PU‘U WA‘AWA‘A BIOLOGICAL ASSESSMENT

PU‘U WA‘AWA‘A, NORTH KONA, HAWAII

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DEPARTMENT OF LAND AND NATURAL RESOURCES
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TABLE OF CONTENTS

GENERAL SETTING

Introduction

The land division or ahupuaʻa of Puʻu Waʻawaʻa is located on the western or leeward side of the Island of Hawaii (North Kona District, TMK 3-7-01, 02, 03, and 04). It lies on the northern flank of Hualalai volcano, extending from sea level to within a mile of the mountain summit (Figure 1). The area is roughly bounded by the 1859 and Kaʻupulehu lava flows. Puʻu Waʻawaʻa is within Kekaha, which is the region of North Kona from Honokohau through Puʻu Anahulu. Kekaha means "a dry and barren place," a good description of the land below the hills or Napuʻu as they were originally called. The ahupuaʻa of Puʻu Waʻawaʻa (Hawaiian: furrowed hill) takes its name from a large volcanic cinder cone that is a prominent landmark in the area. The entire region was forested at one time, but wildfires and more than 100 years of livestock grazing have removed much of the native vegetation.

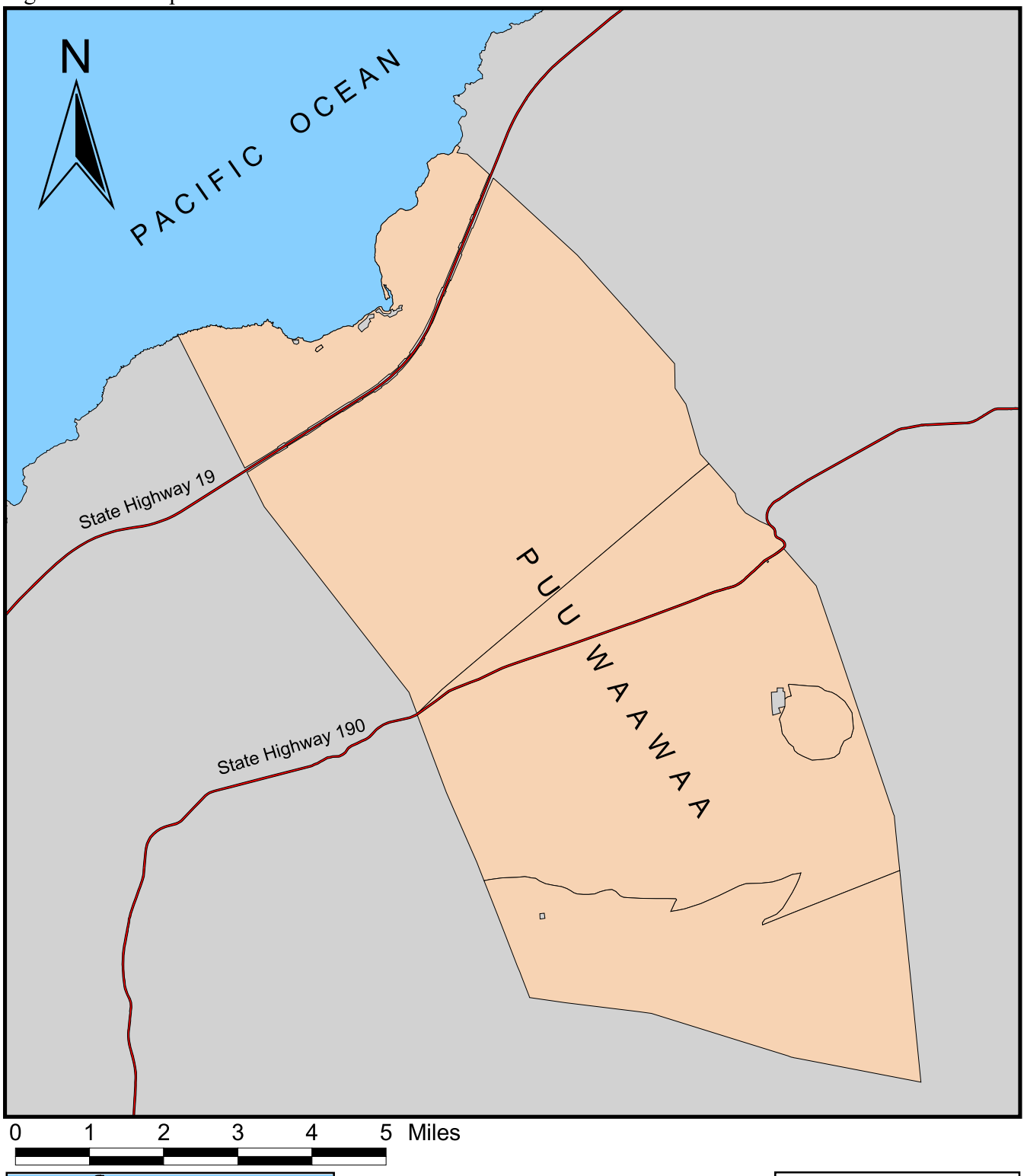
During the Great Mahele (1848), the ahupuaʻa of Puʻu Waʻawaʻa was chosen by Kauikeaouli, King Kamehameha III, for his own personal use. These lands were retained by the King and called "Crown lands". The King gave other lands to supporting Aliʻi and Konohiki, which became known as "Konohiki lands." A third class of lands were given to the Government or Kingdom and were called “Government lands.” These latter parcels were set aside to support government activities, and to provide additional lands for tenancy and leasehold interests. When the monarchy was overthrown in 1893, both Crown and Government lands were ceded to the United States and later to the State of Hawaii.

