39 The Feasibility of Controlling the Brown Treesnake in Small Plots

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There is an urgent need to provide snake-free or snake-reduced habitats for the wildlife species on Guam that have declined or disappeared as a result of predation by the Brown Treesnake, *Boiga irregularis* (Savidge, 1987; Fritts, 1988; Rodda and Fritts, 1992; Rodda et al., this volume, Chap. 2). At present, we know of no practical techniques for reducing or eradicating the snake throughout Guam, a densely populated island of 54,100 ha. Conserving native wildlife and reducing the incidences of snakes boarding ship and aircraft may not require the elimination of snakes from the entire island, however. Elimination of snakes from critical wildlife habitats and sanitized zones in the vicinity of ports and airports would be a worthwhile accomplishment, and recent breakthroughs in trapping technology suggest that local elimination may be feasible.

The capture success rates of recent trapping studies provide some guideposts for assessing the practicality of snake control effectiveness in small plots. Assuming that immigration, emigration, and recruitment are negligible, and that all snakes exhibit capture probabilities equal to the mean of their class in recent trapping experiments (Table 39.1), snake populations will decline exponentially as control measures are applied. The theoretical number of snakes never reaches zero under such conditions; however, if the number of snakes remaining is near zero, we can justifiably relax. In the work reported below, we used a criterion of having less than 0.1 hypothetical snake remaining.

If one were to attempt to clear a 1 ha area of snakes using the average trap effectiveness that we obtained at Orote Point, Guam, in 1988, about 228 days would be needed to capture the snakes (Table 39.1). This time span is sufficiently long that reproductive recruitment would occur during the eradication period, and low rates of immigration throughout the eradication period would offset the snake removals. If the size of the area was increased 10-fold to 10 ha, only a modest number of additional days would be needed for trapping (313 − 228 = 85 days extra). A similar increase would apply to increasing the area to 100 ha, assuming that the many traps and the amount of trap monitoring could be scaled accordingly. Using trap densities of 30/ha, 3000 traps would be needed to clear 100 ha in 397 days. A very large number of people would be needed to monitor this many traps. This

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Table 39.1 The estimated number of days required to eliminate snakes from bounded plots, assuming capture probabilities are constant for all snakes of a class and the values are those obtained during trapping studies at Orote Point, Guam.

Year	Attractant	Traps/ ha	Snakes/ ha	p	Days needed to eliminate Snakes from 1 ha	10 ha	100 ha
1988	gecko or litter	30	50	0.0118	228	313	397
1990	mouse or gecko	44	49	0.2845	19	26	33
1991	mouse	44					
juveniles (<800 mm SVL)			1.5	0.4388	5	9	13
females			15.5	0.1749	27	39	51
males			20.0	0.1114	45	65	84

Note: The required number of nights was computed with the assumption that 0.1 snakes would remain, using the exponential decay function: Number of nights = (log[snakes remaining] − log[snakes beginning])/log(1 − p).

analysis suggests that the 1988 trapping protocol does not provide a practical basis for snake control.

Greater trap success was achieved in 1990 using mouse attractants, and the prospects for snake control were dramatically improved (Table 39.1). The key variable was p, the probability of capturing a given snake on a given night (Table 39.1). With the 1990 p of 0.2845, a 1 ha area could be cleared in 19 days, a 10 ha area in 26 days, and a 100 ha area in 33 days. These intervals are short enough that little snake reproduction and immigration would occur during the snake elimination. Although a large number of traps would be needed to control the snakes on 100 ha, the required effort would be short in duration.

The 1991 trap results differed from previous results in that snakes of different sizes and sexes differed in their vulnerability to capture (p). The open population analysis of the mark-recapture results (Lebreton et al., 1992) indicated that juveniles (<800 mm snout-vent length [SVL]) were relatively easy to capture, and males were relatively difficult (Table 39.1). Although all classes could be captured simultaneously in a control program, the length of time needed to capture all snakes is set by the duration needed to capture the most elusive class, in this case males. Based on the 1990 results, 45 days would be needed to capture all the snakes in a 1 ha plot (the last capture would likely be a male), 65 days would be needed for a 10 ha plot, and 84 for 100 ha. Although these intervals are not prohibitively long, they are almost three times as long as those estimated with the 1990 trap results, in which all snakes were equally catchable. This example provides a warning that heterogeneity among individuals or classes in their catchability could greatly increase the difficulty of controlling snakes on small plots.

