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Distribution and Abundance of the Endangered Hawaiian Hoary Bat, *Lasiurus cinereus semotus*, on the Island of Hawai'i[1]

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ABSTRACT: The endangered Hawaiian hoary bat, *Lasiurus cinereus semotus* (H. Allen), has an island-wide distribution on the island of Hawai'i. However, abundance estimates suggest that its endangered status is appropriate. Although distributed across wide ranges in elevation, temperature, and rainfall, this bat is most often associated with native vegetation. Its diurnal and seasonal activity patterns argue against migration within the island of Hawai'i. These patterns suggest that the Hawaiian bat uses more than one foraging site and that its use of foraging sites is influenced by changes in insect biomass.

THE HAWAIIAN HOARY BAT, *Lasiurus cinereus semotus* (H. Allen), is the only extant species of bat in the Hawaiian Archipelago. Although it has been on the endangered species list since 1970 (Tomich 1986), no recovery plan exists. This is partly because very little is known about the natural history or the distribution and abundance of this bat. Information on its distribution is limited to reports of incidental sightings on the island of Hawai'i (Baldwin 1950, Bryan 1955, Tomich 1986) and Maui (Duvall and Gassman-Duvall 1991) or comes from surveys peripheral to surveys conducted for forest birds (Kepler and Scott 1990). The only focused survey on the distribution and abundance of the Hawaiian hoary bat was an echolocation census conducted by J. H. Fullard (unpublished) on Kaua'i. The little that is known about the distribution and abundance of the Hawaiian hoary bat is confusing. For example, it is reported as both common (R. C. L. Perkins 1913, as cited in Baldwin 1950) and rare (Baldwin 1950, Kepler and Scott 1990) at higher elevations on the island of Hawai'i.

The purpose of this study was to locate areas on the island of Hawai'i where bats occurred regularly and to estimate the abundance of this bat in such areas. Both visual observation and echolocation censuses were used.

MATERIALS AND METHODS

The survey was undertaken on the island of Hawai'i over a 3-yr period (1990 to 1992) for a total of 360 hr spread over 101 days. Bat echolocation calls were monitored by driving at speeds of 25–40 km hr^{-1} along roads accessible to two-wheel-drive vehicles (Figure 1). The echolocation calls were monitored using a QMC Mini Bat Detector (QMC Instruments Ltd., 229 Mile End Road, London E1 4AA, England) tuned to a frequency of 30 khz, which is the peak frequency of the Hawaiian bat's echolocation calls (Belwood and Fullard 1984). Each section of road was traversed at least twice (once in each direction) between 1830 and 2030 hr each night of survey. Sections of road were surveyed on at least two successive nights during September and October of 1990. The direction that surveys were begun on successive nights was reversed to reduce the effects of time of night.

Visual observations were also carried out at localities selected on the basis of the type of habitats in which bats were previously seen foraging (Tomich 1986; Hawaiian Heritage Program, 1992, database of rare and endangered plants, animals, and natural communi-

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ties of the Hawaiian islands, The Nature Conservancy, Honolulu, Hawai'i.). Surveys at these sites commenced at dusk and lasted until dark, a period of about 1 hr. The number of bats at each site was conservatively estimated by counting the maximum number of bats that could be seen at any one time. Counts were made every 10 min, and the largest count in the hour of the survey was recorded. Because these bats dart in and out of foliage and one's field of view, they are not all visible at the same time.

Three of the sites (Kīpāhoehoe, Red Cinder Road, and Ocean View) were also surveyed after dark using a bat detector. During that time surveys were conducted every half hour from 1900 to 2400 hr, and every hour from 2400 to 0600 hr, for two nights at the first two sites and six nights at Ocean View. When using the bat detector each detection was counted as a single bat. A fourth site (Wai'ono Ranch) was also surveyed from just before dawn to about 1 hr after sunrise, on two consecutive days.

Sites where bats were seen on the first night were surveyed again at least once. With the exception of Ocean View, which was surveyed from May 1991 to October 1992; Pōhakuloa, which was surveyed from May to October 1992; and Hawai'i Volcanoes National Park, which was surveyed in October 1992, all sites were surveyed between September and October 1990, and from February to August the following year. The insect fauna at Ocean View was sampled by means of a 22-watt ultraviolet insect light trap (BioQuip Products), from February to October 1992.

