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Authors: Esselstyn, Jacob A., Wiles, Gary J., and Amar, Arjun

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Habitat use of the Pacific sheath-tailed bat (*Emballonura semicaudata*) on Aguiguan, Mariana Islands

JACOB A. ESSELSTYN[1, 2], GARY J. WILES[3], and ARJUN AMAR[1, 4]

[1]*Division of Fish and Wildlife, Rota, Northern Mariana Islands 96951, USA*
[2]*Present address: Natural History Museum and Biodiversity Research Center & Department of Ecology and Evolutionary Biology, University of Kansas, Lawrence, KS 66045, USA; E-mail: esselsty@ku.edu*
[3]*Washington Department of Fish & Wildlife, 600 Capitol Way North, Olympia, WA 98501, USA*
[4]*Present address: Centre for Ecology and Hydrology-Banchory, Hill of Bratherns, Banchory, Aberdeenshire, AB31 4BW, United Kingdom*

We tested for differential habitat use by Pacific sheath-tailed bats (*Emballonura semicaudata*) in three major vegetation types on Aguiguan, Mariana Islands. Acoustic surveys of bat activity were conducted on a 370-m grid with 50 stations that covered the entire island. We controlled for a variety of extraneous factors through sampling design and use of a generalized linear model. Bat activity was significantly higher in native and non-native forests than in non-forest habitats. There was no significant difference between activity levels in the two forest types. However, our sample size in non-native forest was limited to seven stations, thus the conclusion that non-native forest is an important habitat for the species should be viewed with caution. Our finding that *E. semicaudata* may be reliant on forest is critical because forests on Aguiguan are threatened by feral goats.

Key words: *Emballonura semicaudata*, Pacific sheath-tailed bat, habitat use, Aguiguan, Mariana Islands, bat detector, conservation

INTRODUCTION

The Pacific sheath-tailed bat (*Emballonura semicaudata*) is broadly distributed across the tropical Pacific. The species is known from the Mariana and Caroline Islands, Fiji, Tonga, Samoa, and Vanuatu (Flannery, 1995; Koopman, 1997). It is the only microchiropteran in the Mariana Islands, where the endemic subspecies *E. s. rotensis* occurs (Yamashina, 1943; Lemke, 1986; Flannery, 1995; Koopman, 1997).

While some populations of *E. semicaudata* have remained stable (e.g., Carolines — Bruner and Pratt, 1979; Wiles *et al*., 1997), many others have suffered dramatic declines or extirpation (e.g., Marianas, Fiji, and the Samoas — Lemke, 1986; Grant *et al*., 1994; Flannery, 1995; Hutson *et al*., 2001; Tarburton, 2002). Possible causes of these declines have been proposed (e.g., effects of war and pesticides), but no hypotheses are supported by substantial evidence (e.g., Tarburton, 2002).

Emballonura s. rotensis once occurred on the five southernmost Mariana Islands of Saipan, Tinian, Aguiguan, Rota, and Guam (Oustalet, 1895; Yamashina, 1943; Lemke, 1986; Koopman, 1997; Steadman, 1999; P. Krutzsch, in litt.) and possibly on several islands in the northern portion of the archipelago (Lemke, 1986). Of these populations,

only the one on Aguiguan (also known as Agiguan, Aguijan, and Goat Island) persists, with an estimated 400–500 bats (G. J. Wiles and J. A. Esselstyn, unpubl. data).

Little is known of the ecology or natural history of *E. semicaudata*. Although roosting occurs primarily in caves (Lemke, 1986; Grant *et al*., 1994; Flannery, 1995; Tarburton, 2002), no studies of non-roosting habitat preferences have been conducted. Knowledge of habitat associations is critical in any attempt to manage a declining or rare species. As a first step toward improving knowledge of the ecology of *E. semicaudata*, we tested for differential habitat use by the last known population of *E. s. rotensis*.