Land Use Practices

An early Government document (Anon., 1903) described the lands of Puʻu Waʻawaʻa as follows: "This is one of the most northern of the Kona lands, running from the sea to within a mile of the summit of Mount Hualalai, a distance of 15 miles. It has about 6 miles of seacoast, the last landing being at Kiholo, where a few hamlets are. The government road from Kailua to Kawaihae passes through the village at Kiholo. There are very few inhabitants on the land. The only real good land for cultivation is near the Puʻu Waʻawaʻa Cone, distant 8 miles from the coast. Here fruits, particularly peaches, grow luxuriantly; also potatoes and taro. The makai portion of the land, say about one-third, is extremely rocky and would offer but scant pasturage to any herd. Above this, in the wood, is found some of the best grazing land in that part of the country. The forest in places is very heavy, the principal wood being koa and ʻohiʻa (Area about 40,000 acres).”

In the 1880's, Frank Spencer of Waimea grazed 12,000 to 14,000 goats in the Puʻu Anahulu and Puʻu Waʻawaʻa area (J. Greenwell, personal communication). However, organized ranching activities did not begin at Puʻu Waʻawaʻa until 1892 when Robert Hind and Eben Low leased 45,000 acres of Crown lands from the Hawaiian Government for pasture purposes (Henke, 1929). Additional parcels were leased in 1893 (12,000 acres) and again in 1917. Sheep were raised on the ranch in the early days. About 1922, a weed called Spanish needle (*Bidens pilosa*) became established. Seeds from this plant tangled the sheep's wool, making it

Figure 1. The ahupuaa of Puu Waawaa



impossible to card the fabric. As a result, the sheep operation was abandoned. Dairy heifers were raised at Pu‘u Wa‘awa‘a for use in the Hind family dairy on Oahu. Turkeys were also raised with as many as 700 being shipped to Honolulu during some years (Jean Greenwell, personal communication).