RESULTS

Visual Observation

Bats were seen at 16 of the 26 sites visited (Figure 1). Two of the 16 sites were visited only once. These were located at Pu'uhonua o Hōnaunau Historical Park on the leeward coast (maximum count of two bats in 1 hr of visual observation) and at the entrance to the Kūlani Correctional Facility (maximum count of three bats in 1 hr of visual observation) at the end of Stainback Highway. At the remaining 14 sites, bats were observed on two or more consecutive nights, during September and October (Table 1). They can therefore be regarded as sites used regularly by the bats (at least at some times of the year [see *Temporal Patterns*]).

The largest number of bats seen in the hour from dusk to dark at each of the 14 sites is a conservative estimate (Table 1). For example, at the Red Cinder Road site (at about the 70-mile marker on Highway 11), the maximum number of bats observed was 5, but 12 different individuals were captured at this site over 14 trap nights.

In September 1990 I saw a total of 15 bats flying, singly or in pairs, upslope from below Highway 11 over Kīpāhoehoe Natural Area Reserve and disappearing over the horizon high up the slope of Mauna Loa. Similar sightings have been made over the Manukā Natural Area Reserve about 10 miles (16 km) to the south of Kīpāhoehoe (Fujioka and Gon 1988).

Echolocation Monitoring

Almost all of the bats detected by echolocation monitoring were concentrated south of Kailua (Kona) between the 80- and 96-mile markers along Highway 11 (Figure 1). A total of 18 bats (i.e., 18 detections) were detected between the 80- and 96-mile markers over two nights of survey (4.25 ± 1.78 bats per traverse). Not a single observation or echolocation detection was made in northwestern and southwestern Kohala on the leeward side of the Island. However, 40% of all bat sightings occurred on the drier leeward side of the Island south of Kailua, compared with 26% on the wetter windward side.

Context of Observations

ECOLOGICAL. The bats were all in flight and obviously foraging at the 16 sites where they were seen. They displayed the darting, weaving flight, with sudden turns and dives, characteristic of foraging insectivorous bats that catch their prey on the wing. Bats detected (using the bat detector) along Highway 11 may have been foraging as well. Visual obser-