Materials and Methods

Study Area

Aguiguan (14°51'N, 145°33'E) is a small (7.2 km^2), uninhabited, limestone island characterized by a large central plateau that is surrounded by a series of narrow terraces and cliffs (Fig. 1). Maximum elevation is 166 m. Climate is tropical, with a distinct dry season from January to June. Average annual rainfall is probably somewhat less than 2,000 mm (van der Brug, 1985). Vegetation on the main plateau consists primarily of fields of *Lantana camara*, *Chromoleana odorata*, and *Mikania scandens*, with small, scattered areas of non-native forest (*Leucaena leucocephala*, *Acacia confusa*, and *Triphasia trifolia*), and bands of native forest around the periphery. Most fields on Aguiguan do not contain any trees. Non-native forest normally includes some native tree species, usually *Guamia mariannae*, *Ochrosia mariannensis*, or *Melanolepis multiglandulosa*. Non-native forest canopy height is generally 5–10 m. Vegetation on most terraces is dominated by native forest, which generally includes the following trees: *Cynometra ramiflora*, *G. mariannae*, *Pisonia grandis*, *O. mariannensis*, *Aglaia mariannensis*, *Cerbera dilatata*, *Premna obtusifolia*, *Ficus prolixa*, *Drypetes dolichocarpa*, *Erythrina variegata*, and *Psychotria mariana*. Native forest canopy height was estimated at 7 to 15 m in most areas. Grassy and shrubby strand vegetation grows in a narrow coastal band on lower terraces. Both forest types suffer from heavy over-browsing by feral goats (*Capra hircus*), which are abundant on the island and were first introduced between 1818 and 1863 (Butler, 1992). Goat browsing has prevented regeneration of most tree species, thereby creating open, low-clutter forest understories.

Aguiguan was briefly inhabited by humans from 1936 to 1945, when much of the island was cleared for agriculture (Butler, 1992). Although Aguiguan has been uninhabited since 1945, goat hunters from neighboring Tinian regularly visit the island.

Field Surveys

We established observation stations at 370-m intervals on a grid that covered the entire island. The spatial distribution of stations was dictated by available labor and equipment. Fifty stations were surveyed for Pacific sheath-tailed bat activity between 9 and 18 September 2003. The location of each station was recorded with a global positioning system. We experienced some difficulty in finding the exact location of each station in the dark, thus our grid was somewhat irregular, but nevertheless sampled the entire island (Fig. 1).

Habitat type was recorded at all stations as (1) native forest, (2) non-native forest, or (3) non-forest (e.g., open fields and strand vegetation). We estimated the percentage of the island covered by each vegetation type based on the proportion of stations assigned to each habitat category.

An observer listened for echolocation calls at each station for 30 min between 19:00 and 23:15 h using a Pettersson Elektronik AB, D-100 Ultrasound Detector (Uppsala, Sweden). In forests, and at non-forested sites where ground cover was sparse, detectors were set on the ground with the microphone oriented upward at ca. 45°; at some non-forest stations ground cover was dense and detectors were placed slightly above the vegetation. Sampling of all three habitat types was spread throughout the nightly survey period (i.e., 19:00–23:15 h) and over the course of the study (i.e., 9–18 September 2003) to reduce potential problems created by within- and among-night temporal variation in activity. Bat activity was surveyed at all stations by one of two observers (JAE & GJW); each observer used the same individual D-100 detector for all surveys, so any differences between observers/detectors could be assessed and, if necessary, controlled for in the analysis. At each station survey, we noted the start time and counted the number of passes heard. A pass was defined as a sound heard through the detector that was clearly attributable to *E. semicaudata* and lasted for at least one second.