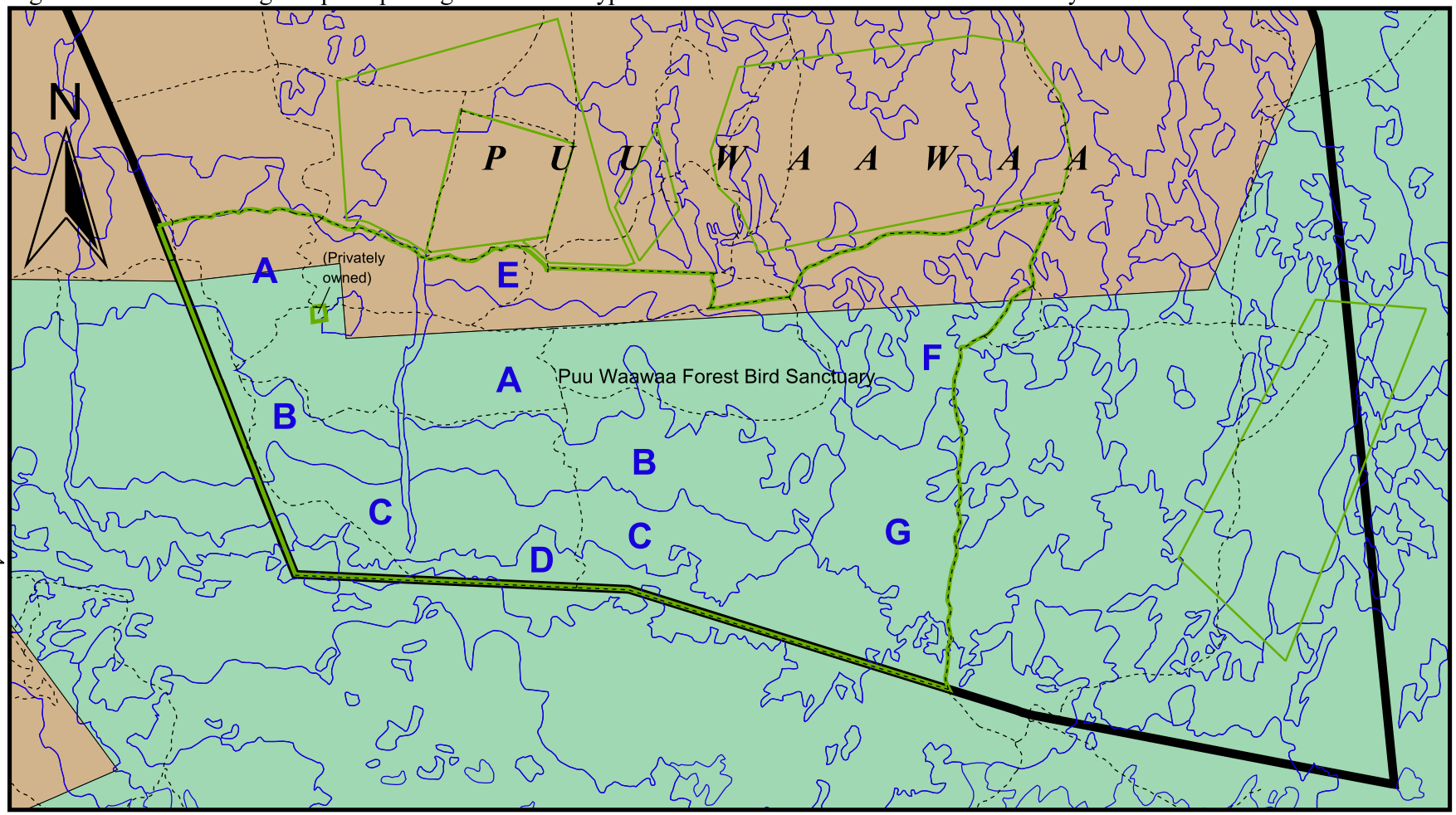
The Pu‘u Wa‘awa‘a Forest Bird Sanctuary (PWWFBS) was established by the State Board of Land and Natural Resources on October 12, 1984. Management responsibility for this parcel was transferred from the State’s Land Division to its Division of Forestry and Wildlife (DOFAW) as a result of the set aside. The sanctuary was specifically created to preserve habitat for endangered forest birds, including the Hawaii crow. It is located upslope of Pu‘u Wa‘awa‘a Ranch, approximately 4 miles above the Mamahaloa highway, and about 18 miles from Kailua-Kona and 22 miles from Waimea, Hawaii. The boundaries extend from 4,000 to 6,500 feet elevation and include 3,806 acres of forest bird habitat. Most of the sanctuary lies within the Conservation District (R Subzone), but approximately 800 acres on the northern boundary are zoned Agriculture (Figure 2).

