35 An Integrated Management Plan for the Brown Treesnake *(Boiga irregularis)* on Pacific Islands

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As of 1994, large-scale snake control programs have been carried out only for the Habu *(Trimeresurus flavoviridis* In addition to educational campaigns designed to reduce snake-human encounters(Sawai et al. 1990; Tanaka et al., this volume, Chap. 8), Japanese wildlife managers have attempted to bar entry of snakes into villages using physical barriers (Miyashita and Wakisaka, 1979; Nishimura, this volume, Chap. 22; Shiroma and Akamine, this volume, Chap. 24), electrifiedbarriers (Hayashi et al., 1983, this volume, Chap. 23; Tanaka et al. 1987), trap capture programs (Tanaka et al. 1987; Katsuren et al., this volume, Chap. 25; Shiroma and Akamine, this volume, Chap. 24), habitat modifications (Yoshida, 1979; Mishima et al., *this* volume, Chap. 28), prey reduction (Tanaka et al., 1987), detector dogs (Shiroma and Ukuta, this volume, Chap. 26), eradication of snakes on small islands (Mishima et al., 1978; Katsuren et al., this volume, Chap. 25), release of toxic prey (Araki and Yoshida, 1990; Katsur-n et al., this volume, Chap. 25), and release of snake predators (Mishima et al., 1978; Abe et al., this volume, Chap. 28). Although the Japanese experience is of value in selecting appropriate measures for control of the Brown Treesnake **(Boiga irregularis),**there are important differences between the snake species in their reliance on subterranean and arboreal refugia (Rodda et al., this volume, Chap. 2; Mishima and Sawai, 1979; Shiroma, 1989), the scale of their movements (Wada et al., 1972; Nishimura, 1983; Rodda et al., this volume, Chap. 17; Tanaka et al., this volume, Chap. 15), their vulnerability to trap capture (Hayashi et al. 1984; Hokama 1989; Shiroma, 1989; Rodda et al., this volume, Chap. 20), their ability to scale barriers (Shiroma and Sasaoka, 1981; Nishimura, 1983, 1984; Campbell, this volume, Chap. 21), their toxicity (Vest et al., 1991; Toriba et al., this volume, Chap. 33), and their ecological interactions (Rodda et al., this volume, Chap. 2; Ota, this volume, Chap. 36). Thus one cannot reflexively apply Japanese techniques to the Brown Treesnake without consideringthe biological differencesbetween these quite disparate snake species.

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The management actions that have been applied to the Brown Treesnake have been limited in scope because of the relatively short time since control research was initiated, and none has been critically evaluated in a large-scale field situation. Educational campaigns conducted by a variety of agencies and nongovernmental organizations have undoubtedly reduced the impacts of the snake on residents and domestic animals, but, by their nature, the independent actions taken by individuals are poorly documented and difficult to monitor or evaluate.

The direct governmental actions that have been taken during the last one to three years include (1) inspection of military cargoes and aircraft (Fritts et al., 1990); (2) trap capture and visual searching for snakes on Saipan, Mariana Islands (Gomez, 1992); (3) protection of trees used by nesting Mariana Crows in Guam (Aguon et al., this volume, Chap. 38); and (4) enactment of regulations prohibiting the transport of Brown Treesnakes (Anon, 1991). Insufficient time has elapsed to permit statistical assessment of the success of these actions. Thus, experiences rather than quantitative data are the main sources of information presently available. In this chapter we review past efforts to control Brown Treesnakes and what they have taught us.

TECHNIQUES FOR BROWN TREESNAKE MANAGEMENT

Public Education

Public education programs have been used by both American and Japanese officials (Sawai and Tanaka, 1979; Fritts, 1988). The American actions have been manifest in a wide variety of communications (mass media, public seminars, workshops, individual contacts, etc.) on all islands with transportation links to Guam. These educational actions do not constitute snake control by themselves, but they enlist large numbers of volunteers to facilitate detection of snakes and implement snake control measures. This leveraging of the control effort is highly cost-effective. Public education will undoubtedly continue to be an important snake management tool.

