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ASSESSMENT FOR PACIFIC SHEATH-TAILED BATS (*EMBALLONURA SEMICAUDATA ROTENSIS*) ON AGUIGUAN, COMMONWEALTH OF THE NORTHERN MARIANA ISLANDS

Compiled by Thomas J. O'Shea and Ernest W. Valdez

Administrative Report

U.S. Department of the Interior
U.S. Geological Survey

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Cover photo: male *E. semicaudata rotensis* from Aguiguan by E.W. Valdez, 2008

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Section I. Executive Summary

By Thomas J. O'Shea and Ernest W. Valdez

The subspecies of the Pacific sheath-tailed bat that once occurred throughout the Mariana Islands (*Emballonura semicaudata rotensis*) has not been well studied biologically, despite its declining status. It is a small insectivorous bat, and in the Mariana Islands it is known to roost only in caves. All available data indicate that it now occurs as a single remnant population on Aguiguan. Overall, the species is categorized as endangered by the International Union for the Conservation of Nature and Natural Resources. The subspecies is protected by law in the Commonwealth of the Northern Mariana Islands (CNMI), and is considered a Category 3 candidate for listing under the U.S. Endangered Species Act. This categorization under U.S. law is based on the imminence and magnitude of threats, but further actions have not had the highest priority possible in part because the remaining population on Aguiguan has been considered to be a subspecies of a more widely found species. However, a thorough quantitative morphometric and molecular genetic analysis is needed to verify if the subspecific level in the taxonomic hierarchy is accurate or if full species designation may be warranted for the population in the Marianas Islands.

In this report we document results from a biological assessment for Pacific sheath-tailed bats carried out in 2008 on Aguiguan and Tinian, CNMI. The field work was done by a team consisting of a former Guam Division of Aquatic and Wildlife Resources biologist with past experience surveying for this species, and four bat biologists from the U.S. Geological Survey (USGS) Fort Collins Science Center, Colo., and the USGS Pacific Island Ecosystems Research Center, Hawaii. The assessment consisted of (1) determining present abundance and use of caves on Aguiguan by these bats and interpreting these data in comparison with a synthesis of the literature and past unpublished data; (2) establishing baseline site occupancy models of spatial foraging habitat use through monitoring of ultrasonic echolocation calls; (3) determining basic aspects of diet through analysis of fecal material; sampling bats through capture to obtain new data on reproduction and body size, as well as to collect samples for future genetic analysis, and; (4) determining characteristics of temperature and humidity in caves. We carried out a limited review of specimens available in research museums, and obtained samples from guano deposits that may prove to be useful if analyzed for contaminants when compared with the analysis of guano from other islands where these bats have become extinct. We also carried out a limited survey for the presence of these bats on Tinian.

Our report summarizes previously unpublished results on numbers of Pacific sheath-tailed bats roosting in caves on Aguiguan in 1995 and 2003, and compares past results with findings from new surveys conducted in 2008. Overall, we examined the abundance, roosting behavior, and distribution of Pacific sheath-tailed bats on Aguiguan by searching caves and hollow trees for roosting bats during the day. Counts of bats at caves show that a small population of Pacific sheath-tailed bats exists on Aguiguan, with a range of 359–466 individuals counted at five of 41 caves surveyed in 2008. Comparison with past counts suggests that this population has increased over the last 13 years, in contrast with overall declines in populations of this and other subspecies of Pacific sheath-tailed bats throughout the 20th century. On Aguiguan bats appeared to prefer roosting in larger caves and displayed fidelity toward five of the seven caves found occupied in the study. Occupied caves were larger than most unoccupied caves but had similar temperature and humidity conditions. In 2008 one cave consistently housed the largest colony, with a range of 308–382 bats counted, whereas counts at other

occupied caves yielded 1–64 individuals. Slight variability occurred in replicate counts on different dates during the 2008 survey. We found no evidence of hollow tree trunks being used as roosts. It is possible that a small number of colonies of these bats may remain undiscovered in currently inaccessible caves on Aguiguan.

Evaluation of trends in colony sizes of cave bats throughout the world generally relies on count data that are uncalibrated index values, which can be difficult to interpret. Therefore, this assessment also sought to utilize a recently developed quantitative approach to establish a baseline site-occupancy model of spatial occurrence of foraging Pacific sheath-tailed bats on Aguiguan. This method uses detection of bat ultrasonic calls to assess presence or absence of foraging bats at night in relation to various habitat attributes. Thirty-one echolocation stations were deployed across Aguiguan between 25 June and 14 July 2008. Twenty-one of the 31 stations recorded ultrasonic pulses from sheath-tailed bats over a period of 19 days, with 35,858 calls recorded. Ten percent of the calls were characterized as peak activity, 40 percent as moderate activity, and 50 percent as brief passes. Analyses show that peak activity and occurrence is related to canopy cover, vegetation stature, and distance to known roosts. Native limestone forest is the preferred foraging habitat. Echolocation calls of Pacific sheath-tailed bats were characterized for the first time, and search-phase calls were similar to those of other emballonurid bats that use a narrow bandwidth and short pulse duration to forage in cluttered vegetation.

There is no prior information on the food habits of the Pacific sheath-tailed bat anywhere in the species range. Herein, we reported on new findings from analysis of fecal material from these bats on Aguiguan. We collected and analyzed 200 fecal pellets of bats from two roosts (Guano Cave and Crevice Cave). The diet of the Pacific sheath-tailed bat was diverse, but mostly consisted of small insects ranging from 1.7 to 6.4 mm in length. Overall, hymenopterans (ants, wasps, and bees), lepidopterans (moths), and coleopterans (beetles) were the three major food items in the diet of bats from both roosts. However, the ranking of volumes of each insect order consumed varied between roosts. At Guano Cave, hymenopterans made up 64 percent of the diet, followed by coleopterans (10 percent), and lepidopterans (8 percent). At Crevice Cave, lepidopterans made up 45 percent of the diet, followed by hymenopterans (41 percent), and coleopterans (10 percent). Within Hymenoptera, most of the prey belonged to ichneumondoidea (parasitoid wasps), followed by formicids (ants belonging to Formicinae and Ponerinae; i.e., trap-jaw ants). Because alates (winged adults) of ants and termites (isopterans) generally have wings only when they are reproductive or establishing new colonies, the fecal samples indicated that it is likely that Pacific sheath-tailed bats take advantage of seasonal food sources. In other areas the occurrences of these winged forms of insects are often present during the onset of rains; we sampled guano at the onset of the rainy season on Aguiguan (late June to early July). Lepidopterans, specifically microlepidopterans, likely were another seasonally abundant prey item. Silken fungus beetles and leaf beetles identified in the guano appear to be forest-dependent species and were a consistent component of the bats' diet. Not only do these and other prey items indicate that these bats forage mainly in forest habitat during late June and early July, but that they also capture prey near (above and below) the canopy. From these diet analyses, we categorized the Pacific sheath-tailed bat as an aerial insectivore or hawker, similar to other emballonurids around the world.

We also collected various other samples and obtained information on the biology and natural history of Pacific sheath-tailed bats on Aguiguan. Standard means were used to capture Pacific sheath-tailed bats in mist nets while they dispersed or foraged through the forest, but these attempts were largely unsuccessful because these bats were highly maneuverable and easily avoided mist nets on close approach. We successfully captured 12 adult bats and one attached suckling young by using hand nets on bats in flight in the forest, or mist nets set in or near caves used as roosts. Both methods have logistical problems and limitations: in addition to the high maneuverability of the bats precluding use of

mist nets in standard configurations, considerable time is required to accrue multiple captures using hand nets. Caves where bats roost are co-occupied by endangered Mariana swiftlets (*Aerodramus bartschi*). Thus, capturing bats at caves has the potential to disturb both the bats and the swiftlets. We found that these bats can be very sensitive to initial handling, but their stress can be reduced by placing bats individually in cloth bags promptly after capture and allowing them to calm for at least 10 minutes in the bags before examining them. We determined body mass, length of forearm, and reproductive condition of the 12 adult bats. In addition to qualitative features of skull morphology, length of forearm has been given as a characteristic that can be used to distinguish some subspecies of *E. semicaudata*. However, these new forearm measurements show that there was considerable overlap in body size between *E. semicaudata rotensis* and the other three subspecies of Pacific sheath-tailed bats. Small wing biopsies were collected from 12 bats prior to release so that basic preliminary genetic analyses can be done to ascertain the genetic diversity of the population on Aguiguan and the depth of genetic division of this subspecies when compared to published data on *E. s. semicaudata* from Fiji. This work will be carried out by USGS geneticists in 2009. We also prepared two museum voucher specimens of *E. s. rotensis*, increasing the number of known specimens from the Mariana Islands available in United States museums from two to four. We reviewed the literature and queried a limited number of online databases to compile updated information on specimens of Pacific sheath-tailed bats that might be available for taxonomic study. Over 380 specimens including other subspecies are available worldwide, and about 22 additional specimens from the Marianas Islands (including Guam) are housed in museums in France and Japan. Expanded study of museum specimens and comparative genetic analyses are needed to better ascertain the systematic status of the Pacific sheath-tailed bat population on Aguiguan.

There is limited information on reproduction in Pacific sheath-tailed bats in the CNMI or elsewhere. Six female bats captured by Wiles and others on Aguiguan late in the rainy season of 2003 (17 September) were apparently not reproductive. In contrast, seven of the eight female bats we captured in June and July 2008 were either pregnant or lactating. We also observed 11 pups at roosts in caves during June and July 2008; all were singletons. None of the bats we captured were volant young of the year. The presence of reproductive females and pups or embryos in June and July, but no volant young, suggests the hypothesis that Pacific sheath-tailed bats on Aguiguan may have a diffuse seasonality in reproduction, such that the period of late gestation, lactation, and maturation of young coincides with the late June to early November rainy season. We observed one large embryo in a female dissected in June 2008, as was also observed in a female dissected by Lemke in June 1984. These dissections and the observations of 11 apparent singleton pups suggest a litter size of one. If reproduction occurs only once per year and litter size is one, then the capacity for population growth in Pacific sheath-tailed bats will be very limited. All bats that we captured at caves in 2008 and by others in years past were females, whereas four bats captured at dusk dispersing along a steep rocky hillside, not near any known colony, were males. This suggests that perhaps males may form bachelor colonies apart from roosts occupied primarily by females, as is known for other Old World species in the genus *Emballonura*. Elaborate social behavior patterns also were suggested by the audible communication sounds produced by bats that we observed foraging and dispersing through the forest and flying into caves.

The scientific literature includes speculation that the extinction of Pacific sheath-tailed bats on other islands may have been attributable at least in part to past use of organochlorine insecticides. However, there is no chemical or toxicological evidence that bears directly on this speculation. Analyses based on other species of insectivorous bats have shown that concentrations of organochlorine insecticides in bat guano can provide diagnostic evidence of mortality and population declines. Aguiguan has been mostly uninhabited since the use of organochlorines became widespread elsewhere

in the world. Thus guano samples from sheath-tailed bats on Aguiguan could provide comparative baselines with which to compare contamination of guano from islands where these bats have become extinct (e.g. Guam). Therefore we used contaminant-free sampling approaches to obtain guano at 3 different depth levels (i.e., surface, 10, and 20 cm below surface) from two areas of a guano pile beneath roosting bats at Guano Cave. These samples are stored in the USGS laboratory at the Fort Collins Science Center in Colorado and can be made available for future chemical analysis. However, because this guano was deposited over many years, the material also likely includes particles of guano from Mariana swiftlets. The degree of mixing of guano from these two sources should be estimated using microscopic techniques prior to chemical analysis.

Pacific sheath-tailed bats are only known to have existed on Tinian based on prehistoric deposits in caves. During the last 4 days and nights of this study we made an effort to document the presence of Pacific sheath-tailed bats on Tinian using echolocation detectors. We also queried knowledgeable individuals, and watched for bats and listened for audible calls during the echolocation surveys. We felt that our best chance for success in documenting bats on Tinian would be echolocation-based sampling in limestone forest areas because of the bats' heavy use of this habitat for foraging on Aguiguan. We deployed two monitoring stations that sampled continuously all night long, both stations set up for one night in a forest in the Mount Lasso area, and for a second night in the Kastiyu Forest. Samples also were taken for one night at each of these sites using improvised walking transects and echolocation detectors during the first part of the night, corresponding to peak times of bat echolocation activity on Aguiguan. No bats were detected. However, this survey was far from exhaustive, and additional effort using echolocation detectors over wider areas of forest and searches of caves will be needed to rule out the possibility that a small remnant population of these bats may still exist on Tinian. Similar echolocation-detector based surveys would also be useful on two other islands in the CNMI (Anatahan and Maug) where tentative sightings were reported in the early 1980s but never subsequently confirmed.

A number of points to consider for future activities stems from the findings of this assessment. These are best characterized as activities related to: (1) management for conservation; (2) monitoring; and (3) research. Considerations for management for conservation include limiting the disturbance of and access to caves used by roosting bats; increasing the extent of native limestone forest, decreasing existing stands of invasive plants, and eliminating or avoiding actions that would reduce the amount of native limestone forest on Aguiguan. Considerations for future monitoring of sheath-tailed bats on Aguiguan include periodic monitoring of numbers of bats utilizing key caves, and monitoring the use of foraging habitat with echolocation detectors and site occupancy models. Considerations for research include searching the more inaccessible areas on Aguiguan for the presence of additional colonies that may occupy caves requiring technical climbing and caving skills to reach; increasing the foundation of ecological knowledge of this species pertinent to its conservation and management, including investigations into seasonal aspects of reproduction, roosting, and foraging biology; conducting a modern analysis of the taxonomic status of *Emballonura semicaudata* and its subspecies using combined quantitative morphometric and molecular genetic approaches; assessing the role of contaminants in the species decline; and further assessing the possible occurrence of Pacific sheath-tailed bats on Tinian and other islands.

Section II. Introduction and Objectives

By Thomas J. O'Shea and Ernest W. Valdez

The subspecies of the Pacific sheath-tailed bat that once occurred throughout the Mariana Islands (*Emballonura semicaudata rotensis*) has not been well studied biologically, despite its declining status. It is a small insectivorous bat and in the Mariana Islands it is known only to roost in caves. Once found throughout the southern Mariana Islands, all available data indicate that it now only occurs as a single remnant population that roosts in a few caves on Aguiguan (e.g. Lemke, 1986; see also Section III of this report). There are three other subspecies of Pacific sheath-tailed bats distributed sporadically across southwestern Oceania (Koopman 1997, Helgen and Flannery 2002). However, there is little information available on basic biology of the species anywhere in its range. Reports on population status (summarized in Section III of this report) suggest that in many areas it has seriously declined in abundance during the 20th century. A variety of factors have been hypothesized as being responsible for this decline, but no single cause has been pinpointed that is applicable to all areas. The most widely cited published assessment of the status of the Pacific sheath-tailed bat in the Mariana Islands is that of Lemke (1986), who reported seeing only a few bats on Aguiguan. Lemke's (1986) assessment prompted Nowak (1994, p. 92) to speculate that "this subspecies may thus rank as one of the world's most critically endangered mammals."

Several accounts are available that summarize the distribution, history of its status, and known aspects of the biology of Pacific sheath-tailed bats (e.g. , Bonaccorso and Allison 2008, Hutson and others 2001, U.S. Fish and Wildlife Service 2007; other citations elsewhere in this report). The declining status of Pacific sheath-tailed bat populations has caused it to be placed in various protected categories by different organizations and governments. Overall, the species is categorized as Endangered by the International Union for the Conservation of Nature and Natural Resources (Hutson and others 2001, Bonaccorso and Allison 2008). The subspecies *E. s. rotensis* in the Commonwealth of the Northern Mariana Islands (CNMI) is protected by CNMI law, and is considered a Category 3 candidate for listing under the U.S. Endangered Species Act of 1973 (U.S. Fish and Wildlife Service 2007). This categorization under U.S. law is based on the imminence and magnitude of threats, but further actions have not had the highest priority possible in part because the remaining population on Aguiguan is currently understood to be a subspecies of a more widely found species (U.S. Fish and Wildlife Service 2007, 2008). The currently accepted subspecies designation, however, is based on examination of a small series of specimens by Yamashina (1943) and a qualitative judgment with little systematic documentation by Koopman (1997). No thorough, modern quantitative morphometric or molecular genetic analyses have been carried out on this species throughout its range to determine if the subspecific level in the taxonomic hierarchy is accurate for the population in the Marianas Islands, or if full species designation may be warranted.

Given the lack of substantial background biological information pertinent to the conservation and management for Pacific sheath-tailed bats, our study had multiple objectives. Our primary effort was dedicated towards summarizing all past information on the use of caves as roosts by these bats on Aguiguan, combined with results of new efforts in 2008 to re-visit these caves and obtain new counts for an up-to-date assessment of trends in abundance. Bats pose major challenges when trying to arrive at valid estimates in population trends, reviewed in a series of papers in the report edited by O'Shea and Bogan (2003) and summarized by O'Shea and others (2003). There are as yet no well-established,

standard methods for estimating bat abundance or colony sizes with a statistically sound theoretical basis. Most bat researchers therefore rely on visual counts of bats emerging at dusk as an index to population size ("emergence counts" of Kunz 2003). As described in Section III of this report, such counts were the basis of the past estimates of colony sizes on Aguiguan and were duplicated in 2008. The surveys in 2008 were further supplemented by using a night vision device and infrared light to make daytime counts in one accessible cave, and by replicate counting to qualitatively assess variability in these counts. Information from the 2008 surveys was then combined with previously unpublished reports and data from the literature to synthesize all past and present knowledge on the distribution and status of this subspecies.

There has been one very recent major statistical advance in sampling bats for trend information. This has been the adapting of the newly developed site occupancy modeling approach in wildlife studies (e.g. MacKenzie and others 2002, 2006) to bats based on presence-absence data obtained through monitoring potential foraging habitat for their ultrasonic echolocation pulses. This combined approach was first used in studies of the endangered Hawaiian hoary bat (*Lasiurus cinereus semotus*) by Gorresen and others (2008). It was adapted for the assessment of habitat use by sheath-tailed bats on Aguiguan in Section IV of this report by Gorresen and others, based in part on earlier demonstrations that bat echolocation activity can be detected in Aguiguan's native limestone forest (Esselstyn and others 2004). This carefully designed monitoring of bat-produced ultrasounds was intended to provide a baseline for future monitoring of sheath-tailed bat habitat use, an improved understanding of the areas these bats use for foraging on Aguiguan, and new information on characteristics of Pacific sheath-tailed bat echolocation calls and activity patterns.

In this report we grouped our results under seven separate topics or groups of topics. Each of the remaining sections treats these topics or groups of topics (Sections III–IX) with separate statements of introductory information, materials and methods, results and discussion, and references cited. A final section summarizes considerations for future research and management for sheath-tailed bats on Aguiguan and elsewhere if pertinent. The other sections of this report deal with some basic biological and natural history information and samples pertinent to the conservation of sheath-tailed bats that were also obtained during the course of fieldwork on Aguiguan in parts of June and July 2008. These include the first description of insect prey in the diet of these bats based on fecal analyses (Section V), results of the first attempts to capture sheath-tailed bats in foraging and dispersal areas (Section VI), new information pertinent to understanding vital parameters of reproduction (Section VII), obtaining of samples of guano for assessment of contaminant concentrations and biopsies for genetic studies in the future (Sections VI and VIII), new information on body size (of relevance to subspecies characteristics), and an updated summary of museums specimens of all subspecies now available for study at research museums around the world (Section VI). We also report on a pilot study that attempted to assess the presence of echolocatmg sheath-tailed bats in likely foraging habitat on Tinian (Section IX), where there has been no evidence of occurrence since pre-historic times.

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REFERENCES CITED

Bonaccorso, F. J., and Allison, A., 2008, *Emballonura semicaudata*: In: International Union for the Conservation of Nature and Natural Resources 2008, 2008 IUCN Red List of Threatened Species, www.iucnredlist.org.

Esselstyn, J. A., Wiles, G.J., and Amar, A., 2004, Habitat use of the Pacific sheath-tailed bat (*Emballonura semicaudata*) on Aguiguan, Mariana Islands: Acta Chiropterologica, vol. 6, p. 303-308.

Gorresen, P. M., Miles, A. C., Todd, C. M. , Bonaccorso, F. J., and Weller, T. J., 2008, Assessing bat detectability and occupancy with multiple automated echolocation detectors: Journal of Mammalogy, vol. 89, p. 11-17.

Helgen, K. M., and Flannery, T. F., 2002, Distribution of the endangered Pacific sheath-tailed bat *Emballonura semicaudata*: Australian Mammalogy, vol. 24, 209-212.

Hutson, A. M., Mickleburgh, S. P., and Racey, P. A. (compilers), 2001, Microchiropteran bats: global status survey and conservation action plan. IUCN/SSC Chiroptera Specialist Group, International Union for the Conservation of Nature and Natural Resources, Gland, Switzerland and Cambridge, United Kingdom.

Koopman, K. F., 1997, The subspecies of *Emballonura semicaudata* (Chiroptera: Emballonuridae): Journal of Mammalogy, vol. 78, p. 358-360.

Kunz, T.H., 2003, Censusing bats: challenges, solutions, and sampling biases, in O'Shea, T. J., and Bogan, M. A., eds., *Monitoring trends in bat populations of the United States and territories: problems and prospects*: Washington, D.C., U.S. Geological Survey, Biological Resources Discipline, Information and Technology Report, USGS/BRD/ITR--2003-003, p. 9-19.

Lemke, T. O., 1986, Distribution and status of the sheath-tailed bat (*Emballonura semicaudata*) in the Mariana Islands: Journal of Mammalogy, vol. 67, p. 743-746.

MacKenzie, D. I., Nichols, J. D. , Lachman, G. B., Droege, S., Royle, J. A., and Langtimm, C.A., 2002, Estimating site occupancy when detection probabilities are less than one: Ecology, vol. 83, p. 2248–2255.

MacKenzie, D. I., Nichols, J. D., Royle, J. A., Pollock, K. H., Bailey, L. L., and Hines, J. E., 2006, *Occupancy estimation and modeling: inferring patterns and dynamics of species occurrence*: San Diego, Calif., Elsevier.

Nowak, R. M., 1994, Walker's bats of the world: Baltimore, Maryland, The Johns Hopkins University Press, 287 p.

O'Shea, T. J., and Bogan, M. A., eds., 2003, Monitoring trends in bat populations of the United States and territories: problems and prospects: U.S. Geological Survey, Biological Resources Discipline, Information and Technology Report, USGS/BRD/ITR--2003-003, 274 p.

O'Shea, T. J., Bogan, M. A., and Ellison, L. E., 2003, Monitoring trends in bat populations of the United States and territories - status of the science and recommendations for the future: Wildlife Society Bulletin, vol. 31, p. 16-29.

Yamashina, M. Y., 1943, On a new subspecies of *Emballonura semicaudata* from the Mariana Islands: Bulletin of the Biogeographical Society of Japan, vol. 13, p. 99-100. (In Japanese, cited by Lemke 1986).

U.S. Fish and Wildlife Service, 2007, 50 CFR Part 17; Endangered and Threatened Wildlife and Plants; Review of Native Species That Are Candidates for Listing as Endangered or Threatened; Annual Notice of Findings on Resubmitted Petitions; Annual Description of Progress on Listing Actions; Proposed Rule. Federal Register, Code of Federal Regulations, (December 6, 2007), vol. 72 (no. 234), p. 69033-69106.

U.S. Fish and Wildlife Service, 2008, 50 CFR Part 17; Endangered and Threatened Wildlife and Plants; Review of Native Species That Are Candidates for Listing as Endangered or Threatened; Annual Notice of Findings on Resubmitted Petitions; Annual Description of Progress on Listing Actions; Proposed Rule. Federal Register, Code of Federal Regulations (December 10, 2008), vol. 73 (no. 238), p. 75175-75244.

Section III. Current and Past Population Status and Use of Caves by Pacific Sheath-Tailed Bats (*Emballonura semicaudata rotensis*) on Aguiguan, Commonwealth of the Northern Mariana Islands

By Gary J. Wiles, David J. Worthington, Jacob A. Esselstyn, Thomas J. O'Shea, and Ernest W. Valdez

ABSTRACT

The Mariana Islands subspecies of the Pacific sheath-tailed bat (*Emballonura semicaudata rotensis*) declined greatly in abundance and distribution during the 20th century. The island of Aguiguan now supports the only persisting population. We examined the abundance, roosting behavior, and distribution of this population by searching caves and hollow trees for roosting bats during surveys in 1995, 2003, and 2008. The only roosts of bats found were in caves. Counts at caves suggest a substantial increase in abundance during the course of the study, with 98 bats recorded at five of 85 caves in 1995, 333–348 bats recorded at six of 57 caves in 2003 (including the discovery of one large previously unknown colony), and 359–466 bats recorded at five of 41 caves in 2008. Bats appeared to prefer roosting in larger caves and displayed significant fidelity toward five of the seven caves that were found occupied by bats during the study. One cave consistently held the largest colony, with a range of 308–382 bats (mean [± SD, standard deviation] = 333 ±33.6, n =4) counted at emergence in 2008. Other caves served as roosts for 1–64 individuals. Most departures from roosts began 3.2 ±8.7 min before sunset and ended 7.1 ±8.1 min after sunset. We found no evidence of hollow tree trunks being used as roosts. As of 2008, the population of *E. s. rotensis* on Aguiguan probably numbered around 450–600 bats. Related research shows that the population relies heavily on native forest, regeneration of which is severely limited by feral goats (*Capra hircus*). Eradication of these goats combined with a reforestation program could increase and enhance foraging habitat of bats. Existing evidence supports the current designation of *E. s. rotensis* by the U.S. Fish and Wildlife Service as a candidate for listing as an endangered species under the U.S. Endangered Species Act.

INTRODUCTION

The Pacific sheath-tailed bat (*Emballonura semicaudata*) is distributed across much of Oceania, and is found on the Mariana and Caroline Islands, Samoa, Tonga, Fiji, and Vanuatu (Flannery 1995, Koopman 1997, Helgen and Flannery 2002). These bats appear to be abundant at some locations, especially in the Caroline Islands (Bruner and Pratt 1979, Wiles and others 1997; G. Wiles, personal observ.), but populations have inexplicably declined on many other islands (Lemke 1986, Grant and others 1994, Flannery 1995, Hutson and others 2001, Tarburton 2002, Palmeirim and others 2007). In the Mariana Islands, where the endemic subspecies *E. s. rotensis* occurs (Koopman 1997), populations of sheath-tailed bats on Guam, Rota, and Saipan disappeared between the late 1940s and 1970s (Lemke 1986, Wiles and others 1995). The species occurred in recent prehistoric times on Tinian (Steadman 1999), but there are no historic records for this island. Lemke (1986) reported possible occurrences on Anatahan and Maug based on tentative sightings in the early 1980s, but populations have not been confirmed on these islands, despite a number of visits by biologists to both islands since 1983. Although there are no previously published records of *E. s. rotensis* from Saipan, P. H. Krutzsch (in

litt.) made several sightings of a few small insectivorous bats on this island in about 1945. These are considered to represent *E. s. rotensis* because no other microchiropteran bats occur in the archipelago.

The only known remaining population of this subspecies of Pacific sheath-tailed bat is on the island of Aguiguan (also known as Aguijan, Agiguan, and Goat Island). Biologists first recorded *E. s. rotensis* on Aguiguan in 1984 and 1985, when "three or four" bats were found in each of two caves (Lemke 1986). Subsequent observations from 1987 to 1992 documented up to 13 bats at one of the caves, but none was found at any of the few other caves examined, suggesting that the overall population was small (Rice and Taisacan 1993). The bats on Aguiguan were the only ones found in a search of 12 islands or island groups in the Northern Mariana Islands in 1983–1985 (Lemke 1986). Our main objective during this study was to conduct a more complete assessment of the Pacific sheath-tailed bat population on Aguiguan, and to synthesize all available past information pertinent to the status of this population. A descriptive inventory and catalog of all caves that were searched for evidence of roosting sheath-tailed bats was developed that included results based on field work in 2008 as well as unpublished data from our visits in 1995, 2002, and 2003. We also provide results of counts of numbers of bats using the caves that were determined to be occupied by bats. Our results are interpreted in relation to past findings of others as reported in the literature. This report also explores possible causes for declines, and discusses possible measures that could enhance conservation of this population. Additional biological findings from field studies in 2008 are also provided in Sections IV–IX of this report.

STUDY AREA

Aguiguan (14°51'N, 145°33'E) is located in the southern Mariana Islands in western Micronesia and is administered by the U.S. Commonwealth of the Northern Mariana Islands (CNMI). The island is small (7.2 km^2) and comprised entirely of raised limestone karst, making it geologically similar to the neighboring islands of Tinian, Saipan, Rota, and much of Guam (Butler 1992, Stafford and others 2004, Jenson and others 2006). A large central plateau dominates the terrain and is bordered by a series of narrow terraces falling to the ocean. Coastal escarpments 10–40 m tall surround most of the shoreline. Maximum elevation is 166 m. Morphology of the island's caves is discussed in Stafford (2003) and Stafford and others (2004). Aguiguan's climate is tropical, with mean daily temperatures ranging from 24 to 32°C. Annual rainfall probably averages somewhat less than 2,000 mm, which is the approximate mean for Saipan 32 km to the north (Butler 1992, Lander 2004). Most rain occurs from July through November.

Aguiguan was mostly covered with native limestone forest until 1936 or 1937, when Japanese colonists began clearing large sections of the main plateau and larger terraces for sugar cane cultivation (Butler 1992). Former crop fields occupy 43 percent of the island and are now largely re-vegetated by weedy thickets of introduced plants, primarily *Lantana camara*, *Chromolaena odorata*, *Mikania scandens*, *Tridax procumbens*, and several grasses (Engbring and others 1986, Butler 1992, Rice 1993*a*). Limestone forest remains on about 45 percent of Aguiguan and grows on smaller terraces and steeper slopes (Esselstyn and others 2004, see Section IV of this report). Common tree species include *Guamia mariannae*, *Cynometra ramiflora*, *Pisonia grandis*, *Ochrosia mariannensis*, *Aglaia mariannensis*, *Ficus prolixa*, *Cerbera dilatata*, *Premna obtusifolia*, *Drypetes dolichocarpa*, *Erythrina variegata*, and *Psychotria mariana* (Chandran and others 1992; G. J. Wiles, personal obs.); canopy height is 7-15 m tall. Goats (*Capra hircus*) were introduced to the island in the mid-1800s (Butler 1992). Decades of overbrowsing by sizable feral goat populations have created an open forest understory dominated by two unpalatable species, *C. ramiflora* and *G. mariannae*, with little ground cover present. Goats have undoubtedly altered the species composition of the forest. Groves of

secondary forest comprised of the introduced trees *Acacia confusa*, *Leucaena leucocephala*, *Triphasia trifolia*, and *Casuarina equisetifolia* occur at a number of disturbed sites. This habitat covers about 10 percent of the island and frequently contains some native trees (e.g., *O. mariannensis*, *G. mariannae*, and *Melanolepis multiglandulosa*) (Esselstyn and others 2004). Grassy and shrubby coastal strand occupies the remainder of the island. A control program greatly reduced goat numbers in 1989–1990 (Rice 1991, 1993*a*), but failed to eradicate them. Goats remained uncommon in 1995, but were again abundant from 2002 through 2008. The island has been uninhabited by people since the end of World War II, but is regularly visited by goat and coconut crab (*Birgus latro*) hunters from Tinian.

MATERIALS AND METHODS

Pacific sheath-tailed bats were surveyed during four trips to Aguiguan on 21–27 March 1995, 30 May–7 June 1995, 9–19 September 2003, and 19 June–15 July 2008. A few additional observations were made from 15–20 March 2002. Our study emphasized finding bats at roosting sites, thus we visited most caves previously known based on the efforts of past researchers (Lemke 1986, Rice and Taisacan 1993). Extensive searches also were made throughout the island for additional caves, rock crevices, and hollow trees that might serve as roosts for these bats. However, searches still remain incomplete because there are undoubtedly caves located in places that are inaccessible without technical climbing skills. We did not find three small caves as reported by Butler (1992) and 13 caves (10 small, 3 possibly medium-sized) as reported by Stafford (2003), although K. W. Stafford (New Mexico Institute of Mining and Technology, Socorro, NMex., personal communication, 2008) reported no sightings of bats in these caves.

All accessible caves were entered and examined for bats or evidence of their occupation, including echolocation calls and guano. Colonies of Mariana swiftlets (*Aerodramus bartschi*), a cave-dwelling aerial insectivore, resided in at least nine of the island's caves. The presence of swiftlet guano often complicated our efforts because it can be difficult to distinguish from bat guano after it ages. However, we attempted to look for the distinctively shaped pellets of recent guano produced by insectivorous bats on walls and floors of caves in places apart from swiftlet nesting areas. Direct counts of bats roosting inside caves during the day were made whenever possible. In 2008, these were aided at some caves by the use of an infrared night vision device (model ATN NVM–14–3A, American Technologies Network Corporation, San Francisco, Calif.) and an infrared illuminator. The interior dimensions of many caves were measured with a hip chain or visually estimated. Most of the entrances to larger caves were also measured. Interior sizes of caves were categorized as small, medium, or large. Small caves were generally $\leq$15 m long and 50 m^2 in floor area. Most consisted of low rock overhangs, narrow vertical crevices, or various cavities that were usually located at the bases of cliffs or underneath large boulders. Medium-sized caves generally had 50–100 m^2 of floor space and often had wider rooms than small caves. Large caves were usually $>$100 m^2 in floor size, with ceiling heights usually reaching 5–30 m. We also visually inspected hollow trees during the 1995 surveys to look for roosting sheath-tailed bats and guano deposits.

Evening emergence counts (Kunz 2003) of sheath-tailed bats were conducted at a number of caves that were potentially suitable for bats. Observers positioned themselves near the cave's opening, either inside or outside, to obtain the best possible vantage point for counting exiting bats. Observers remained quiet and motionless to avoid disturbing bats, and counts ended at total darkness (these bats emerge at early dusk, see below) or at least 15 minutes after the last bat emerged in cases where bats were present. Total numbers of bats exiting a cave were determined by subtracting the number of individuals entering from those departing. Observers used ultrasonic detectors (in 2003, model D–100, Pettersson Elektronik AB, Uppsala, Sweden; in 2008, AnaBat SD1 CF, Titley Electronics, Ballina, New

South Wales, Australia) to assist in the detection of emerging bats at some sites. In 2003 and 2008 a mist net was used to capture a small number of bats flying inside one cave (Guano Cave, described below) on two days when counts at emergence were not conducted. In 2008 no counts were made after this potential disturbance took place. A spreadsheet database of the cave inventory and counts of bats has been archived with the U.S. Fish and Wildlife Service (FWS), Ecological Services field office, Honolulu, Hawaii, and is also available from the authors.

RESULTS

Searches of Caves and Counts of Bats

We inventoried and cataloged 114 caves during the study, including sites recorded by Butler (1992) and Stafford (2003) but not visited by us (Appendix III-A). These represented 18 large, 9 medium, 74 small, and 13 undefined caves. We visited 85 caves in 1995; 57 caves in 2003, including nine not found in 1995; and 41 caves in 2008, including four not found in 1995 or 2003. Caves were distributed throughout much of Aguiguan, almost always in association with cliffs or fault lines. The two largest sites (Krisidu and Dangkolo Caves) featured single main rooms that were >50 m in length, were 15–20 m wide, and had ceiling heights of 15–20 m.

During surveys in 1995, we inspected 78 caves internally and emergence counts were carried out at 10 caves, including two that could not be entered. Ninety-eight bats were recorded at five of the caves (Table III–1). The other five caves had no bats. Guano Cave was the only cave with bats visited in 1995 that was previously known to support bats (Table III–1). The four caves first documented in 1995 as having roosting bats were Cliff Cave, Pillar Cave, East Black Noddy Cave, and Crevice Cave. The largest colony numbered 69 bats at East Black Noddy Cave, with aggregations of 2–17 animals recorded at the other sites (Table III–1). In 2003, we inspected 52 caves internally and made emergence counts at eight caves, including three that were not entered. A total of 333–348 bats was counted at six caves, with bats present at the same five sites that were occupied in 1995 as well as at one newly discovered site (Fault Line Cave 1) that had a single bat (Table III–1). East Black Noddy Cave again held the largest colony, with an emergence count tallying 296 bats on 18 September. Other caves held up to 35 bats (Table III–1). Bat numbers were also larger at Guano and Pillar Caves in 2003 than in 1995.

In 2008, we visited 41 caves, inspected 34 caves internally, and made emergence counts at 18 caves, including seven that were not entered. Using minimum and maximum counts at occupied caves, a range of 359-466 bats was counted at five caves, with bats present at four of the six sites used in 1995 or 2003 and one new site, New Cave 1 (Tables III–1 and III–2). East Black Noddy Cave continued to hold the largest colony, with four emergence counts ranging from 308-382 bats (mean [$\pm$SD] $=333 \pm 33.6$). Internal counts at Guano Cave on six dates using the night vision device varied from 43-64 bats (mean $= 55 \pm 7.0$). Other occupied caves held 2–12 bats. Compared to 2003, counts in 2008 were higher at East Black Noddy, Guano, and Cliff Caves, about the same at Crevice Cave, and declined to zero at Pillar Cave and Fault Line Cave 1 (Table III–1). All occupied caves were used throughout the survey period except New Cave 1, which held at least five bats on 4 July 2008, but none during visits on three other occasions in 2008 (Table III–2). Ten additional caves where multiple surveys were made showed no daytime use by bats (Table III–3).

From our observations it appears that Pacific sheath-tailed bats on Aguiguan prefer larger caves as diurnal roosts. Using our size criteria for caves, bats have been recorded in six large caves, one medium-sized cave, and one of unknown size (Table III–4). Variation in main entrance size of occupied caves ranged from 4 m wide by 25 m tall at Crevice Cave to about 1 m wide by 0.5 m tall at the upper

entrance of East Black Noddy Cave (Table III–4). Swiftlets were present in seven of the eight caves inhabited by bats. We examined the trunk cavities of 22 hollow trees (21 *Pisonia grandis*, 1 *Psychotria mariana*), but found no evidence of occupation by bats. *Pisonia* hollows were typically 1–4 m tall and 20-45 cm in diameter, with their openings usually located near the base of the trunk.

Variability in Counts of Bats at Caves

Counts indicated that minor movement of bats among caves might take place, in some cases perhaps daily. We have no evidence that such movements will add a great deal of variability to the counts. Bats were always present at the two largest colonies, whereas caves with high variability in the presence or absence of bats during different visits all held small numbers of bats at any one time. Landing Cave was visited 11 times between 1984 and 2008, with bats seen on only two visits, both times in small numbers (≤ 4; Table III–1). Seasonal changes in attendance at roosts were not indicated by the results at Landing Cave: bats were present on 22 June in 1984 and 23 May 1992, whereas negative findings were recorded during June on three other visits in different years, as well as in months of January, March, and September (Table III–1). Similarly, Pillar Cave had no bats on five counts in five different years from 1985-1995 during the months of January, March, and June. However, from 2–10 bats were counted at Pillar Cave on three dates in March, June, and September in 1995–2003; no bats used Pillar Cave during the day on two dates in June and July 2008, but 16–21 bats entered the cave after dusk from elsewhere. Day-to-day differences were also noted within years and within field trips: Fault Line Cave 1 had one bat during the day in 2003, but none was present during the day on seven dates the cave was visited in 2008; five bats were observed at New Cave 1 on 4 July, but none on 25 June, 5 July, or 10 July in 2008; Cliff Cave had no bats in March 1995 but seven in June, and Pillar Cave had none in March 1995 but two in June (Tables III–1 and III–2).