Originally, Pu‘u Wa‘awa‘a Ranch encompassed 105,831 acres of land. All of this except 35 acres (rain shed, 2.75 acres and headquarters area, 32.54 acres) is State-managed land. The last lease (General Lease No. S-3589) was let to Dillingham Ranch Inc. for a 40-year period on August 15, 1960. On September 15, 1972 the lease was assigned Mr. F. Newell Bohnett. Pu‘u Wa‘awa‘a Ranch was greatly reduced in size in 1984 when the State Board of Land and Natural Resources withdrew 84,397 acres from the lease as a result of illegal koa harvesting activities. The remaining 21,434 acres continued under pasture lease to Mr. Bohnett until August 14, 2000 when the lease expired. On January 25, 2002, all State-managed lands within the ahupua‘a of Pu‘u Wa‘awa‘a were transferred from the State Land Division to DOFAW and State Parks. Both agencies were directed to develop and implement a management plan that would provide for the restoration of native plant and animal ecosystems, preservation of cultural resources, reforestation, public hunting and recreation, research, pasture management, nature education, and eco-tourism activities.

Geology

The Island of Hawaii is relatively young on a geological time scale. Geologists estimate that the oldest lava flows are less than 500,000 years old (McDougall and Swanson, 1972). Hualalai, an active shield volcano, is the third oldest (130,000 years old) of the five volcanoes on the Island (Moore and Clague, 1992). The summit caldera is buried, but the mountain rises to a height of 8,271 feet above sea level. Three major rift zones radiate from the top of Hualalai. One of these, a poorly defined northern rift, extends through the Kalamalu area of Pu‘u Wa‘awa‘a and is about 10 km long and 5 km wide. Lavas of Hualalai are primarily Holocene in age, but some deposits date to late Pleistocene (Moore and Clague, 1991). The last eruption of Hualalai occurred in 1801 creating the Huehue lava flow. Another eruption is highly probable in the next 200 years, but could occur in the next few decades (Moore, Clague, Rubin and Bohrson, 1987). Walker (1990) considered Hualalai as potentially the most dangerous Hawaiian volcano.

Figure 2. Land use zoning and principal vegetation cover types for the Puu Waawaa Forest Bird Sanctuary.



Seismic activity within Hualalai is currently low and there is no evidence of magmatic movement such as occurs on Kilauea and Mauna Loa (Clague and Dalrymple, 1987). The last major earth quake at Puʻu Waʻawaʻa occurred in 1929. This event consisted of several thousand tremors that came from a source beneath Hualalai (MacDonald and Abbott, 1970). The quake was especially severe at Puʻu Waʻawaʻa. Several ranch buildings were moved from their foundations and rock walls collapsed.

Hualalai's surface lavas are primarily alkalic olivine basalts. Tholeiitic basalts have been found offshore and in onshore drill holes (Walker, 1990). The volcano is virtually un-dissected, but a few intermittent streams are subject to flash flooding. Erosion will probably not have a pronounced effect on the mountain for a long time, possibly for tens of thousands of years (Peterson and Moore, 1987).

Lava Flows

Basaltic lavas are generally classified into two types, ʻaʻa and pahoehoe. ʻAʻa lavas have a rough, clinker like surface overlying a denser core. Pahoehoe usually has a smooth ropy surface. The two forms can erupt from the same volcanic vent and differ primarily in heat and gas content. ʻAʻa is cooler, contains less trapped gasses and flows more slowly than pahoehoe. ʻAʻa and pahoehoe lavas vary greatly in their ability to produce soils and support vegetation. The rough texture of ʻaʻa traps and holds soils better than the smoother pahoehoe. As a result, ʻaʻa flows often support a greater plant diversity than similar aged pahoehoe.