Detectors were set on 30 kHz throughout the study. This was determined to be the appropriate frequency during a visit in March 2002 when JAE, using

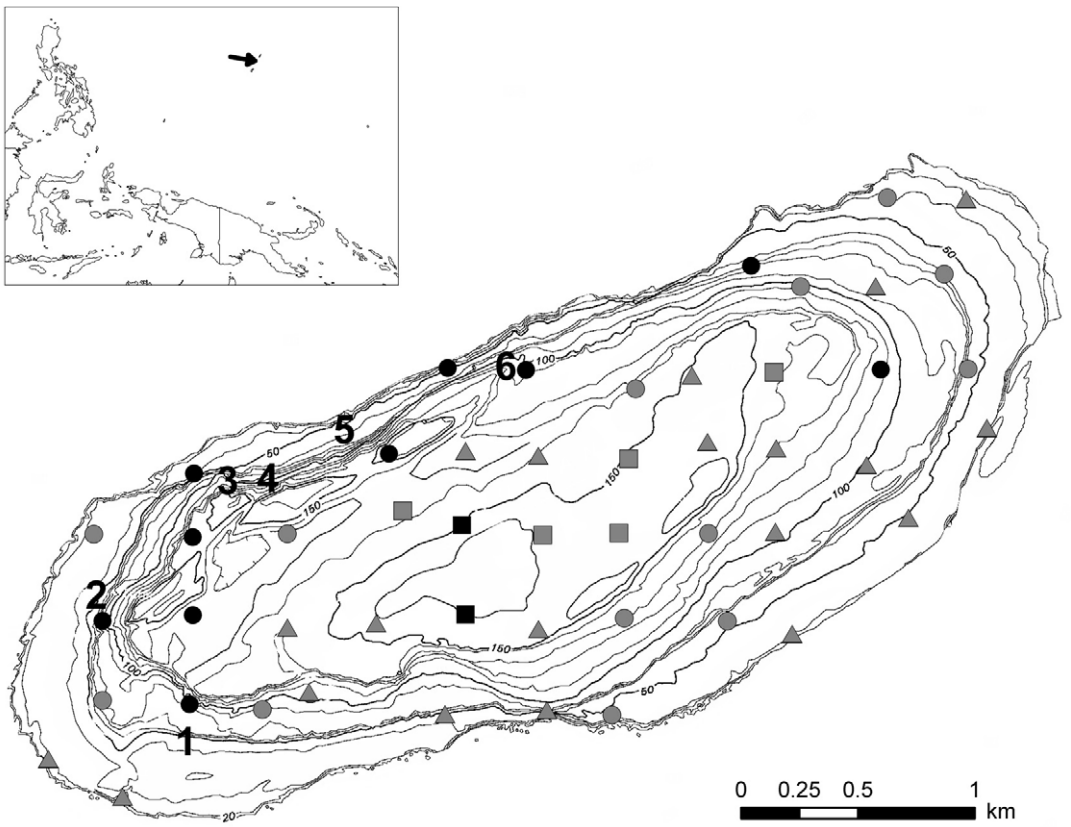

FIG. 1. Map of Aguiguan showing the location of 50 acoustic survey stations. Stations in native forest are marked with a circle, stations in non-native forest are marked with a square, and stations in non-forest habitat are marked with a triangle. Stations where Pacific sheath-tailed bats were detected are black; stations where bat activity was not documented are grey. Roost caves are labeled as follows: 1, Crevice Cave; 2, Guano Cave; 3, Pillar Cave; 4, Cliff Cave; 5, East and Middle Black Noddy caves; and 6, Fault Line Cave One. Inset shows location of Aguiguan in the western Pacific Ocean

an Ultra Sound Advice Mini-3 Bat Detector (London, UK), observed much bat activity (n = 67 passes) at 30 kHz under a variety of circumstances. During this test period, the detector was constantly tuned over a wide range of frequencies, and bats were clearly detected at 30 kHz whenever they were observed.

We performed exit and/or direct counts at seven cave roosts and searched 49 other caves for roosting bats. Two roost sites (Middle Black Noddy and East Black Noddy Caves) were about 10 m apart, and may in fact be linked and house a single colony. More extensive surveys were conducted in 1995, when 78 caves and 21 hollow trees were searched for bats (G. J. Wiles and D. J. Worthington, unpubl. data); six of the seven known roosts were identified at that time. The new roost found in 2003 held a single bat. We believe that we have identified all major roost sites on the island, but we may have overlooked some sites holding small numbers of animals. For the analysis, we assumed that all roost sites were identified.

