INTRODUCTION

Introduced mammalian predators threaten native Hawaiian flora and fauna in various ways. Though endemic Hawaiian birds evolved with native avian predators such as hawks and owls, there was an absence of native mammalian predators. Because mammals and raptors hunt birds in different ways, selective pressures from raptors are likely different than from mammals, thus making birds susceptible to mammalian depredation (Moors et al. 1992, Stone et al. 1984). Non-native mammals consume a variety of native bird, invertebrate, and plant foods (Kami 1966, Scowcroft and Sakai 1983, Male and Loeffler 1997, Sugihara 1997, Wanless et al. 2007), thus potentially reducing the availability of food for forest birds and contributing to habitat degradation. Predation on native plant fruits and seeds also represents a threat to rare plant populations (Chimera 2004) and selective pressures on particular species can potentially create long-term shifts in the composition and structure of plant communities (Allen et al. 1994).

Three species of rats have arrived in the Hawaiian Islands since colonization by humans. Polynesian rats (*Rattus exulans*) were brought by the early Polynesian settlers around 400 AD (Kirch 1982). Norway rats (*R. norvegicus*) were established on the islands shortly after Captain James Cook arrived in 1778, and black rats (*R. rattus*) reached Hawai`i in the late 1800s (Tomich 1986). Both Polynesian and black rats are well adapted to the ecological conditions in forests in Hawai`i (Sugihara 1997). All three rat species contribute to the decline of native forest bird species in Hawai`i, though the black rat is considered the most significant avian predator of the three species due to its arboreal life style (Atkinson 1977, Ebenhard 1988). The extirpation of the Laysan Rail (*Porzana palmeri*) and Laysan Finch (*Telespiza cantans*) from Midway Island in the 1940s was attributed to an extreme rat infestation (Fisher and Baldwin 1946). In addition to being a threat to native bird species, black rats are known to prey on native snails (Hughes unpubl. data), the fruits of sandalwood (*Santalum* spp.), and other vulnerable Hawaiian plant species (Loope et al. 1988). Norway rats are occasionally found in low and mid-elevation forest, residing close to urban and agricultural areas where food is more secure (Tomich 1986, Tobin and Sugihara 1992, Lindsey et al. in press). Thus, Norway rats pose the smallest threat of the three species of rats to native fauna because they do not invade very far into native forests (Tomich 1986, Lindsey et al. in press).

The house mouse (*Mus musculus*) is the most ubiquitous non-native mammal in Hawai`i. House mice can compete with native Hawaiian fauna for food resources as well as provide a food base for more threatening non-native carnivores. Although the house mouse is not typically viewed as a direct predator of native fauna, house mice have recently been documented preying on albatross chicks on the South Atlantic island of Gough (Wanless et al. 2007).

The small Indian mongoose (*Herpestes javanicus*) was released in Hawai`i in 1883 as an unsuccessful biological control agent of rats (Tomich 1986). Mongooses are the largest threat to ground nesting seabirds and contribute to the reduction of Newell's Shearwater (*Puffinus auricularis newelli*) on Moloka`i (Harrison 1990, Ainley et al. 1997). Mongooses have also been a factor in the decline of the endangered Nēnē (*Branta sandvicensis*), as the eggs and brooding females are particularly defenseless on the ground (Banko 1992, Banko et al. 1999). Laboratory tests show that mongooses are good tree climbers (Stone and Loope 1987) and may also depredate native forest bird species.

Domestic cats (*Felis catus*) arrived in the Hawaiian Islands with European explorers and settlers, and feral populations became established by the early 1800s (Tomich 1986). Feral cats are present on all the main Hawaiian Islands. They range from sea level, where populations are higher as a result of abandoned pets and feeding by humans, to isolated montane forests and alpine areas of Maui and Hawai`i (Simons 1983, Hu et al. 2001, Winter 2003, Hess et al. 2004). Feral cats are a major predator of native forest and ground-nesting birds. The endangered Hawaiian Goose or Nene and the endangered Hawaiian Petrel (*Pterodroma phaeopygia sandwichensis*), both ground-nesting species, have suffered depredation by feral cats (Simons 1983, Banko 1988, Natividad Hodges 1994, Baker and Baker 1996, Natividad Hodges and Nagata 2001). Feral cats also depredate roosting forest birds, and have been observed taking nestlings from nests (Hess et al. 2004).