Two historic lava flows dominate the Puʻu Waʻawaʻa region. They are the 1859 flow from Mauna Loa and the 1800-1801 Kaʻupulehu flow from Hualalai. Lava from these flows covered thousands of acres of native forest and was responsible for the destruction of several coastal Hawaiian villages and fish ponds. Both flows are poorly vegetated and only slightly weathered. Most lavas between the historic flows originated on Hualalai. These vary greatly in age and intermingle to form a mosaic pattern in the lava bed.

Lava Tubes

Lava tubes are important geological features on Hawaiian volcanoes. These subterranean systems form almost exclusively in pahoehoe flows. Lava tubes usually develop when the surface of lava, flowing in a channel, cools and hardens. As the eruption ceases, the molten lava drains from the tube leaving an empty passage. Sections of lava tube often collapse creating skylights, sinkholes, cracks and trenches. These openings can be very deep and often have vertical or undercut walls. The forest bird sanctuary and adjacent pastures are riddled with large volcanic openings and scattered tree molds. Many holes are undercut, concealed by dense vegetation or divided by a thin land bridge, making foot travel in heavily vegetated sections extremely hazardous. Large pit craters are present at several locations. These consist of steep-sided depressions that formed when molten ground under them collapsed. Several occur in the Kileo section and an exceptionally deep one is present in the western half of the PWWFBS.

Hawaii's lava tubes are a treasure chest of natural resources. They have important biological, geological, cultural, aesthetic, recreational and educational values. Cave entrances and passages provide important habitat for many kinds of plants and animals. Subterranean bacteria and fungi are able to complete their entire life cycles in the dark zone of caves. These organisms are poorly known, but probably have considerable ecological importance. Bacteria, fungi and slimes grow on walls, plant roots, and animal feces inside lava tubes at Puʻu Waʻawaʻa. Two species of very tiny, pale white mushrooms (*Marasmiellus* spp.) were found on ʻohiʻa (*Metrosideros polymorpha*) roots in the dark zone of several caves. Mosses (*Homaliodendron flabellatum*), liverworts (*Dumortiera hirsuta*), ferns (various genera) and mints (*Phyllostegia* & *Stenogyne*) flourish in cave openings where increased shade and moisture create a microhabitat conducive to their survival. Volcanic sinkholes and skylights form natural exclosures where rare and endangered vascular plants can persist without being damaged by wild and domestic herbivores. Five officially listed or proposed endangered plant taxa grow within lava tube entrances at Puʻu Waʻawaʻa. Arthropods, snails, birds, bats, rats, and goats also inhabit lava tubes. Native forest birds, especially ʻapapane (*Himatione sanguinea*) and ʻomaʻo (*Myadestes obscurus*), frequently nest on the floor or on ledges in lava tube openings. Non-native barn owls (*Tyto alba*) and pigeons also roost and nest in cave entrances. In dry areas, non-native finches have been seen entering the twilight zone of lava tubes where they apparently drink water that collects on cave floors.

Volcanic caves were important in the Hawaiian culture. Several names (ana, lua, pao, and ʻaʻaʻa) were associated with these formations, all of which had similar meanings. Native Hawaiian people used lava tubes and rock caverns for many purposes. These included shelter, water catchment, food storage, burials and personal protection. Ancient Hawaiian burials and charcoal from torches are found in Puʻu Waʻawaʻa's lava tubes. Some passages have 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. 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 Puʻu Waʻawaʻa shelter cave middens.

Handy and Handy (1972) described how Hawaiians living in the Puʻu Waʻawaʻa area (Kekaha) obtained their drinking water from caves. According to the account, troughs, three to six feet deep and shaped like a canoe hull were made from ʻohiʻa, koa, and kukui wood. These containers along with gourds and wooden calabashes were used to collect water dripping from the ceiling of caves. Kukui nut torches were said to be used as a light source while collecting water in dark cave interiors.

