20 A State-of-the-Art Trap for the Brown Treesnake

Gordon H. Rodda
Thomas H. Fritts
Craig S. Clark
Steve W. Gotte
David Chiszar

Traps can be used to reduce the density of snakes in high-priority sites such as homes, ports, airports, and wildlife areas. To be of practical value, however, traps must capture a high percentage of the resident snakes and must be easy to use. Between 1985 and 1993 we greatly improved trap convenience and effectiveness. Savidge (1986, 1987, 1991) used traps to quantify snake densities and document Brown Treesnake (*Boiga irregularis*) predation on trapped birds. Fritts and his coworkers (Fritts and Scott, 1985; Fritts et al., 1989) tested several trap designs and demonstrated the effectiveness of an inanimate attractant. Rodda et al. (1992b) showed the practicality of using live geckos as lures, discovered that large numbers of snakes were escaping from open-funnel traps, and showed that selected design elements (olfactory guide ropes, soft flaps, double funnel entrances) were not successful. Fritts and McCoid (unpubl. data) demonstrated that snap traps baited with mammal attractants were relatively ineffective (less than 0.0002 captures per trap-night). More recently, we showed (Rodda et al., 1992a) that high capture rates are possible with live mice as attractants, opaque chambers are effective, and flap entrances can be successful. Rodda and Fritts (1991) argued that increased trap effectiveness made it practical to use traps for operational snake control. Rodda and Fritts (1992) discussed the merits of traps and other capture methods for scientific sampling of Brown Treesnake populations. To date, we have used 49 snake trap designs for a total of more than 24,000 trap-nights of tests. In this chapter we describe the state-of-the-art trap, review the experiments that led to the currently favored design, and outline unresolved facets of Brown Treesnake trap design.

DEFINITIONS

The capture rate of a trap is the number of captures per trapping event, often given as a percentage. In the studies described below, each trapping event is a single trap for a single night, or one trap-night. Thus a 2% capture rate represents two snakes captured from 100 traps set for one night (or from one trap set for 100 nights, etc.). As a result of multiple captures, we sometimes obtain capture rates greater than 100%.

Traps were checked each morning; however, we have seen snakes enter and escape from a trap before the morning trap check. The frequency of escapes can be estimated using a crushable object in the trap (we used a piece of aluminum foil shaped into a cylinder). Brown Treesnakes larger than about 1 m snout-vent length (SVL) invariably crush the foil cylinder while moving around in the trap. Smaller snakes usually crush the foil cylinder. Thus the presence of crushed foil in a snakeless trap (a "crush") indicates at least one escape. The presence of crushed foil in a trap that holds a snake at the standard trap check time is not counted as a crush; it is a capture. The escape rate is the number of crushes as a percentage of the corresponding trap entries (entries = crushes + captures). The retention rate is the complement of the escape rate (e.g., if the escape rate is 40%, the retention rate is 60%). The entrance rate is entries per trap-night. Because of escapes, the capture rate is smaller than the corresponding entrance rate. The capture rate (captures/trap-night) equals the product of entrance rate ([crushes + captures]/trap-night) and retention rate (1 − [crushes/{crushes + captures}]).

Entrance rate is a useful statistic for comparing the potency of attractants. Retention rates are useful for documenting the efficacies of features that prevent or discourage snakes from escaping. Capture rate is a widely used statistic for comparing overall trap effectiveness. To compare capture rates, however, trapping events should be of the same duration, unless escape rates are negligible and all captures are independent (assumptions rarely satisfied).

Capture rate is a statistic often used to compare trapping results from different sites. More captures are expected in areas with more snakes, however, and a highly effective trap might have 2% success in an area with few snakes while a poor trap might have 7% success in an area of high snake density. Thus a better measure for comparing trap effectiveness is $\hat{p}$, the estimated average probability that a given snake will be caught during a capture event; $\hat{p}$ is a density-corrected expression of capture rate. If an array of traps exhibits a $\hat{p}$ of 25%, about one-fourth of all snakes will be captured by that array in a single event. Thus $\hat{p}$ is useful for comparing trap array efficacies. However, all measures of capture success, including $\hat{p}$, are sensitive to the interaction between the environment and trap design. For example, traps that work well in areas with few prey may be less effective (have a lower $\hat{p}$) in areas of high prey abundance. Closely spaced traps will catch a greater proportion of the resident snakes (higher $\hat{p}$) than will widely spaced traps, but the capture rate (captures/trap-night) will often be lower for closely spaced traps. Trap effectiveness ($\hat{p}$ or capture rate) depends on context. A disadvantage of $\hat{p}$ is that the abundance of snakes must be known to estimate it. Snake abundance is not known for most trap sites, and when available, the population size estimates often have extremely wide confidence intervals.

The two values used to compare overall trap efficacies, $\hat{p}$ and capture rate, are easy to confuse with each other because they are similar in magnitude and both are often given as percentages. The capture rate and $\hat{p}$ are equal only when the population of snakes being sampled coincidentally numbers 100; $\hat{p}$ can only be used to describe the yield from an array of traps; capture rate can be computed for arrays or single traps.

SUMMARY OF METHODS

Readers should consult the papers cited above for full methodological details. Our successful Brown Treesnake traps are "minnow" traps: mesh cylinders about 50 cm long × 20–30 cm diameter with inward-pointing funnel ends. We captured a few snakes using adhesive traps, but our capture rates with these traps were too low for control use in field situations. The minnow traps had live prey or prey compounds as attractants. Mice were protected by metal cages; they could not be eaten by snakes. Most traps were hung 1–2 m high, spaced 15 m apart in a square array in a forest. Traps were checked each morning, at which time captured snakes were marked and released at their place of capture. Attractant animals were replaced or refreshed as needed. We monitored the traps for periods ranging from 20 to 49 days. Because it is impossible to directly compare trap efficacies from different sites and times, we prefer to compare design permutations that are tested simultaneously in a randomized Latin square array. Most comparisons had three dimensions, each with two states, for a total of eight permutations. The use of balanced designs allows us to base statistical comparisons on numbers of entries or captures rather than rate values. We use rates to compare nonsimultaneous comparisons.

