NATURAL RESOURCES MANAGEMENT PLAN
for
PU‘U WA‘AWA‘A FOREST BIRD SANCTUARY

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Photo courtesy of Paul Banko

STATE OF HAWAI‘I
DEPARTMENT OF LAND AND NATURAL RESOURCES
DIVISION OF FORESTRY AND WILDLIFE

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EXECUTIVE SUMMARY

The Puʻu Waʻawaʻa Forest Bird Sanctuary is one of the most biologically diverse landscapes on the Island of Hawaii. It currently supports many rare plants and animals, thirteen of which are listed as endangered (7 plants, 2 insects, 3 birds, and 1 mammal). The sanctuary also includes federally designated Critical Habitat for three plant and three wildlife species. An extensive lava tube complex contains priceless subfossil bird deposits and provides habitat for an extraordinary array of cave-adapted arthropods. This plan addresses specific objectives and strategies for the restoration and sustainable management of the area's resources. Actions are recommend for infrastructure maintenance and improvements, forest management, invasive weed control, wildlife management, lava tube management, information and education, wildfire suppression, resource monitoring, and human activity management.

INTRODUCTION

Government lands now included within the Puʻu Waʻawaʻa Forest Bird Sanctuary (PWWFBS) were formerly leased by Puʻu Waʻawaʻa Ranch for pasture purposes. These lands were grazed for decades by domestic livestock and feral animals. In 1984, a state biologist discovered that the ranch lessee was illegally harvesting koa (*Acacia koa*) trees in the upper part of the ranch. It was determined that the logging operations extended from Shangri-la to Halepiula, between 4,000 and 5,100 feet (1219 and 1554 m) elevation. This discovery prompted the Hawaii Board of Land and Natural Resources to withdraw 3,806 acres (1540 ha) from the ranch lease to penalize the lessee. Withdrawn lands were returned to the Land Division inventory for future disposition. The Division of Forestry and Wildlife (DOFAW) subsequently requested the parcel for protecting forest bird habitat and it was formally transferred to them by Board action on October 12, 1984. The land was specifically set aside to preserve habitat for endangered forest birds, especially the ʻalala or Hawaiian crow (*Corvus hawaiiensis*). On July 22, 2002, Governor Benjamin Cayetano issued executive Order No. 3937 formally designating the area as a state wildlife sanctuary. Title 13, Chapter 125, Rules Regulating Wildlife Sanctuaries, provides the legal basis for sanctuary protection.

On January 25, 2002 the Board of Land and Natural Resources transferred responsibility for State managed lands within the ahupuaʻa of Puʻu Waʻawaʻa and Puʻu Anahulu from the Land Division to the Division of Forestry and Wildlife (DOFAW) and State Parks. Subsequently, DOFAW and State Parks have worked both internally and with the Puʻu Waʻawaʻa Advisory Council to develop a management plan for Puʻu Waʻawaʻa and the lands of Puʻu Anahulu makai of Queen Kaʻahumanu Highway – an area comprising approximately 40,711 acres (16,475 ha). In July 2003 the State of Hawaii approved the Management Plan for the Ahupuaʻa of Puʻu Waʻawaʻa and the Makai Lands of Puʻu Anahulu. The Natural Resource Management section of this plan delineates 11 conservation units. In order to maximize and prioritize management activities the Puʻu Waʻawaʻa Advisory Council will develop individual management plans for each unit. DOFAW drafted an initial management plan for the sanctuary in December, 1985. That plan emphasized management actions needed for protecting Hawaiian crow habitat. This revision replaces the earlier plan and includes objectives and strategies for the long-term protection and preservation of native ecosystems in the PWWFBS.

On December 12, 2006, the Department of Land and Natural Resources (DLNR) and U. S. Forest Service (USFS) signed a 35 year Cooperative Agreement for the establishment and administration of the Hawaii Experimental Tropical Forest (HETF) at Pu‘u Wa‘awa‘a. Under this agreement, the Pu‘u Wa‘awa‘a Forest Reserve and PWWFBS serve as a center for long-term research and a focal point for developing and transferring knowledge and expertise for the management of tropical forests. On January 26, 2007 the BLNR granted a non-exclusive permit to the USDA Forest Service to use State lands situated at Pu‘u Wa‘awa‘a as a Hawai‘i Experimental Tropical Forest unit.

PROPERTY DESCRIPTION

Location and Land Use

The sanctuary is located on the northern flank of Hualalai volcano in the ahupua‘a of Pu‘u Wa‘awa‘a, Island of Hawaii (TMK: (3) 7-1-01-007). It is approximately 4 (6.4 k) miles above Mamahaloa Highway, about 18 miles (28.8 k) from Kailua-Kona, and 22 miles (35.2 k) from Waimea town (fig. 1). The area extends from 4,000 to 6,500 feet (1219 to 1981 m) elevation and includes four paddocks (Halepiula mauka Kona, Halepiula mauka Waimea, Waihou mauka, and Po‘ohoho‘o) that were formerly part of Pu‘u Wa‘awa‘a Ranch. These paddocks are delineated by rock walls and/or old fencing (fig. 2). Parcels owned by Bishop Estate adjoin the sanctuary on the south and west boundaries. Pu‘u Wa‘awa‘a Forest Reserve lies to the east and north. Lands adjacent to the sanctuary are used for ranching, public hunting, recreation, and conservation. A review of Pu‘u Wa‘awa‘a land use history, geologic features, climate, and biological resources was reviewed by Giffin, 2009.

Most of the sanctuary lies within the Conservation District (R Subzone), but approximately 800 acres (324 ha) on the northern boundary are zoned Agriculture. Additionally, Critical Habitat has been designated by the U.S. Fish and Wildlife service for a number of plants and animals at Pu‘u Wa‘awa‘a. Critical Habitat is a term in the Endangered Species Act identifying geographic areas that are essential for the conservation of threatened or endangered species and may require special management considerations. Portions of three (3) plant and three (3) wildlife critical habitat units occur within the Forest Bird Sanctuary. These units are designated for the following species:

- *Argyroxiphium kauense*
- *Delissea undulata*
- *Solanum incompletum*
- *Corvus hawaiiensis*
- *Loxops coccineus*
- *Manduca blackburni*

Prior to 1985, Pu‘u Wa‘awa‘a Ranch had grazed cattle in the sanctuary area for decades. Regeneration of endemic shrubs and trees, including koa, was almost totally lacking and forest cover was declining. Very few young trees were present and old ones were dying without replacements. The forest understory was being replaced by non-native pasture grasses and invasive weeds. If grazing had continued, the entire sanctuary would have been transformed from native forest to open parkland and pasture. Other ranching related activities have also contributed to forest degradation at Pu‘u Wa‘awa‘a. These included forest clearing for pasture

improvement, illegal harvesting of koa, ʻohiʻa (*Metrosideros collina*), and hapuʻu (*Cibotium glaucum*), and the purposeful and accidental introduction of exotic birds and plants.

In July, 1985 cattle were finally removed from most of the sanctuary. A small herd remained in the Henahena paddock until October, 1989, when a section of new boundary fence was completed. The forest experienced extensive recovery after livestock removal. Koa and ʻohiʻa seedlings germinated by the thousands. Most of these grew rapidly and exhibited excellent survival. Other species of native plants also responded to reduced grazing pressure. Those showing the greatest recovery were mamaki (*Pipturis albidus*), pilo (*Coprosma* spp.), and ʻolapa (*Cheirondendron trigynum*). Several rare plants, not recorded for several decades, have reappeared and show signs of increasing distribution.

The removal of domestic livestock created new management problems. Non-native pest plants, which were formerly suppressed by cattle, began to proliferate. The most serious was banana poka (*Passiflora tarminiana*). Without cattle, these vines began spreading and now infest most sections of the forest. German ivy (*Delairea odorata*), silk oak (*Grevillea robusta*) and fountain grass (*Pennisetum setaceum*) also threaten native plant communities. Silk oak has been successfully controlled in the sanctuary, and a concerted effort is under way to control fountain grass.

Private in Holding

A privately owned parcel of land (2.75 acres, 1.1 ha) is situated inside the sanctuary at Halepiula. There is no legal road easement serving that parcel, but DOFAW has issued an access permit to the property owner. The landowner has indicated that he intends to fence the property and construct a private environmental research facility. Planning, permitting, and land clearing activities are currently underway for that parcel.

Rainfall

The sanctuary climate is similar to other upland Kona forests. The Halepiula rain shed area (4,600 ft. (1402 m) elevation) is the wettest part of the sanctuary. From 1938 to 1974, the median annual rainfall at the shed was 46.7 inches (119 cm). Maximum and minimum annual rainfall during the same 37-year period was 97.4 and 17.6 inches (277.4 and 44.7 cm), respectively. Months of greatest rainfall were March thru July with a peak in precipitation during May (Div. of Water Resource Management, 1991). The timing of maximum rainfall was somewhat different in 1992 and 1993 based on data collected at the sanctuary cabin rain gauge (4,000 ft. (1219 m) elevation). The wettest period was late fall and early winter. Rainfall in the sanctuary increases considerably from east to west. The Shangri-la area is much drier than Halepiula. Rainfall also decreases rapidly with increasing elevation (Juvik and Tango 2003).

The sanctuary forest serves as an important watershed, not only for charging leeward Hawaiʻi aquifers, but also for the role that percolating water plays in nearshore fisheries at Kiholo Bay Marine Life Conservation District.

Soils

Sanctuary soils can generally be classified as Lithic Ustifolists or Lithic and Pachic Haplustands. These are shallow to moderately deep, well-drained soils that formed in organic material or ash

deposits (USDA, 2008). Several soil series are present, but those covering the greatest area are Puuiki, Kamawai, Halekula, and a mixture of Kamawai and Puuiki types (fig. 3). Soil depth is less than 10 inches (25.4 cm) deep on pahoehoe and no more than 20 inches (50.8 cm) deep on `a`a (Robert Gavenda, pers comm.).

Geology

Lava flows in the forest bird sanctuary originated on Hualalai volcano and are relatively recent geologically. Wolfe and Morris (1996) mapped these lavas into three general age classes. The youngest flows (750 to 1,500 years old) are found near the upper boundary, generally above 5,600 feet (1707 m) elevation. Slightly older flows (1,500 to 3,000 years old) are distributed throughout the sanctuary and cover the greatest area. The oldest flow (3,000 to 5,000 years old) begins at an unnamed vent above the upper boundary and extends through the central portion of the sanctuary (fig. 4). A radiocarbon-dated charcoal sample collected near the Halepiula rain shed revealed that lava flows in that area were deposited 2,740 $\pm$ 100 years before present. Lava substrates within the sanctuary consist of rough ʻaʻa, smooth pahoehoe, and a mix of both lavas (fig. 5).

Potato hill is the largest and oldest cinder cone within the sanctuary being 10,000 to 25,000 years old. It may have been a sweet potato (*Ipomoea batatas*) cultivation site in the past and possibly derived its name from that plant. No Hawaiian name is recorded for potato hill, but some evidence suggests that it was also known as Puʻu Henahena. Poʻohohoʻo is a younger cinder cone situated near the lower sanctuary boundary. This hill is less than 5,000 years old (Wolfe and Morris, 1996). Its dual craters were used as reservoirs by the former Puʻu Waʻawaʻa Ranch. An asphalt catchment apron collects water for storage. Many more small volcanic vents and cinder cones are scattered throughout the area, but most unnamed.

RESOURCE FEATURES

Vegetation

At least three native forest communities are represented in the forest bird sanctuary. They include koa/ʻohiʻa montane mesic forest, ʻohiʻa montane dry forest and koa/mamane (*Acacia/Sophora*) forest (Wagner et al., 1990). Most of the area is within the mesic forest zone. As the name implies, koa and ʻohiʻa are the dominant tree species in the overstory layer. Kolea (*Myrsine lessertiana*) dominates the mid-story layer while native short-stature trees and shrubs form the understory layer. Kikuyu grass (*Pennisetum clandestinum*) and native ferns, especially the shuttlecock shaped laukahi (*Dryopteris wallichiana*), cover the ground in drier sections of the sanctuary. Other ferns including hoio (*Athyrium sandwichianum*), akolea (*Athyrium microphyllum*), and palapalai (*Microlepia setosa*) are common in wetter, shaded areas. No tree fern stratum exists although hapu`u (*Cibotium glaucum*) is scattered throughout the forest.

Forest Cover: Forest cover maps for the Island of Hawaii were prepared by Jacobi (1982) based on 1977 aerial photographs. These maps indicate that the lower half of the sanctuary is sparsely vegetated while the upper half is more heavily forested. Vegetation near the lower boundary is dominated by open stands of ʻohiʻa and koa (1,290 acres, 522 ha). Canopy cover increases at mid elevations where the largest and best developed koa trees are found (569 acres, 230 ha). A band of closed canopy, tall ʻohiʻa (with scattered stands of koa) lies above the koa belt (510 acres, 206

ha). This community fades into a scattered stand of moderate stature ʻohiʻa at the upper edge of the sanctuary (305 acres, 123 ha). An open to closed canopy ʻohiʻa forest is also found along the eastern boundary of the sanctuary (805 acres, 326 ha). Scattered stands of mamane occur along the lower sanctuary boundary and near Potato hill. Several areas have been totally cleared of vegetation (327 acres, 132 ha) as a result of previous agricultural practices (fig. 6).

Plant species composition and tree size vary from one area to another in the sanctuary. Trees more typical of dry montane forests (*Sophora, Chamaesyce,* and *Santalum*) are common near the eastern boundary. These are replaced by taller koa and ʻohiʻa plus species typical of wetter montane forests (*Cheirodendron, Ilex,* and *Clermontia*) near the western boundary. Differences in tree size and forest structure appear to be related to lava flow age, soil type, moisture regime, and elevation.