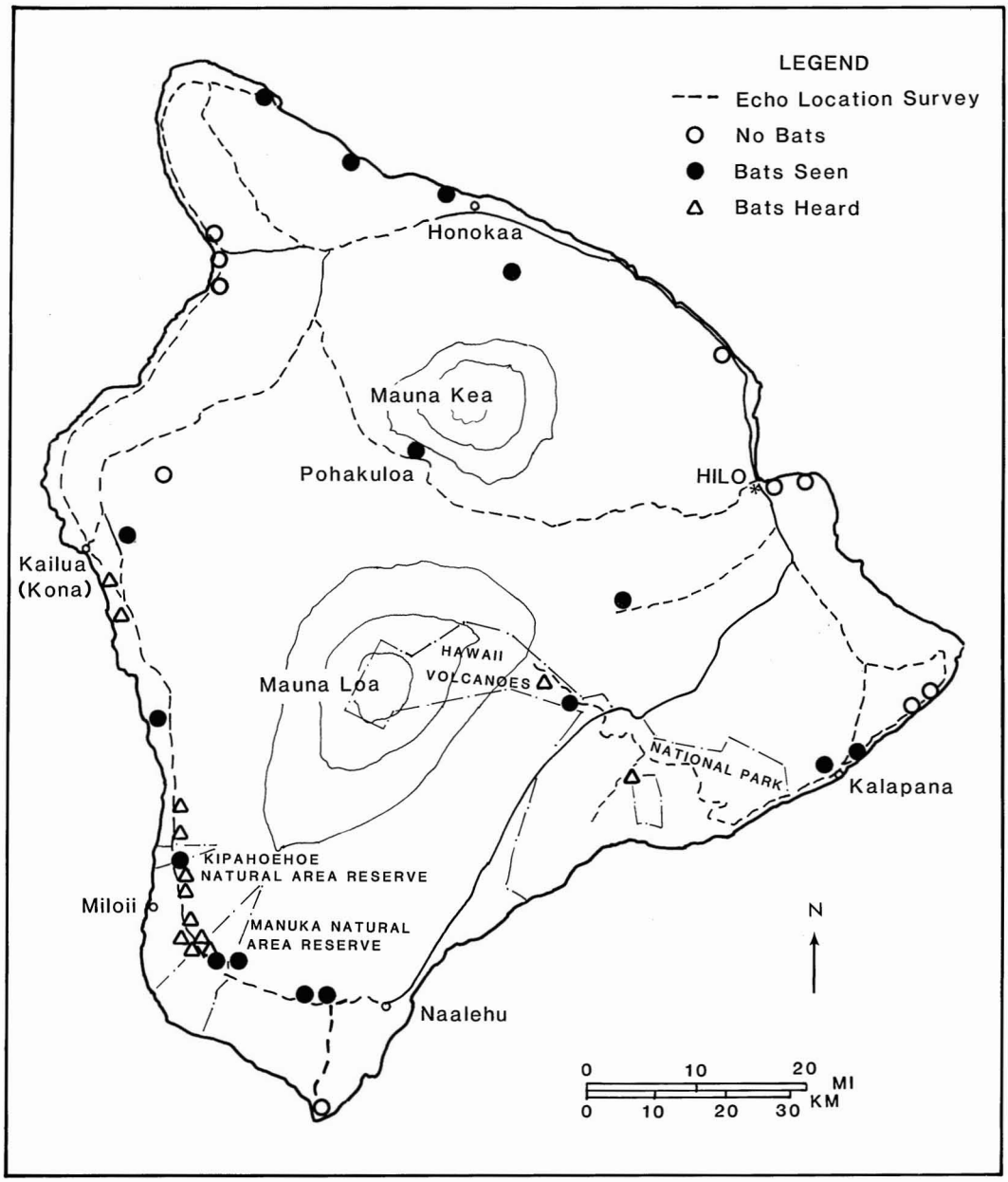

FIGURE 1. Distribution of Hawaiian hoary bat sightings and echolocation detections on the island of Hawai'i. Circles indicate 26 sites surveyed for bats: open circles indicate sites at which no bats were seen; closed circles indicate sites where bats were seen on at least two consecutive nights. Dashed lines indicate the roads along which echolocation surveys were conducted; triangles indicate areas where bats were heard during the echolocation surveys.

TABLE 1

NUMBERS OF BATS AT EACH FORAGING SITE ON THE ISLAND OF HAWAI'I

LOCATION	% OF VISITS BATS WERE OBSERVED	NO. OF VISITS	NO. OF BATS
Kīpāhoehoe Natural Area Reserve (Highway 11, 90- to 92-mile markers)	100	5	10
Manukā Natural Area Reserve (Highway 11, 80- to 82-mile markers)	100	5	4
Red Cinder Road (off Highway 11, near 70-mile marker)	77	13	5
Highway 11 (70-mile marker)	60	5	7–10
Kaimū Bay (Puna)	100	2	3–4
Kalapana (Puna, over new lava flow)	100	2	5
Kalōpā State Park (Hāmākua)	100	2	2
Honoka'a (St. George's Cemetery, Lehua Street)	100	5	2–3
Waimanu Bay (North Kohala)	100	2	5
Kēōkea Bay (North Kohala)	100	2	11
Ocean View (intersection of Hukilau and Tree Fern avenues, South Kona)	100	6	4
Pōhakuloa (Bradshaw Military Airfield)	100	7	7–10
Wai'ono Ranch (Kailua-Kona)	100	4	3–5
Hawai'i Volcanoes National Park	100	2	2–3

NOTE: Data are results of surveys conducted between August and October (see text).

vations of foraging bats before nightfall along Highway 11, especially those parts of the road at or near Kīpāhoehoe and Manukā Natural Area Reserves, suggest that the bats detected after nightfall along this section of road may have been foraging as well.

The 15 bats observed flying over Kīpāhoehoe Natural Area Reserve in September 1990 appeared to be in transit. These bats were flying very high (>150 m) and did not display the darting and weaving flight characteristic of a foraging bat.

TEMPORAL PATTERNS. *Diurnal activity patterns.* The commencement and duration of foraging activity varied slightly from site to site. For example, during September and October (1990 and 1991) bats started foraging at Red Cinder Road at 1800 hr or immediately thereafter. At the Ocean View and Kīpāhoehoe sites, on the other hand, they first appeared between 1830 and 1845 hr. At the latter two sites the bats remained active until about 0200 hr. There was, however, a peak in activity just before sunset (four bats visible in the hour from dusk to dark), which dropped slightly as the night progressed (two bats detected per hour). At Red Cinder Road, activity came to an almost complete stop at about 1900 hr. In five nights of surveying, only one bat was detected briefly after 1900 hr—at 2100 hr on two separate occasions. Pōhakuloa (Bradshaw Military Airfield) was different in that there did not appear to be a drop in activity. The number of bats remained constant at least until 0230 hr when observation ceased.