SELECTED RESULTS

Trap Design

Our currently favored trap, a modified commercial minnow trap, has a body of 6 mm galvanized steel mesh. In a simultaneous comparison, commercial minnow traps (Cuba Specialty Co., Fillmore, N.Y.) outperformed hand-made window-screen traps (Fritts, 1988). Minnow traps caught more snakes (211 vs. 164; $G = 5.906$, $df = 1$, $P = 0.015$), and more snakes entered minnow traps (305 vs. 223; $G = 12.78$, $df = 1$, $P = 0.0003$). There was no evidence that the escape rate differed between trap types (94 of 305 vs. 59 of 223; $G = 1.19$, $df = 1$, $P = 0.27$). Commercial traps are of uniform quality and are easier to use. Window-screen traps are more easily damaged by nontarget animals, especially crabs. Both types are useful, however: commercial minnow traps capture only about 25% more snakes than window-screen traps, and window-screen traps may be preferred on islands where commercial traps are difficult to acquire. Bulk window screening is easy to transport to remote sites for assembly of traps in situ.

Solid plastic traps performed very poorly in a matched comparison with window-screen traps (capture rates 0.09% vs. 0.96%) and should not be used without additional testing. This result differs from that experienced by Habu (*Trimeresurus flavoviridis*), researchers, who routinely use solid traps (Hayashi et al., 1979, 1984b; Tanaka et al., 1987; Hattori, this volume, Chap. 18), although some solid designs work poorly (Kihara et al., 1978). The arboreal Brown Treesnake may be less inclined than the terrestrial Habu to enter a burrowlike solid trap.

The designs we currently favor are traps with either a plastic roof (to protect the attractant) or a surrounding cylinder of black plastic sheeting forming a sleeve. Unlike the solid plastic traps, which performed poorly, our plastic-sleeved mesh traps are not completely opaque, and they allow air flow through the mesh ends. We hypothesized that darkened traps might provide an appealing refugium for Brown Treesnakes. In addition, Lankford (1989) showed that Brown Treesnakes were more likely to enter chambers to investigate chemical cues if the contents of the chambers were not visible. We compared the capture rates of traps surrounded by black plastic with identical traps with only the top half of the trap covered by black plastic. The number of snakes entering the sleeved traps was insignificantly greater (277 vs. 251; $G = 1.28$, $df = 1$, $P = 0.26$), although there was a slight but significant reduction in the escape rate with sleeves (66.5% vs. 75.1%; $G = 4.68$, $df = 1$, $P = 0.030$) and therefore a significantly higher number of captures (208 vs. 167; $G = 4.49$, $df = 1$, $P = 0.034$). This supports the use of a sleeve in situations for which the escape rate is a consideration. The sleeve may be undesirable on flap traps, which have a negligible escape rate, because the sleeves trap heat and may place additional thermal stress on captive and attractant animals.

Inside each trap we place a hide, or refugium tube, a 200–300 mm length of 50 mm (inside) diameter black plastic pipe. These may function by withholding visual information in the manner noted by Lankford (1989). In a simultaneous comparison, more snakes entered traps with hide tubes than entered traps lacking hide tubes (283 vs. 234; $G = 4.65$, $df = 1$, $P = 0.03$). In that test, with open-funnel traps, fewer snakes escaped from the traps with hide tubes; thus the capture totals differed more (215 vs. 130; $G = 21.16$, $df = 1$, $P < 0.0001$). The escape rate difference may be due to the snakes being less motivated to escape when they have ready access to tubes that give them shelter from bright light, drying wind, and rising daytime temperatures. However, the significant improvement in number of entries into traps having hide tubes suggests that tubes should be used even in traps from which escape is not possible. To our knowledge, refugium tubes have not been used to enhance capture success in other snake species.

Trap Placement

Our current trap is placed 1–2 m high in forested areas. We have not tested traps in urban or agricultural areas. In one test we placed traps at the top of a chainlink fence known to be regularly used by Brown Treesnakes. The capture rate was very low (0.19%), for reasons that have not been determined. When we compared breast-high placement of traps in forested areas with ground-level traps, we had few captures in either location (average capture rate 0.08%). Although the breast-high traps captured seven snakes and the ground-level traps captured only one, this difference was not significant with such a small sample size ($G = 2.75$, $df = 1$, $P = 0.097$). Damage from nontarget animals such as crabs was much greater in the ground-level traps, leading us to discontinue their use.

We did not use drift fences or features other than attractants to concentrate snakes near the traps (cf. Imler, 1945; Campbell and Christman, 1982). Drift fences have been widely used for capturing terrestrial snakes, but most Brown Treesnakes in Guam move above ground level. Furthermore, the soil in Guam does not allow the routine placement of drift fences. Inspired by Chiszar et al. (1988), who found that captive Brown Treesnakes used odor trails to locate rodent nests, we attempted to lead snakes to traps by draping bird-litter-scented ropes through the forest toward the entrances of traps. The traps with the olfactory guide ropes captured fewer, not more, snakes (15 vs. 24). We discontinued the use of these ropes, although we believe the concept is valid and will work if an appropriate chemical cue can be discovered.

We found it judicious to minimize disturbances by limiting visits to trap areas. The traps that were monitored immediately after construction of adjacent trails exhibited three to five days of below-average trap success, whereas traps that were monitored after leaving the forest undisturbed for the preceding five days exhibited normal entrance rates from the first day. Trapping success in the middle of the trapping period was usually reduced on the nights when we concurrently conducted visual searches of trap areas. We are still testing the effects of disturbance. Our working hypothesis is that trap captures are higher when trap areas are not disturbed.

The most effective traps are those placed in areas known to produce high trap yields. This recommendation has little practical value, but it does point up an unresolved problem in the placement of traps. There is a poorly understood interaction between trap design and the environment. For example, identical gecko-attractant traps had capture rates of 2.9% and 0.14% at two sites on Guam (Orote Point and Northwest Field, respectively). Although snakes were estimated to be about 60% more abundant at Orote, this does not account for the 2086% greater trap success there. Identical traps with mouse attractants had capture rates of 25.3% at Orote in 1990, 18.3% at Orote in 1991, and 3.3% at a different Northwest Field site in 1992. Again, differences in snake density account for only part of the difference in capture rates. Preliminary data indicate that the structure of the forest and the abundance of natural prey may influence snake trap success. Seasonal changes in capture success need to be evaluated. All interactions between trap design and environment merit further testing.

The distance between traps depends on the reasons for trapping. If the goal is to maximize p (the percentage of the population trapped), the traps should be set as close together as is practical. If the per-trap capture rate is to be maximized, traps should be spaced more than 15 m apart. This criterion is based on several lines of evidence indicating that traps placed 15 m apart (or less, presumably) are in some sense competing for the same snakes (Rodda et al., 1992a, for Brown Treesnakes; for Habu, see Hayashi et al., 1979; Hattori, this volume, Chap. 18). For example, mouse-attractant traps at Orote exhibited the following capture rates: 18.3% for traps spaced at a trap density of 44/ha in 1991, 25.3% for traps spaced at 22/ha in 1990, and 60.1% for traps spaced at 5/ha in 1992. Snake densities did not differ significantly among these venues.