Physical Barriers

Homes and some other structures can be protected from snakes by blocking all openings accessible to snakes (Sawai and Tanaka, 1979; Rodda, n.d.). Because of the need to withstand typhoons, most structures on Guam and the Ryukyus are constructed out of materials that lend themselves to snakeproofing, in contrast to more traditional buildings found on many Pacific islands. In the case of the Brown Treesnake, initial efforts to seal homes against the Brown Treesnake were frequently ineffective as a result of misconceptions regarding the snake's size and its ability to reach elevated sites. Campbell found that small Brown Treesnakes could penetrate holes as small as 5×28 mm, at least in semiflexible plastic fencing. D. Chiszar (pers. comm., 1992) observed wet snakes adhering to vertical plastic surfaces. P. Conry (pers. comm., 1992) observed Brown Treesnakes climbing vertical poles by alternating head and tail grips, a modification of the concertina locomotor technique employed by many snakes. Fritts and Chiszar (1998; Fritts, 1987a 1987b; Chiszar, 1990) conducted a series of experiments to document the Brown Treesnake's extraordinary ability to climb wires and rough surfaces, and its inability to ascend smooth masonry. Routes of access for the Brown Treesnake are sufficiently documented that the physical obstruction of entry points to homes and buildings is a viable and important technique for snake exclusion in residential and commercial structures (Table 35.1).

Physical and electrical exclusion of Brown Treesnakes from trees is summarized by Aguon et al. (this volume, Chap. 38). Although this technology is currently employed on a limited basis (Table 35.1), the long-term consequences to trees and the maintenance costs of this approach are still being studied. Because only a small area is protected, it seems likely that this approach will be used only on trees for which snake control is of exceptionally high importance.

Table 35.1 Techniques for Brown Treesnake management.

Technique	In use	Available now	Available soon	Requires substantial development
Public education	X			
Physical or electrical barriers				
for building interiors	X			
for trees	X			
for power poles		X		
for forested areas			X	
for urban areas			X	
Capture				
hand/visual	X			
trap	X			
dog assisted	X			
Habitat alterations				
illumination			X	
prey reduction			X	
structural habitat alteration	X			
Chemical control				
toxicants				X
fumigants		X		
pheromone assisted				X
repellents				X
attractants				X
Biological control				
pathogens				X
parasites				X

Techniques for the physical exclusion of Brown Treesnakes from power supply structures are available (Fritts and Chiszar, this volume, Chap. 4) but have not been implemented (Table 35.1) by the electrical utility companies.

The potential for exclusion of Brown Treesnakes from forested areas (Table 35.1) was explored by Rodda et al. (this volume, Chap. 39). The use of barriers to exclude Habu from urban areas is well developed in Japan (Miyashita and Wakisaka, 1979; Tanaka et al. 1987; Shiroma and Akamine, this volume, Chap. 24), but the high cost and incomplete success are discouraging. Furthermore, the well-developed climbing abilities of the Brown Treesnake suggest that more sophisticated barriers will be needed for this species (Campbell, this volume, Chap. 21). Although additional development of this approach is needed (Table 35.1), there do not appear to be any fundamental obstacles to be overcome. Unelectrified urban barriers can now be constructed in areas where tall, smooth walls are architecturally appropriate and complement needs for security, visual screening, or noise abatement. Because of the high initial cost, the first sites to be protected are most likely to be transportation facilities.

Capture

At present, Brown Treesnakes are captured most effectively by hand or in funnel traps (Table 35.1). The Hawaii Department of Agriculture has several dogs trained to detect snakes, but this program has not yet been fully implemented or evaluated (Imamura, this volume, Chap. 27). The Japanese experience with dogs (Shiroma and Ukuta, this volume, Chap. 26) is encouraging, but costs and efficacy under various circumstances have yet to be clarified in either country.

Hand capture is limited by the captor's willingness to handle potentially dangerous snakes (Rodda and Fritts, 1992) and ability to find snakes in situations where the snakes are not obvious. Visual searches are strongly dependent on observer motivation, ability, and physical presence, whereas the monitoring of snake traps is less influenced by these factors. Traps constitute a controlled circumstance in which apprehensive personnel can participate with little risk. Traps continue to work on weekends, during adverse weather, in late night hours and in remote areas not frequently visited, whereas visual searches are less practical in these circumstances.