Rare Plants: The most intact and botanically diverse section of sanctuary forest occurs in the Halepiula mauka Waimea paddock, generally above 5,100 feet (1554 m) elevation. This area also supports the greatest number of threatened and endangered plant and animal species. Maps prepared by Wolfe and Morris (1996) show that lava flows in the Halepiula mauka Waimea paddock are among the oldest in the sanctuary being 3,000 to 5,000 years old.
Over 100 species of native plants occur within the sanctuary. Six taxa are listed as endangered and numerous others are considered rare or threatened (Appendix 1). The endangered species are *Asplenium peruvianum*, Hawaiian vetch (*Vicia menziesii*), ʻaiea (*Nothocestrum breviflorum*), *Phyllostegia warshaueri*, *Phyllostegia velutina*, and Laukahi kuahiwi (*Plantago hawaiensis*). A single haha plant (*Cyanea stictophylla*) was present in the wild until 2003 when it died. Detailed accounts of botanical resources at Puʻu Waʻawaʻa can be found in reports prepared for the Hawaii Division of Forestry and Wildlife by Takeuchi, 1991; The Nature Conservancy, 1992; and Giffin, 2009).

Mitigation for Loss of Endangered Plant Species: The continuation of a public game mammal hunting program at Puʻu Waʻawaʻa is expected to result in the incidental take of all unprotected plant species listed as endangered. DOFAW is currently preparing a Habitat Conservation Plan for Game Mammal Management that will describe strategies and actions needed to mitigate impacts caused by game animals. Plant species most affected will be outplanted and protected in suitable areas (onsite and offsite) at a rate of three to one for each case of incidental take. The forest bird sanctuary is expected to offer prime habitat for mitigation efforts.

Wildlife

Many groups of terrestrial animals are conspicuously absent from the native fauna. Reptiles, amphibians, and mammals, except for bats, were unable to reach the island without the aid of man. As a result, Hawaiʻi's native terrestrial fauna is dominated by only three groups of animals: mollusks, arthropods (especially insects), and birds.

Native Invertebrates: Puʻu Waʻawaʻa supports the last remaining vestige of natural habitat for a large number of endemic invertebrates. Of special concern is the survival of unique insects like the endangered Blackburn's sphinx moth (*Manduca blackburni*) and a long-horned beetle (*Plagithmysus simplicicollis*). Both are dependent on the endangered ʻaiea tree (*Nothocestrum breviflorum*) for their continued survival. *Plagithmysus* e*legans*, another long-horned beetle, is

restricted to the rare papala tree (*Charpentiera obovata*). The two beetle species mentioned above have not been observed in the sanctuary, but occur near the lower boundary. Both are doomed to extinction if their host plants are lost. The koa bug (*Coleotichus blackburniae*) is threatened with extinction even though its host (*Acacia koa*) is generally common. Parasitism, by introduced biological control agents for the southern green stink bug, is thought to be the major cause of their decline.

Native Birds: The first avian species that arrived in Hawaii encountered environmental conditions (extreme geographic isolation, a tropical climate, mountainous topography, and extremes in rainfall and temperature) that encouraged adaptive radiation and reduced the value of flight. Over time, wing size was reduced as compared to continental relatives and a few species became flightless. Several kinds of flightless birds roamed the sanctuary forest in prehistoric times. These included large herbivorous geese (*Branta* sp.) and small rails (*Porzana* spp.). The flightless goose was Hawaii's largest land animal, standing about three feet (0.91 m) tall. This species existed until at least 500 years ago, probably grazing on grasses and fern fronds. Flightless rails survived until the turn of the century and a few live specimens were collected by early naturalists. All of Hawaii's flightless birds are now extinct, but preserved bones of these animals can still be found in lava tubes scattered throughout the sanctuary (Giffin, 1992).
Birds are the dominant form of native wildlife found in the sanctuary today. The endemic honey creepers include ʻamakihi (*Hemignathus virens*), ʻapapane (*Himatione sanguinea*), iʻiwi (*Vestiaria coccinea*), Hawaii akepa (*Loxops coccineus*), and Hawaii creeper (*Oreomystis mana*). Other species present are a monarchine flycatcher or ʻelepaio (*Chasiempis sandwichensis*), ʻio or Hawaiian hawk (*Buteo solitarius*), and pueo or Hawaiian owl (*Asio flammeus sandwichensis*). Amakihi, apapane and iʻiwi are the three most abundant species, respectively. Distribution and abundance of sanctuary birds was summarized by Giffin (1990, 1991). ʻAlala or Hawaiian crows (*Corvus hawaiiensis*) were formerly present in the sanctuary, but are now extirpated. Nene or Hawaiian geese (*Branta sandwicensis*) are restricted to open areas below the sanctuary. The Hawaii akepa, Hawaiʻi creeper, ʻio, ʻalala, and nene are all listed as endangered. The current status of endangered bird species is summarized below:

Hawaii akepa are colorful insectivorous birds that glean insects from tree foliage, usually ʻohiʻa leaf buds and koa phyllodes. Males are red-orange while females are greenish above and yellowish below. They often move about the forest in small flocks. Hawaii akepa populations still exist on the upper slopes of Mauna Kea, Mauna Loa and Hualalai. The greatest concentration of these birds in Kona is centered on the northern side of Hualalai. In 1978, almost 99 percent of the estimated 660 +/- 250 Hualalai birds inhabited the koa-ʻohiʻa forest at Puʻu Waʻawaʻa (Scott et al., 1986). Most of these were found within the forest bird sanctuary. The distribution of akepa sightings in the forest bird sanctuary was compiled three times between 1978 and 1991. A total of 64 detections was recorded. This information indicated that akepa were most abundant between 4,600 and 5,600 feet (1402 and 1707 m) elevation. The upper and lower limits of distribution ranged from 6,000 to 4,400 feet (1829 to 1341 m) elevation. Old growth ʻohiʻa -koa forests with ground ferns and other native vegetation have been identified as essential habitat for Hawaii akepa. Field studies at Hakalau National Wildlife Refuge indicate that these birds are tree cavity nesters. Only large diameter trees (over 26 inches (66 cm) DBH) are generally selected for nest construction (L. Freed, pers. comm.).

Hawai‘i creepers still exist on all major Hawaii Island volcanoes except Kohala Mountain. They are most common in mesic and wet forests above 4,900 feet (1494 m) elevation (Scott et al., 1986). These small green birds feed on insects, spiders, and other invertebrates. They glean arthropods from the trunk and larger branches of ‘ohi‘a and koa trees. Both sexes are similar in coloration. In 1978, an estimated 220 creepers lived in the koa-‘ohi‘a forest on north Hualalai (Scott et al., 1986). The distribution of this species in the forest bird sanctuary was compiled three times between 1978 and 1991. A total of 48 detections was recorded. Almost all birds were found between 4,900 and 5,800 feet (1494 and 1768 m) elevation. The upper and lower limits of distribution ranged from 6,300 to 4,400 feet (1920 to 1341 m) elevation (fig. 7).

The endangered Hawaiian Hawk or `io is relatively common at Pu‘u Wa‘awa‘a. These birds of prey are often seen hunting in the sanctuary forest and adjacent pasture lands. The population consists almost entirely of light phase color morphs. The best `io breeding habitat at Pu‘u Wa‘awa‘a is restricted to a narrow band of dry montane forest near the lower sanctuary boundary. All except one of the 13 nests located to date were in this forest type. Nests have been observed from 3,140 to 4,600 feet (957 to 1402 m) elevation and were constructed in kolea, ‘ohi‘a, and koa trees. Females have been noted incubating eggs in April and most young are fledged by mid July. Little is known about the food habits of adult birds, but they have been observed feeding on rodents, game birds, myna birds, `amakihi and pig remains. Baseline surveys of big island raptor abundance were initiated in December, 1993 by the USFWS. One of the survey routes included Pu‘u Wa‘awa‘a.

The endangered ‘alala or Hawaiian crow is the only corvid presently found on the Hawaiian archipelago. It is one of the rarest birds on the island today. Crows were historically known only from the Island of Hawaii with the entire breeding population being restricted to the forested slopes of Hualalai and Mauna Loa. Its range extended south from Puuanahulu in North Kona around to Kilauea crater in the Ka`u district. ‘Alala were formerly abundant at Pu‘u Wa‘awa‘a. They occupied several habitat types including lowland dry, montane mesic, and subalpine forests. In the 1950's, several pairs were often seen together at Pu‘u Wa‘awa‘a Ranch headquarters (B. Paris, pers. comm.). ‘Alala nested in the sanctuary near Halepiula (5,100 feet (1554 m) elevation) until 1981. The known population on Hualalai declined from at least 26 birds in 1974 to one individual by 1990. A crow was last seen at Pu‘u Wa‘awa‘a on March 14, 1991. This lone individual was foraging on the western boundary of the forest bird sanctuary at 5,350 feet (1631 m) elevation. Giffin (1983, 1987) documented the decline of wild ‘alala on Hualalai volcano.

Nene sightings have been made at Pu‘u Wa‘awa‘a since the turn of the century. Flocks of up to 33 birds were sometimes observed near Pu‘u Wa‘awa‘a cinder cone in the early 1940's. The area also served as an important breeding ground. Nene nested in the Waihou and Halekula paddocks between 2,300 and 4,000 feet (701 to 1219 m) elevation. Nests were also reported above Halekula in 1941 and at Poohohoo hill in 1942 (Baldwin, 1945). Recent nene nests have been found on Puuanahulu ridge, Big Island Country Club, and the meeting house reservoir. Nene are not known to nest or forage in the forest bird sanctuary.

Non-native Birds: A major game bird release program took place on Pu‘u Wa‘awa‘a Ranch from 1959 to 1972. At least 33 species of wild fowl were imported from several different countries and liberated on the ranch (Lewin, 1971). Some of the released game birds became

established and spread island-wide. Many species of songbirds were also imported from outside the United States and propagated by the owners of Pu‘u Wa‘awa‘a Ranch. Aviaries for these birds were maintained near ranch headquarters by Mr. L. S. Dillingham. A former ranch employee, Mr. Sunchiro Yano, indicated (pers. comm.) that there was never a deliberate release program for songbirds, but that some individuals escaped from their cages in the 1960's. The entire collection was finally released when the ranch was sold to F. Newell Bohnett in 1972. It uncertain what species of songbirds escaped or were released at Pu‘u Wa‘awa‘a. However, it’s likely that the following were set free: yellow-billed cardinal (*Paroaria capitata*), Red-cheeked cordon-bleu (*Uraeginthus bengalus*), lavender waxbill (*Estrilda caerulescens*), saffron finch (*Sicalis flaveola*), warbling silverbill (*Lonchura malabarica*), and yellow-fronted canary (*Serinus mozambicus*). All of these species are currently established in the wild. The most abundant songbirds currently inhabiting the sanctuary are Japanese white-eyes, house finches, northern cardinals, and red-billed leiothrix, respectively.

Parakeets and parrots are the most recent addition to Pu‘u Wa‘awa‘a 's exotic avifauna. On September 29, 1993, a flock 31 parakeets (conures) was sighted feeding in the sanctuary at 5,200 feet (1585 m) elevation. These birds are undoubtedly part of a group of 35 Mitred (*Aratinga mitrata*) and red fronted or Wagler's (*Aratinga wagleri*) parakeets that escaped from a private aviary in Kona (Kaloko Subdivision). The former owner of these birds indicated that they were imported from South America in 1989 and escaped the same year. Wild parakeets are said to be breeding in deep sinkholes on the western slope of Hualalai (T. Casey, Pers. Comm.). Up to 13 burrowing parrots (*Cyanoliseus patagonus*) have also been observed at Halepiula rain shed.

Native Mammals: The native bat or ope‘ape‘a (*Lasiurus cinereus semotus*) is Hawaii's only endemic land mammal. This rare mouse-like creature is a subspecies of the mainland hoary bat and is listed as endangered. Bats are occasionally seen darting about the sanctuary and its environs. They are most active at dusk as they forage on flying insects. Native hoary bats seldom enter caves, preferring instead to roost in trees. A second smaller species of bat (Vespertilionidae) once inhabited Pu‘u Wa‘awa‘a, but this animal is now extinct. Bones of this prehistoric bat have also been found in Pu‘u Wa‘awa‘a 's lava tubes.

Subterranean Ecosystems

The forest bird sanctuary is riddled with lava tubes, volcanic openings, and scattered tree molds. This abundance of volcanic formations is relatively unique within the islands. The greatest concentration of lava tubes is situated between Potato Hill and Po‘ohoho‘o cone. Over 40 lava tube openings have been located and mapped in that area to date. Many of these are undercut, concealed by dense vegetation, or divided by thin land bridges, making foot travel in heavily vegetated sections extremely hazardous. Lava tube passages extend from above the sanctuary boundary down to about 3,000 feet (914 m) elevation. At least three primary systems (*Ambigua*, Shangri-la, and *Delissea*) and another 4-5 secondary systems occur in 1,500 to 3,000 year old lava flows (fig. 8). Most passages are highly segmented being blocked by breakdown piles and other lava barriers. The lava tubes vary in size from a few feet high to huge caverns.

Large sinkholes occur at several locations in the sanctuary. These consist of steep-sided depressions that formed when the ground underneath them collapsed due to volcanic activity. An exceptionally large sinkhole occurs in the western half of the PWWFBS at 5,350 ft. (1631 m)

elevation. This pit is about 75 feet (23 m) wide and over 100 feet (30.5 m) deep. An endangered mint (*Phyllostegia warshaueri*) and other plants grow on the crater floor. A notable lava tube opening also occurs in the eastern half of the sanctuary. This skylight supports the only known population of *Phyllostegia ambigua* on Hualalai volcano. Additionally, numerous subfossil bones of flightless geese occur just inside the lava tube entrance. None of these bones have been removed for paleontological studies and the site is essentially undisturbed.