Early morning foraging was observed. Between three and five bats were observed on two consecutive mornings foraging just before dawn and for at least 45 min after sunrise at Wai'ono Ranch (Kailua-Kona). At Kīpāhoehoe, the only other site at which bats were observed foraging at dawn, a single bat was seen on one of the two mornings of sampling. Early morning foraging in bats has also been reported on Maui (Duvall and Gassman-Duvall 1991).

Seasonal activity patterns. There appeared to be a drop in activity at most foraging sites between February and August (Table 2). At Kīpāhoehoe, Manukā, and Red Cinder Road, bat sightings dropped to three bats over three nights of sampling. Bats did not spend much time at these sites. Most of them made one to three foraging circuits before disappearing. At Ocean View, sightings dropped to one bat over four nights of sampling in February and

TABLE 2

NUMBERS[a] OF BATS AT VARIOUS FORAGING SITES FOR DIFFERENT MONTHS

LOCATION	MONTH[b]					
	FEBRUARY	MAY	JUNE	AUGUST	SEPTEMBER	OCTOBER
Kīpāhoehoe Natural Area Reserve	0.5 ± 0.5 (2)	0 (2)	—	1 (1)	10 ± 0.0 (2)	—
Manukā Natural Area Reserve	0.5 ± 0.5 (2)	1 ± 0.0 (2)	—	0 (1)	4 ± 0.0 (2)	—
Red Cinder Road	0.5 ± 0.5 (2)	0 (2)	—	0 (1)	5 ± 0.0 (2)	3.6 ± 2.2 (11)
Highway 11 (70-mile marker)	0 (2)	0 (2)	—	0 (1)	5.7 ± 2.6 (2)	—
Kaimū Bay	0 (2)	0 (2)	—	0 (1)	3.5 ± 0.5 (2)	—
Kalōpā State Park	0 (2)	0 (2)	—	0 (1)	2 ± 0.0 (2)	—
Kēōkea Bay	0 (2)	0 (2)	—	0 (1)	11 ± 0.0 (2)	—
Ocean View	0.25 ± 0.5 (4)	3.4 ± 0.5 (5)	3.4 ± 0.5 (2)	5.6 ± 2.5 (4)	4.5 ± 1.7 (4)	3.5 ± 1.7 (2)
Pōhakuloa (Multipurpose Range Complex)[c]	0.75 ± 0.5 (4)	0.2 ± 0.5 (4)	0.7 ± 1.0 (4)	0.5 ± 0.6 (4)	2.7 ± 2.1 (4)	—

[a] Mean ± SD, sample size in parentheses.
[b] See text for year.
[c] Data from Hawaiian Heritage Program database (see text).

to four bats over three nights of sampling in March. From May to August the numbers of bats increased at this site and returned to the September/October (1991) levels (Table 2), with the exception of a decrease in activity during July and October (Figure 2). The drop in activity at Ocean View seems to be correlated with a drop in insect biomass (Figure 2). In the Multipurpose Range Complex of the Pōhakuloa Military Training Area, along the Bobcat trail (1800 m elevation), between one and three bats were seen and/or detected over a sampling period of four nights for each month between February and August 1992 (Table 2). This number increased to 11 bats over four sampling nights in August (Hawaiian Heritage Program database). Incidental sightings of bats at Hakalau Forest National Wildlife Refuge (1890 m elevation) by Jaan Lepson (pers. comm.) followed the same pattern. Although bats were seen between January and August, most sightings occurred from September to December. No bats were seen or detected at any of the other sites between February and August during the survey reported here (Table 2). Bat numbers remained constant at Pōhakuloa (Bradshaw Military Airfield) from May to October.

Environmental Correlates

HABITAT CHARACTERISTICS. The 14 foraging sites can be divided into four habitat categories: native vegetation, exotic vegetation, mixed (native and exotic) vegetation, and open ocean (Table 3). Of the 81 bats observed at these sites (Table 1), 44% were associated with native vegetation, 16% with exotic vegetation, 9% with mixed vegetation, and 25% foraged over open ocean. Bats were therefore associated more with native vegetation than with exotic vegetation, contrary to what Kepler and Scott (1990) found.