Three roosts consistently had bats on each visit from 1995–2008: Guano Cave, East Black Noddy Cave complex, and Crevice Cave. The Guano and East Black Noddy caves have the largest colonies known, whereas Crevice Cave had only 2–3 adult bats on each count. Counts made during the day inside Guano Cave using a night vision device on six dates between 20 June and 7 July in 2008 (Table III–2) were different on each date, ranging from 43 to 64 bats (coefficient of variation 12.8 percent). Counts made during fly-outs at dusk at East Black Noddy Cave on four dates also varied similarly (coefficient of variation 10.1 percent), and ranged between 308 and 382 bats. It is likely that some of this variation is due to movements of bats among different roosts, as is more clearly seen in the caves that vary from none to a small number of bats. However, counts are also subject to a number of other sources of variability including observer variability, environmental effects, and bias from unknown sources. Even using the night vision device with supplemental infrared illumination at Guano Cave, a single observer recording three separate tallies on each visit on five dates in 2008 had variability in counts within each day. On three of the five days the three separate counts only varied by a single bat each day. On two dates however, the three counts varied by a range of seven bats on one day and by 11 bats on the other. The range was primarily attributable to variability in the ability to discern large pups that roosted next to their mothers.

Observations of Sheath-Tailed Bat Behavior at Caves

Roosting behaviors of bats were observed only at Guano and Crevice Caves. At Guano Cave in 1995, all bats roosted in one area of the cave and were spaced apart by about 7–20 cm on the open dome-like ceiling in a small chute at the rear of the cave's dark main room. The roosting area was the highest point in the cave. This same dome also was used in 2003 and 2008. In 2008 the night vision equipment allowed more detailed observation. The bats roosted singly (or a female next to young), were spaced about 5–30 cm apart on the ceiling and upper walls of the dome. They appeared to have most of

their ventral surfaces appressed to the rock surface with heads facing downwards, and were dispersed in a pattern intermediate between a regular and random spacing. This cave was also occupied by about 250 or more cave swiftlets. Most swiftlets did not roost in the dome occupied by the bats, but in adjoining areas of the large main room that were nearer the cave entrance. The few swiftlets that also roosted in the chamber were lower than the bats and against the walls of the dome. At Crevice Cave in 1995, three bats roosted about 30 cm apart while roosting prone against the vertical wall of a side chamber. Although the room was in the darkest portion of the cave, the animals remained in dim twilight. This location was also occupied in 2003 and 2008. Because emergence and roost counts were similar at both caves, we are confident that few if any uncounted bats were hidden in cracks or crevices (we found no evidence that Pacific sheath-tailed bats at Aguiguan roost in narrow crevices or cracks in rock, and this is generally consistent with the literature for the species elsewhere). Bats were not detected during inspections of the main room at East Black Noddy Cave in 1995 and by K. W. Stafford (New Mexico Institute of Mining and Technology, Socorro, NMex., personal communication, 2008) in 2003, and therefore presumably roosted in an unexamined 7-m-long passage leading in from the upper entrance. We did not observe roosting bats at Pillar Cave, suggesting that roosting occurred in an inaccessible area. We were unable to enter Cliff Cave, and the bats at Fault Line Cave 1 and New Cave 1 were disturbed before they were observed.

Overall, total duration of sheath-tailed bat emergences from roosting caves averaged 18.3 ±11.7 (SD) min, with most exits occurring during a mean period of 10.4 ± 5.6 min (Table III–5). On average, most departures began 3.2 ±8.7 min before sunset and ended 7.1 ±8.1 min after sunset. There was little or no overlap of activity between sheath-tailed bats and swiftlets during most (6 of 8) counts, with the period of most bat exits ending an average of 3.6 ±6.6 min before the period of most swiftlet entries (Table III–5). However, scheduling of the emergence periods varied with colony size, with larger colonies emerging over longer periods, beginning earlier in relation to sunset, and ending closer to the time when swiftlets began entering the cave to roost for the night (Table III–6). Bats sometimes emitted audible high-pitched calls prior to emerging, presumably as they flew about inside the cave. Most individuals exited their caves by flying straight from the entrance, but some circled briefly outside before leaving the vicinity. At East Black Noddy and Guano Caves, a few emerging bats made one or several circling forays 5–15 m outside the caves' entrances, and then re-entered the cave or departed. Bats at smaller colonies exited singly, but at East Black Noddy Cave, some departed in groups of two to four. On 17 September 2003, a light rain shower several minutes after all bats had departed East Black Noddy Cave caused 50–75 bats to return immediately to the cave. This suggested that some bats linger in the general vicinity of the cave after emerging. Inspections of Guano Cave after counting ended in 2003 and 2008 showed that no bats remained inside immediately after the evening emergence was completed. We captured six bats inside Guano Cave during the day in 2003, all of which were females.

In 2008, post-emergence use of caves as night roosts was detected at three caves, none of which were found to be used as day roosts during field work this year. We recorded 13 bats entering Pillar Cave from 1847 to 1902 h (MPT, Northern Mariana Islands time) on 21 June, with chattering vocalizations heard from inside the cave several times afterwards, indicating that roosting had occurred. At least one of the calls came from the cave's outer room. Inspection of the cave with night vision equipment from 2000 to 2015 h found no bats present. On 7 July, during our only other evening count at this site, 21 bats entered from 1841 to 1856 h and appeared to remain inside. On 24 June we observed a single bat circling repeatedly inside the main entryway of Cave 63 (a small cave) at 1937 h . On 11 July at 1847 we observed similar behavior by a bat that flew into the main opening of Fault Line Cave 1 and made audible vocalizations (short "chirps") as it remained inside for a few minutes. It then exited through a small opening at the ceiling of the cave after one of us entered at the main opening.

One other notable observation was that of an early evening (1841-1920 h) passage of at least 43–47 sheath-tailed bats flying singly past the vicinity of Caves 66–68, 94, 95, and 101 on several nights (see also Section VI of this report). All of the bats followed a similar route through the forest understory, coming uphill from undetermined source to the west and continuing to the south or east. None came from any of the caves in the immediate area. Use of bat detectors revealed that few if any of the bats remained in the area after 1920 to at least 2200.

DISCUSSION

Pacific Sheath-Tailed Bats on Aguiguan

Our surveys in 1995, 2003, and 2008 represent the only attempts to assess the status of the Pacific sheath-tailed bat population on Aguiguan since 1984 (Lemke 1986). Over this period of time counts increased. We counted totals of 98 bats in 1995, 333–348 bats in 2003, and 359–466 bats in 2008. Bats occurred in only seven of the 95 caves examined (i.e., those entered or surveyed using emergence counts), even though many unoccupied sites appeared suitable as roosts. Despite good coverage of the island's inland cave system during the study, a few undocumented caves occupied by colonies of unknown size may be present. By comparison, most of the coastal cliffs ringing the island could not be surveyed for caves because they are difficult and dangerous to access. Several large caves are known to exist in these escarpments, thus further assessment for their use as roosts by bats is needed, especially because *E. semicaudata* inhabits sea caves elsewhere in its range (Grant and others 1994). With the exception of one area, acoustic surveys conducted across the island in 2003 and 2008 did not detect concentrations of bat activity away from areas with known colonies (Esselstyn and others 2004, Section IV of this report). Substantial early evening bat activity was noted in 2008 and to a lesser extent in 2003 at an acoustic station near the island's northeast coast, suggesting the presence of an undocumented colony in that general area. However, Pacific sheath-tailed bats are known to commute distances exceeding 5 km to reach foraging sites in Palau (Wiles and others 1997), thus it may be possible that the bats at this station originated from East Black Noddy Cave, which is located 1.7 km to the west. Based on the likelihood that small numbers of additional colonies may remain undetected, it is possible that the total current sheath-tailed bat population on Aguiguan numbers more than our maximum count of 466.

Our surveys documented larger numbers of sheath-tailed bats in 1995 than those counted by previous observers (Lemke 1986, Rice and Taisacan 1993), but much of this can be attributed to improved survey coverage. However, data indicate that marked population growth had occurred since 1995. Colony size grew at three of five caves from 1995 to 2003, with numbers expanding more than fourfold at the largest colony. Additional but more modest growth continued from 2003 to 2008. Bat numbers at Guano Cave are particularly illustrative and have increased from four in 1985 (Lemke 1986) to about 55 in 2008. Perhaps the population of sheath-tailed bats on Aguiguan has been increasing since the mid-1980s after a past bottleneck. Typhoons can be a major source of bat mortality on other Pacific islands (see below), and at least two major typhoons struck the island during this time (Lander 2004; Curt Kessler, U.S. Fish and Wildlife Service, personal communication 2008). However, the increase in numbers suggests that the sheath-tailed bat population on Aguiguan was not severely impacted by these typhoons. Although our results show some variability in counts that indicate likely movements of small numbers of bats among roosts, and potential biases are noted in variation in counts from other sources, such variation seems unlikely to explain the large increases in colony sizes documented at some caves. Instead we think our results reflect true growth in the populations that use the two major caves. Surveys at East Black Noddy (upper entrance) and Guano Caves included counts made by the same person (G. J.

Wiles) in all three surveys and were in close agreement with simultaneous counts made by the other observers, thus major inter-observer variability should not be an important source of error in our results.

The trend towards an increasing population of Pacific sheath-tailed bats on Aguiguan since 1995 is especially noteworthy given the many reported declines elsewhere in the species' range in recent decades (Lemke 1986, Grant and others 1994, Flannery 1995, Hutson and others 2001, Tarburton 2002, Palmeirim and others 2007). Is it theoretically plausible that the changes in counts we observed are due to intrinsic population growth? A basic underlying model (e.g. Eberhardt 2002) often used in analyses of population trend data is:

$$N_t = N_0\lambda^t,$$

where:
N_0 is the initial population size
Nt is population size at time t
λ is the population growth rate.

An estimate of λ can be calculated using the equation:

$$\ln(N_t) = \ln(N_0) + t\ln(\lambda).$$

Although this model is based on a number of assumptions that are unknown for Pacific sheath-tailed bats and is usually applied for multiple time series, we used it in a simplified way to determine if it is plausible for the observed increases to be due to intrinsic population growth. Application of the model to mean counts yields an estimated $\lambda = 1.13$ at Black Noddy Cave, and $\lambda = 1.10$ at Guano Cave, between 1995 and 2008. There have been few empirically derived estimates for annual population growth rates in insectivorous bats, but those that have been calculated for growing populations of other species of bats using more sophisticated models and accurate vital parameter data are consistent with the calculations of λ for these two largest colonies of Pacific sheath-tailed bats at Aguiguan. These estimates for other species of insectivorous bats with seasonal breeding and litter sizes of one range from $\lambda = 1.03$-1.22 (Frick and others 2007, Pryde and others 2005). We do not suggest that the specific growth rates we calculated above should be considered accurate for this population, but only that they crudely demonstrate that it is indeed plausible that the magnitudes of the observed changes in counts may be due to population growth. The future trend of the population of sheath-tailed bats on Aguiguan is impossible to predict, but numbers of bats counted in 2003 and 2008 resemble those of the ecologically similar Mariana swiftlet, whose surveyed numbers regularly exceed 400 birds (Cruz and others, 2008; G. J. Wiles, unpubl. data). This current similarity in abundance may indicate that bat numbers are reaching their upper limit on the island.

The colony of up to 382 bats at East Black Noddy Cave is by far the largest ever recorded for *E. s. rotensis*. Counts at other roosts on Aguiguan ranged from 1–64 individuals. Our capture of six females and no males at Guano Cave in 2003 and five females and no males at this cave in 2008 (see Section VI of this report) suggests that this colony may have been comprised mostly of females. Aggregations of fewer than 25 bats and segregation of the sexes are common roosting traits among bats in the genus Emballonura (Flannery 1995, Bonaccorso 1998, Nowak 1999). Nevertheless, larger colonies with up to several hundred bats may have once been common in the Mariana Islands, as has been found with *E. s. palauensis* in Palau (Wiles and Conry 1990, Wiles and others 1997). Roosts of this size are also known for *E. s. sulcata* in Chuuk (Bruner and Pratt 1979). Amerson and others (1982) documented a cave in American Samoa with perhaps as many as 10,000 *E. s. semicaudata*.

Aguiguan's bats appear to roost exclusively in caves, which resembles the behavior of *E. s. semicaudata* and *E. s. palauensis* (Grant and others 1994, Wiles and others 1997). By contrast, some *E. s. sulcata* colonies select tree cavities as day roosts on Pohnpei (D. W. Buden, personal commun.). Most other members of the genus reside in caves (e.g. Goodman and others 2006, Bonaccorso 1998), especially in or near the twilight zones of smaller caves, but several species also roost in foliage, hollow logs, and human-built structures (Flannery 1995, Nowak 1999, Kingston and others 2006). Results of surveys on Aguiguan (Table III–1) indicate that sheath-tailed bats may exhibit strong fidelity to some of these caves. Guano Cave, for example, appears to have been occupied since at least 1985, while three other caves (Crevice, East Black Noddy, and Cliff caves) were occupied during each of our visits in 1995, 2003, and 2008. Other sites, such as Pillar, Landing, Fault Line 1, and New 1 Caves, may be inhabited temporarily. We caution that we cannot vouch for the accuracy of counts made prior to May 1995 when none of us was present, especially those at Cliff and Pillar Caves. Surveys in 2008 were the first to attempt replicate counts at the same roosts on different days. Results from East Black Noddy and Guano Caves indicate that numbers of bats roosting at these sites will vary over periods of several days. Emergence counts like those made at East Black Noddy Cave can be susceptible to observer error, which may account for some of the variation recorded. However, the direct counts of roosting bats made at Guano Cave with night vision equipment should be more accurate. We recommend that future surveys at these two important roosts routinely incorporate counts on multiple dates to better assess their variation. The lack of measures of variation in counts of emerging bats is a common problem in studies of most species of bats throughout the U.S. and territories, but is critical for assessing trends in abundance (Ellison and others 2003).

This study is the first to document the use of caves as night roosts by *E. semicaudata*. Night-roosting behavior has many potential functions in bats (Ormsbee and others 2007). Each of the three caves observed to be in use at night in this study was occupied at dusk or shortly thereafter, suggesting that food digestion was not a goal of the animals involved. Based on the presence of multiple animals and vocalizations, Pillar Cave may have served as a site for social interaction, such as mating or information transfer.

Decline of *E. s. rotensis* in the Marianas Islands

Causes for the overall decline of *E. s. rotensis* in the southern Marianas are unclear. Extirpations of sheath-tailed bats on Rota, Saipan, and Guam roughly coincided with declines or population losses in Mariana swiftlets, suggesting that both species experienced common threats, perhaps because of their similar roosting and feeding habits. Swiftlets no longer occur on Rota, but persist in low to moderate numbers on Saipan and Guam (Engbring and others 1986; Cruz and others 2008; G. J. Wiles, Washington Department of Fish and Wildlife, unpubl. data, 2008).

Human occupation and warfare during World War II heavily impacted many caves in the Marianas, when Japanese troops used caves as defensive fortifications. Grenades and flame-throwers were commonly used by the U.S. military to eliminate Japanese soldiers using these fortified caves. Such disturbance presumably harmed numerous bat and swiftlet colonies, but unless populations were completely eliminated should have been a temporary effect that would have subsided after the war. Since then, visitation of caves by hunters, vandals, hikers, and guano miners has continued (U.S. Fish and Wildlife Service 1992), but has probably not been extensive enough at most sites since the 1980s to be problematic. On Aguiguan, several caves (including Guano Cave and Fault Line Cave 1) show evidence of extensive use by the Japanese before or during the war, and it is unlikely that bats occupied the caves at that time. However, there was no combat or destructive use of munitions in caves on Aguiguan (Butler 1992). Guano Cave has also been used for small-scale guano mining (U.S. Fish and Wildlife Service 1992). Many caves on other islands show similar signs of disturbance (U.S. Fish and

Wildlife Service 1992; G.J. Wiles, personal commun. 2008). By contrast, Cliff Cave has probably never been entered by humans because of its high cliffside location. East Black Noddy Cave, which holds the largest documented number of bats on Aguiguan, has also probably received very little disturbance from people since the war because it is difficult to access. Entry of caves by introduced ungulates is also potentially disruptive, especially on Aguiguan, where feral goats habitually seek shelter in many caves.

Historical pesticide contamination may have posed significant problems for sheath-tailed bats in the Marianas, but this has not been thoroughly investigated (see Section VIII of this report). Liberal use of compounds such as DDT and malathion is known to have occurred between the 1940s and 1970s (Baker 1946, Townes 1946, Drahos 1977, Jenkins 1983). Applications were most intense on Guam, Saipan, and Tinian (Townes 1946) because of their larger human populations and the presence of American military bases. Residues of the break-down product DDE have been found in swiftlet tissues and guano samples from Guam (Drahos 1977, Grue 1985), but tests by Grue (1985) yielded no evidence to support the hypothesis that poisoning by DDT or DDE had caused declines among Guam's avifauna. Concentrations of DDT and DDE in swiftlet guano measured in 1981 were much less than those associated with avian mortality or reproductive failure, and an order of magnitude less than concentrations in bat guano that can be linked to mortality in insectivorous bats (Clark and others, 1982, 1995; Clark and Shore 2001). Concentrations of contaminants have never been measured in sheath-tailed bat guano or tissues. Additionally, the carbamate and organophosphate insecticides that were also used are not persistent in tissues or guano, and exposure of bats or swiftlets to these compounds has not been assessed. Some of these compounds were likely responsible for deaths of bats in the United States in the 1960s (Clark and Shore 2001). It is also possible that sheath-tailed bats and swiftlets could have been at risk if they or their insect prey base were more susceptible to pesticide contamination than other animals because of physiological differences in organochlorine accumulation or differential vulnerability at various stages in their life history (Clark and Shore 2001). However, DDT was used extensively in Palau in the 1940s (Baker 1946) and probably thereafter, but sheath-tailed bats remain abundant there (Wiles and others 1997). Development of DDT as an insecticide did not occur until the 1940s (Metcalf 1973). It is unknown if other pesticides were used by Japanese colonists on sugar plantations at Aguiguan prior to World War II. Aguiguan was neither populated nor used agriculturally after the war, and thus it is unlikely that significant amounts of pesticides were applied to the island during the period when they were in use elsewhere in the Marianas. A likely absence of the intensive use of pesticides on Aguiguan could have contributed to the persistence of sheath-tailed bats there. The apparently low numbers of bats on Aguiguan in the 1980s in comparison with 2008 (e.g. at Guano Cave) are enigmatic in relation to effects of contaminants. Samples of guano from Aguiguan were taken in 2008 (see Section VIII of this report) and their analysis for contaminants might be instructive in this regard.

Because *E. s. rotensis* forages almost exclusively in forests (Esselstyn and others 2004; see Section IV of this report), it seems likely that extensive deforestation in the southern Marianas has contributed to reduced populations of sheath-tailed bats. From the 1920s to early 1940s, Japanese colonists cleared from 75 percent to as much as 98 percent of Saipan, Tinian, and Rota (Bowers 1951) and about 43 percent of Aguiguan (Engbring and others 1986) for agriculture and other activities. Construction of major American military installations on Guam, Saipan, and Tinian during and after the war caused additional habitat loss, as did extensive civilian development on Saipan and Guam in subsequent decades. On Aguiguan, few of the fields cleared before the onset of World War II have returned to forest cover. This means that the sheath-tailed bat population is largely restricted to feeding within the remaining 4 km^2 of forested land available on the island. There was no use of munitions in

caves on Aguiguan during World War II (Butler 1992), and the large number of unoccupied inland caves with suitable temperatures (see also Section VI) suggests that roost site availability does not limit the population of sheath-tailed bats on Aguiguan. Deforestation is likely the major current limiting factor, and is known to be a major cause of bat declines and losses elsewhere in the world (e.g., Brosset and others 1996, Lane and others 2006; Wiles and Brooke, in press).

We found no evidence of predation on sheath-tailed bats on Aguiguan. Monitor lizards (*Varanus indicus*), which were likely introduced to the Marianas after European contact (Pregill 1998), are abundant on Aguiguan and represent a potential predator of sheath-tailed bats. They are adept climbers and may be able to reach day-roosting bats in hollow tree trunks or smaller caves with low ceilings. Although such predation may currently be insignificant, it may have influenced the selection of the roost sites in larger caves now used by bats. Introduced rats and large geckos are common in some caves and have the potential to take young bats at roosts on occasion. Rats are unlikely to reach the high walls and ceilings used by bats in most caves, however, and adult bats are typically alert and will fly readily when threatened. Avian predation is probably limited to occasional owls in migration and the resident diurnal collared kingfisher (*Todirhamphus chloris*). Predation by the introduced brown tree snake (*Boiga irregularis*) has devastated native wildlife populations on Guam (Fritts and Rodda 1998) and currently prevents swiftlet recovery on the island (Wiles and others, 2003). Brown tree snakes conceivably contributed to declines or caused losses in sheath-tailed bats in southern Guam during the 1950s and 1960s, but probably played no role in the bat's subsequent demise in northern Guam. Snakes did not invade northernmost Guam in significant numbers until the late 1970s (Savidge 1987, Wiles and others 2003), which was at least a decade after serious declines in *E. s. rotensis* numbers were noted there (Perez 1972) and 6–7 years after the last known sighting in 1972. Brown tree snakes do not occur on Aguiguan, but have the potential to be predators of sheath-tailed bats if they were to reach the island.

Grant and others (1994) identified a succession of severe typhoons as a possible contributing factor in the recent decline of *E. s. semicaudata* in Samoa. This cause is unlikely to be related to the overall decline throughout the Marianas. However, because of Aguiguan's small land area and bat population, it is conceivable that an unusually intense storm or series of storms could severely impact the species by precluding foraging during storms, damaging important foraging habitat by destroying vegetation that its prey depends upon, or flooding colonies in seaside caves. Direct mortality from high winds blowing into exposed caves is also possible, as seen on Guam, where Supertyphoon Pongsona killed at least 30 roosting swiftlets at a cave in 2002 (Craig Clark, U.S. Department of Agriculture Wildlife Services Guam, personal commun., 2002).

When viewed in conjunction with the extirpation of Pacific sheath-tailed bats on other Mariana Islands, this study suggests that *E. s. rotensis* is highly vulnerable to extinction, with probably no more than a few hundred of these bats restricted to one very small island. Preservation of this bat hinges on the maintenance of forested habitat and safe roosting sites. If eradication or strict management of goats were deployed, this would greatly improve regeneration of native tree species and insure the long-term stability of native forests on the island. Reforestation could be initiated to replant sizable areas of weedy fields with native trees. *Emballonura s. rotensis* and virtually all other native wildlife species would benefit from such treatment. Although not frequent, human visitation to Aguiguan occurs, primarily by hunters from Tinian. Interest in developing the island for ecotourism has also been expressed in the past (Justine B. de Cruz, CNMI Division of Fish and Wildlife, personal commun., 2002). If human visitation increases from hunting or ecotourism, bat colonies at some of the easily accessible and reasonably well known caves (e.g., Guano Cave) could be at risk from irresponsible visitation. Additionally, ongoing efforts to prevent the establishment of brown tree snakes in the CNMI are an obvious priority for protecting this bat population.

Expanded study of sheath-tailed bats on Aguiguan is needed to provide additional information on population size, vital parameters, basic ecology and natural history, genetics, and important limiting factors. A priority for future surveys should be improved assessment of use of coastal caves in areas that cannot be reached without technical climbing expertise, as well as additional efforts to re-survey areas with caves visited in the past. We recommend that additional paleontological work, similar to that conducted by Koopman and Steadman (1995) and Steadman (1999), be conducted to learn more about past use of caves by these bats on Aguiguan.

Despite its rarity, neither the Pacific sheath-tailed bat nor its habitat is afforded protection in the U.S. possessions where it presently occurs. The species is on the CNMI list of threatened or endangered species, but this law provides no protection to the bat or its habitat. Under U.S. federal law, the U.S. Fish and Wildlife Service has categorized the bat as a candidate species, meaning that sufficient information is available to consider listing it as threatened or endangered. However, lack of funding, its subspecific status, and other constraints have precluded proceeding with listing (U.S. Fish and Wildlife Service 2002, 2007). Greater legal protection might help enhance its habitat and conservation.

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REFERENCES CITED

Amerson, A. B., Jr., Whistler, W. A. and Schwaner, T. D., 1982, Wildlife and wildlife habitat of American Samoa. Vol. II: Washington, D.C., U.S. Fish and Wildlife Service.

Baker, R. H., 1946, Some effects of the war on the wildlife of Micronesia: Transactions of the North American Wildlife Conference, vol. 11, p. 205-213.

Bonaccorso, F. J., 1998, Bats of Papua New Guinea: Washington, D.C., Conservation International.

Bowers, N. M., 1951, Problems of resettlement on Saipan, Tinian, and Rota, Mariana Islands: Ann Arbor, Michigan, Ph.D. thesis, University of Michigan.

Brosset, A., Charles-Dominique, P., Cockie, A., Cosson, J.-F., and Masson, D., 1996, Bat communities and deforestation in French Guiana: Canadian Journal of Zoology, vol. 74, p. 1974-1982.

Bruner, P. L., and Pratt, H. D., 1979, Notes on the status and natural history of Micronesian bats: 'Elepaio, vol. 40, p.1-4.

Butler, B. M., 1992, An archaeological survey of Aguiguan (Aguijan), Northern Mariana Islands: Saipan, Commonwealth of the Northern Mariana Islands, Division of Historic Preservation, Micronesian Archaeological Survey Report No. 29.

Chandran, R., Craig, R. J., Keys, Z., Sheu, C., and Dubrall, J., 1992, The structure and tree species cornposition of Aguiguan forests, *in* Craig, R. J., ed. The Aguiguan expedition: Saipan, Commonwealth of the Northern Mariana Islands, Proceedings Marianas Research Symposium, Vol. 1, Northern Marianas College.

Clark, D. R., Jr., and Shore, R. F., 2001, Chiroptera, *in* Shore, R. F., and Rattner, B. A., eds., Ecotoxicology of wild mammals: Chichester, West Sussex, United Kingdom, John Wiley & Sons, p. 159-214.

Clark, D. R., Jr., LaVal, R. K., and Tuttle, M. D., 1982, Estimating pesticide burdens of bats from guano analyses: Bulletin of Environmental Contamination and Toxicology, vol. 29, p. 214–220.

Clark, D. R.. Jr., Moreno-Valdez, A., and Mora, M. A., 1995, Organochlorine residues in bat guano from nine Mexican caves 1991: Ecotoxicology, vol. 4, p. 258–265.

Craig, R. J., and Chandran, R., 1992, Wildlife species recorded during the Aguiguan expedition: 20-25 May, 1992, *in* Craig, R. J., ed. The Aguiguan expedition: Saipan, Commonwealth of the Northern Mariana Islands, Proceedings Marianas Research Symposium, Vol. 1, Northern Marianas College, p. 1-7.

Cruz, J. B., Kremer, S. R., Martin, G., Williams, L. L., and Camacho, V. A., 2008, Relative abundance and distribution of Mariana swiftlets (Aves: Apodidae) in the Northern Mariana Islands: Pacific Science, vol. 62, p. 233-246.

Drahos, N. 1977. Status of the Vanikoro swiftlet on Guam (*Collocalia vanikorensis* Quoy and Gaimard): Mangilao, Guam, Division of Aquatic and Wildlife Resources.

Division of Fish and Wildlife (Commonwealth of the Northern Mariana Islands), 2000, Summary of wildlife surveys, Aguiguan Island, March 31-April 8, 2000: Saipan, Commonwealth of the Northern Mariana Islands, Division of Fish and Wildlife.

Eberhardt, L.L., 2002, A paradigm for population analysis of long-lived vertebrates: Ecology, vol. 83, p. 2841-2854.

Ellison, L. E., O'Shea, T. J., Bogan, M. A., Everette, A. L., and Schneider, D. M., 2003, Existing data on colonies of bats in the United States: summary and analysis of the U.S. Geological Survey's bat population database, *in* O'Shea, T.J. , and Bogan, M. A., eds., Monitoring trends in bat populations of the United States and Territories: problems and prospects: Washington, D. C., U.S. Geological Survey Information and Technology Report USGS/BRD/ITR-20030-0003, p. 127-237.

Engbring, J., Ramsey, F. L., and Wildman, V. J., 1986, Micronesian forest bird survey, 1982: Saipan, Tinian, Agiguan, and Rota: Honolulu, Hawaii, U. S. Fish and Wildlife Service.

Esselstyn, J. A., Wiles, G. J., and Amar, A., 2004, Habitat use of the Pacific sheath-tailed bat (*Emballonura semicaudata*) on Aguiguan, Mariana Islands: Acta Chiropterologica, vol. 6, p. 303-308.

Flannery, T., 1995, Mammals of the South-West Pacific & Moluccan Islands: Ithaca, New York, Cornell University Press.

Frick, W.F., Rainey, W.E., and Pierson, E. D., 2007, Potential effects of environmental contamination on Yuma myotis demography and population growth: Ecological Applications, vol. 17, p. 1213-1222.

Fritts, T. H., and G. H. Rodda, G. H., 1998, The role of introduced species in the degradation of island ecosystems: a case history of Guam: Annual Review of Ecology and Systematics, vol. 29, p. 113-140.

Goodman, S. M., Cardiff, S. G., Ranivo, J., Russell, A. L., and Yoder, A.D., 2006, A New Species of *Emballonura* (Chiroptera: Emballonuridae) from the Dry Regions of Madagascar: American Museum Novitates, no. 3538, p. 1-24.

Grant, G. S., Banack, S. A., and Trail, P., 1994, Decline of the sheath-tailed bat *Emballonura semicaudata* (Chiroptera: Emballonuridae) on American Samoa: Micronesica, vol. 27, p. 133-137.

Grue, C. E., 1985, Pesticides and the decline of Guam's native birds: Nature, vol. 316, p. 301.

Helgen, K. M., and Flannery, T. F., 2002, Distribution of the endangered Pacific sheath-tailed bat *Emballonura semicaudata*: Australian Mammalogy, vol. 24, 209-212.

Hutson, A. M., Mickleburgh, S. P., and Racey, P. A., 2001, Microchiropteran bats: Global status survey and conservation plan: Gland, Switzerland and Cambridge, UK, IUCN/SSC Chiropteran Specialist Group, 258 p.

Jenkins, J. M., 1983, The native forest birds of Guam: Ornithological Monographs, vol. 31, p. 1-61.

Jenson, J. W., Keel, T. M., Mylroie, J. R., Mylroie, J. E., Stafford, K. W., Taboroši, D., and Wexel, C., 2006, Karst of the Mariana Islands: the interaction of tectonics, glacio-eustasy, and freshwater/seawater mixing in island carbonates, *in* Harmon, R. S., and Wicks, C., eds., Perspectives on karst geomorphology, hydrology, and geochemistry, Geological Society of America Special Paper, vol. 404, p. 129-138.

Kingston, T., Lim, B. L., and Akbar, Z., 2006, Bats of Krau Wildlife Reserve: Bangi, Malaysia, Penerbit Universiti Kebangsaan Malaysia.

Koopman, K. F., 1997, The subspecies of *Emballonura semicaudata* (Chiroptera: Emballonuridae): Journal of Mammalogy, vol. 78, p. 358-360.

Koopman, K. F., and D. W. Steadman, D. W., 1995, Extinction and biogeography of bats on 'Eua, Kingdom of Tonga: American Museum Novitates, No. 3125, p.1-13.

Kunz, T.H., 2003, Censusing bats: Challenges, solutions, and sampling biases, *in* O'Shea, T. J., and Bogan, M. A., eds., Monitoring trends in bat populations of the United States and territories: Problems and prospects: Washington, D.C., U.S. Geological Survey, Biological Resources Discipline, Information and Technology Report, USGS/BRD/ITR--2003-003, p. 9-19.

Lander, M. A., 2004, Rainfall climatology for Saipan: distribution, return-periods, El Nino, tropical cyclones, and long-term variations: Mangilao, Guam, Technical Report 103, Water and Environmental Research Institute, University of Guam.

Lane, D. J. W., Kingston, T., and Lee, B. P. Y.-H., 2006, Dramatic decline in bat species richness in Singapore, with implications for Southeast Asia: Biological Conservation, vol. 131, p. 584-593.

Lemke, T. O., 1986, Distribution and status of the sheath-tailed bat (*Emballonura semicaudata*) in the Mariana Islands: Journal of Mammalogy, vol. 67, p.743-746.

Metcalfe, R.L., 1973, A century of DDT: Journal of Agricultural and Food Chemistry, vol. 21, p. 511-519.

Nowak, R. M., 1999, Walker's mammals of the world. Vol. 1. 6th ed.: Baltimore, Maryland, Johns Hopkins University Press.

Ormsbee, P. C., Kiser, J. D., and Perlmeter, S. I., 2007, Importance of night roosts to the ecology of bats, *in* Lacki, M. J., Hayes, J. P., and Kurta, A., eds., Bats in forests: Conservation and management, Baltimore, Maryland, Johns Hopkins University Press, p. 129-151

Palmeirim, J. M., Champion, A., Naikatini, A., Niukula, J., Tuiwawa, M., Fisher, M., Yabaki-Gounder, M., Thorsteinsdóttir, S., Qalovaki, S., and Dunn, T., 2007, Distribution, status and conservation of the bats of the Fiji Islands: Oryx, vol. 41, p. 509-519.

Perez, G. S. A., 1972, Observations of Guam bats: Micronesica, vol. 8, p. 141-149.

Pregill, G., 1998, Squamate reptiles from prehistoric sites in the Mariana Islands: Copeia, vol. 1998, p. 64-75.

Pryde, M. A., O'Donnell, C. F. J., and Barker, R. J., 2005, Factors influencing survival and long-term population viability of New Zealand long-tailed bats (*Chalinolobus tuberculatus*): implications for conservation: Biological Conservation, vol. 126, p. 175-185.

Reichel, J. D., and Glass, P. O., 1988, Land and freshwater bird investigations, *in* Five-year progress report, fiscal years 1983-1987, Pittman-Robertson Federal Aid in Wildlife Restoration Program: Saipan, Commonwealth of the Northern Mariana Islands, Division of Fish and Wildlife, p. 106-130

Rice, C. G., 1991. Goat removal from Aguijan Island: lessons for future efforts: Transactions of the Western Section of the Wildlife Society, vol. 27, p. 42-46.

Rice, C. G., 1993*a*, Feral ungulate research, *in* Five-year progress report, fiscal years 1988-1992, Pittman-Robertson Federal Aid in Wildlife Restoration Program: Saipan, Commonwealth of the Northern Mariana Islands, Division of Fish and Wildlife, p. 303-319.

Rice, C. G. 1993*b*. Island swiftlet research, *in* Five-year progress report, fiscal years 1988-1992, Pittman-Robertson Federal Aid in Wildlife Restoration Program: Saipan, Commonwealth of the Northern Mariana Islands, Division of Fish and Wildlife, p. 241-255.

Rice, C. G., and E. Taisacan, 1993, Marianas fruit bat surveys, *in* Five-year progress report, fiscal years 1988-1992, Pittman-Robertson Federal Aid in Wildlife Restoration Program: Saipan, Commonwealth of the Northern Mariana Islands, Division of Fish and Wildlife, p. 35-47.

Savidge, J. A., 1987, Extinction of an island forest avifauna by an introduced snake: Ecology, vol. 68, p. 660-668.

Stafford, K. W. 2003. Structural controls on megaporosity in eogenetic carbonate rocks: Tinian, CNMI. M.S. thesis, Mississippi State University, Mississippi State, Mississippi.

Stafford, K., Mylroie, J., Taboroši, D., and Jenson, J., 2004. Eogenetic karst development on a small, tectonically active, carbonate island: Aguijan, Mariana Islands: Cave and Karst Science (Transactions of the British Cave Research Association), vol. 31, p. 101-108.

Steadman, D. W., 1999, The prehistory of vertebrates, especially birds, on Tinian, Aguiguan, and Rota, Northern Mariana Islands: Micronesica, vol. 31, p. 319-345.

Tarburton, M. K., 2002. Demise of the Polynesian sheath-tailed bat *Emballonura semicaudata* in Samoa: Micronesica, vol. 34, p. 105-108.

Townes, H. K., 1946, Entomology. Part I. Non-agricultural plants. Economic Survey of Micronesia, Vol. 12: Honolulu, Hawaii, U.S. Commercial Company.

U.S. Fish and Wildlife Service, 1992, Recovery plan for the Mariana Islands population of the Vanikoro swiftlet, *Aerodramus vanikorensis bartschi*: Portland, Oregon, U. S. Fish and Wildlife Service.

U.S. Fish and Wildlife Service, 2002, , 50 CFR Part 17; Endangered and threatened wildlife and plants; review of plant and animal species that are candidates or proposed for listing as endangered or threatened, annual notice of findings on recycled petitions, annual description of progress on listing actions; notice of review. Federal Register, Code of Federal Regulations, vol. 67 (number 114): 40657-40679.

U.S. Fish and Wildlife Service, 2007, 50 CFR Part 17; Endangered and threatened wildlife and plants; review of native species that are candidates for listing as endangered or threatened; annual notice of findings on resubmitted petitions; annual description of progress on listing actions; proposed rule. Federal Register, Code of Federal Regulations (December 6, 2007) vol. 72 (number 234): 69033-69106.

Wiles, G. J., and Brooke, A. P., in press, Conservation threats to bats in the tropical Pacific islands and insular Southeast Asia, *in* Fleming, T. H., and Racey, P., eds., Island bats: ecology, evolution, and conservation: Chicago, Illinois, University of Chicago Press.

Wiles, G. J., and Conry, P. J., 1990, Terrestrial vertebrates of the Ngerukewid Islands Wildlife Preserve, Palau Islands: Micronesica, vol. 23, p. 41-66.

Wiles, G. J., Aguon, C. F., Davis, G. W., and Grout, D. J., 1995, The status and distribution of endangered animals and plants in northern Guam: Micronesica, vol. 28, p. 31-49.

Wiles, G. J., Bart, J., Beck, R. E. Jr., and Aguon, C. F., 2003, Impacts of the brown tree snake: patterns of decline and species persistence in Guam's avifauna: Conservation Biology, vol. 17, p. 1350-1360.

Wiles, G. J., Engbring, J., and Otobed, D., 1997, Abundance, biology, and human exploitation of bats in the Palau Islands: Journal of Zoology (London), vol. 241, p. 203-227.