Lava tube passages provide habitat for many species of unusual and rare subterranean invertebrates (insects, spiders, and crustaceans). At least two species of obligate cave arthropods discovered at Pu‘u Wa‘awa‘a are new to science and are not known to exist elsewhere. They are a blind cixiid planthopper (*Oliarus makaiki*) and an eyeless terrestrial crustacean or amphipod (family Talitridae). Other rare cave-adapted insects found in the sanctuary include cave moths (*Schrankia howarthi*.), millipedes (*Nannolene* sp.), centipedes (*Lithobius* sp.), crickets (*Thaumatogryllus cavicola & Caconemobius* sp.), planthoppers (*Oliarus polyphemus*), thread-legged bugs (*Nesidiolestes ana*), and carabid beetles (*Mecyclothorax aa*).
Cave-adapted organisms are highly vulnerable to environmental contaminants. These species can be adversely affected by toxic substances that are carried into caves when polluted water infiltrates lava rocks. Non-native grasses have little value for cave invertebrates, but the effects of applying herbicide to these species when they grow above lava tubes is not known. Rodents are a major predator on subterranean invertebrates. They are implicated in the extinction of several noctuid moth species that were known to roost in Hawaiian lava tubes (F. Howarth, pers. comm.). Even humans have an impact on cave organisms. They damage cave habitats by unintentionally breaking plant roots, trampling cave creatures, and polluting their environment with cigarette smoke or garbage.

Plant communities growing above lava tubes are an integral part of subterranean ecosystems. Roots of native species, especially ‘ohi‘a and mamane, are the primary source of energy for Hawaiian cave life. Any damage to surface vegetation by land clearing, soil erosion, invasive plants, or ungulate activity adversely affects the underground environment and survival of endemic cave organisms. Fire is perhaps the most destructive agent for underground life as it destroys their nutrient sources.

Historic and Cultural Resources
Hawaiians likely utilized upland forests, including the sanctuary, for specialized resource extraction like bird catching/collecting, harvesting hardwood, and gathering forest plants for traditional and medicinal usage. Cave resources were an integral component of traditional Hawaiian activities and served multiple functions including habitation, water collection, food storage, refuge, and burial/interment (Dougherty and Moniz-Nakamura, 2008). Sanctuary lava tubes contain charcoal from torches and man-made structures such as rock platforms, trails paved with smooth stones, fire pits, calabash cradles for catching water, and rock walls. Midden deposits in some shelter caves contain bird bones and marine invertebrate shells left by ancient Hawaiians. Live or freshly killed animals were apparently carried into caves where they were consumed and their remains discarded on the floor. Bones of nene (*Branta sandvicensis*) and dark-rumped petrel (*Pterodroma phaeopygia sandwichensis*) were the primary bird species identified in Pu‘u Wa‘awa‘a shelter cave middens.

A historic-era stone wall begins near the southwest corner of the sanctuary, extends eastward about two miles along the upper boundary before turning down slope, and ends below Potato Hill. Two other features abut the sanctuary, the Shangri-la cabin site (burned structure) above Potato hill, and the Waihou stone corral below the sanctuary cabin. A network of unimproved ranch roads provides access to most sections of the sanctuary.

THREATS TO ECOSYSTEM RECOVERY

Invasive Plants

Non-native plants readily invade disturbed ecosystems. A long history of land abuse at Pu‘u Wa‘awa‘a has encouraged major shifts in vegetation composition. More than 60 non-native species are present in the sanctuary. Established species presenting the greatest threat to forest recovery are, banana poka (*Passiflora tarminiana*), silk oak (*Grevillea robusta*), fountain grass (*Pennisetum setaceum*), daisy fleabane (*Erigeron karvinskianus*), fire weed (*Senecio madagascariensis*), and German ivy (*Delairea odorata*). All of these weedy plants form monotypic stands that displace and compete with native species over large areas and result in the extirpation of rare or endangered species. Appendix 2 lists invasive species that threaten native forest recovery in the sanctuary and provides strategies for controlling these species.

Invasive Insects

Big-headed ants (*Pheidole megacephala*) are a serious threat to the survival of endemic forest insects at Pu‘u Wa‘awa‘a. Long-horned beetles (*Plagithmysus* spp.) emerging from the dead wood of native trees were often observed being attacked by armies of ants. Ants were noted chewing off the antennae and fore legs of these insects and probably killed most of them before they could exit their pupal cells and take flight. Ants are also known to prey on other native insects and are suspected of significantly affecting the survival of nestling birds. Native vegetation is also affected by ants. They “farm” aphids which can severely weaken host plants and kill seedlings. Big-headed ants have not been observed in the sanctuary, but they are present at lower elevations.

Yellow-jacket wasps (*Vespula pensylvanica*) are present in the sanctuary and extremely high population densities have been noted seasonally. These predatory insects pose a threat to native insects, birds, and humans. Control efforts should consist of poisoning nests whenever found. European honey bees (*Apis mellifera*) are another common sanctuary pest. They establish hives in cracks and holes of old trees. These highly social bees aggressively displace native yellow-faced bees and compete with them for nectar and pollen resources.

Black twig borers (*Xylosandrus compactus*) attack native trees and are a major threat to several rare and endangered species. *Vicia* and other herbaceous plants are often damaged by introduced slugs. At least two species (including *Milax gagates*) of these gastropods browse on the vine's tender shoots and inhibit plant growth.

Non-native Mammals

Three species of non-native game mammals inhabit the sanctuary. They are feral sheep (*Ovis aries*), goats (*Capra hircus*), and pigs (*Sus scrofa*). All three species are detrimental to native forest regeneration. Feral sheep and goats occur in very low numbers, primarily in the dryer

eastern half of the sanctuary. However, several small herds have been seen in dense rain forest near the western boundary. Feral pigs are much more abundant and occur throughout the sanctuary, but no population estimate is available. Over 800 ungulates were removed from the sanctuary by DOFAW in 2007 and 2008 (Nick Agorastos, pers. comm.). Other non-native animals inhabiting the sanctuary are small Indian mongooses (*Herpestes auropunctatus*), Polynesian rats (*Rattus exulans*), roof rats (*Rattus rattus*), house mice (*Mus domesticus*), feral cats, and wild dogs. All of these are considered a threat to native plants and animals.

Pigs constitute a major threat to native vegetation. Their feeding, rooting and wallowing destroys native ground cover, encourages the spread of non-native weeds, and prevents the effective regeneration of certain endemic plants. Pig activities also create conditions favorable for breeding mosquitoes which transmit avian diseases. Sanctuary pigs carry a number of pathogenic parasites and diseases that create a public health hazard for humans and their dogs. Serological evidence collected by DOFAW biologists in 1971 indicated that brucellosis (*Brucella suis*) was infecting 37.5 % of the sanctuary pigs (Giffin, 1978). Blood samples collected by hunters also indicate high incidence of Psuedorabies (*Porcine herpesvirus*) in the feral pig population (John Polhemus, pers. comm.). Humans are not potential hosts for this disease, but it is fatal to pigs, dogs, and cats.

Wildfire

On March 5, 1995 a major wildfire was accidently started at Puʻu Waʻawaʻa when campers staying at Shangri-la cabin, accidentally started a grass fire. This fire quickly burned down the ranch cabin and spread into the adjacent PWWFBS. Over 600 acres (243 ha) of valuable forest bird habitat were burned in the lower northeast corner of the sanctuary. Another 300 acres (121 ha) of native vegetation in adjacent Henahena paddock were also burned. The smoldering fire was finally extinguished on March 15th when heavy rains drenched the area. The abundant new growth of ʻohiʻa and koa that had covered the area when cattle were removed six years earlier was lost in the sanctuary fire. Some large kolea, ʻohiʻa, and koa trees also caught fire and fell to the ground. Many trees remained standing, but suffered fire damage to bark and foliage.

Even though native plants evolved in the presence of hot volcanic lava flows, most species have not developed the capability to survive wildfires. One year after the sanctuary fire, vegetation recovery was better than expected. Most large kolea, ʻohiʻa, and koa trees survived the blaze and thousands of mamane, koa, and a`ali`i seedlings germinated. The survival of native ground ferns was also surprising. Fronds of two native species (*Dryopteris* and *Polystichum*) were completely consumed by the fire, but they readily resprouted after the first rains. Unfortunately, non-native grasses also responded to the fire. Fountain grass was fairly uncommon in the sanctuary prior to the incident. This species exhibited an explosive invasion immediately after the burn. Bulldozers traveled through mature stands of fountain grass in order to get to the fire area. Seeds were apparently picked up by the tractors and in scattered in the sanctuary. The recovering forest also attracted large numbers of feral sheep. These animals consumed much of the new tree growth (koa and mamane) because they could not be excluded with existing fences.

RESOURCE MANAGEMENT OBJECTIVES AND STRATEGIES

Sanctuary management actions will focus on a number of key parameters. These include

reduction of direct habitat losses, restoration of vegetative cover, reduction of ungulate damage to vegetation, control of predators and competitors, prevention of wildlife disease, and development of buffer zones that protect vegetation from wildfire.

1. Infrastructure Maintenance and Improvements

Objective*: *Provide an adequate work force to implement sanctuary management goals.

Background: The DOFAW wildlife program is technically responsible for managing the sanctuary under an ahupuaʻa concept. However, due to a lack of resources, including personnel, the Puʻu Waʻawaʻa Coordinator and Natural Area Reserves staff have assisted with much of the development and maintenance operations. No other personnel are permanently assigned to carry out management objectives in the sanctuary.

Strategies:

- Hire a full-time field crew consisting of a crew leader with supervisory experience and two (2) RCUH technicians or specialist grade employees. Both technician positions should be filled with individuals who have invasive vegetation control and wildlife management experience.
- Initiate a volunteer program specifically for the purpose of assisting the full-time staff with sanctuary management activities.

Objective*: *Improve and maintain all external and internal sanctuary access roads.

Background: A network of 4WD roads extends from Mamahaloa Highway to the sanctuary's lower boundary. Driving time is approximately 40 minutes. Sanctuary perimeter (12 miles) and interior roads (8.3 miles) also serve the unit. No new roads are needed, but all existing access routes must remain open for proper sanctuary management.

Strategies:

- Maintain all perimeter and interior roads in good condition for vehicular access.
- Prevent erosion on all access roads.
- Utilize the network of perimeter and interior roads as defendable fire breaks through a combination of roadside brush management, herbicide application, and mowing of grass.
- Develop and maintain designated parking areas within and adjacent to the sanctuary for visitors, researchers, and DOFAW staff.
- Develop protocols to reduce the risk of vehicular transported weeds.

Objective*: *Maintain all boundary fences in ungulate proof condition.

Background: Fencing plays a critical role in native habitat protection. The exclusion of ungulates by fencing allows native vegetation to recover from past damage. All sanctuary boundaries are currently ungulate-proof . Several miles of interior paddock fences also exist, but most of these are in poor condition. A rock wall, constructed decades ago by ranch employees, parallels a portion of the upper boundary. This wall turns at a point above Poʻohohoʻo cinder cone and extends downhill, ending near Potato Hill.

Strategies:

- Maintain all 12 miles of perimeter fence in ungulate-proof condition.
- Assist Hualalai Ranch with maintenance and replacement of common boundary fences as needed.
- Inspect gates monthly to ensure that they are closed (and/or locked) at all times.
- Reconstruct existing internal fences to create three subunits for more effective ungulate control.
- Schedule periodic replacement of old fences.

Objective*: *Post and maintain boundary, directional, and informational signs.

Background: Signage provides information, aids in access control, marks boundaries, and helps educate the public. Redwood informational signs (2 X 5 ½ feet; 6.1 X 17.1 cm) are posted at entrance gates near the sanctuary cabin, lower boundary, and eastern boundary. Rare plant exclosures are posted with informational signs.

Strategies:

- Maintain existing access, boundary, and entrance signs.
- Sanctuary boundary signs should be post at regular intervals on perimeter fences. These signs should read: "BOUNDARY - PUʻU WAʻAWAʻA FOREST BIRD SANCTARY".
- Develop informational signs for interpretive purposes and to mark established trails.
- Post signs prohibiting open fires, littering, and pets.

Objective*: *Restore and maintain the water catchment system at Halepiula

Background: In 1940, Puʻu Waʻawaʻa Ranch constructed a rain catchment system at Halepiula (4,600 feet; 1402 m) elevation to collect water for distribution to ranch paddocks. The system included rain sheds (iron and asphalt collection aprons), water storage tanks, and transmission pipes. These structures cover an area of approximately 20 acres (20.81 ha), excluding 2.75 acres (1.1 ha) of privately owned land. If renovated, this system could provide essential water for fire suppression, outplanting, wildlife, and support human use at the sanctuary cabin.

Strategies:

- Clean, repair, and install new liners in the two existing water tanks at Halepiula.
- Refurbish the water catchment aprons by spraying weeds, patching asphalt surfaces, or installing new aprons.
- Remove old metal and tank materials from the site.

Objective*: *Maintain the sanctuary cabin and rare plant seed orchard.

Background: In November, 1991, a two-room Panabode type cabin, and one 6,000 gallon redwood water tank were constructed by DOFAW on the sanctuary's lower boundary (4,000 feet (1219 m) elevation). Two additional water tanks (2,500 gallons; 9,464 liters) each) and a water catchment shed were installed at the cabin site a few years later. This facility provides shelter for DOFAW field staff while working in the sanctuary. The fenced area also serves as a rare plant

seed orchard.

Strategies:

- Paint and repair the cabin at regular intervals.
- Maintain water and electrical generation systems.
- Maintain fences around the cabin.
- Maintain native plants within the seed orchard.