The shape of the mathematical function describing capture rate by trap spacing has not been established for any species-environment combination. The function will depend on trap design elements such as attractant type, because the sampling radius of a trap is partially dependent on the attraction radius of the attractant. For example, a trap could capture snakes within 100 m of the trap during a given night. The natural movements of the snakes might account for 90 m of this sampling area, while snakes that travel to within 10 m of the trap might be attracted to the prey. Two traps placed 50 m apart in such a situation have the potential to capture the same snake in the same night. Once caught, a snake is unavailable to neighboring traps. If the traps are checked weekly, the sampling radius of such a trap might be 500 m, of which 490 m might be due to the snakes' weekly movements. Thus the degree of competition among traps will depend on the frequency of trap checks. If capture rate is to be maximized, traps that are checked infrequently should be relatively widely spaced.

A practical problem arises when traps are used to reduce snake densities near an object such as a freight container or a nest tree of an endangered bird (Aguon et al., this volume, Chap. 38). If more snakes are attracted toward traps than are actually captured, placing the trap near the nest or container could increase the chances that a snake approaching a trap would find the nest or seek refuge in the container. The problem can be viewed as a matter of determining the degree to which the sampling radius of a trap is the result of the attraction radius of the trap or the natural movements of the snake. The natural movements of the snake cannot be controlled, but the traps should be placed so that their attraction zones draw snakes away from protected objects. We have not identified a way to precisely quantify the limits of the trap attraction zone.

Attractants

We used live mice as attractants. In similar but not identical situations, mouse-attractant traps exhibited capture rates of around 24% compared with 6% for live quail, 3% for live geckos, and 1% for bird litter. No direct comparison between endothermic prey has been conducted because live quail are no longer readily available on Guam. In a simultaneous comparison between live mice and live geckos, the mouse-attractant traps had not only more entries (465 vs. 52; $G = 379.3$, $df = 1$, $P < 0.0001$), but also a lower escape rate (30% vs. 60%). Thus the capture rates varied 15-fold (324 vs. 21; $G = 314.6$, $df = 1$, $P < 0.0001$). Work in progress with inanimate attractants indicates that blood, a commercial catfish bait, and a commercial snake bait did not differ among themselves in attracting snakes. Each exhibited approximately 1/20th the capture rate of traps supplied with live mice in a simultaneous comparison. Despite this limited success, we will continue to test inanimate attractants, because the discovery of a durable inanimate attractant would greatly improve the convenience of snake trapping. Habu researchers have reached similar conclusions: rodents are a highly effective attractant (e.g., Hayashi et al., 1979), but inanimate attractants are a high research priority (Kihara et al., 1978; Niwa et al., this volume, Chap. 11; Hattori et al., this volume, Chap. 18).

In the trap, the live mouse is housed in a rectangular chamber of 3 mm metal mesh closed with a rigid but porous metal cap (Fig. 20.1) and furnished with a slice of potato for moisture and a mix of grains for food. We replenish these every five days.

Entrances

The state-of-the-art trap has a device for keeping the snakes in the trap. Arboreal snakes tend to spread their weight over a large number of supports; thus we have not experimented with a treadle trap, as we judge that the sensitivity required to detect the partial weight of a small snake (total mass < 10 g) would probably result in a trap that triggered prematurely in response to movements of the trap in the wind or movements of the attractant animals or trap motion induced by other animals, especially crabs, climbing on the outside of the trap. Furthermore, treadle traps are usually limited to one capture before they must be reset; our traps frequently have multiple captures per night. We experimented with long entrance funnels to reduce the escape rate; but in a matched comparison, the long funnels had a *higher* escape rate (38% vs. 32%).

One successful device for forcing a snake to remain in a trap is a glueboard. We used the paper glueboards sold for capturing household mice (Victor Holdfast traps, Woodstream Corp., Lititz, Pa.). In a simultaneous test of traps in which the glueboard was either flat in the trap or rolled inside the hide tube, the rolled glueboards caught almost twice as many snakes (34 vs. 20), although the small sample precluded statistical significance ($G = 3.67$, $df = 1$, $P = 0.055$). Surprisingly, a larger proportion of snakes were not stuck to the glueboard in the traps with the exposed glueboards (7 of 20 vs. 2 of 34; $G = 5.32$, $df = 1$, $P = 0.021$). Thus traps with glueboards inside tubes not only catch more snakes, but such glueboards are also more likely to adhere to their victims. When open-fun-

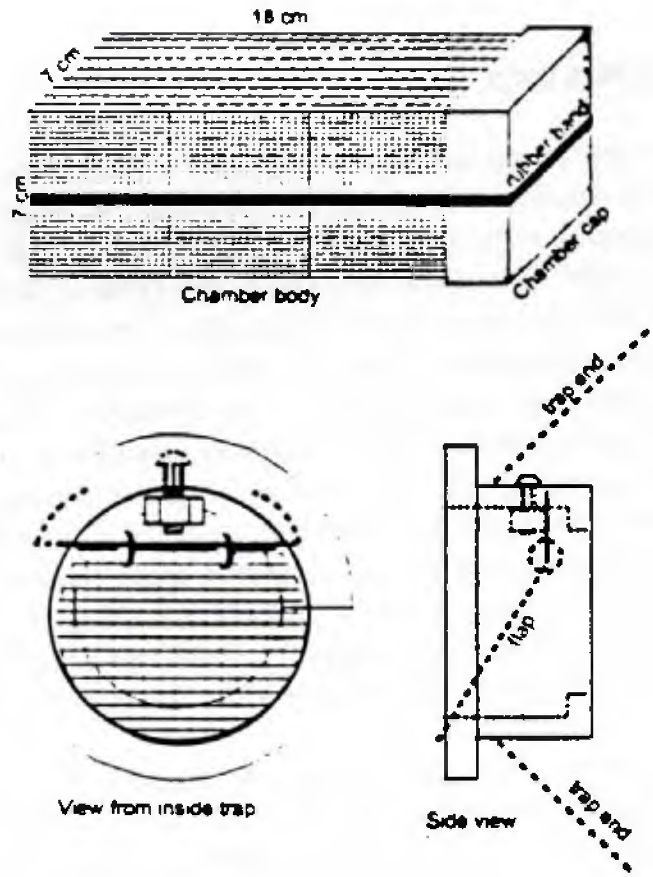

Figure 20.1 Designs for mouse chambers and entrance flaps. The mouse chamber body is constructed of 3-mm galvanized steel mesh made into a tube with a double-roll seam. The tube is squared and cut at the corners on one end to create four end flaps, which are folded to close one end of the box. The chamber cap is made from perforated sheet metal stamped into a shallow open box slightly larger than the chamber body. The chamber body is slipped inside the cap, and the two are held together by a heavy rubber band.