TEMPERATURE. The foraging sites of the Hawaiian bat extend over an elevational

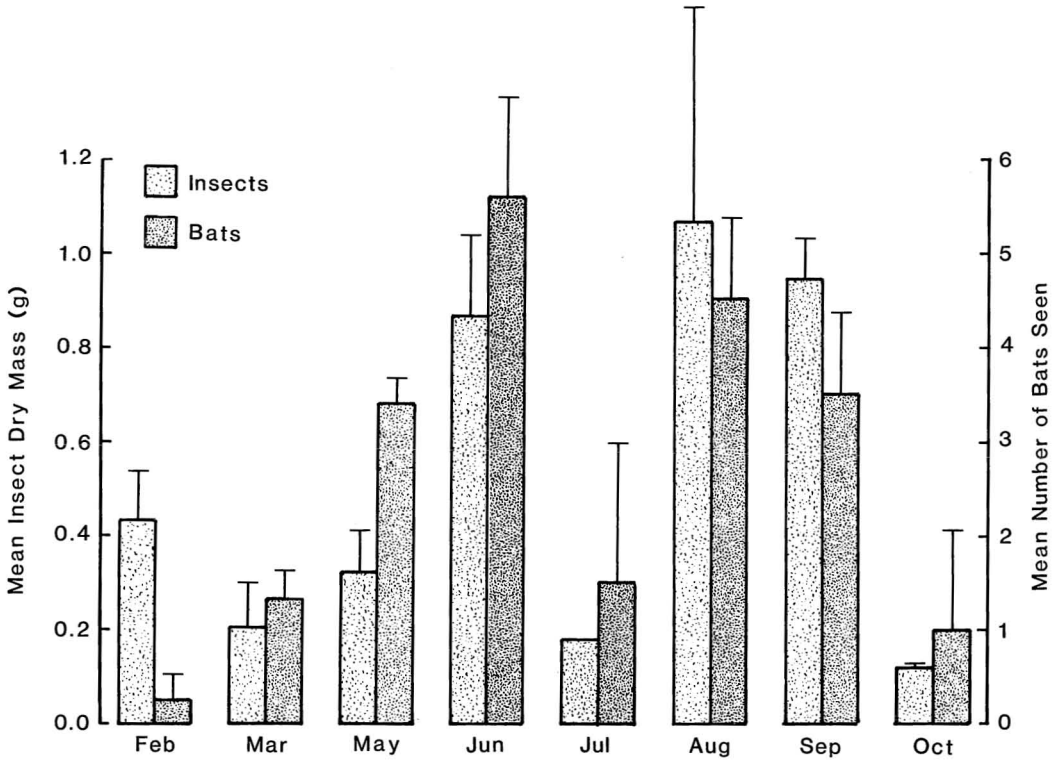

FIGURE 2. Mean insect biomass and mean numbers of the Hawaiian hoary bat seen at Ocean View on the island of Hawai'i, in different months of 1992.

TABLE 3

ELEVATION AND VEGETATION ASSOCIATED WITH EACH BAT FORAGING SITE

LOCATION	ELEVATION (m)	VEGETATION	TYPE[a]
Kīpāhoehoe Natural Area Reserve	386	*'Ō'hia* lowland mesic forest	N
Manukā Natural Area Reserve	548	*'Ō'hia* lowland mesic forest	N
Red Cinder Road	593	*'Ō'hia* lowland mesic forest/eucalyptus	M
Highway 11 (70-mile marker)	593	Eucalyptus trees/exotic shrubs	E
Kaimū Bay	Sea level	Open ocean	
Kalapana	60	Open lava	
Kalōpā State Park	549	*'Ō'hia*/eucalyptus forest	M
Honoka'a	354	Eucalyptus/macadamia orchard	E
Waimanu Bay	Sea level	Open ocean	
Kēōkea Bay	Sea level	Open ocean	
Ocean View	665	*'Ō'hia* lowland mesic forest	N
Pōhakuloa	1,830	*Mamani–naio* (*Sophora chrysophylla–Myoporum sandwicense*) open woodland	N
Wai'ono Ranch	1,070	*'Ō'hia* forest interspersed with grass fields	N
Hawai'i Volcanoes National Park	1,220	*Koa* (*Acacia koa*) forest	N

