DOE/OR/22088--1

U.S. FISH AND WILDLIFE SERVICE
Pacific Islands Office, Ecological Services

SURVEYS ON THE DISTRIBUTION AND ABUNDANCE OF THE HAWAIIAN HOARY BAT (*LASIURUS CINEREUS SEMOTUS*) IN THE VICINITY OF PROPOSED GEOTHERMAL PROJECT SUBZONES IN THE DISTRICT OF PUNA, HAWAI'I

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Final Report
August 1994

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INTRODUCTION

In 1993 the U.S. Fish and Wildlife Service (USFWS) entered into an interagency agreement with the Department of Energy (DOE) to conduct wildlife surveys relative to identifying potential impacts of geothermal resource development on the native biota of the east rift zone of Kilauea volcano in the Puna district on the island of Hawai`i. This report presents data on the endangered Hawaiian hoary bat (Hawaiian bat), or ope`ape`a (*Lasiurus cinereus semotus*), within the proposed Hawai`i geothermal subzones. Potential effects of geothermal development on Hawaiian bat populations are also discussed.

Surveys were conducted to determine the distribution and abundance of bats throughout the District of Puna. Baseline information was collected to evaluate the status of bats within the study area and to identify important foraging habitats. Little specific data exists in the published literature on the population status and potential limiting factors affecting the Hawaiian bat. A USFWS recovery plan does not exist for this endangered species.

Species Biology

The Hawaiian bat is the only land mammal native to Hawai`i. Its colonization of Hawai`i was most likely the result of a group of bats or a single pregnant female that became disoriented during migration and accidently crossed the Pacific Ocean. Bats have been recorded on all the main Hawaiian islands, with the largest populations on Kaua`i and Hawai`i (Tomich 1974). On Hawai`i they inhabit both wet and dry areas, but are thought to be more abundant on the drier, leeward side of the island. They are most often seen between sea level and 1,000 m (3,280 ft) elevation, but occur as high as 4,115 m (13,500 ft) (Kepler and Scott 1990; Kramer 1971; Kujioka and Gon 1988; Tomich 1974).

The Hawaiian hoary bat was observed during the earliest expeditions to the Islands, but it was not scientifically named and described until 1890 (Kramer 1971; Tomich 1986). The Hawaiian bat is a subspecies of *Lasiurus cinereus* from North and South America. Smaller than the American species, the wingtip-to-tip length of the Hawaiian subspecies measures 26.9-34.6 cm (10.5 to 13.5 inches), and its body length is 8.2-9.7 cm (3.2 to 3.8 inches). The ears are small and lie close to the head. They weigh from 14 up to 22 grams (0.5-0.8 oz) (Kramer 1971; Tomich 1986). The USFWS listed the Hawaiian hoary bat endangered in 1970 (USFWS 1973).

Little information exists on the reproductive biology of the Hawaiian bat. Baldwin (1950) concluded they breed in early summer, based on finding a pregnant female bat in May carrying two fetuses. He collected a second female in November that was not pregnant. Kepler and Scott (1990) reported that a female bat was found in June on Kaua`i carrying two full-term fetuses. An additional immature bat, recovered from a barbed wire fence on June 23, had been born earlier that summer. In this respect, the Hawaiian hoary bat does not differ from its American ancestors which give birth to two young in June. (Bogan 1972, as cited in Kepler and Scott 1990).

Isolation and lack of competition from other bat species has caused some evolutionary changes in the Hawaiian bat since its arrival to the islands (Jacobs 1993a; Kramer 1971). Two physical characteristics that have changed over time in the Hawaiian hoary bat are body and skull size. The body size of the bat has undergone a 45 percent decrease, resulting in a reduction of the ratio of mass to wing area. This allows the bat to forage in dense vegetation where a slower, more erratic flight is necessary. Skull size has increased, with the larger skull giving the bat more jaw power, apparently enabling it to eat a broader variety of insects (Jacobs 1993a).

The Hawaiian hoary bat is an insectivore, selecting prey primarily based on size, abundance, and ease of capture (Belwood and Fullard 1984; Jacobs 1993a). Jacobs (1993c) found that bats consumed mostly beetles in closed forest but more moths in open areas. Bats typically leave their roosts before sunset and return around midnight ($\pm$ 2 hrs) (Jacobs 1993c; Kepler and Scott 1990). Dawn bat activity has also been recorded (Duvall and Gassmann-Duvall 1991; Jacobs 1993a; USFWS 1993). Bats are generally not as active in heavy rainfall, but strong winds, fog, and low temperatures do not seem to affect feeding activity (Belwood and Fullard 1989). The mainland Hoary bat is most active between 0-22 degrees C, indicating its feeding activity and distribution is limited by temperature (Jones 1965).

Bats have been documented foraging over open ocean, streams, ponds, forest clearings and edges, lava flows and some agricultural fields (Baldwin 1950; Kujioka and Gon 1988; Kepler and Scott 1990; Tomich 1974). Bats have also been observed foraging in closed canopy forest (Jacobs 1993a; USFWS 1993). Jacobs (1993b) found the Hawaiian hoary bat traveled between at least two different foraging areas each night, and many different sites were used by an individual over a period of two weeks. Tomich reported "regular" feeding areas and Kramer (1971) described bats foraging activities as pre-determined. Contrary to findings by Kepler and Scott (1990), Jacobs observed bats foraging more frequently in areas with native vegetation than in areas dominated by exotic vegetation.

Hawaiian bats roost singly in tree foliage, and show a high degree of roost fidelity (Jacobs 1993b). Females give birth and raise young at the roost site. A Hawaiian bat was reported roosting in a hala (*Pandanus tectorius*) tree (Baldwin 1950); and Bryan (1955) collected one roosting in a kukui (*Aleurites moluccana*) tree. Other observations by Kramer (1971) include roost sites in pukeawe (*Styphelia tameiameiae*) and java plum (*Eugenia cumini*). However, a recent radio-telemetry study indicated significant use of native ohia (*Meterosideros polymorpha*) trees for roosting (Jacobs 1993b). Jacobs suggests native forests are significant to the survival of the Hawaiian bat, supporting previous conclusions by Fullard (1989) and Tomich (1974).

OBJECTIVES

Hawaiian bats have been suspected to be roosting, breeding, and foraging within the proposed geothermal project area. However, limited data exist on the current distribution of bats in the Puna district. Survey objectives were to determine:

1) the presence and distribution of Hawaiian hoary bats within the vicinity of geothermal subzones and surrounding areas;

2) the relative abundance of bats in geothermal subzones and surrounding areas;

3) the location of foraging areas;

4) habitat characteristics of foraging areas;

5) temporal and seasonal activity patterns.

6) potential impacts on the bat due to development in the Puna area.

Field work on these objectives was conducted only in areas with unrestricted land access. Initially we intended to also identify the location and characteristics of roosting areas, however, due to limited ground access these tasks were not addressed.

METHODS

Surveys were conducted in the Puna District on the island of Hawai`i (Figure 2) where we were able to obtain permission for land access. The areas surveyed and survey effort in each area are given in Table 1. Most surveys were conducted on primary and secondary roads.

Bat surveys were conducted from September 9 through December 12, 1993 with the exception of one preliminary survey conducted on August 10, 1993. A total of 162 hours was surveyed using bat detectors. Total survey time only included the time during which bat detectors were in use. Observers began surveys 30 minutes before sunset and continued until 2100 - 2200 hrs. All transects (or bat routes) were sampled at different times and in reversed directions to reduce the effects of time of night on detection rates. Pre-dawn and morning surveys were also conducted from approximately 400 to 700 hours.

Bat observations were also recorded July through October while seabird surveys were being conducted. Incidental bat sightings were recorded with seabird surveys, but these observations were all visual detections and are not included in the "survey hours" for this report.