Table III-1. Numbers of Pacific sheath-tailed bats recorded at seven caves on Aguiguan, Mariana Islands, from 1984–2008, as determined by direct counts of day-roosting bats or evening emergence counts. Fields with hyphens indicate that no counts were made.

	Cave									
					East Black Noddy					
Date	Landing	Guano	Cliff	Pillar	Upper Entrance	Middle Entrance	Crevice	Fault Line Cave 1	New Cave 1	References[a]
22 June 1984	3-4[b]	-	-	-	-	-	-	-	-	1
January 1985	0[b,c]	4[b]	0[c]	0[c]	-	-	-	-	-	1, 2
18 July 1985	-	2[b]	-	-	-	-	-	-	-	3
28 Feb-1 March 1987	0[c]	3[b]	-	0[c]	-	-	-	-	-	3, 4, 5
6-9 June 1988	0[c]	5[b]	-	0[c]	-	-	-	-	0[c]	3, 4, 5
21 September 1989	-	13[b]	-	-	-	-	-	-	-	3, 5
March 1992	0[b]	9[b]	0[c]	0[c]	-	-	-	-	-	3, 4
23 May 1992	2[c]	-	-	-	-	-	-	-	-	6
23, 26 March 1995	0[b]	15[b], 16[b]	0[c]	0[c]	64[c]	5[c]	-	-	-	7
31 May-6 June 1995	0[b,c]	17[b,c], 16[b]	7[c]	2[c]	-	-	3[b,c]	-	-	7
15-20 March 2002	0[b]	15[c]	-	5[c]	-	-	-	-	-	7
13, 28 May 2003	-	-	-	-	-[d]	-[d]	2[b]	-	-	8
9-19 Sept 2003	0[b]	25-35[c]	4[e]	5-10[c]	280[c]	16[c]	2[c]	1[b]	0[b]	7
19 June-15 July 2008	0[b]	55[b,f]	6-12[c]	0[c]	277[c,g]	56[c,g]	2, 3[b,c]	0[b]	0, 5[b,c]	7

Note: Results from Cliff and Pillar Caves in 1985-1992 were obtained during evening arrival counts of Mariana swiftlets (Rice 1993*b*, Rice and Taisacan 1993). Bats were not detected during bat emergence counts at Dangkolo, Krisidu, West Black Noddy, New Cave 3, and No. 18 Caves in 1995; at Dangkolo, Krisidu, and E Caves in 2003; or at Dangkolo, New Caves 2 and 3, No. 26, 28, 64, 65, 66, 67, 95, and 102 Caves in 2008.

[a] References: 1, Lemke (1986); 2, Reichel and Glass (1988); 3, Rice and Taisacan (1993); 4, Rice (1993*b*); 5, unpublished CNMI Division of Fish and Wildlife trip reports; 6, Craig and Chandran (1992); 7, this study; and 8, K. W. Stafford (personal commun., 2008).

[b] Direct roost count.

[c] Emergence count.

[d] Bats were not detected and were likely missed.

[e] Partial emergence count.

[f] Number represents the mean of six direct roost counts made with a night vision device.

[g] Number represents the mean of multiple emergence counts (see Table III-2).

Table III–2. Count results at caves occupied by Pacific sheath-tailed bats on Aguiguan, Mariana Islands, from 19 June–15 July 2008.

Cave	Date	No. Bats Recorded	Survey Period	Survey Method	Notes
New Cave 1	25 June	0	Dusk	Emergence	Only the large entrance was counted
New Cave 1	4 July	5	Day	Internal	Bats were seen briefly only while in flight; caves walls not scanned for more bats
New Cave 1	5 July	0	Day	Internal	
New Cave 1	5 July	0	Dusk	Emergence	Both entrances counted
New Cave 1	10 July	0	Day	Internal	
Crevice Cave	23 June	3	Day	Internal	2 adults, 1 pup
Crevice Cave	23 June	2	Dusk	Emergence	
Crevice Cave	27 June	4	Dusk, night	Emergence, internal	3 adults departed, 1 pup remained
Crevice Cave	10 July	2	Day	Internal	2 adults
Guano Cave	20 June	56	Day	Internal	Night vision device used for count
Guano Cave	21 June	52	Day	Internal	Night vision device used for count
Guano Cave	25 June	64	Day	Internal	Night vision device used for count
Guano Cave	28 June	43	Day	Internal	Night vision device used for count
Guano Cave	30 June	58	Day	Internal	Night vision device used for count
Guano Cave	7 July	54	Day	Internal	Night vision device used for count
East Black Noddy Cave	22 June	308	Dusk	Emergence	270 bats counted at west entrance, 38 at middle entrance
East Black Noddy Cave	27 June	382	Dusk	Emergence	321 bats counted at west entrance, 61 at middle entrance
East Black Noddy Cave	1 July	323	Dusk	Emergence	260 bats counted at west entrance, 63 at middle entrance
East Black Noddy Cave	5 July	317	Dusk	Emergence	255 bats counted at west entrance, 62 at middle entrance

Table III–3. Survey efforts at caves visited more than once that were not occupied by day-roosting Pacific sheath-tailed bats on Aguiguan, Mariana Islands, from 19 June–15 July 2008.

Cave	Date	Survey Period	Survey Method	Notes
Dankolo Cave	23 June	Day	Internal	
Dankolo Cave	27 June	Day	Internal	
Dankolo Cave	27 June	Dusk	Emergence	
Dankolo Cave	10 July	Day	Internal	
Cave 28	23 June	Day	Internal	
Cave 28	23 June	Dusk	Emergence	
Stairway Cave	27 June	Day	Internal	
Stairway Cave	9 July	Day	Internal	
Cave 65	24 June	Dusk	Emergence	
Cave 65	26 June	Day	Internal	
Cave 66	24 June	Dusk	Emergence	
Cave 66	26 June	Day	Entrance	
Cave 66	26 June	Dusk	Emergence	
Cave 67	26 June	Day	Internal	
Cave 67	26 June	Dusk	Emergence	
Cave 68	24 June	Day	Internal	
Cave 68	27 June	Day	Internal	
Cave 68	3 July	Day	Internal	
Cave 68	13 July	Day	Internal	
Pillar Cave	21 June	Day	Internal	
Pillar Cave	21 June	Dusk	Emergence	16 bats entered cave at dusk to roost
Pillar Cave	7 July	Day	Internal	
Pillar Cave	7 July	Dusk	Emergence	21 bats entered cave at dusk to roost
Fault Line Cave 1	21 June	Day	Internal	
Fault Line Cave 1	24 June	Day	Internal	
Fault Line Cave 1	26 June	Dusk	Emergence	Only the rear entrance was counted
Fault Line Cave 1	30 June	Day	Internal	
Fault Line Cave 1	11 July	Day	Internal	

Fault Line Cave 1	11 July	Dusk	Internal	1 bat seen entering cave; cave inspection found no other bats
Fault Line Cave 1	13 July	Day	Internal	
Fault Line Cave 1	14 July	Day	Internal	
Cave 95	24 June	Day	Entrance	
Cave 95	26 June	Dusk	Emergence	

Table III–4. Descriptions of caves occupied by Pacific sheath-tailed bats on Aguiguan, Mariana Islands. (S) designates sites with swiftlet colonies.

Cave Name	Description
Cliff Cave	Size unknown, but probably medium-sized or large. Located high up a cliff; not entered. Cave has two entrances, with west opening being larger at about 1 m wide by 2.5 m tall. (S)
Crevice Cave	Large. Main section is a narrow crevice 30 m long, 1–2 m wide, and 25 m tall. It extends vertically to the terrace above and is open at the top along its entire length. Bats inhabit a small dimly-lit upward curving chamber off to side, which is 5 m long, 0.3–1.2 m wide, 8 m tall, and the darkest part of the cave. Main entrance is 4 m wide by 25 m tall. (S)
East Black Noddy Cave	Large. Main room angles steeply upward and is 12 m long by 45 m wide, with a ceiling height of 3–5 m. Floor is a jumbled mass of boulders. A smaller room is at the bottom. Both rooms are completely dark. Three entrances exist. An upper western entrance, 1 m wide by 0.5 m tall, is located high up a cliff and connects to the main room via a 7-m-long and 2-m-wide passage. A lower middle entrance, 2 m wide by 3 m tall, is a nearly vertical shaft going upward about 12 m. A lower eastern entrance, 0.3 m wide by 0.6 m tall, connects to the smaller room. (S)
Fault Line Cave 1	Medium-sized. Main chamber is 15 m long, 5–6 m wide, 10 m tall, and dimly lit. Two main openings present, with largest being 0.6-1.0 m wide and 2 m tall.
Guano Cave	Large. Main chamber is 20 m long, 3–5.5 m wide, and 7–18 m tall, with nearly vertical walls and a dome-like ceiling. A smaller side chamber is 5 m long, 2–3 m wide, and 7–9 m tall. Both rooms are completely dark. Two entrances occur side by side and measure 7 m wide by 2 m tall and 1 m wide by 4 m tall. (S)
Landing Cave	Large. Main chamber is 23 m long, 15 m wide, and 16 m tall at highest point. Two smaller chambers extend roughly 35 and 13 m beyond rear of main chamber. Much of cave is well lit, but portions are completely dark. Cave is damp and algae grow on most surfaces. Entrance is about 8.5 m wide and 16 m high. (S)
New Cave 1	Large. Main chamber is 9–10 m long, 5 m wide, and 7–10 m tall, with two large entrance chambers connecting to it. The largest of these is 10 m long, 3–6 m wide, and 4–15 m tall, and full of boulders; the second is 15 m long, 2–5 m wide, and 2–5 m tall. At least two other smaller openings also present. (S).
Pillar Cave	Large. A single tunnel. Front section is a large well-lit dome, 20 m long, 5–10 m wide, and 8–15 m tall. Rear section is narrow and dark, 30 m long, 0.7–2.5 m wide, and 3–10 m tall. Entrance is 10 m wide. (S)

Table III–5. Emergence times of Pacific sheath-tailed bats and arrival times of Mariana swiftlets during evening counts at caves on Aguiguan, Mariana Islands. Fields with hyphen indicate data not recorded.

Cave	Date	Time of Sunset (hr)	Sheath-Tailed Bats		Arrival Times of Most Swiftlets (hr)
			Time of initial and Final Exits (hr)	Time of Most Exits (hr)	
East Black Noddy Cave	26 March 1995	1829	1828–1841	1830–1838	1840–1900
East Black Noddy Cave	17 Sept 2003	1818	1810–1828	1812–1823	1820–1845
East Black Noddy Cave	18 Sept 2003	1818	1808–1828	1810–1823	-
East Black Noddy Cave	22 June 2008	1850	1833–1857	1835–1850	1852–1910
East Black Noddy Cave	27 June 2008	1851	1836–1912	1844–1902	1905–1915
East Black Noddy Cave	1 July 2008	1851	1835–1911	1840–1855	-
East Black Noddy Cave	5 July 2008	1852	1834–1905	1840–1900	-
Guano Cave	23 March 1995	1829	1839–1846	1839–1846	1840–1855
Guano Cave	31 May 1995	1844	1844–1855	1844–1855	1902–1919
Guano Cave	18 March 2002	1828	1833–1912	1833–1851	-
Guano Cave	10 Sept 2003	1824	1807–1825	1810–1820	-
Guano Cave	21 June 2008	1850	1837–1900	-	-
Cliff Cave	1 June 1995	1844	1840–1850	1840–1850	1900–1910
Cliff Cave	21 June 2008	1850	1852–1903	1852–1900	-
Pillar Cave	1 June 1995	1844	1846	1846	1900–1914
Pillar Cave	15 March 2002	1828	1845–1850	1845–1850	-
Crevice Cave	6 June 1995	1845	1837–1900	1837–1840	-
Crevice Cave	23 June 2008	1850	1844–1848	1844–1848	-

Table III–6. Characteristics of Pacific sheath-tailed bat emergence periods in relation to colony size. Specific times for emergence periods appear in Table III–5.

Characteristic	**Large Colonies (≥ 232 bats)**	**Small Colonies (≤ 69 bats)**
	Mean ± SD	Mean ± SD
Length of emergence period from 1st bat to last	27.5 ± 7.9 min (n = 6)	13.8 ± 10.6 min (n = 12)
Length of period when "most" bats emerged	15.3 ± 3.3 min (n = 6)	7.7 ± 4.6 min (n = 11)
Beginning time in relation to sunset	9.8 ± 3.4 min before (n = 6)	0.5 ± 8.6 min after (n = 11)
Ending time in relation to sunset	5.5 ± 3.7 min after (n = 6)	8.1 ± 9.8 min after (n = 11)
Ending of period when "most" bats emerged in relation to period of most swiftlet entries	0.7 ± 3.2 min before (n = 3)	5.4 ± 7.7 min before (n = 5)

Appendix III–A. Descriptive catalog of all caves visited on Aguiguan in March, May, and June 1995, September 2003, and June-July 2008. Caves were entered whenever possible and were categorized as small, medium, or large in overall size (see Methods section of this report). Cave and entrance dimensions (m) were measured or visually estimated for many of the caves and are reported with the following abbreviations: L, long; w, wide; and t, tall. Caves had no Pacific sheath-tailed bats, Mariana swiftlets, guano, or nests unless specifically mentioned. Coordinates are those taken in 2008, and are in datum WGS 84, UTM zone 55 P.

No.	Other Name	Description and Comments
1.	Landing	Large. About 100 m north of the old boat landing site and about 30 m inland from ocean in an indentation in the cliff wall. Main chamber is 23 L x 15 w, and 16 t at highest point. Two smaller chambers extend about 35 L and 13 L beyond rear of main chamber. Entrance: about 8.5 w x 16 t. Curtain-like rock formations are present. Cave is damp with algae growing on most surfaces. Bats present in 1984 and 1992, swiftlets are currently present. A little human-made debris present.
2.	Guano	Large. Main chamber (20 L x 3-5.5 w x 7-18 t) branches to left with a smaller side chamber (5 L x 2-3 w x 7-9 t) on the right. Two entrances (7 w x 2 t, 1 w x 4 t) separated by a rock. All bats roost in main chamber. Swiftlets are present. Old boards and other human debris present. Coordinates 343039E, 1642089N
3.	-	Small. Cave-like hole under a huge boulder; 4 l, low ceiling, has a second opening on other side, small flowstone pillar inside. Cave is located in the "Crack."
4.	-	Small. Vertical crevice; 5 L x 0.3-0.6 w x 3 t. Small opening at end. Cave is located in the "Crack."
5.	-	Small. Horizontal hole beneath a large boulder; 9 L x 2 t. Cave is located in the "Crack" just below Cave 3.
6.	-	Small. Hole in cliff face.
7.	-	Small. Hole in cliff face.
8.	-	Small. Hole in cliff face.
9.	-	Small. Hole in cliff face.
10.	-	Small. Hole in cliff face.
11.	New 1	Large. Located 25-30 m southwest of New Cave 3 along the same small limestone ridge and at same elevation. Main chamber is 9-10 L x 5 w x 7-10 t, with two large entrance chambers leading into it and at least two other smaller openings also present. Largest entrance chamber is 10 L x 3-6 w x 4-15 t, full of boulders indicating past ceiling collapse, 2-3 large vertical *Ficus* roots present, not safe to enter main chamber via this entrance. Second entrance chamber is 15 L x 2-5 w x 2-5 t, main chamber accessible via this entrance. Both entrances used by swiftlets. Appears suitable for bats, swiftlets are present. Formerly known as #6 Cave when first discovered in the late 1980s; its location was incorrectly mapped in some CNMI field trip reports (e.g., Reichel and Camacho 1989). Coordinates 343187E, 1641656N
12.	E	Size unknown. Located along cliff face below old Japanese road. Single entrance is split into three parts by two boulders. These open into a nearly vertical shaft (20-25 m deep) that is too steep to descend without equipment. Chamber continues on out of sight at bottom. Two entrance openings measure: 1.5 w x 1 t, 0.3 w x 1 t. Perhaps suitable for bats.

13.	D	Small. Next to Cave B and near Caves A and C. Entrance splits off into two smallish chambers, with longest being 10 l. Most of cave is well lit. Entrance: 5 w x 1-2 t. Parts appear suitable for bats. Part of Orphan Kids Cave Complex in Stafford (2003). Coordinates 343205E, 1641432N.
14.	C	Small. Near Caves A, B, and D. Vertical crevice that is a true cave; 10 L x 0.5-1 w x 6 t.
15.	B	Medium. Next to Cave D and near Caves A and C. Main shaft slopes downward (35 L x 2-7 w), with a smaller one angling slightly upward (10 l). A smallish room exists midway just before shafts split. Main entrance: 1 w x 1 t. Upper shaft has a second tiny opening. Perhaps suitable for bats, but not swiftlets. Part of Orphan Kids Cave Complex in Stafford (2003).
16.	A	Medium. Near Caves B, C, and D. Room slopes down at 45-degree angle; 19 L x 4-12 w. Upper section is well lit. Two entrances: 5.2 w x 1.5 t, 2 w x 0.7 t. Part of Orphan Kids Cave Complex in Stafford (2003). Coordinates 343190E, 1641390N.
17.	Crevice	Large. Main portion of cave is a narrow crevice that appears to be open along the top; 30 L x 1-2 w x 25 t. Crevice is so tall that it extends to the terrace above. Entrance: 4 w x 25 t. Floor angles upward, with a 2-m tall step of loose rock midway through, which makes access to rear difficult. Most of cave is dimly lit, but a rear room has more light. Cave is reminiscent of a slot canyon in the southwestern U.S. A small upward curving side crevice is located 13 m from the entrance on the right wall; 5 L x 0.3-1.2 w x 8 t; several bats are present here, with a small amount of guano found on the floor at the entrance of this feature. Guano is absent from rest of cave. Insect Bat Cave in Stafford (2003). Coordinates 343541E, 1641526N
18.	-	Small. Vertical crevice about 50 m east of Crevice Cave. Tall but not too long. Extends upward to the terrace above, with potential for a hidden cave to be located much higher up the cliffside.
19.	Dangkolo	Large. Huge central room (52 L x 15 w x 20 t), with two deeper side chambers, one at each rear corner. Side chambers are 6-10 m deeper than main room. Entrance: 4 w x 0.9 t. Cave is extremely damp, with a faint mist hanging in air. Appears suitable for bats, swiftlets are present. Coordinates 343542E, 1641686N.
20.	-	Small. Vertical crevice with darkened ceiling; 3-10 l. Appear suitable for bats.
21.	-	Small. Vertical crevice with darkened ceiling; 3-10 l. Appear suitable for bats.
22.	-	Small. Vertical crevice with darkened ceiling; 3-10 l. Appear suitable for bats.
23.	-	Small. Low ceiling.
24.	-	Small. Low ceiling.
25.	-	Small. Located close to large natural window in top of cliff face.
26.	-	Large. An attractive cave, open and well lit; 18 L x 8 w x 4–10 t. Perhaps suitable for bats, but probably not for swiftlets. Hollow Column Cave in Stafford (2003).
27.	-	Small. Located about 4 m high in an indentation in the cliff; 4.5 L x 2 w x 6 t. Open and well lit. Goat sign.
28.	-	Medium. Vertical slot; 25 L x 2–3 w x 10 t. Fairly well lit, but two high ceiling domes appear dark enough to be suitable for bats and swiftlets; a small (0.6 w x 1.0 l) dome just inside the entrance looks good for bats too. Large rocks cover much of floor part way inside. Large broken stalagmite leans across cave near entrance. Goat sign. Toppled Column Cave in Stafford (2003). Coordinates 343914E, 1641548N.
29.	-	Small. Located part way up cliff side. A crevice that may extend inward a fair distance. Did not enter; entry would require some effort to climb up the cliff. Perhaps suitable for bats. Part of Natural Arch Cave in Stafford (2003).

30.	-	Small. Located about 4 m high on a sheer rock wall. Entrance: 7–8 w x 1 t, with a pillar located near the middle. Did not enter. Interior appears dark. May be too shallow for bats, but should be checked. Part of Natural Arch Cave in Stafford (2003).
31.	-	Medium. Main room is 10 L x 9 w x 10 t, with a large open ledge on the right side. A smaller room (6 t) in the rear is located about 3.5 m above the floor and angles upward to a dome ceiling. The smaller room appears especially suitable for bats and swiftlets. Note: cliffs above this site and the last few previous caves contain a series of good ledges and formations at mid-level. Smaller and crevices could be present and may potentially hold bats.
32.	-	Large. Main room: 23 L x 6-8 w x 8–10 t. Large opening: 10 w. Two darker domes in the rear. Appears quite suitable for bats and swiftlets. Goat sign. Part of Diamond Cave in Stafford (2003).
33.	-	Small. Adjacent to previous cave, with 3 columns located in between them. Chamber is a tunnel: 15 L x 0.6–5 w x 2–6 t. Higher dome in rear appears suitable for bats. Goat sign. Part of Diamond Cave in Stafford (2003).
34.	-	Large. Must climb up about 4 m to enter cave. Main room is large and auditorium-like; 15 L x 31 w x 10 t. Open, airy, and well lit. Entrance: 31 w x 10 t. A smaller dark room (4 w) is located in the rear and is elevated 10 m above main floor. Could not enter small room, but no bats or swiftlets were present. Small room appears excellent for both species. Goat sign in main room. *Lantana* grows in front of main entrance. Goat Cave in Stafford (2003).
35.	-	Small. A small overhang; 3 L x 4 w x 1 t.
36.	Krisidu	Large. Huge main room (75 L x 20 w x 15 t), with a smaller but long tunnel extending farther inward from right rear corner. Entrance: 7 w x 1.3 t. Very moist inside. Appears suitable bats and swiftlets. Site No. 48 in Butler (1992); Liyang Atkiya in Stafford (2003).
37.	Stairway	Large. Located just west of the foot path leading down cliff side. Main room is large and open; 8 L x 30 w x 5–7 t. A small dark side chamber is on right side of main room; 20 L x 2–4 w x 1-2.2 t. Lots of boards and human debris in main room. Side room appears suitable for bats, swiftlets are present. Site No. 11 in Butler (1992). Coordinates 345682E, 1642066N.
38.	-	Small. Attractive cave, somewhat circular; 6 L x 8 w x 1-2 t. Two pillars inside. A 4-inch by 4-inch plank and some small pieces of wood are inside. Goat sign.
39.	-	Small. 4–6 L x 10 w x 1.2–2 t. Two entrances and two pillars. Goat sign.
40.	-	Small. Narrow horizontal crevice under rocks.
41.	-	Small. Narrow horizontal crevice under rocks.
42.	-	Small. Horizontal crevice under a rock; 5 L x 3–6 w x 0.8–1.3 t.
43.	-	Small. Comprised of two vertical crevices, 2.5–4 t, with dark areas.
44.	-	Small. Horizontal crevice under a boulder, with two rocks supporting the east side; 6 L x 8 w x 1–2 t.
45.	-	Small. Cave-like hole in lower cliff wall; 0.7–2 t.
46.	-	Small. Cave-like hole in lower cliff wall, with two low side rooms; 0.3–1 t. May be Site No. 44 in Butler (1992) and Waypoint Cave in Stafford (2003).
47.	-	Small. Cave-like hole in lower cliff wall, with two low side rooms; 0.3–1 t. May be Site No. 44 in Butler (1992) and Waypoint Cave in Stafford (2003).
48.	-	Small. Narrow vertical crevice in lower cliff; 10 L x <1 w x 10 t. South wall is a fallen rock slab.

49. - Medium. A two-leveled hole (one hole above the other) in lower cliff. Cannot reach the upper hole, which has dark entrance and is 2 w x 2 t. Rest of site is open. May be suitable for bats. Site No. 45 in Butler (1992); part of Tridacnid Cave Complex in Stafford (2003).

50. - Large. Very open and well lit; 20 L x 7–15 w. Entrance: 8 w x 6 t. A small hole in the right upper rear corner may be suitable for bats. It is high above the floor, but its interior is not visible from below. Much goat sign. Site No. 45 in Butler (1992); part of Tridacnid Cave Complex in Stafford (2003).

51. - Large. Attached by an elevated cliff side ledge to the previous cave. Comprised of two rooms (totaling 35 w), with the ceiling low (1 t) almost throughout, but reaching 2 t in part of the front room. Back room is completely dark. Two entrances: one is 4 w x 1 t, second is small. Unexploded bomb near entrance. Cave appears suitable for bats. Site No. 45 in Butler (1992); part of Tridacnid Cave Complex in Stafford (2003).

52. - Small. Located along bottom of cliff. May be Cabrito Cave in Stafford (2003).

53. - Small. Located along bottom of cliff. May be Cabrito Cave in Stafford (2003).

54. - Small. Located along bottom of cliff. Cave is: 10 L x 2.5–4 w x 2–3 t. Moderately lit. Discarded piece of Tupperware lies outside front of cave.

55. - Small. Circular main room (7 L x 5–6 m x 3–4 t), with small chamber on side (1 t). Entrance: 2.5 w x 3 t. Appears suitable for bats. Much goat sign inside.

56. - Small. Located at bottom of a cliff wall; 8 L x 3–7 w x 0.7–1 t. Rock fortification is piled on left side of entrance. Goat sign and skulls inside.

57. - Size unknown, perhaps large, viewed from long distance. A large vertical slot located in the upper third of a coastal cliff. Entrance is perhaps 3 w x 12–14 t. Cave depth difficult to judge, but may not be deep. Perhaps suitable for bats and swiftlets.

58. - Size unknown, perhaps small, viewed from long distance. A small vertical slot located near top of a coastal cliff. Cannot judge cave depth. Perhaps suitable for bats and swiftlets.

59. - Size unknown, perhaps small, viewed from long distance. A horizontal cave located half way up a coastal cliff. Two or three dark openings present, not large. Cannot judge cave depth. Perhaps suitable for bats.

60. - Small. Located at the opposite end of the same crevice holding the previous cave. A covered-over T-shaped crevice. One side is very narrow and cannot be entered. Not suitable for bats.

61. - Small. Located at end of a large fissure. Cave is 10 L x 2 w x 10 t. Dark at rear, with several small crevices at rear.

62. - Small. Could not enter. Deep vertical crevice; 10 L x 1 w x 16 t. Most of crevice is open at top, but several small holes lead out of sight and appear potentially suitable for bats.

63. - Small. Difficult to enter. A well-lit nearly vertical crevice (1.8 L x 5 w x 4 t) is the main room, with a small chamber (6 L x 1 w x 3 t) on east side and a narrow crevice (3 L x 0.4 w x 3 t) on the west side; entrance is 6 w x 1.5 l. Located beneath some boulders on edge of open forest and east side of karst rock associated with the "Fault Line"; located 10–15 m east of Cave 65. Part of the "Fault Line" cave complex. One bat seen circling inside entrance room after dark in 2008, but follow-up daytime visit 2 days later found no roosting bats.

64. - Large. An interesting cave with many different features, making description difficult. A large and fairly well lit central room is present, with a smaller room to the north that is accessed by crawling through a diagonal slot; combined size of rooms is 16 L x 8–10 w x 1–15 (?) t. A long narrow crevice (16 L x 0.3 w) extends from

		opposite end of main room. At least five entrances present; largest is 2 t x 0.4 w, another larger entrance is partially covered by several *Ficus* roots. Part of the "Fault Line" cave complex. No human debris or guano. Appears suitable for bats, but entrances may be too small for swiftlets. Coordinates 344844E, 1643303N.
65.	-	Small. Cave is a thin vertical side crevice along east side of a large open fissure; 9 L x 0.3 w x 3.5 t. Crevice is too narrow to continue after 2 m. Part of the "Fault Line" cave complex. Coordinates 344840E, 1643270N.
66.	-	Medium. At the end of a fissure. Could not get down to the cave floor or see the rear of the lower main room. Entrance: 4 w x 1–5 t, with a tall (11 t) slender crevice on left side. Part of the "Fault Line" cave complex. Perhaps suitable for bats.
67.	-	Small. At end of an open slanting fissure; 10 L x 1–1.2 w x 5–6 t. A true cave exists at rear, which is 5 L x 0.3–0.5 w x 1–5 t. Part of the "Fault Line" cave complex. Dark, but probably not suitable for bats. Not suitable for swiftlets.
68.	-	Medium. Comprised of a series of small low rooms, with multiple entrances, runs along base of hillside and is never more than a few m deep. Overall floor space is fairly large; about 40–50 m long, parts of cave are only 0.8–1.2 m tall. One room is 1.5–1.8 t and a side crevice is 3–4 t. Lighting is dim to almost dark. Old boards present. Looks suitable for bats. Site No. 6 in Butler (1992). Coordinates 344765E, 1643135N.
69.	-	Small. An overhang in a cliff face; 3 w x 4 t. One of David Steadman's (1999) excavation sites.
70.	-	Small. A vertical crevice; 6 L x 3 t.
71.	-	Small. A crevice turning into a small cave; 10–15 L x 2–3 t. Dimly lit inside.
72.	-	Small. Rockshelter under a large boulder; 5 L x 6 w x 2.5 t.
73.	-	Small. Rockshelter under a large boulder; several meters in all dimensions.
74.	-	Small. A vertical crevice; 5 L x 2 w x 15 t.
75.	-	Small. Rockshelter overhang; 4 L x 6 w x 0.8 t.
76.	East Black Noddy	Large. Located at east end of a broad circular indentation in cliff side along the north shore. Three entrances, as mapped by Stafford (2003), all of which are somewhat cryptic until closer inspection is made. Middle entrance (2 w x 3 t) is a nearly vertical shaft going upward about 12 m from ground level, but is too steep to climb safely. East entrance (0.3 w x 0.6 t) is a few meters to the left on an adjacent ledge. West (uppermost) entrance is circular in shape and about 0.6–1 m in diameter and is located about 11–13 m high on cliff face near a wavy rock formation; this is about 15 m west of middle entrance and about 3 m east of the rock pillar standing below on the ground. Human entry is easiest via the east entrance, which accesses a small first room attached to a much larger main room (12 L x 45 w x 3–5 t). This room angles steeply upward, but climbing is treacherous. Middle entrance is not visible from this room. Bats and swiftlets are present. Part of Swiftlet Cave in Stafford (2003). Coordinates 344004E, 1642923N.
77.		Cave number not in use.
78.	West Black Noddy	Large. Located at west end of a broad circular indentation in cliff side along the north shore. A single open room (20 L x 10 w x 12 t) with a large entrance (12 w x 12 t). Most of cave is dimly lit, but a small indentation on south wall may be dark enough to attract bats and swiftlets. Part of Swiftlet Cave in Stafford (2003).
79.	-	Small. A crevice among boulders, dimly lit, open on both ends; 5 L x 1.5 w x 3 t.
80.	-	Small. Rockshelter under a boulder; 10 L x 3 w x 1 t.

81.	Cliff	Size unknown, probably medium or large. Located high up cliff side and is too treacherous to reach without climbing gear. Cave has two entrances: west opening is largest, with two pillars inside giving the appearance of splitting the opening into three sections; may be 1 w x 2.5 t overall. East opening is a bit higher and has some rock extending down over part of the top. Bats and swiftlets are present. Viewed from coordinates 343432E, 1642715N.
82.	Pillar	Large. Long narrow cave, with a pillar inside near the entrance. Front section of cave is a large well-lit dome; 20 L x 5–10 w x 8–15 t. Rear section is a dark narrow tunnel; 30 L x 0.7–2.5 w x 3–7 t, but is 10 t in one area. Entrance: 10 w. Bats and swiftlets are present. Coordinates 343363E, 1642648N.
83.	-	Small. Rockshelter; 7 L x 5 w x 2 t. Fairly well lit inside.
84.	-	Small. Located in rock pile; 3 L x 0.3–0.7 w x 0.7–1.2 t. Dark at the end. May be Booney Bee Sink in Stafford (2003).
85.	-	Small. Upward angled rock overhang, narrow in rear; 5 L x 1.2–5 w x 1–4 t. Perhaps suitable for bats.
86.	-	Small. Overhang under boulder; 8 L x 5 w x 1 t. Three openings, dimly lit inside, well ventilated. Goat sign inside. Fortified, two rocks piles at entrances, with one entrance having four wooden posts present to support boulder. Probably Site No. 25 in Butler (1992). Coordinates 343408E, 1642122N.
89.	-	Small. Single room, 7 L x 3–5 w x 2 t. Probably moderately well lit at times. Goat sign. Listed as Find Site 3 in Butler (1992).
91.		Cave number not in use.
92.	Elvin's	Small. Begins with a 4-m deep vertical entry shaft, floor then angles downward out of sight. Difficult to enter. No dimensions available. Located along the east wall of a long (> 100 m) fissure just west of New Cave 1.
93.	-	Large. Large open rockshelter-like site under a huge fallen boulder, with overall size being 20 L x 30 w x 1–5 t. Most of underhang is well lit, but two small dark areas are present at base of boulder. Site does not look suitable for bats. A smaller overhang occurs on backside of boulder.
94.	Fault Line 1	Medium. Main room is 15 L x 5–6 w x about 10 t overall. Lower half of room has a level floor, while the other half angles steeply upward. Roof is formed by a large fallen rock slab. Two main openings exist, with several small holes present at top of one side. Largest entrance is triangular shaped and is 2 t x 0.6–1 w. Second entrance is a diagonal crevice and is tight to squeeze through. Part of the "Fault Line" cave complex. Some old lumber and human debris occur inside. One bat present in 2003. May be appropriate for swiftlets. Included under Site No. 6 by Butler (1992).
95.	-	Small. Located adjacent to and below Fault Line Cave 1. Roof is formed by a fallen rock, with main room being 12 L x 1–2.5 w x 4–7 t. Mostly well-lit, but has a couple of darker areas. Three entrances, with the lower one being an open crevice that is 3–4 L x 0.3–1 w x 2–6 t. Part of the "Fault Line" cave complex. Probably not suitable for bats or swiftlets.
96.	-	Small. A narrow crevice, 10 L x 0.3 w x 6–7 t. Mostly open, but has some closed ceiling in rear. Located just west of the "Fault Line" near a natural arch in the rocks. Part of the "Fault Line" cave complex.
97.	-	Small. Located on lower side of a boulder next to cliff base; 2 L x 1.5 w x 0.5 t; *Ficus* roots cover part of the entrance.

98.	New 2	Small. Located in same karst hole as the main entrance to New Cave 1; found opposite this entrance perhaps 5–10 m away; also located about 25 m southwest of New Cave 3. Cave has one room, 10 L x 5 w x 2 t.
99.	New 3	Large. Located along the same small limestone ridge as New Caves 1 and 2, about 25 m to the northeast. Two entrances are known. The southwest entrance is 1 x 1.5 w and drops into a deep shaft that could not be entered; swiftlets mostly enter this hole. The northeast entrance (50 m northeast of the first entrance) is actually comprised of four entrances. These fall sharply downward about 20 m, but the shaft is too steep to descend. A rope is needed for access. The chamber at the bottom is fairly dark, extends inward out of sight, and could be large. Main opening at this entrance is 5 w x 2.5 t and occurs under a fairly flat rock; single small openings occur on both sides of the main entrance; swiftlets mostly exit this entrance. Many old boards and other human debris lay on the inner level below the entrance, but nothing is visible at the bottom. Appears suitable for bats, swiftlets are present. Site No. 55 in Butler (1992). NE entrance coordinates 343232E, 1641708N; SW entrance coordinates 343201E, 1641682N.
100.	-	Size unknown, probably small. Located partway down along the west wall of the "stairway" passage near Stairway Cave. A narrow crevice in the rock leads to a vertical shaft estimated at 30 m deep. The shaft and its entrance are triangular shaped and about 5 m wide on each side. Cannot see the bottom well enough to know whether rooms are present.
101.	-	Size unknown, probably small. Uppermost site in the "Fault Line" cave complex; located about 30 m uphill from Fault Line Cave 1. Has 3 main entrances that fall 15 m to a level floor; these are too steep to enter. Dimensions not estimated. Cannot see entire interior, thus may be larger than expected.
102.	-	Small. Located between Caves 63 and 66 at south end of the bottom "step" inside the "Fault Line." Dimensions: 4 L x 1.5 w x 2.5 t. Part of the "Fault Line" cave complex.
103.	-	Medium. The entire feature is large in size, but most of it is uncovered by ceilings. A front vestibule (24 L x 4–8 w x 18 t) and two large side rooms (east room: 22 L x 8 w x 8–12 t; west room: 20 L x 8 w x 12–14 t) are all uncovered and therefore do not provide cave environments. Front vestibule empties out onto a sheer cliff, which falls about 30 m to the terrace below. The only true cave occurs in the middle of the south wall. It has an entry chamber (10 L x 2–3 w x 2–3 t) that goes straight in, with a side room (also 10 L x 2–3 w x 2–3 t) facing west near the rear. Looks suitable for bats. Entry is via the side of the front vestibule and requires a fairly risky climb down. Coordinates 344316E, 1642923N.

Other Caves Described in Butler (1992).

87.	-	Listed as Site No. 30. Located at cliff base. A rockshelter with a lower chamber (5 l) on east side leading upward to a larger overhang (3–4 L x 15 w) with a low ceiling. Larger overhang is 3 m above ground level; its floor has been leveled with stacked rocks. Human debris present.
88.	-	Listed as Site No. 29, with photograph presented. Located at cliff base. Small rockshelter; 3–4 L x 3 w. Vertical logs positioned across part of entrance.
90.	-	Listed as Site No. 56. Entrance opens into a "large" dark room that was not visited. Rocks stacked around the entrance.

Other Caves Described in Stafford (2003).

104.	-	Listed as Swarming Termites Cave. Located in the eastern region of the middle terrace. Small.
105.	-	Listed as Liyang Lomuk. Located in the north-central region of the middle terrace. Small.
106.	-	Listed as Lizard Cave. Located in the north-central region of the middle terrace. Small.
107.	-	Listed as Spider Cave. Located in the north-central region of the middle terrace. Small.
108.	-	Listed as Scorpion Cave. Located in the north-central region of the middle terrace. Medium-sized?
109.	-	Listed as Goat Fracture Cave. Located in the northwest region of the lower terrace. Small.
110.	-	Listed as Anvil Cave. Located in the northwest region of the upper terrace. Medium-sized?
111.	-	Listed as Dove Cave. Located in the northwest region of the upper terrace. Small.
112.	-	Listed as Almost Cave. Located in the northwest region of the upper terrace. Small.
113.	-	Listed as Screaming Bat Cave. Located in the northwest region of the upper terrace. Two small caves present. Named for several fruit bats vocalizing nearby at night (K. Stafford, personal commun.).
114.	-	Listed as Biting Mosquitoes Cave. Located in the northwest region of the upper terrace. Small.
115.	-	Listed as Isotope Cave. Located in the northwest region of the upper terrace. Medium-sized?
116.	-	Listed as Pepper Cave. Located in the northwest region of the upper terrace. Small.