The flap housing is a plumbing fitting, a 2 × 1.5 inch flush bushing of ABS plastic. It is drilled to accommodate the hinge pin and the bolt above the hinge pin. The bolt functions only to fill the space above the hinge that a very small snake could escape through. A tilted flap is shown; a vertical flap has a smaller door that hangs vertically against the inner lip of the housing. The flap is made from either 6-mm black plastic mesh or galvanized steel mesh, and is attached to the hinge pin with small metal rings (bent wire or jewelry rings). When using wire mesh flaps it may be necessary to fold over protruding wires so they do not bind on the housing. The hinge pin may be either a straightened chrome-plated paper clip or stainless steel wire. The hinge pin is longer than the width of the housing, with the excess length bent sharply around the outside of the housing. The housing is forced into the 55 mm opening of a crawfish-style minnow trap (Cuba Specialty Co., Fillmore, N.Y., or equivalent) from the inside. The flange on the housing makes it impossible for a snake to push the housing out; the trap ends squeeze the housing between the screw head–hinge pin ends and the flange, making it difficult for the housing to be pushed in (animals are not likely to push inward, except against the flap, which opens easily).

nel (i.e., flapless) traps were supplied with glueboards, the estimated escape rate dropped from 38 to 4%.

A disadvantage of glueboards is that they must be replaced periodically. The frequency with which glueboards must be replaced has not been established, but the accumulation of dust and moisture on the glue surface degrades the adhesive properties of glueboards on a scale of days. Glueboards cost $0.50–1 each. Kihara and Yamashita (1979) tested the ability of glueboards to administer dermal toxicants to Habu. Knight (1986) reported high capture rates for glueboards used to capture snakes in and under buildings. To our knowledge, glueboards have not been used previously to retain snakes in enclosure traps.

In the 1991 experiment described above, flapless traps had an average escape rate of 38%. That experiment used live mice as attractant and included hide tubes in the traps. Both features reduced escape rates. In a recent experiment with traps possessing hide tubes and mouse attractant, however, the escape rate was 66%. Traps lacking these features sometimes have average escape rates in excess of 80%. Thus it is possible to substantially improve the capture rate by adding a flap, glueboard, or other device to force snakes to remain in traps. In our experiments all flap designs had escape rates of 2–4%, and we found no difference in escape rate among the flap designs tested.

A disadvantage of some flap designs is that snakes may be so reluctant to enter a flap trap that the number of captures is lower than that for open-funnel traps, despite the greater escape rate from open-funnel traps. These flaps reduce capture rates. Such a result occurred in our tests of clear acrylic flaps, soft plastic screening flaps, double funnels (the outer entrance was open, the inner entrance had a soft, springy flap), several tests of metal 6-mm-mesh flaps, and our first test of plastic 6-mm-mesh flaps. Given that the latter two were both constructed from 6 mm mesh, they were surprisingly different in their capture totals in the first matched comparison (53 vs. 4 captures; $G = 53.9$, $df = 1$, $P < 0.0001$). A later experiment showed that there is a three-way interaction between flap material, the angle of the flap, and whether or not the flap is painted. A full factorial array of the eight permutations from the above three factors, plus an open-funnel control condition, produced three clusters of capture rates. Four permutations constituted the low-effectiveness cluster: the two configurations of plastic flaps that were painted (the black plastic was painted silver to be the same color as the unpainted metal flaps) and the two metal flaps that were vertical (i.e., flush with the surrounding housing; Fig. 20.1). The open-funnel traps were intermediate in capture rate. The high-effectiveness cluster had capture rates about 1.7 times those of the open funnels ($G = 4.23$, $df = 1$, $P = 0.04$) and 2.5–2.8 times the capture rates of the poor cluster ($G = 16.29$, $df = 1$, $P < 0.001$). The high-effectiveness cluster consisted of the tilted metal flaps (paint did not matter with metal flaps) and the unpainted black plastic flaps (angle did not matter with plastic flaps). The state-of-the-art trap has one of the four better flap designs.

We are puzzled by the absence of an obvious explanation for the variation in capture yields among flap designs. The best flap designs that we have tested have a lower entry rate than open-funnel traps, but a higher capture rate. Therefore, an opportunity exists to discover a flap design that combines the high entrance rate of an open-funnel trap with the low escape rate of a flap trap. Flaps and other entrance obstructions have been widely used in snake traps (Dargan and Stickel, 1949; Fitch, 1951; Vogt and Hine, 1982; see Appendix), but only Habu researchers have systematically tested flaps for their effect on capture rate (Kihara et al., 1978; Hayashi et al., 1979; Hattori, this volume, Chap. 18). In light of our Brown Treesnake results, experiments that compare a single flap design with an open funnel are not sufficient to reveal the full range of efficacies that flaps may have.

Sampling Considerations

Unfortunately, our current trap designs preferentially capture medium- and large-sized snakes. Habu traps have the same problem (Hayashi et al., 1984a; Shiroma and Araki, 1986; Shiroma, 1989; Hattori, this volume, Chap. 18). In all Brown Treesnake trap experiments conducted to date, the snakes captured by hand in the vicinity of the traps exhibited a wider range of sizes than those captured by traps. In some comparisons, a few hand-captured snakes were larger than the trap captives, but most of the difference is attributable to the paucity of small snakes captured by traps (Fig. 20.2). Traps that use geckos as attractants catch smaller snakes than traps that use mice (Fig. 20.3), but we have been unable to extend the range

