INTRODUCTION

As the only extant terrestrial mammal native to Hawai`i, the Hawaiian hoary bat (Lasiurus cinereus semotus) is important to the biodiversity of vertebrate fauna in this highly isolated island ecosystem. Ancient Hawaiians called this solitary and elusive bat `Ope`ape`a, or half-leaf, as its wings resembled the half-leaf remaining on a taro stalk after the top half has been removed for cooking (Pukui and Elbert 1986). The Hawaiian hoary bat is one of three subspecies including Lasiurus cinereus cinereus of North America and the South American subspecies, Lasiurus cinereus villosissimus (Tomich 1974). Although the Hawaiian hoary bat was listed as an endangered species in 1970, and is presently protected by both federal and state laws (U.S. Fish and Wildlife Service 1970), current information regarding natural history and population status of this bat is scarce, resulting in incomplete and sometimes conflicting reports.

Population estimates for the Hawaiian hoary bat have ranged from hundreds (Altonn 1960) to thousands of individuals (Tomich 1974), but these numbers are based on anecdotal and incomplete data. To date, researchers know very little about population numbers and yearly trends for this species (Fullard 1989; Tuttle 1995). Menard (2001) suggests that abundance and distribution patterns may fluctuate according to season and altitude on the island of Hawai`i. Based on visual and audio observations of flying bats, she noted that during the “non-breeding period” from September to March, Hawaiian hoary bats were marginally more common in the eastern highlands of the Hakalau Forest National Wildlife Refuge (three sites ranging from 1604 m to 1890 m elevation, mean July minimum temperatures 8-10°C), than during the “breeding period” from April to August when bats seem to shift into the lowlands of the island (20 sites ranging from 0 to 1,280 m, mean July minimum temperatures 11-20°C). This occurrence of bats in the lowlands from April to August agrees in part with Tomich (1986a), who noted that during those months Hawaiian hoary bats “were regularly seen” at sites from 300 m to 790 m elevation along the Hamakua Coast on the northern section of Hawai`i Island. However, in apparent contrast to the high occurrence of bats that Menard reported from April to August at coastal sites, Tomich (1986a) considered bats as “scarce” at the coast from May through August. Contradicting observations by both Menard and Tomich, Jacobs (1994) found no evidence of altitudinal or regional migration at foraging sites distributed over a broad altitudinal and geographical range on the island of Hawai`i during a study from February to August in 1992.

Sightings of the Hawaiian hoary bat have occurred from sea level to as high as 4,115 m at the summit crater of Mauna Loa Volcano (Tomich 1974). They have been observed flying and/or resting in a wide variety of both native and non-native vegetation types and landscapes (Tomich 1986b; Kepler and Scott 1990; Jacobs 1994; Reynolds et al. 1998; Menard 2001). L. cinereus semotus is typically a solitary foliage roosting bat, but some bats will use man-made structures and rock crevices (Tomich 1974). Furthermore, it is unclear to what extent this subspecies uses lava tubes. On 2 August 1977, Fujioka and Gon (1988) observed 16 bats flying around an overhanging ledge of a collapsed lava tube on the island of Hawai`i, and others have found bat remains in lava tubes on Hawai`i and Maui (Tomich 1974).
The Hawaiian hoary bat’s ability to adapt to various habitats combined with limited and inconsistent information has made associating it with particular habitat types very difficult. As a result, it is not possible to designate critical roosting and foraging habitat for this subspecies, so even the most basic management strategies are difficult to implement (U.S. Fish and Wildlife Service 1998). The U.S. Fish and Wildlife Service (1998) developed a Recovery Plan for the Hawaiian Hoary Bat, which aims to downlist this subspecies. However, this can only happen after populations on the island of Hawai‘i are stable or increasing for at least five consecutive years. Threats to this species remain unclear, but habitat loss, pesticide use, predation (Tuttle 1995), and roost disturbance are issues to consider when developing management and monitoring strategies.

The three main objectives of the Hawaiian hoary bat inventory were to: 1) Determine presence/no detection of bats in national parks and adjacent areas on the islands of Hawai‘i, Maui, and Moloka‘i, 2) assess distribution and relative activity levels of bats in these national parks, and 3) suggest general associations between bats and selected habitats and elevations. Results of the Hawaiian hoary bat inventory will be used as a tool in development of a long-term monitoring protocol for these bats in the Pacific Island Network (PACN).