Objective*: *Assist the USFS with maintenance of HETF facilities

Background: The USFS proposes to construct a free-standing weather tower at approximately 5,500 feet (1676 m) elevation in the central portion of the sanctuary. Climatological sensors, data loggers, and a small solar panel will be attached to the station. A HIPPNET plot (Hawaii Permanent Plot Network) is also proposed at the weather tower site. This project is coordinated by the USDA Forest Service, University of Hawaii at Hilo, and the University of California, Los Angeles. The group is also a member of the Center for Tropical Forest Science (CTFS), a global network of plots utilizing the same methodology. Its purpose is to understand Hawaiian forest dynamics in native-dominated systems over a long-time scale. The actual plot is 10 acres (4 ha) in size, but 40 acres (16 ha) will by covered by the plot and its associated buffer zone. This area will be maintained weed free. All non-native species will be removed after initial plot setup. Construction on the tower and plot is expected to begin in 2009.

Strategies:

- Complete a Section 7 consultation with USFWS prior to weather tower construction.
- Sanitize all construction materials and equipment to insure that invasive plants and animals are not introduced at the site.
- Maintain roads leading to the HETF site.
- Assist HIPPNET crews with weed removal
- Link to HETF and HIPPNET web sites for real time climate data.

2. Forest Management

Objective*: *Restoration of habitats for native plant and animal species.

Background: The maintenance of Hawaii's biological diversity has become an increasing concern as habitat alteration and other land use practices increase the fragmentation of native habitats. Many native species are extremely sensitive to changes in their environment. Alterations such as loss of habitat, introduction of non-native competitors and predators, and diseases may result in the local extirpation or extinction of rare species. An important aspect of managing biological diversity is to focus on ecosystems and a variety of native habitats and species, rather than restricting efforts to single species or population.

Limited plant protection has already been achieved through formal sanctuary designation, removal of cattle, and reduction of feral animal numbers. Native vegetation is still threatened, however, by remaining ungulates, invasive weeds, rodents, slugs, ants, and other non-native

organisms. Efforts are needed to increase native tree cover and associated understory vegetation. Reforestation will improve wildlife habitat, enhance biological diversity, and promote recovery of rare plants and animals.

Strategies:

- Obtain seeds of key native species for propagation and outplanting.
- Provide seeds to plant nurseries and seed banks (Volcano Rare Plant Facility, Lyon Arboretum) where appropriate sanitation protocols are in place to prevent accidental introduction of unwanted invasive species like ants, slugs, snails, twig borers, etc. Currently, DOFAW nurseries do not meet these criteria.
- Outplant seedlings and broadcast seed at priority restoration sites.
- Scarify soil and break up matted grasses with a bulldozer in degraded areas to promote germination of koa seedlings.
- Rehabilitate burn areas and other highly disturbed sites by scarifying soil and/or outplanting native species.

Objective*: *Maintain rare plant exclosures

Background**:** Several rare plant exclosures have been constructed within the sanctuary for species protection and to provide a source of seeds for propagation and outplanting. The sanctuary cabin and *Phyllostegia velutina* exclosures were constructed specifically for outplanting nursery grown seedlings. Those sites were not previously occupied by native plant communities. The *Vicia* and *Phyllostegia ambigua* exclosures were fenced to protect the only known wild populations of these plants on Hualalai volcano.

Strategies:

- Check and maintain exclosure fences each quarter.
- Remove banapoka vines and other invasive plants from all exclosures at least annually.
- Control slugs, ants, and rodents if needed.

3. Invasive Weed Control

Objective*: *Prevent the introduction and spread of habitat modifying weeds.

Background: Alien, invasive plants pose a particular threat to native vegetation. These species were introduced into the islands beginning with the first Polynesians and introductions continue today. Alien species often have few ecological controls and thrive under disturbed conditions created and maintained by man and his introduced animals. For these reasons, invasive plants may aggressively out-compete native species, degrade habitats, and impact sensitive plant communities. In most cases, it will not be possible or even desirable to eliminate invasive plant species altogether. Therefore, the following recommendations focus on targeting those species with the greatest potential for habitat alteration. Noxious weed control and other plant management actions are needed throughout the sanctuary. Initially, work should focus on priority weeds and priority areas, especially the Halepiula mauka Waimea paddock. This area has the greatest potential for forest recovery and contains the greatest concentration of rare

plants.

Strategies:

- Locate/control high priority weed infestations and prevent their spread.
- Apply herbicide to target plants along roads and fence lines.
- Control weeds by herbicide application, manual removal, bio-controls, and reforestation (planting of "infrastructure species" like koa and mamane).
- Limit pulsed grazing with domestic livestock because this technique will compromise reforestation efforts and damage outplanted species.
- Prevent new habitat-modifying weeds from establishing/spreading.
- Monitor efficacy of invasive weed control activities.
- Kill all silk oak trees in a one-half mile wide buffer zone around the sanctuary.

4. Wildlife Management

Objective*: *Eliminate feral pigs, sheep, and goats.

Background: Feral pigs, sheep, and goats cause damage to native forests by feeding directly on plants (foliage, branches, and bark), uprooting vegetation, and by disturbing soils which can potentially facilitate the spread of invasive plants. These animals (especially pigs) transport noxious weed seeds on their fur and in their feces. Sustained yield hunting is not an objective within the PWWFBS. The prime management objective is total elimination of feral ungulates in the sanctuary.

Strategies:

- Remove all feral ungulates from the sanctuary using a variety of methods including organized drives, trapping, hunting with dogs, snaring, and staff hunting.
- Monitor the sanctuary for ingress of feral ungulates and domestic livestock.
- Check fences monthly for damage and repair all breeches in the fence.
- Reconstruct interior sanctuary fences to facilitate effective ungulate removal.
- Locate and block all lava tube openings used by ungulates to enter the sanctuary.

Objective*: *Control non-native predators

Background: Rats, mongooses, feral cats, and feral dogs are known threats to native plants and animals. Rats damage the flowers, fruit, seeds and bark of native plants. Their appetite for seeds is probably a major reason for the reproductive failure of certain species. Mongooses and rats are important predators of native wildlife including arthropods, snails, and birds. They typically consume the eggs and young of ʻalala, nene, and game birds. Feral cats are equally destructive to native wildlife species.

Strategies:

- Establish an Integrated Pest Management plan for the control and complete removal of invasive predators.
- Trap rats and mongooses around native plant exclosures.

- Consider the use rodenticides such as Zinc Phosphide for rats and Diphacinone for mongooses.
- Control feral dogs and cats by trapping, shooting, and other methods.

***Objective*: *Control Invertebrate pests*.**

Background: Big-headed ants, honey bees, and yellow-jacket wasps pose a major threat to ecosystem restoration at Puʻu Waʻawaʻa. Continued efforts are needed to control these pests.

Strategies:
- Prevent the spread of big-headed ants and destroy nests with Amdro bait.
- Ensure all nursery grown plants are obtained from ant free facilities.
- Restrict importation of construction materials and supplies from ant infested areas.
- Poison yellow-jacket and honey bee nesting colonies whenever found. Dusting hives with Ficam B (1% Bendiocarb) may be effective.
- Keep all commercial honey bee hives more than five miles from sanctuary boundaries.
- Control slugs by baiting plants in exclosures with metaldehyde snail bait. Bug-geta (Ortho brand) snail and slug bait pellets are recommended for this pest (S. Montgomery, pers. comm.).
- Monitor and identify other potential invertebrate pests.

Objective*: *Restore native arthropod habitat

Background: Many native invertebrates are obligate specialists on rare host plants. Since some of these plants are in turn threatened or endangered, their importance in terms of Hawaiian invertebrate conservation is considerable. Several native arthropod species are currently facing local extirpation or extinction at Puʻu Waʻawaʻa due to the loss of their host plants. Long-horned beetles (*Plagithmysus* spp.) are probably the most impacted as they are highly specialized feeders and many of their host trees are rare or endangered. *Drosophila heteroneura* flies are dependent on lobelias to complete their life cycle, but these plants have almost been extirpated by wild sheep and domestic cattle. Yellow-faced bees (*Hylaeus* spp.) show a marked preference for akoko flowers and may be affected by the loss of these trees. Heteropteran bugs (*Sarona* and *Nysius* species) are attracted to naʻenaʻe (*Dubautia plantaginea*) and a number of other plants.

Strategies:
- Propagate and outplant host plant species that support rare insect associations. These include *Nothocestrum breviflorum, Clermontia clermontioides, Dubautia plantaginea, Chamaesyce olowaluana, Phyllostegia velutina, Cyanea stictophylla*, *Charpentiera obovata*, and *Melicope volcanica*.
- Place outplanted host species in close proximity to existing wild individuals or interspersed among them. Protect/fence plant colonies as needed. This will facilitate natural colonization of the new plants by target arthropod species.
- Avoid application of pesticides on the entire host plant population unless absolutely necessary.
- Monitor the presence or absence of rare host-dependent insects on new plant

communities to determine the effectiveness of management actions.

- Control potential predators.

Objective*: *Restore forest bird habitat

Background: Koa is a keystone species for endemic Hawaiian wildlife and should be the focus of habitat restoration activities in the sanctuary. This fast growing tree in the pea family (Fabaceae) is considered one of the most important host plants for endemic Hawaiian invertebrates. Arthropods associated with koa at Pu‘u Wa‘awa‘a include several species of moths (Geometridae), beetles (Cerambycidae, Nitidulidae, Anobiidae), koa bugs (Scutelleridae), yellow-faced bees (Colletidae), and planthoppers (Cixiidae, Delphacidae). These insects and their larvae provide a major food source for native forest birds. Hawaiian birds use koa for nesting, roosting, and other needs in their life cycle. Some nectivorous avian species even switch to an insectivorous diet when rearing their young. The success of many wildlife species at Pu‘u Wa‘awa‘a depends on the presence of koa as a forest dominant. ‘Alala and other native forest birds also feed extensively on the fruit of ‘olapa, pilo, ho‘awa, ‘oha wai, mamake, and manono.

Strategies:

- Plant native food-producing trees used by birds.
- Scarify sections of open grassland in the sanctuary to stimulate koa regeneration.
- Control potential predators.

Objective*: *Reduce* (*with the goal of eliminating*) *vectors capable of transmitting diseases to birds.

Background: Disease is considered one of the major factors limiting the abundance and distribution of endemic forest birds in Hawaii. Two of the most serious bird diseases are mosquito-transmitted avian malaria and fowl pox. The first is caused by a protozoan parasite (*Plasmodium relictum*) while the latter is a viral infection. Both diseases have been shown to have a devastating effect on native birds. Carter Atkinson (pers. comm.) found that one bite from an infected mosquito was sufficient to kill 90 percent of the i‘iwi in an experimental group. Recent disease studies revealed that a *Plasmodium* sp. was present in the blood of game birds at Pu‘u Wa‘awa‘a. This finding increases concerns about the possible function of game birds as reservoir hosts for malaria.

The southern house mosquito (*Culex pipiens quinquefasciatus*) has been implicated as the primary vector of malaria and pox in Hawaii's forest birds. A major source of sanctuary mosquito production has been identified at the Halepiula rain shed. Abandoned water tanks and even those currently in use are teeming with mosquito larvae. Abandoned tanks should be drained and then dismantled. Water in those being used for ranching purposes should be treated periodically to kill larvae.

Strategies:

- Control vectors of avian diseases (mosquitoes) by eliminating standing water where practical.

- Introduce mosquito fish or predaceous beetles into water tanks where appropriate.
- Apply chemicals or BTI, a natural toxin produced by *Bacillus thuringiensis*, in water sources that cannot be drained. Products available for application of BGTI are Bactimos and Altosid briquets.
- Submit all sick or dead birds to a veterinary laboratory for disease testing.

Objective*: *Reduce population density of non-native birds.

Background: Interspecific competition with non-native birds is another factor responsible for the decline of native bird species. Japanese white-eye and red-billed leiothrix have been implicated in reducing populations of native forest birds through habitat overlap and competing food habits (Banko and Banko, 1976). In addition, turkeys, peacocks, and kalij pheasants are major dispersers of non-native plant seeds. These birds also uproot and feed on native ferns and harvest seedlings, especially at outplanting sites.

Strategies:
- Reduce the abundance of banana poka flowers, a major food source for white-eyes.
- Reduce game bird numbers through public hunting and/or staff control efforts.

Objective*: *Prevent the extirpation of endangered bird populations.

Background: The endangered Hawaii creeper and akepa are the two species at Puʻu Waʻawaʻa that need the greatest management attention. Almost nothing is known about their habitat requirements or factors limiting their survival. A research project is urgently needed to obtain basic life history information for these species. Recommendations are also needed for management actions to prevent the extirpation of these birds on Hualalai.

Strategies:
- Initiate life history studies on akepa and creepers.
- Monitor the abundance and distribution of endangered birds annually.
- Analyze population data using the VCP computer program.
- Develop additional nesting sites by providing nest boxes or drilling holes in dead trees.

5. Lava Tube Management

Objective*: *Protect lava tube ecosystems

Background: Lava tube protection is important for many reasons. Caves are of special scientific interest and are often beautifully decorated with unusual lava formations. Lava tube systems support significant floral and fauna assemblages and play an important role in maintaining biological diversity. Caves contain objects of archeological, cultural, paleontological, and geological significance. They are, however, intrinsically fragile, being susceptible to rapid deterioration through vandalism, siltation, flooding, agricultural development, indiscriminate forest clearing, quarrying, and recreational activities. Passages may be damaged or collapsed by driving vehicles or heavy equipment over them. Hawaii's cave protection law (2002) provides

the legal basis for protecting lava tubes.

Strategies:

- Survey and map all major lava tube systems including their entrances.
- Conduct archeological surveys to locate and identify important cultural features.
- Construct fences to prevent domestic and wild herbivores from grazing vegetation growing over important lava tubes.
- Establish bait stations to poison rodents in fenced areas and at cave entrances.
- Control fountain grass and other introduced plant species in fenced areas.