Before this inventory small mammal trapping had not occurred in Kalaupapa National Historical Park (KALA). This inventory was conducted to document the presence or absence of these six mammalian species in the park. Our survey provides baseline data for future studies and information for management decisions regarding these species. This inventory also helps to fulfill the goal of the National Park Service Inventory and Monitoring program to document 90% of vertebrates and vascular plants in national parks.

There is a high level of interest in controlling introduced rodent and small mammal populations in managed areas in Hawai`i to reduce predation on native plants and animals. In order to achieve meaningful results and be cost effective, recent programs focus on the use of rodenticides; however, there are concerns for environmental health and for non-target species in the implementation of these programs.

One recent project undertaken by the State of Hawaii Department of Land and Natural Resources and the United States Fish and Wildlife Service set out to eradicate rats from Mōkapu Islet just outside the KALA boundary. The removal of rats serves to protect the rare native plant species hō`awa (*Pittosporum halophilum*) and loulu palm (*Pritchardia hillebrandii*) and several ground-nesting seabirds including Wedge-tailed Shearwaters (`ua`u kani, *Puffinus pacificus*), Red-tailed Tropicbirds (koa`e `ula, *Phaethon rubricauda*), and White-tailed Tropicbirds (koa`e kea, *Phaethon lepturus*) (Wilson 2008). These same species occur on the adjacent islands of Huelo and `Ōkala, but no rodents have been found there to date. Rodenticide poisons readily break down in sunlight and bind to inert substances making them unavailable to the biotic food chain. As a precaution, efforts were made to control the application of the aerial-broadcast rodenticide so it would be restricted to the island. Project managers of the Mōkapu Islet eradication program sampled several marine organisms before and after the application of rodenticide and found no poison in the non-target species sampled (Swenson 2008). Other studies examined the effects of rodenticides on non-target species and their pathways in food webs. The findings predicted low probabilities that non-target rare native forest birds and native snails would be affected by these poisons (Johnston et al. 2005). There is potential for properly selected and conducted rodent poison control programs in Hawai`i.

Habitat Description

Located on the island of Moloka`i, KALA is 5,261 hectares in size and encompasses Kalawao County (Figures 1 and 2). The county includes the Kalaupapa Peninsula and settlement of the same name, a volcanic crater, adjacent cliffs and valleys, and submerged lands and water out to 400 m from shore. Kalaupapa Peninsula was formed 400,000 years ago from lava flows of a tiny rejuvenated-stage shield volcano that developed immediately off the north shore of the island (Juvik and Juvik 1998, Ziegler 2002). The volcano shield is about three kilometers across and rises to 122 m above sea level. The islets, which lie almost one kilometer from shore, are isolated by marine erosion (MacDonald et al. 1983). Though within the park's boundary, the islets are owned and managed by the state as bird sanctuaries. The island's north shore sea cliffs that rise up to one kilometer (Ziegler 2002) are the result of a great landslide 1.5 million years ago. The landslide slid northward and propelled kilometer-sized blocks into the ocean as far as 161 km offshore (Juvik and Juvik 1998).

Figure 1. Aerial photo of Kalaupapa Peninsula looking eastward, Kalaupapa National Historical Park, 2005.