Survey techniques

Tunable hand-held echolocation detectors (QMC Mini2 Bat Detector, QMC Instruments Ltd. London, England) were used to locate bats (Figure 3). When the detectors are tuned to the desired frequency, echolocation signals detected from bats in the area are indicated by an audible tone. Based on their echolocation signal, bats can be detected, identified, and characterized (by behavior) as feeding or cruising. Cruising or traveling bats do not display the darting and weaving typical of feeding bats (Jacobs 1993a), and their echolocation rate is constant and slower, compared to the erratic high pulsed signal emitted by foraging bats (Thomas and West 1989). Hawaiian hoary bats emit signals between 25-30 kHZ (Bellwood and Fullard 1984; Fenton 1981; Jacobs 1993a; Thomas and West 1984). Spotlights were also used to locate bats, and to observe their behavior after dark.

The number of bats recorded during a sample period is a conservative estimate that includes the number of bats visible at the same time, with the number of bat passes recorded as an index of bat activity. A bat pass is a sequence of two or more echolocation calls detected when a bat flies within range of the microphone on the bat detector (Thomas and West 1989). Each separate bat identified visually or with the bat detector was counted as a detection.

Three types of surveys were conducted to sample areas. Walking surveys (WS) were timed searches conducted by one or more observers in areas generally only accessible by foot. Extensive point surveys (PS) were conducted on primary roads. For these counts observers used bat detectors for five minutes at each mile marker or point. Observers looked for bats between survey points until dark. Continuous surveys (CS) were conducted on secondary and tertiary roads. Two observers (one driver and one detector) traveled 1.6-24 km/hr (1-15 miles/hr) while a bat detector was held outside the vehicle. The driver stopped when bats were detected, and observers identified the number of bats in the area, their behavior, and the habitat bats appeared to be using. Data collected for all three types of surveys included time of start, time of end, bat detector on, bat detector off, survey area, survey type, sunset, sunrise, number of bats detected, number of bat passes, direction of flight, type of flight, site description and habitat use, weather, moon phase, and distance estimates from bat to observer.

RESULTS

Number of detections

We recorded 173 bat detections during 162 survey hours for a mean detection rate of 1.13 detections/hr. The total survey distance was 730 km (453 miles). Our estimate of total bats counted was 129 (.8 bats/hr), with 315 total bat passes. The largest aggregation of bats, (8 bats) was recorded flying over lava fields at Kalapana toward the ocean. Six foraging bats were in and above Pu`ulena crater (Table 2). The number of incidental bats observed from July-August is given in Table 3. A group of 7 bats foraging by Pu`u Kaliu was recorded during seabird surveys. Of all bats detected, 15% were cruising, and 43% were foraging. Unidentified bat passes comprised 42% of our detections. We did not find roosting bats during our surveys.

Bats were found at 20 out of 41 sites searched (Figures 4 and 5). However, some designated "areas" are much larger than others (Table 2). We pooled data from sites with similar habitat characteristics for the summaries presented in this report. Bats were observed from 0-780 m (0-2,560 ft) elevation; however, most detections were made below 200 m (656 ft).

Habitat use

Bats were observed foraging in native vegetation, lowland and coastal areas with dense exotic vegetation, and areas of mixed native and introduced vegetation. Bats were found in 44% of the areas surveyed that had native vegetation, 36% of the areas classified as dominated by introduced plants, and 45% of the areas of mixed native and introduced vegetation (Table 1).

Of the 173 bat detections, 57% were made in open areas or forest edges. These sites included old lava flows, pit craters, residential and agricultural clearings, and roads. Bats foraging over open water comprised 1% of our detections. Bats foraging in forested areas, both above and below the canopy, made up 25% of the detections. The remaining 17% of the bats detected could not be located visually.

Tables 4 and 5 describe the habitat types within the survey areas. Areas where bats were not detected included Puna Trail, papaya fields, Puna Geothermal Venture complex, Kea`au Shopping Plaza, and the residential subdivisions, with the exception of Hawaiian Acres.

Timing of bat activity

The abundance of bats appeared to decline from August - December (Figure 6). Detection rates dropped from 2.38 detections/hr in August to 0.29 detections/hr in December. Survey areas visited on consecutive months also showed a decrease in bat activity (Table 5).

There appeared to be distinct daily peaks in bat activity. Average number of bat detections was highest at sunset (26 bats per hour), then decreased to 0-1 bats three hours after sunset (Figure 7). The mean evening detection rate was 1 bat/hour. Average morning detection rate was 2.47 bats/hr, but with a peak of 14 bat detections 30 minutes before sunrise (Figure 8).

DISCUSSION

Bats are the dominant nocturnal insect predators in Hawai`i. In this role, Hawaiian hoary bats occupy an important niche in this island ecosystem. Continental bat populations are threatened by habitat loss, pesticides, and roost disturbance (Bat Conservation International 1991). Bats suffer mortality due to habitat destruction; avian, reptilian, and mammalian predators; and human disturbance. Other endangered insectivorous bats (e.g., *Myotis griscens* and *Tadarida brasiliensis*) have been found dead with lethal concentrations of pesticides (dieldrin) in their tissues (Clark *et al.* 1978). The Hawaiian hoary bat is similarly at risk from introduced predators, pesticides, habitat loss, and roost disturbance.

The distribution of bats is most likely influenced by the availability of insects and roosting sites (Jones 1965) Although data show the Hawaiian bat uses non-native or modified habitats for foraging, the availability of roosting sites in undisturbed natural forest habitats is believed to be essential in order for these bats to survive (Fullard 1989; Jacobs 1993a; Tomich 1986). On the island of O`ahu, where the native forests have almost all been completely degraded or destroyed, the Hawaiian bat is rarely seen. It is believed that O`ahu once supported numbers of bats comparable to, or greater than, that found on the island of Hawai`i today (Tomich 1974).

Relative abundance

The actual number of bats at each site was a conservative estimate based on the number of separate bats observed. Our total number of bats observed per hour was 0.84. Our detection rates were higher than more extensive surveys conducted previously by other researchers. Jacobs (1991) island wide surveys had a detection rate of 0.2 bats/hr. Jacobs (1991) also conducted about 4 hours of surveys in Puna on the Pahoa-Kalapana Highway, and on the coastal road (Route 137) and Kama`ili road. Bats were seen foraging over Kaimu Bay during these surveys; however, he did not give detection rates specifically for Puna. Island-wide bat observations were also collected incidentally during the USFWS Hawai`i Forest Bird Surveys. Surveyors detected one bat per 58 person days (Kepler and Scott 1990). These sightings were incidental to bird surveys and did not include the use of bat detectors.

Seasonal variation in abundance

Previous researchers found that most Hawaiian bat sightings occur from September through December at elevations below 2,000 m (6,562 ft) (Jacobs 1993a), and that bat activity declines January to August (Kramer 1971; Kepler and Scott 1990; Jacobs 1993a). It has been hypothesized that migration to other islands (Kramer 1971) or winter dormancy (Kepler and Scott 1990) could cause this seasonal variation in bat activity. It may also be the result of fledging juveniles that require more time to feed and are, therefore, more visible during the fall months (Kepler and Scott 1990).

Mainland *L. cinereus* migrate altitudinally and latitudinally to avoid hot weather (Jones 1965). Tomich (1986) and Jacobs (1991) suggest Hawaiian bats exhibit similar behavior. The distribution and abundance of bat populations in Puna appears to vary seasonally, with fewer bats detected in December, the last month of our sampling, than in late summer. This should be considered when further studies are conducted on this species.

Foraging areas and roosting sites

Survey areas where bats were observed foraging more than once (Table 2) near Geothermal Subzones included Lava Trees State Park, Pu`ulena Crater, Pu`u Kaliu, Lower Heiheiahulu, Kaohe Homesteads, and Kapoho Crater. These areas are important foraging sites, each probably representing one of several sites visited regularly by the bats. Most bats were observed foraging in coastal areas with a closed canopy forest or along the edges of forest and pit craters.