Section IV. Habitat Occupancy and Detection of the Pacific Sheath-Tailed Bat (*Emballonura semicaudata rotensis*) on Aguiguan, Commonwealth of the Northern Mariana Islands

By P. Marcos Gorresen, Frank J. Bonaccorso, and Corinna A. Pinzari

ABSTRACT

Occupancy analysis was used to quantify Pacific sheath-tailed bat (*Emballonura semicaudata*) foraging activity and its relationship to forest structure and proximity to cave roosts on Aguiguan Island in the Commonwealth of the Northern Marianas. Bat occurrence was most closely associated with canopy cover, vegetation stature and distance to known roosts. The metrics generated by this study can serve as a quantitative baseline for future assessments of status following changes in habitat due to management activities (e.g., feral goat control) or other factors (e.g., typhoon impacts). Additionally, we provide quantitative descriptions of the echolocation calls of *E. semicaudata*. Search-phase calls were characterized by a relatively narrow bandwidth and short pulse duration typical of insectivores that forage within vegetative clutter. Two distinctly characteristic frequencies were recorded: 30.97 $\pm$1.08 kHz and 63.15 $\pm$2.20 kHz.

INTRODUCTION

The Pacific sheath-tailed bat (*Emballonura semicaudata*) was once common and widely distributed across the southwestern tropical Pacific. It is the only insectivorous bat recorded for much of this region (Koopman 1997), and four subspecies have been described: *E. s. rotensis* from the Mariana Islands (Guam and the U.S. Commonwealth of the Northern Mariana Islands (CNMI)), *E. s. palauensis* from Palau, *E. s. sulcata* from the Caroline Islands (Chuuk and Pohnpei), and *E. s. semicaudata* from Vanuatu, Fiji, Tonga, and Samoa (Independent and American). Although populations appear sizable and stable in some locations, mainly in the Caroline Islands (Wiles and others 1997), they have declined considerably in other areas, including the Mariana Islands, Fiji, Samoa, and possibly Tonga (Hutson and others 2001, Helgen and Flannery 2002). In the Marianas, the endemic subspecies *E. s. rotensis* formerly inhabited Guam, Rota, Aguiguan, Tinian, Saipan, and possibly Anatahan and Maug (Lemke 1986, Flannery 1995, Ellison and others 2003). Currently, it appears to be almost entirely extirpated from the Mariana archipelago, with a single remnant population of this subspecies occurring on the small uninhabited island of Aguiguan. The species is listed as Endangered by the World Conservation Union (Chiroptera Specialist Group 2000) and the Government of CNMI (Anonymous 1991). *Emballonura. s. rotensis* and *E. s. semicaudata* are category 3 candidates for listing under the U.S. Endangered Species Act (U.S. Fish and Wildlife Service 2007). The threats to the Aguiguan population primarily include habitat loss from past clearing of native forest for agriculture, with subsequent replacement by invasive vegetation (Esselstyn and others 2004), habitat degradation from feral goat browsing (goats were introduced in the mid-1800s; Esselstyn and others 2004), and a small population size with limited distribution that leaves it vulnerable to extirpation by typhoons (Chiroptera Specialist Group 2000).

Current status assessments of *E. s. rotensis* on Aguiguan indicate that the population numbers about 450-600 individuals based on counts of 359-466 bats at caves (see Section III of this report),

roosts are limited to caves (Section III of this report), and the bat primarily uses forest habitat (Esselstyn and others 2004). Although critical for assessments of population status, the estimation of population size is complicated when bats use more than one roost and when the location of occupied caves are incompletely known, particularly if surveys of caves for bats are not completed simultaneously or in a short time period. Movement of bats among alternate caves may cause counts to be annually or seasonally variable even if population size remains fairly constant. Consequently, variability in counts can make assessments of bat population trends difficult (for more details on problems in estimating bat population size see papers in O'Shea and Bogan 2003).

Occupancy analysis is a fairly new technique only recently being applied to bat studies in which echolocation calls are used as a measure of occurrence and activity (Gorresen and others 2008). The technique corrects for bias in estimates of spatial occurrence by accounting for imperfect detection (i.e., bats present but not detected; MacKenzie and others 2002). It also generates metrics with associated variance estimates that permit comparative analyses (e.g., assessment of occupancy and distribution over time or among regions). We used occupancy analysis primarily to quantify Pacific sheath-tailed bat foraging activity on Aguiguan. Secondary objectives included further study of the relationship of foraging activity to forest structure and land-cover composition and the temporal use of forest habitat and proximity to cave roosts. We also provide quantitative descriptions of the echolocation calls of *E. s. rotensis* because there is little published information on the calls of this or other species of the genus *Emballonura*.

MATERIALS AND METHODS

Study Area

Detailed descriptions of the environment on Aguiguan (14°51' N, 145°33' E) are available in Engbring and others (1986), Esselstyn and others (2004) and Wiles and others (Section III of this report), and are summarized below from these sources. Aguiguan is located in the southern Mariana Islands in western Micronesia. It is a small (7.0 km^2) limestone island with a flat central plateau encircled by escarpments and terraces. A ridgeline along the northern edge of the island attains a maximum elevation of 166 m.

Landcover on Aguiguan is comprised of 4 general types of vegetation: native limestone forest; non-native forest; non-native shrubland; and coastal scrub and grassy areas. Native limestone forest occurs on about 49 percent of the island and is mostly found on steep slopes and terraces. The forest canopy reaches up to 15 m and intense browsing by feral goats (*Capra hircus*) has formed an open understory in most areas. Although Aguiguan is now uninhabited by people, the central plateau (making up about 42 percent of the island area) was cleared for agriculture between about 1936 and the early 1940s. This area is now primarily comprised of non-native secondary shrub and forest vegetation. Shrubland consists of dense 1-3 m tall thickets and most non-native forest occurs in small patches 5–10 m in stature. Coastal scrub, grass and unvegetated areas make up the remaining 9 percent of the island's landcover.

Study Design and Analysis

Thirty-one stations were surveyed for Pacific sheath-tailed bat activity between 25 June and 14 July 2008. Stations were established at or near locations initially sampled by Esselstyn and others (2004) and generally spaced at 370-m intervals. Sampling techniques and measures of bat activity and habitat use followed the approach developed by Gorresen and others (2008) for the endangered Hawaiian hoary bat (*Lasiurus cinereus semotus*) in which bat vocalizations (i.e., echolocation "calls")

were recorded at a series of stations ("sites") on consecutive nights. Calls were recorded on Aguiguan with Anabat II detectors (Titley Electronics, Ballina, New South Wales, Australia) over 3-5 nights at each site, and were written to a compact flash card with a Zero-Crossings Analysis Interface Module (ZCAIM; Titley Electronics). Call files were processed with AnalookW software (version 3.3f; Titley Electronics; available at *http://www.hoarybat.com*; last accessed July 2008) to filter ambient noise. Graphic files were visually inspected to ensure that residual noise was not interpreted as echolocation calls or call components ("pulses"). Descriptive characteristics of search-phase echolocation calls extracted by AnalookW included: minimum (F_{min}), maximum (F_{max}), and characteristic (F_c) frequencies (kHz); frequency range (difference between F_{max} and F_{min}); pulse duration (ms); and time (T_c) from the start of pulse to F_c (ms). Parameters F_c and T_c were derived only from the "body" (i.e., flattest portion) of the pulse as defined AnalookW, whereas the entire pulse was used to characterize the other parameters. Detailed definitions of these call parameters are provided by Gannon and others (2004). *Emballonura semicaudata* is the only species of echolocating bat known from the Marianas Islands (Flannery 1995, Esselstyn and others 2004) and there were thus no questions about the species identity of the calls we recorded.

Occupancy analysis (MacKenzie and others 2002) was used to assess the relationship between habitat attributes and the proportion of occupied sites (Ψ), to adjust Ψ for a detection probability (p) of less than one, and to produce associated measures of uncertainty for comparative analyses. Occupancy analysis was performed with the software program PRESENCE (version 2.0, available at *http://www.mbr-pwrc.usgs.gov/software.html*; last accessed September 2008).

We developed *a priori* models in which bat occupancy was a function of habitat covariates; i.e., Ψ (Cov)$p(\cdot)$. We used our constant parameter model, $\Psi(\cdot)p(\cdot)$, as a reference null model from which to compare habitat effects on occupancy. Because of small sample size, interactions between covariates were not examined. Weather conditions were uniform during the 3-week period of sampling, therefore no sampling covariates were used to adjust detection probabilities; i.e., $\Psi(\cdot)p$(Cov) models were not examined (e.g., where p could be a function of wind or rain).

Habitat attributes that were visually and qualitatively assigned into binary categories included understory clutter (open-uncluttered; closed-cluttered) and dominant vegetation (native; exotic). Attributes with more than 2 levels were quantified with indicator variables, and included stem diameter at breast height (dbh; <10, 10-30 and >30 cm dbh), vegetation stature (<5; 5-10; >10 m height) and canopy cover (<30 percent; 30-70 percent; >70 percent closure). Proximity from each survey station to 7 known roost sites was calculated as the nearest neighbor distance in ArcGIS 9.2 (ESRI 2006). To improve model performance, proximity was standardized to have a mean of 0 and a standard deviation of 1 (Donovan and Hines 2007). The seven known roosts analyzed included Landing, Pillar, Guano, Crevice, Cliff, East Black Noddy, Fault Line 1 (as described in Section III of this report).

Although habitat use may be defined simply by the occurrence of a species, this is a non-discriminating criterion because bats can commute through areas not used for foraging. Therefore we distinguished areas of higher and lower activity based on the number of echolocation pulses in recorded bat call files. In addition to the use of a "no threshold" of activity (i.e., all echolocation pulses were used), we identified observations where the total number of pulses within each 1-min period exceeded one of three nested series of thresholds: 50th (median), 70th, and 90th percentile. These higher activity events were coded as 1 in matrices that tallied their incidence for each site and each night. Zeros were assigned to matrix cells for periods in which there was no recorded activity or pulse numbers were below the selected activity threshold. Detection probability and occupancy estimates for each survey site were calculated using the program PRESENCE. The relationship of known roost proximity to bat arrival time (defined as the first hour with detections) was examined by correlation analysis. Bat

activity and habitat attribute data have been archived with the U.S. Fish and Wildlife Service (FWS), Ecological Services field office, Honolulu, Hawai'I, and is also available from the authors.

Occupancy models were first ranked according to Aikaike's Information Criteria (AIC) values as adjusted for small sample size (AIC_c; Burnham and Anderson 2002). We subsequently used single-variable models within 2 AIC_c units of the best model as candidates for building 2-variable models. Models with a greater number of covariates were not considered because of the relatively small number of sites (n =31). Interpretive results are presented only for the top-ranked models. Model goodness-of-fit was assessed with a parametric bootstrap procedure (MacKenzie and Bailey 2004), in which a Pearson X^2 test statistic p-value <0.05 and an estimated over-dispersion parameter <0.5 or >1.5 were measures indicative of poor model fit.

RESULTS

Bat Echolocation Calls

Pacific sheath-tailed bats were recorded at 22 of the 31 sites (Figure IV–1) sampled over a period of 19 nights on Aguiguan (for a total of 109 detector-nights). The distribution of pulses (35,858 total from 1,224 tallies of 1-minute duration) was highly skewed with a large proportion of filtered call files comprised of few pulses (Figure IV–2). One-half of all bat detections consisted of brief passes with less than 15 pulses per 1-minute interval. In contrast, 10 percent of observations were of peak activity events indicative of sustained foraging bouts with between 63 and 422 pulses. Another 40 percent of observations ($\geq 50^{th}$ to $<90^{th}$ percentile) were of moderate activity in which total pulses per 1-minute interval numbered between 15 and 62.

The search-phase echolocation calls of *E. s. rotensis* were characterized by a fairly uniform narrowband, quasi-constant frequency (QCF) structure (Figure IV–3). The central shallow-modulated part of a QCF pulse was accompanied by a descending FM terminal element, and an ascending component to each pulse was also usually present. Two distinctly characteristic frequencies (F_c) were recorded: a 30.97 ± 1.08 kHz ("low"), and 63.15 ± 2.20 kHz ("high") (Table IV–1). Despite greater atmospheric attenuation at higher frequencies under humid conditions (Lawrence and Simmons 1982), about three-quarters of the characteristic frequencies recorded were of the high harmonics (relative humidity was usually >80 percent on Aguiguan; see Section VI of this report). Although the Anabat echolocation system does not fully measure multi-harmonic information (Fenton and others 1999), the proportion of low versus high frequencies recorded may reflect shifts in the main energy from one dominant harmonic to another (e.g., "harmonic alternation"; Jung and others 2007), or the effects of microphone sensitivity (higher frequencies are more readily detected than lower frequencies) and the distance between a bat and detector (lower frequencies are less affected by distance; Chris Corben, personal commun., 2008; *http://users.lmi.net/corben/hrmncs.htm#Harmonics*). No evidence of other harmonics was observed, but these may be present (e.g., 3rd and 4th harmonics; Ibáñez and others 2002) and "masked" by more dominant harmonics. The overall frequency range (i.e., difference between the maximum and minimum frequencies) was fairly narrow for both harmonics (low: 1.83 ±1.10 kHz; high: 11.04 ±4.05 kHz). Both low and high frequency pulses were of relatively short duration and the time to attain a characteristic frequency comprised most of the pulse extent (low: 1.44 ±0.47 ms, T_c = 1.31 ±0.37 ms; high: 2.75 ±0.56 ms, T_c =1.73 ±0.46 ms).

Habitat, Occupancy and Detection Probability

Canopy cover, vegetation stature, and distance (proximity to known roosts) were covariates that best explained bat occurrence across all threshold levels in models that accurately fit the data (Table IV–

2). Each of these variables alone or in combination with one another accounted for up to 57 percent of AIC_c model weight.

Bat occupancy was related to canopy closure in a somewhat complex manner. It was highest at sites with high canopy closure and lowest at sites with moderate canopy closure, whereas it appeared intermediate at sites with low canopy closure (Table IV–3 and Figure IV–4). This may simply be due to the effects of small sample size on parameter estimation (n =3, for low canopy closure sites). It may also reflect bat use of open canopied habitats adjacent to forest (all 3 sites were within 200 m of forest edge). Generally, occupancy in habitat characterized by high canopy closure was about 0.80 (e.g., $\hat{\Psi}$ = 0.84 ±0.09 and 0.79 ±0.11 in single-covariate 50th and 70th percentile models, respectively). Higher levels of other covariates acted to increase occupancy to over 0.90 (e.g., $\hat{\Psi}$ for high canopy closure sites near known roosts was 0.93 ±0.06 for the 50th percentile model).

Vegetation stature exhibited a positive and direct relationship with occupancy, particularly in combination with other covariates. For example, occupancy in tall stature forest ranged between 0.55 ± 0.36 and 0.96 ±0.06 depending on proximity to known roost caves, and 0.06 or less for mid- and low stature sites (90th percentile model; Table IV–3 and Figure IV–4).

Similarly, proximity to known roost caves consistently appeared as a significant covariate accounting for bat occupancy. Generally, occupancy at sites near roosts was about 0.85 (e.g., $\hat{\Psi}$ =0.87 ±0.09 and 0.83 ±0.10 in single-covariate 50th and 70th percentile models, respectively; Table IV–3). Higher levels of other covariates also acted to further augment occupancy estimates. In addition to its effect upon the likelihood of bat use of particular habitats, roost proximity was also closely related to the timing of bat arrival at a site. The hour of first bat detections occurred significantly earlier at sites near caves (r =0.64, p-value = 0.002; Figure IV–1). Detections at sites far from roost caves also tended to occur infrequently and at irregular intervals.

Bat occurrence was widespread on Aguiguan (observed Ψ =0.71, when all bat detections were included; Table IV–4). As expected, peak bat activity was limited to a smaller proportion of sampled area than that indicated by simple presence alone. The 50th, 70th and 90th percentile null reference models (i.e., those with no habitat covariates) exhibited average $\hat{\Psi}$ of 0.62 ±0.09, 0.59 ±0.09, and 0.27 ±0.08, respectively. In other words, whereas bats were detected across almost 3/4 of all sites, peak activity was observed at only 1/4 of the sampled landscape. Likewise, the probability of detecting bats was related to the activity threshold level. For example, p for all detections was 0.76 ±0.05 but declined to 0.61 ±0.09 for the 90th percentile threshold.

DISCUSSION

As first established by Esselstyn and others (2004), Pacific sheath-tailed bat activity was found to be closely associated with native limestone forest and proximity to known cave roosts. We also determined bat occupancy to be related to habitat characteristics typical of more structurally developed and mature native forest; i.e., closed canopied and tall stature stands. However, scattered detections in open (non-forest) areas were notable because they indicate an ability to traverse and perhaps forage over such habitats. Moreover, the existence of at least one unknown roost is suggested by the early arrival and high activity of bats near several northeastern sample sites (stations "e" and "i"; Figure IV–1). Such roosts may contribute additional individuals to the current counts of 359–466 bats (Section III of this report).

The high number of unoccupied but apparently suitable caves (Sections III and VI of this report) suggests that the population size of *E. s. rotensis* may not be limited by roost availability. Instead, population size may be restricted by the small amount of mature native limestone forest (3.4 km^2) present on Aguiguan. On the other hand, the mobility of sheath-tailed bats (Wiles and others (1997)

report commuting distances of at least 5 km in Palau) and their (albeit limited) use of exotic or less structurally complex vegetation is encouraging because it may mean that moderately more habitat is available than that solely provided by native limestone forest. Alternatively, it could also indicate that the population may be exceeding carrying capacity of the preferred habitat and that activity in areas with non-native vegetation represents a "spilling over" into suboptimal habitat.

The search-phase calls produced by *E. s. rotensis* were characterized by a relatively narrow bandwidth and short pulse duration typical of insectivores which forage close to and among vegetative clutter (Neuweiler 1989, Jung and others 2007). These call attributes are similar to other emballonurids that forage near vegetation such as *Rhynchonycteris naso* and *Balantiopteryx* spp. (O'Farrell and Miller 1997, Ibáñez and others 2002). This inference is supported from our direct observations and those by Esselstyn and others (2004) of bats flying slowly and "erratically" while foraging within forest between 1 m of the ground and up to tree-tops. Esselstyn and others, (2004) also observed bats foraging above the forest canopy. Use of open areas near forest edges also was confirmed by our echolocation recordings.

The metrics generated by this study can serve as a quantitative baseline for future assessments of status following changes in habitat due to management activities (e.g., feral goat control) or other factors (e.g., typhoon impacts). For instance, our sites can be re-sampled and analyzed with multi-season models (MacKenzie and others 2002) to determine whether the proportion of occupied sites that exhibit peak activity have decreased or increased following loss or recovery of native limestone forest. We also found the use of nested activity thresholds for quantifying peak bat activity to be useful in identifying high occupancy locations and making inferences about important habitat attributes.

Although relative variance (as measured by CV) of $\hat{\Psi}$ and p was generally greater at higher activity thresholds, standard errors were similar across thresholds (e.g., $\hat{\Psi}$ ($\overline{\text{SE}}$) (standard error) for all null models was about 0.08; Table IV–4). This means that future occupancy surveys may focus on sites with high expected activity without incurring additional analytical costs. These "core" sites are generally in tall stature native limestone forest and are more easily traversed and sampled than the dense thickets of exotic shrub (primarily *Lantana camara*) that comprise about one-half the island's landcover.

The current study was designed to randomly resurvey as many as possible of the 50 sites established on a systematic grid by Esselstyn and others (2004). However, not all locations were accessible (because of impenetrable *Lantana camara* thickets and the brief 19-day period available to us), and the 31 sites actually surveyed do not represent a fully random subset of the original 50 locations. Departure from a probabilistic sampling design may bias $\hat{\Psi}$ and p (upward in our case since proportionally fewer sites in non-forest were available to us than initially available to Esselstyn and others 2004). Therefore, future surveys of Pacific sheath-tailed bat occupancy on Aguiguan should seek to fully sample the grid of 50 sites if island-wide characterization of habitat use is a primary objective. However, if monitoring bat activity in preferred habitat is the main objective, the $\hat{\Psi}$ and p variances produced by this study may be used as a guide to generate a revised sampling design following the methods presented by Bailey and others (2007). For example, a design comprised of 30 sites sampled for 4 nights (or alternatively, 25 sites for 5 nights) is needed to attain a desired coefficient of variation (CV) of ≤ 0.05 given an expected Ψ of 0.93 and $p = 0.78$ (as observed for the median activity threshold in mature native limestone forest near known roosts; Tables IV–3 and IV–4).

The importance of native limestone forest to the persistence of *E. s. rotensis* on Aguiguan cannot be over-emphasized. Bat species specialized to forage near or within forests on average face a greater extinction risk than aerial insectivores or species with comparatively flexible foraging strategies (Kingston and others 2003, Safi and Kerth 2004, Lane and others 2006). Moreover, minimum area thresholds of species occurrence indicate that island occupancy by insectivorous bats may be strongly

limited by resource requirements (Frick and others 2008). Given the island's very limited resource base and size, the extreme isolation of the population, its vulnerability to typhoons (e.g., Grant and others 1994), and the species' relatively narrow habitat preference and specialized foraging strategy, efforts to reverse the decline in native limestone forest on Aguiguan may help to ensure the long-term survival of the Pacific sheath-tailed bat.

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REFERENCES CITED

Anonymous, 1991, Threatened or endangered species: Commonwealth of the Northern Mariana Islands, Commonwealth Register, vol. 13, p. 7537.

Bailey, L. L., Hines, J. E., Nichols, J. D., and MacKenzie, D. I., 2007, Sampling design trade-offs in occupancy studies with imperfect detection: examples and software: Ecological Applications, vol. 17, p. 281-290.

Burnham, K. P., and Anderson, D. R., 2002, Model selection and multimodel inference: a practical information-theoretic approach, second edition: New York, U.S.A., Springer-Verlag.

Chiroptera Specialist Group 2000. *Emballonura semicaudata*. In: IUCN 2007. 2007 IUCN Red List of Threatened Species. Downloaded on 02 September 2008 from http://www.iucnredlist.org.

Donovan, T. M., and Hines, J., 2007, Exercises in occupancy modeling and estimation. Downloaded on 04 September 2008 from http://www.uvm.edu/envnr/vtcfwru/spreadsheets/occupancy/occupancy.htm.

Ellison, L. E., O'Shea, T. J., Bogan, M. A., Everette, A. L., and Schneider, D. M., 2003. Existing data on colonies of bats in the United States: summary and analysis of the U.S. Geological Survey's bat population database, *in* O'Shea, T.J. , and Bogan, M. A., eds., Monitoring trends in bat populations of the United States and Territories: problems and prospects: Washington, D. C., U.S. Geological Survey Information and Technology Report USGS/BRD/ITR-20030-0003, p. 127-237.

Engbring, J., Ramsey, F. L., and Wildman, V. J., 1986, Micronesian forest bird survey, 1982: Saipan, Tinian, Agiguan, and Rota: Honolulu, Hawaii, U. S. Fish and Wildlife Service.

ESRI, 2006, ESRI ArcMap 9.2: Environmental Systems Research Institute, Inc., Redlands, Calif.

Esselstyn, J. A., Wiles, G. J., and Amar, A., 2004, Habitat use of the Pacific sheath-tailed bat (*Emballonura semicaudata*) on Aguiguan, Mariana Islands: Acta Chiropterologica, vol. 6, p. 303-308.

Fenton, M. B., Rydell, J., Vonhof, M. J., Eklöf, J., and Lancaster, W. C., 1999, Constant-frequency and frequency-modulated components in the echolocation calls of three species of small bats (Emballonuridae, Thyropteridae, and Vespertilionidae): Canadian Journal of Zoology, vol. 77, p. 1891-1900.

Flannery, T., 1995, Mammals of the South-West Pacific & Moluccan Islands: Ithaca, NY, Cornell University Press.

Frick, W. E., Hayes, J. P., and Heady, P. A., 2008, Patterns of island occupancy in bats: influences of area and isolation on insular incidence of volant mammals: Global Ecology and Biogeography, vol. 17, p. 622-632.

Gannon, W. L., O'Farrell, M. J., Corben, C., and Bedrick, E. J., 2004, Call character lexicon and analysis of field recorded bat echolocation calls, *in* Thomas, J. A. , Moss, C. F., and Vater, M. , eds., Echolocation of bats and dolphins: Chicago, Illinois, University of Chicago Press, p. 478-484.

Gorresen, P. M., Miles, A. C., Todd, C. M. , Bonaccorso, F. J., and Weller, T. J., 2008, Assessing bat detectability and occupancy with multiple automated echolocation detectors: Journal of Mammalogy, vol. 89, p. 11-17.

Grant, G. S., Banack, S. A., and Trail, P., 1994, Decline of the sheath-tailed bat *Emballonura semicaudata* (Chiroptera: Emballonuridae) on American Samoa: Micronesica, vol. 27, p. 133-137.

Helgen, K. M., and Flannery, T. F., 2002, Distribution of the endangered Pacific sheath-tailed bat *Emballonura semicaudata*: Australian Mammalogy, vol. 24, 209-212.

Hutson, A. M., Mickleburgh, S. P., and Racey, P. A. (compilers), 2001, Microchiropteran bats: global status survey and conservation action plan. IUCN/SSC Chiroptera Specialist Group, International Union for the Conservation of Nature and Natural Resources, Gland, Switzerland and Cambridge, United Kingdom.

Ibáñez, C., Juste, J., López-Wilchis, R., Albuja V., L., and Núñez-Garduño, A., 2002, Echolocation of three species of sac-winged bats (*Balantiopteryx*): Journal of Mammalogy, vol. 83, p. 1049-1057.

Jung, K., Kalko, E. K. V., von Helversen, O., 2007, Echolocation calls in Central American emballonurid bats: signal design and call frequency alternation: Journal of Zoology, vol. 272, p. 125-137.

Kingston, T., C. M. Francis, Z. Akbar, and T. H. Kunz. 2003. Species richness in an insectivorous bat assemblage from Malaysia. Journal of Tropical Ecology 19:67-79.

Koopman, K. F. 1997. The subspecies of *Emballonura semicaudata* (Chiroptera: Emballonuridae). Journal of Mammalogy 78:358-360.

Lane, D. J. W., Kingston, T., and Lee, B. P. Y.-H., 2006, Dramatic decline in bat species richness in Singapore, with implications for Southeast Asia: Biological Conservation, vol. 131, p. 584-593.

Lawrence, B. D., and Simmons, J. A., 1982, Measurements of atmospheric attenuation at ultrasonic frequencies and the significance for echolocation by bats: Journal of the Acoustical Society of America, vol. 71, p. 585–590.

Lemke, T. O., 1986, Distribution and status of the sheath-tailed bat (*Emballonura semicaudata*) in the Mariana Islands: Journal of Mammalogy, vol. 67, p. 743-746.

MacKenzie, D. I., and Bailey, L. L., 2004, Assessing the fit of site-occupancy models: Journal of Agricultural, Biological, and Environmental Statistics, vol. 9, p. 300-318.

MacKenzie, D. I., Nichols, J. D. , Lachman, G. B., Droege, S., Royle, J. A., and Langtimm, C.A., 2002, Estimating site occupancy when detection probabilities are less than one: Ecology, vol. 83, p. 2248–2255.

Neuweiler, G., 1989, Foraging ecology and audition in echolocating bats: Trends in Ecology and Evolution, vol. 4, p. 160-166.

O'Farrell, M. J., and Miller, B. W., 1997, A new examination of echolocation calls of some Neotropical bats (Emballonuridae and Mormoopidae): Journal of Mammalogy, vol. 78, p. 954-963.

O'Shea, T. J., and Bogan, M. A., eds., 2003, Monitoring trends in bat populations of the United States and territories: problems and prospects: U.S. Geological Survey, Biological Resources Discipline, Information and Technology Report, USGS/BRD/ITR--2003-003, 274 p.

Safi, K., and Kerth, G., 2004, A comparative analysis of specialization and extinction risk in temperate-zone bats: Conservation Biology, vol. 18, p. 1293-1303.

U.S. Fish and Wildlife Service, 2007, 50 CFR Part 17; Endangered and Threatened Wildlife and Plants; Review of Native Species That Are Candidates for Listing as Endangered or Threatened; Annual

Notice of Findings on Resubmitted Petitions; Annual Description of Progress on Listing Actions; Proposed Rule. Federal Register , Code of Federal Regulations (December 6, 2007), vol. 72 (no. 234), p. 69033-69106.

Wiles, G. J., Engbring, J., and Otobed, D., 1997, Abundance, biology, and human exploitation of bats in the Palau Islands: Journal of Zoology (London), vol. 241, p. 203-227.

Table IV–1. Characteristics of "low" and "high" harmonics in the search-phase calls of *E. s. rotensis*. Variables measured include: minimum (F_{min}), and maximum (F_{max}) frequencies (kHz); frequency range (F_{max} - F_{min}); characteristic (F_c) frequency (kHz); duration of entire pulse (ms); and time (T_c) from the start of pulse to F_c (ms). The number of call files and pulses examined were 33 and 245 for low harmonics and 45 and 509 for high harmonics, respectively.

Harmonic	Parameter	F_{min}	F_{max}	Range	F_c	Duration	Tc
"Low"	Minimum	26.85	31.01	0.24	27.03	0.49	0.49
	Maximum	32.79	33.33	5.39	33.06	3.11	2.36
	Mean	30.43	32.26	1.83	30.97	1.44	1.31
	SD	1.13	0.64	1.10	1.08	0.47	0.37
"High"	Minimum	40.20	58.82	1.43	50.63	0.26	0.28
	Maximum	64.00	67.23	23.29	66.12	4.07	3.80
	mean	53.33	64.37	11.04	63.15	2.75	1.73
	SD	4.12	1.22	4.05	2.20	0.56	0.46

Table IV–2. Summary of model selection for 4 activity threshold levels: none, 50th, 70th, and 90th percentiles of bat call pulse number. ΔAIC_c is the relative difference in AIC_c values from the model with the smallest value; w is the AIC_c model weight; k is the number of parameters; X^2 is the test statistic for model fit; p-value is the probability of observing a test statistic $\geq X^2$ based upon 999 parametric bootstraps; and $\hat{c}$ is the estimated over-dispersion parameter. Estimated occupancy is presented in Table IV–3 only for models (indicated below in bold) for which Δ AIC_c ≤ 2 and model goodness-of-fit is adequate (p-value ≥ 0.05 and $\hat{c}$ ranging between 0.5 and 1.5).

Threshold	Model	ΔAIC_c	w	k	X^2	p-value	$\hat{c}$
none	canopy	0.00	0.80	4	147.2	0.024	2.62
none	distance	3.96	0.11	3	153.0	0.023	2.70
none	null	5.82	0.04	2	172.8	0.030	2.94
none	native-exotic	7.42	0.02	3	181.3	0.018	3.21
none	understory	8.28	0.01	3	172.9	0.024	3.11
none	stature	9.88	0.01	4	171.0	0.022	3.08
none	stem diameter	9.88	0.01	4	181.5	0.018	3.22
50	**canopy & distance**	0.00	0.31	5	55.5	0.357	1.01
50	**distance**	0.07	0.30	3	50.8	0.403	0.92
50	**canopy**	0.15	0.28	4	50.2	0.386	0.96
50	null	4.12	0.04	2	48.4	0.435	0.85
50	stature	4.77	0.03	4	50.4	0.391	0.89
50	native-exotic	5.26	0.02	3	48.5	0.398	0.86
50	understory	6.18	0.01	3	48.5	0.406	0.88
50	stem diameter	6.53	0.01	4	48.9	0.370	0.90
70	**distance**	0.00	0.25	3	38.6	0.761	0.69
70	**canopy**	0.62	0.18	4	38.5	0.765	0.71
70	**canopy & stature**	0.76	0.17	6	40.4	0.705	0.74
70	**canopy & distance**	1.29	0.13	5	40.9	0.717	0.73
70	stature	2.28	0.08	4	39.0	0.712	0.71
70	null	2.71	0.06	2	38.2	0.718	0.69
70	distance & stature	2.73	0.06	5	39.3	0.720	0.71
70	native-exotic	4.24	0.03	3	38.5	0.698	0.70
70	stem diameter	4.64	0.02	4	38.6	0.717	0.68
70	understory	5.16	0.02	3	38.1	0.735	0.69
90	**distance & stature**	0.00	0.57	5	82.8	0.099	1.52
90	stem diameter [1]	2.15	0.19	4	121	0.012	2.24
90	distance	3.05	0.12	3	68.8	0.238	1.25
90	stature	3.90	0.08	4	95.0	0.064	1.74
90	stem diam. & stature	6.04	0.03	6	111.1	0.014	2.05
90	native-exotic	10.37	0.00	3	132.7	0.027	2.37
90	understory	10.49	0.00	3	76.6	0.193	1.40
90	canopy	12.28	0.00	4	81.3	0.148	1.46
90	null	12.86	0.00	2	94.5	0.118	1.69

[1] Model "stem diameter & distance" failed to converge and was excluded from output.

Table IV–3. Occupancy estimates ($\hat{\Psi}$) for existing combinations of variables. Results are shown only for top-ranked models (indicated in bold in Table IV–2) for each of 3 activity threshold levels: 50th, 70th, and 90th percentiles of bat call pulse number (the "no threshold" models did not meet goodness-of-fit criteria and are not presented). Estimates for the continuous variable "distance" are derived from mid-range examples of post hoc categories "near", "middle", and "far". Results are sorted by ascending occupancy estimate within each threshold and model.

Threshold	Model	$\hat{\Psi}$	SE	95 percent CI
50	canopy "middle", distance "far"	0.092	0.092	-0.088 – 0.272
50	canopy "middle", distance "middle"	0.323	0.158	0.012 – 0.633
50	canopy "low", distance "far"	0.422	0.349	-0.263 – 1.106
50	canopy "high", distance "far"	0.559	0.243	0.084 – 1.035
50	canopy "middle", distance "near"	0.562	0.239	0.093 – 1.031
50	canopy "low", distance "near"	0.746	0.257	0.242 – 1.249
50	canopy "high", distance "middle"	0.817	0.103	0.615 – 1.020
50	canopy "high", distance "near"	0.928	0.064	0.803 – 1.053
50	canopy "middle"	0.274	0.135	0.010 – 0.539
50	canopy "low"	0.667	0.272	0.133 – 1.201
50	canopy "high"	0.839	0.094	0.655 – 1.023
50	distance "far"	0.196	0.140	-0.079 – 0.471
50	distance "middle"	0.633	0.099	0.440 – 0.827
50	distance "near"	0.869	0.087	0.698 – 1.041
70	canopy "middle", stature "middle"	0.112	0.107	-0.097 – 0.321
70	canopy "low", stature "middle"	0.582	0.380	-0.163 – 1.327
70	canopy "high", stature "middle"	0.681	0.150	0.387 – 0.974
70	canopy "middle", stature "tall"	0.712	0.247	0.229 – 1.194
70	canopy "high", stature "short"	0.791	0.241	0.319 – 1.263
70	canopy "high", stature "tall"	0.977	0.036	0.906 – 1.047
70	canopy "middle", distance "far"	0.115	0.107	-0.095 – 0.326
70	canopy "middle", distance "middle"	0.322	0.157	0.014 – 0.629
70	canopy "low", distance "far"	0.463	0.351	-0.224 – 1.150
70	canopy "high", distance "far"	0.466	0.275	-0.073 – 1.005
70	canopy "middle", distance "near"	0.521	0.242	0.046 – 0.995
70	canopy "low", distance "near"	0.734	0.260	0.224 – 1.244
70	canopy "high", distance "middle"	0.750	0.121	0.513 – 0.986
70	canopy "high", distance "near"	0.884	0.087	0.713 – 1.055
70	canopy "middle"	0.277	0.137	0.010 – 0.545
70	canopy "low"	0.668	0.273	0.134 – 1.203
70	canopy "high"	0.792	0.107	0.583 – 1.001
70	distance "far"	0.210	0.147	-0.078 – 0.498
70	distance "middle"	0.506	0.109	0.293 – 0.720
70	distance "near"	0.832	0.103	0.629 – 1.034
90	distance "far", stature "short"	0.000	0.000	0.000 – 0.000
90	distance "near", stature "short"	0.000	0.000	0.000 – 0.000
90	distance "far", stature "middle"	0.006	0.014	-0.021 – 0.034
90	distance "middle", stature "middle"	0.060	0.067	-0.070 – 0.191
90	distance "middle", stature "tall"	0.554	0.363	-0.157 – 1.265
90	distance "near", stature "tall"	0.959	0.064	0.834 – 1.083

Table IV–4. Occupancy ($\hat{\Psi}$) and detection probability (p) estimates for null and top-ranked models (indicated in bold in Table IV–2) for each of 4 activity threshold levels: "none", and 50th, 70th, and 90th percentiles of bat call pulse number. "Null" indicates models with no habitat covariates included. "Obs Ψ" is the observed or "naïve" estimate for occupancy (i.e., not adjusted for detection probability). Mean, standard error (SE) and associated coefficient of variation (CV) were derived from parameter estimates for all sampled sites.