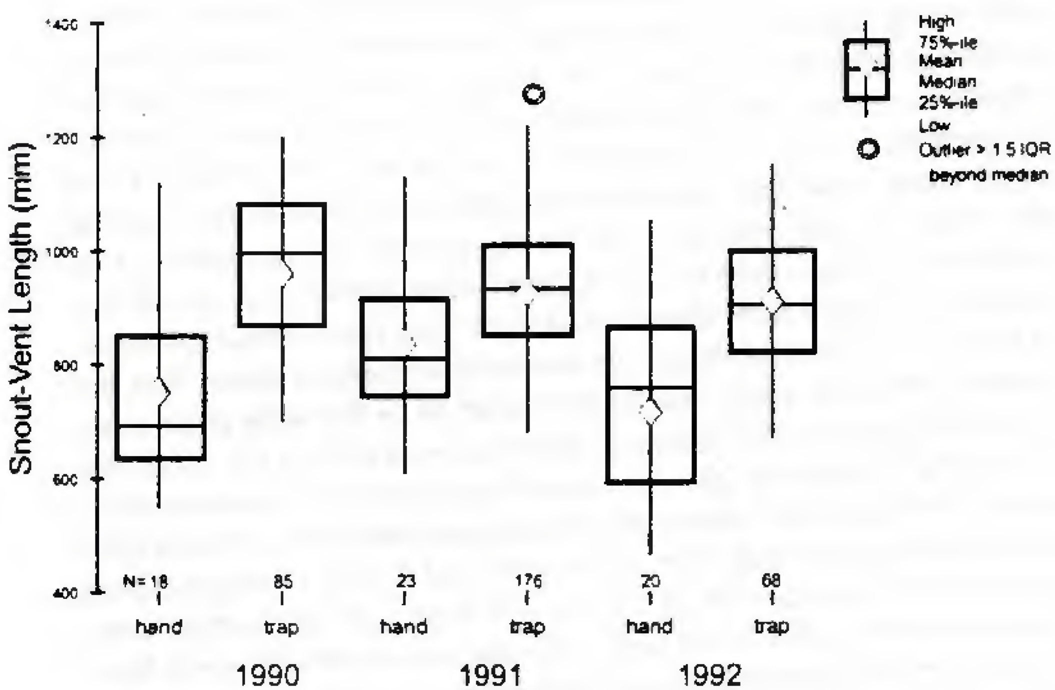

Figure 20.2 Size distribution of snakes caught by trap or hand at three venues. The sample sizes are numbers of different snakes.

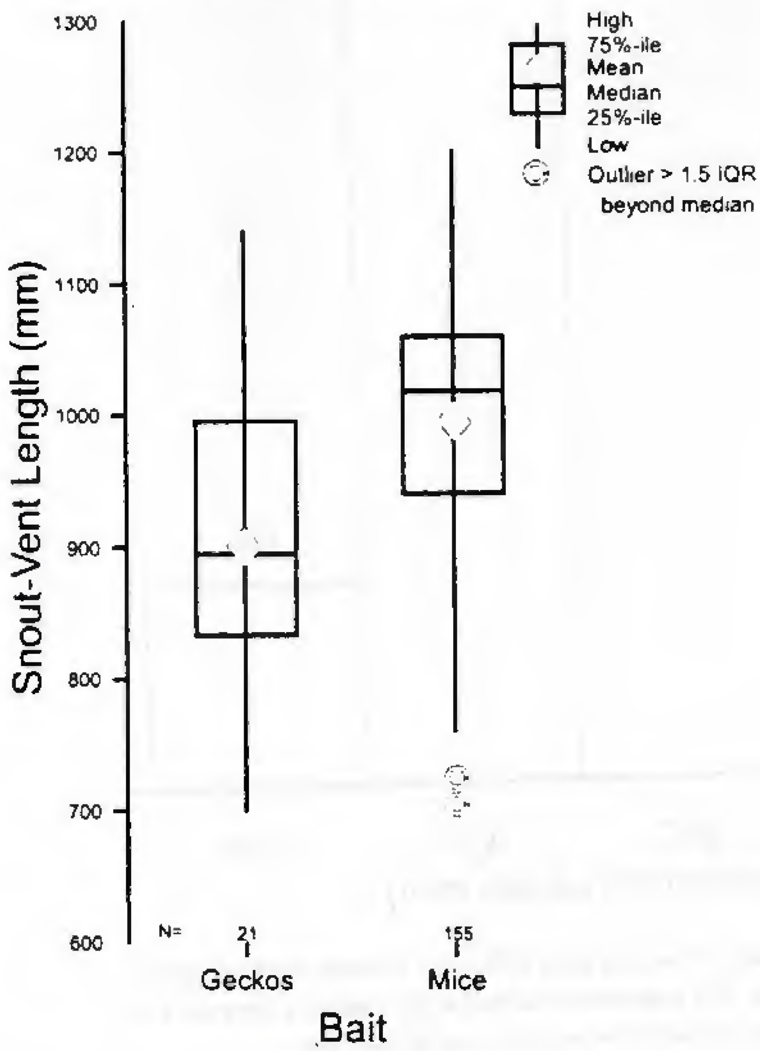

Figure 20.3 The size distribution of snakes caught in mouse- or gecko-attractant traps at Orote Point, Guam, in 1990. Sample sizes as in Figure 20.2.

of sizes caught by simultaneously including in traps both gecko and mouse attractants (a nonsignificant contrary result was obtained).

When snakes of various sizes were placed in empty open-funnel traps, the smaller snakes were the ones more likely to escape (Fig. 20.4); however, we observed a size discrepancy between trap- and hand-caught snakes even when using traps with negligible escape rates (flaps or glueboards; Fig. 20.2, 1992 series). Thus, it appears that small snakes are less likely to enter traps. This limits but does not nullify the utility of snake traps for control purposes. We have assigned a high priority to research to overcome this problem, but the means of solving it are not apparent.

THE UTILITY OF TRAPPING AS A CONTROL TECHNIQUE

The traps we currently favor cost about US$6–12 each for the trap and mouse chamber. There is no commercial supplier for the entrance flaps or mouse chamber (Fig. 20.1). The labor involved in preparing these depends on the quantity