In our experience on Guam, snake traps produced a greater number of captures per person-hour than hand capture (Rodda and Fritts, 1992; Rodda et al., this volume, Chap. 20), although traps may be less effective in areas where wild prey are relatively abundant (e.g., Saipan has abundant feral rats; Barbehenn, 1974). We are encouraged in our use of traps by the widespread success of traps for controlling medium-sized vertebrates (poison is usually the technique of choice for killing small animals such as rats, and hunting is the usual tool for large animals such as ungulates). For example, traps were used to eradicate the Nutria (Coypu myocastor) from the island of Great Britain. Like the Brown Treesnake the

Nutria is cryptic, secretive, and nocturnal (Gosling, 1989; Gosling and Baker, 1989). Another difficult animal, the Stoat (*Mustela erminea*) was eradicated from a 309 ha island (Maud) off the coast of New Zealand using traps (Veitch and Bell, 1990).

Habitat Alterations

Two techniques that may soon be applicable are the use of bright lights to discourage visits by the nocturnal Brown Treesnake and the reduction of prey abundance to make selected areas less attractive to snakes (Table 35.1). The use of bright lights seems intuitively reasonable because the Brown Treesnake is a nocturnal animal; there is anecdotal evidence of reduced snake visitation of brightly lit facilities managed by the Guam Power Authority (O. Wood, pers. comm., 1992). On the other hand, it is possible that snakes would habituate to the presence of bright lights if these were constantly deployed at night. Snake prey such as geckos may be attracted to the insects that swarm around lights, and the geckos could attract snakes. We see snakes in certain well-lit areas in Guam, but no systematic studies of the complex relationship between snakes and light have been undertaken to date. Consequently, this relationship is an important target for research.

High prey abundance contributes to the success of Brown Treesnakes (Rodda et al., this volume, Chap. 17), but it is not known if cost-effective ways can be found to reduce prey abundance, or if reduced prey abundance in small areas has a measurable effect on the local density of snakes on short- or long-term scales. The high natural movement rate of Brown Treesnakes (Rodda et al., this volume, Chaps. 2, 17, and 30) suggests that in the absence of barriers, snakes will diffuse into an area despite a locally sparse prey base, but whether or not they will move through rather than remain in areas with limited prey is unknown. Efforts to reduce Habu by reducing rat abundance have not been adequately evaluated, and the high recurring cost of rat control has discouraged implementation of this potentially important strategy (Tanaka et al., 1987).

Chemical Control

All avenues of chemical control for the Brown Treesnake (Table 35.1) warrant further work (Savarie and Bruggers, this volume, Chap. 34; Mason, this volume, Chap. 13). Lack of information regarding the natural sexual behavior of the Brown Treesnake has impaired the identification of reproductive pheromones (Mason, this volume, Chap. 13). Reptilian toxicology and pharmacology are fields in their infancies (Savarie and Bruggers, this volume, Chap. 34). Basic research along these lines must be conducted before we are likely to discover environmentally safe and practical Brown Treesnake toxicants. Habu toxicologists have undoubtedly been limited by the same paucity of information that affects Brown

Treesnake researchers. We are aware of no significant breakthroughs in the use of poisons for Habu control on a large scale, although numerous repellent compounds have been explored (Shiroma, 1985, 1986; Nishimura, 1988, 1990, 1991, 1992). Toxicants have been used with considerable success in some rat control programs, including the total eradication of rats from small islands (Moors, 1984; Veitch and Bell, 1990); thus there is encouragement for pursuing a snake toxicant research program. Without a substantially greater infusion of funds, however, implementation of any chemical control program for the Brown Treesnake seems unlikely before the year 2005.

Biological Control

Reptilian physiology is relatively well known compared with reptilian epidemiology, parasitology, and community ecology. Ishii and his coworkers (*this* volume, Chap. 31) conducted a series of parasite tests with the Habu, but to date, no practical biological control methods have been developed. Initial Brown Treesnake experiments with acarine parasites and viral contagions (T. H. Fritts, pers. comm., 1992; Nichols, 1992) have not revealed any lethal effects. Haemogregarine parasites were proposed by Telford (this volume, Chap. 30), but the development of practical applications of this approach is likely to require many years and large amounts of money. The low potential for using snake predators to control the Brown Treesnake is discussed by Rodda *et* al. (this volume, Chap. 17). There are few examples of successful biological control of vertebrates (Davis et al. 1976; Wodzicki, 1978), and islands seem to be especially dangerous places in which to experiment with this approach (Howarth, this volume, Chap. 32).