Threshold	Model	Obs Ψ	$\bar{\hat{\Psi}}$ ($\overline{\text{SE}}$)	CV	p (SE)	CV
none	Null	0.71	0.72 (0.08)	0.11	0.76 (0.05)	0.07
50	Null	0.61	0.62 (0.09)	0.14	0.78 (0.05)	0.07
50	canopy & distance	0.61	0.63 (0.14)	0.22	0.78 (0.05)	0.07
50	Canopy	0.61	0.57 (0.14)	0.24	0.78 (0.05)	0.07
50	Distance	0.61	0.63 (0.11)	0.17	0.78 (0.05)	0.07
70	Null	0.58	0.59 (0.09)	0.15	0.70 (0.06)	0.09
70	canopy & stature	0.58	0.58 (0.16)	0.27	0.70 (0.06)	0.09
70	canopy & distance	0.58	0.60 (0.15)	0.25	0.70 (0.06)	0.09
70	Canopy	0.58	0.56 (0.15)	0.26	0.69 (0.06)	0.09
70	Distance	0.58	0.60 (0.11)	0.19	0.70 (0.06)	0.09
90	Null	0.26	0.27 (0.08)	0.31	0.59 (0.10)	0.17
90	distance & stature	0.26	0.27 (0.08)	0.32	0.61 (0.09)	0.16

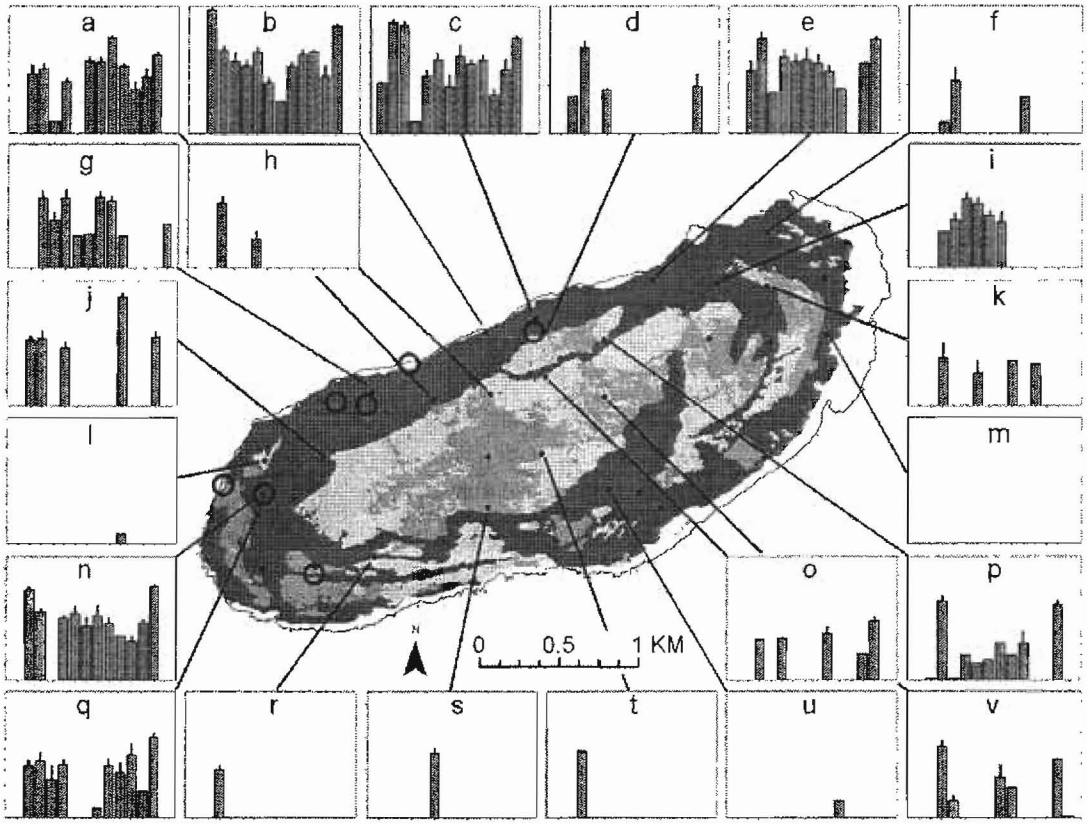


Figure IV–1. Distribution of survey stations and *E. s. rotensis* activity by hour of night for all sites with detections on Aguiguan. X axis on each inset bar graph is hour of night beginning at 1700 and ending at 0600. Y axis is natural log of mean pulse total (+1 standard deviation (SD); major tick marks range from 10^0 to 10^3). Bars with no SD whisker had only a single observation in the hour. Graph axes are shown in detail for each site (labeled a–v) in Appendix IV–1. Open circles on background image indicate known roost locations and points designate sample sites. Landcover classes shown include native limestone forest (dark gray), non-native forest (mid-tone gray), non-native shrubland (light gray), and coastal scrub, grass and unvegetated areas (white). Landcover map courtesy of Fred Amidon (USFWS).

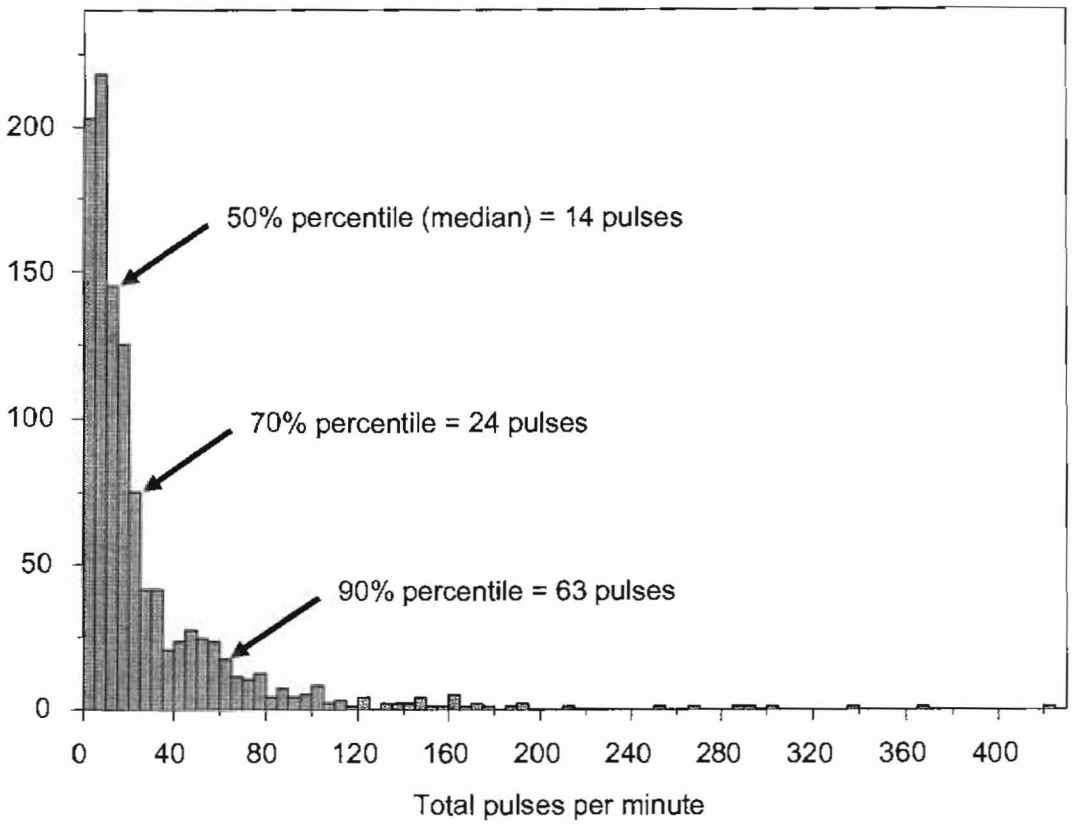


Figure IV–2. Distribution of total bat call pulses per 1-minute interval (n =1,224). Y-axis is number of intervals. One-half of all bat detections consisted of brief passes with less than 15 pulses. Higher thresholds of activity indicative of sustained bouts of foraging were defined with 50th, 70th, and 90th percentiles of pulse number.

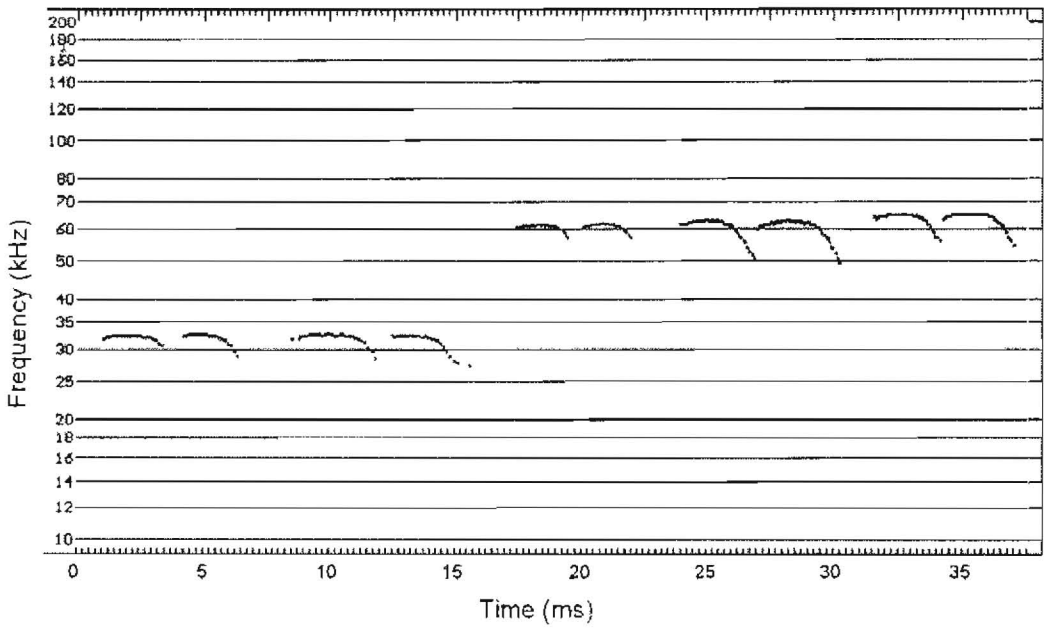
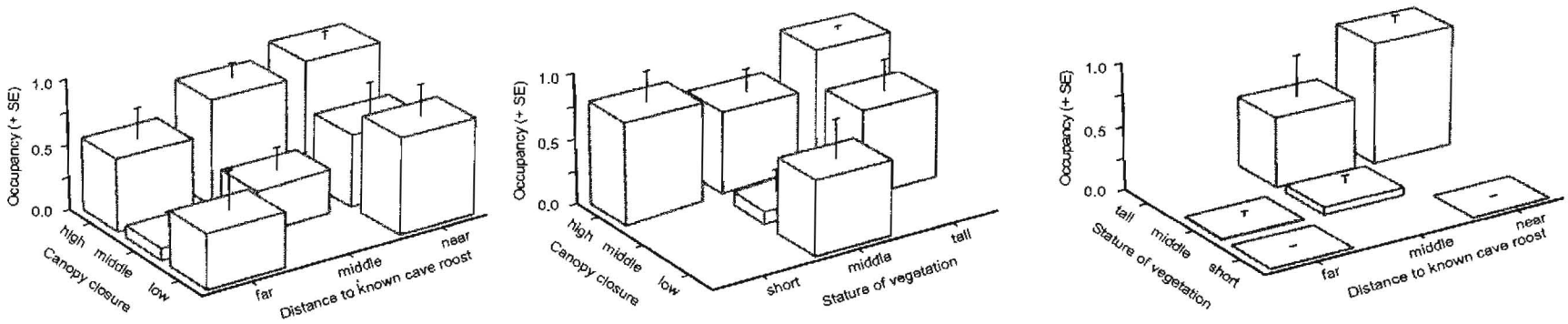


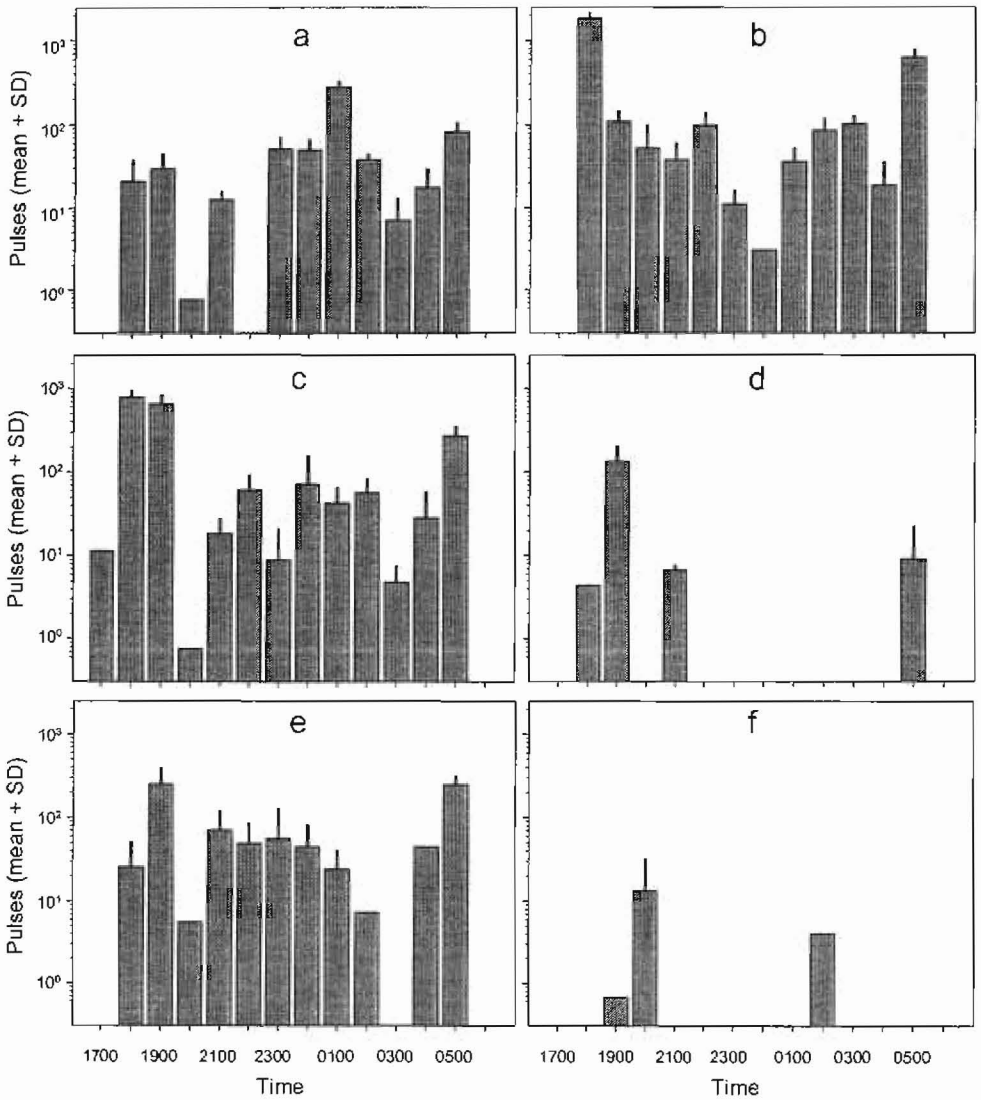
Figure IV–3. Examples of pairs of characteristic pulses in the search-phase calls of *E. s. rotensis*. Note that paired examples were derived from different Anabat call files, and the time between pulses was compressed to permit display of various pulses.

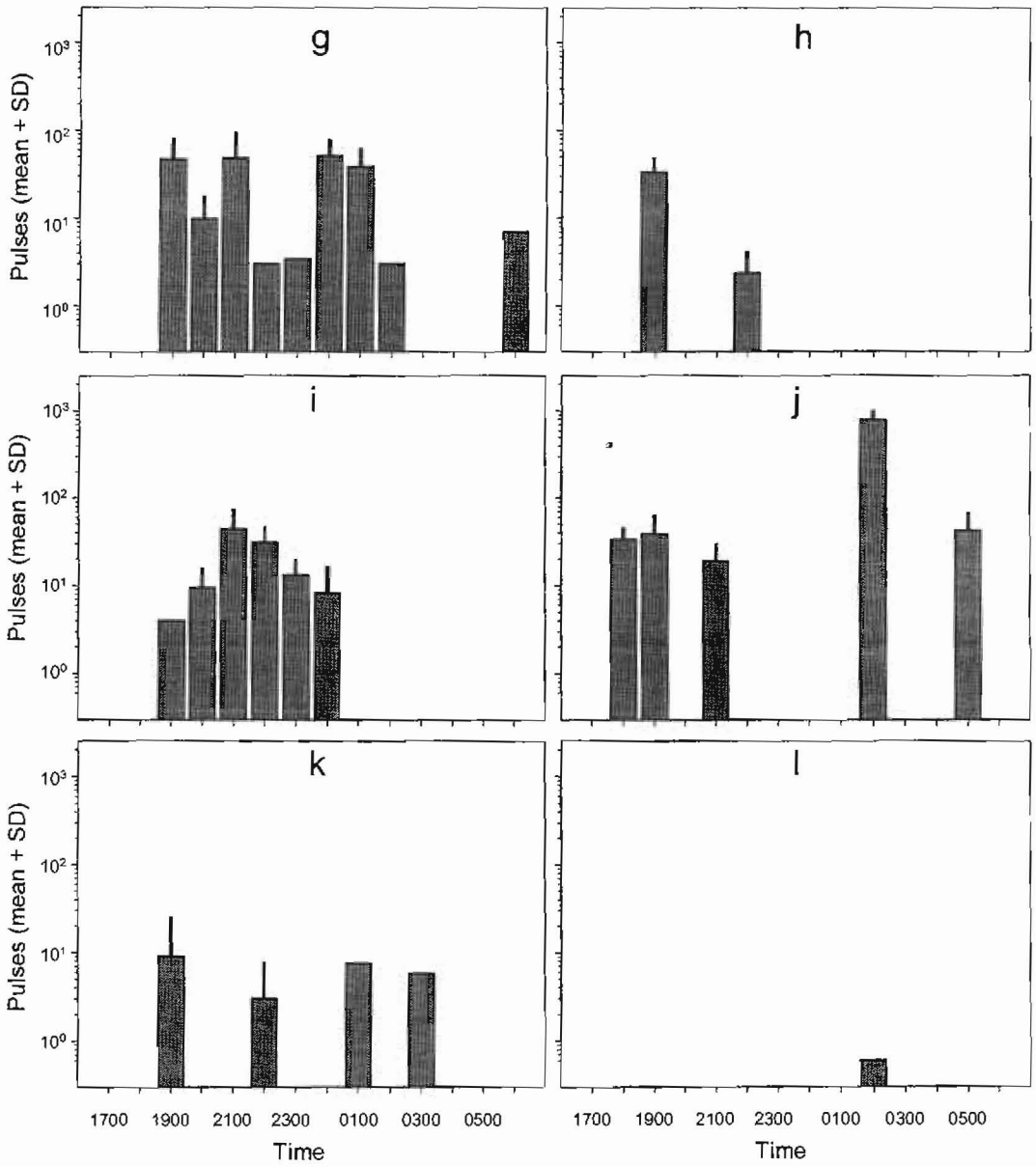


50th percentile threshold 70th percentile threshold 90th percentile threshold

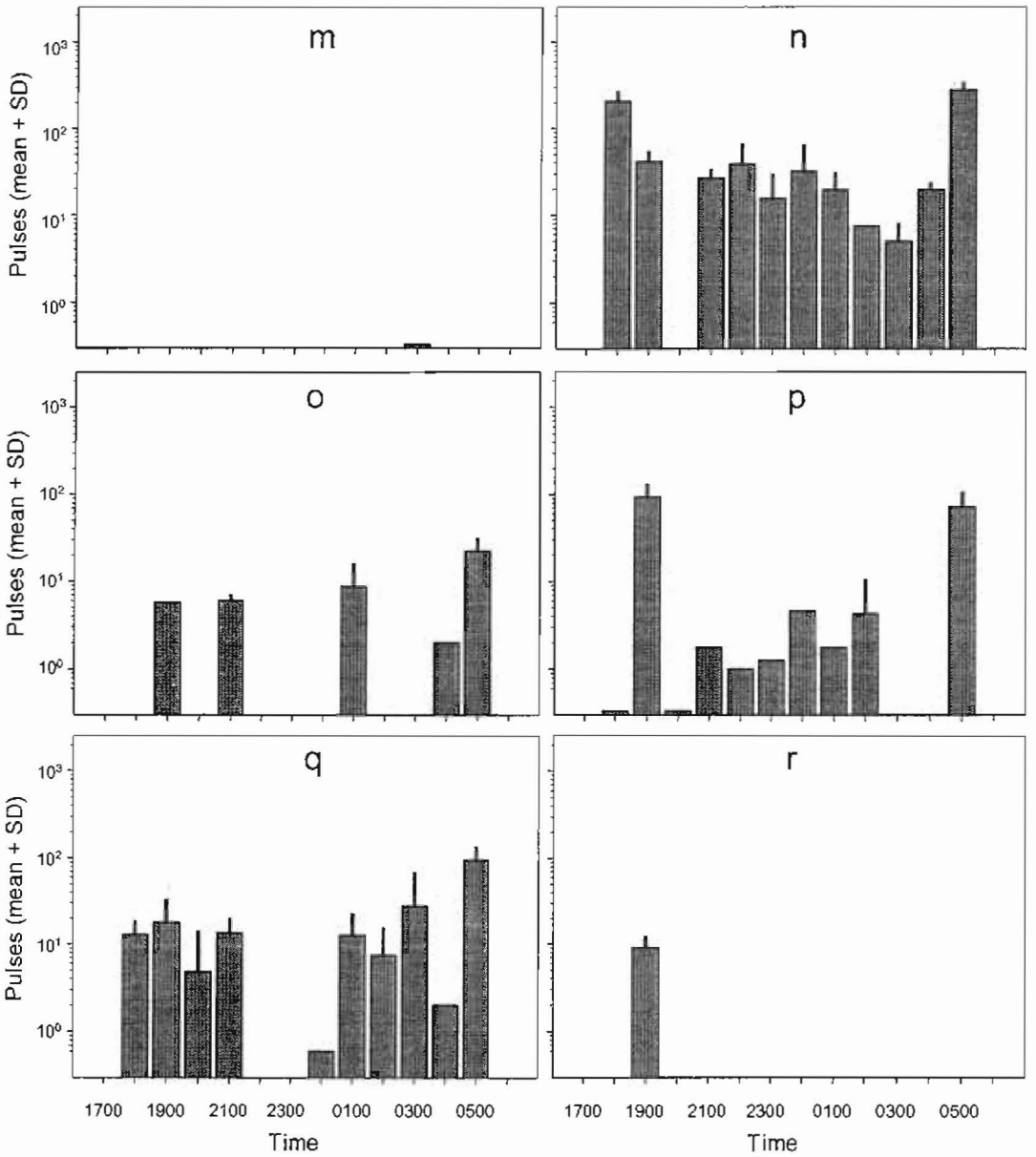
Figure IV–4. Occupancy estimates (mean ± 1 standard error (SE, whisker) for existing combinations of habitat covariates at the 50th, 70th, and 90th percentile thresholds of activity (results shown only for models with lowest AIC_c values and adequate goodness-of-fit).

Appendix IV–1. *E. s. rotensis* activity by hour of night for all sites with detections on Aguiguan. X axis on each inset bar graph is hour of night beginning at 1700 and ending at 0600. Y axis is natural log of mean pulse total (+1 standard deviation (SD)). Bars with no SD whisker had only a single observation in the hour. Graphs are shown as insets for each site (labeled a–v) in Figure IV–1.

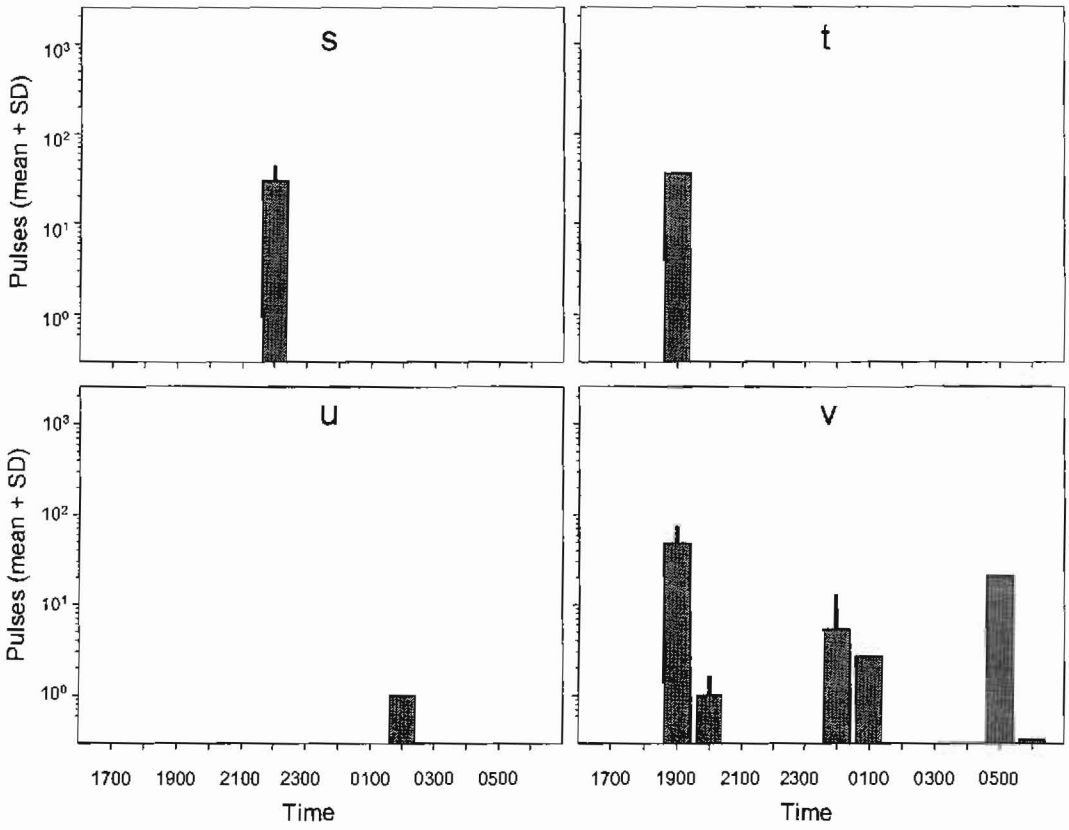




Appendix IV–1 continued



Appendix IV–1 continued



Appendix IV–1 continued.

Section V. Food Habits of the Pacific Sheath-Tailed Bat (*Emballonura semicaudata rotensis*) on Aguiguan, Commonwealth of the Northern Mariana Islands

By Ernest W. Valdez

ABSTRACT

*Emballonura semicaudata rotensis*is is an endemic subspecies of the Pacific sheath-tailed bat known only from the Mariana Islands. It is extinct on all of the Mariana Islands where it once occurred except for the small limestone island of Aguiguan that supports an isolated remnant population. There is no information about the food habits of Pacific sheath-tailed bats. In 2008, I conducted an investigation of food habits of *E. s. rotensis* based on analysis of fresh fecal pellets from bats roosting in Guano and Crevice Caves on Aguiguan. One hundred pellets from each roost were analyzed, and major orders of insects consumed by *E. s. rotensis* from Guano Cave (based on percent volume) included hymenopterans (64 percent), coleopterans (10 percent), lepidopterans (8 percent), isopterans (8 percent), and psocopterans (5 percent). Major prey items of bats from Crevice Cave included lepidopterans (45 percent), hymenopterans (41 percent), coleopterans (10 percent), and isopterans (5 percent). Most of the identified hymenopterans found in the guano from both roosts belonged to ichneumondoidea, followed by prey items belonging to formicinae and ponerinae. Because alates of formicines and ponerines, as well as isopterans, generally have wings only when they are reproductive or establishing new colonies, often at the onset of rains, it is likely that these food items occur in the diet of *E. s. rotensis* seasonally. Microlepidopterans were another probably seasonally abundant prey item consumed by *E. s. rotensis*. Beetles (Coleoptera) that were likely forest-dependent species were a consistent component of the diet. Most insect prey items were small ranging from 1.7 to 6.4 mm in length. From observations and diet analyses, *E. s. rotensis* can be categorized as an aerial insectivore or hawker, similar to other emballonurids around the world.

INTRODUCTION

Emballonura semicaudata rotensis, the subspecies of the Pacific sheath-tailed bat unique to the Marianas Islands, is an insectivorous microchiropteran that occurred historically on multiple islands including Guam (Lemke 1986, Koopman 1997). This bat is now extinct throughout its range except for the small (7.2 km^2) uninhabited island of Aguiguan in the Commonwealth of the Northern Mariana Islands (CNMI, Hutson and others 2001). At present, this bat is listed as a Category 3 candidate for listing under the U.S. Endangered Species Act (U.S. Fish and Wildlife Service 2007) and is categorized as Endangered by the International Union for the Conservation of Nature and Natural Resources (Bonaccorso and Allison 2008, Hutson and others 2001). Exact reasons for its decline are unknown, but it is has been suggested that *E. s. rotensis* had succumbed to a series of events during a short period of time that eventually led to its demise throughout most of its historic range (Hutson and others 2001, U.S. Fish and Wildlife Service 2007, 2008; Bonaccorso and Allison 2008). Some of these events include: disturbance of caves (especially during military operations during World War II), the only structures known to be used as roosts by these colonial bats in the CNMI (see Section III of this report); loss or destruction of forest habitat used by foraging bats during World War II and subsequent clearing

for development; use of insecticides; typhoons; and introduced ungulates and perhaps invasive predators on some islands. All these factors are cited as possibly directly or indirectly impacting populations of this subspecies (Hutson and others 2001, Bonaccorso and Allison, 2008, Cruz and others 2008). Although the use of insecticides and loss of forest habitat have been suggested as possible causes of declines, there is no baseline information about the kinds of insects that these bats eat and the possible habitat affinities of these insects. Understanding food requirements is an important component for conservation and management of wildlife. Therefore, the objective of the work reported in this section was to determine the food habits of Pacific sheath-tailed bats on Aguiguan.

MATERIALS AND METHODS

The food habits of insectivorous bats are typically determined by identification of chitinous fragments of insects in guano (Whitaker 1988). These bats masticate insects into small fragments that are best identified in guano rather than in stomach contents because the latter contain larger amounts of unidentifiable digestible material and require sacrificing individuals to obtain ingesta. Guano can be sampled non-invasively, which is of importance in studies of bats that are of conservation concern. On Aguiguan guano was sampled beneath daytime roosts of Pacific sheath-tailed bats at two caves. Guano Cave (Datum: WGS 84; UTM zone 55P, 343039E, 1642089N, elev. 100m), the larger of the two roosts, houses one of the larger colonies of sheath-tailed bats on Aguiguan, with 43–64 bats counted in the roost in June and July of 2008 (see Section III of this report). This cave is also shared by a colony of about 200 or more Mariana swiftlets (*Aerodramus bartschi*). Roosting bats were positioned about 15–20 m above the cave floor in a distinctive domed ceiling at the end of the deepest chamber of the cave, whereas most of the swiftlet nests were located closer to the outside opening on the inside wall of the same chamber, about 3–15 m above the cave floor. Most of the guano on the floor of the cave had accumulated over many years and had disintegrated into a fine powder, making it difficult to distinguish bat guano from swiftlet guano. To obtain comparative material, on 25 June 2008 a 1 m x 1 m plastic sheet was placed on the cave floor directly beneath the roosting bats and a similar sheet beneath the area where swiftlets roosted. On 30 June 2008, the sheets were retrieved from the roost and placed in plastic re-sealable bags.

Guano was also sampled at a second roost that was not used by swiftlets. On 27 June 2008 a 0.5 m x 0.5 m plastic sheet was placed 1 m beneath a small group of bats (2–3 adults, 1 pup) in Crevice Cave (Datum: WGS 84; 55P, 343541E, 1641526N, elev. 72 m). This roost can be described as a chute, chimney, or vertical solution tube in the back portion of the main cave. Because only 3 bats were observed using this roost, the plastic sheet was left under the bats for a longer period of time (13 days) to allow for a larger accumulation of guano.

A small reference collection was made of arthropods (mostly insects) from Aguiguan specifically to aid in identification of fragments observed during microscopic fecal analysis (not for comparisons of arthropod community affinities). Insects were collected mostly at night following techniques described by Kunz (1988), including use of a sweep net, beating of vegetation, and setting out a black light. I also attempted to collect insects using sticky-traps made of 76.2mm x 127mm index cards coated with an insect barrier (Tanglefoot Tree Pest Barrier ®). These traps were attached to twine and hung vertically from the canopy, but this method was abandoned after rains disintegrated the cards. Arthropods were placed in vials of 95 percent ethanol and identified at the Museum of Southwestern Biology, University of New Mexico, Albuquerque.

In the field I examined fecal material of bats and swiftlets to ascertain if these could be readily distinguished in the fresh samples. Intact fecal pellets produced by *E. s. rotensis* were elliptical and averaged about 4 mm long by 2 mm wide. Intact guano produced by swiftlets was globular, as observed

for other small insectivorous birds, but varied in size. Swiftlet guano also could be differentiated by uric acid crystals combined with digested insects; uric acid crystals were not present in bat guano. Finally, microscopic inspection affirmed gross differences: insect matter consumed by bats was always chewed into much smaller fragments than those found in swiftlet fecal matter. Using the aforementioned criteria for distinguishing bird and bat guano, formed guano pellets of *E. s. rotensis* were sorted from powdered guano, then fecal material was grouped according to roost. Pellets were randomly sub-sampled and analyzed following techniques described by Whitaker (1988). Fecal pellets were placed in watch glasses with 95 percent ethanol and teased apart under a stereo-zoom microscope. Insect prey found in the guano were identified to the lowest taxonomic level, usually to family, using Chujo (1970), Borror and White (1970), White (1983), Whitaker (1988), Arnett (2000), Arnett and Thomas (2001), Arnett and others (2002), and Triplehorn and Johnson (2005) as guides for identification.

A single pellet represented one sample, and a total of 200 intact fecal pellets (100 from each roost) were analyzed. Percent volume and frequency were calculated for each prey item (Whitaker 1988). In addition to fecal analyses, digital calipers (Mitutoyo ®) were used to measure length and width, in mm to the nearest 0.01, of a single representative from the reference collection of arthropods that were similar in appearance to matched prey items found in the diet of *E. s. rotensis*.

RESULTS

The major food items consumed by *E. s. rotensis* from Guano Cave were hymenopterans at 64 percent volume and 95 percent occurrence (Table V–1). Prey items belonging to Ichneumonoidea (parasitic wasps) had the greatest percent volume (25 percent) and percent occurrence (45 percent) among identified hymenopterans. Prey items in the Formicidae (ants) were also identified within the Hymenoptera, including ants belonging to Formicinae (7 percent volume, 12 percent occurrence) and Ponerinae (2 percent volume, 12 percent occurrence, Table V–1). The ponerines (i.e., trap-jaw ants) were identified by the distinct shape of their mandibles, antennae, and fragments of head capsules, and the individuals consumed by *E. s. rotensis* appear to belong to the genus *Anochetus*. Other key prey items found in the guano of *E. s. rotensis* from Guano Cave included coleopterans (beetles) at 10 percent volume and 73 percent occurrence, followed by microlepidopterans (moths, 8 percent volume, 38 percent occurrence), isopterans (termites, 8 percent volume, 10 percent occurrence), and psocopterans (bark lice, 5 percent volume, 26 percent occurrence, Table V–1). All other identified prey items had values of 1 percent volume or less and did not occur frequently (Table V–1).

Pacific sheath-tailed bat fecal samples from Crevice Cave primarily contained microlepidopterans (45 percent volume, 86 percent occurrence) and hymenopterans (41 percent volume, 82 percent occurrence; Table VI–1). Ichneumonoids had the greatest percent volume (31 percent) and percent occurrence (46 percent) values among identified hymenopterans. Formicines contributed to 7 percent of the volume and were encountered in 26 percent of the samples (Table V–1). Coleopterans contributed to 10 percent of the volume consumed by the bats at Crevice Cave and were encountered in 68 percent of the samples examined (Table V–1). Within Coleoptera, beetles belonging to the Cryptophagidae (silken fungus beetles) accounted for 3 percent of the volume and were encountered in 18 percent per cent of the samples (Table V–1). Isopterans contributed to 5 percent of the volume and occurred in 6 percent of the samples from Crevice Cave (TableV–1). All other identified prey items had values less than 1 percent for percent volume and 5 percent or less for percent occurrence.

Measurements of arthropods matched with those consumed by Pacific sheath-tailed bats ranged in size from the smallest, a scolytine at 1.72 mm x 0.85 mm to the largest, a ponerine, at 7.6 mm x 1.63 mm (Table V–2). Isopterans were the next largest prey item at 6.13 mm x 1.55 mm, and could be

considered the longest (11.87 mm) if wings are included in the measurements. There was no voucher specimen of an ichneumonoid from Aguiguan in my reference collection. Therefore, I used the size of the ichneumonoid wings found in the guano to estimate total size of the prey item, and then measured a formicid of similar size to provide an approximate length and width (Table V–2).

DISCUSSION

Results from this study represent the first documented information on the food habits of Pacific sheath-tailed bats. From observations of dusk and night-time flights of these bats in the forest on Aguiguan (described in Section VI of this report) and those by Esselstyn and others (2004), foraging activity occurs near (above and below) the canopy of the native forest. Sampling of echolocation activity on Aguiguan during the same period when guano was collected (see Section IV of this report) also indicated that Pacific sheath-tailed bat activity occurred mostly in stands of native limestone forest. The activity observations and the types of food items determined from analyses of guano demonstrate that Pacific sheath-tailed bats on Aguiguan share the same feeding behavior (i.e., aerial insectivore or hawker) as noted for other members of Emballonuridae (Bonaccorso 1998, Lim and Engstrom, 2001). However, prey items found in this study differ slightly from those of other emballonurids elsewhere (Bradbury and Vehrencamp 1976).

Results indicate that sizes of prey items or related insects consumed by Pacific sheath-tailed bats on Aguiguan were small (ranging from 1.7 mm to 6.4 mm in length). Hymenopterans, coleopterans, and lepidopterans were the three major groups of insects consumed by bats from both roosts. However, ranking of orders by greatest percentages of volumes and frequency of occurrence differed between roosts. Although there were noticeable differences for hymenopterans at both roosts, the greatest observed differences were for the percent volumes of lepidopterans, with a greater consumption of moths in samples from Crevice Cave. The overall percentages of volumes and frequencies of occurrence for coleopterans in the diet of *E. s. rotensis* were nearly equal in guano sampled at the two roosts.

Within the Hymenoptera, the percentages of volumes and occurrences of ichneumonoids consumed by bats from both roosts were similar. These parasitic wasps seemed to be a consistent prey item of Pacific sheath-tailed bats during the time guano was sampled. Based on samples from Guano Cave, formicids found in the diet of these bats may have been taken opportunistically during periods when alates form large swarms; usually during breeding or establishment of new colonies (Triplehorn and Johnson 2004). This also holds true for isopteran alates present in the bat guano (Triplehorn and Johnson 2004). Often swarms of ant and termite alates are associated with the onset of seasonal rains (Triplehorn and Johnson 2004). Rebello and Martius (1994) noted that in the Central Amazon region of Brazil peak periods of isopteran alate abundance occurred at the beginning and end of rainy seasons, but were lowest during the height of the rainy season. Guano was collected on Aguiguan during the early part of the rainy season (late June to early July) and the presence of these ant and termite alates may be consistent with opportunistic feeding on these insects by Pacific sheath-tailed bats during the onset of the rains. Opportunistic feeding on winged formicids or isopterans by insectivorous bats is not uncommon and has been reported for other species elsewhere (Razakarivony and others 2005, Rakotoarivelo and others 2007).

Even though Crevice and Guano Caves were only about 500 m apart, there was a slightly higher presence of lepidopterans over hymenopterans in guano from Crevice Cave. The higher abundance of lepidopterans at Crevice Cave may reflect greater availability and abundance of these insects, as noted for ant and termite alates. The intraspecific partitioning of resources and territories among individual

bats has been noted for other emballonurids (Bradbury and Vehrencamp 1976) and could be a contributing factor for difference in food habits of bats sampled at different roosts.

From analyses of guano, I found fragments of coleopterans in some fecal pellets that had been broken down into a paste-like texture, likely by chitinase produced by bacteria in the gastrointestinal tracts of the bats. Whitaker and others (2004) noted that during summer feeding by bats in North America, harder and larger pieces of insects often pass through the digestive tracts of bats undigested. In part this is related to the fast (approximately 30–60 min) transit time in the digestion of food by insectivorous bats (e.g., *Myotis lucifugus*; Buchler 1975). However, Whitaker and others (2004) also suggested that after an insect has been chewed into small pieces, the presence of chitinase helps break down connective tissue, making it easier to digest prey items. Whitaker and others (2004) also found that during winter months, chitinase activities are lower because bats are in torpor and often have little food present in their digestive system. Because chitin remains in the gut for a longer period of time, this allows for a longer period for the breakdown of insect parts by chitinases. Because of the presence of highly digested beetle parts in the guano, some Pacific sheath-tailed bats may digest certain food items longer (i.e., beetles) with chitinase, especially during periods when food resources are low or preferred items are unavailable.

