Journal of Chemical Ecology, Vol. 28, No. 12, December 2002 (© 2002)

PREDATORY RESPONSE OF BROWN TREE SNAKES TO CHEMICAL STIMULI FROM HUMAN SKIN

MICHAEL J. GREENE,* SHANTEL L. STARK, and ROBERT T. MASON

Department of Zoology
Oregon State University
3029 Cordley Hall
Corvallis, Oregon 97331-2914, USA

(Received September 10, 2001; accepted July 12, 2002)

Abstract—The brown tree snake (*Boiga irregularis*) is an exotic pest species on Pacific islands, most notably on Guam where it has caused considerable ecological and economic damage. On Guam, the snake commonly associates with people and can be found near or in human habitations. Bites are common, approximately 1 of 1200 emergency room visits to Guam hospitals were reported to be the result of *B. irregularis* bites; 80% of these victims were attacked while sleeping. Most of the attacks occurred on fingers and hands and the attacks appeared to be predatory, rather than defensive, in nature. In order to characterize the mechanism releasing this unusual behavior, we measured the predatory response of *B. irregularis* to chemical stimuli from humans and controls using a lab population that originated from Guam and a wild population from the species' native range in Queensland, Australia. To quantify behavior we measured the proportion of snakes displaying predatory behavior to each of the stimuli, the latency to attack, and the number of tongue-flicks displayed. We quantified predatory behavior using the tongue-flick attack score for repeated measures [TFAS(R)], a common method for quantifying predatory behavior in squamate reptiles. Captive brown tree snakes responded to human skin stimuli with feeding behavior, including predatory attacks, at the same frequency as they did to prey stimuli derived from mice, while never responding to controls with such behavior. Captive snakes also responded to human skin stimuli and prey stimuli with significantly higher TFAS(R) scores than to controls, although there were no differences between the human and mouse stimuli. Wild-caught animals in Australia also responded with predatory attacks to human skin stimuli, while not showing predatory behavior to a blank control and with higher TFAS(R) scores to human skin stimuli than to the control. As *B. irregularis* is a generalized predator that relies heavily on chemical signals to recognize prey,

---

* To whom correspondence should be addressed at current address: Department of Biological Sciences, Stanford University, 371 Serra Mall, Stanford, California 94305, USA. E-mail: greene@ants.stanford.edu

0098-0331/02/1200-2465/0 © 2002 Plenum Publishing Corporation

we hypothesize that the snakes recognize compounds on human skin that may be shared with other prey.

Key Words—Brown tree snake, *Boiga irregularis*, invasive pest species, predatory behavior, feeding stimulus.

INTRODUCTION

The brown tree snake (*Boiga irregularis*) has caused significant ecological and economic damage on the Pacific island of Guam where it was accidentally introduced during or shortly after World War II (Rodda et al., 1992, 1997). The snake flourished on the island, reaching estimated densities of up to 100 snakes per hectare (Rodda et al., 1992). Pest damage includes power outages caused by snakes climbing onto power lines and short-circuiting the system while searching for prey that result in revenue and equipment losses (Fritts et al., 1987).

A generalist predator, brown tree snakes have caused the extinction or extirpation of 9 of 12 native forest birds from the island of Guam, three of which were endemic (Savidge, 1987). In addition, the snakes have negatively affected domestic animals and pets, rodents, lizards, and the endangered Marianas fruit bat, *Pteropus mariannas* (Wiles, 1987; Savidge, 1988; Greene, 1989; Fritts and McCoid, 1991; Rodda and Fritts, 1992). They feed on carrion in the field (R. T. Mason, personal observation; Shivik and Clark, 1997) and also attempt to ingest their own bodies, cage walls, and items in their cage if prey odors or blood are present (M. J. Greene, personal observation). Incidences of cannibalism have been reported on Guam (Engeman et al., 1996). Noteworthy is the fact that they have been reported to attack and kill animals much larger than they can swallow, such as chickens, newborn pigs, and puppies (Fritts, 1988; Fritts et al., 1994).

The brown tree snake associates with humans, and bites are common; approximately 1 of 1200 visits to Guam hospital emergency rooms were reported to be for brown tree snake bites (Fritts, 1988; Fritts and McCoid, 1999). Eighty percent of bite victims surveyed after being treated at medical facilities were bitten while sleeping (Fritts et al., 1994). Of these victims, 52% were younger than 5 years of age, all of whom were bitten while sleeping (Fritts et al., 1994). Fifty-three percent of the victims 5 years of age and older were bitten while sleeping (Fritts et al., 1994).