[a]N, native; E, exotic; M, mixed (native and exotic).

range of 0–1830 m (Table 3). The climatic conditions experienced by these bats therefore range from tropical to temperate. At elevations below 1500 m, temperatures above 35°C are infrequent and the range between the coldest and warmest months averages 6.5°C. The average temperature at Hilo (sea level) in August is 24.1°C and in January is 21.6°C. The average temperature at Mauna Loa Observatory (3398 m) in January is 5°C and in August is 8°C (Blumenstock and Price 1972). However, at times the upper slopes and summits of Mauna Loa and Mauna Kea are covered in snow during winter months. Cold air formed immediately above this snow cover descends into areas like Pōhakuloa and Hakalau, causing temperatures as low as −15°C (Blumenstock and Price 1972). The Pōhakuloa and Hakalau sites are at elevations of about 1830 and 1890 m, respectively. The result is that these sites often experience frost during winter.

RAINFALL. Bats were observed most frequently in areas with moderate rainfall. Eight of the 14 foraging sites had a mean annual rainfall ranging from 1016 mm to 1905 mm. Four had a mean annual rainfall ranging from 1905 to 2540 mm. Pōhakuloa had a mean annual rainfall of 508 mm (rainfall figures from Armstrong [1973]).

Bats at Red Cinder Road and Kīpāhoehoe sites generally were not active when it rained. In fact on nights when it rained just before or just after the time the bats were usually seen at those sites, the foraging aggregations did not appear and at most one or two bats were seen. However, at Kalōpā State Park on the windward side of the Island, two bats were observed foraging in a light rain for at least 30 min.

WIND. In general there was little to no wind at the inland foraging sites. The tall vegetation characteristic of most of these sites provided a natural windbreak. However, these bats are fairly strong flyers. I have observed them flying without much difficulty in fairly strong winds. At Pōhakuloa, where the vegetation was predominantly low *mamani–naio* (*Sophora chrysophylla–Myoporum sandwicense*) forest, wind speed ranged from 3 to 6 km hr^{-1}, occasionally gusting to 11 km hr^{-1}, on 60% of the nights surveyed.

DISCUSSION

Visual observations and echolocation monitoring suggest that the Hawaiian hoary bat is fairly widespread around the island of Hawai'i. Although bats appear to be more abundant on the drier leeward side of the Island, they may not be as rare on the windward side of the Island as previously thought (Kepler and Scott 1990). The largest foraging aggregation (11 bats) was seen in September 1990 over Kēōkea Bay on the windward coast. Large groups of bats have been reported on the windward side of the island: 12 bats over Hilo Bay in September 1963 and 22 bats at Honoka'a landing in October 1964 (Tomich 1986). A more extensive survey of that coastline needs to be undertaken. I have received reports from surfers of bats foraging over water all along that coast.

There seems to be a decrease in bat activity from February to August (Table 2). The drop in activity occurs over a wide elevational and geographical range. In addition, bats are present as early as May at Ocean View and Pōhakuloa (Bradshaw Military Airfield), two sites with very different elevations and geographical locations. These patterns argue against an elevational or geographic migration within the island of Hawai'i.

The drop in bat activity with the drop in insect biomass at Ocean View suggests that these bats may use a number of foraging sites over a course of a night or a few days. The particular sites used depend on local insect biomass. Radio telemetry data (unpublished data) indicate that bats do use more than one foraging site per night and that a bat may stay away from a previously visited site for up to 2 weeks. If this is the case, the apparent drop in activity from February to August at some sites may be associated with times when bats were foraging elsewhere because of low insect biomass at those sites on nights when they were surveyed.

The apparent increase in bat activity in September/October (in terms of the number of sites at which bats were seen) may be the result of young of the year fledging. Capture data (unpublished data) suggest that lactation occurs in June and July and young are fledged sometime in August.

In conclusion, the numbers of bats reported here for the different sites at different times of the year suggest that the Hawaiian hoary bat is rare and that its endangered status is appropriate. The fact that the habitats used by this bat are more often than not associated with native vegetation suggests that the major threat to its existence in Hawai'i may be the destruction of native vegetation. Protection of native vegetation is, therefore, essential to the survival of *Lasiurus cinereus semotus* in Hawai'i. This may become even more evident when the roosting ecology of this bat is studied.

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