The concurrent analyses by Gorresen and others (Section IV in this report) show that native limestone forest habitat is a key component to the foraging behavior of Pacific sheath-tailed bats on Aguiguan. Coleopterans identified from fecal analyses also provide specific information on the importance of native forests. For example, cryptophagids feed on fungi and vegetation matter at different levels of decay, and many scolytines feed on dying trees (Triplehorn and Johnson 2005). Because of their ecology and fidelity to dying or decaying trees the presence of these beetles in the diet of Pacific sheath-tailed bats on Aguiguan provides additional evidence that the bats are foraging in and near the forests. Although beetles are not present in large volumes, they occur in a large proportion of the fecal pellets examined and are thus an important part of the diet.

The results of this study suggest that during the onset of the rainy season (late June to early July), native forests are important in providing food resources for Pacific sheath-tailed bats. Resource managers may want to consider forest management practices that are not likely to be harmful to populations of small insects for future conservation efforts for this bat on Aguiguan. For example, use of herbicides to control invasive vegetation could take into account likely effects on native plants that support insect populations, and use of insecticides in native forests could also take into account the effects on the prey base of the bats. This study only represents a snap-shot of time in understanding what prey items are consumed by Pacific sheath-tailed bats on Aguiguan. The diet of this bat could be complex, likely includes other unidentified food items, and may change with variation in seasonal availability of prey, environmental variation, or reproductive conditions of the bats. Therefore, to inform management decisions regarding forest and perhaps other habitat needed for foraging by bats, future studies are needed to investigate the feeding ecology and behavior of these bats during other periods of the year.

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REFERENCES CITED

Arnett, R. H., Jr., 2000, American insects: A handbook of insects north of Mexico, Second ed. : Boca Raton, Fla., CRC Press, 1024 p.

Arnett, R. H., Jr., and Thomas, M. C., 2001, American beetles, Archostemata, Myxophaga, Adephaga, Polyphaga: Staphyliniformia, Vol. 1. : Boca Raton, Fla., CRC Press, 443 p.

Arnett, R. H, Jr., Thomas, M. C., Skelley, P. E., and Frank, J. H., 2002, American beetles, Polyphaga: Scarabaeoidea through Curculionidea: Boca Raton, Fla., CRC Press, 861 p.

Bonaccorso, F. J., 1998, Bats of Papua New Guinea: Washington, D.C., Conservation International, 489 p.

Bonaccorso, F. J., and Allison, A., 2008, *Emballonura semicaudata*, *in* International Union for the Conservation of Nature and Natural Resources 2008, 2008 IUCN Red List of Threatened Species, www.iucnredlist.org.

Borror, D. J., and White, R. E., 1970, A field guide to insects, America north of Mexico: The Peterson field guide series: 404 p.

Bradbury, J. W., and Vehrencamp, S. L., 1976, Social organization and foraging in emballonurid bats: Behavioral Ecology and Sociobiology, vol. 1, p. 337–381.

Buchler, E. R., 1975, Food transit time in Myotis lucifugus (Chiroptera: Vespertilionidae): Journal of Mammalogy, vol. 56, p. 252–255.

Chujo, M., 1970, Coleoptera—Cryptophagidae and Mycetophagidae: Insects of Micronesia, vol. 16, p. 271–278.

Cruz, J B., Kremer, S. R., Martin, G., Williams, L. L., and Camacho, V. A., 2008, Relative abundance and distribution of Mariana swiftlets (Aves: Apodidae) in the Northern Mariana Islands: Pacific Science, vol. 62, p. 233–246.

Esselstyn, J. A., Wiles, G.J., and Amar, A., 2004, Habitat use of the Pacific sheath-tailed bat (*Emballonura semicaudata*) on Aguiguan, Mariana Islands: Acta Chiropterologica, vol. 6, p. 303–308.

Gorresen, P. M., Bonaccorso, F. J., and Pinzari, C. A., 2008, Habitat occupancy and detection of the Pacific sheath-tailed bat (*Emballonura semicaudata*) on Aguiguan, Mariana Islands: U.S. Geological Survey, Fort Collins, Colorado, this administrative report.

Hutson, A. M., Mickleburgh, S. P., and Racey, P. A., 2001, Microchiropteran bats: Global status survey and conservation plan: IUCN/SSC Chiropteran Specialist Group: IUCN, Gland, Switzerland and Cambridge, UK x +258pp.

Koopman, K. F., 1997, The subspecies of *Emballonura semicaudata* (Chiroptera: Emballonuridae): Journal of Mammalogy, vol. 78, p. 358–360.

Kunz, T. H., 1988, Methods of assessing the availability of prey to insectivorous bats, *in* Kunz, T. H. , ed., Ecological and behavioral methods for the study of bats: Washington, D.C. , Smithsonian Institution Press, p. 191–210.

Lemke, T. O., 1986, Distribution and status of the sheath-tailed bat (*Emballonura semicaudata*) in the Mariana Islands: Journal of Mammalogy, vol. 67, p. 743–746.

Lim, B. K., and Engstrom, M. D., 2001, Bat community structure at Iwokrama Forest, Guyana: Journal of Tropical Ecology, vol. 17, p. 647–665.

Rakotoarivelo, A. A., Ranaivoson, N., Ramilijaona, O. R., Kofoky, A. F., Racey, P. A., and Jenkins, R. K. B., 2007, Seasonal food habits of five sympatric forest microchiropterans in western Madagascar: Journal of Mammalogy, vol. 88, p. 959–966.

Razakarivony, V. R., Rajemison, B. and Goodman, S. M., 2005, The diet of Malagasy Microchiroptera based on stomach contents: Mammalian Biology, vol. 70, p. 312–316.

Rebello, A. M. C., and Martius, C., 1994, Dispersal flights of termites in Amazonian forests (Isoptera): Sociobiology, vol. 24, p. 127–146.

Triplehorn, C. A., and Johnson, P. J., 2005, Borror and Delong's introduction to the study of insects, 7th ed.: Florence, KY, Brooks Cole Publishing, 864 p.

U.S. Fish and Wildlife Service, 2007, 50 CFR Part 17; Endangered and Threatened Wildlife and Plants; Review of Native Species That Are Candidates for Listing as Endangered or Threatened; Annual Notice of Findings on Resubmitted Petitions; Annual Description of Progress on Listing Actions; Proposed Rule. Federal Register, Code of Federal Regulations (December 6, 2007) 72 (234): 69033–69106.

U.S. Fish and Wildlife Service, 2008, 50 CFR Part 17; Endangered and Threatened Wildlife and Plants; Review of Native Species That Are Candidates for Listing as Endangered or Threatened; Annual Notice of Findings on Resubmitted Petitions; Annual Description of Progress on Listing Actions; Proposed Rule. Federal Register, Code of Federal Regulations (December 10, 2008), vol. 73 (no. 238), p. 75175–75244.

White, R. E., 1983, A field guide to the beetles of North America, The Peterson field guide series: New York, NY, Houghton Mifflin Co., 368 p.

Whitaker, J. O., Jr., 1988, Food habits of insectivorous bats, *in* Kunz, T. H. ed., Ecological and behavioral methods for the study of bats: Washington, D.C., Smithsonian Institution Press, p. 171–189.

Whitaker, J. O., Jr., Dannelly, H. K., and Prentice, D. A., 2004, Chitinase in insectivorous bats: Journal of Mammalogy, vol. 85, p. 15–18.

Table V–1. Percent volumes and percent occurrences of food items of the Pacific sheath-tailed bat (*Emballonura semicaudata rotensis*) from Aguiguan, as determined by fecal analyses. Sample sizes from each cave are noted in parentheses. Values in bold represent overall percentages for volumes and occurrences of each order. Samples were collected in June and July 2008.

	Guano Cave (n=100)		Crevice Cave (n=100)	
Prey Item	**percent Vol.**	**percent Occurrence**	**percent Vol.**	**percent Occurrence**
Ichneumonoidea	25	45	31	46
Formicinae	7	12	7	26
Ponerinae	2	12		
Unkn. Hymenoptera	31	63	3	18
HYMENOPTERA	**64**	**95**	**41**	**82**
Curculionidae	◁	2		
Scolytinae	1	9		
Cryptophagidae	◁	4	3	18
Mordellidae	◁	3	◁	6
Chrysomelidae			1	1
Unkn. Coleoptera	8	60	6	53
COLEOPTERA	**10**	**73**	**10**	**68**
Microlepidoptera	8	38	45	86
LEPIDOPTERA	**8**	**38**	**45**	**86**
ISOPTERA	**8**	**10**	**5**	**6**
Pseudocaeciliidae	5	26	◁	2
PSOCOPTERA	**5**	**26**	**<1**	**2**
Cicadellidae	◁	4	◁	2
Unkn. Auchenorhyncha	◁	7	◁	2
HEMIPTERA: Auchenorhyncha	**<1**	**11**	**<1**	**4**
DIPTERA	**<1**	**1**	**<1**	**5**
UNKNOWN INSECT	**1**	**10**	**<1**	**20**
FEATHER FRAGMENT	**1**	**24**		
UNKNOWN	**2**	**4**		

Table V–2. Measurements (length and width) of a single representative from some of the prey items consumed by Pacific sheath-tailed bats on Aguiguan were recorded to the nearest 0.01 mm. Lengths are measured from tip of head or mandible, whichever extends furthest, to the end of body; lengths in parentheses represent length of head to posterior tip of wings. Widths are measured at the widest point of the insect, including head or body, but not legs. Missing values are marked with hyphens. Asterisks denote the estimated length and width of consumed Ichneumonoidea, based on measurements of a formicid of similar wing size.

Insect	Length in mm	Width in mm
Ichneumonoidea*	3.38 (4.15)	0.73
Formicinae	5.10 (6.07)	1.20
Ponerinae	7.60 (-)	1.63
Curculionidae	2.37	1.20
Scolytinae (large)	2.57	0.95
Scolytinae (small)	1.72	0.85
Cryptophagidae	3.28	1.50
Mordellidae	3.32	1.26
Chrysomelidae	6.07	3.91
Microlepidoptera	2.69 (3.14)	0.94
Isoptera	6.13 (11.87)	1.55
Pseudocaeciliidae	2.75 (3.36)	0.98
Cicadellidae	2.89 (3.76)	1.36

Section VI. Capture, Morphometrics, Museum Specimens, and Other Sampling and Observations of Pacific Sheath-Tailed Bats (*Emballonura semicaudata rotensis*) on Aguiguan, Commonwealth of the Northern Mariana Islands

By Thomas J. O'Shea and Ernest W. Valdez

ABSTRACT

In 2008 we used standard means to capture Pacific sheath-tailed bats in mist nets on Aguiguan while they dispersed or foraged through the forest, but these attempts were largely unsuccessful because the bats were highly maneuverable and easily avoided mist nets on close approach. We successfully captured 12 adult bats and one attached suckling young by using hand nets on bats in flight in native forest, or mist nets set in or near caves used as roosts. Both methods have logistical problems and limitations: in addition to the high maneuverability of the bats precluding use of mist nets in standard configurations, considerable time is required to accrue multiple captures using hand nets, and caves where bats roost are co-occupied by endangered Mariana swiftlets (*Aerodramus bartschi*). We also found that these bats can be very sensitive to initial handling and provide suggestions for capturing and handling bats in future studies. Despite limited numbers of bats captured, forearm measurements show for the first time that there is considerable overlap in body size with the other three subspecies of *Emballonura semicaudata*. In addition to variation in skull morphology, size was previously thought to be another trait that may vary with subspecies. Small wing biopsies were collected from these bats prior to release for some basic preliminary genetic analyses to ascertain genetic diversity of the population on Aguiguan, and the depth of division of this subspecies based on comparison with published data on genetics of *E. semicaudata semicaudata* from Fiji. Although not part of the original proposal, laboratory phases of the genetics analyses are planned for 2009 by the U.S. Geological Survey. Two museum voucher specimens of *Emballonura semicaudata rotensis* were prepared, increasing the number of specimens from the Mariana Islands available in United States museums from two to four. Considerable numbers of specimens of the other subspecies are available worldwide (over 300), and about 22 additional specimens of *Emballonura semicaudata rotensis* from the Marianas Islands (including Guam) are housed in museums in France and Japan. Expanded study of museum specimens and comparative genetic analyses would be needed to fully ascertain the systematic status of the Pacific sheath-tailed bat population in the Mariana Islands. All bats captured at caves by us in 2008 and by others in years past were females, whereas the 4 bats we captured at dusk dispersing along a steep rocky hillside, not near any known colony, were males. This tentatively suggests that perhaps males may form bachelor colonies apart from roosts occupied primarily by females, as is known for other species of Old World species in the genus *Emballonura*. Elaborate social behavior patterns were also suggested by the audible communication sounds produced by bats that were observed foraging and dispersing through native forest and flying into caves. Thermal characteristics of caves on Aguiguan show little variability, and relative humidity is high. Cave temperatures are similar to those used by other tropical emballonurids elsewhere, and do not suggest that the availability of caves with special thermal or humidity characteristics is a limiting factor for Pacific sheath-tailed bats on Aguiguan.

Introduction

There have been few attempts to capture Pacific sheath-tailed bats for scientific research in the Commonwealth of the Northern Mariana Islands or Guam. Lemke (1986) summarized the early literature documenting the taking of two bats for museum voucher specimens on Aguiguan in 1984, 14 bats for taxonomic study on Rota in 1932, and six bat specimens on Guam in 1887, all obtained by unspecified techniques. We were interested in capturing bats on Aguiguan for a variety of purposes, particularly at locations other than roosts, in order to gain additional data pertaining to body size, reproduction, and population sex and age composition. There is very little prior information on these biological attributes of this subspecies. We also sought to (1) obtain biopsy samples that could be used in future genetics research aimed at determining both the genetic diversity and degree of genetic distinctiveness in this population, (2) examine and sample the bats for ectoparasites, (3) sample fresh guano for food habits analysis, and (4) deploy miniature radio transmitters to assess movements and possibly determine the locations of previously unknown roosts. In separate sections of this report we provide results of findings on reproduction (Section VII) and food habits (Section V). Herein, a summary is provided of all other efforts at capturing sheath-tailed bats on Aguiguan and resulting data and observations. We also provide a summary of available museum records for *Emballonura semicaudata* from throughout its range that may be useful to future researchers, and a descriptive summary of the temperature regimes and humidity in some of the caves on Aguiguan. The purpose of describing temperature and humidity regimes of caves was to determine if enough variability in these factors existed to support a hypothesis that numbers of suitable caves might be a limiting factor for this population. Suggestions are offered for future researchers regarding the capture of sheath-tailed bats on Aguiguan and how the risks of capture stress can be minimized.

MATERIALS AND METHODS

Capturing, Handling, and Sampling Bats

In most studies elsewhere, small insectivorous bats are typically captured at roosts or as they fly close to open sources of freshwater in pools and ponds to drink or feed or at constricted "flyways" along edges or through vegetation (Kunz and others 1996). There were no sources of open freshwater on Aguiguan and we did not observe natural flyways that would facilitate capture of bats. Additionally, sampling directly at roosts in this study was complicated by the presence of endangered cave swiftlets at nearly all roost locations and their overlapping times of ingress and egress with bats at dusk; it was also complicated by the potential of creating disturbance to the extent that bats might abandon roosts. Therefore, we initially attempted to capture bats in flight in the forest as they were foraging or dispersing from roosts, or at caves on return flights from foraging after swiftlets had settled in for the night. We risked disturbance by capturing bats within a roost during the day only once at Crevice Cave and once at Guano Cave; both instances took place near the end of the study.

We attempted to capture bats in the following seven ways, which met with only limited or no success. These were: (1) placing mist nets in native forest a short distance below Guano Cave with the intent to capture bats as they returned from foraging, after swiftlets had gone to roost; (2) placing mist nets within the outer opening of East Black Noddy Cave with the intent to capture bats as they returned from foraging (after swiftlets had gone to roost and most bats had emerged); (3) placing mist nets in native forest below the canopy on the first forested terrace above East Black Noddy Cave to capture

them as they foraged or dispersed to forage; (4) placing mist nets in the forest below the canopy at various other locations in native limestone forest to capture them as they foraged; (5) setting a short mist net across the opening of the outer, shallow, chamber of Guano Cave to intercept bats taking refuge after we intentionally disturbed them, a few at a time, during the day in their regular roost within the same cave; (6) similarly using a short mist net and insect sweep net at Crevice Cave during the day; and (7) using a hand insect sweep net and stationary mist nets to capture bats in flight as they dispersed up the hillside among the boulders and cliffs in native forest near Fault Line Cave 1 (Cave 94). Locations and descriptions of caves are provided in Section III of this report.

Captured bats were examined to determine sex and age (adult or volant juvenile based on the degree of closure of the phalangeal epiphyses following Anthony (1988)), and weighed on a Pesola spring balance calibrated in the field (to 0.1 g). Wings, ears, uropatagia, and fur of bats were examined with a 20x magnification visor and fine-point forceps for visible ectoparasites. Prior to field preparation of museum vouchers, specimens were also examined under a 14–60 x stereo-zoom microscope for ectoparasites. We also measured forearm length (to 0.1 mm) with dial calipers, and took small (3 mm diameter) circular punches of the wing membrane in the proximal plagiopatagium using skin biopsy tools after sterilization of the wing with a general antiseptic. Biopsies were immediately placed in 95 percent ethanol in the field and were stored at -80°C after return to the laboratory in Fort Collins, Colo., in late July. Sampling of wing tissues following this methodology is a standard procedure in bat genetics research (e.g. Worthington Wilmer and Barratt 1996, Neubaum and others 2007). Other methods also are standard procedures in bat field research (see Kunz 1988).

Records of Specimens in Museums

Records of *Emballonura semicaudata* in various museum collections around the world were tabulated to provide an estimate of the range of localities and number of specimens that may be available for future studies of the taxonomy of these bats. We tabulated sources from the literature that refer to specimens, and also queried the online database of the Global Biodiversity Information Facility (*http://www.gbif.org/*). The results are probably a minimum number because some major museums do not have searchable databases online. However, there also may be some overlap between specimens referenced in publications and those retrieved online, although we avoided duplicate counting of these when obvious.

Temperature and Humidity of Caves

Relative humidity was sampled manually using a sling psychrometer at about 1.5 m above ground, recording wet and dry bulb temperatures. Temperatures were sampled using Thermocron iButton data loggers (model DS1921, Dallas Semiconductor Corporation) that are factory calibrated at a level of precision of ± 1°C. We programmed the loggers to record temperature hourly. Two data loggers were placed together at each sampling point to insure redundancy in obtaining temperature data in the event one logger failed. When both loggers were functional the average of the two readings was taken (most differences were low and none at caves exceeded 1.5°C, see results). Summary statistics were calculated for each station based on time periods that ran for complete 24 hour cycles to avoid including biases from any particular time of day. For logistic reasons we could not run all loggers simultaneously for the same number of days. Therefore, we also provide and compare summary statistics for all stations between 7 July and 10 July, a period when all loggers were operating simultaneously. In most cases we took temperature readings at the rock surface because these bats roost singly appressed to the

rock walls or ceilings (see Section III of this report). We had access to two roosts that were regularly occupied by bats. No attempts were made to measure temperatures at the precise places where bats roosted because we did not want to risk disturbing them. Data loggers were placed at two locations in Crevice Cave after the bats left to forage at dusk, with the highest about 0.5 m from where the bats roosted. At Guano Cave temperatures were recorded directly below the area used by the roosting bats (see Section III of this report) up to a height of 6 m, about 4–6 m directly below the area occupied by roosting bats. Here, at a more shallow domed area closer to the mouth of Guano Cave, and at Fault Line Cave 1 we took readings at multiple heights above the cave floor by taping data loggers to tall poles we propped against the cave wall. Ambient temperatures for the study period were taken at base camp on the Aguiguan central plateau (coordinates 344803E and 1642496N, WGS 84, UTM zone 55 P). At camp, paired data loggers were suspended on a cord in mottled shade at heights that were 1 m, 2 m, and 3 m above cleared level ground. Gathering of data on temperature and humidity within caves was a preliminary, exploratory attempt to characterize the amount of variability in these attributes. The analysis of the temperature data from these caves is limited to calculation of summary statistics for hourly temperature readings at each station, with a qualitative discussion of their attributes and variability in relation to knowledge about cave environments used by emballonurids and other tropical bats elsewhere.

RESULTS AND DISCUSSION

Capture and Handling

We attempted to capture bats on 13 different dates during our field work on Aguiguan (Table VI–1). We captured 12 adult bats, plus an attached single young of one female (Table VI–2). None of these had any visible ectoparasites. The first three bats captured appeared stunned by handling, and one of these died. In the latter case, the bat was held for about 10 minutes while photographed using a flash, measured, and examined under illumination of a headlamp. This handling routine was also followed in the case of the two stunned bats; however, these two bats were placed in small cloth bags after handling, then later sampled for wing biopsies prior to release. During subsequent captures we immediately placed captured bats individually in small cloth bags with minimal handling or shining of lights before taking measurements or inspecting them closely. When thus handled the bats seemed less stunned and flew readily upon release. It appears that to avoid stunning or death, sheath-tailed bats should not be subject to intense handling immediately following the initial shock of capture. Instead, the bats should be placed individually in cloth bags and left undisturbed and out of the beams of headlamps for 10 minutes or more before resuming handling (10 minutes was the shortest interval measured between placing a bat in a cloth bag and its removal and release without signs of stunning).

Our original intent to apply radio transmitters to Pacific sheath-tailed bats was abandoned in part because of the possible detrimental effects of the lengthy handling (20–40 minutes or more) prior to release that tagging would require. This extra time would be necessary to allow the colostomy cement used for attachment of the tag to dry under the high humidity at Aguiguan. We intended to apply tags primarily to bats captured during foraging to try to locate unknown roosts, but such capture attempts were only minimally successful (see below) until the last few days of our field work when subsequent tracking would be infeasible. However, considering the capture successes on 11–13 July (Tables VI–1 and VI–2) when no mortality and almost no stunning occurred after quickly placing bats in cloth bags and not handling them for at least 10 mins after capture, future researchers should not be discouraged completely from using radio telemetry as a tool to answer specific biological questions about sheath-

tailed bats. All of the bats captured within Guano Cave on 12 July flew readily on release after being held in cloth bags from 10 mins to up to 2 hours (1 case) and then handled for about 5–10 minutes additional time after being held in bags. None flew outside of the cave in the daylight, and all returned to the main roosting chamber. Future researchers can use the approach of initially holding the bats in cloth bags with minimal disturbance prior to handling, and cautiously attempt to attach radio tags to a small number of bats to further determine if radiotagging will be a feasible tool for study. Radiotagging to locate roosts may have other limitations: one tag we activated and placed within Guano Cave below roosting bats had the signal severely attenuated by the rock and was only detectable at the cave mouth.

We observed Pacific sheath-tailed bats easily avoid mist nets on multiple occasions when we tended nets in the forest, and in the rocks along likely dispersal routes and foraging areas. These bats are light and maneuverable fliers. Other species of *Emballonura* elsewhere in the Paleotropics are also known to be highly acrobatic flyers, adapted to foraging in the understory for aerial and foliage-perched insects (Bonaccorso 1998). Pacific sheath-tailed bats on Aguiguan easily detected and avoided nets in open areas, turning to fly over or along the lengths of nets when within 1 m or less of the mesh (some of these observations are listed in Table VI–1). We found that the best method for capturing bats under these circumstances was to use a hand-held insect collecting net, sweeping flying bats into it. This seemed to be especially efficient when bats were flying close to mist nets. Unfortunately, this method is most effective only during the short interval at dusk, such as when we captured bats dispersing in the vicinity of Fault Line Cave 1 (Cave 94). Few bats were observed in this area after the first 30–60 minutes after dark. Using sweep nets will only yield a small number of bats, caught one at a time during a short period each night. Obtaining larger samples will require considerable effort on multiple nights using more than one observer with sweep nets. Use of sweep nets might be suitable, for example, in capturing small numbers of bats for possible radiotagging to attempt to locate unknown roosts or foraging areas. Capturing bats at roosts may be more efficient for obtaining larger sample sizes for assessment of reproduction, sex, age and morphometrics. Attempts in the future will need to devise ways to sample bats at roosts without unintentional capturing of cave swiftlets which occupy the same caves used by the bats. Development of novel methods for capturing these bats should also be considered.

Observations of Feeding and Dispersing Bats, and Sex and Age Composition of Captured Bats

Our attempts to capture bats in the vicinity of Fault Line Cave 1 (Tables VI–1 through VI–3) were based on observations made early in the study during searches for previously unknown roosts along the fault line that is a dominant feature of the area (see Section III of this report). We saw Pacific sheath-tailed bats dispersing uphill and foraging at various heights under the canopy, ranging from about 1.5 to 5 m, while we were standing near openings of inaccessible caves to observe possible emergences of bats at dusk (none emerged). Some of these bats would pause to forage in a characteristic "beat" (in the sense of Vaughan 1959) flying back and forth in elliptical patterns about 20 m long for a few (e.g. 2–4) minutes, including insect pursuit phases heard on echolocation detectors, whereas most seemed to fly directly through the area heading uphill. Multiple bats were seen foraging and dispersing through this area on several nights (Table VI–4). This minor concentration of bats led us to believe that there is an undiscovered roost nearby. This is suggested by the following lines of evidence: (1) The first observations of bats in flight ranged from 1831 to 1850 h, overlapping with the times of initial exits of sheath-tailed bats observed at caves used as roosts elsewhere on the island (Section III of this report); (2) This much activity was not observed at dusk below the forest canopy at a distance of about 90 m above and 115 m inland from the largest known colony at East Black Noddy Cave (see below); (3) Echolocation activity at dusk at a point near the sea cliffs below the fault line was low when monitored with a hand-held bat detector on 2 July, indicating that not many bats had followed

the cliff edges from Black Noddy Cave to enter the forest and fly up the fault line at this point on the island; (4)We captured four bats as they dispersed through the area, and all were adult males (this was the only place males were captured), whereas all 12 bats we captured at Guano Cave and East Black Noddy Cave were adult females, as were 6 and 2 bats captured at Guano Cave in 2003 and1985, respectively (see Lemke 1986). This suggests that the unknown roost may harbor a bachelor colony. Such predominantly male colonies are known for some other insectivorous bat species, as well as in other species of *Emballonura* in the paleotropics (Bonaccorso 1998). All these observations are preliminary, however, and more dedicated field work will be necessary to determine if males form bachelor colonies and if undiscovered roosts exist in the "Fault Line" area (near Caves 66–68, 94, 95, and 101) of Aguiguan. These bats have been observed commuting distances of 5 km during evening dispersal (Wiles and others 1997), so it is also possible that the observations were of bats originating at a more distant site than the immediate area where they were observed. Sex composition of bats using caves could also vary seasonally and with mating or breeding behavior, but this also will require additional detailed field research to determine.

A few other noteworthy observations were made of sheath-tailed bats at dusk or while foraging or dispersing. As noted above, mist nets were set up under the canopy in native forest on the first terrace above East Black Noddy Cave on 1 July (Table VI–1). Although 323 bats were observed exiting the cave that night between 1835 and 1911 h (Section III of this report), only 2 bats were observed in native forest about 115 m away and 90 m above the cave (see coordinates in Table VI–1) during and after the emergence period (Table VI–1). This suggests that the bats using this cave either disperse widely soon after exiting, or do not enter below the canopy until they are farther from the cave.

Interesting observations were made at Pillar Cave at dusk on 21 June and 7 July (see also Section III of this report) when 13 and 21 bats, respectively, entered the cave from elsewhere and used multiple audible communication sounds between 1841 h and 1902 h. No bats were observed roosting in this cave during the day in 2008, but smaller numbers (2–10) had used the cave in 1995, 2002, and 2003 (Section III of this report). These and other observations suggest that these bats use some caves at night for social reasons. We also heard social calls given by some bats dispersing at dusk in the vicinity of Fault Line Cave 1, and by one bat that entered this cave at dusk on 13 July. It entered the cave while emitting single audible chirps with 1–5 sec pauses between chirps, until it exited the cave through a small opening in the ceiling. Audible calls of these bats were high pitched chirps that varied from about 1 to 5 syllables, and to our ears reminded us of directive calls of pallid bats (*Antrozous pallidus*) heard in the deserts of the southwestern United States (e.g. Orr 1954, Brown 1976, O'Shea and Vaughan 1977). Communication calls of sheath-tailed bats were also heard as these bats dispersed and foraged in native forest. On 2 July we tended nets set below the canopy in the forest and noted a few bats dispersing through the area up until 1900 h, but then there was no notable activity of bats in flight. Beginning around 2215 h we began to observe bats flying between the forest floor and canopy producing audible social calls, and once saw three bats flying in a group. On the following night we saw bats in the same area earlier, from 1900–2250 h, heard audible calls, and observed one bat chasing another near but below the canopy. Bat social activity and behavior may change from place to place and from night to night as well as seasonally.

Museum Specimens, Morphometrics, and Subspecies Designations

The female bat that died during handling and a subsequently captured male that appeared stunned were saved as museum study skins and skeletons, with soft tissues (heart, kidney, liver, spleen, lungs, and muscle) preserved in 95 percent ethanol. These two specimens are a small but important addition to the few specimens of this subspecies available in museum collections and have been deposited in the Museum of Southwestern Biology (MSB) at the University of New Mexico,

Albuquerque (MSB 125656 and 125657). Soft tissues are cataloged as NK104278 and 104279. Historic specimens were reviewed by Lemke (1986) and are briefly repeated here. There are six specimens in France's National Museum of Natural History in Paris. These were collected in 1887 on Guam. Four of these six were mentioned by Oustalet (1895, cited by Lemke 1986) but no details about them have been published other than Lemke's (1986) clarifications. In 1932 a total of 14 bats were collected on Rota and formed the basis of the subspecies description by Yamashina (1943). In June 1984, Lemke (1986) collected two females at Guano Cave on Aguiguan, and these specimens are housed at the American Museum of Natural History (AMNH 256514 and 256515). These and the two specimens we collected are the only samples of this subspecies in museum collections in the United States.

Published data on morphometrics of this subspecies are apparently limited to perhaps two bats mentioned by Yamashina (1943) and the two bats collected by Lemke (1986). The forearm lengths and body masses we measured on bats released after capture provide an improved estimate of the range of body sizes known for *Emballonura semicaudata rotensis* based on both the minima and maxima of forearm lengths of adult males and adult females (Table VI–3). It is important to note that the subspecies designations for *E. semicaudata* follow geographic distributions, but also have been morphologically defined on the basis of body size and qualitative features of skull morphology in small numbers of specimens, with a linear series from smallest to largest defined as *E. s. semicaudata-E. s. palauensis-E. s. rotensis-E. s. sulcata* (Koopman 1997, Helgen and Flannery 2002). Our measurements of forearm lengths show that the Aguiguan population has overlap in body size with each of these other three subspecies, making size alone a poor criterion for subspecies definitions.

We updated summaries of museum specimen records for all subspecies of *Emballonura semicaudata* previously provided in part by Lemke (1986), Koopman (1997), and Helgen and Flannery (2002). This new summary is not exhaustive, but suggests that at least 386 specimens from wide areas of the species range are housed in the world's museums (Table VI–5). Subspecies designations made in the past (see reviews in Koopman 1997, Helgen and Flannery 2002) were based on far fewer specimens than are now known to be available, and did not include any genetic analyses. A comprehensive systematic review and new morphometric and genetic analyses would be desirable to improve our understanding of the degree of differentiation among these taxa. The current ranking of *Emballonura semicaudata rotensis* as a Category 3 candidate for listing under the U.S. Endangered Species Act is based largely on its systematic status as a subspecies of a more widely ranging species (U.S. Fish and Wildlife Service 2007).

Wing Biopsies for Genetics Studies

Wing biopsies were obtained from all 12 adult bats captured during this study. These are now archived at -80°C at the USGS laboratory at Fort Collins, Colo., with plans for molecular genetics studies in 2009 by USGS staff at the Rocky Mountain Center for Conservation Genetics and Systematics at the University of Denver. Analysis of these samples will focus on understanding the current level of genetic diversity in the isolated population on Aguiguan, as well as assessing the overall level of differentiation of this population in comparison with another, previously analyzed population of *Emballonura semicaudata semicaudata* on Fiji (Colgan and Soheili 2008). The latter analysis also might help ascertain if a subspecies designation is appropriate or if genetic divisions of sheath-tailed bats in the Mariana Islands are even deeper. To our knowledge, the only genetics research involving Pacific sheath-tailed bats was the comparative analysis of *E. semicaudata* from Fiji with three other full species of *Emballonura* and a fifth emballonurid species, *Mosia nigrescens*, from the southwestern Pacific (Colgan and Soheili 2008). This study examined segments of the mitochondrial DNA genome in *E. semicaudata* from 12 bats sampled at three locations on Fiji. Objectives of the study were aimed at understanding biogeography and evolutionary processes as exemplified by the regional bat fauna rather

than at estimating the genetic diversity or depth of divergences within *E. semicaudata*. However, the development of primers and data on gene sequences deposited in GenBank by Colgan and Soheili (2008) provides basic information that will expedite a preliminary analysis of variation in mtDNA of Pacific sheath-tailed bats on Aguiguan by USGS biologists. Results of the mtDNA studies may be expanded to other segments of the genome depending on preliminary findings.

Cave Temperatures and Humidity

We deployed and recovered 58 functional temperature data loggers at 31 stations: 3 stations in camp, and 28 stations at seven caves (Tables VI–6 and VI–7). Duplicate readings were obtained at 27 of the 31 stations, with four other stations based on single logger records. Agreement on temperature readings between the loggers at each station was good. The distribution of differences between 5,828 hourly readings of paired loggers placed at caves was: 0.0°C (58.9 percent of readings), 0.5°C(30.4 percent), 1.0°C(10.4 percent), 1.5°C(0.2 percent), >1.5°C (0.0 percent).

Temperatures at camp during the recording period averaged about 27°C, fluctuating over a 10°C range from a minimum of 22°C to a maximum of 32.8°C (Table VI–6). Temperatures at stations in all caves were much less variable, ranging from no variation to at most 3°C, with mean temperatures at all stations in caves ranging narrowly from 26°C to 27°C. During the period when all recording stations were operating simultaneously (Table VI–7), minimum and maximum temperatures at all stations within caves varied by 0 to 2°C; temperatures within most caves at depths of 20 m or more and heights of 1–3 m above cave floors were essentially constant, although the inner chamber at Guano Cave fluctuated by about 1°C during this period. Slightly greater fluctuations were recorded over longer periods. Variation with height within caves was also minor in the three caves where this was measured (Guano Cave at two locations, Dangkolo Cave, and Fault Line Cave 1): means at various heights were within 1°C or less, and differed by only fractions of degrees over a height range of 6 m directly below the roosting bats at Guano Cave. Maximum temperatures in all caves over the full recording periods also spanned a narrow range, from 26°C to 28°C (Table VI–6).

Overall there were no obvious major differences in thermal regimes of the caves we sampled regardless of history of occupancy by bats. Given that the manufacturer's specifications for these data loggers are ±1°C , the differences in mean temperatures we observed when computational averages were rounded to the nearest °C were at most 1°C, with rounded means at all stations within caves either 26°C or 27°C (Tables VI–6 and VI–7). Stations within two caves that had no history of occupancy by bats (Dangkolo Cave and Cave 68) averaged 26°C and did not reach the maxima recorded in Guano Cave (most stations in Guano Cave averaged 27°C), the only cave we sampled that was used consistently by bats on every visit from 1984 through 2008 (see Section III in this report). Maxima at stations in Guano cave reached 27°C to 28°C. Crevice Cave, used by a very small number of bats since discovered as a roost in 1995, also averaged 27°C and had maxima of 27°C to 28°C (Tables VI–6 and VI–7). Caves with inconsistent histories of use by bats varied from means of 26°C (Fault Line Cave 1, New Cave 1) to 27°C (Pillar Cave). Perhaps the slightly warmer caves are preferred, but it seems doubtful to us that a 1°C difference between rounded means is biologically meaningful given this limited sampling effort to characterize the thermal environments of these caves. This is even more evident considering the low variability in temperatures in this region and the thermal characteristics of other roosts used by other emballonurids elsewhere (see below).

Although additional sampling of cave temperatures at greater levels of accuracy and using a more systematic series of sampling stations might reveal some subtle differences in thermal environments among caves, subtle differences in cave temperature patterns are unlikely to limit their use as roosts by these bats. Most caves we observed (see Section III of this report) do not appear to have major internal complexities that might create strong heterogeneity in internal microclimates. Cave

temperatures anywhere in the world typically reflect the mean annual surface air temperatures of a region (e.g. Dwyer 1971). There are no long-term temperature data readily available for Aguiguan or neighboring islands, but the mean annual temperatures at three weather stations on Guam are 26.2 °C, 26.9 °C, and 27.7 °C (National Oceanic and Atmospheric Administration 2008), very consistent with the temperatures at the stations we sampled in caves on Aguiguan. Mean annual maxima and minima at these three weather stations on Guam varied between 22.6°C and 30.7 °C, suggesting that even if caves were more complex the ranges of air temperatures that might occur in trapped internal air masses would be small. We did not observe any major air movement within the 41 caves we investigated in 2008 to indicate that highly complex thermal patterns might be found in these caves.

Furthermore, it is thought that the thermal environments of caves used by those species of bats that do not regularly enter torpor are less important than those of caves used by more heterothermic bats at higher latitudes (Dwyer 1971). We believe that Pacific sheath-tailed bats do not enter torpor readily and normally maintain a resting body temperature that is high enough to allow alertness and quick flight under the thermal conditions prevailing in the caves on Aguiguan. Maintenance of homeothermy under normal environmental conditions is also typical for other tropical emballonurids (Bonaccorso 1998). These bats always seemed wary, readily flew within the roost when we approached from outside, did not cluster, and did not become torpid when we placed them in cloth sacks. (Indeed, it is possible that some of the stunning and the death we observed in the first bats we captured may have been due to heat stress from struggling while held in gloves in the high humidity on Aguiguan.) The lack of regular use of torpor has been demonstrated experimentally in some (but not all) species of emballonurids elsewhere in the world (e.g. Genoud and others 1990, Genoud and Bonaccorso 1986). Temperatures of roosts used by two of these other species of emballonurids that do not normally enter torpor also have been measured (although measurements were over shorter periods than some on Aguiguan). Two tree roosts of *Saccopteryx bilineata* (an 8.2 g emballonurid) in Costa Rica fluctuated less than 1 °C daily and had mean temperatures of 26.1 °C and 26.5 °C; temperatures at a third roost ranged 26.4 °C to 27.5 °C at noon (Genoud and Bonaccorso 1986). Temperatures in roosts used by the 5 g emballonurid *Peropteryx macrotis* in caves in Venezuela averaged 27.8 $\pm$1 °C (Genoud and others 1990). Temperatures in six caves used by a third species of small (5.3 g) emballonurid (*Balantiopteryx plicata*) in Mexico averaged 26.7 $\pm$3.1 (SD) °C (Avila-Flores and Medellin 2004). The similarity in temperatures of roosts used by these other emballonurids with those we measured in the Aguiguan caves is noteworthy, and is also suggestive that the thermal characteristics of caves on Aguiguan do not limit their use by Pacific sheath-tailed bats.