Control on any small plot must consider immigration of snakes from outside the control area. We tested the importance of immigration by removing all snakes for a 15 day period at Orote Point in 1991. Had our removals captured 25% of the population nightly without offsetting immigration, the number of snakes present and the number of nightly captures should have quickly declined (Fig. 39.1A). Instead, there was no decrement in captures that would indicate that the population of snakes was decreasing (Fig. 39.1B). Snakes were apparently entering the control area from surrounding areas nearly as fast as we were able to remove them.

Habu managers have addressed the immigration problem with snake barriers (Hayashi et al., this volume, Chap. 23; Nishimura, this volume, Chap. 22). To date, efforts to remove Habu from villages surrounded by snake barriers have not resulted in the complete elimination of the snake; however, any reduction of snake populations may be beneficial. Inspired by the Japanese designs for exclosures, we launched a three-phase project focused on exclosures for the Brown Treesnake.

The goals of our project are to determine the feasibility of controlling the Brown Treesnake in small plots by combining removal and barrier methodologies. Specifically, we seek to (1) assess costs, (2) determine applicability to difficult terrain, (3) evaluate how size of exclosure affects a project's cost-effectiveness, (4) determine the degree to which snake populations can be reduced with various exclosure designs, and (5) test the permanence of the exclosures.

We view the resultant techniques to be at least partially applicable to port and airport sanitization programs to prevent the snake from dispersing from Guam. A barrier that stops snake movements in forested areas will probably also block snake movements on an airport tarmac. We believe initial investigations should be directed at forested plots because the low density of naturally occurring snakes in urban areas makes it extremely difficult to monitor the degree of snake reduction obtained in urban areas; discoveries of snakes in ports are ambiguous, as they may have entered in cargo or vehicles rather than having breached port perimeter barriers or evaded local control devices; and different control techniques are needed for urban and forest areas (the techniques that are best suited to snake eradication in ports, e.g., fumigation and breakdown searches, are not appropriate for forest plots).

Our plan is to eradicate snakes by surrounding a selected forest plot with a snake barrier and lowering the snake population inside the barrier with some combination of active and passive control techniques. Active control methods involve the direct removal of the resident snakes by poisoning, trapping, or hand capture. Passive control methods depend on the cumulative population depletion that occurs when snakes move across barriers that do not allow them to return.

FACTORS OF SCALE IN EXCLOSURE DESIGN

There is little doubt that Brown Treesnakes can be excluded from small areas by a combination of barriers and control. The central question is how large an area