6. Information and Education

Objective*: *Promote public awareness and support of management actions

Background: Hawaii is famous for its rain forests and spectacular birds. Hawaiian birds are perhaps the world's best example of adaptive radiation. There is also considerable demand from scientists and the general public for viewing these creatures in the wild. The sanctuary can provide a means for exposing the public to Hawaii's natural environment and aid in their understanding and appreciation of native wildlife. An Interpretive Field Manual for the sanctuary was prepared in 1995 by the Hawaii Division of Forestry and Wildlife (Giffin, 1995). Its purpose was to assist visitors and leaders of volunteer work groups with the interpretation of natural resources. The manual begins with a brief description of the sanctuary and then reviews flora and fauna of the area. Included are maps, plant and animals species lists, and a selection of native plant and bird photographs.

Strategies:

- Develop narrative/graphics/handouts for “show me” tours.
- Develop/deliver PowerPoint programs for priority audiences.
- Develop/submit grant proposals too address management funding needs
- Develop environmental interpretive trails or motorized drives for guided nature study.
- Develop informational materials describing the biological resources of the sanctuary and surrounding area.
- Organize volunteer work programs for sanctuary projects and lead tours for environmental groups.
- Encourage academic research on approved projects.

7. Wildfire Suppression

Objective*: *Minimize the risk of wildfire.

Background: Forest fires are a common occurrence at Puʻu Waʻawaʻa. The combination of highly flammable exotic grasses and dry atmospheric conditions creates an extreme fire hazard during most months each year. Native dryland forests occur below the sanctuary and are highly susceptible to fire. Large wildfires have been a common occurrence in recent years. Fires generally originate along the Mamalahoa Highway (Highway 190), but several have started at more isolated sites. A series of firebreaks have been constructed along the highway to help retard the spread of roadside fires. No firebreaks are available at higher elevations or around the

sanctuary.

Strategies:

- Update regional fire plan with all cooperators
- Complete fire training for staff
- Establish/implement fire prevention and response protocols for staff and visitors.
- Identify/purchase needed fire suppression equipment.
- Plan/construct additional water catchment/storage capability.
- Maintain defendable fuel breaks along the makai boundary of the sanctuary and at other strategic points in the adjacent forest reserve through mowing, grazed corridors, and herbicide treatment of roadside brush.
- Removed tall vegetation from sanctuary roads by mowing.
- Establish fuel free parking areas for vehicles and safe zones for people.
- Remove fire fuels around the perimeter of rare plant exclosures by hand pulling or mowing.
- Increase initial attack capability by maintaining a small cache of fire suppression tools (shovels, flappers, dip tank, and portable pump) at the sanctuary cabin.
- Develop FBS closure plan based on web based satellite fuel load monitoring.

8. Resource Monitoring

Objective*: *Prioritize and document the efficacy of management actions

Background: Resource monitoring and recording changes over time provide critically important data for managing biological resources. It allows for the determination of trends, as well as noting the results of management actions. It provides a consistent, definitive way of knowing what is going on with the resource. For example, transects designed to monitor vegetation recovery in the sanctuary will document changes in the plant community, including the distribution and abundance of invasive plant species, and will help gauge the ability of disturbed habitat to recover in the absence of ungulate activity.

Eleven permanent photo-plot stations were established in the sanctuary in 1989. This was done to graphically demonstrate trends in vegetation recovery after the removal of domestic livestock. Photo stations were situated from 4,000 to 4,980 feet (1219 to 1518 m) elevation. Each point was marked with a numbered iron post. The original series of photos (26 slides) was exposed in November of the same year. Photos for stations 1 thru 5 (Henahena area) were taken one month after the area was fenced and cattle were removed. All other photos were exposed 4 years after cattle removal. At least two photos were taken at each station. Field of view directions were recorded using magnetic bearings. Photos exposed in 1989 and 1994 are on file in the Kamuela wildlife office.

Strategies:

- Establish/monitor ungulate transects
- Establish/monitor vegetation transects to assess forest recovery
- Monitor efficacy of invasive weed control activities.

- Monitor established photo plots and take photos every 5 years.
- Utilize new technologies in satellite imagery including LIDAR

9. Human Activity Management

Objective*: *Manage, minimize and eliminate, if possible, damaging human activity and impacts

Background: Management, research, educational and public recreational activities have the potential to damage sanctuary resources. Some of the areas attractions may be hazardous. Staff and visitors alike need timely information.

Strategies:

- Conduct hazard assessment, particularly in areas of high human activity.
- Determine and recommend activity intensity levels for features in the sanctuary.
- Create and post informational, advisory, boundary, and warning signage as needed.
- Generate other informational material as needed.