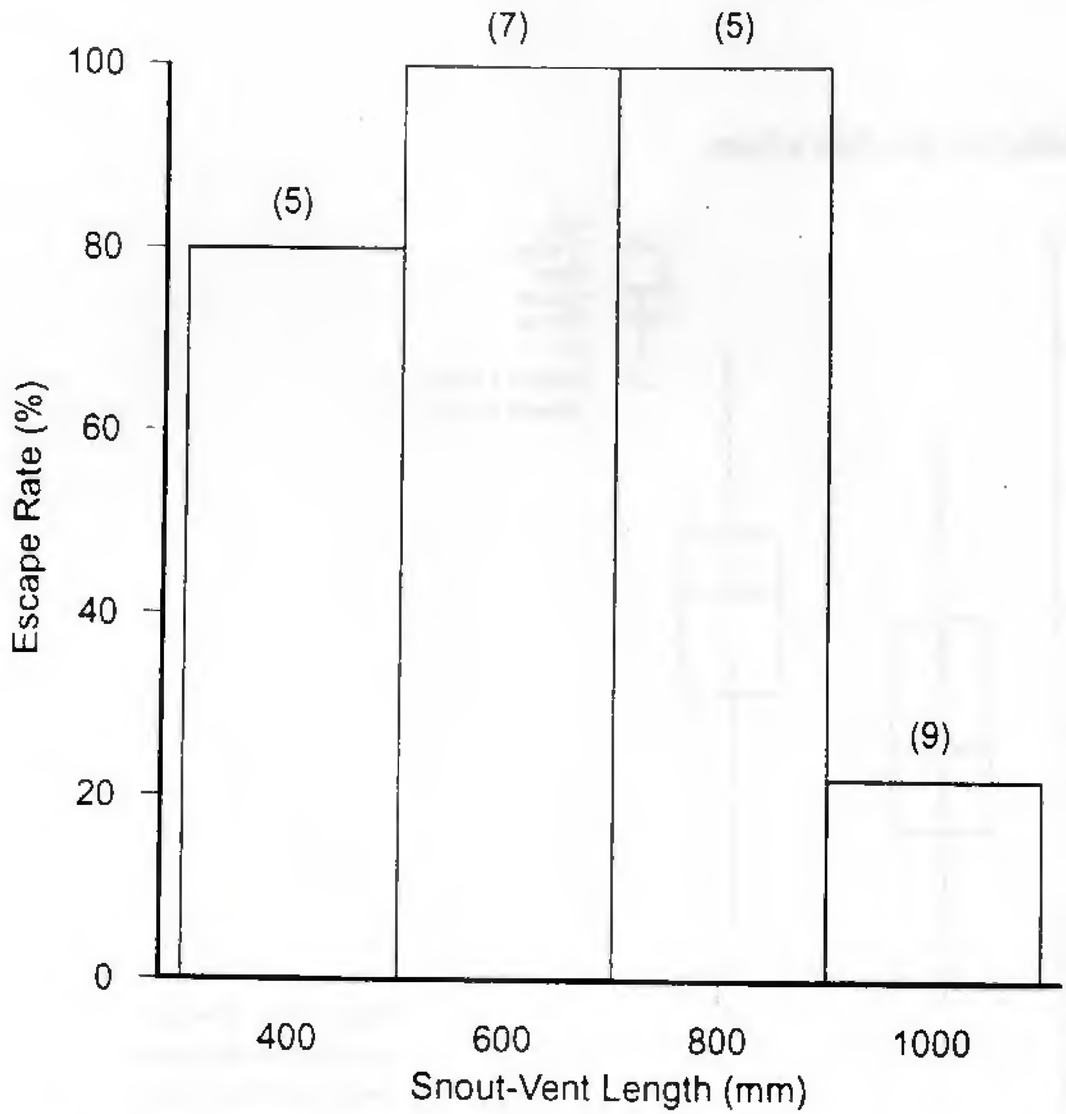

Figure 20.4 The escape rates of snakes of various sizes following evening confinement in unbaited open-funnel screening traps. The traps were checked at the standard time the following morning. The sample sizes are in parentheses at the top of each bar.

desired; materials are $0.50–1 per flap. Prices and availability vary locally for mice. Once established, a colony of 100 mice requires about one hour per day of maintenance. The cost of establishing a trapping area depends on the amount of clearing of vegetation necessary for access to the traps. We spent around 50 person-hours constructing a kilometer of access trails. The labor cost of setting the traps and the labor cost of monitoring the traps depends on the spacing between traps. It takes only a minute or two to hang a prepared trap; it takes a few seconds to check an empty trap that is not damaged. In addition to time spent processing captives, the major time costs while monitoring are replenishing mouse food and traveling between traps. Replacing mouse food takes about 1 minute per trap; traveling between traps takes about 1.5 minutes per 100 m in easy terrain. The number of traps that can be monitored on a routine basis depends on the spacing between traps, the amount of damage the traps sustain, and the frequency of trap checks. We judge that for traps spaced at 25 m intervals, a team of two full-time persons should be able to monitor 300–600 readily accessible traps weekly.

The crucial statistic for assessing the value of trapping for reducing snake populations is $\hat{p}$. We have not been able to determine the cause of variation among sites in $\hat{p}$. Seasonal variation is likely to play a role. The worst site tested to date exhibited an average $\hat{p}$ of about 7%, but we have obtained $\hat{p}$ values as high as 28% with the same traps. The higher rate should make possible the very rapid reduction of snake populations in bounded areas (Rodda et al., this volume, Chap. 39).

In some situations, such as when manpower or traps are limited, it may be desirable to maximize capture rate rather than $\hat{p}$. The discovery of a potential new population, such as on Saipan, calls for a high capture rate to delimit the incipient population. Very high capture rates were obtained with widely spaced traps. For example, the 20 mouse-attractant traps at Orote Point in 1992 achieved an average capture rate over 41 days of 60%. The three best traps in this array averaged 117, 107, and 102%.

A Brief Review of Snake Trapping

How do the Brown Treesnake capture rates compare with those of other snake-trapping experiments? No values for $\hat{p}$ are available. We compiled literature capture rates for 322 species–trap-type permutations (Appendix). Studies using only pitfall traps were not included. About one-third of the available values are for Habu. Typical Habu studies differed in character from the other studies with regard to their use of drift fences (not used), attractant (used), and exit barriers (used). Enclosure traps were used in all cases: snap, treadle, and adhesive traps were not successful at capturing wild snakes.

Drift fences were used in 43% (91 of 214) of the non-Habu studies, but in only 3% (3 of 108) of the Habu studies. To our knowledge, the effect of drift fences on snake capture has not been quantified; an opportunity exists to make this comparison starting with the substantial body of data on Habu trapping in the absence of drift fences.

Only 2% (2 of 108) of Habu trap studies omitted attractants, whereas 49% (105 of 214) of the other studies used none. This may account for the generally higher success rate obtained in the Habu studies (Fig. 20.5). Several varieties of rodents have been used as attractants (*Mus* were used in 107 of 109 non-Habu trap experiments and 87 of 106 Habu trap arrays using attractants), but there is little experience with other types of attractant for any species other than the Brown Treesnake.