Fifty percent of all victims attacked while sleeping were bitten on the fingers and hands while the remaining victims were bitten on the arms, legs, neck, back, and face (Fritts et al., 1994). The bite patterns suggest that the snakes were attempting to ingest the fingers and hands of these victims in the same manner they would a prey item (Fritts et al., 1990). Several cases have been reported where parents have found brown tree snakes chewing on the limbs of their children while coiled around the necks and bodies of the children (Fritts et al., 1990; Fritts and McCoid, 1999).

The brown tree snake is a rear-fanged colubrid containing venom of low toxicity to humans (Weinstein et al., 1991; Vest et al., 1991). The venom is delivered through grooved rear fangs when the snake is making deliberate chewing motions on the body of a prey item (Kardong and Lavin-Murcio, 1993). Envenomation is difficult during defensive strikes because the snakes normally respond to provocation with lunging strikes and quick bites (Johnson, 1975). Defensive strikes are quick and involve the front of the jaw, while predatory bites require slower, more deliberate use of the rear fangs in the posterior of the buccal cavity. Envenomation has been reported when snakes attacked sleeping humans (Fritts et al., 1990, 1994).

No deaths have resulted from brown tree snake bites, although many symptoms requiring medical attention have been reported (Fritts et al., 1990, 1994). The most common were discoloration, swelling, and blebs at the bite location. In addition, high pulse, respiratory arrest, lethargy, and droopy eyelids have been described in several cases (Fritts et al., 1990, 1994). It is rare for snakes to attack humans in a predatory manner; aside from a few large constrictors, kraits (*Bungaris* spp) are the only other snakes reported to attack humans in such a way (Minton and Minton, 1980; Fritts et al., 1990).

Initial observations made with captive brown tree snakes in our laboratory showed that they were attracted to objects touched by human hands. In many instances, tongue-flicking behavior displayed to the human odors on these objects was similar to that displayed when feeding on dead prey items, including short, directed tongue-flicks to the objects. Tongue-flicking in snakes serves to transfer chemicals from the environment to the snake's vomeronasal organ, which detects primarily nonvolatile chemical cues (Halpern, 1992). The experiments presented here were designed to measure the feeding response of *B. irregularis* to human skin chemical stimuli and controls by using a bioassay that is sensitive to, and accounts for, both tongue-flicking behavior and predatory behavior.

METHODS AND MATERIALS

Laboratory Snake Bioassay. Ten adult brown tree snakes (3 females and 7 males) were randomly selected from our captive colony for use. The snakes were originally collected on Guam and housed in our laboratory colony for over 6 years before the experiment (Greene et al., 1997). They were fed a diet of thawed frozen mice and chicks every 2–3 weeks, but were not fed 2 weeks prior to the experiment. Ambient room temperature was 23–30°C (mean: 25°C), and relative humidity was 75–80% in the snake room, simulating conditions on Guam. Lighting (14L:10D) was provided by overhead fluorescent lights and by natural sunlight entering the room through windows.

Four treatments were tested in the experiment: (1) a blank control (untreated cotton swab), (2) a general lipid control (a mixture of 100 m vegetable oil in 5 ml hexane), (3) a mouse treatment (positive control), and (4) a human skin treatment.

The mouse treatment was produced by rubbing a swab on the fur and skin of a thawed house mouse (*Mus musculus*) 10 times. The human skin treatment was created by rubbing a single cotton swab on the skin of the arms of four adult humans (2 females and 2 males) five times each. All swabs were used immediately after preparation. The general lipid control was produced by applying 0.5 ml of the dilute lipid to a swab and allowing the solvent to evaporate.

Experiments were conducted during scotophase when the snakes were normally active following methods patterned after earlier studies by Burghardt (1970, 1975; Burghardt et al., 1988). Snakes were tested in their home cages by placing treated or control cotton swabs in the cage approximately 2-cm from the snake's snout. Treatments were presented in a randomized sequential order in a single session with 15 min between tests. The order of snakes tested was random. In all trials, snakes tongue-flicked the swabs within 2 min, making it unnecessary to stimulate a response by lightly touching the swab to the snouts. Trials in which the snake displayed defensive behaviors to the presence of the swab, such as defensive striking or head-hiding (Johnson, 1975), were suspended and redone during a subsequent session.