METHODS

Study Area
Historically found on all the main Hawaiian Islands, Hawaiian hoary bat populations appear to be highest on Hawai‘i and Kaua‘i (Tomich 1974). We conducted intensive bat surveys in four national parks on the island of Hawai‘i: Hawai‘i Volcanoes National Park (HAVO), Pu‘uhonua o Hōnaunau National Historical Park (PUHO), Kaloko-Honokōhau National Historical Park (KAHO), and Pu‘ukoholā Heiau National Historic Site (PUHE). Although we did not systematically survey the Ala Kahakai National Historic Trail (ALKA), parts of the trail pass through all four parks on Hawai‘i. In addition, we surveyed Kalaupapa National Historical Park (KALA) on Moloka‘i and Haleakalā National Park (HALE) on Maui. In and around all parks, surveys included areas of variable vegetation cover. Maps showing points and transects surveyed and vegetation types are shown in the results section. However, vegetation classifications vary slightly between parks, or were not identified such as in PUHE and KALA, since GIS layers are currently not standardized.

Hawai‘i Volcanoes National Park
Established on the island of Hawai‘i in 1916, HAVO is approximately 134,679 ha in size, extending from sea level to 4,169 m elevation. It encompasses the summits and rift zones of two of the world’s most active volcanoes, Kīlauea and Mauna Loa, and includes the newly acquired Kahuku addition on the Southwest Rift Zone of Mauna Loa, as well as nearly 13,354 ha of rain forest in the ʻŌla‘a Tract. The park, largely surrounded by natural areas and lightly populated rural areas, has only minimal development within its boundaries.
Since 1983, Kilauea has been continuously erupting, while Mauna Loa’s last eruption occurred in 1984. In addition to geological processes and volcanic activity, scientists and visitors alike recognize HAVO for its unique flora and fauna. Seven ecological zones, including seacoast, lowland forest, mid-elevation woodland, rain forest, upland forest, subalpine, and alpine, are found within the park and harbor distinct plant and animal communities. Other natural features contributing to the park’s bio-diversity are cave ecosystems, anchialine pools, and wetlands.

**Pu’uhonua o Hōnaunau National Historical Park**
PUHO, on the island of Hawai‘i’s western side, is located makai, or seaward, of Hōnaunau and is 74 ha in size. This park is located at the shoreline of Mauna Loa Volcano and is mostly coastal in nature. Brackish fishponds and wetlands, anchialine pools, springs, a cliff, and coastal strand communities are found in the park. Towards the southern border there is a stretch of coastal dry forest of mostly alien species, including opiuma (*Pithecellobium dulce*), koa haole (*Leucaena leucocephala*), and kiawe (*Prosopis pallida*).

**Kaloko-Honokōhau National Historical Park**
Located on the shoreline of the Hualalai Volcano on western Hawai‘i Island, KAHO is 469 ha in size with almost half of this area in marine waters. Natural resources include coral reefs, beaches and rocky shores, anchialine pools, two man-made brackish fishponds with associated wetlands, former dryland forest, and bare lava fields.

**Pu’ukoholā Heiau National Historic Site**
PUHE, another coastal national park located on the western side of Hawai‘i Island, sits on a bluff overlooking Kawaihae Harbor in South Kohala. Because it lies on the leeward side of the island and tends to receive little precipitation, the park and surrounding land are arid with little vegetation. In the rainy season, two streams flow in the park and converge to reach the ocean only when flow is high. On its north side, PUHE borders a small boat harbor with commercial shipping facilities, while the southern edge of the park abuts Samuel M. Spencer County Park. A county road runs just inside the northeastern boundary line and the western coastal boundary borders a shallow harbor partially enclosed by a stone breakwater. Of the park’s nearly 35 ha, 25 ha are federally controlled and 10 ha remain non-federal. A stream, which originates outside the park, feeds a small wetland area, providing habitat for *Palemon debilis* (glass shrimp) and many freshwater plants.