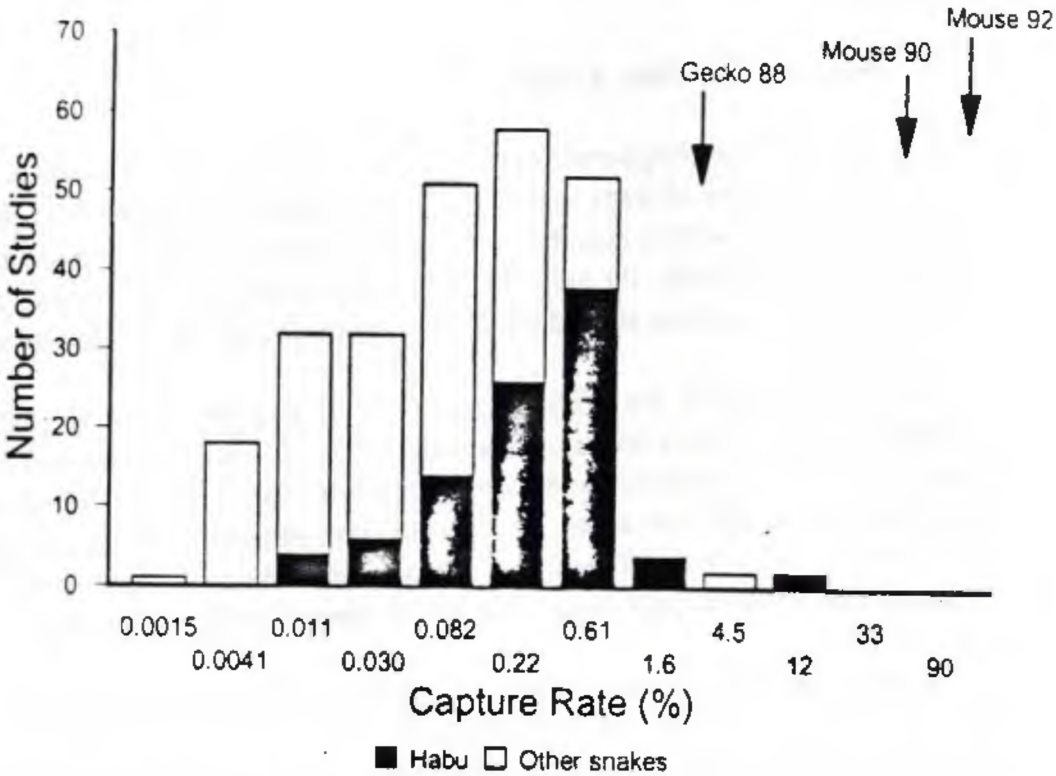

Figure 20.5 The distribution of capture rates in a sample of papers that describe snake trapping (Brown Treesnake studies excluded). Studies of *Trimeresurus flavoviridis* are shown in solid bars. The average capture rates for three Brown Treesnake studies from Orote Point, Guam, are shown by the arrows at above right ("gecko" and "mouse" designate the attractant used in those studies; the numbers indicate the year). The abscissa is logarithmic, in increments of $1.0\log_e$. Studies that obtained zero captures do not appear on this logarithmic distribution.

Note that the values in Figure 20.5 have been natural log transformed to normalize the distribution; the range of values in Figure 20.5 covers more than five orders of magnitude. Studies also varied about 5000-fold in the amount of sampling effort they represented. The median Habu study reported on about 2260 trap-days; the median of the other species was 6400 trap-days. The median capture rate of the other studies was 0.017%, about 1/16th the comparable value for Habu studies (0.268%). This suggests that Habu traps are relatively effective and that opportunities exist for significantly improving the yields from most non-Habu snake-trapping projects.

None of the Habu studies used open funnels, whereas 48% (103 of 214) of the other studies used open or frayed open funnels ("metal whiskers"). A great number of entrance types are in use, especially for the non-Habu studies. In light of the significance associated with entrance design in the Brown Treesnake studies, there appears to be a need for validation of the entrance designs used in most other snake studies.

Most North American snake traps had a body of mesh, although traps that were partially or wholly solid were used in 92% (99 of 108) of the Habu studies. Only 56% (119 of 214) of the other studies used such traps; most of these were projects conducted incidental to Habu studies. The appropriateness of a material probably varies from species to species, but it is notable that Okinawa-style Habu traps utilize mesh sides, whereas Amami-style Habu traps are completely solid. In matched comparisons of solid and mesh-sided traps for the Habu, the mesh-sided traps proved superior in some cases and inferior in others, but the Okinawa-style traps have not been compared directly with the Amami-style traps (Kihara et al., 1978; Shiroma and Akamine, 1987; Shiroma and Arakaki, 1989; Shiroma, 1990; Shiroma and Nohara, 1991; Nishimura, 1992).

Compared with both Habu and other species trap experiments, the Brown Treesnake capture rates are relatively high (Fig. 20.5 arrows). Most published capture rate values greater than 1% were obtained in special situations (Appendix). For example, the 11.6% capture rate for *Diadophis punctatus* must be considered in light of the extremely high densities (719–1849/ha) reported for this diminutive snake (Appendix). The 28.45% capture rate reported for *Entechinus (Cyclophiops) semicarinatus* is an aggregate of all captures along a 90 m fence trap, and is therefore not comparable with the enclosure traps typically used. For ordinary enclosure traps, the highest capture rates for large snake species were around 2.5% for Habu and 6% for *Pituophis melanoleucus*. These indicate that the 25–60% capture rates of Brown Treesnakes are exceptional.

ACKNOWLEDGMENTS

We thank Michael McCoid (Guam Division of Aquatic and Wildlife Resources) for providing mice and laboratory facilities; the U.S. Department of the Interior's Office of Territorial and International Affairs for support; the U.S. Department of Defense for financial support and access to base forests; Renée Rondeau, Brian Smith, Lisa Close, Matt Reid, and Todd Mabee for assistance monitoring traps; and R. Rondeau, Earl W. Campbell III, and Ken Dodd for suggesting improvements to the manuscript.

LITERATURE CITED

Campbell, H. S., and S. P. Christman. 1982. Field techniques for herpetofaunal community analysis. *In* N. J. Scott Jr., ed., Herpetological Communities, pp. 193–200. U.S. Fish Wildl. Serv. Wildl. Res. Rep. 13.

Chiszar, D., K. Kandler, R. Lee, and H. M. Smith. 1988. Stimulus control of predatory attack in the Brown Tree Snake (*Boiga irregularis*). 2. Use of chemical cues during foraging. Amphibia-Reptilia 9:77–88.

Dargan, L. M., and W. H. Stickel. 1949. An experiment with snake trapping. Copeia 1949:264–268.

Fitch, H. S. 1951. A simplified type of funnel trap for reptiles. Herpetologica 7:77–80.

Fritts, T. H. 1988. The Brown Tree Snake, *Boiga irregularis*, a Threat to Pacific Islands. U.S. Fish Wildl. Serv., Biol. Rep. 88(31).

Fritts, T. H., and N. J. Scott Jr. 1985. The Brown Tree Snake on Guam: Studies of its ecology, control, and threats to other islands. Report to U.S. Fish and Wildlife Service, Region 1, Portland, Ore.