Trials began when the focal snake tongue-flicked the swab for the first time. Subsequently, the number of tongue-flicks that made direct contact with the swab was counted for 180 sec or until the snake attempted to ingest the cotton swab (in preliminary observations, the latency to attack dead mice ranged from 7 to 288 sec). The feeding behaviors measured were: (1) close-contact tongue-flicking and (2) attacks. We have only observed close-contact tongue-flicking by *B. irregularis* during feeding events on dead prey items, never during predation on live prey or during defensive attacks (M. J. Greene, unpublished data). The behavior consists of short, directed tongue-flicks at the dead prey item with the snout positioned a few millimeters away in which only the bifurcated tips of the tongue protrude from the mouth.

The tongue-flick attack score for repeated measures [TFAS(R)] was used to quantify the predatory response to the swabs (Cooper and Burghardt, 1990). TFAS(R) is a composite measure (combining tongue-flick frequency and latency to attack data) that weighs trials in which snakes attack the stimulus more heavily than trials in which no attacks occur. $\mathrm{TFAS(R)} = \mathrm{TF} + (\mathrm{TL} - \text{latency})$, where TF is the maximum number of tongue-flicks directed at the swabs for any treatment by the focal snake, TL is the trial length in seconds, and latency is the time in seconds to attack the swab from the start of the trial. Higher scores indicate a greater predatory response (Cooper and Burghardt, 1990).

Wild-Caught Snake Bioassay. This experiment was conducted using brown tree snakes collected from their native range in Queensland, Australia. Immediately after capture, snakes were brought back to a laboratory at the University of Queensland where they were housed and tested. Snakes were housed in captivity for less than 7 days, and all interactions with humans were minimized before testing. Eight snakes (3 males and 5 females) were tested in their home cages using the same protocol as the laboratory study except that only the human odor and blank control treatments were tested (the mouse and general lipid controls were not conducted with the wild snakes because neither were available in the field at the time of the study). Snakes were tested by using a switchback method; on the first night, snakes were randomly chosen to receive either the control or human odor treatment while receiving the other treatment on the second night.

RESULTS

Laboratory Snake Bioassay. The snakes displayed predatory behaviors more often to the mouse and human skin stimuli swabs than to the control swabs (Cochran's Q test: $Q = 26.2$; $df = 3$; $P < 0.001$; Figure 1A). They responded with predatory behavior in 8 of 10 trials (6 attacks) to human skin stimuli and in 10 of 10 trials (6 attacks) to mouse odor, while never displaying predatory behaviors to either control. TFAS(R) scores were higher for the mouse and human treatments than for the controls (Friedman ANOVA: $Fr = 13.6$; $df = 3$; $P < 0.004$; Figure 2A); however, the response to the human stimulus did not differ from the response to the mouse stimulus ($Fr = 0.001$; $df = 1$; $P < 0.999$). There were no sex differences in TFAS(R) scores for any of the stimuli (Mann-Whitney U test: $P > 0.05$ for all comparisons).

Wild-Caught Snake Bioassay. The results were consistent with laboratory data; the snakes responded to the human skin swabs with predatory behavior in 6 of 7 trials (4 attacks) while never displaying predatory behavior to the control ($Q = 6.00$; $df = 1$; $P < 0.014$; Figure 1B). The snakes had a higher TFAS(R) to human skin stimuli than to the control ($Fr = 7.00$; $df = 1$; $P < 0.008$; Figure 2B). There were no sex differences in TFAS(R) scores for any of the stimuli (Mann-Whitney U test: $P > 0.05$ for all comparisons).

DISCUSSION

Captive brown tree snakes collected on Guam and wild-caught snakes from their native habitat in Australia responded to human skin stimuli with predatory behavior. Specifically, close-contact tongue-flicking and deliberate predatory attacks were displayed to both the human- and mouse-treated swabs (a positive control), while never to the negative controls. These data confirm earlier observations in our laboratory of brown tree snakes investigating items touched by human skin, and they may provide a mechanism to explain why the snakes attack sleeping humans on Guam.