Mainland hoary bats, *L. cinereus*, regularly roost in the same trees (clinging to the same twigs and same leaves) during the breeding season (McClure 1942). Bat species of the genus *Lasiurus* in Iowa roosted at densities of one family group per 4 acres (McClure 1942). The roosting densities of Hawaiian bats are not known

Jacobs (1993b) found that bats displayed roost fidelity in ohia trees, and commuted to two or more foraging locations per night. Bats are believed to utilize large areas for feeding and move extensively between foraging sites. Some foraging areas were greater than 13 km (8.1 mi) from roosts (Jacobs 1993b). Hawaiian hoary bats are potentially roosting in the geothermal subzones and migrating through subzones to additional foraging sites. A group of 8 bats was seen before dusk travelling over lava flows along Route 130 to the lower elevations. These bats were probably flying to a lower elevation foraging site.

POTENTIAL IMPACTS OF DEVELOPMENT

By being aware of the major impacts that potentially disrupt bat populations, the effects of proposed developments in the Puna area may be reduced. The following concerns should be taken into consideration when assessing the effects of geothermal resources development in this area.

1) Destruction of roost trees, especially during the breeding season could cause bat mortality. Geothermal project proposals indicate development will clear 916 ha (2,263 acres) out of 55,250 ha (136,520 acres) of project land (Towill 1982). A 9 m (30 ft) access road 12 km (7.5 miles) long and an unspecified number of secondary roads are also proposed. Additionally, there will be clearing for transmission lines, conductor string sites, and powerlines. Land clearing, especially of ohia trees would potentially destroy bat roosting habitat.

2) Roads and clearings facilitate predator access and potentially increase the threats of predation on roosting bats. Rat, cat, dog, barn owl, and mongoose populations are most dense in areas associated with human activity (Erlich *et al* 1992). They hunt in clearings and other open areas (Clark *et al.* 1978).

3) Installation of transmission lines and other construction activities could disrupt foraging and migrating activity patterns. However, it is not known to what extent new land alterations and mandmade structures disrupt Hawaiian hoary bat behavior.

4) Geothermal emissions may negatively affect bats by reducing the insect populations surrounding the project and potentially depleting bat food sources, or impact important foraging areas. However, we are not aware of any studies addressing the effects of Geothermal emissions on bat or insect populations.

5) Noise levels of the proposed geothermal project may be potentially disruptive to roosting and foraging bats in the project vicinity. However, it is not known to what extent external noise levels interfere with echolocation.

MANAGEMENT RECOMMENDATIONS

The following management measures are recommended to reduce the impacts likely to occur if the proposed geothermal development project is carried out:

1) Conduct pre-construction surveys of areas proposed for land clearing to identify use of the areas by bats for both foraging and roosting. A radio telemetry study should be conducted to locate important roosting sites within the proposed project areas.

2) Avoid disturbance of roosting and foraging areas.

3) Time construction outside the bats' breeding and fledging season (May-September).

4) Conduct predator trapping in cleared areas to reduce the impacts of new predator corridors.

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Table 1. Areas in Puna surveyed September - December 1993 for Hawaiian hoary bats, vegetation type (native, introduced, mixed), and total survey effort in minutes per area.

Area	Vegetation type[1]	Number of minutes surveyed
Ainaloa Greenhouse	mixed	45
Crescent Acres	native	60
Halekamahina Crater	mixed	53
Hawaiian Acres	native	66
Hawaiian Beaches	introduced	30
Heiheiahulu (Lower)	native	744
Heiheiahulu Road	mixed	157
Herbert C. Shipman Park	introduced	40
Hawaii Tropical Products	introduced	29
Hinalo Road	mixed	104
Isaac Hale Beach Park	introduced	98
Kahakai Road	introduced	55
Kahaualea NAR	native	691
Kalapana	mixed	25
Kahuwai Crater	mixed	337
Kamaili Road	mixed	255
Kaohe Homesteads	mixed	228
Kapoho Crater	introduced	190
Keaau Macnut Farm	introduced	111
Keaau Plaza	introduced	20
Keaau School	introduced	44
Kehena Vista Point	introduced	20
Lava Trees State Park	mixed	84
Leilani Estates	native	104
Lighthouse Road	mixed[2]	31

Table 1. (Continued)

Area	Vegetation type[1]	Number of minutes surveyed
Kumakahi Lighthouse	mixed[2]	175
Mackenzie Beach State Park	introduced	10
Nanawale Homesteads	native	136
Orchidland Estates	mixed	226
Orchidland Wiki Wiki	mixed	71
Pahoa High School	introduced	26
Pahoa-Pohoiki Road	mixed	168
Pawai Crater	mixed	408
Puna Geothermal Venture	introduced	293
Puna Trail	introduced	142
Puna Biomass Power Company	introduced	169
Puu Kaliu	native	307
Puulena Crater	mixed	1270
Railroad Avenue Loop	introduced	246
Route 130	mixed	621
Route 132	mixed	329
Route 137	mixed	823
U.S. Cellular Tower	introduced	184
TOTAL SURVEY TIME		9225

[1] Vegetation type is based on the dominant overstory plants.

Table 2. Summary of survey results: Number of times each area was surveyed, percentage of surveys with bat detections, detection rates, and estimated number of bats per site.

Area	Number of times surveyed	Percentage of surveys with bats detected	Detection rate (detections/hour)	Estimated number of bats[1]
Ainaloa Greenhouse	1	0	0	0
Crescent Acres	1	0	0	0
Halekamahina Crater	1	0	0	0
Hawaiian Acres	2	50	0.91	1
Hawaiian Beaches	6	0	0	0
Heiheiahulu (Lower)	12	8	0.48	1
Heiheiahulu Road	4	0	0	0
Herbert C. Shipman Park	3	67	2.99	2
HI Tropical Products	1	0	0	0
Hinalo Road	3	33	0.58	1
Isaac Hale Beach Park	5	20	1.23	2
Kahakai Road	3	0	0	0
Kahaualea NAR	10	13	0.05	1
Kalapana	3	67	7.14	3
Kahuwai Crater	1	0	0	0
Kamaili Road	6	67	2.12	4
Kaohe Homesteads	3	33	0.79	2
Kapoho Crater	4	25	0.63	2
Keaau Macnut Farm	2	55	1.62	2-3
Keaau Plaza	2	0	0	0
Keaau School	4	0	0	0
Kehena Vista Point	4	0	0	0
Lava Tree State Park	4	100	4.29	0
Leilani Estates	6	0	0	0
Kumakahi Lighthouse	5	0	0	0
Lighthouse Road	4	0	0	0
Mackenzie Beach Park	1	0	0	0

Table 2. (Continued)

Area	Number of times surveyed	Percentage of surveys with bats detected	Detection rate (detections/hour)	Estimated number of bats[1]
Nanawale Homesteads	5	0	0	0
Orchidland Estates	2	0	0	0
Orchidland Wiki Wiki	2	0	0	0
Pahoa High School	2	50	6.98	3
Pahoa-Pohoiki Road	5	20	0.36	1
Pawai Crater	4	25	0.15	0
Puna Geothermal Venture	8	0	0	0
Puna Trail	3	0	0	0
Puna Biomass Power Co.	6	0	0	0
[illegible]u Kaliu	4	50	1.37	4
Puulena Crater	19	68	2.88	6
Railroad Avenue Loop	4	0	0	0
Route 130	15	27	1.35	8
Route 132	11	27	0.91	2
Route 137	16	44	2.84	8-9
U.S. Cellular Tower	3	33	0.33	1

[1] Estimated number of bats is the greatest number of bats observed at a site during a single survey.

Table 3. Incidental Hawaiian hoary bat sightings in the Puna District in 1993.

Location	Survey dates	Number of bats[a]
Heiheiahulu	Aug. 08	1
	Sept. 19	2
Herbert C. Shipman Park	Oct. 28	1
Kalapana	Sept. 20	1
Kahuwai Crater	Sept. 19	1
Pahoa High School	Sept. 14	3
	Sept. 28	2
Pu'u Kaliu	Aug. 25	7
	Sept. 02	1
Pu'ulena Crater	July 28	1
	July 29	2
	Aug. 25	1
	Aug. 26	1
	Aug. 31	4
	Sept. 01	2
	Sept. 09	1($\pm$3)
	Sept. 22	1
	Oct. 14	6($\pm$2)
	Oct. 15	1
	Oct. 19	1
	Total number of bats:	40-45

[a] Total bats includes the maximum number of bats visible.