Relative humidity in caves was high. We recorded relative humidity at about 1.5 m height above the cave floor in five caves. Three were identical at 92 percent, whereas New Cave 1 and Dangkolo Cave were slightly more humid at 96 percent. The latter cave has no history of bat occupancy and was the only cave we entered that had occasional dripping water. Relative humidity taken at various times and locations outside of caves were generally lower, ranging from 74 percent to 92 percent (Table VI–8). The role of humidity in use of caves by bats on Aguiguan, if any, remains to be studied. Humidity was not measured in a large number of caves, and given the lack of access to pools of freshwater for drinking, roost environments that minimize evaporative water loss may be of importance to these bats. However, given the uniformly high humidity in the caves that were measured it seems unlikely that variability in humidity among caves will be great enough to be a factor limiting sheath-tailed bat populations on Aguiguan. The humidity we observed was also within the ranges in caves utilized as roosts by many other bats in the tropics (e.g. 70–98 percent in 12 species summarized by McNab 1969).

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REFERENCES CITED

Anthony, E.L.P., 1988, Age determination in bats, *in* Kunz, T.H., ed., Ecological and behavioral methods for the study of bats: Washington, D.C., Smithsonian Institution Press, p. 47–58.

Avila-Flores, R., and Medellin, R., 2004, Ecological, taxonomic, and physiological correlates of cave use by Mexican bats: Journal of Mammalogy, vol. 85, p. 675-687.

Bonaccorso, F. J., 1998, Bats of Papua New Guinea: Washington, D.C., Conservation International, 489 p.

Brown, P., 1976, Vocal communication in the pallid bat, Antrozous pallidus: Zeitschrift für Tierpsychologie, vol. 41, p. 34-54.

Bruner, P. L., and Pratt, H. D., 1979, Notes on the status and natural history of Micronesian bats: 'Elepaio, vol. 40, p.1-4.

Colgan, D. J., and Soheili, S., 2008, Evolutionary lineages in *Emballonura* and *Mosia* bats (Mammalia: Microchiroptera) from the Southwestern Pacific: Pacific Science, vol. 62, p. 219-232.

Dobson, G. E., 1878, Catalogue of the Chiroptera in the British Museum: London, British Museum (Natural History), 567 p.

Dwyer, P. D., 1971, Temperature regulation and cave-dwelling in bats: an evolutionary perspective: Mammalia, vol. 35, p. 424-455.

Flannery, T., 1995, Mammals of the South-West Pacific and Moluccan Islands: Ithaca, New York, Cornell University Press, 464 p.

Genoud, M., and Bonaccorso, F. J., 1986, Temperature regulation, rate of metabolism, and roost temperature in the greater white-lined bat *Saccopteryx bilineata* (Emballonuridae): Physiological Zoology, vol. 59, p. 49-54.

Genoud, M., Bonaccorso, F. J., and Arends, A., 1990, Rate of metabolism and temperature regulation in two small tropical insectivorous bats (*Peropteryx macrotis* and *Natalus tumidirostris*): Comparative Biochemistry and Physiology Part A, vol. 97, p. 229-234.

Griffiths, T. A., K. F. Koopman, and A. Starrett, 1991, The systematic relationship of Emballonura nigrescens to other species of Emballonura and to Coleura (Chiroptera: Emballonuridae): American Museum Novitates, no. 2996, p. 1-16.

Helgen, K. M., and Flannery, T. F., 2002, Distribution of the endangered Pacific sheath-tailed bat *Emballonura semicaudata*: Australian Mammalogy, vol. 24, p. 209-212.

Johnson, D. H., 1962, IV. A. Rodents and other Micronesian mammals collected, *in* Storer, T. I., ed., Pacific island rat ecology: Honolulu, Hawaii, Bernice P. Bishop Museum Bulletin, vol. 225, p. 21-38.

Koopman, K. F., 1997, The subspecies of *Emballonura semicaudata* (Chiroptera: Emballonuridae): Journal of Mammalogy, vol. 78, p. 358-360.

Kunz, T. H., ed., 1988, Ecological and behavioral methods for the study of bats: Washington, D.C., Smithsonian Institution Press.

Kunz, T.H., Tidemann, C. R., and Richards, G. C., 1996, Small volant mammals, *in* Wilson, D. E., Cole, F. R., Nichols, J. S., Rudran, R., and Foster, M. S., eds., Measuring and monitoring biological diversity—Standard methods for mammals: Washington, D.C., Smithsonian Institution Press, p. 122–146.

Lemke, T. O. 1986. Distribution and status of the sheath-tailed bat (*Emballonura semicaudata*) in the Mariana Islands: Journal of Mammalogy, vol. 67, p. 743-746.

McNab, B. K., 1969, The economics of temperature regulation in Neotropical bats: Comparative Biochemistry and Physiology, vol. 31, p. 227-268.

Neubaum, M. A., Douglas, M. R., Douglas, M. E., and O'Shea, T. J., 2007, Molecular ecology of the big brown bat (*Eptesicus fuscus*): genetic and natural history variation in a hybrid zone: Journal of Mammalogy, vol. 88, p. 1230–1238.

National Oceanic and Atmospheric Administration, 2008, Monthly station normals of temperature, precipitation, and heating and cooling degree days 1971-2000, 91 Pacific Islands: Asheville, North Carolina, National Climatic Data Center, Climatography of the United States No. 81, 11 p.

Orr, R. T., 1954, The natural history of the pallid bat, *Antrozous pallidus* (Le Conte): Proceedings of the California Academy of Sciences, vol. 28, p. 165-264.

O'Shea, T. J., and Vaughan, T. A., 1977, Nocturnal and seasonal activities of the pallid bat, *Antrozous pallidus*: Journal of Mammalogy, vol. 58, p.269-284.

Oustalet, M. E., 1895, Les mammiféres et les oiseaux des Iles Mariannes. Nouvelles Archives du Museum d'Histoire Naturelle Paris Série 3, vol. 7, p.141-228. (Cited by Lemke 1986).

Sanborn, C. C., 1949, Notes on the Caroline sheath-tailed bat (*Emballonura sulcata* Miller): Natural History Miscellanea, The Chicago Academy of Sciences, vol. 48, p. 1-2.

Tate, G. H. H., 1934, Bats from the Pacific Islands, including a new fruit bat from Guam : American Museum Novitates, vol. 713, p. 1-3.

Tate, G.H.H., and Archbold, R., 1939, Results of the Archbold Expeditions. No. 23, a revision of the genus Emballonura (Chiroptera): American Museum Novitates, vol. 1035, p. 1-14.

U.S. Fish and Wildlife Service, 2007, 50 CFR Part 17; Endangered and Threatened Wildlife and Plants; Review of Native Species That Are Candidates for Listing as Endangered or Threatened; Annual Notice of Findings on Resubmitted Petitions; Annual Description of Progress on Listing Actions; Proposed Rule. Federal Register, Code of Federal Regulations (December 6, 2007)72 (234): 69033-69106.

Vaughan, T. A., 1959, Functional morphology of three bats: Eumops, Myotis, Macrotus: University of Kansas Publications, Museum of Natural History, vol. 12, 153 p.

Wiles, G. J., Engbring, J., and Otobed, D., 1997, Abundance, biology, and human exploitation of bats in the Palau Islands: Journal of Zoology (London), vol. 241, p. 203-227.

Worthington Wilmer, J., and Barratt, E., 1996, A non-lethal method of tissue sampling for genetic studies of chiropterans: Bat Research News, vol. 37, p. 1–3.

Yamashina, M. Y., 1943, On a new subspecies of *Emballonura semicaudata* from the Mariana Islands: Bulletin of the Biogeographical Society of Japan, vol. 13, p. 99-100. (In Japanese, cited by Lemke 1986).

Yamashina, M. Y., 1932, New species of bat from the Japanese South Pacific mandated islands: Transactions of the Natural History Society of Formosa, vol. 22, p. 240-241. (In Japanese, cited by Lemke 1986).

Table VI–1. Efforts made to capture Pacific sheath-tailed bats on Aguiguan in June and July 2008, with a summary of results and observations. Locations are in Universal Transverse Mercator (UTM), zone 55 P, WGS 84 datum; elevations and estimated location errors are available on request. Time is MPT, Northern Mariana Islands time zone.

Date	Location	Number and Lengths of Nets Deployed, Other Methods	Time	Results
26 June	Vicinity of Fault Line Cave 1 (=Cave 94, across gaps in boulders and cliffs, 344804 E, 1643215 N.	1–6 m, 1–9 m; bottoms 2.5–3.0 m above ground	1800–2200	In the dusk from 1846 to 1913 we watched 14 bats fly to within 1–2 m of the net and turn to the side, and 8 fly directly to net and then up and over the top. No captures.
28 June	Slope about 40 m below Guano Cave (= Cave 2) 343039E, 1642089N ; mouth of Guano Cave	2–12 m nets in forest on slope below cave; 1–2.6 m net at mouth of Guano Cave. Intent to capture bats returning rather than bats emerging	1830–2200	No bats captured. Some bats returned to cave but likely entered above the net,
29 June	Vicinity of Fault Line Cave 1 (=Cave 94), across gaps in boulders and cliffs, 344804 E, 1643215 N; in forest on terrace ca. 100 m inland from Cave 94	1–9 m across gap, 1–18 m in forest. Insect sweep net as bats dispersed at dusk	1800–2200	Watched two bats circle, go over, and fly parallel to 9 m net within 1 m of mesh. Captured one male in sweep net. Male appeared "stunned" during 20 mins of handling. Put it on a cliff wall about 2.5 m above ground, where it remained for 30 mins, then flew off after disturbed by light from headlamp.
30 June	Slope about 40 m below Guano Cave (= Cave 2), 343039E, 1642089N	1–12 m in forest on slope below cave	1815–2015	One adult female captured in mist net. Held in hand for 10 mins while measuring, photographing. Bat died.
1 July	Forest on terrace above East Black Noddy Cave (= Cave 76), 343939 E, 1642819 N	1–12 m, 1–18 m in "v" under canopy, in open flat section of younger forest. Bottoms 1.5 m above ground	1800–2215	No bats seen approaching the nets at dusk. Only 2 bats seen under canopy, both 1840–1850. One heard at 1907, no further bat activity noticed.
1 July	East Black Noddy Cave (=Cave 76), 344004E, 1642923N	1–9 m across mouth of the smaller of the two caves. Bottom 1 m above ground	1950–2230	Bats were observed exiting the cave, and circled near the rim of the cliff, then dispersed. A bat was captured exiting the cave, after mass exodus, but escaped from net. A second bat, a pregnant female, was captured. It appeared stunned after handling for 13 mins, was placed on a rock wall but did not fly off until 20 mins later.
2–3 July	Forest on terrace below Fault Line Cave 1 area, 344767 E,	1–9 m, 3–12 m, 1–18 m. Bottoms 2 m above ground	1800–0015	Bats were observed foraging in the area, and on multiple occasions we watched them fly within 1 m of a net and

	1643240 N			turn. No bats captured.
3–4 July	Forest on terrace below Fault Line Cave 1 area, 344767 E, 1643240 N	2–9 m, 3–12 m, 2–18 m. Bottoms 2 m above ground.	1800–0015	Bats were observed foraging in the area, and on multiple occasions we watched them fly within 1 m of a net and turn. No bats captured.
5 July	East Black Noddy Cave (=Cave 76), 344004E, 1642923N, small opening	1–9 m across mouth of the smaller of the two caves. Bottom 1 m above ground	2030–2230	Bats observed exiting cave. Audible calls heard from bats outside of cave, after exiting. These calls were similar to audible coaxing calls made by other species of bats elsewhere (e.g., *Antrozous pallidus*). Two bats were captured at the same time, with one capture of a bat entering the cave and the other exiting.
6 July	Vicinity of Cave 94, in boulders and cliffs above fault line, 344804 E, 1643215 N.	Insect sweep net	1800– 1910	A minimum of 17 bats dispersed past and overhead, but none was caught in the insect sweep net. No captures.
10 July	Crevice Cave (= Cave 17), 0343541 E, 1641526 N	1–2.6 m net across opening during day, sweep net inside	Day	Two bats present, evaded capture.
11 July	Vicinity of Cave 94, in boulders and cliffs above fault line, 344804 E, 1643215 N	1– 6 m net 2–5 m above rocks; insect sweep net	1800–2000	Multiple bats dispersed past and overhead at dusk, one male caught in the insect sweep net. Placed in bag, held for 30 min and handled for 10 min additional, flew readily on release
12 July	Guano Cave (= Cave 2), 343031 E, 1642084 N	2–2.6 m nets on 3 m poles across opening to second chamber that bats use as a refuge when disturbed during the day. Disturbance was shining light until 1–2 bats fled the main chamber, repeated at 15–30 min intervals	1400–1630	Five bats (including one attached young) captured in three episodes. All immediately placed in cloth bags and held for 10–30 mins, female with young for 2 hrs. None was stunned or unable to fly off readily on release.
13 July	Vicinity of fault Line Cave 1 (=Cave 94), in boulders and cliffs above fault line, 344804 E, 1643215 N	1– 6 m net 2–5 m above rocks; sweep net	1800–2000	Multiple bats dispersed past and overhead at dusk. One male caught in mist net, stunned, was sacrificed as voucher specimen. Second male caught in the insect sweep net as it veered away from the mist net. Placed in bag, held and handled over 30 min period, flew readily on release

Table VI–2 . Records of sheath-tailed bats captured at Aguiguan, June-July 2008. See Table VI–1 for details on locations and methods of capture, Table VII–1 for information about reproductive status. Abbreviations: A = adult, F= female, M= male, ND = not determined, Y = young.

Field ID	Date	General Location	Age & Sex	Forearm, Body Mass	Samples Taken	Comments
STB-1	29 June	Vicinity of Cave 94	A M	43.5 mm, ND	Wing biopsy	No visible ectoparasites. Held 21 mins without placing in bag, appeared stunned afterwards. Placed on cliff face where it remained still for 30 mins before flying off.
STB-2	30 June	Vicinity of Cave 2	A F	45.0 mm, 7.6 g	Wing biopsy	No visible ectoparasites. Held in hand 10 mins while measuring, photographing, without placing in bag. Bat died. Voucher specimen, U.S. Geological Survey Collection, Museum of Southwestern Biology, study skin and skeleton (catalog no. MSB125656), organs (heart, kidney, liver, spleen, lungs, and muscle; catalog no. NK104278) in 95 percent ethanol.
STB-3	1 July	Cave 76	A F	45.3 mm, 7.7 g	Wing biopsy,	No visible ectoparasites. Bat appeared stunned after handling for 13 mins without holding in bag, was placed on a rock wall but did not fly off until 20 mins later.
STB-4	5 July	Cave 76	A F	46.1 mm, 6.5 g	Wing biopsy, 1 guano pellet	No visible ectoparasites.
STB-5	5 July	Cave 76	A F	45.5 mm, 8.0 g	Wing biopsy, 3 guano pellets	No visible ectoparasites.
STB-6	11 July	Vicinity of Cave 94	A M	45.9 mm, 5.8 g	Wing biopsy	No visible ectoparasites. Held in bag about 30 mins, handled 10 mins thereafter. Flew readily on release.
STB-7	12 July	Cave 2	A F	45.3 mm, 6.5 g	Wing biopsy	No visible ectoparasites. Held in cloth bag for about 30 mins, handled 10 mins, placed back in bag 90 min. Flew readily on release.
STB-8	12 July	Cave 2	Y F	[24.4 mm, 2.3 g]	None	Attached nursing young of STB-7.
STB-9	12 July	Cave 2	A F	43.8 mm, 5.8 g	Wing biopsy	No visible ectoparasites. Held in cloth bag about 15 mins, 5 mins handling. Flew readily on release.
STB-10	12 July	Cave 2	A F	47.0 mm, 7.0 g	Wing biopsy	No visible ectoparasites. Held in cloth bag about 25 mins, 5 mins handling. Flew readily on release.
STB-11	12 July	Cave 2	A F	46.4 mm, 5.8 g	Wing biopsy	No visible ectoparasites. Held for 10 mins in cloth bag, about 5 mins for handling. Flew readily on release.
STB-12	13 July	Vicinity of Cave 94	A M	46.0 mm, 5.7 g	Wing biopsy	No visible ectoparasites. Stunned after 10 mins of handling.

							Voucher specimen, U.S. Geological Survey Collection, Musenm of Southwestern Biology, study skin and skeleton (catalog no. MSB125657), organs (heart, kidney, liver, spleen, lungs, and muscle; catalog no. NK104279) in 95 percent ethanol
STB-13	13 July	Vicinity of Cave 94	A	M	45.5 mm, 5.1 g	Wing biopsy	No visible ectoparasites. Kept in cloth bag for about 25 mins, handled about 5 mins. Flew readily on release.

Table VI–3. Data on forearm lengths and body mass of *Emballonura semicaudata* from throughout the species distribution in comparison with measurements of bats from Aguiguan. Measurements given are ranges or individual measurements. NR =not reported. Numbers in parentheses are sample sizes if different from sample description. Subspecies names and distribution follow Koopman (1997).

Sample	Body Mass (range in g)	Forearm Length (range in mm)	Source
E. semicaudata rotensis: 8 adult females, Aguiguan, 2008	5.8–8.0	43.8–47.0	This study
E. semicaudata rotensis: 4 adult males, Aguiguan, 2008	5.1–5.8 (3)	43.5–46.0 (4)	This study
E. semicaudata rotensis: 6 adult females, Aguiguan, 2003	NR	44.5–47.3	Esselstyn (unpublished)
E. semicaudata rotensis: 2 adult females, Aguiguan, 1984	5–7	44–45	Lemke (1986)
E. semicaudata rotensis: 1 male, 1 female	NR	45, 45	Yamashina (1943); T. Yamasaki (Yamashina Institute for Ornithology, personal commun., 2008)
E. semicaudata semicaudata: 3 adult males, Fiji	5.5–5.5	44.4–45.5	Flannery (1995)
E. semicaudata semicaudata : 5 adult females, Fiji	6.5–8.0	45.3–47.9	Flannery (1995)
E. semicaudata semicaudata: type specimen	NR	41.0	Tate and Archbold (1939)
E. semicaudata palauensis: 4 males, 7 females	NR	39–44.5	Tate and Archbold (1939)
E. semicaudata palauensis: 2 females	NR	42–43	Johnson (1962)
Emballonura semicaudata sulcata: 8 females, 1 male, Pohnpei	NR	48.5–52.5	Sanborn (1949)
Emballonura semicaudata sulcata: 4 adult males, Pohnpei and Chuuk	4, 4 (2)	46–49.5	Tate (1934), Tate and Archbold (1939), Bruner and Pratt (1979)
Emballonura semicaudata sulcata: 4 adult females, Pohnpei and Chuuk	4–6 (3)	43–54	Bruner and Pratt (1979)
Emballonura semicaudata sulcata: 3 adult males, Pohnpei	7.0–7.5	49–51	Johnson (1962)
E. semicaudata sulcata: 11 adults, sex or location unspecified	NR	48.4–52.5	Literature summary in Lemke (1986)

Table VI–4. Observations of bats dispersing in the Fault Line area in the vicinity of Cave 66 and Cave 94, during June and July 2008. Observer initials in parentheses: EM, Elvin Masga; EWV, Ernest W. Valdez; GC, Greg Camacho; GJW, Gary J. Wiles; PMG, P. Marcos Gorresen; TJO, Thomas J. O'Shea.

Location	Date	Time 1st Bat Seen	Summary of Observations
Near Cave 66 344840, 1643270	24 June	1849	1849–1913 (TJO): 17 bats observed flying through the forest below canopy, most uphill but 3 noted coming downhill. Heard ultrasonic calls on bat detector in isolation 39 times, and multiple times while bats observed flying back and forth in foraging beats (including feeding "buzzes" or pursuit calls). On at least 5 instances bats were feeding rather than flying directly through the area. Audible vocalizations (social calls) were heard on 3 occasions. Most feeding seemed to be at least 3 m above ground and over the fault line fissure. 1914– 1945 (TJO): 1 bat seen at 1935, heard echolocation calls on bat detector in isolation 9 times, 1 seen foraging 1938–1942 in headlight beam over an elliptical foraging beat with accompanying feeding buzzes on bat detector. Distinctive audible vocalizations heard on 3 occasions.
Near Cave 94, near 344804 E, 1643215 N	24 June	--	1850–1900 (EM): 47 bats observed flying uphill below canopy at this station
Near Cave 94, near 344804 E, 1643215 N	26 June	1841	1841–1913 (GJW): Counted 25–30 bats (PMG nearby saw 43) coming up hillside from lower terrace to the northwest. None seen emerging from caves. Most traveled uphill, all under canopy, early bats easily visible in fading light. Some fly 2–3 feet above ground, some stop to circle and forage briefly, continue uphill. Collared kingfishers still active. PMG counts highest at 1900–1910. GC reported seeing a few split off and fly east low over the top of the canopy. 1846–1913 (TJO): 27 bats observed flying uphill below canopy, did not use bat detector.
Near Cave 94, near 344804 E, 1643215 N	29 June	1837	1837–1842 (TJO): 2 bats dispersed uphill below canopy, 1 made several audible calls. Observation period limited because of bat capture.
Near Cave 94, near 344804 E, 1643215 N	6 July	1850	1850–1908 (TJO): 12 bats observed flying uphill below canopy, 6 ultrasonic calls on bat detector, heard >6 audible calls. Two fed together in the same elliptical foraging beat for two minutes 1857–1859; another two feeding separately at 1902–1903, feeding buzzes on bat detector. Light drizzle may have affected activity.
Near Cave 94, near 344804 E, 1643215 N	11 July	1831	1831–1853 (TJO, EWV): 18 bats observed flying uphill below canopy, 10 ultrasonic calls on bat detector, heard >30 audible calls. One bat foraged in an elliptical beat below the canopy and 4–8 m above ground for 1–2 mins. Observation period limited because of bat capture at 1853.
Near Cave 94, near 344804 E, 1643215 N	13 July	1836	1836–1853 (TJO): 7 bats observed flying uphill below canopy, did not use bat detector. Observation period limited because of bat capture at 1853.

Table VI–5. Summary of records of standard museum specimens (study skins and skulls, or fluid preserved whole bats) of *Emballonura semicaudata*. This summary is based primarily on published records available to us through 2008 and queries of the online database maintained by the Global Biodiversity Information Facility (GBIF, *http://www.gbif.org/*). It is not exhaustive, but probably includes most of the specimens housed in museum collections. Slight overlap may occur among sources.

Collecting Locality	Number of Specimens	Museum Collection	Source of Information
Aguiguan	2	American Museum of Natural History	Lemke (1986)
Aguiguan	2	Museum of Southwestern Biology	This study
American Samoa	1	Museum of Vertebrate Zoology, University of California Berkeley	GBIF
American Samoa	24	Museum of Vertebrate Zoology, University of California Berkeley	Helgen and Flannery (2002)
American Samoa	2	Bernice Pauahi Bishop Museum	GBIF
American Samoa	31	United States National Museum of Natural History	GBIF
Fiji	47	Harvard University Museum of Comparative Zoology	GBIF
Fiji	1	Los Angeles County Museum	GBIF
Fiji	9	United States National Museum of Natural History	GBIF
Fiji	2	Australian Museum, Sydney	Helgen and Flannery (2002)
Fiji	8	Australian Museum, Sydney	Colgan and Soheili (2008)
Fiji	15	Institut vor Taxonomie, Amsterdam	Helgen and Flannery (2002)
Fiji	1	Academy of Natural Sciences, Philadelphia	Helgen and Flannery (2002)
Guam	6	Museum National d'Histoire Naturelle, Paris	Lemke (1986)
Palau	68	United States National Museum of Natural History	GBIF
Palau	16	Yamashina Institute for Ornithology, Chiba, Japan	Yamashina (1932) cited by Lemke (1986); T. Yamasaki (personal commun., 2008)
Pohnpei	1	Florida Museum of Natural History	GBIF
Pohnpei	2	Bernice Pauahi Bishop Museum	GBIF
Pohnpei	7	California Academy of Sciences	GBIF
Pohnpei	21	Field Museum of Natural History	GBIF
Pohnpei	5	United States National Museum of Natural History	GBIF
Rota, CNMI	14	Yamashina Institute for Ornithology, Chiba, Japan	Yamashina (1943), T. Yamasaki (personal commun., 2008)
Samoa	7	Harvard University Museum of Comparative Zoology	GBIF
Samoa	16	Bernice Pauahi Bishop Museum	GBIF
Samoa	1	Bell Museum of Natural History	Helgen and Flannery (2002)
Tonga	2	Burke Museum, University of Washington	GBIF

Tonga	3	Los Angeles County Museum	GBIF
Tonga	7	United States National Museum of Natural History	GBIF
Tonga	1	Western Australia Museum	Helgen and Flannery (2002)
Truk	3	Louisiana State University Museum of Natural Science	GBIF
Truk and Pohnpei	32	Yamashina Institute for Ornithology, Chiba, Japan	Yamashina (1943) cited by Lemke (1986); T. Yamasaki (personal commun., 2008)
Vanuatu	1	Harvard University Museum of Comparative Zoology	GBIF; see also Helgen and Flannery (2002)
Vanuatu	1	British Museum of Natural History	Dobson (1878) cited in Koopman (1997)
Unspecified	19	Museum fur Naturkunde, Berlin	GBIF
Unspecified	1	Swedish Museum of Natural History	GBIF
Unspecified	1	Los Angeles County Museum	GBIF
Pohnpei	Unspecified	American Museum of Natural History	Koopman (1997)
Unspecified	6	American Museum of Natural History	Griffiths and others (1991)

Table VI–6. Summary statistics for temperature data (°C) from data logger sampling stations on Aguiguan, 2008.

Station	Period	Number of Hourly Readings	Computational Mean (95 percent CI)	Rounded Mean	Rang e	Min	Max
Camp							
Camp 1 m above ground	6/26, 1430 to 7/13, 1330	408	26.8 (26.55, 26.99)	27	9.7	22.3	32
Camp 2 m above ground	6/27, 1430 to 7/13, 1330	408	27.0 (26.77, 27.25)	27	10.0	22	32
Camp 3 m above ground	6/26, 1430 to 7/13, 1330	408	27.1 (26.90, 27.37)	27	10.5	22.3	32.8
Guano Cave							
Guano Cave entrance, 2 m high	6/30, 1900 to 7/11 1800	264	27.05 (27.01, 27.09)	27	1.3	26.3	27.5
Guano Cave 10 m depth, 2 m high	7/7, 1700 to 7/11 1600	96	26.58 (26.55, 26.60	27	0.5	26.5	27.0
Guano Cave inner chamber below bats, 1 m high	6/25, 1500 to 7/12, 1400	408	26.75 (26.71, 26.79)	27	2.5	25.3	27.8
Guano Cave inner chamber below bats, 2 m high	6/25, 1500 to 7/12, 1400	408	26.84 (26.79, 26.88)	27	3.0	25	28
Guano Cave inner chamber below bats, 6 m high	6/25, 1500 to 7/12, 1400	408	26.48 (26.44, 26.52)	26	2.5	25	27.5
Guano cave outer chamber 2 m high	7/7, 1800 to 7/11, 1700	96	26.26 (26.17, 26.34)	26	1.8	25.3	27
Guano cave outer chamber 3 m high	7/7, 1800 to 7/11, 1700	96	26.18 (26.10, 26.27	26	2	25	27
Guano cave outer chamber 4 m high	7/7, 1700 to 7/11, 1600	96	26.59 (26.53, 26.66)	27	1.5	26	27.5
Guano cave outer chamber 5 m high	7/7, 1700 to 7/11, 1600	96	27.09 (27.03, 27.15)	27	1	26.5	27.5
Guano cave outer chamber 6 m high	7/7, 1800 to 7/11, 1700	96	27.16 (27.12, 27.19)	27	0.75	26.75	27.5
Crevice Cave							
Crevice Cave at entrance, 2 m high	6/27, 1800 to 7/9, 1700	288	26.86 (26.81, 26.91	27	2.5	25.5	28
Crevice Cave at 3 m depth, 3 m high	6/27, 1800 to 7/9, 1700	288	26.60 (26.57, 26.63)	27	1.5	25.75	27.25
Crevice Cave at 5 m depth, 4 m high	6/27, 1800 to 7/9, 1700	288	27.12 (27.10, 27.14)	27	0.75	26.75	27.5

Fault Line Cave 1							
Fault Line Cave at entrance, 2 m high	6/30, 1700 to 7/13, 1600	312	26.11 (26.05, 26.18)	26	2.5	25	27.5
Fault Line Cave 1, 8 m depth, 1 m high	6/30, 1700 to 7/13, 1600	312	26.05 (25.98, 26.11)	26	3.0	24.5	27.5
Fault Line Cave 1, 8 m depth, 2 m high	6/30, 1700 to 7/13, 1600	312	26.20 (26.14, 26.26)	26	2.75	24.5	27.25
Fault Line Cave 1, 8 m depth, 3 m high	6/30, 1700 to 7/13, 1600	312	26.45 (26.39, 26.51)	26	2.5	25	27.5
New Cave 1							
New Cave 1, 10 m deep, 6 m above lower chamber	7/5, 1800 to 7/9, 1700	96	25.80 (25.75, 25.85)	26	1	25.25	26.25
Pillar Cave							
Pillar Cave at entrance, 2 m high	7/7, 1900 to 7/11, 1800	96	27.32 (27.23, 27.40)	27	1.5	26.5	28
Pillar Cave, 35 m deep, 2 m high	7/7, 2000 to 7/11, 1900	96	27	27	0	27	27
Dangkolo Cave							
Dangkolo Cave entrance 2 m high	6/27, 1700 to 7/9, 1600	288	27.14 (27.09, 27.18)	27	1.75	26.25	28
Dangkolo Cave 10 m depth, 1 m high	6/27, 1700 to 7/9, 1600	288	26.22 (26.21, 26.23)	26	0.5	26	26.5
Dangkolo Cave 20 m depth, 1 m high	6/27, 1700 to 7/9, 1600	288	26	26	0	26	26
Dangkolo Cave 45 m depth, 1 m high	6/27, 1700 to 7/9, 1600	288	26.5	26	0	26	26
Dangkolo Cave 45 m depth, 2 m high	6/27, 1700 to 7/9, 1600	288	26.5	26	0.25	26.25	26.5
Dangkolo Cave 45 m depth, 3 m high	6/27, 1700 to 7/9, 1600	288	26.5	26	0	26.5	26.5
Cave 68							
Cave 68, rear (uphill) chamber, 5 m above ground, 3 m below opening	7/3, 1700 to 7/13, 1600	240	25.72 (25.66, 25.78)	26	2	24.75	26.75
Cave 68, 18 m depth from lower entrance, 2 m high	7/3, 1700 to 7/13, 1600	240	26.23 (26.18, 26.27)	26	1.25	25.5	26.75

Table VI–7. Summary statistics for temperature data (°C) from data logger sampling stations on Aguiguan, 2008, during the period from 7 July (1900 h) to 10 July (1500 h) when data were recorded simultaneously at all locations. For each station N =68 hourly readings.

Station	Computational Mean (95 percent CI)	Rounded Mean	Range	Minimum	Maximum
Camp 1 m above ground	25.5 (25.14, 25.83)	26	6	23	29
Camp 2 m above ground	25.6 (25.26, 25.99)	26	6.5	23	29.5
Camp 3 m above ground	25.8 (25.41, 26.17)	26	7	23.3	30.3
Guano Cave					
Guano Cave entrance	26.8 (26.74, 26.90)	27	1.3	26.3	27.5
Guano Cave 10 m depth, 2 m high	26.60 (26.56, 26.63)	27	0.5	26.5	27.0
Guano Cave inner chamber below bats, 1 m high	26.57 (26.49, 26.65)	27	1.3	25.8	27.0
Guano Cave inner chamber below bats, 2 m high	26.63 (26.55, 26.70)	27	1	26	27
Guano Cave inner chamber below bats, 6 m high	26.25 (26.18, 26.32)	26	1	25.8	26.8
Guano cave outer chamber, 2 m high	26.24 (26.14, 26.35)	26	1.7	25.3	27
Guano cave outer chamber, 3 m high	26.17 (26.06, 26.27)	26	2	25	27
Guano cave outer chamber, 4 m high	26.58 (26.51, 26.66)	27	1	26	27
Guano cave outer chamber, 5 m high	27.09 (27.01, 27.17)	27	1	26.5	27.5
Guano cave outer chamber, 6 m high	27.19 (27.14, 27.23)	27	0.75	26.75	27.5
Crevice Cave					
Crevice Cave at entrance, 2 m high	26.69 (26.55, 26.84)	27	2	25.75	27.75
Crevice cave at 3 m depth, 3 m high	26.42 (26.32, 26.53)	26	21.5	25.75	27.25
Crevice Cave at 5 m depth, 4 m high	27.00 (26.95, 27.05)	27	0.5	26.75	27.25
Fault Line Cave 1					
Fault Line Cave at entrance, 2 m high	25.78 (25.68, 25.88)	26	1.5	25	26.5
Fault Line Cave 1, 8 m depth, 1 m high	25.89 (25.77, 26.01)	26	1.5	25	26.5
Fault Line Cave 1, 8 m depth, 2 m high	25.99 (25.89, 26.09)	26	1.5	25	26.5
Fault Line Cave 1, 8 m	26.29 (26.20, 26.38)	26	1.5	25.5	27

depth, 3 m high					
New Cave 1					
New Cave 1, 10 m deep, 6 m above lower chamber	25.71 (25.64, 25.78)	26	1	25.25	26.25
Pillar Cave					
Pillar Cave at entrance, 2 m high	27.35 (27.23, 27.46)	27	1.5	26.5	28
Pillar Cave, 35 m deep, 2 m high	27	27	0	27	27
Dangkolo Cave					
Dangkolo Cave entrance, 2 m high	26.74 (26.66, 26.83)	27	1.5	26	27.5
Dangkolo Cave 10 m depth, 1 m high	26.09 (26.06, 26.12)	26	0.5	25.75	26.25
Dangkolo Cave 20 m depth, 1 m high	26	26	0	26	26
Dangkolo Cave 45 m depth, 1 m high	26.5	26	0	26.5	26.5
Dangkolo Cave 45 m depth, 2 m high	26.45 (26.42, 26.47)	26	0.25	26.25	26.5
Dangkolo Cave 45 m depth, 3 m high	26.5	26	0	26.5	26.5
Cave 68					
Cave 68 rear (uphill) chamber, 5 m above ground, 3 m below opening	25.65 (25.57, 25.73)	26	1.25	25	26.25
Cave 68, 18 m depth from lower entrance, 2 m high	26.16 (26.11, 26.22)	26	0.75	25.75	26.5

Table VI–8. Relative humidity at caves and other locations on Aguiguan, 2008. Time is MPT, Northern Mariana Islands time zone.

Date	Time	Location	Relative Humidity (Percent)
5 July	1700	New Cave 1, 10 m depth	96
6 July	1345	Fault Line Cave 1, 18 m depth	92
7 July	1515	Guano Cave, 10 m depth	92
7 July	1820	Pillar Cave at 35 m 1 m high	92
10 July	1600	Dangkolo Cave at 40 m depth	96
6 July	1345	Outside mouth of Fault Line Cave 1	88
7 July	1530	Outside mouth of Guano Cave	84
7 July	1825	Outside mouth of Pillar Cave	92 (drizzling)
4 July	1115	Camp	74
4 July	1118	Camp	75
5 July	0940	Camp	81
5 July	1200	Camp	78

Section VII. Reproduction of Pacific Sheath-Tailed Bats (*Emballonura semicaudata rotensis*) on Aguiguan, Commonwealth of the Northern Mariana Islands

By Thomas J. O'Shea and Ernest W. Valdez

ABSTRACT

There is very little information available about reproduction in Pacific sheath-tailed bats or other species of the genus *Emballonura*. Basic information about ecological aspects of reproduction is important for understanding the population dynamics of rare mammals. We found that seven of eight adult females captured at two caves on Aguiguan in June and July 2008 were reproductive (5 were pregnant and 2 were lactating). A pregnant female was reported in the literature in June 1984, but none of the six adult female bats examined in September of 2003 by other researchers were pregnant. We also observed 11 pups at roosts in June and July 2008, but captured no volant young of the year. These observations suggest that Pacific sheath-tailed bats on Aguiguan may have a diffuse seasonality in reproduction, timing the period of late gestation, lactation, and maturation of young to coincide with the late June- early November rainy season. One large embryo was observed in a female dissected in June 2008, as was also observed in a female dissected in June 1984, and each of the pups observed in caves were singletons. These observations suggest a litter size of one. Although additional sampling is needed to fully understand patterns of reproduction in these bats on Aguiguan, findings are consistent with the scant literature on other species of *Emballonura* and with the population dynamics of many other species of bats. If reproduction occurs annually and litter size is one, then the capacity for population growth in Pacific sheath-tailed bats is very limited.

INTRODUCTION

Basic information on ecological aspects of reproduction is essential to understanding the population dynamics of rare species of mammals. Little information is available in the literature on reproduction in Pacific sheath-tailed bats in the Mariana Islands or elsewhere. Lemke (1986) reported that one of two females captured at Guano Cave on Aguiguan on 22 June 1984 was pregnant with a single fetus. On 17 September 2003 six females were captured at Guano Cave, palpated, and released by Jake Esselstyn (University of Kansas, personal commun., 2008) and others. None of the bats handled by Esselstyn was palpably pregnant. We are unaware of any other records describing reproduction in this species in the Mariana Islands or anywhere else in its range. Our objectives in this section are to highlight and synthesize the limited findings pertinent to this topic based on our investigations on Aguiguan in 2008 and related information.

MATERIALS AND METHODS

We employed standard field methods for assessing reproductive condition in bats. Females were palpated to determine pregnancy, the condition of the teats was assessed to determine if bats were in lactation, and males were examined to determine if testes or cauda epididymides were engorged (Racey

1988). Age classes (adult or large volant juvenile) were assigned based on the degree of closure of the phalangeal epiphyses (Anthony 1988). Reproductive condition was also assessed by examination of internal organs of two bats saved as voucher specimens. We also report on the reproductive condition of six bats examined by Jake Esselstyn (University of Kansas, personal commun., 2008) and others at Guano Cave in 2003 following similar techniques. Observations of young bats in caves were made using the night vision equipment described in Section III of this report.

RESULTS AND DISCUSSION

Reproductive status of adult female bats captured at two caves on Aguiguan from late June to mid-July 2008 show that most (seven of eight, or 87 percent) were in active reproductive condition (five pregnant and two lactating). These and other records suggest a hypothesis that birthing in Pacific sheath-tailed bats on Aguiguan is diffusely seasonal and timed to coincide with the rainy season. General ecosystem productivity (including small insects) is likely to be higher in the rainy season than in the dry months. The general seasonal pattern in the region is that almost four times as much rainfall occurs in the wet season than in the dry season (Lander 2004). The lowest monthly rainfall occurs in December through May. Rainfall increases in June, is highest in July through October, and then decreases in November (Lander 2004). In other tropical areas of the world, insectivorous bats time their reproduction to coincide with rainy season productivity and aré non-reproductive during dry seasons; this is thought to be due to increases in food abundance as a result of seasonably predictable rainfall (*e.g.* Bernard and Cumming 1997; Fleming and others 1972), and accompanying higher insect abundance (McWilliam 1987; Bradbury and Vehrencamp 1976).