Umiʻi Manu Lava Tube System: An exceptionally large lava tube occurs along the northern rift zone near Kalamalu Cone. This system formed about 3,000 to 5,000 years ago (D. Clague, personal communication) in pahoehoe lava that flowed from an unnamed vent (hill 6383) on Hualalai volcano. Since no name could be found for this lava tube and because it contained numerous remains of dead birds, the term Umiʻi Manu (Hawaiian: bird trap) Cave was used to identify the feature. The tube extends from 6,200 to 4,300 feet elevation. Its steep elevation

gradient (almost 2,000 feet) makes this lava tube one of the deepest (in terms of elevation extent) in the United States. Tube length is also exceptional. Almost two miles of passage can be traversed underground. Sinkholes and skylights provide access to the lava tube at various locations. Walk-in entrances are located at 4,500, 4,740, 4,870 and 5,200 feet elevation. An unusually large sinkhole (60 feet wide and 40 feet deep) occurs at 5,860 feet elevation. This opening is only accessible by rope or cable ladder. The entire Umiʻi Manu system lies within a montane dry forest kipuka. Surface vegetation is dominated by naio (*Myoporum sandwicense*) and aʻaliʻi *(Dodonaea viscose)* with scattered kolea *(Myrsine lanaiensis)* and mamane (*Sophora chrysophylla*) trees.

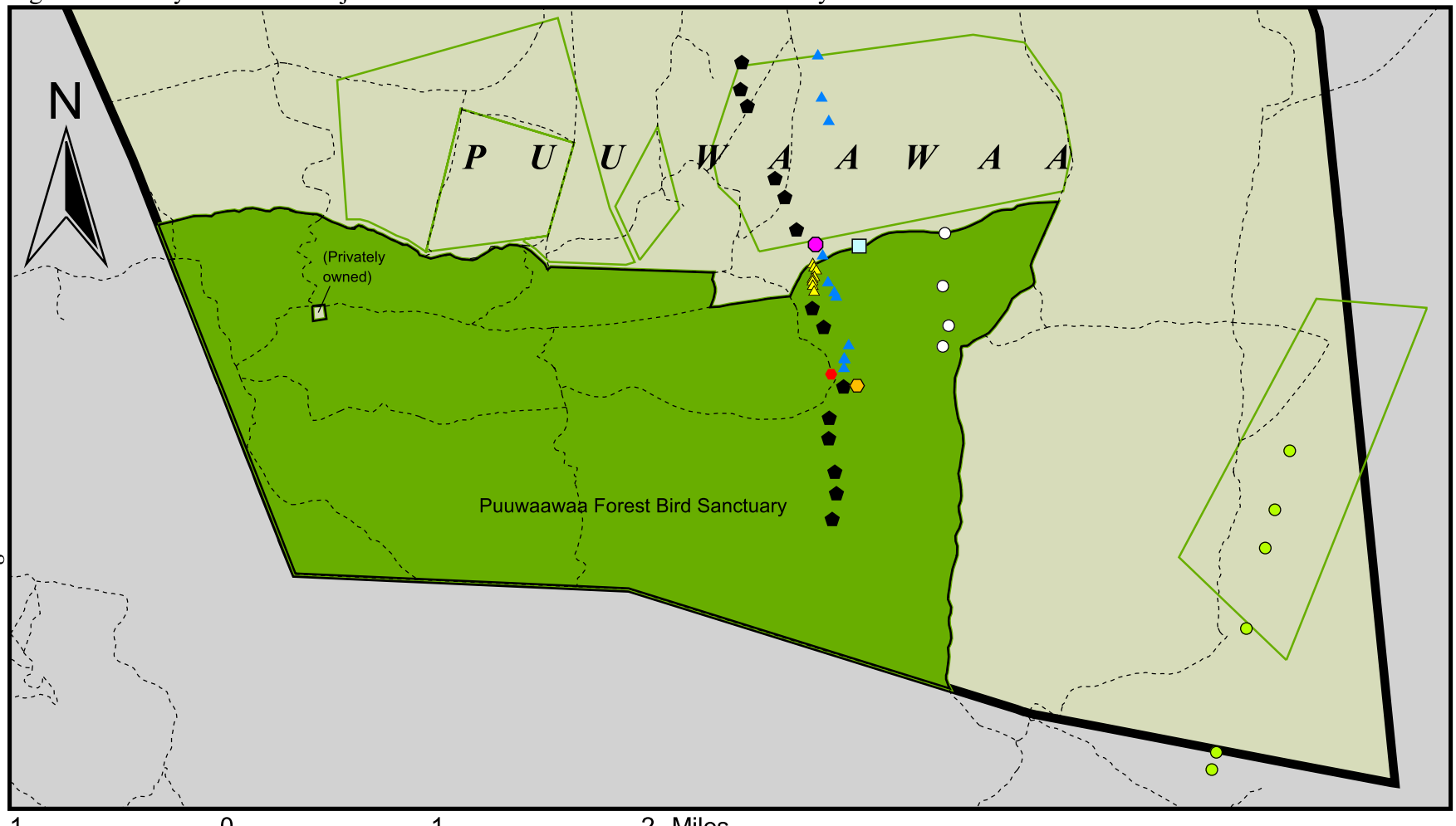
Umiʻi Manu Cave contains many unusual geological formations (speleothems). The ceiling and floor are decorated with lavacicles, stalactites, stalagmites, pillars, driblet spires and triangular ceiling pendants, all composed of lava. Mineral deposits also cover passage walls and ceilings. These include coraloids, evaporites and a soft spongy substance sometimes called "moonmilk". Air in the cave is typically cool and humid. Air temperature, measured inside the cave at 4,300 feet elevation, was 57.4º F in July 1995. Relative humidity was 92.0 percent on the same date. Cave walls are usually damp and water from ceiling drip collects in rock cavities on the floor. The cave passage is often drafty, especially in sections located between two open skylights.