The terrestrial landscape of the park consists of wet and mesic forest, dryland forest and shrub, and coastal strand communities. The wet and mesic forests range from intact native forests dominated by `ōhi`a (*Metrosideros polymorpha*) and tree ferns at high elevation (730–1180 m), to non-native dominated Java plum (*Syzygium cumini*) and strawberry guava (*Psidium cattleianum*) forest in the lowlands (20–200 m). Java plum and guava forests on valley bottoms typically have an open understory, which is the result of high densities of feral goats, pigs, and deer, while Christmas berry (*Schinus terebinthifolius*) and lantana (*Lantana camara*) form dense thickets on the peninsula following the release of grazing pressure from the removal of horses and cattle in the 1980s (Scowcroft and Hobdy 1987, National Park Service 2000, 2004). The ground cover within high elevation native forests consists of uluhe (*Dicranopteris linearis*) ferns, shrubby alani (*Melicope* spp.), ha`iwale (*Cyrtandra* spp.), and kanawao (*Broussasia arguta*), and grasses such as naturalized *Ehrharta stipoides* with some scattered non-native vegetation. The densely vegetated remnant dryland forest in Kauhakō Crater,

found in the center of the peninsula, is represented by native wiliwili (*Erythrina sandwicensis*) tree stands with a variety of native shrubs and trees, but is dominated by non-native plants.

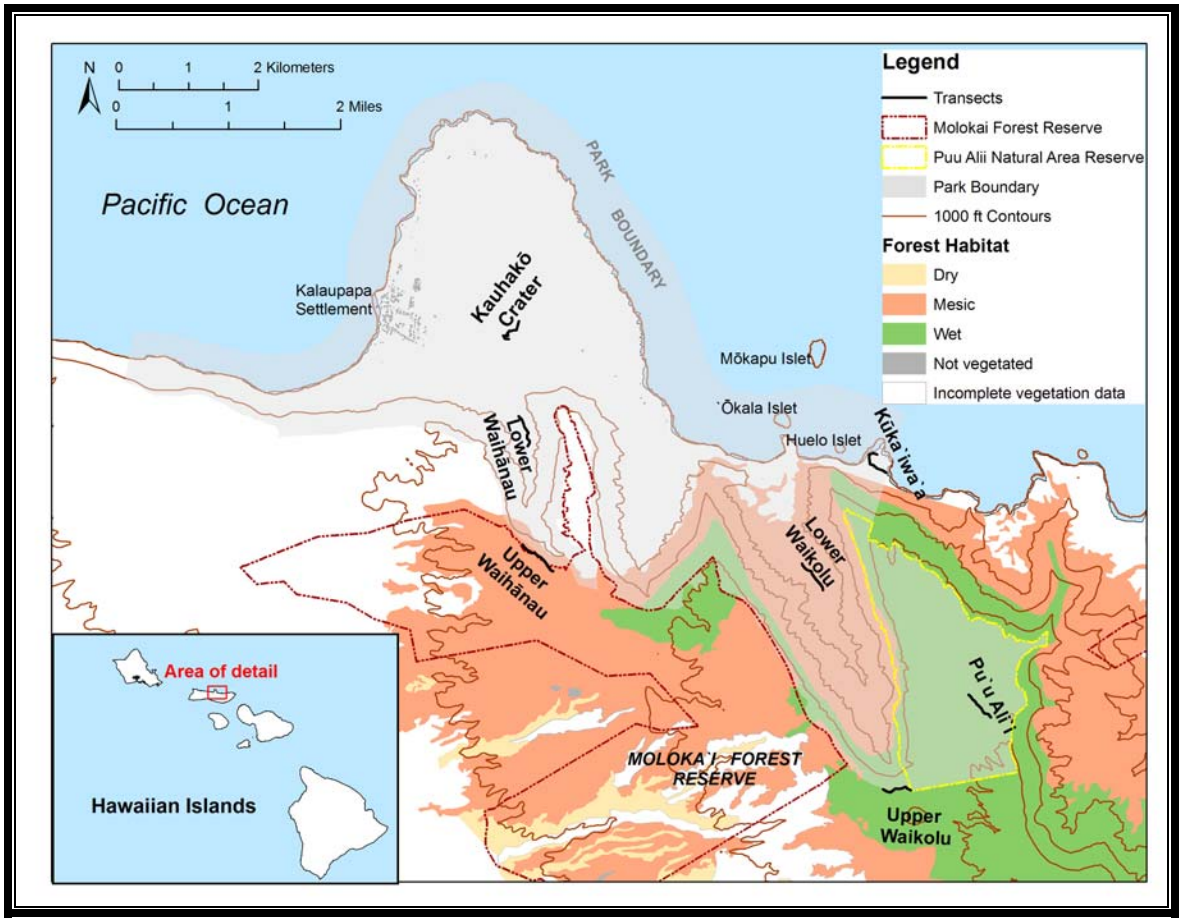

Figure 2. Map of non-native mammal survey transects at Kalaupapa National Historical Park, March–May 2005.