We propose that foraging brown tree snakes accidentally make contact with sleeping humans when searching for natural prey in and around homes on Guam. By tongue-flicking the skin of sleeping humans, the snakes may detect

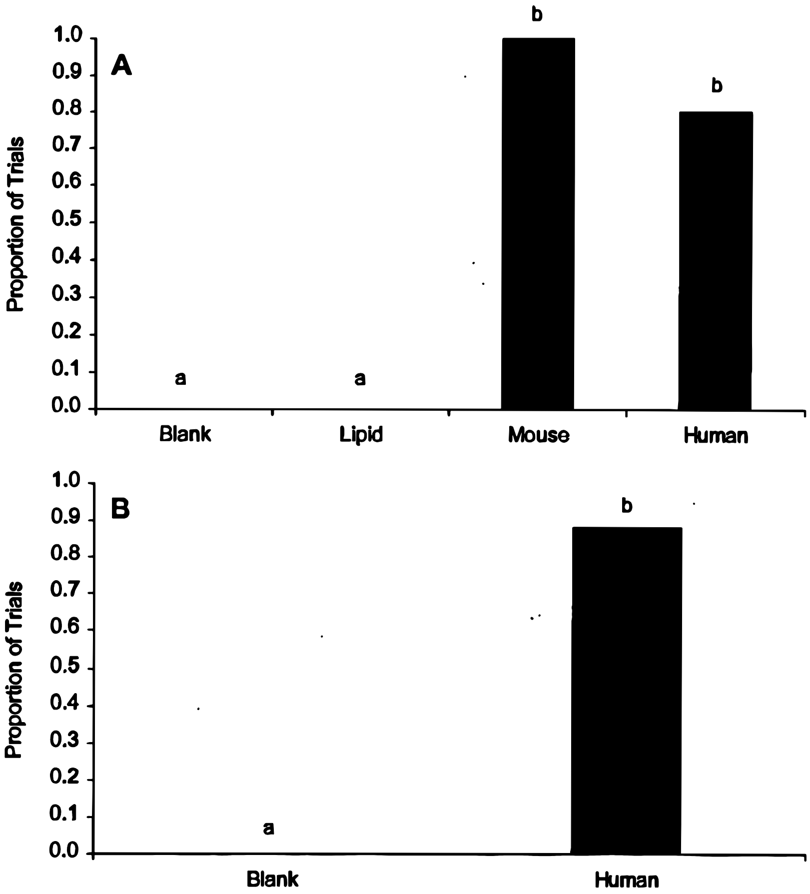

FIG. 1. The proportion of trials in which snakes displayed predatory behavior (close contact tongue-flicks or attacks) to the stimuli for (A) captive snakes originally caught on Guam and for (B) wild-caught snakes from Queensland, Australia. Letters indicate statistical significance between experimental treatments.

semiochemicals that release stereotypical feeding behavior even though the snakes could not ingest the person being attacked. It is unclear if snakes would be attracted to homes specifically because of the presence of human odor, or if the snakes may make accidental contact with humans while searching for prey. This is not the first study to document a predatory response to human stimuli; Chiszar et al. (1993) demonstrated that brown tree snakes show a strong predatory response to human postpartum and menstrual blood.

It appears that the compounds that release feeding behavior from human skin and mice are relatively nonvolatile in nature (for example, the experimental

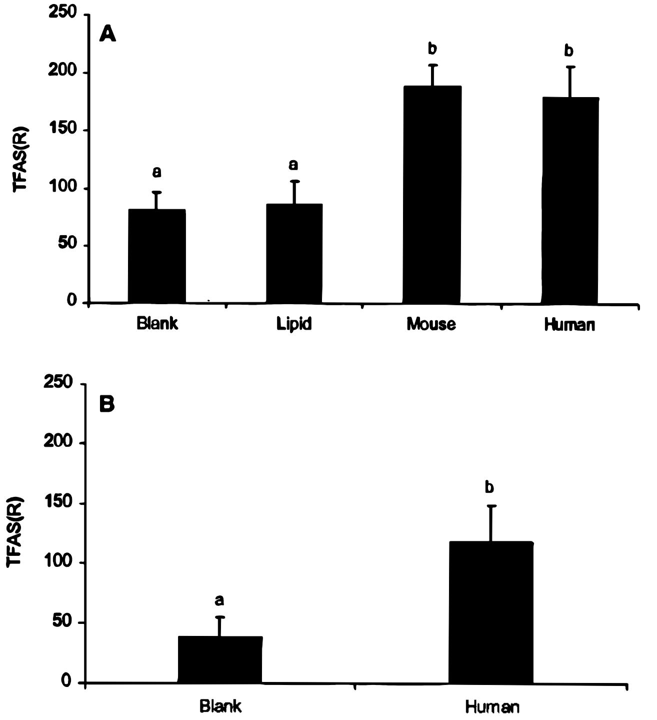

FIG. 2. Tongue-flick attack scores [TFAS(R)] displayed by focal snakes for (A) captive snakes and for (B) wild-caught snakes. Higher TFAS(R) indicate a greater predatory response. Letters indicate statistical significance.