**Kalaupapa National Historical Park**
Located on the island of Moloka‘i, KALA is roughly 4,370 ha in size. The Kalaupapa Peninsula, adjacent cliffs and valleys, and submerged lands and waters out to 400 m from shore make up the park. Sea cliffs, narrow valleys, a volcanic crater, rain forest, lavatubes, caves, and offshore islands and waters are all present within park boundaries. Kauhakō Crater, formed by a remnant volcanic rim rising over 137 m, contains a crater lake more than 244 m deep, while Waikolu Valley contains the only perennial stream in
the park. Through cooperative agreements, the National Park Service manages almost all of this land.

Hawaiian people inhabited the Kalaupapa peninsula and valleys for hundreds of years, before the settlement at Kalawao was established in 1866. Many surviving Hansen's disease patients still live in the community of Kalaupapa, on the leeward side of the peninsula.

**Haleakalā National Park**

Originally designated as part of Hawai`i National Park in 1916, HALE was established as a separate entity in 1961. The park is located on east Maui and rises from sea level, at Ka`āpahu and ʻOhe`o, westward to the summit of Mount Haleakalā (3,055 m). HALE encompasses 12,215 ha, of which 10,003 ha are designated as wilderness. It is exposed to both moist windward tradewinds, where slopes may receive 305 cm of annual rainfall, and drier leeward air. The Summit District of the drier west side of the park is comprised of Haleakalā Crater, portions of its outer slopes, and the upper ends of the Kaupō and Koolau gaps. The wetter Kīpahulu District includes Kīpahulu, Kuiki and Kaumakani planezes, upper Hāna rain forest, ʻOhe`o/Puhilele coastal areas, and the new Ka`āpahu addition. HALE contains a number of natural ecosystems, including alpine cinder desert, sub-alpine shrublands, sub-alpine grasslands, montane bogs and lakes, rain forests, mesic forest, and coastal strand. The park also contains the ʻOhe`o stream ecosystem, which is a natural riparian habitat with its entire length inside national park boundaries.

**Selection of Survey Points and Transects**

Non-random fixed survey points and transect locations were determined based on the size of each park, accessibility and safety, and potential suitability of habitat for roosting and/or foraging bats (i.e., forested areas along roads and trails, areas of high insect density, and/or locations of previous bat observations). Survey areas were limited to the parks and immediate vicinities.

Because of its large size, limited accessibility, and extremes in elevation, we established 24 survey points in HAVO, with 12 “high elevation” points (between 1,005 m and 2,011 m) and 12 “low elevation” points (sea level to 1,005 m). Points were spaced a straight-line distance of 2,500 m apart. We distributed points along Hilina Pali Road, Chain of Craters Road, Crater Rim Drive, Highway 11, and Mauna Loa Strip Road (Figure 1).

For the smaller parks (PUHE, KAHO, PUHO), surveys were conducted at points within park boundaries and in immediately surrounding areas. We spaced survey points in these parks 800 m apart. We surveyed PUHO from points located along the 1871 Trail, the Great Wall shoreline, and on Highway 160. We conducted surveys in KAHO at points placed along trails and boundary lines, at the adjacent Honokōhau Harbor, the Aimakapa and Kaloko Fishponds, and near the visitors’ center. A central point was located within park boundaries at PUHE, the smallest of the west Hawai`i parks, on an overlook between the heiau and the newly constructed visitors’ center, and additional points were distributed throughout the surrounding vicinity (Figure 2).
Figure 1. High and low elevation repeat survey points established in Hawai`i Volcanoes National Park on the island of Hawai`i during Hawaiian hoary bat surveys from April to August 2005.
Figure 2. Repeat survey points established in Pu`uhonua o Hōnaunau National Historical Park (PUHO), Kaloko-Honokōhau National Historical Park (KAHO), and Pu`ukoholā Heiau National Historic Site (PUHE) on the west side of Hawai`i Island during Hawaiian hoary bat surveys from April to August 2005.
Surveys of KALA (Figure 11) and HALE (Figure 12) were limited due to time and budget constraints; however, we surveyed sections of major trails and roads in late-May/early-June 2005. We selected survey areas in these parks based upon accessibility and safety, previous bat sightings by park staff, and habitat characteristics (i.e., areas near freshwater, possible foraging and/or roosting habitat, and shelter from the strong year-round winds in KALA).