SOLUTIONS AVAILABLE AT PRESENT

If techniques for the control of the Brown Treesnake had been developed many years ago, it would now be possible to identify the single most effective technique for use in a given situation. However, the many uncertainties associated with snake management suggest that a bet-hedging strategy be adopted. That *is,* invoke several snake control techniques that appear cost-effective, increasing the probability that the best tactic for the particular situation will be among those selected.

An additional reason for using diverse tactics is that a given tactic may control only one segment of the snake population. For example, considerable evidence from both Habu and Brown Treesnake trap research programs indicates that snake traps are most effective for adult snakes and ineffective for small snakes (Shiroma and Akamine, 1988; Rod& et al., this volume, Chap. 20). Failure to control all age classes will ensure that juveniles remain in the population. Such a trend was observed in a population of American watersnakes *(Nerodia sipedon)* inhabiting a fish hatchery where employees were paid a bounty per snake killed (Bauman and Metter, 1975). Employees removed mostly larger adult snakes because they were easier to capture. Eventually this culling lowered the mean size of the snakes inhabiting the hatchery, but did not reduce the total number of snakes at the site. Conversely, a combination of techniques that controlled both adult and juvenile segments of the population would reduce not only numbers of adults but also the numbers of individuals entering the adult population in subsequent years.

Brown Treesnake control is needed in a variety of situations. Fritts and Chiszar this volume, Chap. 4) described tactics used to protect electrical grids. In this chapter we consider four other situations: protection of infants from snakebite, conservation of native animals on Guam, confinement of extralimital Brown Treesnake populations to Guam, and eradication of incipient populations on newly infested islands.

Protection of Infants from Snakebite

Existing techniques to seal homes with physical snake barriers (Fritts, 1988; Rodda, n.d) are probably sufficient to keep snakes from entering homes if properly employed. Supplementary control measures, such as snake trapping and prey reduction, are probably too costly for the additional increment of benefit achieved, and there is the risk of inadvertently drawing snakes from surrounding areas into the vicinity of infants when using snake traps supplied with prey as attractants. Symptomatic medical care of envenomated infants has been sufficient for all bites recorded to date, and careful medical observation of envenomated infants is likely to be more important than the development of antivenins (Fritts and McCoid, this volume, Chap. 6). Public education of parents and physicians will continue to be the most cost-effective governmental action that *can* be taken to reduce the risk of snakebite to infants.

Conservation of Native Animals on Guam

Aguon et al. (this volume, Chap. 38) detailed the techniques that they used to isolate individual Mariana Crow (*Corvus kubaryi*) nest trees from reptilian predators. Development of additional techniques is a high priority, and several extant or newly maturing technologies appear suitable. Rodda et al. (this volume, Chap. 30) described a mix of approaches that are under development to protect forested areas using snake exdosures. If demonstrably cost-effective, these exclosures could be applied to most habitats lacking complex topographies (i.e., rocky substrates or very steep slopes). Unfortunately, complex topographies have the greatest prospect for long-term preservation as wildlife habitat on Guam and on other islands. In addition, some wildlife—for example, fruit bats (*Pteropus mariannus*) -actively seek out cliffside localities, apparently to avoid human harassment. An additional limitation of any exclosure, whether focused on individual trees or large areas, is the high cost of construction and maintenance.

Thus there does not seem to be a high probability of using exclosures for large portions of Guam and other islands.

If the native wildlife is to be protected throughout Guam, alternative control technologies will be necessary. Chemical and biological control techniques have the potential for widespread use, but their use for long-term protection of native wildlife is unprecedented (see above).

Reducing Dispersal of the Brown Treesnake from Guam

Although Brown Treesnakes have repeatedly reached other Pacific islands (Fritts et al., this volume, Chap. 14), none of these dispersal events is known to have resulted in new populations. If the rate of dissemination of propagules can be kept below the level at which colonists of the opposite sex can locate each other, it may be possible to protect many Pacific islands without needing to stop every snake. We believe the implementation of measures to keep the Brown Treesnake from spreading to other islands is the most cost-effective snake control action at the present time.

