introducing disease to other reptile species on Guam or to other areas, including the native range of the brown tree snake. In addition, the tendency for virulent host-pathogen relations to evolve toward symbiosis suggests that introduction of a virulent pathogen by itself may not provide a long-term solution. For example, the introduction of myxomatosis virus to control rabbit populations in Australia, although achieving high initial mortality and population reduction, met with varying degrees of success over the long term largely because of the alteration of host/virus relationships through the evolution of genetic resistance in the rabbit, new virus strains, and changes in invertebrate vectors. However, theoretical evidence suggests that parasites of intermediate or low virulence may effect the largest depression in host population density and maintain themselves at lower host population densities. In addition, recombinant DNA technology offers the potential for engineering of microorganisms to enable species-specific population control through other mechanisms such as immunocontraception (discussed below).

W. Reproductive Inhibition, Genetic Control Mechanisms, and Fertility Control

Immunological fertility control has been achieved in feral horses, white-tailed deer, and zoo ungulates through the induction of autoimmune responses. In these cases, proteins controlling reproduction were used to immunize the animal and obtain the desired immune response to interfere with specific components of the reproductive cycle. The advantage of this approach is that it provides tissue specificity; however, such systems lack species specificity and require the individual handling of animals. A clear advancement of this approach would be the identification and utilization of species-specific proteins associated with reproductive function. Recently, a number of species-specific proteins associated with reptilian egg production and embryonic development have been identified. Proteins of this type offer the potential to develop immunological fertility control which is species-specific in snakes. If this immunological fertility control method is combined with species-specific vector-mediated transmission, an effective method of immunocontraception for the brown tree snake could result.

Recent advances in molecular biology and genetic engineering have resulted in the development of a wide variety of genetically modified organisms, and their introduction into the environment to solve agricultural pest problems and increase agricultural production. The use of genetically engineered organisms in wild vertebrates has been largely restricted to the delivery of vaccines, such as an engineered vaccinia virus-rabies recombinant vaccine to protect wild raccoons and foxes against rabies. Biotechnological capabilities also exist to develop genetically engineered organisms, called vectors, to deliver reproductive inhibitors. As with other biological control programs, application to the brown tree snake problem would require environmental safeguards that it must (1) be specific for the target species, (2) be effective, and not allow for the development of resistance, and (3) have no adverse environmental effects. It must also pose no risk to brown tree snake populations in their native range.

Mechanisms of genetic control have been known since the late 1940s and are considered a form of classical genetics. It depends on strictly mechanical interruption of meiosis to result indirectly (after one generation) or directly (in the parental generation) in sterility due to either chromosome breakage or to misalignment of heterologous chromosomes in the resultant sperm or eggs. If applied toward a target generation once removed from the parents exposed to the agent causing the effect on the chromosomes, then the effect can be spread rapidly into a population and even transmitted to future generations at some measurable frequency. The path of cytogenetic mechanism is usually: chromosome breakage --> recombination into viable chromosomes carriers and inviable chromosome carriers --> and either transmission into the following generation (viable chromosome carriers) or death (inviable carriers). The cytogenetic mechanisms themselves include potential translocations, reversions, inversions, and deletions of the chromosomes (Swanson et al 1968).

The inversion type can be made stable if duplications and/or deletions do not occur in the total chromosome complement and balanced translocation has occurred. This inversion type, when coupled with an induceable lethal gene which locks such a gene in place so it cannot be removed or broken up my subsequent natural recombinant events, can be a method of introducing a genetic "time-bomb", called a Conditional lethal, into a population. The "bomb" results in death when, for example, a certain environmental event takes place to induce the gene to become active in all individuals carrying the defect. This type of genetic "time bomb" has not been used in natural population control, but has been demonstrated in *Drosophila melanogaster* under laboratory conditions (Suzuki 1970). Environmental "triggers" for the bomb which are known to exist from studies of a wide range of organisms could include temperature-dependent genes, genes such as specific induceable esterases which would turn on when the activating ester was sprayed or fed into a natural population, humidity-response genes, hormone-induced genes (e.g., those that turn on at ovipositioning), or any gene which can be linked to a specific environmental response. Use of such a system as the genetic "time bomb" could allow the induceable lethal to spread widely in a population before activating the trigger gene. It has the advantage of continuing to operate into the future at estimatable rates allowing long-term control with possible augmentation.

Research to address this potential biological control method would include (1) determining the reproductive cycle of the brown tree snake and the nuances in behavior, temperature, etc. which effect it; (2) establishing basic knowledge on the chromosome number, structure, recombinant ability, etc., of brown tree snake cytology; (3) determining an effective and environmentally neutral way of delivering the agent causing cytogenetic disruption, and (4) modeling of the effects to understand and make predictable its behavior upon release into nature. A field testable, deleterious system could be developed within a four-year period; a genetic time-bomb approach would take several years longer.

The development of an effective and safe vector-induced immunocontraceptive offers a potential long-term control method for the brown tree snake on Guam and newly established populations on other islands. It may also contribute to the prevention of the establishment of other new populations by the immunoneutering of potential invaders.

Appendix C

Literature Considered in the Brown Tree Snake Control Plan

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