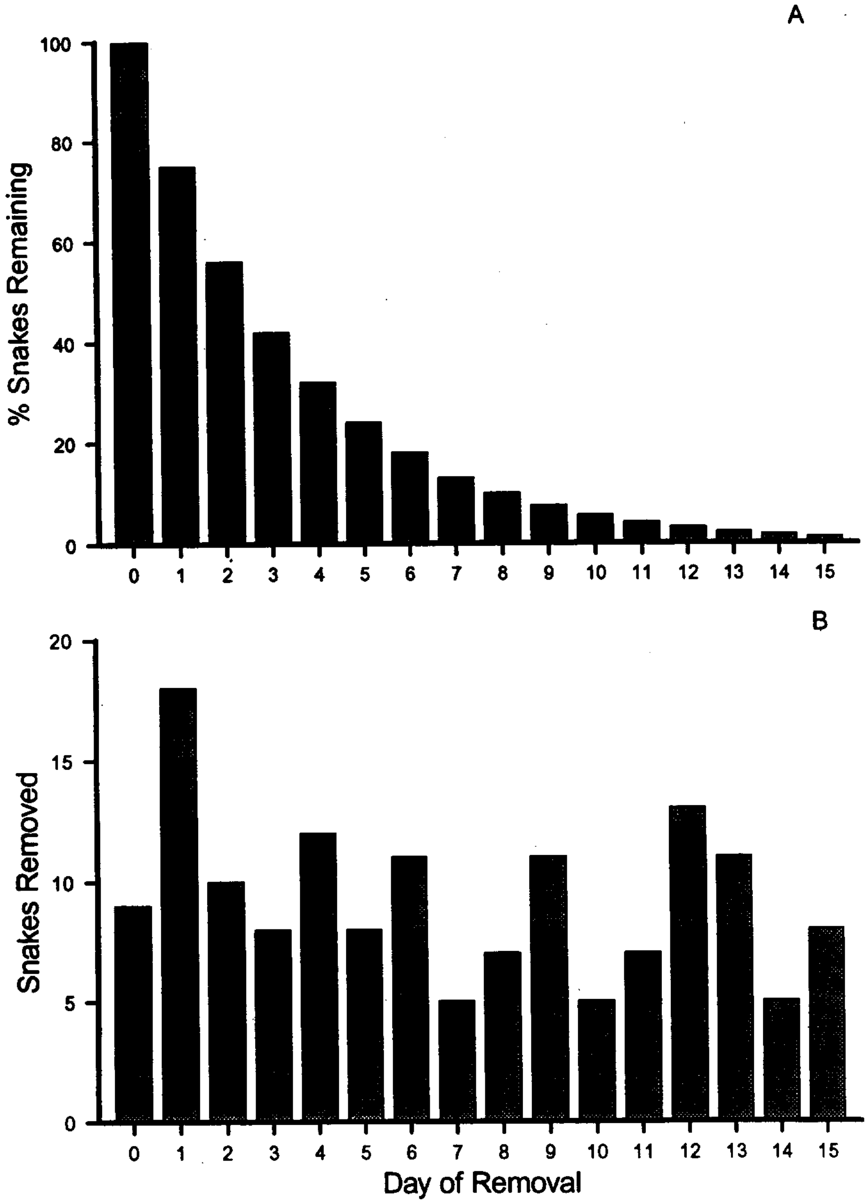

Figure 39.1 Evidence for high immigration-emigration rates of *Boiga irregularis* based on a comparison of theoretical removal schedule for snakes captured at the rate of 25% of the population removed per day, assuming no immigration or emigration (A), and actual number of snakes removed from a 1.5 ha plot on Orote Peninsula, Guam, during 15 days in 1991, with no barriers to immigration or emigration (B).

can be cost-effectively managed with this approach. The costs and efficacies of various approaches can be expected to scale at different rates. For example, barrier costs scale approximately as the periphery of the area. Active control costs scale proportionally to the surface area rather than the diameter. Passive control measures depend for their effectiveness on the nearness of the barrier to any spot in the interior. Using passive control methods in very large areas may require that the area be elongate or subdivided by internal barriers, thus increasing perimeter length and barrier costs.

These conceptual issues must be mated with practicalities. For example, although barrier costs are relatively less expensive for large areas, larger areas are more likely to include difficult terrain (such as subterranean fissures, streams, or boulder piles), which requires enormously increased expenditures or entails reduced effectiveness. Furthermore, the forest on Guam has been fragmented by intensive development and there are few available sites for larger plots. There are hundreds of potential sites for 1 ha plots, but only a few forested tracts of 100 ha, and the latter include patches of difficult terrain.

Compared with passive control, active control requires more labor and manipulation of the site and is therefore more expensive (although possibly more effective) at all plot sizes (Fig. 39.2). The cost curves have different shapes because the expense of passive techniques scales with the length of the barrier, whereas the expense of active control increases directly as the size of the area protected.

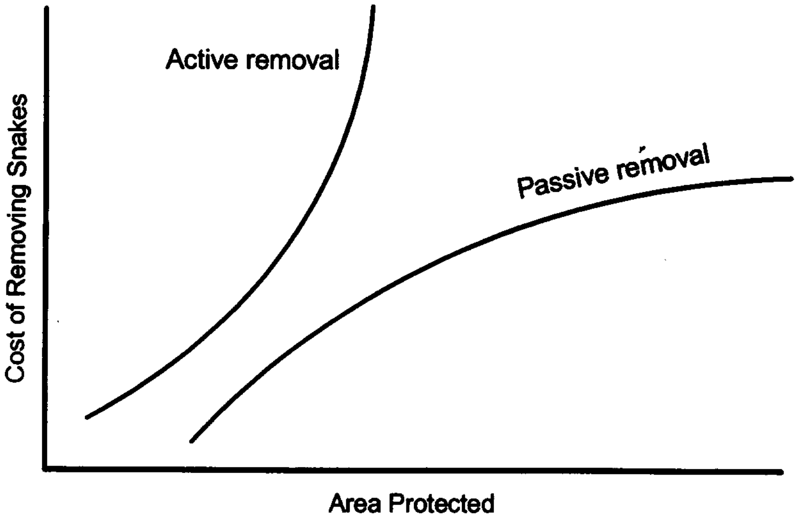

Figure 39.2 Relation between the size of the area protected and the cost of removing snakes from the area by either active removal, such as trapping and hand capture, or passive removal, in which immigration is prohibited and emigration encouraged with a one-way barrier fence.

Unfortunately, in very large areas it becomes more difficult to eliminate all snakes, as the uncertainty of whether the last snake has been caught is compounded by the uncertainty as to where any holdouts are located. For very large plots to be successful, as yet undeveloped technologies such as biological control or broadcast toxicants may be needed.