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FIGURES

Figure 1. The Ahupuaa of Puu Waawaa

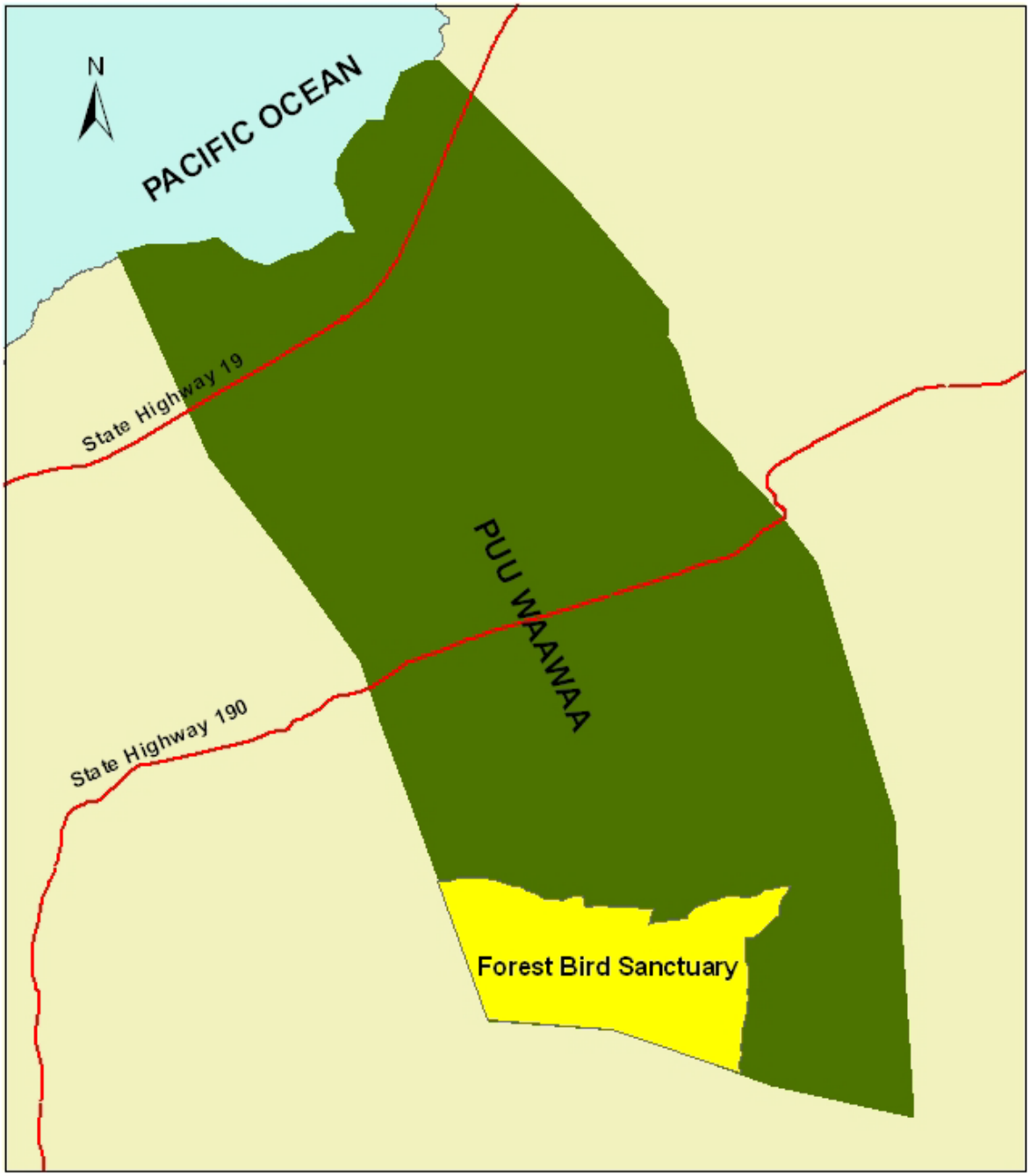


Figure 2. Ranch Paddocks & Land Use Zoning for Bird Sanctuary

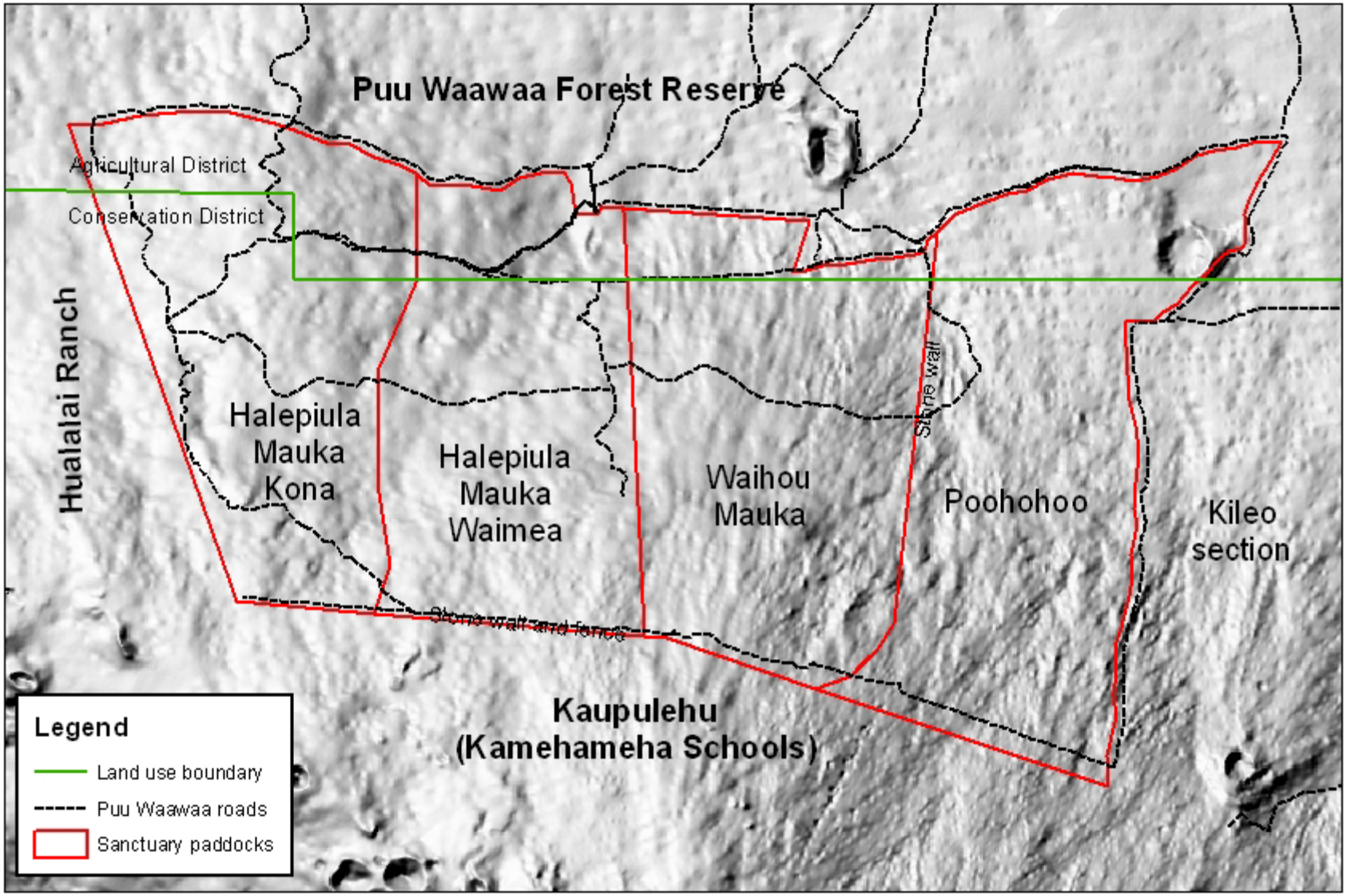


Figure 3. Soil Type Distribution for Forest Bird Sanctuary

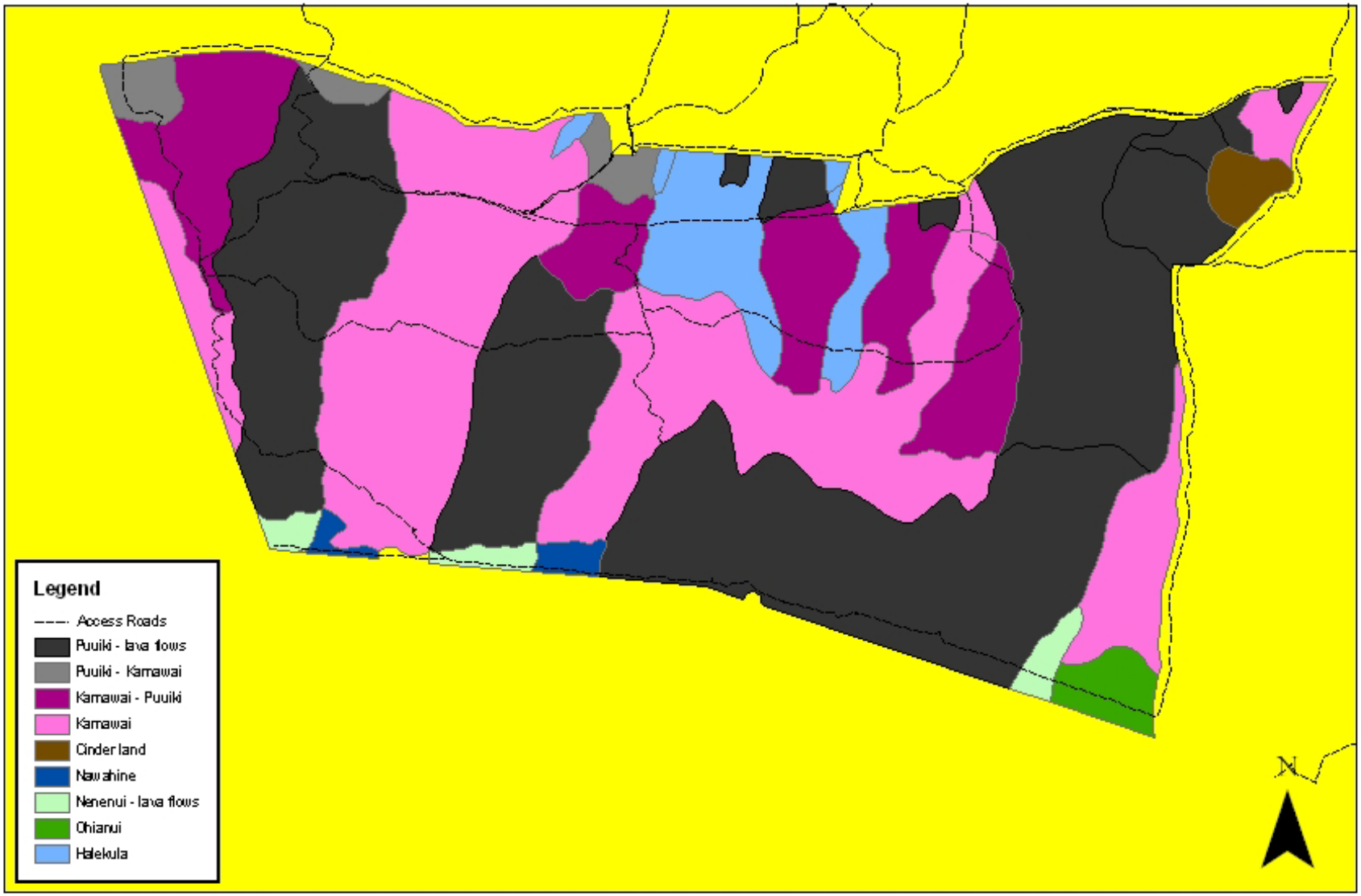


Figure 4. Lava Flow Age Groups for Forest Bird Sanctuary

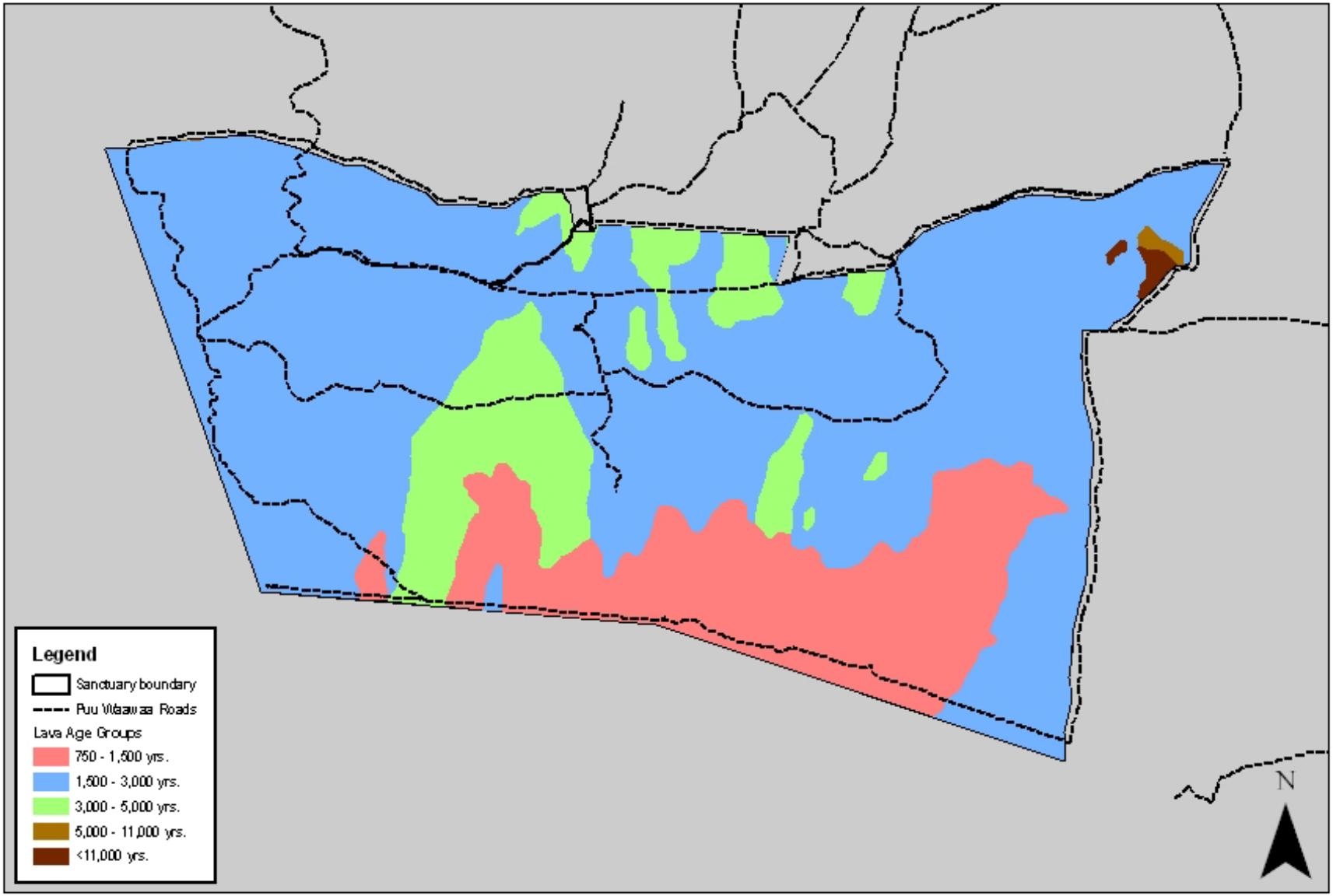


Figure 5. Lava Substrates for the Forest Bird Sanctuary

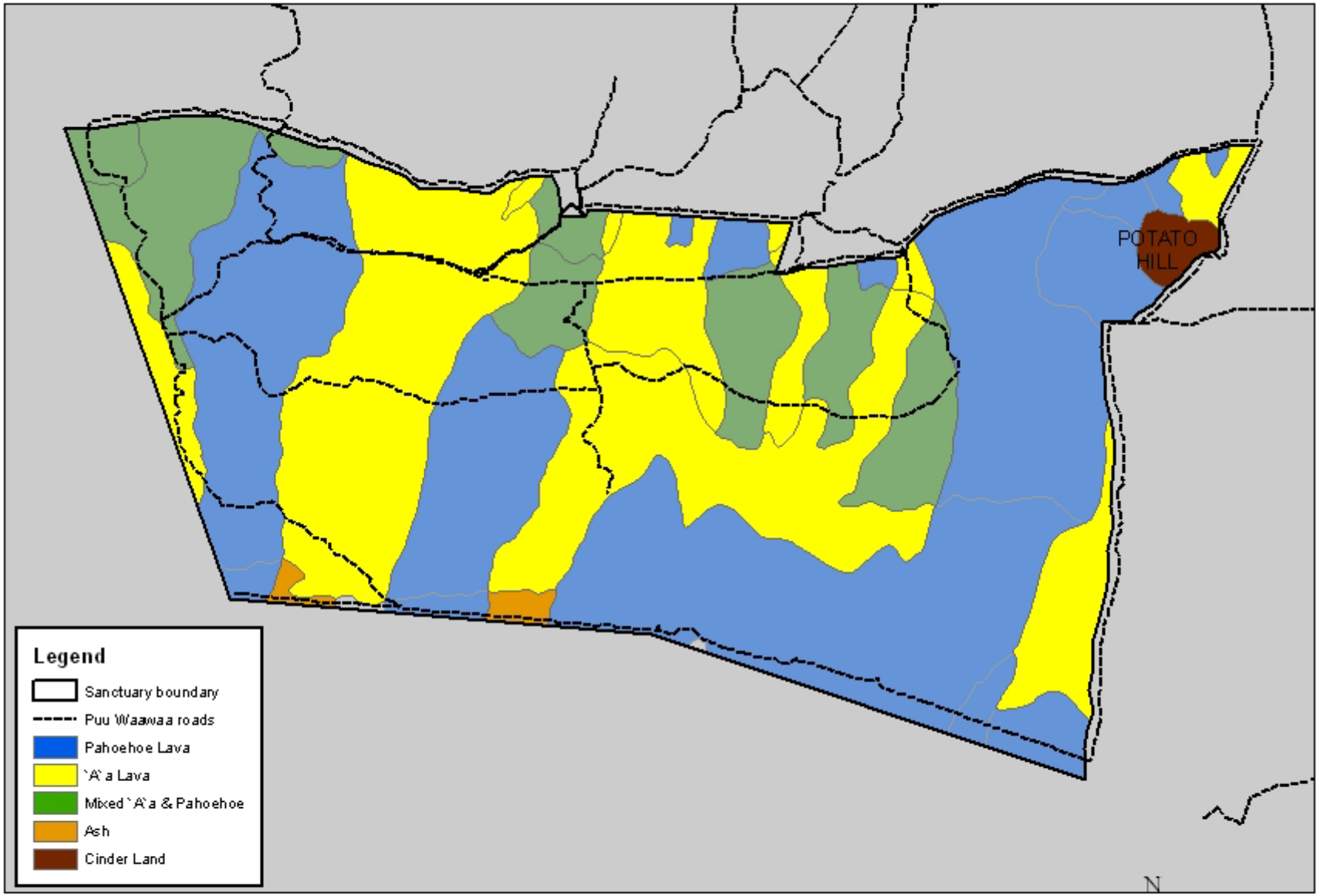


Figure 6. Vegetation Cover Types for the Forest Bird Sanctuary

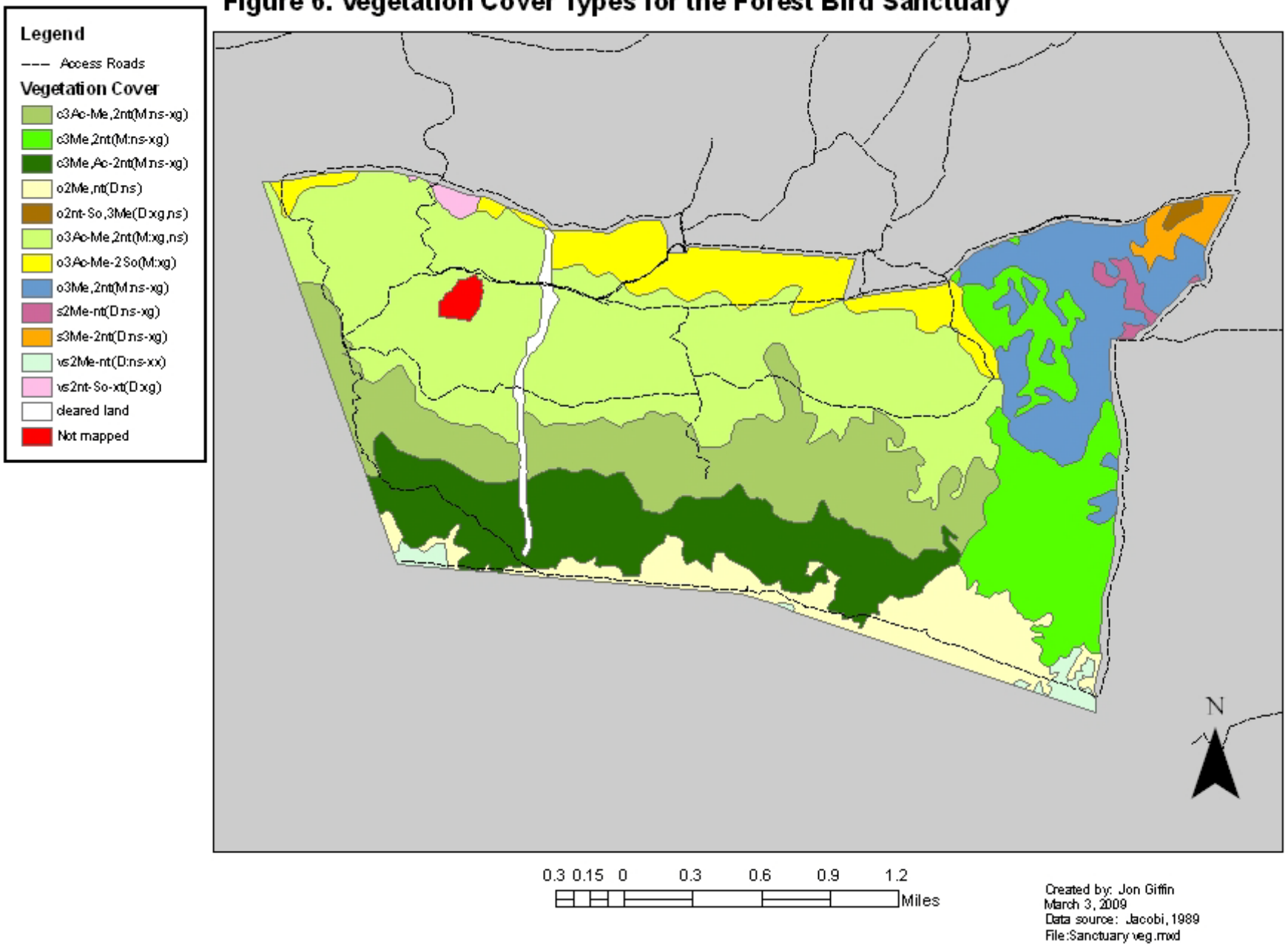


Fig. 7. Field sightings and nest observations for selected native birds in the Puu Waawaa Forest Bird Sanctuary.