Although sampling efforts have been very limited, several lines of evidence support a hypothesis of diffuse seasonal reproduction in Pacific sheath-tailed bats on Aguiguan. Esselstyn (University of Kansas, personal commun., 2008) and others captured six adult females at Guano Cave later in the rainy season on 17 September 2003. None of these was pregnant. Using the night viewing device, we observed a pup on 23 and 27 June in the roost at Crevice Cave that also held 2–3 adults; 10 smaller bats were each observed roosting in very close association with 10 single larger adults within the colony at Guano Cave on 25 June. We assume these smaller bats at Guano Cave each were juveniles roosting with their mothers. Volant juvenile bats can be readily distinguished from adults based on epiphyseal closure and ossification for several months after birth (Anthony 1988). All of the 12 Pacific sheath-tailed bats we caught in flight at three different locations in June and July were adults (Table VII–1); the absence of readily discernible young bats in our samples suggests that reproduction was limited over the preceding few months of the late dry season. The pregnant females handled all seemed to be in fairly advanced pregnancy based on abdominal distension, and this was supported by the presence of a large fetus (crown-rump length of 23 mm) in the museum voucher specimen taken on 30 June (see Section VI of this report). The fetus observed by Lemke (1986) on 22 June 1984 was advanced but slightly smaller at 19 mm in crown-rump length. The other female he examined, however, was non-reproductive. In addition to possible seasonality in birthing, our observations of roosting pups, the single attached young caught with its mother at Guano Cave (Table VII–1, see also Table VI–2, Section VI of this report), and the dissections of two females by us and Lemke (1986) all suggest a litter size of one. Very little information is available on litter size in other species in the genus *Emballonura*, but litter sizes of one seem consistent with our observations of Pacific sheath-tailed bats on Aguiguan. A litter size of one has been reported for *Emballonura tiavato* and *Emballonura atrata* on Madagascar, where reproduction may be seasonal but available data are also limited (Goodman and others 2006). Only single embryos have been reported thus far in the few samples of *Emballonura beccarii* and *Emballonura dianae* that have been taken on Papua New Guinea (Bonaccorso 1998), and single

embryos have been reported for *Emballonura monticola* (Nowak 1994). A seasonal birthing period coinciding with the rainy season is known for other emballonurids, but the pattern in Pacific sheath-tailed bats on Aguiguan suggested by our data could be more complex and will require additional sampling to verify. For example, some Neotropical emballonurids also give birth to singletons once annually in synchrony with rainy seasons, whereas other species of emballonurids may have more than one birthing period each year (Bradbury and Vehrencamp 1976).

The single male that we dissected had no swelling of the cauda epididymides and small testes (measuring 1 x 3 mm) that were withdrawn into the inguinal canal, indicating that it was not in mating condition. The other three males we captured showed no external evidence of distended testes or epididymides. Perhaps mating occurs earlier in the year during the dry season. This would be compatible with mating systems of other emballonurids which include defending access to feeding areas (e.g. Bradbury and Emmons 1974, Bradbury and Vehrencamp 1976), if food is a more limited resource in the dry season.

Although bats are a diverse group with about 1,200 species worldwide and can show a concomitant variability in life history traits, most have limited potential for population growth based on reproduction alone (and thus require high adult survival to prevent population declines). Sexual maturity in bats is usually not reached until one year of age or older; birth typically occurs once annually (but some species of tropical bats in aseasonal environments may reproduce year-round), and litter size is small but can vary among species and habitats from one to four, with most producing one or two young at parturition (see review of ecological aspects of bat reproduction in Racey and Entwistle 2000). Our observations suggest that Pacific sheath-tailed bats on Aguiguan may be at the low range of reproductive potential for bats if they give birth once annually with litter sizes of one. This low reproductive potential will limit the ability of the population to grow quickly.

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REFERENCES CITED

Anthony, E. L. P., 1988, Age determination in bats, *in* Kunz, T. H., ed., Ecological and behavioral methods for the study of bats: Washington, D.C., Smithsonian Institution Press, p. 47–58.

Bernard, R. T. F., and Cumming, G. S., 1997, African bats: evolution of reproductive patterns and delays: Quarterly Review of Biology, vol. 72, p. 253-274.

Bonaccorso, F. J., 1998, Bats of Papua New Guinea: Washington, D.C., Conservation International, 489 p.

Bradbury, J. W., and Emmons, L. H., 1974, Social organization of some Trinidad bats. I. Emballonuridae: Zeitschrift für Tierpsychologie, vol. 36, p. 137-183.

Bradbury, J. W., and Vehrencamp, S. L., 1976, Social organization and foraging in emballonurid bats: Behavioral Ecology and Sociobiology, vol. 1, p. 337-381.

Fleming, T. H., Hooper, E. T., and Wilson, D. E., 1972, Three Central American bat communities: structure, reproductive cycles, and movement patterns: Ecology, vol. 53, p. 555-569.

Goodman, S. M., Cardiff, S. G., Ranivo, J., Russell, A. L., and Yoder, A.D., 2006, A New Species of *Emballonura* (Chiroptera: Emballonuridae) from the Dry Regions of Madagascar: American Museum Novitates, no. 3538, p. 1-24.

Lander, M. A., 2004, A rainfall climatology for Saipan: distribution, return-periods, El Niño, tropical cyclones, and long-term variations: Mangilao, Guam, University of Guam Water and Environmental Research Institute of the Western Pacific, Technical Report 103, 50 p.

Lemke, T. O., 1986, Distribution and status of the sheath-tailed bat (*Emballonura semicaudata*) in the Mariana Islands: Journal of Mammalogy, vol. 67, p. 743-746.

McWilliam, A. N., 1987, The reproductive and social biology of *Coleura afra* in a seasonal environment, *in* Fenton, M. B., Racey, P., and Rayner, J. M. V. , eds., Recent advances in the study of bats: Cambridge, England, Cambridge University Press, p. 324-350.

Nowak, R. M., 1994, Walker's Bats of the World: Baltimore, Maryland, Johns Hopkins University Press. 287 p.

Racey, P. A., 1988, Reproductive assessment in bats, *in* Kunz, T.H., ed., Ecological and behavioral methods for the study of bats: Baltimore, Md., Smithsonian Institution Press, p. 31–46.

Racey, P. A., and Entwistle, A. C., 2000, Life-history and reproductive strategies of bats, *in* Crichton, E. G., and Krutzsch, P. O. H., eds., Reproductive biology of bats: Academic Press, San Diego, CA., p. 363-414

Table VII–1. Summary of reproductive status of bats captured on Aguiguan, June–July 2008. A, adult; Y, young; M, male; F, female.

Field ID	Date	General Location	Age & Sex	Reproductive Condition
STB-1	29 June	Vicinity of Fault Line Cave 1 (Cave 94)	A M	Non-reproductive
STB-2	30 June	Vicinity of Guano Cave (Cave 2)	A F	Pregnant
STB-3	1 July	East Black Noddy Cave (Cave 76)	A F	Pregnant
STB-4	5 July	East Black Noddy Cave (Cave 76)	A F	Lactating
STB-5	5 July	East Black Noddy Cave (Cave 76)	A F	Pregnant
STB-6	11 July	Vicinity of Fault Line Cave 1 (Cave 94)	A M	Non-reproductive
STB-7	12 July	Guano Cave (Cave 2)	A F	Lactating
STB-8	12 July	Guano Cave (Cave 2)	Y F	Small nursing young attached to adult
STB-9	12 July	Guano Cave (Cave 2)	A F	Pregnant
STB-10	12 July	Guano Cave (Cave 2)	A F	Pregnant
STB-11	12 July	Guano Cave (Cave 2)	A F	Non-reproductive
STB-12	13 July	Vicinity of Fault Line Cave 1 (Cave 94)	A M	Non-reproductive
STB-13	13 July	Vicinity of Fault Line Cave 1 (Cave 94)	A M	Non-reproductive

Section VIII. Sampling Guano of Pacific Sheath-Tailed Bats (*Emballonura semicaudata*) on Aguiguan for Organochlorine Insecticides and Other Contaminants

By Thomas J. O'Shea and Ernest W. Valdez

ABSTRACT

Past studies have shown that guano of bats can be used to assess the degree of contamination with organochlorine pesticides and the likelihood that the observed level of exposure has caused bat mortality. The scientific literature on conservation of Pacific sheath-tailed bats speculates that past organochlorine pesticide contamination may have played a role in their decline in some areas. However, Pacific sheath-tailed bats have never been assessed for organochlorine contaminants anywhere in their range. We obtained a small number of guano samples at different depths in an area of accumulation at Guano Cave on Aguiguan using chemically cleaned glass jars with teflon-lined lids. These samples are stored at the U.S. Geological Survey laboratory in Fort Collins, Colo., and can be made available for chemical analysis. They may be particularly useful for comparison with samples that may be taken in the future at other islands where these bats have declined, because there is no known history of organochlorine pesticide use on Aguiguan. However, our samples likely include some guano from swiftlets (*Aerodramus bartschi*). Attempts to assess the degree of mixing of the two kinds of guano based on microscopic examination will be necessary prior to analysis of these and any comparative samples from other locations.

INTRODUCTION

There has been speculation that exposure to insecticides (particularly the persistent organochlorines) has been a contributing cause of the decline of Pacific sheath-tailed bats in the Mariana Islands and elsewhere (Esselstyn and others 2004, Flannery 1995, Tarburton 2002). The organochlorine insecticide DDT and the organophosphate malathion were applied in Guam, Saipan, and Tinian between the 1940s and 1970s (Baker 1946, Townes 1946, Drahos 1977, Jenkins 1983). Researchers also have speculated that declines in swiftlets and sheath-tailed bats on Guam were linked (Lemke 1986). However, there is no firm chemical or toxicological supporting evidence that the disappearance of swiftlets was a result of pesticide exposure. Concentrations of DDE (a major break-down product of DDT) in swiftlet tissues and swiftlet guano samples from Guam measured in 1981 were much less than those associated with avian mortality or reproductive failure in studies of other species of birds (Grue 1985), and an order of magnitude less than concentrations in bat guano that have been linked to mortality or population declines in other species of insectivorous bats (Clark and others, 1982, 1995; Clark and Shore 2001). Nonetheless there continue to be suspicions that swiftlet and bat declines in years past may have been a result of exposure to DDT or other pesticides (Cruz and others 2008).

Concentrations of contaminants have never been measured in sheath-tailed bat guano or tissues. DDT was used extensively in Palau in the 1940s (Baker 1946) but sheath-tailed bats have been characterized as abundant there in the recent past (Wiles and others 1997). The carbamate and organophosphate insecticides that were also widely used globally are not persistent in tissues or guano

of birds or mammals, and exposure of bats or swiftlets to these compounds has not been assessed. However, it has been speculated that these additional classes of insecticides were likely responsible for deaths of bats in the United States in the 1960s (Clark and Shore 2001), so that such past poisoning also seems feasible (although only speculatively so) in the Mariana Islands. It is unknown but seemingly unlikely that there is any history of major organochlorine insecticide use on Aguiguan. Most of the plantation activity of the Japanese colonists was prior to the 1940s when other substances may have been used for pest control, including elemental based compounds; recognition and introduction of DDT as an insecticide did not occur until the 1940s (Metcalf 1973). However, count data suggest that the population of sheath-tailed bats on Aguiguan was lower in the early 1980s than it has been in more recent years (see Section III of this report).

Determining concentrations of contaminants in samples of guano from sheath-tailed bats on Aguiguan might be instructive, particularly in relation to samples from elsewhere in the CNMI or Guam where sheath-tailed bats have disappeared. Concentrations of organochlorines (particularly DDT, DDE, and dieldrin) in guano that are associated with declines or direct mortality in other species of insectivorous bats have been established (Clark and others 1982) and used to evaluate the likely impacts of exposure on bat populations (e.g., Clark and others 1988, 1995, O'Shea and others 2001). Comparison of concentrations of organochlorines in samples of guano from sheath-tailed bats on Aguiguan with samples from other colonies of sheath-tailed bats that have gone extinct (e.g. on Guam) might also be useful in evaluating the degree of any past threat associated with these substances. Therefore we also sought to use careful protocols to collect a small series of guano samples from below roosts of sheath-tailed bats in Guano Cave on Aguiguan for archival and possible future analyses.

METHODS AND MATERIALS

Samples were collected in Guano Cave directly below the high domed ceiling where the bats roost daily (see Sections III and V of this report), and which does not appear to be heavily used by nesting cave swiftlets. However, mixing of swiftlet guano with sheath-tailed bat guano could have occurred, particularly over the long periods of time during which the guano pile was formed. Microscopic examination of subsamples will be required to quantify the extent of this mixing. Samples were placed in chemically cleaned 120 ml glass jars with teflon-lined lids that were pre-washed following EPA procedures and specifications (Eagle Picher Lot G3255020). The samples were removed from the surface layer, and from depths at 10 and 20 cm, using a stainless steel spoon wrapped in aluminum foil, with the foil changed between each sample. Duplicate samples were taken from areas about 15 cm apart. Original teflon-lined lids were sealed to the jars using adhesive tape.

RESULT AND DISCUSSION

We obtained six samples of guano at three depths below the sheath-tailed bat roosting area in Guano cave (Table VIII–1). The amounts listed are similar to those collected in other studies of contaminants in guano of insectivorous bats (e.g. Clark and others 1995) and sufficient to allow duplicate analyses of subsamples. Given the small numbers of bats utilizing this site over the last few decades (Section III of this report), we suspect the three different depths represent substantial differences in dates of deposition. However, there are no means to calibrate the layers of guano at this cave, and interpretations of differences in findings at the three depths will only be relative to each other. These samples are currently stored at room temperature at the U.S. Geological Survey Fort Collins Science Center in Colorado and can be made available for analysis, particularly if similar material can be obtained at additional locations for comparison. Unlike animal tissues, which must be kept frozen in

storage and shipment, bat guano can be stored at room temperature, but samples or subsamples should be dried in a dessicator to constant dry weight prior to any subsampling for chemical analyses (e.g. Clark and others 1982, 1995, O'Shea and others 2001). Future chemical analyses should attempt to include as many persistent contaminants as possible (e.g. metals as well as organochlorines) given the logistic difficulty of obtaining these samples. It would also be useful to examine small subsamples microscopically to verify by degree of mastication that the material taken at various depths below the surface layer are primarily of bat origin rather than from swiftlets (see Section V of this report). We recommend that these samples be analyzed for a range of persistent contaminants in conjunction with samples that may be obtained from caves on Guam and from elsewhere in the CNMI where these bats formerly roosted but no longer occur.

REFERENCE CITED:

Baker, R. H., 1946, Some effects of the war on the wildlife of Micronesia: Transactions of the North American Wildlife Conference, vol. 11, p. 205-213.

Clark, D. R., Jr., and Shore, R. F., 2001, Chiroptera, in Shore, R.F. and Rattner, B.A., eds., Ecotoxicology of Wild Mammals: London, John Wiley & Sons, Ltd., p. 159-214.

Clark, D. R., Jr., Bagley, F. M., and Johnson, W.W., 1988, Northern Alabama colonies of the endangered grey bat *Myotis grisescens* - organochlorine contamination and mortality: Biological Conservation, vol. 43, p. 213-225.

Clark, D. R., Jr., LaVal, R. K., and Tuttle, M. D., 1982, Estimating pesticide burdens of bats from guano analyses: Bulletin of Environmental Contamination and Toxicology, vol. 29, p. 214-220.

Clark, D. R., Jr., Moreno-Valdez, A., and Mora, M. A., 1995, Organochlorine residues in bat guano from nine Mexican caves, 1991: Ecotoxicology, vol. 4, p. 258-265.

Cruz, J B., Kremer, S. R., Martin, G., Williams, L. L., and Camacho, V. A., 2008, Relative abundance and distribution of Mariana swiftlets (Aves: Apodidae) in the Northern Mariana Islands: Pacific Science, vol. 62, p. 233-246.

Drahos, N., 1977, Status of the Vanikoro swiftlet on Guam (Collocalia vanikorensis Quoy and Gaimard): Mangilao, Guam , Division of Aquatic and Wildlife Resources.

Esselstyn, J. A., Wiles, G.J., and Amar, A., 2004, Habitat use of the Pacific sheath-tailed bat (*Emballonura semicaudata*) on Aguiguan, Mariana Islands: Acta Chiropterologica, vol. 6, p. 303-308.

Flannery, T. 1995. Mammals of the South-West Pacific & Moluccan Islands: Ithaca, NY., Cornell University Press.

Grue, C. E., 1985, Pesticides and the decline of Guam's native birds: Nature, vol. 316, p. 301.

Helgen, K. M., and Flannery, T. F., 2002, Distribution of the endangered Pacific sheath-tailed bat *Emballonura semicaudata*: Australian Mammalogy, vol. 24, 209-212.

Jenkins, J. M., 1983, The native forest birds of Guam: Ornithological Monographs, vol. 31, p. 1-61.

Lemke, T. O., 1986, Distribution and status of the sheath-tailed bat (*Emballonura semicaudata*) in the Mariana Islands: Journal of Mammalogy, vol. 67, p. 743-746.

Metcalf, R. L., 1973, A century of DDT: Journal of Agricultural and Food Chemistry, vol. 21, p. 511-519.

O'Shea, T. J., Everette, A. L., and Ellison, L. E., 2001, Cyclodiene, DDE, DDT, arsenic and mercury contamination of big brown bats foraging at a Colorado superfund site: Archives of Environmental Contamination and Toxicology, vol. 40, p. 112-120.

Tarburton, M. K., 2002, Demise of the Polynesian sheath-tailed bat *Emballonura semicaudata* in Samoa: Micronesica, vol. 34, p.105-108.

Townes, H. K., 1946, Entomology. Part I. Non-agricultural plants. Economic Survey of Micronesia, Vol. 12: Honolulu, Hawaii., U.S. Commercial Company

Wiles, G. J., Engbring, J., and Otobed, D., 1997, Abundance, biology, and human exploitation of bats in the Palau Islands: Journal of Zoology (London), vol. 241, p. 203-227.

Table VIII–1. List of samples of guano obtained from Guano Cave for possible future analyses for contaminants.

Sample Jar Serial Number	USGS Sample Id	Depth of Sample	Approximate Sample Mass
A1374270	7-12-08 S-1	Surface layer at location 1	14 g
A1374275	7-12-08 S-2	Surface layer at location 2	12 g
A1374261	7-12-08 10-cm 1	10 cm at location 1	20 g
A1374287	7-12-08 10-cm 2	10 cm at location 2	16 g
A1374256	7-12-08 20-cm 1	20 cm at location 1	24 g
A1374290	7-12-08 20-cm 2	20 cm at location 2	24 g

Section IX. Assessment for Pacific Sheath-Tailed Bats (*Emballonura semicaudata rotensis*) on Tinian, Commonwealth of the Northern Mariana Islands

By Thomas J. O'Shea, Ernest W. Valdez, and Frank J. Bonaccorso

ABSTRACT

Pacific sheath-tailed bats are unknown from Tinian except from prehistoric deposits in caves. Ultrasonic detectors were used to sample for the presence of echolocating bats in areas of native forest on Mount Lasso and in the Kastiyu Forest on four nights. We did not detect any bats. We did not see any bats in flight during this sampling, and did not receive verbal reports from knowledgeable residents that would indicate their presence. We also found no records of specimens in museums. Native forest habitat was found to be very important in supporting the population of sheath-tailed bats on Aguiguan. However, native vegetation was impacted by Chamorro settlers prior to European contact, and by subsequent introduced ungulate grazing; thereafter most of the native forest on Tinian was cleared for sugar cane plantations by Japanese colonists in the 1920s and 1930s. If sheath-tailed bats survived this loss of foraging habitat, their roosts in caves may have been destroyed by military activities during World War II. Our lack of findings provides further negative evidence that these bats occur on Tinian, but our sampling efforts were very limited. Additional sampling with echolocation detectors across a wider area of forest and searches of caves are needed to further rule out the possibility that a relict population of these bats may remain on Tinian.

INTRODUCTION

Pacific sheath-tailed bats are not known from Tinian other than in prehistoric times. Bones of this species have been found in three caves, crevices or rock shelters in the Carolinas area of Tinian in prehistoric stratigraphic layers, at least one of which has been dated at 2,400–2,200 years bp (before present) by radiocarbon analysis (Steadman 1999). In contrast, the contemporary presence of sheath-tailed bats on Tinian has never been documented by biologists, and there are no specimens (other than zooarchaeological material) from Tinian known in museum collections (Lemke 1986, Helgen and Flannery 2002; see also Section VI of this report). We had a limited amount of time available to make an assessment for the presence of Pacific sheath-tailed bats on Tinian. We arrived on Tinian during the day of 15 July 2008 and were scheduled to leave on 19 July. With 4 days and nights available it was decided that the most efficient approach to identify the presence of these bats would be to use echolocation detectors in likely foraging habitat each night, rather than search caves in cliffs during the day. Stafford (2003) had previously conducted a geological inventory of 88 caves on Tinian, and did not see roosting bats in them (K. W. Stafford, personal commun. 2008). Detection of even a single bat echolocation call would provide evidence to support additional survey effort in the future. We concentrated our use of echolocation detector equipment to native forest on Tinian, based on findings on Aguiguan that foraging and associated echolocation activity of Pacific sheath-tailed bats is limited primarily to this habitat (Esselstyn and others 2004; see also Section IV of this report).

MATERIALS AND METHODS

Two widely separated stands of native forest were chosen to sample echolocation activity. One was a section of forest on Mount Lasso in the north central interior of Tinian. This area of the forest was also used during herpetological surveys in 2008 (Gordon Rodda, U.S. Geological Survey, personal commun., 2008). The second area sampled was 10 km to the southeast of the Mount Lasso area on the southeastern part of Tinian in the Kastiyu Forest, as recommended by Commonwealth of the Northern Mariana Islands (CNMI) Division of Fish and Wildlife staff (Elvin Masga and Ton Castro, personal commun.). This area was closer to sections of sea cliffs with caves than was the Mount Lasso forest, although a few small caves were also known from the Mount Lasso area.

On 15 July 2008 we activated two fixed echolocation detector stations using some of the equipment that had been used in the Aguiguan study (Section IV of this report). These stations were located on a trail through the forest at Mount Lasso. Location 1 was located on Mount Lasso along the forest edge at a clearing near the trailhead, 352715E, 1663323N, elevation 196 m (UTM zone 55 P, WGS 84). Location 2 was under the canopy at an area with limited understory vegetation about 525 m NNW of Location 1, at 352609E and 1663835N, elevation 156 m (UTM zone 55 P, WGS 84). Each Anabat sampling station was programmed to sample continuously all night long (see Section IV of this report for more details on the equipment and methods used at sampling stations). On 16 July 2008 we placed the echolocation detector units in the Kastiyu Forest. Location 1 in the Kastiyu Forest was at 355660E and 1653903N, elevation 161 m. The second station at the Kastiyu forest was about 400 m SSE of Location 1, at 355732E and 1653511N, elevation 158 m. Both locations where detector stations were established in the Kastiyu Forest area were below the canopy, about 30 m interior from the forest edge.

In addition to the fixed sampling stations that automatically collected echolocation activity all night long, we also sampled using *ad hoc* walking transects and hand-held Anabat II SD1 CF ultrasonic detectors at Mount Lasso and the Kastiyu Forest on 17 and 18 July 2008. These transects were sampled from dusk until about 2130 h, typically a period of peak detection of foraging bats on Aguiguan (see Section IV of this report). At the Mount Lasso site we walked the interior forest trail on a path about 870 m long, beginning at a point at 352715E, 1663323N and ending at 352287E and 1663969N (travelling through the point where the second fixed station of 15 July was located). Two observers each held separate ultrasonic detectors aimed upward at the surrounding airspace with moderately high sensitivity settings and an audible broadcast setting. Detectors were deployed throughout the entire length of the transect and return. At the Kastiyu Forest area where we sampled there were no interior forest trails. Therefore we walked a route along the immediate forest edge on an overgrown road bed over a distance of 0.5 km with the detectors on continuously. An old fence line separated the forest from the old road bed, which was typically within 10 m of the canopy edge. Every 125 m we crossed the fence and entered into the forest at a perpendicular distance of about 30 m into the forest interior from the transect and stood about 15 m apart with each detector scanning upward across the air space for a 5 min fixed point sample. The entire transect route was walked and returned twice. The coordinates for each end of the transect and the locations for fixed point stations at the Kastiyu Forest are given in Table IX–1.

In addition to echolocation detector sampling we also queried employees of the CNMI Division of Wildlife and Tinian Department of Land and Natural Resources and other people for local knowledge about this bat on Tinian, and we kept alert for visual observations of bats in flight when traveling at night by foot or by vehicle.

RESULTS AND DISCUSSION

No ultrasounds were detected in our limited sampling with echolocation detectors at two forested areas on Tinian. This is consistent with the lack of any previous historic records of Pacific sheath-tailed bats on Tinian (e.g. Lemke 1986, Helgen and Flannery 2002). No records of museum specimens from Tinian were located in our search of museum databases (see also Section VI in this report). Additionally, we saw no bats in flight at any time, and there was no apparent local knowledge of the existence of these bats on Tinian based on our limited number of conversations with residents and Tinian Department of Land and Natural Resources and CNMI Division of Fish and Wildlife employees. This is also consistent with the verbal report by K. W. Stafford (New Mexico Institute of Mining and Technology, personal commun., 2008) that he saw none of these bats during his geological inventory of 88 caves on Tinian (Stafford 2003). Eleven caves specifically searched for bats in 1984–1985, failed to have evidence of occupancy by bats, although investigators suggested that additional caves should be searched in the Kastiyu area (Wiles and others 1990).

Although Pacific sheath-tailed bats are present in deposits in caves from prehistoric times (Steadman 1999), a long history of habitat degradation by human influences may have negatively impacted their foraging habitat. Tinian has a larger land mass than Aguiguan and has areas with considerable karst topography, cliffs, and caves, but the few remaining "native" forested areas on Tinian are small. As reviewed by Wiles and others (1990), the Chamorro people probably strongly modified native vegetation of Tinian prior to European contact, which was exacerbated by introduction of exotic ungulates thereafter. Thousands of cattle roamed the island and a large population of feral pigs existed between the 1700s and 1900s. During the 1920s and 1930s, Japanese colonists cleared most of the island for sugar cane plantations, with very little native forest left standing. According to one estimate (Bowers 1951) as little as 2 percent of the island may have been left in native forest. It is likely that the extensive development and clearing, military activity, and combat operations on Tinian during and after World War II also impacted caves as roosting habitat and forests as foraging habitat. Local knowledge indicated that accessible caves were used as strongholds by soldiers, and were subject to grenade explosions and flamethrower operations during the invasion by the United States. If Pacific sheath-tailed bats were present on Tinian after loss of forest habitat to agriculture prior to World War II, it is likely that populations were severely reduced or eliminated during the war and perhaps thereafter (see Lemke 1986, and Section III of this report for a history of investigations on sheath-tailed bat distribution in the Mariana Islands). If these bats currently exist on Tinian despite the absence of any historic records or contemporary evidence, then it is likely that they do so in a very small remnant population that will take considerable effort to discover. Such efforts will require additional use of ultrasonic detectors and intensive searches of caves for roosting bats. Searches of many of these caves will require specialists with technical climbing and caving skills. Additional effort at surveying forests using echolocation detectors should be devoted to a larger area of forest in the Kastiyu and Carolinas area of southeastern Tinian. This region has a significant amount of karst geology and associated caves (Stafford 2003) as well as native limestone forest, some of which may have never been cleared for agriculture because of the karst substrate. If a relict population of Pacific sheath-tailed bats exists on Tinian it would most likely be in this general location.

Similarly, the literature also reports possible sightings of small numbers of these bats on Anatahan and the east island of Maug in the late 1970s and early 1980s (Lemke 1986, 1987). These two northern islands should be surveyed more intensively for sheath-tailed bats using echolocation detectors as well as searches of caves (other subspecies of Pacific sheath-tailed bats will roost in hollow trees and overhangs in other island groups) to rule out the possibility of an established population on an island other than Aguiguan. Discovery of a second population in the Marianas Islands would help bolster the

prospects for survival of this subspecies. Consideration of other management options such as translocation from Aguiguan to other locations could be deferred until further assessments on other islands are completed. There are 1,200 species of bats worldwide, with many species of conservation concern. However, with one exception, translocation of insectivorous bat populations for conservation has to our knowledge never been successfully attempted. The exception involved the unusual case of the short-tailed bat (*Mystacina tuberculata*) in New Zealand. This translocation required an intermediate step of captive breeding, and has been too recent to judge its ultimate success (New Zealand Department of Conservation, 2008).

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REFERENCES CITED

Bowers, W. N., 1951, Problems of resettlement on Saipan, Tinian and Rota, Mariana Islands: Ann Arbor, Michigan, Ph.D. Dissertation, University of Michigan, 492 p.

Esselstyn, J. A., Wiles, G. J., and Amar, A., 2004, Habitat use of the Pacific sheath-tailed bat (*Emballonura semicaudata*) on Aguiguan, Mariana Islands: Acta Chiropterologica, vol. 6, p. 303-308.

Helgen, K. M., and Flannery, T. F., 2002, Distribution of the endangered Pacific sheath-tailed bat *Emballonura semicaudata*: Australian Mammalogy, vol. 24, 209-212.

Lemke, T. O., 1986, Distribution and status of the sheath-tailed bat (*Emballonura semicaudata*) in the Mariana Islands: Journal of Mammalogy, vol. 67, p. 743-746.

Lemke, T. O., 1987, Sheath-tailed bats rediscovered in the Mariana Islands: Bats Magazine, vol. 5, p. 5-7.

New Zealand Department of Conservation, 2008, Short-tailed bat translocation, available at: *http://www.doc.govt.nz/ conservation/ native-animals/bats/short-tailed-bat/docs-work/short-tailed-bat-translocation/*. Last accessed 23 December 2008.

Stafford, K. W., 2003, Structural controls on megaporosity in eogenetic carbonate rocks: Tinian, CNMI. M.S. Thesis, Mississippi State University, Mississippi State, Mississippi. 340 p.

Steadman, D. W. 1999. The prehistory of vertebrates, especially birds, on Tinian, Aguiguan, and Rota, Northern Mariana Islands. Micronesica, vol. 31, p. 319-345.

Wiles, G. J., Amerson, A. B., and Beck, R. E., Jr., 1990, The mammals of Tinian, Mariana Islands: Micronesica, vol. 23, p. 167-180.

Table IX–1. Coordinates (UTM zone 55P, Datum: WGS 84;) for start point, end point, and fixed point stations using the Anabat detectors in Kastiyu Forest on 18 July 2008.

Location	Easting Coordinate	Northing Coordinate
Transect beginning	355635E	1654000N
Forest interior station 1	355660E	1653903N
Forest interior station 2	355662E	1653767N
Forest interior station 3	355692E	1653629N
Forest interior station 4 and transect end	355732E	1653511N

Section X. The Pacific Sheath-Tailed Bat (*Emballonura semicaudata*) On Aguiguan, Commonwealth of the Northern Mariana Islands: Applying the Results of this Work to Future Management, Monitoring, and Research

By Thomas J. O'Shea, Ernest W. Valdez, and Gary J. Wiles

A number of considerations for future activities stem from the findings of this assessment. These are best characterized as activities related to management for conservation, monitoring, and research.

CONSIDERATIONS FOR MANAGEMENT AND CONSERVATION

Increasing the extent of native limestone forest, decreasing existing stands of invasive plants, and eliminating or avoiding actions that would reduce the amount of native limestone forest on Aguiguan would likely benefit these bats. Results presented in Section IV of this report show that Pacific sheath-tailed bats on Aguiguan forage primarily in native limestone forest, particularly in stands of taller stature. The importance of this habitat may also be reflected by some elements of their diet as reported in Section V of this report. Browsing by feral goats has limited the regeneration of native forest and has likely altered tree species composition and diversity by favoring unpalatable species. Control or elimination of goats could favor forest regeneration. If such control takes place, foraging activity of sheath-tailed bats should be monitored to ensure that a developing understory provides favorable feeding habitat compared with the existing open conditions maintained by goats. A program of managing extensive areas of non-native vegetation to encourage its replacement by native forest could enhance the amount of foraging habitat available to Pacific sheath-tailed bats on Aguiguan. Similarly, new activities that could be destructive to the remnant forest should be avoided.

Limiting disturbance and access to caves used by roosting bats would benefit these bats as it has other cave-roosting bat assemblages elsewhere. Although many caves exist on Aguiguan, only a few are used as roosts by Pacific sheath-tailed bats, despite seeming similarities among caves in structure and conditions of temperature and humidity (see Sections III and VI of this report). Only two caves are known to regularly have 50 or more bats. These caves have histories of use by bats that indicate occupancy by sheath-tailed bats on every visit since first discovered by researchers. They are also occupied by endangered Mariana swiftlets (*Aerodramus bartschi*). Under current levels of visitation of Aguiguan by people, activities that might disturb bats or swiftlets at caves seem minimal. However, any increase in visitation by people or increases in other activities that could disturb these colonies could have strong negative effects. Disturbance is well known to have long-lasting negative effects on other species of bats around the world that rely on caves for roosts, and a variety of techniques for protecting caves used by bats have been developed.

CONSIDERATIONS FOR MONITORING

Monitoring numbers of bats utilizing key caves on Aguiguan could provide necessary population trend information. Monitoring numbers of bats at caves will provide an index of population status

(increasing, stable, or declining) over time, and will allow measurement of responses to habitat change (e.g. from typhoons or habitat management). Use of caves by bats could be monitored using emergence counts or by making internal counts with night vision equipment where possible. Counts should be made on a regular basis using a standard protocol. Caves with a history of use and past series of counts identified in Section III of this report can be focal points, but new colonies that may be discovered with time could also be added. Monitoring should include some initial efforts to further assess daily and seasonal variability in counts, as well as to quantify possible observer effects. Results from variability assessments can be used to guide scheduling and levels of effort (e.g. seasons and numbers of replicate counts at a site) for monitoring.

Monitoring of the use of foraging habitat on Aguiguan by Pacific sheath-tailed bats using echolocation detectors and site occupancy models could provide information on the relative value of various habitats. Replication of sampling efforts described in Section IV of this report using echolocation detectors and site occupancy models could be carried out periodically to assess changes in the amount of activity and in habitat use by foraging sheath-tailed bats. Monitoring can detect changes in habitat use over time, changes in response to catastrophic typhoons, and changes in response to management intended to improve the population status of these bats.

CONSIDERATIONS FOR RESEARCH

Searching the more inaccessible areas on Aguiguan for the presence of additional colonies of Pacific sheath-tailed bats that may occupy caves requiring technical climbing and caving skills to reach is suggested by our limited observations. Pacific sheath-tailed bats on Aguiguan currently appear to roost only in caves, and occupy just a small fraction of known caves (Section III of this report). Some of our observations of foraging activity and of bats dispersing early at dusk (Sections IV and VI) leave open the possibility that one or more undiscovered colonies of sheath-tailed bats may still exist on Aguiguan. If so, these are likely to be in caves that are in inaccessible sections of cliffs, or caves with deep shaft-like entrances that will require technical skills for climbing and caving to search properly. Future searches for roosts should include a team of bat biologists combined with persons with good technical climbing and caving skills and appropriate safety training, dedicated exclusively to searching less accessible caves for colonies of sheath-tailed bats.

Increasing the foundation of ecological knowledge of this species is necessary to develop conservation and management strategies. The biology of Pacific sheath-tailed bats anywhere in their range is poorly known. Although we made a few new observations on the biology of these bats during the course of this assessment, determination of potentially important patterns in their ecology will require additional intensive sampling. As examples, if reproduction or foraging habitat use follows a seasonal pattern, then management needs may differ by season; understanding of vital parameters such as timing of reproduction and litter size could influence expectations for time needed for population recovery; possibilities for complexity in social behavior such as foraging territoriality (known in other emballonurid bats) could limit population density given the restricted area of native forest currently available. A focused multi-year program of research on the natural history, ecology, and biology of Pacific sheath-tailed bats on Aguiguan would provide much information of potential use for management. Development of capture techniques, analysis of cave deposits for past histories of use by these bats and other animals, analysis of fecal material for past exposure to contaminants and more in-depth assessment of diet, and further sampling to estimate genetic diversity are other areas of research

that could improve biological knowledge about this population pertinent to its conservation and management.

Conducting a modern analysis of the taxonomic status of Emballonura semicaudata and its subspecies using combined quantitative morphometric and molecular genetics approaches may be useful to developing conservation strategies. The management of the Aguiguan population as a subspecies of a more widely distributed Pacific sheath-tailed bat is based on a limited taxonomic understanding. The current systematic status of the subspecies in the Mariana Islands rests largely on qualitative features of skull morphology described 65 years ago after examination of a limited number of specimens. The subspecies designation was also based on size, which our measurements of bats from Aguiguan (Section VI of this report) suggest may no longer be a valid criterion. Review of subspecific distinctions in 1997 was also limited in scope. There are a large number of specimens in existence in various museum collections that could be used in a systematic reassessment, and there are also a number of molecular genetic approaches that are now routinely used in the study of bat taxonomy. Modern techniques employing a variety of morphometric and molecular genetic analyses could be applied to a study of the systematics of this species throughout its range, including the Mariana Islands and American Samoa (where a different putative subspecies of *E. semicaudata* is also a Category 3 candidate for listing under the U.S. Endangered Species Act). New sampling using wing biopsy techniques like those applied on Aguiguan may be necessary at some locations.

Further assessments for the occurrence of Pacific sheath-tailed bats on Tinian and other islands in the Commonwealth of the Northern Mariana Islands may be fruitful. Our negative findings on Tinian (Section IX of this report) were based on very limited sampling and could be expanded to more conclusively rule out the possibility that Tinian may still be occupied by a remnant population of Pacific sheath-tailed bats. Similarly, the literature also reports possible sightings of these bats on Anatahan and the east island of Maug in the late 1970s and early 1980s. These two northern islands could be surveyed more intensively for sheath-tailed bats using echolocation detectors to rule out the possibility of an established population on an island other than Aguiguan. Discovery of a second population in the Mariana Islands would help bolster the prospects for survival of this subspecies. Consideration of other management options such as translocation from Aguiguan to other locations could be deferred until further assessments on other islands are completed. Although there are 1,200 species of bats worldwide, with many species of conservation concern, to our knowledge translocation of an insectivorous bat population for conservation has been attempted only once. This involved the short-tailed bat (*Mystacina tuberculata*) in New Zealand and required an intermediate step of captive breeding. This translocation has been too recent to judge its ultimate success.

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