If one were to construct an expanding concentric series of snake exclosures in a snake-infested forest, the more peripheral plots would tend to reduce snake contact with interior barriers and hence reduce the risk of barrier failure. In this sense, the greater the aggregate area protected, the less the relative risk of barrier failure.

THE LEGACY PROJECT

To identify actual values for these theoretical curves, we are embarking on a staged investigation of exclosure technology using progressively larger exclosures. With support from the U.S. Department of Defense's Legacy program, phase I of the project will involve four 1 ha areas, in which we will quantify the leakage rate of snake barriers and determine if prey species increase in abundance after the snakes are removed. In phase II we will compare the cost-effectiveness of active or passive control technologies at the 5–10 ha scale. Phase III will use 35–50 ha exclosures in the operational protection of endangered species.

Phase I

Two of the four 1 ha plots to be used in phase I are control plots; there will be no removal or exclusion of snakes from these plots. The remaining two plots will have barriers and active (trapping and hand collecting) and passive (one-way fences) snake control. If necessary, we will use a variety of attractants and trap designs to capture the full spectrum of snake sizes (see Rodda et al., this volume, Chap. 20). For 18 months all four plots will be subjected to identical monitoring of snakes, geckos, skinks, rats, and birds. All plots are in simplified, early second-growth tangantangan (*Leucaena leucocephala*) forest. They are near each other, but not coterminous, in a 7 ha area near the northern tip of Guam (Fig. 39.3).

Predator and prey populations in all four areas will be monitored prior to exclosure construction. Following construction, but before the electric fence is activated, all plots will be monitored for a second pretreatment assessment to estimate disturbance due to construction activities. All snakes and rodents captured during the pretreatment monitoring will be released after being permanently marked with PIT tags (passive integrated transponders; Camper and Dixon, 1988). The barrier will be an electrified fence, following the design of Campbell (this volume, Chap. 21). Once the barrier is electrically activated, all snakes found within the treatment plots will be removed. Removal will continue until no snakes have been captured for a uninterrupted period of 20–32 days (until the probability of a remaining snake is <0.05, as estimated by $\hat{p}$). Three

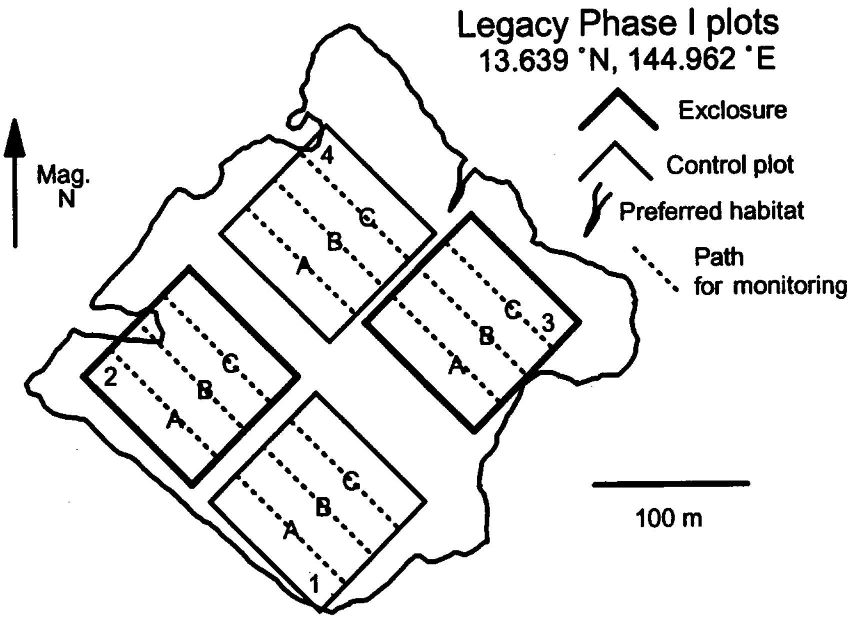

Figure 39.3 Arrangement of treatment (snakes removed) and control plots in phase I of the Legacy exclosure program.

months after beginning the snake removal we will conduct a second formal snake removal to capture any snakes present, focusing especially on hatchlings that might have emerged in the exclosures during the intervening period. Post-treatment monitoring of all species in all plots will continue for 18 months.

We will check each captured snake for the presence of PIT tags. All new snakes captured in the control and surrounding areas will be released after PIT tagging. If snakes that were released with PIT tags in the control plots or areas surrounding the exclosures appear inside, we will know snakes are breaching the barrier fences. We will compare the prey densities in the treatment versus control plots and between pre- and posttreatment censuses for evidence that predator removal has had an effect.