**Survey Methods**

We conducted acoustic surveys for *L. cinereus semotus* in these national parks between April and July of 2005. Visual observations were important to locate flying bats during sunset and early-morning surveys, but we focused primarily on using acoustic detection equipment. We used ultrasonic detectors to determine the presence or absence of echolocating bats at fixed points and along transects and to listen for feeding activity.

Handheld Mini-III ultrasonic bat detectors (Ultra Sound Advice, U.K.) were used to convert bat echolocation calls into clicks that are audible to human ears. One limitation of using bat detectors is the difficulty in distinguishing multiple species of bats; however, because only one species of bat is present in the Hawaiian Islands, this was not a constraint. Following methods used by Jacobs (1994), the Mini-III detectors were set to 30 kHz, which is the peak foraging echolocation frequency used by the Hawaiian hoary bat (Belwood and Fullard 1984). Surveys began one half-hour before sunset and continued for two hours post sunset, ensuring that periods of greatest evening bat activity were monitored (Menard 2001). Occasionally, we did surveys for one hour before sunrise, to account for possible morning activity at selected sites (Reynolds et al. 1998).

Acoustic detections were categorized as ‘passes’ (single or multiple low repetition clicks) or ‘buzzes’ (rapidly repeating clicks which occur more frequently as the bat approaches a prey item), which indicate feeding (Fullard 1989; Jacobs 1993; Cabrera 1996). We did not attempt to capture the number of passes or feeding buzzes/unit time, we simply recorded presence/absence of a bat and presence/absence of a feeding buzz. In order to make general suggestions regarding habitat associations (i.e., areas where hoary bats were observed foraging), we relied on the detection of feeding buzzes. Because it is not possible to differentiate between several passes by one bat or single passes by several bats (Fenton 1970; British Columbia Resources Inventory Committee 1998; Johnston 2002), direct population density estimates are not feasible (Thomas and West 1989; British Columbia Resources Inventory Committee 1998; Johnston 2002). In addition to audio detections, we recorded visual observations and attempted to count individuals only when sufficient light permitted.

Locations of bats detected visually or aurally, as well as transects and points visited, were recorded with a Garmin 76C GPS unit using the Universal Transverse Mercator, North American Datum 1983, zone 5Q.

**Repeat Surveys**

Repeat surveys were conducted at all fixed points in four national parks (HAVO, KAHO, PUHE, and PUHO) on the island of Hawai‘i. This allowed for continued monitoring of specific sites within each park over several months. We visited each point on at least six
separate occasions over a 14-week period from mid-April to late-July, with at least one week between visits. We surveyed each point both acoustically and visually, depending on available sunlight, for 15 minutes. Random visit order was used to reduce temporal effects on detection probabilities (Jacobs 1994; Reynolds et al. 1998). Bat presence/no detection was recorded along with notes regarding feeding buzzes, habitat, number of bats identified, mode of detection (visual or aural), weather variables, and time of detection. Presence/no detection data collected in the Hawai`i Island parks during repeat surveys were analyzed using program PRESENCE (Hines and MacKenzie 2004). Because few species are so conspicuous that they are always detected when present at a site, the probability that a site is actually occupied may be underestimated (i.e., naïve estimate). Therefore, through analysis of detection histories from repeatedly surveyed sites, the probability of detecting the species is determined, which then allows researchers to generate an unbiased estimate of the proportion of sites occupied (Psi) (MacKenzie et al. 2002). We used a single season output model for data analysis with program PRESENCE, which assumes that all parameters are constant across sites and no changes are occurring to the state of occupancy to any sites during the sampling season.

**Non-Repeat Surveys**
In order to provide more thorough survey coverage of important selected areas and to supplement park distribution records, we conducted non-repeat surveys in all parks between February and July. These surveys included one-time visits to selected points and transects that were traveled by foot or by a slowly moving vehicle (<24 km/h). Transects were generally selected along trails and roads that could be safely walked at night. Random stops (5-20 minutes duration) were made in open areas along these transects and in areas believed to be potentially suitable for roosting/foraging bats. We report information collected through non-repeat surveys as incidental sightings.

Data from this inventory for all six national were entered into NPSpecies - the National Park Service Biodiversity Database available at [https://science1.nature.nps.gov/npspecies/web/main/start](https://science1.nature.nps.gov/npspecies/web/main/start)