Data Analysis

An index of proximity from each survey station to known roost sites was calculated as:

$$P = \frac{\sum_{i=1}^{6}[(1/d^2)\ n_i]}{c}$$

where P = proximity, d = distance to roost site in kilometers (measured in ArcView 3.1 to the nearest meter), n = estimated population of roost i, and c = number of roost locations. Estimates of roost populations were taken from direct and exit counts conducted between 10 and 18 September 2003: East and Middle

Black Noddy Caves, 296 bats (exit counts); Guano Cave, 30 bats (exit and direct counts); Pillar Cave, 7 bats (exit counts); Cliff Cave, 4 bats (exit count); Crevice Cave, 2 bats (exit count); and Fault Line Cave One, 1 bat (direct count).

We examined relative activity in the three habitat types using a generalized linear model according to the GENMOD procedure in SAS version 8 (SAS Institute, 1999). For this analysis, we assumed that passes were independent events, acoustic events occurred in the habitat type in which they were documented, and the number of passes recorded reflected amount of use. We first constructed a model controlling for potential nuisance variables. These included (1) proximity to known colonies (continuous co-variate), (2) observer/detector used (categorical variable), and (3) time of survey (continuous co-variate). We used a type III analysis and a stepwise elimination process whereby the least significant term in the model was removed until only terms that were significant at the 10% level remained. Finally, we added habitat type into the model and examined the significance of its effect. Because activity levels were recorded as a count of passes during the 30-min surveys, models were analyzed using a Poisson error structure and log-link function. Over-dispersion was controlled for in the model using the d-scale parameter (SAS Institute, 1999).

Opportunistic Observations

Additionally, we observed active bats on numerous occasions during our stay in September 2003 and other trips to the island in March 1995, May–June 1995, and March 2002. Behavior and habitat use were noted for all animals.

Results

We estimated that Aguiguan is covered by ca. 46% native forest, 14% non-native forest, and 40% non-forest. Bat activity was detected at 12 stations (Fig. 1). Ten of the 12 stations were in native forest and two were in non-native forest. We did not detect bat activity at any of the 20 stations in non-forest habitats.

Number of passes at a station was positively influenced by proximity to colonies ($F_{1, 46} = 9.64$, $P < 0.01$). Observer/detector used had a significant effect ($F_{1, 46} = 8.24$, $P < 0.01$), as did the time at which a station was surveyed ($F_{1, 46} = 12.25$, $P < 0.001$). After controlling for the influence of these variables, habitat type had a significant influence on number of passes ($F_{2, 44} = 14.18$, $P < 0.001$). Activity levels were significantly higher in native ($F_{1, 44} = 26.89$, $P < 0.001$) and non-native forests ($F_{1, 44} = 15.93$, $P < 0.001$) than in areas of non-forest. No significant difference existed in the number of passes between native and non-native forest ($F_{1, 44} = 1.48$, $P = 0.23$; Fig. 2).

We encountered active *E. semicaudata* on numerous occasions ($n = 46$ individuals) outside of station surveys and colony counts, with all but one individual documented in native forest. Bats were regularly seen foraging in the forest understory to within 1 m of the ground, with some activity at tree-top level and above the forest canopy. The only bat seen outside native forest was observed in March 2002 circling rapidly at twilight around a row of large ironwood trees (*Casuarina equisetifolia*) in an open field, approximately 50 m from the nearest forest edge.