Phase II

Active and passive control measures will have been used in combination in phase I to maximize snake eradication. To compare their relative efficacies, we will use them separately, on 5–10 ha exclosures, in phase II. The 5–10 ha exclosure size was chosen with the recognition that this size is large enough to protect bird and mammal colonies or individuals but is still a managable size for problem resolution. It is too small to protect viable populations of most endotherms.

We will select the designs to be tested in phase II on the basis of phase I experience. We will build two 5–10 ha exclosures (which may be internally subdivided), one of which will incorporate active removal while the other relies exclusively on passive control. The passively managed area will be visited by humans only when required for population monitoring. Humans will enter the active control plots for monitoring, trapping, and hand capture. We recognize that it is unlikely that all snakes will vanish from the passively managed exclosure. However, our goal of determining the relative cost-effectiveness of the two techniques will be met by whatever combination of costs and snake reduction are obtained. In both sites we will omit the expensive monitoring of lizards, but we will monitor snakes (to assess the degree of control obtained), rodents (to determine if rat control becomes necessary), and birds (to document the primary benefits of snake exclusion).

Phase III

The goal of phase III is the cost-effective protection of endangered species in perpetuity using one or more 35–50 ha exclosures. Although any population confined to a 35 ha exclosure is not a substitute for a wild population, we believe a self-sustaining semiwild population is vastly preferable to a captive population. Captive animals are often deprived of essential natural experiences that promote the learning of vital skills and may lose the ability to perform essential maintenance behaviors. Captive populations may evolve in inappropriate directions in response to artificial features of captivity, including inadvertent selection by human caretakers. Small wild populations, by contrast, are unlikely to be seriously influenced by factors affecting captive individuals, and extensive management experience with semiwild populations can be used to address the more tractable conservation biology questions that will eventually arise with small protected wild populations (Schonewald-Cox et al., 1983; Soulé, 1987; Berger and Cunningham, 1994). In addition, the existence of free-ranging native birds may promote public interest, appreciation of, and support for wildlife on a remote island whose inhabitants have few opportunities to view native vertebrates.

The phase III exclosure may have internal subdivisions to facilitate sequential active or passive removal of snakes. Active control will be used only if necessary. Control actions will be repeated at appropriate intervals to offset the unavoidable leakage of snakes into the area. The phase III exclosure will be an appropriate place to eradicate other introduced species (Savidge, 1984), such as noxious weeds or disruptive exotic ungulates. We believe the phase III exclosures have the potential to be a model of comprehensive restoration ecology, providing an irreplaceable opportunity for the public to experience the full vitality of native Pacific ecosystems.

IS SNAKE CONTROL FEASIBLE IN SMALL PLOTS?

Habu researchers have not been successful at eradicating snakes from any areas (Hayashi et al., 1983, 1984; Tanaka et al., 1987; Shiroma and Akamine, this volume, Chap. 24), including small islands (Katsuren et al., this volume, Chap. 25). Knowing this, why are we forging ahead? One reason is that total eradication of Brown Treesnakes is probably not necessary to restore native endotherms. In many ecosystems, including those of oceanic islands such as Palau, native birds and mammals thrive in communities that include abundant snake species. Coexistence is possible, in part, because the native snakes in those areas have not reached the extraordinary densities attained by the Brown Treesnake during its initial irruption on Guam (Rodda et al., this volume, Chap. 17). Although research to determine the level of snake predation that can be sustained by populations of Guam's native endotherms should receive a high priority, we expect that some predation may be possible without loss of species.

A second reason for optimism is that controlling the Brown Treesnake in forested areas on Guam may be easier than controlling the Habu in villages in Japan, for three reasons: (1) trap success rates for Brown Treesnakes are 10–100-fold higher (Rodda et al., this volume, Chap. 20); (2) Brown Treesnakes move more often and move greater distances than Habu, facilitating passive control (compare Tanaka et al., this volume, Chap. 15, with Rodda et al., Chap. 2) and facilitating control over large and partially inaccessible areas; and (3) complete barriers can be used to control Brown Treesnakes in forests, whereas all Habu barriers require gaps to allow human passage. We believe these differences will allow us to control Brown Treesnakes in small exclosures. Our challenge is to determine the circumstances under which exclosures can be a cost-effective management tool.

Addendum

At press time, snake elimination from 1 ha exclosures has been successful, with an associated increase of 50–100% in the abundance of lizard prey after one year of snake exclusion—GHR.

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