Most of the available techniques (Table 35.1), and many of the techniques under development, could be used to reduce dispersal of the Brown Treesnake from Guam (Fritts, 1989; Fritts et al., 1990). Public education is most important, as it informs people regarding the inadvisability of transporting Brown Treesnakes to other Pacific islands from Guam and about the need for reporting all snake sighting. Physical and electrical barriers can keep snakes out of the areas on Guam where cargo, aircraft, or maritime vessels are kept. Military customs personnel are presently conducting visual searches for snakes while examining items being shipped from Guam, but off-island civilian shipments are not inspected specifically for the presence of snakes. It would be highly desirable to use a suitable snake fumigant on both civilian and military shipments (Savarie and Bruggers, this volume, Chap. 34). Detector dogs could be used in lieu of or in addition to fumigants as a means to stop unseen snakes in shipments (Imamura, this volume, Chap. 27). Visual searches and trapping programs could also reduce the densities of snakes in the vicinity of ports and airports. Ports and airports could be made less attractive to Brown Treesnakes by reducing prey availability around cargo and vessels. If bright lights are found to deter snakes, it may be practical to illuminate cargo and vessels, or at least to illuminate the pathways by which snakes might attain access to them. This would discourage entry of snakes, yet would not require lighting the entire vessel storage area. All of the chemical control approaches (Table 35.1) could be used to control snakes in the vicinity of cargo and vessels.

Many items that leave Guam are packaged in pallets and containers at sites away from the port and airports. Thus, to completely ensure that snakes do not enter cargo or vessels, it is necessary to extend snake control measures beyond the physical boundaries of the ports and airports. The area that must be protected is nonetheless only a tiny fraction of the area inhabited by snakes. Thus confining the snakes to Guam is intrinsically more cost-effective than eradicating them on a new island. There are underutilized techniques now available or soon to be available for confining the Brown Treesnake on Guam. To date, the main obstacle to the implementation of these methods has been a lack of clear jurisdictional responsibility and a reluctance to commit the funds and time necessary to prevent a future problem of unknown magnitude. In many cases, the benefit to be received by preventing the dispersal of the snake from Guam accrues to a different entity than the institution that would undertake the additional costs of confinement. Such a dilemma constitutes a serious impediment to effective snake control.

Eradication of Incipient Populations on Newly Infested Islands

The mismatch between who benefits and who pays does not apply to eradicating incipient populations. The governments of islands subjected to an incipient colonization of Brown Treesnakes are likely to receive the full benefit of their own actions to eradicate the population. But it is often difficult to garner local funding and expertise for threats that, like incipient snake colonies, are largely invisible. Furthermore, there are considerable uncertainties as to the appropriate level and mix of actions necessary to eradicate a new colony. A tendency exists to expect federal funds and agencies to assume responsibility for "outside" problems, but the federal budget process is extremely slow and imprecise in addressing local problems.

One special problem is that founder populations may be difficult to detect or locate; it is much easier to apply the full force of available techniques if the geographic extent of an infestation is known. Another problem is that new infestations are likely to be in urban areas, where landownership is finely divided, jurisdictions are fragmented, and access is limited or difficult.

No one has ever tried to eradicate an incipient snake colony. The actions now being taken to eradicate the Brown Treesnake from Saipan are unprecedented. If it is not possible to do that, it may at least be practical to depress the snake population to a level that would permit native wildlife to survive (Rodda et al., this volume, Chap. 20).

To assist in the delimitation of an infestation, public education may be used to inform and enlist a large number of volunteers for snake detection. Snake traps are among the most effective detection tools, but visual searches may be needed to find small snakes (Rodda and Fritts, 1992; Rodda et al., this volume, Chap. 30). Dogs have assisted in the eradication of many vertebrates (Veitch and Bell, 1990) and the capture of some vertebrates, even some arboreal reptiles (Dugan 1982), but to date no dogs have been trained to locate Brown Treesnakes in field situations.

The task of eradicating a Brown Treesnake colony will probably require large expenditures of funds, vast numbers of traps and snake searchers, and chemical tools such as toxicants. Experience will be attained on a small scale during establishment of the exclosures described by Rodda et al. (this volume, Chap. 30). Although it remains to be seen whether eradication of the Brown Treesnake is possible, the cost of containing an incipient Brown Treesnake colony will likely be far less than the cost of controlling a well-established infestation.

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