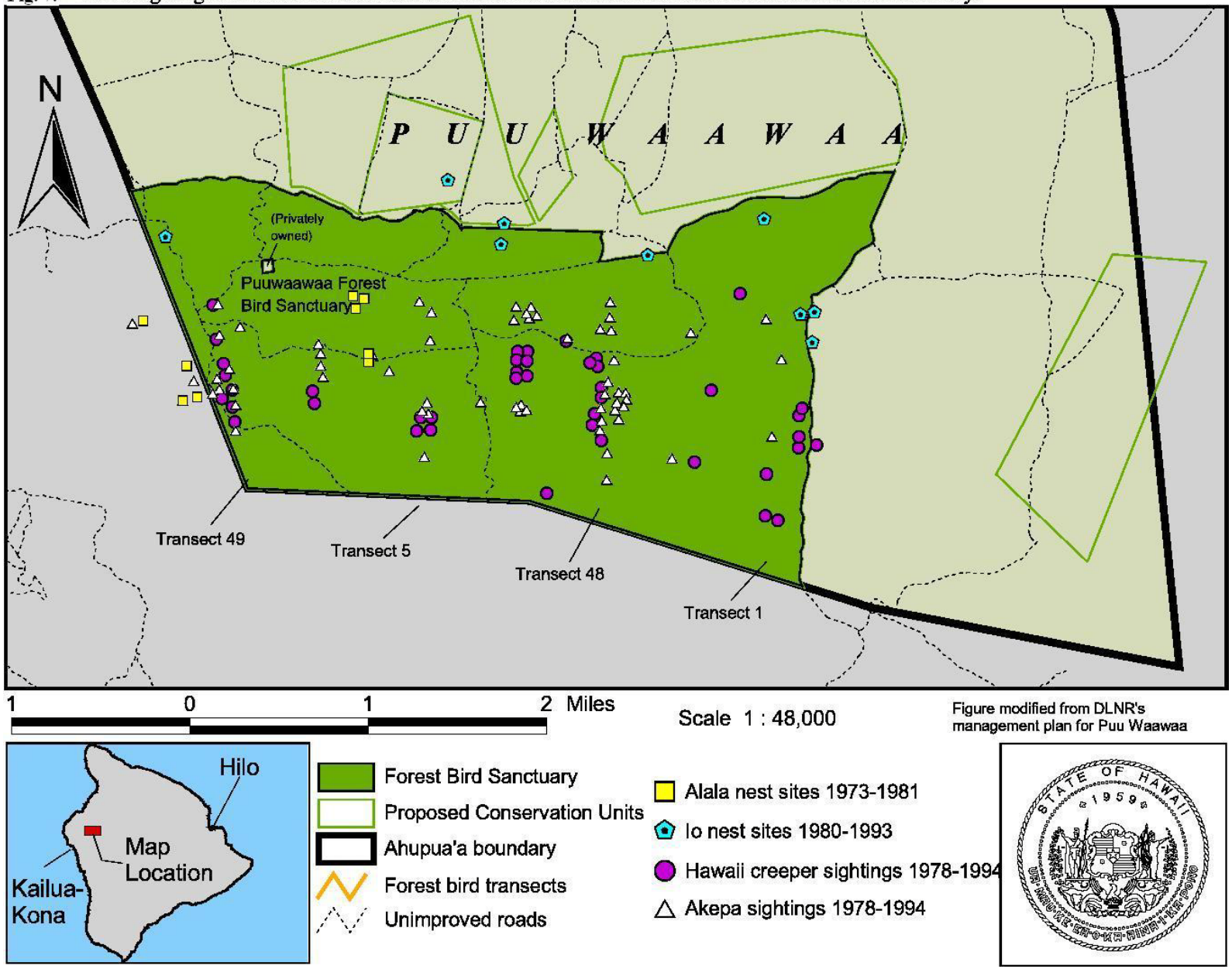
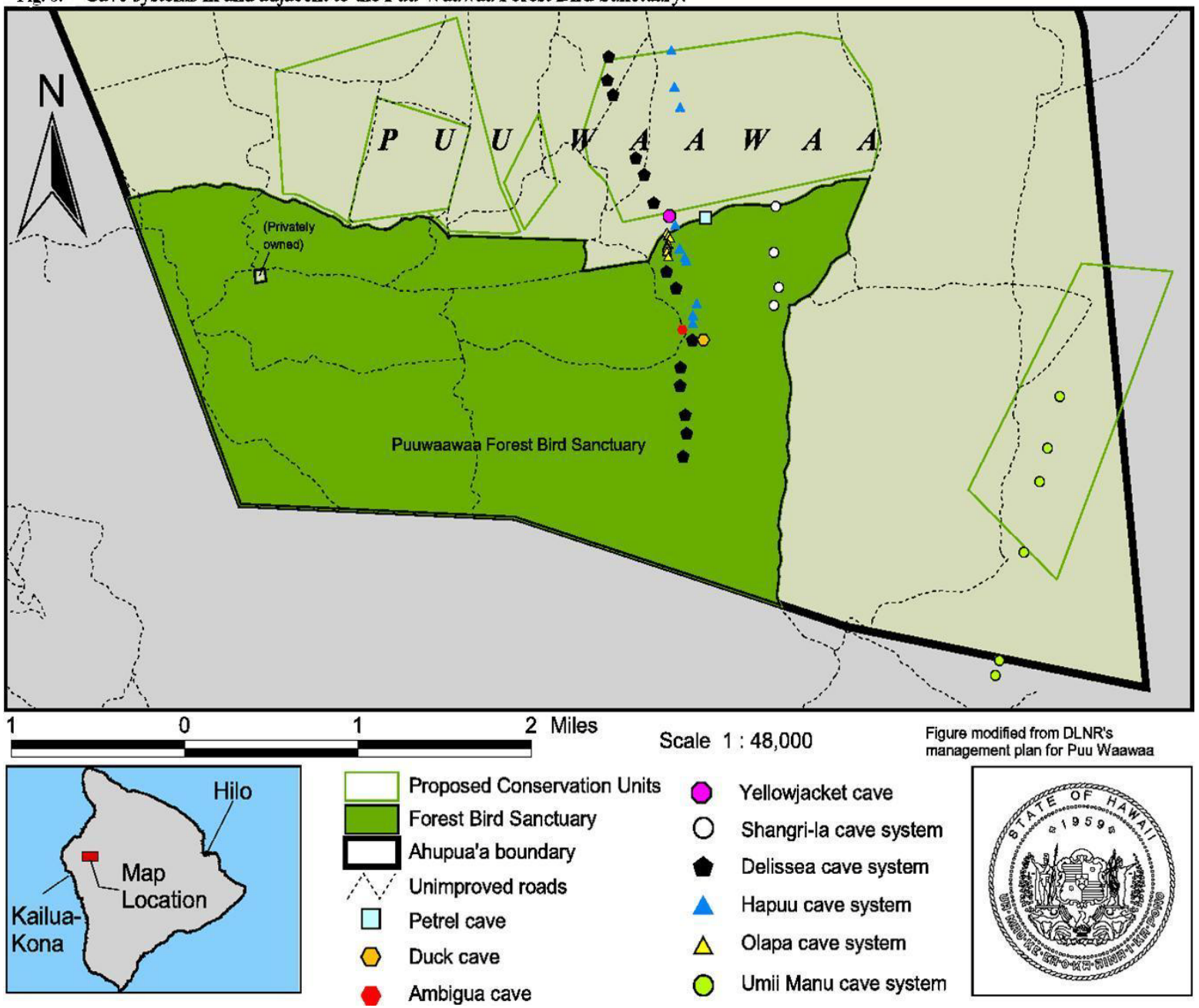


Fig. 8. Cave systems in and adjacent to the Puu Waawaa Forest Bird Sanctuary.



APPENDIX 1. Rare Species List for the Forest Bird Sanctuary.

A. Legally protected species presently occurring within the sanctuary

1. Plants:	**Status:**
Asplenium peruvianum var. *insulare*	Endangered
Nothocestrum breviflorum	Endangered
Phyllostegia velutina	Endangered
Phyllostegia warshaueri	Endangered
Plantago hawaiiensis	Endangered
Vicia menziesii	Endangered
Chamaesyce olowaluana	Species of concern
Cyrtandra menziesii	Species of concern
Eragrostis deflexa	Species of concern
Fragaria chiloensis ssp. *sandwicensis*	Species of concern
Phytolacca sandwicensis	Species of concern
Rubus macraei	Species of concern
Sisyrinchium acre	Species of concern
Stenogyne micrantha	Species of concern
Bidens micrantha ssp. *ctenophylla*	Candidate for listing

2. Arthropods:	**Status:**
Manduca blackburni	Endangered
Agrotis melanonera	Species of Concern
Anomis vulpicolor	Species of Concern
*Caconemobius varius**	Species of Concern
Coleotichus blackburniae	Species of Concern
Micromus usingeri	Species of Concern
Ectemnius rubrocaudatus	Species of Concern
Hylaeus coniceps	Species of Concern
Hylaeus difficilis	Species of Concern
Hylaeus filicum	Species of Concern
Hylaeus hula	Species of Concern
Hylaeus kona	Species of Concern
Hylaeus laetus	Species of Concern
Hylaeus pubescens	Species of Concern
Hypocala velans	Species of Concern
Omiodes anastreptoides	Species of Concern
*Thaumatogryllus cavicola**	Species of Concern

3. Vertebrates:	**Status:**
Buteo solitarius	Endangered
Lasiurus cinereus semotus	Endangered
Loxops coccineus coccineus	Endangered
Oreomystis mana	Endangered

APPENDIX 1. (continued)

Asio flammeus sandwichensis	Species of Concern
Chasiempis sandwichensis	Species of Concern

B. Legally protected species historically known to occur within the sanctuary

1. Plants:	**Status:**
Cyanea stictophylla	Endangered
Pittosporum hawaiiense	Species of concern

2. Arthropods:	**Status:**
Drosophila heteroneura	Endangered

3. Mollusks	**Status:**
Partulina confusa	Species of concern

4. Vertebrates:	**Status:**
Anas wyvilliana	Endangered
Branta sandvicensis	Endangered
Corvus hawaiiensis	Endangered
Hemignathus munroi	Endangered
Pterodroma phaeopygia sandwichensis	Endangered

C. Rare species with no legal protection presently in the sanctuary

1. Plants:	**Status:**
Phyllostegia ambigua	Rare
Polystichum hillebrandii	Rare

2. Arthropods:	**Status:**
Eupithecia scoriodes	Rare
Hylaeus dimidiatus	Rare
Hylaeus paradoxicus	Rare
Misumenops aridus	Rare
Ochalia sp.	Rare
Plagithmysus debilis	Rare
Plagithmysus nodifer	Rare
Plagithmysus perkinsi	Rare
Prognostola cremnopis	Rare
Scotorythra demetrias	Rare
Scotorythra ortharcha	Rare
Hylaeus akoko	New to science
*Mecyclothorax aa**	New to science
Mecyclothorax giffini	New to science
Micromus longispinosus (flightless form)	New to science
Nesosydne sp. (*Cyanea stictophylla*)	New to science

APPENDIX 1. (continued)

Orthotylus hedyoticola (*Hedotis terminalis*)	New to science
Sarona n. sp. (*Phyllostegia velutina*)	New to science
Sarona n. sp. (*Ilex anomala*)	New to science
Sarona n. sp. (*Melicope volcanica*)	New to science
Schrankia (*howarthi*)* +	New to science
Scotorythra prestoni	New to science
Scotorythra rivera	New to science

* Obligate cave species
+ Species description in progress

APPENDIX 2. Forest Bird Studies and Weed Control Techniques

Forest Bird Surveys

In 1978, detailed surveys of forest birds were conducted on the Island of Hawaii as part of a State-wide Hawaii Forest Bird Survey (HFBS). Transects were established on Hualalai and other volcanoes to mark survey routes. Portions of two transects (#48 and #49) passed through the PWWFBS. Birds were counted along these transects from May 25-28, 1978 using the variable plot technique (Scott et al. 1986).

In 1990, DOFAW biologists attempted to relocate the original USFWS transects at Pu‘u Wa‘awa‘a. No remnants of these lines could be found, however. In order to duplicate earlier surveys, both transects were re-established using USFWS maps to determine their original starting points. Sampling stations were marked at 440 feet (134 m) intervals using a hip chain to measure distances. Two additional transects (#5 and #10 were established in 1991 using similar methods.

Bird counts were made on all transects in May, 1990 and then again on the same month in 1991. Data from these surveys were analyzed using the methods of Ramsey and Scott (1979, 1981). The variable circular plot (VCP) computer program (ver. 2), developed by Edward O. Garton, was employed to summarize the data and calculate bird population statistics. Results of this work were reported by Giffin (1990, 1991).