Table 4. Site description and elevation for surveys areas in which bats were absent or not detected in 1993.

Area	Elevation in meters (feet)	Site description
Ainaloa Greenhouse	170 (560)	cleared area with greenhouse containing bright lights in a residential area
Crescent Acres	399-487 (1310-1597)	residential development with open ohia/uluhe forest and scattered exotics
Halekamahina Crater	152 (500)	small pit crater, mixed lowland forest surrounded by ag land
Hawaiian Beaches Park	6 (20)	coastal, mixed lowland forest and scrub, residential area
Heiheiahulu Road	232-427 (760-1400)	Residential subdivision with mixed exotics and open ohia/uluhe forest
HI Tropical Products (Keaau)	61 (200)	warehouse surrounded by agricultural land and fragmented mixed lowland forest
Kahakai Road	12-189 (40-620)	residential area with some ohia/uluhe and mixed lowland forest
Keaau Plaza	73 (240)	shopping center and parking lot with bright lights and exotic fragmented vegetation
Keaau School	73 (240)	manicured area with fragmented vegetation
Kehena Vista Point	12 (40)	coastal mixed lowland forest and scrub
Leilani Estates	183-295 (600-968)	fragmented residential area with ohia forest and largely exotic understory
Kumakahi Lighthouse	12 (40)	lava flow with early pioneer vegetation
Lighthouse Road	12-34 (40-110)	lava flow with pioneer exotic vegetation

Table 4. (Continued)

Area	Elevation in meters (feet)	Site description
Mackenzie Beach State Park	3 (10)	coastal, closed exotic canopy, open exotic understory
Nanawale Homesteads	116-201 (380-660)	residential area with fragmented ohia/uluhe forest
Orchid Land Estates	122-256 (400-840)	fragmented ohia woodland with uluhe understory
Orchidland Wiki Wiki	165 (540)	residential area with fragmented mixed lowland forest
Puna Geothermal Venture	183 (600)	fragmented mixed lowland forest with pu'u and industrial development areas surrounded by ag land
Puna Trail	6-18 (20-60)	mixed lowland forest and agricultural land
Puna Biomass Power Company	61 (200)	fallow sugar cane and mixed lowland forest
Railroad Avenue Loop	49-140 (160-460)	papaya fields and mixed lowland forest

Table 5. Site description and elevation for survey areas where bats were detected in 1993.

Area	Elevation in m (ft)	Site description
Hawaiian Acres	213-412 (700-1352)	native ohia forest with matted fern understory
Heiheiahulu	442 (1450)	pasture land surrounded by pu'us and craters
Herbert C. Shipman Park	104 (340)	mixed lowland forest surrounding manicured park
Hinalo Road	174 (570)	residential with open ohia/uluhe and mixed lowland forest
Isaac Hale Beach Park	3 (10)	coastal mixed lowland forest scrub, bordering agricultural land
Kahaualea NAR	707 (2320)	wet ohia forest with predominantly native understory species
Kalapana	3 (10)	lava flow with pioneer vegetation
Kamaili Road	15 - 146	
0.1 mi from Route 137	15 (50)	closed exotic canopy with mostly exotic subcanopy and shrub layers
0.6 mi from Route 137	24 (80)	agricultural land with fragmented open exotic canopy and understory
1 mi from Route 137	70 (230)	agricultural land with fragmented open exotic canopy and understory
2.6 mi from Route 137	146 (480)	open exotic canopy and understory with a few scattered ohia
0.4 mi from Route 137	30 (100)	agricultural land surrounded by mixed lowland forest
Kaohe Homesteads	256-326 (840-1070)	agricultural land bordering native forest with largely exotic subcanopy
Kapoho Crater	5 (15)	mixed lowland forest surrounded by pasture and agricultural land
Keaau Macnut Farm	61 (200)	agricultural land with fragmented mixed lowland forest
Lava Tree State Park	189 (620)	mixed lowland forest with ohia/uluhe bordering manicured park

Table 5. (Continued)

Area	Elevation in m (ft)	Site description
Pahoa High School	207 (680)	developed and manicured area with fragmented vegetation
Pahoa-Pohoiki Road	37 (120)	mixed lowland forest surrounded by agricultural land and ohia forest
Pawai Crater	152 (500)	pit crater, mixed lowland forest with substantial ohia
Puu Kaliu	305 (1000)	closed ohia canopy with exotic understory and heavy excavation on south side of pu'u
Puulena Crater	183 (600)	large crater 100 me deep surrounded by mixed lowland forest with ohia/uluhe
<u>Route 130</u>		
Mile 19	82 (270)	ohia forest with largely exotic subcanopy and shrub layers
Mile 19.8	46 (150)	mixed lowland forest, largely exotic open canopy and shrub layers
Mile 21	21 (70)	open forest, primarily ohia
<u>Route 132</u>		
Mile 2.5	189 (620)	mixed lowland forest with substantial ohia/uluhe forest
Mile 7	50 (166)	largely exotic canopy and understory surrounding agricultural land
<u>Route 137</u>		
Mile 5.2	9 (30)	open ohia canopy with largely exotic understory
Mile 5.4	11 (35)	very scattered ohia canopy with largely exotic understory
Mile 5.6	15 (50)	lava flow with pioneer ohia and exotics
Mile 5.9	19 (63)	mixed lowland forest with largely exotic canopy and shrub layers bordering lava

Table 5. (Continued)

Area	Elevation in m (ft)	Site description
Route 137		
Mile 15.1	12 (40)	closed exotic canopy with mostly exotic subcanopy and shrub layers
Mile 15.8	15 (50)	coastal, mostly exotic canopy and understory
Mile 16.5	12 (40)	closed ohia and exotic canopy with mostly exotic understory
Mile 17	9 (30)	scrub land bordering mixed lowland forest
Mile 18	15 (50)	mixed lowland forest bordering scrub
Mile 18.3	21 (70)	exotic canopy with exotic shrub layer
Mile 18.5	3 (10)	coastal, largely exotic open canopy and shrub layer
Mile 18.8	24 (80)	open exotic canopy, mostly exotic shrub layer
Mile 19	20 (65)	coastal mixed lowland forest
Mile 19.3	29 (95)	dry forest surrounded by mixed lowland forest
Mile 21.2	6 (20)	closed canopy of mixed ohia and exotics, completely exotic understory
Mile 22.3	3 (10)	partially developed mixed introduced vegetation

Appendix 1. Summary of detections at all survey sites for different months.