treatments elicited feeding behavior from the snakes several weeks after being stored in a refrigerator). Mammalian skin is covered in a thin film of lipids, composed mainly of sebaceous lipids. Sebaceous glands, associated primarily with hair follicles, secrete a mixture of lipids called sebum onto the skin surface and hair of mammals, while other skin lipids are derived from epidermal cells (Strauss et al., 1991). We hypothesize that this lipid film is a source for the semiochemicals that release feeding behavior in the brown tree snake (Strauss et al., 1991). Human skin lipids are composed of triglycerides (57%), wax esters (26%), squalene (12%), sterol esters (3%), and free sterols (2%) (Greene et al., 1970; Strauss et al., 1991). In mice, the lipid layer is composed mainly of wax diesters (65%), free sterols (13%), sterol esters (10%), and free fatty alcohols (6%) (Wilkinson and Karasek, 1966; Strauss et al., 1991).

The overlap in lipid compounds (or in other types of compounds) between mice and humans might provide an explanation as to why brown tree snakes attempt to prey upon humans. The brown tree snake is known to feed on a diversity of vertebrate prey, including many species of mammals. We hypothesize that brown tree snakes recognize mammalian prey versus prey of other vertebrate taxa by detecting some skin component common to many mammalian species. Future experiments will examine this in depth; chemical studies will be conducted to determine the chemical structures of compounds that elicit predatory behavior. It would be useful to determine if brown tree snakes respond to specific compounds, or to a broad array of compounds that might be common to their vertebrate prey.

Acknowledgments—The authors thank M. P. LeMaster for thoughtful comments on the manuscript. This work was supported by a grant-in-aid award from the Sigma Xi Scientific Research Society to M.J.G. and by grants from the US Fish & Wildlife Service (USDI 14-16-0009-1577), the National Science Foundation (INT-9114567), as well as a National Science Foundation National Young Investigator Award (IBN-9357245) to RTM. This research was conducted under the authority of US Fish & Wildlife Permit No. PRT-769753 and Oregon State University Institutional Animal Care and Use Committee Protocol No. LAR-932.

REFERENCES

BURGHARDT, G. M. 1970. Chemical perception in reptiles, pp. 241–308, *in* J. W. Johnston, D. G. Moulton, and A. Turk (eds.). Advances in Chemoreception, Vol. 1, Communication by Chemical Signals. Appleton-Century-Crofts, New York.

BURGHARDT, G. M. 1975. Chemical prey preference polymorphism in newborn garter snakes *Thamnophis sirtalis*. *Behaviour* 52:202–225.

BURGHARDT, G. M., GOSS, S. E., and SCHELL, F. M. 1988. Comparison of earthworm- and fish-derived chemicals eliciting prey attack by garter snakes (*Thamnophis*). *J. Chem. Ecol.* 14:855–881.

CHISZAR, D., DUNN, T. M., and SMITH, H. M. 1993. Response of brown tree snakes (*Boiga irregularis*) to human blood. *J. Chem. Ecol.* 19:91–96.

COOPER, W. E., JR. and BURGHARDT, G. M. 1990. A comparative analysis of scoring methods for chemical discrimination of prey by squamate reptiles. *J. Chem. Ecol.* 16:45–65.

ENGEMAN, R. M., RODDA, G. H., RODRIGUEZ, D. V., and LINNELL, M. A. 1996. Brown tree snake (*Boiga irregularis*) cannibalism. *The SNAKE* 27:149–152.

FRITTS, T. H. 1988. The brown tree snake, *Boiga irregularis*, a threat to Pacific Islands. US Fish and Wildlife Biological Report 88(31).

FRITTS, T. H. and MCCOID, M. J. 1991. Predation by the brown tree snake *Boiga irregularis* on poultry and other domesticated animals on Guam. *The SNAKE* 23:75–80.

FRITTS, T. H. and MCCOID, M. J. 1999. The threat to humans from snakebite by snakes of the genus *Boiga* based on data from Guam and other areas, pp. 116–127, *in* G. H. Rodda, Y. Sawai, D. Chiszar, and H. Tanaka (eds.). Problem Snake Management—The Habu and the Brown Treesnake. Cornell University Press, Ithaca, New York.