Henahena Lava Tubes: A series of lava tubes are situated between Potato Hill and Poohohoo Cone, extending from the upper boundary of the PWWFBS down to about 3,000 feet elevation on Puʻu Waʻawaʻa Ranch (Figure 3). This area is exceptional in that it contains a greater concentration of lava tubes than anywhere else at Puʻu Waʻawaʻa. At least two primary lava tubes (Shangri-la and Delissea) and another 8-10 secondary passages have been surveyed. Lava tubes in this area form branched passages and many have multiple openings. Most passages are highly segmented, however, being blocked by breakdown piles and other lava barriers. The lava tubes vary in size from a few centimeters to huge caverns. Henahena lava flows are much younger (1,500 - 3,000 years old) than those at Kalamalu. Vegetation is also different with ʻohiʻa and mamane dominating this area. Henahena lava tubes may be the most biologically significant features on Hualalai volcano. These caves provide habitat for many species of rare subterranean invertebrates and contain important deposits of subfossil birds bones and land snail shells. Cave openings also support many rare plant species.

Cinder Cones

An extinct volcanic vent known as Puʻu Waʻawaʻa cone and its associated 900-feet-thick lava flow (Puʻu Anahulu ridge) are the oldest geologic formations on Hualalai (100,000 + years old). This distinctive hill is over 1 mile in diameter and rises 1,220 feet above the surrounding landscape to a height of 3,967 feet elevation. Erosion, following a radial drainage pattern, has cut many gullies and ridges on the cone's slopes. This geologically unique landform is composed of trachyte pumice and contains scattered blocks of trachyte obsidian or black volcanic glass. Trachyte is one of the most silicic lavas known in Hawaii (Walker, 1990). Due to its older age, high degree of soil development and complex topography, Puʻu Waʻawaʻa cone has greater botanical diversity and supports a different plant community than the surrounding area.

Figure 3. Cave systems in and adjacent to the Puu Waawaa Forest Bird Sanctuary.



Vegetation on the cone can be classified as an olopua (*Nestegis*) montane forest (Wagner et al., 1990). At least 21 species of native trees have been reported from this rare mesic community. Some like the manele or soapberry (*Sapindus saponaria*) are found nowhere else in the region.