	MONTH			
AREA	**SEPTEMBER**	**OCTOBER**	**NOVEMBER**	**DECEMBER**
AINALOA GREENHOUSE	NS	0	NS	NS
CRESCENT ACRES	NS	NS	NS	0
HALEKAMA-HINA CRATER	NS	NS	NS	0
HAWAIIAN ACRES	NS	NS	NS	0
HAWAIIAN BEACHES	0	0	0	0
HEIHEIAHULU	1	0	NS	NS
HEIHEIAHULU ROAD	0	0	NS	NS
HERBERT SHIPMAN PK	NS	2	NS	0
HI TROPICAL PRODCTS	NS	0	NS	NS
HINALO ROAD	1	NS	NS	NS
ISAAC HALE BEACH PK	2	0	0	0
KAHAKAI ROAD	0	0	NS	0
KAHAUALEA NAR	NS	NS	0	NS
KAHUWAI CRATER	NS	NS	0	NS
KALAPANA	2	1	NS	0
KAMAILI ROAD	5	2	0	2

Appendix 1. (Continued)

	MONTH			
AREA	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
KAOHE HOMESTEADS	NS	3	NS	NS
KAPOHO CRATER	NS	NS	0	2
KEAAU MACNUT FARM	0	2-3	0	NS
KEAAU PLAZA	NS	NS	0	NS
KEAAU SCHOOL	NS	0	0	0
KEHENA VISTA POINT	0	0	0	0
LAVA TREE STATE PK	5-6	NS	NS	NS
LEILANI ESTATES	0	0	0	NS
LIGHTHOUSE	0	0	0	NS
LIGHTHOUSE ROAD	0	0	0	NS
MACKENZIE STATE PK	0	NS	NS	NS
NANAWALE HOMESTEADS	0	0	0	0
ORCHIDLAND ESTATES	NS	NS	NS	0
ORCHIDLAND WIKIWIKI	NS	0	NS	NS
PAHOA HIGH SCHOOL	NS	3	NS	NS
PAHOA/ POHOIKI ROAD	0	NS	1	NS

Appendix 1. (Continued)

	MONTH			
AREA	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
PAWAI CRATER	1	0	NS	NS
PGV/PAPAYA FIELD	0	0	0	0
PUNA TRAIL	NS	0	0	NS
PUNA BIOMASS CO	NS	0	0	NS
PU'U KALIU	4	3	NS	NS
PU'ULENA CRATER	33	5	NS	NS
RAILROAD AVE LOOP	NS	0	0	0
ROUTE 130	14	0	0	0
ROUTE 132	2	2	0	0
ROUTE 137	27	4	4	0
US CELLULAR TOWER	0	NS	1	NS

NS = not surveyed for that month

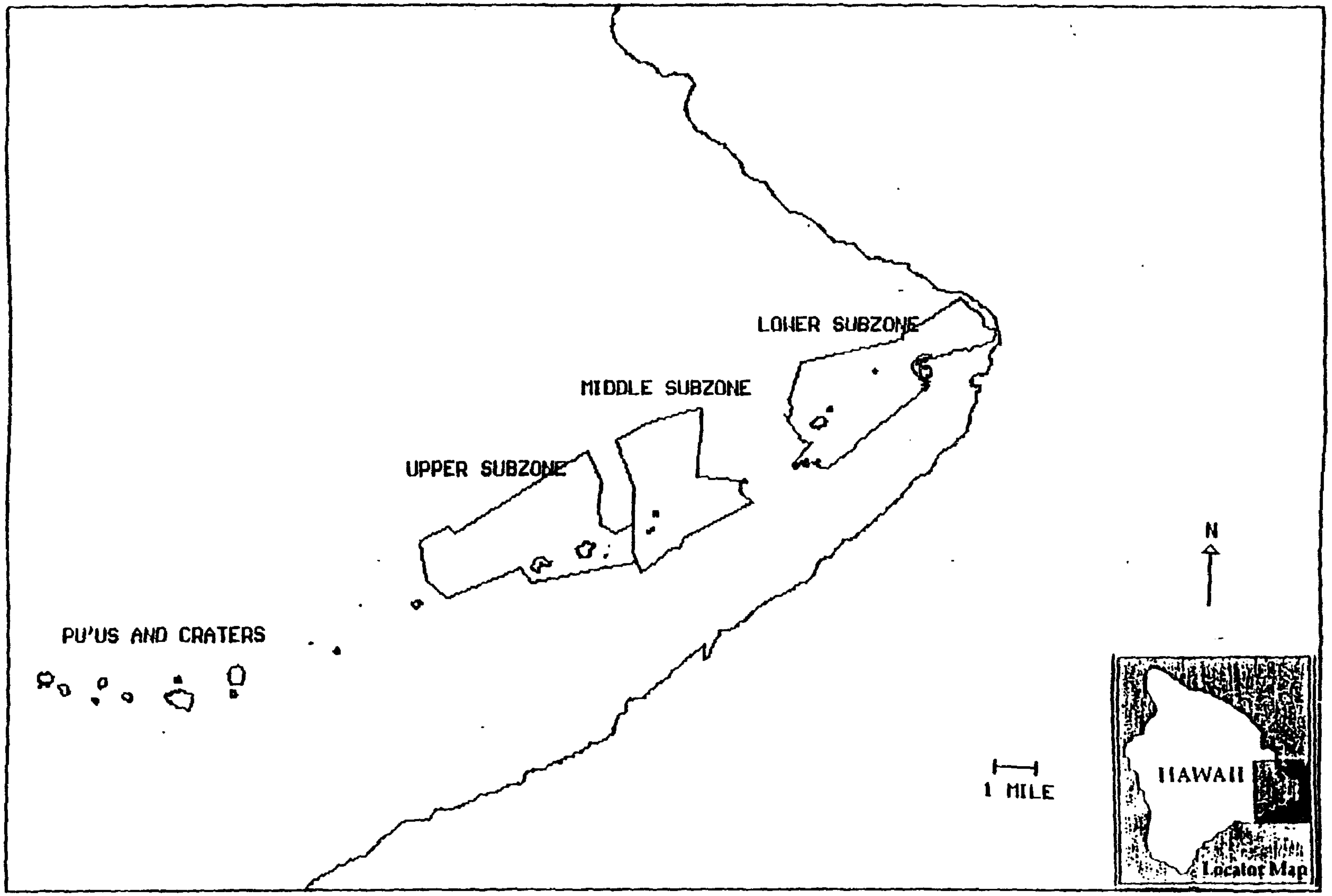

Figure 1. Geothermal subzones: proposed project areas.