Fritts, T. H., N. J. Scott Jr., and B. E. Smith. 1989. Trapping *Boiga irregularis* on Guam using bird odors. J. Herpetol. 23:189–192.

Hayashi, Y., S. Hattori, and H. Tanaka. 1984a. The electric net trap for venomous snake, Habu, *Trimeresurus flavoviridis*. Japan. J. Exp. Med. 54:207–210.

Hayashi, Y., H. Kihara, H. Tanaka, and M. Kurosawa. 1984b. Evaluation of a bait trap for Habu, the venomous snake, *Trimeresurus flavoviridis*. Japan. J. Exp. Med. 54:171–175.

Hayashi, Y., H. Kihara, H. Tanaka, Y. Noboru, H. Yamashita, and T. Minami. 1979. Studies on attractancy of Habu (*Trimeresurus flavoviridis*) in the field on Tokunoshima Island [in Japanese with English summary]. Snake 11:45–53, 126–127.

Imler, R. H. 1945. Bullsnakes and their control on a Nebraska wildlife refuge. J. Wildl. Manage. 9:265–273.

Kihara, H., Y. Hayashi, and I. Wakisaka. 1978. Studies on attractants to Habu using traps [in Japanese with English summary]. Snake 10:46–55, 98.

Kihara, H., and H. Yamashita. 1979. Development of a new type trap with adhesive seat containing pesticides [in Japanese with English summary]. Snake 11:6–10, 119.

Knight, J. E. 1986. A humane method for removing snakes from dwellings. Wildl. Soc. Bull. 14:301–303.

Lankford, J. D. 1989. Stimulus control of foraging in Brown Tree Snakes (*Boiga irregularis*). J. Colo.-Wyo. Acad. Sci. 21:12 (abstr.).

Nishimura, M. 1992. Trapped numbers of *Trimeresurus flavoviridis* and *Dinodon semicarinatus*—analyses of the published data [in Japanese with English summary]. Biol. Mag. Okinawa 30:15–23.

Rodda, G. H., and T. H. Fritts. 1991. The practicality of snake *elimination* from small bounded plots. Report on file with National Ecology Reseach Center, Washington, D.C.

———. 1992. Sampling techniques for an arboreal snake, *Boiga irregularis*. Micronesica 25:23–40.

Rodda, G. H., T. H. Fritts, C. S. Clark, S. W. Gotte, E. W. Campbell III, and M. J. McCoid. 1992a. Trap technology and population dynamics 1990–1992. Report on file with National Ecology Research Center, Washington, D.C.

Rodda, G. H., R. J. Rondeau, T. H. Fritts, and O. E. Maughan. 1992b. Trapping the arboreal snake *Boiga irregularis*. Amphibia-Reptilia 13:47–56.

Savidge, J. A. 1986. The role of disease and predation in the decline of Guam's avifauna. Ph.D. diss. Univ. Illinois, Urbana-Champaign.

———. 1991. Population characteristics of the introduced Brown Tree Snake (*Boiga irregularis*) on Guam. Biotropica 23:294–300.

SHIROMA, H. 1989. On the population estimate of the Habu, *Trimeresurus flavoviridis*, by removal method with traps. *In* M. Matsui, T. Hikida, and R. C. Goris, eds., Current Herpetology in East Asia, pp. 384–392. Kyoto: Herpetological Society of Japan.

——. 1990. Catching Habu, *Trimeresurus flavoviridis*, by traps [in Japanese]. *In* C. Yoshida, ed., Reports of Ecological Researches to Diminish Bites of Habu (*Trimeresurus flavoviridis*) in Okinawa Prefecture, vol. 13, pp. 105–107. Ozato, Okinawa, Japan: Habu Study Sect., Okinawa Prefectural Inst. of Health and Env.

SHIROMA, H., AND H. AKAMINE. 1987. Some improvements of Habu (*Trimeresurus flavoviridis*) trap 2 [in Japanese]. *In* C. Yoshida, ed., Reports of Ecological Researches to Diminish Bites of Habu (*Trimeresurus flavoviridis*) in Okinawa Prefecture, vol. 10, pp. 49–52. Ozato, Okinawa, Japan: Habu Study Sect., Okinawa Prefectural Inst. of Health and Env.

SHIROMA, H., AND S. ARAKAKI. 1989a. Comparing the trapping efficiencies of two types of Habu (*Trimeresurus flavoviridis*) trap [in Japanese]. *In* C. Yoshida, ed., Reports of Ecological Researches to Diminish Bites of Habu (*Trimeresurus flavoviridis*) in Okinawa Prefecture, vol. 12, pp. 75–77. Ozato, Okinawa, Japan: Habu Study Sect., Okinawa Prefectural Inst. of Health and Env.

SHIROMA, H., AND Y. ARAKI. 1986. An estimation of density of Habu, *Trimeresurus flavoviridis*, in a forest of Okinawa Island [in Japanese with English summary]. Biol. Mag. Okinawa 24:43–48.

SHIROMA, H., AND Y. NOHARA. 1991. Catching Habu, *Trimeresurus flavoviridis*, by traps II [in Japanese]. *In* C. Yoshida, ed., Reports of Ecological Researches to Diminish Bites of Habu (*Trimeresurus flavoviridis*) in Okinawa Prefecture, vol. 14, pp. 97–100. Ozato, Okinawa, Japan: Habu Study Sect., Okinawa Prefectural Inst. of Health and Env.

TANAKA, H., Y. HAYASHI, H. KIHARA, S. HATTORI, S. MISHIMA, Y. WADA, M. KUROSAWA, AND Y. SAWAI. 1987. Population control of Habu, *Trimeresurus flavoviridis*, the venomous snake, studied on Tokunoshima Island by a research group FY 1980 to 1983. Snake 19:26–40.

VOGT, R. C., AND R. L. HINE. 1982. Evaluation of techniques for assessment of amphibian and reptile populations in Wisconsin. *In* N. J. Scott Jr., ed., Herpetological Communities, pp. 201–217. U.S. Fish Wildl. Serv., Wildl. Res. Rep. 13.

Rodda, Gordon H., Thomas H. Fritts, Craig S. Clark, Steve W. Gotte, and David Chiszar. 1999. A State-of-the-Art Trap for the Brown Tree Snake. Pp. 268-284. IN Rodda, G., Y. Sawai, D. Chiszar, and H. Tanaka (Eds.), Problem Snake Management: The Habu and the Brown Treesnake. Comstock Publishing Associates, Ithaca, N. Y. 534 pp.