METHODS

Species distribution data from this inventory will be entered into NPSpecies (https://science1.nature.nps.gov/npspecies/web/main/start), the National Park Service Biodiversity Database. Currently, only National Park Service employees or contractors can access NPSpecies, but a website with accessibility for the public is being developed.

Transect Establishment

This inventory was conducted along seven 500-m transects consisting of a combination of newly established and pre-existing transects (Figure 2 and Table 1). Each transect consisted of 11 stations, except for the Kūkaʻiwaʻa transect which had nine stations (75 stations total). The transects surveyed all coincide with the longer transects surveyed for the 2005 Forest Bird Inventory (Marshall and Kozar 2008). Waihānau Valley is the westernmost valley on Molokaʻi's northern shore. The lower Waihānau transect (180 m elevation) runs north-south along the narrow floor of the valley, proximal to the intermittent stream. The upper Waihānau transect occurs at about 750 m elevation and

follows Pu`u Kauwā Road in the Moloka`i Forest Reserve. The transect overlooks Waihānau Valley and Kalaupapa Peninsula (Figure 3). Kauhakō Crater is the highest natural point on the peninsula at 122 m (Figure 4). The transect runs along the crater rim, descends, and follows along the plateau above the lake.

Table 1. Transect descriptions of the small mammal inventory, Kalaupapa National Historical Park, March–May 2005.

Transect	Elevation* (m)	Vegetation
Pu`u Ali`i NAR	1150–1180	Native: `ōhi`a, treefern, shrub
Upper Waikolu	1100–1140	Native: `ōhi`a, treefern, shrub
Upper Waihānau	730–780	Mixed: `ōhi`a as well as non-native trees
Lower Waihānau	160–200	Non-native: Java plum, guava spp.
Lower Waikolu	140–160	Non-native: guava spp., kukui (*Aleurites moluccana*)
Kauhakō Crater	30–100	Mixed: Christmas berry, lantana, wiliwili
Kūka`iwa`a	20–40	Mixed: hala (*Pandanus tectorius*), Java plum

*describes the elevation range covered by the transect—not necessarily beginning and end elevations of the transect; elevation ranges were determined using 20-m contour lines.

Figure 3. Photo of Kauhakō Crater and Kalaupapa Peninsula from upper Waihānau, Kalaupapa National Historical Park, 2005.

Figure 4. Aerial photo of Kauhakō Crater and Waihānau Valley, Kalaupapa National Historical Park, 2005.

Waikolu Valley lies east of Waihānau (Figure 5), and has been a water source for Moloka`i since the early 1900s. The lower Waikolu transect (150 m elevation) runs north-south, along an old aqueduct pipe. A Hawai`i Forest Bird Survey (HFBS) transect covers the upper Waikolu rim (1,100 m) area along the Hanalilolilo trail. The Pu`u Ali`i Natural Area Reserve (NAR) is a summit plateau inhabited by wet forests, fern and shrub montane cliff communities, wet shrublands, and intermittent stream communities. It is an important part of the Moloka`i watershed and contains forest bird habitat. In Pu`u Ali`i NAR (1,160 m elevation) a pre-existing HFBS transect was utilized. Kūka`iwa`a (30 m elevation) is a small peninsula east of Waikolu Valley, lying close to the offshore islets (Figure 6). The Kūka`iwa`a transect runs along a 250 m fence transecting the peninsula east-west, then wraps around to the open coastal area.

Transects and stations were recorded with a Global Positioning System (GPS) Garmin GPSmap76 unit, utilizing the Universal Transverse Mercator, North American Datum 1983, Zone 4N.