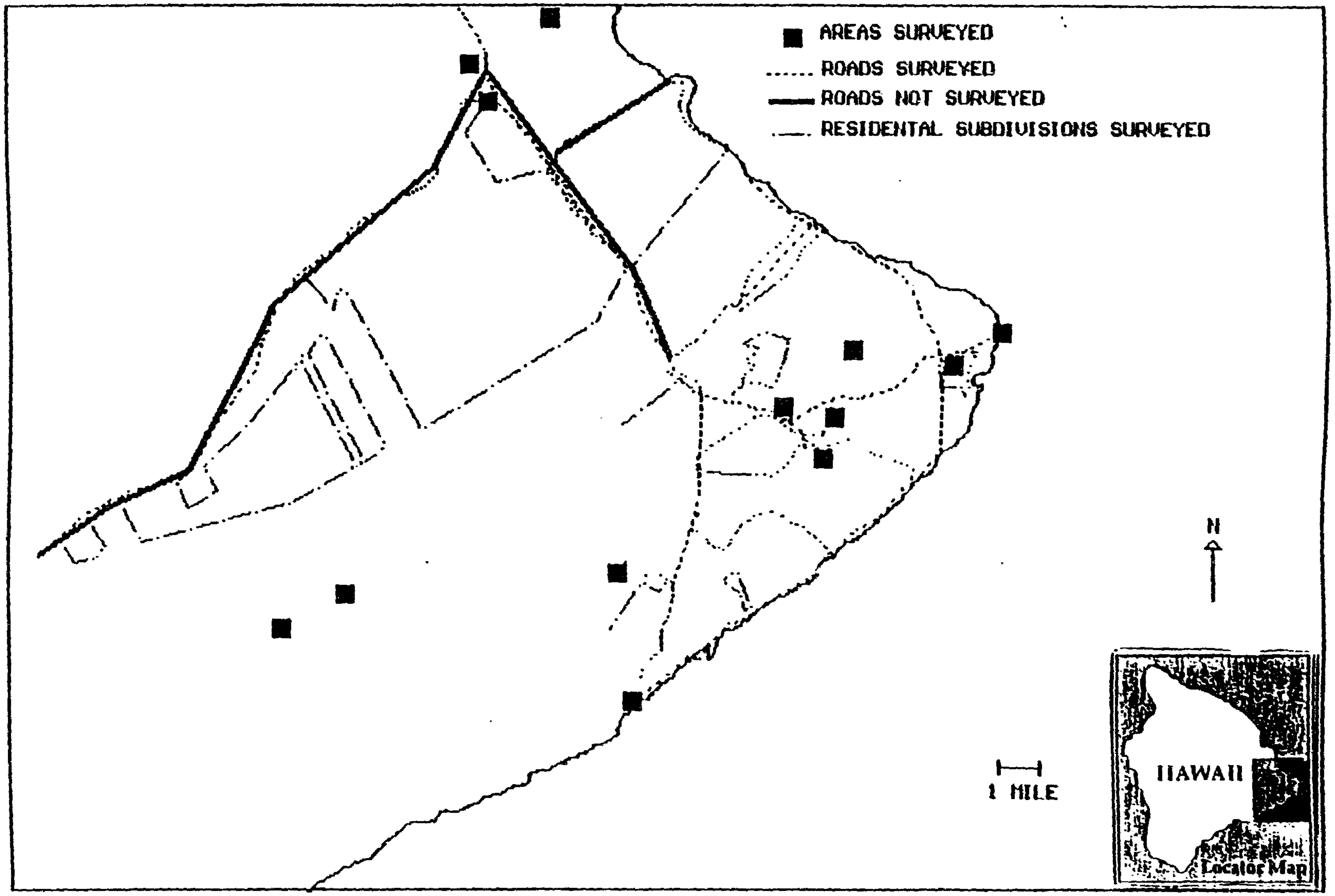

Figure 2. Areas searched for Hawaiian hoary bats September - December 1993.

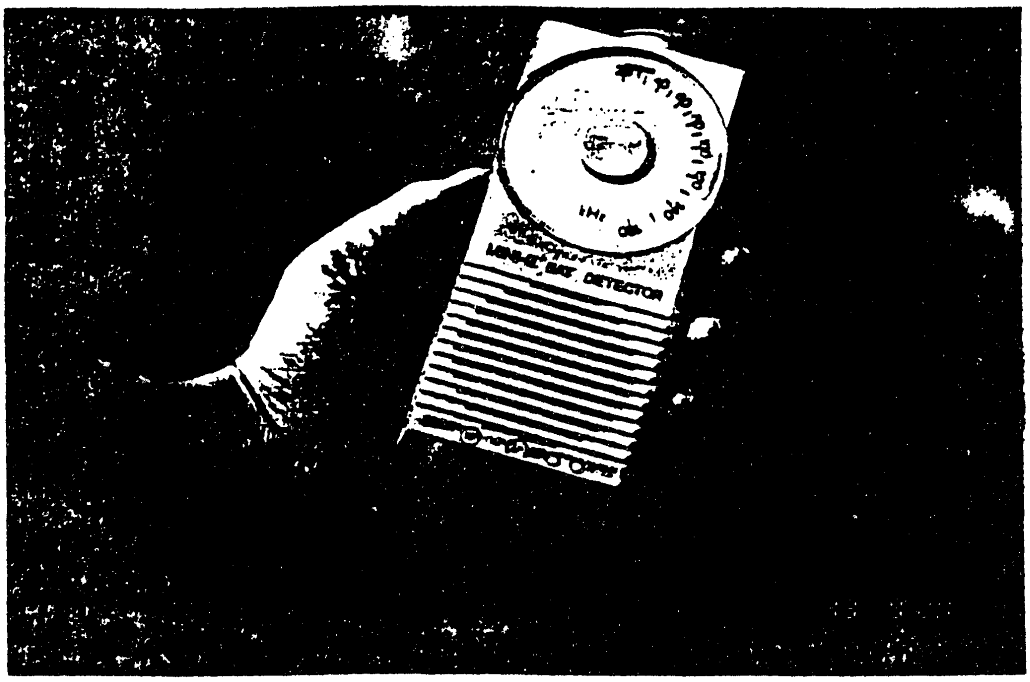

Figure 3. Tunable echolocation detectors (QMC Mini2 Bat Detectors) were used to survey for Hawaiian hoary bats at frequencies between 25-30 kHz.

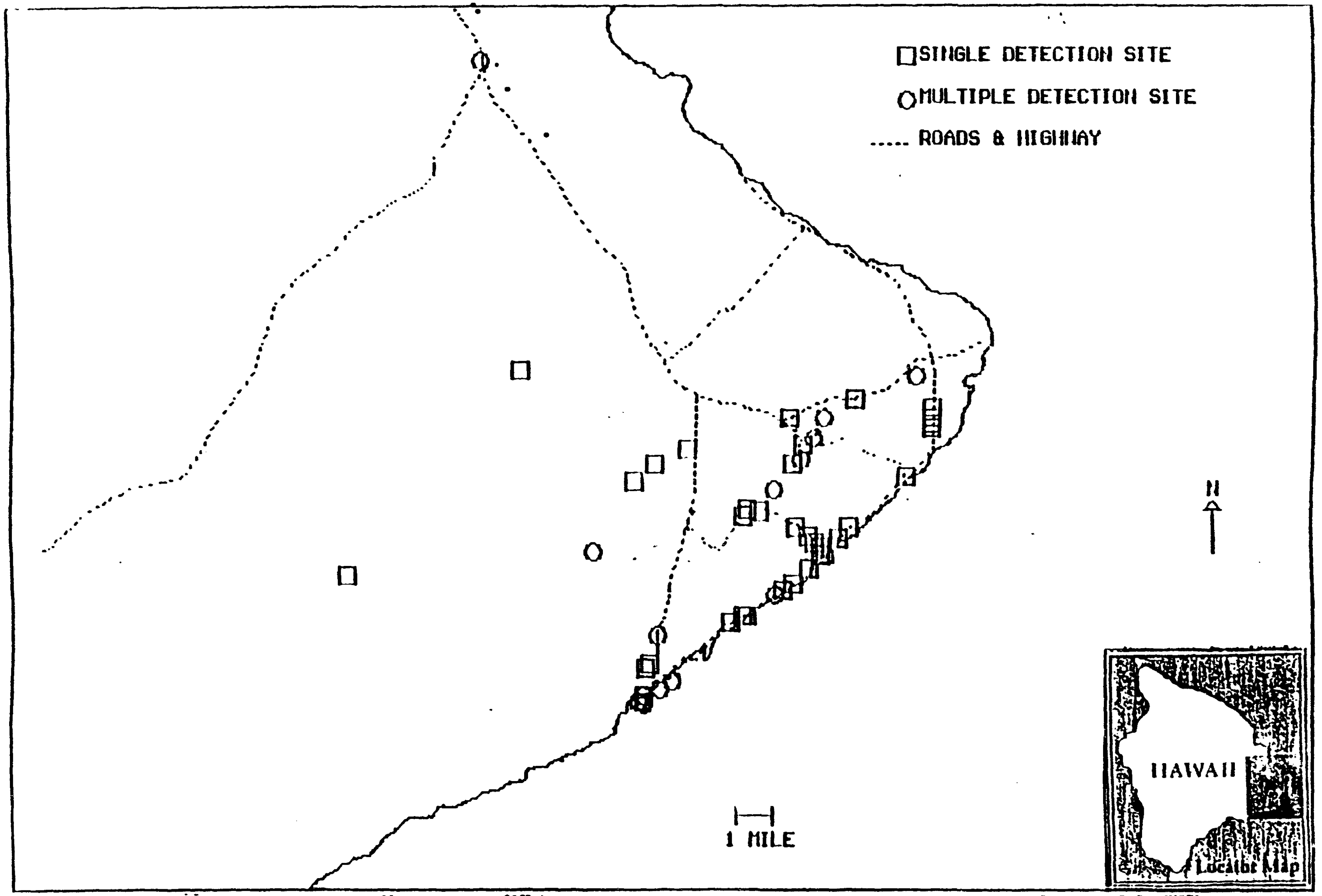

Figure 4. Locations where Hawaiian hoary bats were detected in Puna in 1993. Areas were surveyed August 10, and September 9 - December 12. Squares represent a single at detection and circles indicate more than one bat detection at that location.