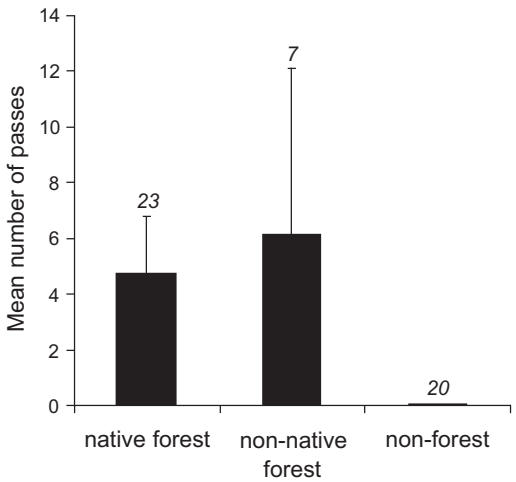

Fig. 2. Mean number of passes per station by Pacific sheath-tailed bats in three habitat types sampled on Aguiguan, Mariana Islands. Passes were documented at 10 native forest stations, two non-native forest stations, and no non-forest stations. Error bars represent 1 SE with number of stations surveyed given above each error bar

Discussion

Our study documents a clear association of *E. semicaudata* with forests on Aguiguan; non-forest habitats appear to be largely avoided by the species. The acoustic survey provided only a snapshot of habitat use, but our anecdotal observations, which have a much greater temporal spread found 45 of 46 animals in native forest, and thus reinforce the conclusion that forests are the most important foraging habitat for Pacific sheath-tailed bats on Aguiguan. Although our temporal sampling was limited, our geographical coverage sampled the entire range of what is likely the only surviving population of *E. s. rotensis*. Furthermore, we consider the observed difference in relative activity between forest and non-forest habitats to be conservative because ultrasonic detectors generally detect echolocation calls at greater distances in open environments than in forests (Hayes, 2000). Thus, because we likely sampled a greater volume of space at non-forest stations than at stations in forest, the difference in relative activity between the two habitat types may be greater than estimated.

The similar activity levels documented in native and non-native forests should be viewed with caution. Only seven stations were located in non-native forests and activity was documented at two of these (42 passes and 1 pass each). With such a small sample, the potential for edge effects to influence results increases (i.e., violation of the assumption that passes occur in the habitat type in which they were documented). Indeed, at both of these stations, observers noted that calls were faint, indicating that the bats may not have been close. We did not see any of the bats at these stations, nor did we detect *E. semicaudata* in non-native forests at other times.

Habitat preferences of *E. semicaudata* have not been studied on other Pacific islands; however, Bruner and Pratt (1979) observed active *E. semicaudata* beneath the canopy of dense native forest on Pohnpei and commonly over town streets in Palau and Chuuk. Additionally, GJW has seen *E. semicaudata* foraging over roads on Pohnpei and a large lawn with scattered coconut trees (*Cocos nucifera*) in Chuuk. Combined, these observations suggest that there is variation in habitat use among and within subspecies.

Preservation of forest on Aguiguan is critical because of the reliance of *E. s. rotensis* and a number of other wildlife species (e.g., *Pteropus mariannus*) on this habitat (Engbring *et al*., 1986; Wiles *et al*., 1989). Forests are currently somewhat extensive on the island (ca. 60%, although this translates to only 4.3 km^2 in area), yet prospects for their long-term persistence are uncertain because feral goats are severely limiting regeneration of most tree species. Only two apparently unpalatable tree species (*Guamia mariannae* and *Cynometra ramiflora*) appear capable of reproducing under the current level of browse. If the goat population is not eradicated or permanently reduced, Aguiguan's forests will very likely lose much of their present diversity, and experience great structural alterations. Given sufficient time, it is conceivable that goats could eliminate forests from the island. It is difficult to predict how *E. s. rotensis* may respond to extensive habitat alterations, but extinction of the subspecies seems a possibility. Unfortunately, local opposition to eradication of goats is substantial because hunters from Tinian wish to maintain a readily available supply of game. Nevertheless, if control programs are undertaken in the future, knowledge of the foraging behavior of *E. s. rotensis* would be valuable in predicting potential changes in habitat use in response to an expected increase in forest understory clutter.

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