FRITTS, T. H., SCOTT, N. J., JR., and SAVIDGE, J. A. 1987. Activity of the arboreal brown tree snake (*Boiga irregularis*) on Guam as determined by electrical outages. *The SNAKE* 19:51–58.

FRITTS, T. H., MCCOID, M . J., and HADDOCK, R. L. 1990. Risks to infants on Guam from bites of the brown tree snake (*Boiga irregularis*). *Am. J. Trop. Med. Hyg.* 42:607–611.

FRITTS, T. H., MCCOID, M. J., and HADDOCK, R. L. 1994. Symptoms and circumstances associated with bites by the brown tree snake (Colubridae: *Boiga irregularis*) on Guam. *J. Herpetol.* 28:27–33.

GREENE, H. W. 1989. Ecological, evolutionary, and conservation implications of feeding biology in old world cat-eyed snakes, genus *Boiga* (Colubridae). *Proc. Calif. Acad. Sci.* 46:193–207.

GREENE, M. J., NICHOLS, D. K., HOYT, R. J., and MASON, R. T. 1997. The brown tree snake *(Boiga irregularis)* as a laboratory animal. *Lab Anim.* 26:28–31.

GREENE, R. S., DOWNING, D. T., POCHI, P. E., and STRAUSS, J. S. 1970. Anatomical variation in the amount and composition of human skin surface lipid. *J. Invest. Dermatol.* 54:240–247.

HALPERN, M. 1992. Nasal chemical senses in reptiles: structure and function, pp. 424–298, *in* C. Gans and D. Crews (eds.). Biology of the Reptilia, Vol. 18. The University of Chicago Press, Chicago, Illinois.

JOHNSON, C. R. 1975. Defensive display behavior in some Australian and Papuan-New Guinean pygopodid lizards, boid, colubrid, and elapid snakes. *Zool. J. Linn. Soc.* 56:265–282.

KARDONG, K. V. and LAVIN-MURCIO, P. A. 1993. Venom delivery of snakes as high-pressure and low-pressure systems. *Copeia* 1993:644–650.

MINTON, S. A., JR. and MINTON, M. R. 1980. Venomous Reptiles. Charles Scribner and Sons, New York.

RODDA, G. H. and FRITTS, T. H. 1992. The impact of the introduction of the colubrid snake *Boiga irregularis* on Guam's lizards. *J. Herpetol.* 26:166–174.

RODDA, G. H., FRITTS, T. H., and CONRY, P. J. 1992. Origin and population growth of the brown tree snake, *Boiga irregularis*, on Guam. *Pac. Sci.* 46:46–57.

RODDA, G. H., FRITTS, T. H., and CHISZAR, D. 1997. Disappearance of Guam's Wildlife. *BioScience* 47:565–574.

SAVIDGE, J. A. 1987. Extinction of an island avifauna by an introduced snake. *Ecology* 68:660–668.

SAVIDGE, J. A. 1988. Food habits of *Boiga irregularis*, an introduced predator on Guam. *J. Herpetol.* 22:275–282.

SHIVIK, J. A. and CLARK, L. 1997. Carrion seeking in brown tree snakes: Importance of olfactory and visual cues. *J. Exp. Zool.* 279:549–553.

STRAUSS, J. S., DOWNING, D. T., EBLING, F. J., and STEWART, M. E. 1991. Sebaceous glands, pp. 712–740, *in* L. A. Goldsmith (ed.). Physiology, Biochemistry, and Molecular Biology of the Skin, 2nd ed. Oxford University Press, Oxford.

VEST, D. K., MACKESSY, S. P., and KARDONG, K. V. 1991. The unique Duvernoy's secretion of the brown tree snake (*Boiga irregularis*). *Toxicon* 29:532–535.

WEINSTEIN, S. A., CHISZAR, D., BELL, R. C., and SMITH, L. A. 1991. Lethal potency and fractionation of Duvernoy's secretion from the brown tree snake, *Boiga irregularis*. *Toxicon* 29:401–407.

WILES, G. J. 1987. Current research and future management of Marianas fruit bats (Chiroptera: Pteropodidae) on Guam. *Aust. Mammal.* 19:93–95.

WILKINSON, D. I. and KARASEK, M. A., 1966. Skin lipids of a normal and mutant (asebic) mouse strain. *J. Invest. Dermatol.* 47:449–455.