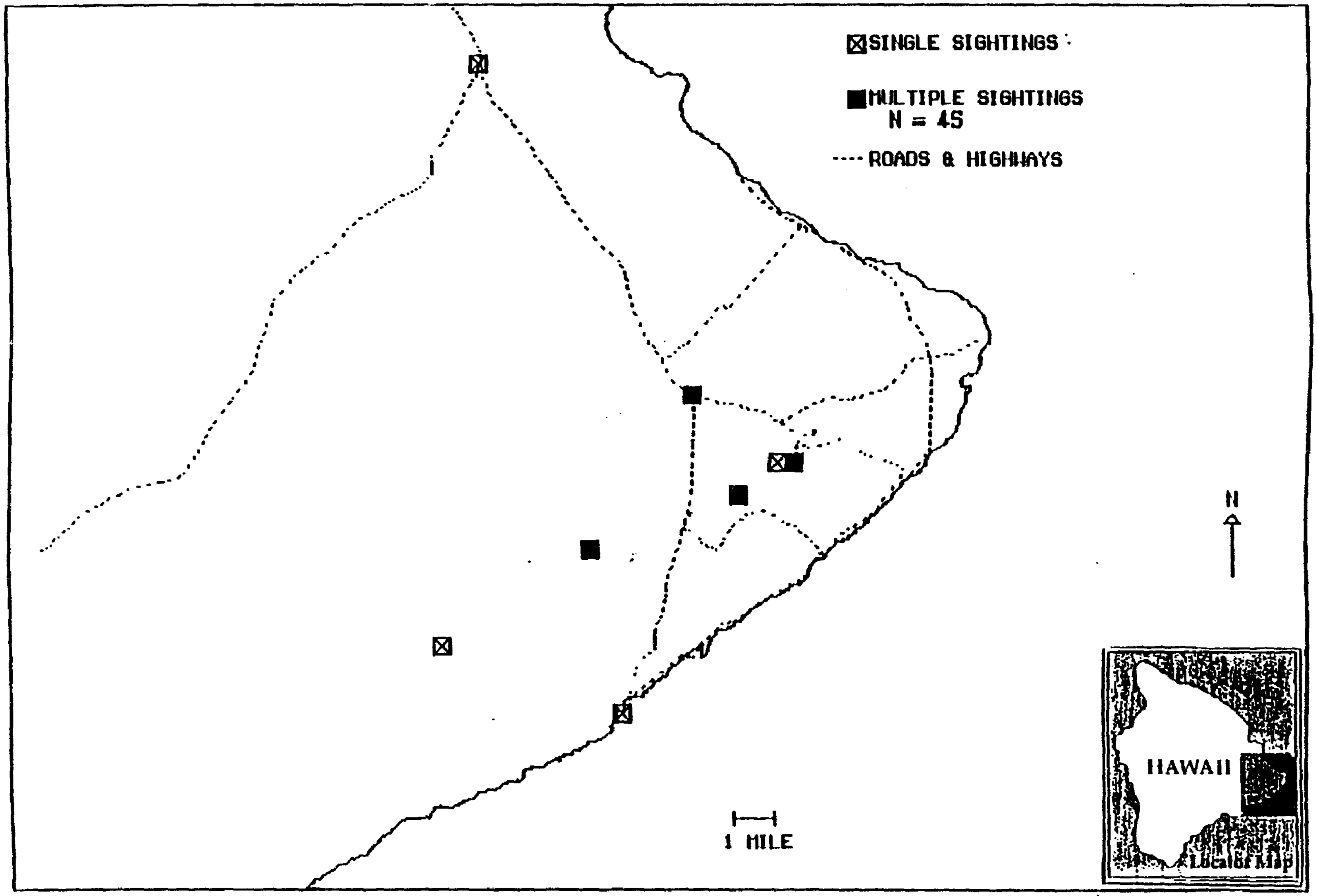

Figure 5. Locations of incidental bat sightings during seabird surveys (July - October 1993). A total of 45 bats were observed.

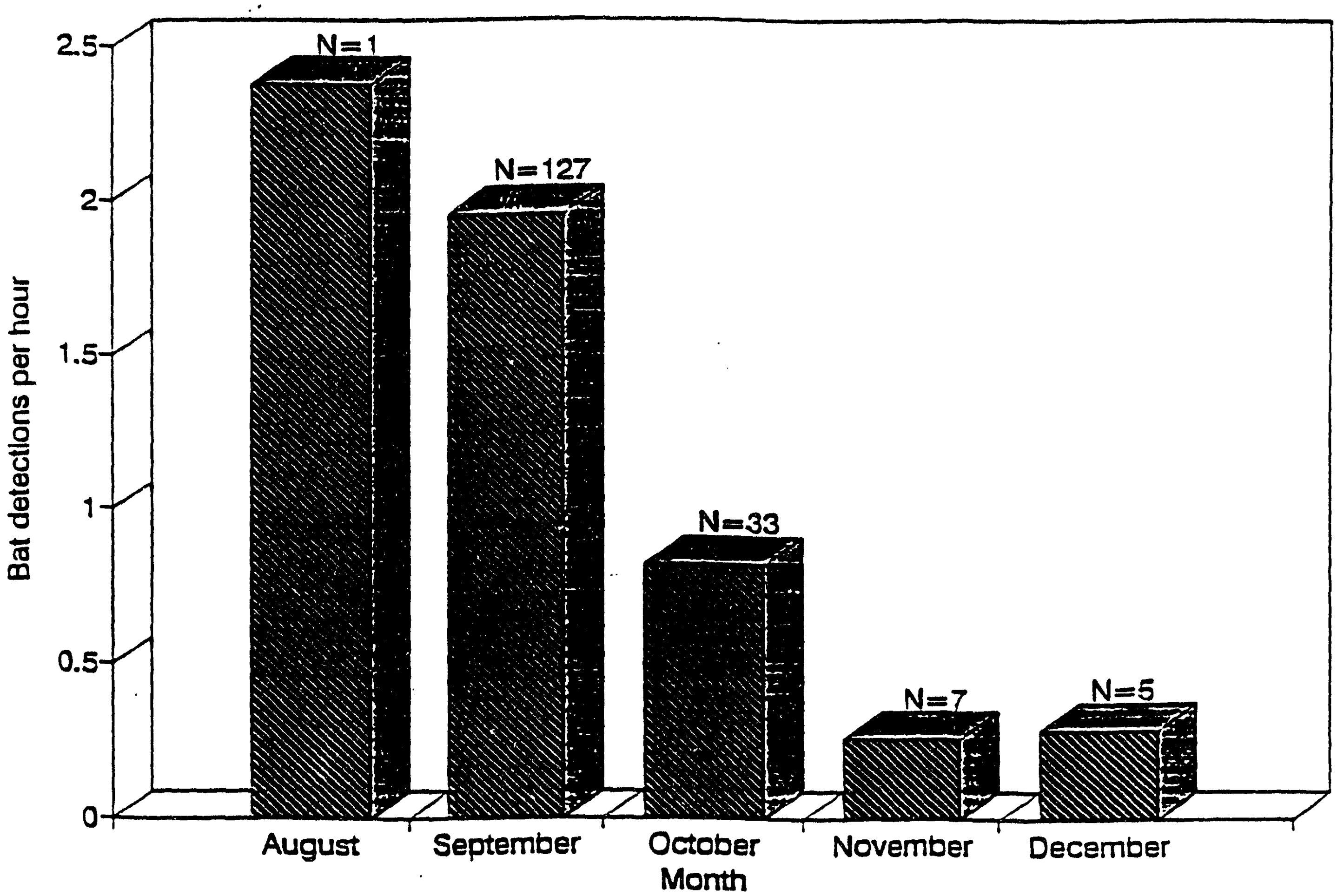

Figure 6. Mean monthly detection rates of the Hawaiian hoary bat (detections/hour) August - December 1993. N = detections per month.