Avian Disease

In 1994, DOFAW initiated two projects to sample the prevalence of avian diseases at the PWWFBS. One phase of the project was designed to sample the incidence of malaria in mosquitoes. The other sought to test birds directly for evidence of diseases. Mosquitoes were sampled twice monthly along different elevational gradients to determine the presence and relative abundance of *Plasmodium*-infected mosquitoes. Battery powered CDC Reiter ovipositor traps (purchased from John H. Hock Company, Gainesville, Florida) were used for this purpose. The traps were baited with a 5 day old infusion of fermented rabbit pellets and yeast. Two traps were set at each site and operated nonstop for three consecutive nights every two weeks over a one year period (January 1994 to January 30, 1995). Two sample sites were established on Pu‘u Wa‘awa‘a Ranch and two more in the forest bird sanctuary. The ranch sites were located near the manager’s house (2,367 ft. (722 m) elev.) and in an upland pasture (2,940 ft. (896 m) elev.). Sanctuary trap sites were situated at the state cabin (4,000 ft. (1219 m) elev.) and at Halepiula rain shed (4,600 ft. (1402 m) elev.). This latter site is considered the wettest location at Pu‘u Wa‘awa‘a.

Results of the mosquito trapping study indicated that *Culex* mosquitoes were uncommon at Pu‘u Wa‘awa‘a. No mosquitoes were captured in any of the traps at any site. Since the bait used is designed to attract gravid *Culex* females, and because this type of trap was successful at other locations on the island, it appears that the incidence of *Culex* mosquitoes was extremely low during the project period. The day-biting forest or tiger mosquito (*Aedes albopictus*) was often seen at the lower elevation trap sites, but was never captured in the traps. This species is not implicated in transmitting avian malaria.

Testing of native and introduced forest birds to determine the prevalence of active malarial and pox virus infections was also initiated in January, 1994 and continued until October, 1995. Birds were captured in mist nets by a team of veterinarians and biologists. Week-long netting operations were undertaken on three different occasions (January 3-6 1994, November 29-December 2, 1994, and October 22-26, 1995). Birds were also captured at three different sites (5,400, 4,700 and 3,900 ft. (1646, 1433 and 1189 m) elevation). All birds were captured in ʻohiʻa/koa or ʻohiʻa/mamane forests. Captured birds were banded, weighed, measured, and screened for active malarial infections (via blood smear), previous malarial exposure (via antibody titer), and active pox virus infections. Pox lesions were surgically removed by attending veterinarians and saved for viral isolation.

A total of 381 birds was captured during the 20 month study period. Blood samples were obtained from 10 species and 367 individuals as follows: apapane (5), ʻamakihi (302), ʻelepaio (1), ʻiʻiwi (7), Japanese white eye (39), northern cardinal (3), nutmeg mannikin (5), saffron finch (1), warbling silverbill (3), and red-billed leiothrix (2). Final test results were never published, but only two birds (both amakihi) tested positive for malaria. One additional amakihi was found dead at the capture site. This bird exhibited an enlarged spleen and liver, typical symptoms of malaria. Impression smears of heart, liver and spleen blood showed numerous malaria parasites (pers. comm., Greg Massey, DVM).

ʻOmaʻo Translocation

An experimental translocation of ʻomaʻo (*Phaeornis obscurus*) was initiated at Puʻu Waʻawaʻa in September, 1996. This project was a cooperative study between the Peregrine Fund, Biological Resources Division of USGS, and Hawaii Division of Forestry and Wildlife. The primary objectives of the study were to develop and refine recovery procedures for the critically-endangered puaiohi on Kauai, the nearest relative of the ʻomaʻo, and to re-establish ʻomaʻo in leeward Hawaii where they were extirpated sometime after the turn of the century. The subfossil record indicates that ʻomaʻo were widely distributed at Puʻu Waʻawaʻa in the past. Preserved remains of this species are common in lava tubes between 700 and 5,880 feet (700 and 1792 m) elevation.

A total of 25 captive-reared and 16 wild caught ʻomaʻo were released at Puʻu Waʻawaʻa. Birds were set free from two hack towers located at 5,400 feet (1646 m) elevation in the central portion of the sanctuary. Released birds persisted for a few years, and there was some evidence of reproduction, but the species is no longer present. (Fancy et al, 2001).

Invasive Weed Control

Domestic livestock are a pervasive biological force in Hawaii. Cattle are generally acknowledged to be the primary agent of forest destruction. These herbivores are known to readily consume native plants including young koa trees. Cattle effectively restrict natural forest regeneration and alter stand structure and floral composition. When heavy grazing is allowed to continue over many years, it leads to forest destruction. Old trees die without replacements and exotic species replace the native flora. Wild and domestic livestock converted the Waihou section of Puʻu Waʻawaʻa Ranch from dense native forest to a mountain desert in less than 100 years. Ironically, cattle may be the best agent to control banana poka in previously damaged forests.

Banana Poka: Banana poka (*Passiflora tarminiana*) is a woody vine native to South America. In koa-ʻohiʻa forests, it often climbs trees, enshrouding them with an impenetrable mat of vegetation. If left unchecked, the vine will eventually smother trees causing their death. Banana poka was first reported at Puʻu Waʻawaʻa Ranch (Waihou section) in 1921 by L.W. Bryan (Pung, 1971). Birds, both native and non-native, as well as feral pigs eat the fruit of this plant, but they are also the chief dispersal agent of seeds. Livestock grazing over the years kept this vine in check at Puʻu Waʻawaʻa. In 1985, cattle were removed from the sanctuary and the small scattered infestations of poka began to spread. Today, the vine is a serious pest throughout the sanctuary and at other places on Hualalai.

Various methods of banana poka control have been attempted over the years. Cattle readily eat banana poka leaves and stems, but they also forage on native species. Manual clearing and application of herbicides are effective, but both methods are labor intensive. Biological agents may be the best hope for wide-spread control. Adult South American moths (*Cyanotricha necryia*) were released in the sanctuary on September 3, 1991. A total of 300 individuals was set free at two different sites in the Halepiula area (4,600 ft. (1402 m) elevation). First-instar larvae of this iridescent blue moth feed on leaf margins of poka and defoliate the plant. Follow-up surveys using light traps have failed to produce any evidence of moth survival.

A phytopathogenic fungus (*Septoria passiflorae*) was released at Puʻu Waʻawaʻa by the USDA, Animal and Plant Health Inspection Service, in August, 1996. The organism apparently established, but failed to have any long-term impact on poka survival (Trujillo et al., 2001).

Manual and chemical methods should be the first line of defense for banana poka control. Plants arising from large diameter vines (>1/2 inch) can be killed by severing the stem with a machete and then applying herbicide to the cut surface. Treatments with a 10 percent concentration of Garlon (Triclopir) in forest crop oil will prohibit resprouting and lead to death of the plant. Small clumps of vines can be controlled by spraying foliage with a 2 percent solution (2.5 fl. oz./gal.) of Garlon 3A in water.

Cattle readily feed on banana poka leaves, shoots, and flowers (Grace, 1995). Their preference for this plant can be used as an effective management tool for controlling banana poka infestations. Various levels of cattle grazing intensity and duration should be tested to determine the optimum number of animals needed for poka control while minimizing forest damage. Results of these studies can be used to design a grazing program for areas infested with poka. Domestic livestock should not be allowed to grazing in the Halepiula mauka Waimea paddock due to its botanical richness and abundance of rare and endangered plants. Hand clearing and application of herbicides are recommended for poka control in this paddock. Other sections of the sanctuary are less susceptible to livestock damage if grazing is pulsed for very short periods. Grazing treatments should be followed immediately by manual clearing to remove large vines from trees.

Silky Oak: *Grevillea robusta* is a tall, fast growing tree native to Australia. Its wind-dispersed seeds are able to germinate in bare, rocky soil. The plant is drought tolerant and develops dense stands that completely shade out other tree species. The leaves of *G. robusta* produce an allelopathic substance that inhibits the establishment of other species under its canopy (Stone and

Scott, 1985). This plant is a major threat to native forest ecosystems in Hawaii.

Silky oak was introduced into north Kona at and early date. It was planted at Huehue Ranch prior to 1919 (H. Springer, pers. Comm.) and probably spread to Pu‘u Wa‘awa‘a Ranch a short time later. It is currently found throughout the Pu‘u Wa‘awa‘a area. Only a few mature trees were present in the sanctuary in 1989, but hundreds of seedlings and saplings were scattered about the area. All known silky oak plants were removed from the sanctuary by 1990, but seedlings continued to sprout. These plants are now removed by DOFAW staff whenever found.

Good success has been achieved in killing silky oak by manual and chemical methods. Small trees can be killed by severing the trunk (near ground level) and immediately treating the cut surface with a 50 percent concentration of Garlon 4 and forest crop oil. Large diameter trees are effectively killed by girdling and applying herbicide. Santos et al. (1989) noted that Garlon 4 (2.5 percent concentration) in diesel oil and applied in continuous frill cuts was highly effective in killing silky oak as well.

German Ivy: *Delairea odorata* is a climbing vine that grows rapidly into the forest canopy. It affects other plants by covering them with dense foliage. Seeds are dispersed by the wind. This plant is currently widespread in the sanctuary. It forms dense thickets during periods of heavy rainfall, but dies back somewhat during dryer periods.

Some success has been achieved in controlling German ivy by foliar spraying with Roundup. In certain situations, vines can be manually removed. Grazing by domestic livestock also appears to have some potential for controlling this noxious weed. Limited cattle grazing should be tested to control German ivy. This activity should be carried out in conjunction with banana poka control operations.

Lantana: *Lantana camara* and pamakani (*Ageritina riparia*) are also a problem in the sanctuary . Existing bio-control organisms are suppressing both species somewhat, but plant density appears to be increasing.

Blackberry: *Rubus argutus* is a thorny shrub with trailing stems. Once established, it rapidly forms impenetrable thickets and readily invades new areas. This plant produces seedy fruits, which are purple-black in color. Wild *Rubus* replaces endemic vegetation and forms physical barriers that are difficult for hikers to penetrate. The plant is spread by native and exotic birds and by wild pigs. Only a few patches of blackberry have been found in the sanctuary to date (Shangri-la and Halepiula). These plants were successfully removed with Garlon 3A. If blackberry plants are found in the sanctuary, they should be immediately destroyed to prevent the spread of this weed. Santos et al. (1986) used a 2 percent foliar spray of Garlon 3A in water to control Florida blackberry (*Rubus argutus*)

Fountain grass: *Pennisetum setaceum* is an introduced bunch grass that poses a serious threat to native forest ecosystems. It produces large amounts of organic matter, even in areas that are arid and where soil conditions are too poor for other grasses. When dry or green, the grass is very volatile and creates a serious fire hazard. Fire stimulates germination of seeds and the species quickly invades burned areas. This plant suppresses the germination and growth of other plants.

W. Takeuchi (1991) noted that fountain grass provides a two-way physical barrier for other species. It prevents seeds from contacting the substrate and then stifles any seedlings with a biomass that slow-growing natives cannot penetrate. Fountain grass has low palatability for livestock and offers little in the form of food for game birds and other types of wildlife. This plant probably hastens plant succession on barren lava flows by increasing the accumulation of organic matter.

Fountain grass was imported from Africa as an ornamental. It was planted at Huehue Ranch prior to 1919 (H. Springer, pers. comm.), and undoubtedly spread from there to Pu‘u Wa‘awa‘a a short time later. Today, this plant is a serious pest throughout the Pu‘u Wa‘awa‘a region and is responsible for forest fires that have destroyed thousands of acres of native dry land forest. This grass is widely scattered in the sanctuary, occurring up to 6,200 feet (1890 m) elevation.

Kikuyu grass: *Pennisetum clandestinum* is a rapidly growing, rhizomatous plant from Africa. It forms dense stands of grass several feet high and even climbs into trees and shrubs. Kikuyu is a federally declared noxious weed that competes with native species and inhibits their reproduction. The yellow sugarcane aphid (*Sipha flava*), a recent accidental introduction, is known to greatly stress patches of Kikuyu. This insect, in combination with other environmental factors, such as drought, grazing, or other insects may result in the death of Kikuyu grass plants (M. Thorne, pers. comm.). Yellow sugarcane aphids are found in the sanctuary and have affected Kikuyu is some areas. Kikuyu grass is shade intolerant and appears to be decreasing in the sanctuary as tree cover increases. The native basket fern (*Dryopteris wallichiana*) seems to compete well with Kikuyu and may eventually replace it in recovering native forest.

Meadow ricegrass: *Ehrharta stipoides* is another pest in the sanctuary. This species is shade tolerant and it may replace Kikuyu over time. However, it is less of a fire hazard than Kikuyu and does not suppress native seedling recruitment as much as Kikuyu (Nick Agorastos, pers. comm.).

Grasses can be effectively controlled with Roundup (glyphosate). Good control has been achieved over large areas by spraying grasses according to labeling instructions. Long term alternatives to herbicide control of grasses should be researched further in the near future. Perhaps, reforestation can be integrated into a long term method for exotic grass exclusion.

Marijuana (*Cannabis sativa*): Signs of past marijuana cultivation have been noted in the sanctuary. This illegal activity creates hazards for recreational users and causes management problems. Growers damage the forest by clearing native plants for cultivation plots, adding chemicals to the soil, and by introducing seeds of invasive species.

Fireweed (*Senecio madagascariencis*): Native to Madagascar and southern Africa. This plant is a serious pasture problem in Queensland and New South Wales, Australia. First observed in North Kohala by Parker Ranch personnel about 1985, from whence it spread southward toward and beyond Kamuela. Infestations occur in pastures along the Saddle Road and, apparently spread by a shipment of cattle, in Kikuyu. It is spread by wind, vehicles, and the transfer of cinder and soil and of livestock from contaminated areas. Ragwort is toxic (pyrrolizidine alkaloids) to cattle and horses, and although sheep and goats are somewhat tolerant, they can become ill or be killed by

grazing too much fireweed. Extent of spread nor the impact to native plants and birds in the PWWFBS has not been documented.