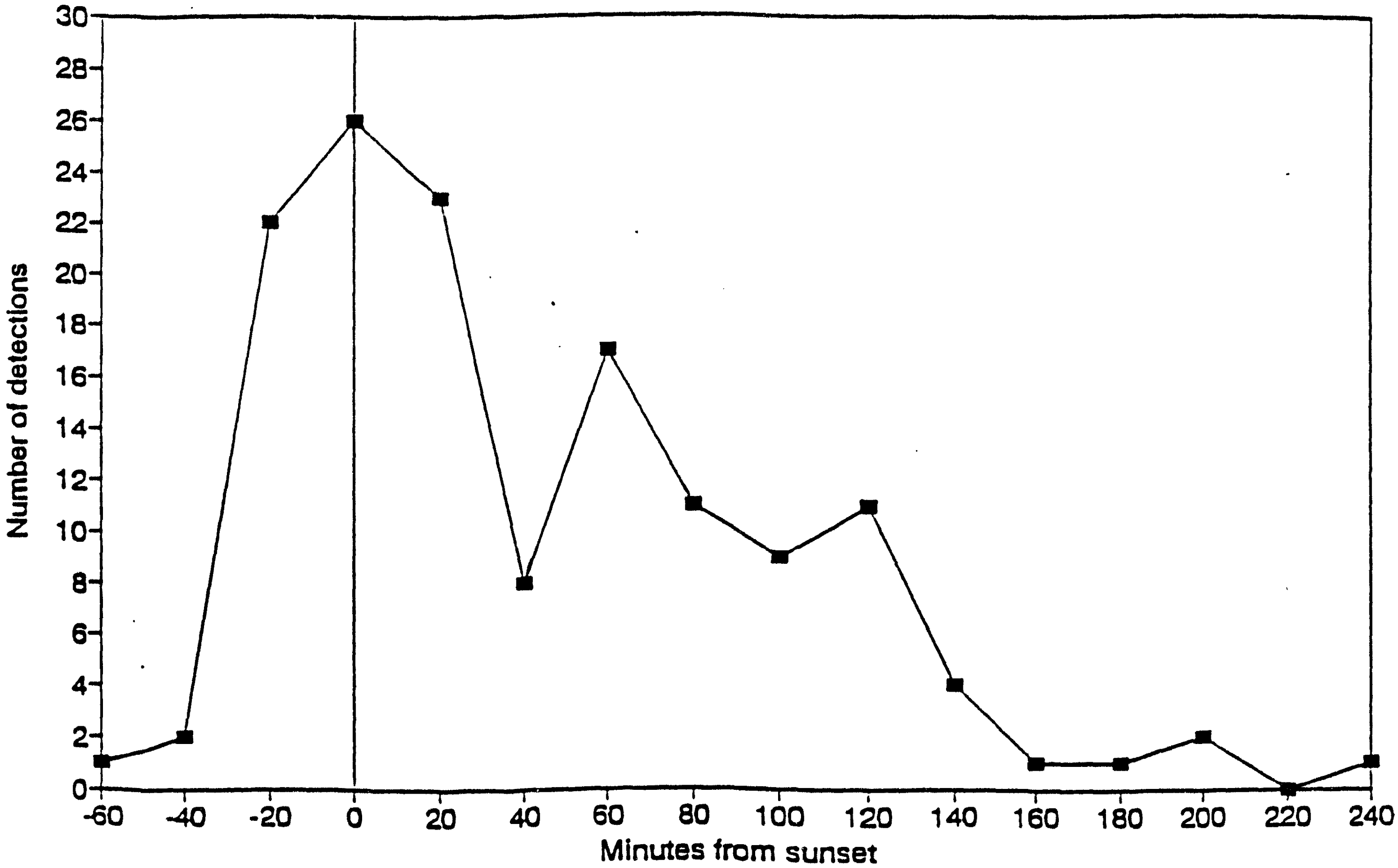

Figure 7. Evening activity patterns of the Hawaiian hoary bat. Each point represents a twenty minute interval. Detection times (by minutes after sunset) are based on detections made between August and December 1993.

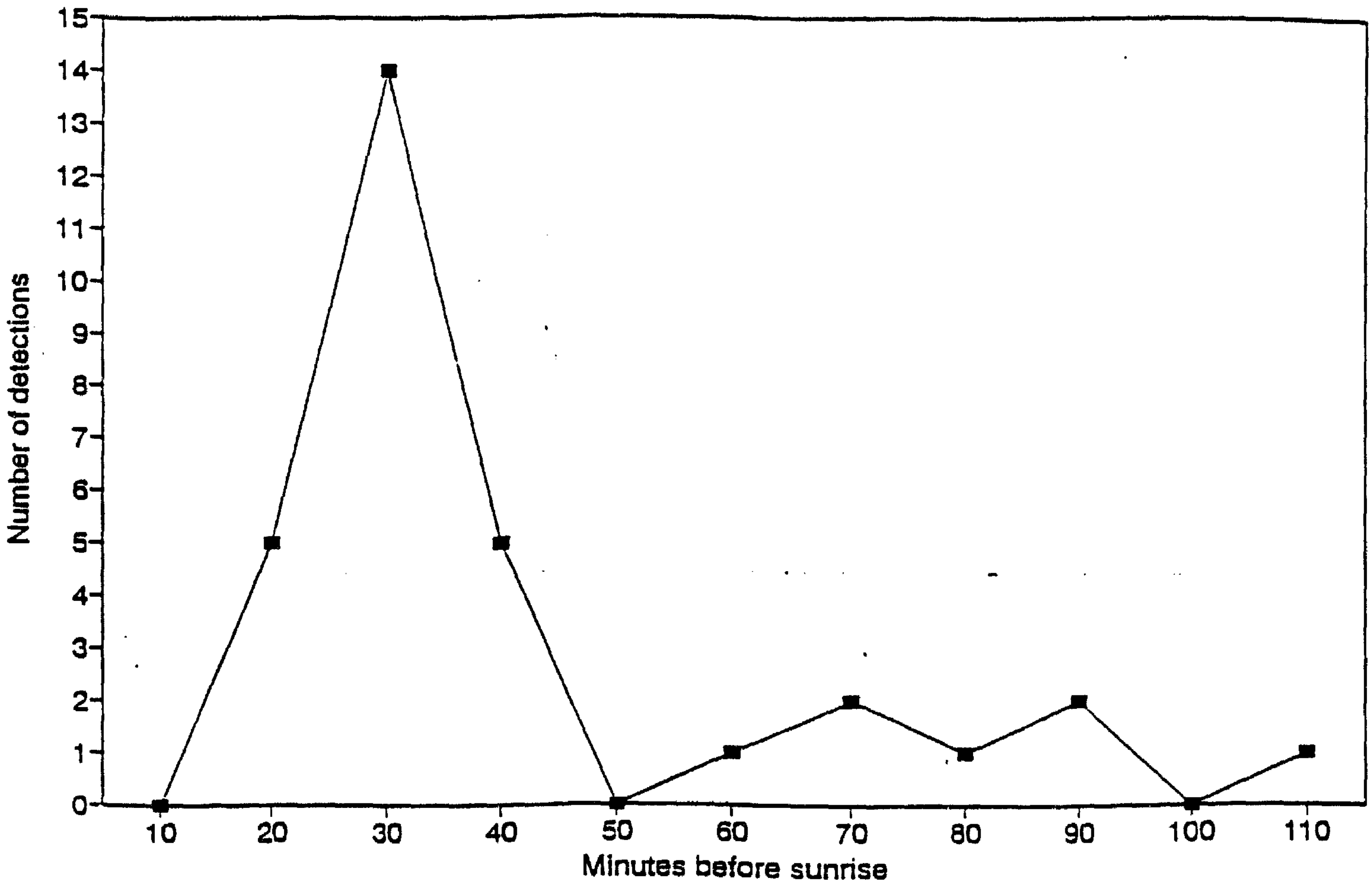

Figure 8. Morning activity patterns of the Hawaiian hoary bat. Each point represents a ten minute interval. Detection times (by minutes before sunrise) are based on detections made between August and December 1993.