Several other prominent cinder cones occur at Puʻu Waʻawaʻa. These include Potato Hill, Puʻu Iki, Poohohoo and Kileo cones. Poohohoo's dual craters have been fitted with rubber liners to store water for ranch use. An asphalt catchment system collects water for the reservoirs. Many more small volcanic vents and cinder cones are scattered throughout the area, but most are unnamed.

Soils

The most recent comprehensive soil survey of the Island of Hawaii (USDA, 1973) shows several different soil types at Puʻu Waʻawaʻa. However, these soils were mapped in the wrong climate zones and, therefore, are invalid according to Robert Gavenda, USDA Soil Scientist (personal communication). Recent field surveys indicate that the deepest soils at Puʻu Waʻawaʻa are the Waʻawaʻa series that occur on Puʻu Waʻawaʻa cinder cone. They are almost 2 meters deep.

The ages of Hualalai lava flows have been summarized using correlations between soil depth and age (Moore and Clague, 1991). Little or no soil cover (except in wet forest areas) occurs on lavas less than 5,000 years old. On lavas between 5,000-10,000 years old there is 10-20 cm of soil. Flows over 10,000 years old accumulate soils more than 20 cm deep.

Climate

The weather pattern at Puʻu Waʻawaʻa is similar to that found along the Kona coast. Mornings are generally clear and sunny. During the day, the surface of Hualalai absorbs large amounts of solar radiation. This heats air over the mountain and creates updrafts. This rising air mass draws in moist marine air that condenses as it moves upward. The result is afternoon cloud cover and/or rain. The cycle reverses in the evening. Cold air descends from the mountain summit and drives cloud cover out to sea. Mean monthly temperatures measured at Halepiula rain shed (K. Grace, personal communication) were highest in September (71.6º F) and lowest in February (41.7º F). Winter frost sometimes occurs at upper elevations.

Northeasterly trade winds have little influence on Puʻu Waʻawaʻa because of its leeward location in respect to other large mountains. Winds are generally light, but increase slightly during the winter months. Strong frontal storms pass through the area once or twice a year and winds can reach hurricane force. These storms often uproot large trees or break trunks and limbs. Volcanic smog or "vog", released by Kilauea Volcano, is often blown to west Hawaii by the trade winds and trapped there under an inversion layer. This haze consists of sulfur dioxide, ammonium sulfate and ammonium hydrogen sulfate. On windless days, this natural pollutant sometimes drifts in from Kona and blankets Puʻu Waʻawaʻa. Volcanic haze usually persists until winds shift and cause it to be blown out to sea.

Pu‘u Wa‘awa‘a’s climate is relatively dry compared to other upland forests in Kona. The Halepiula rain shed area (4,600 feet elevation) is the wettest part of the ahupua‘a. From 1938 to 1974, the median annual rainfall at the shed was 46.7 inches. Maximum and minimum annual rainfall during the same 37-year period was 97.4 and 17.6 inches, respectively. Months of greatest rainfall were March through July with a peak in precipitation during May (Division of Water Resource Management, 1991). The timing of maximum rainfall was somewhat different in 1992 and 1993 based on data collected at the forest bird sanctuary cabin (4,000 feet elevation), when the wettest period occurred from late fall to early winter. The Shangri-la area is much drier than Halepiula. Differences in precipitation also occur with increasing elevation. The rainfall zone changes from mesic at mid elevations to xeric at the upper and lower boundaries.

METHODS

Data presented in this assessment were collected part-time over a 12 year period, 1990-2002. The project was not conceived as a formal investigation, but rather evolved as an approach to document biological discoveries being made during the course of routine management activities at Pu‘u Wa‘awa‘a.

Plant species lists were initially complied from existing survey reports. New specimens encountered in the field were identified by DOFAW biologists or by botanists associated with the U.S Fish and Wildlife Service (USFWS), National Park Service, The Nature Conservancy, Bishop Museum or the National Museum of Natural History.

Snail species lists were compiled from various literature sources and from collection information at Bishop Museum. Specimens collected by DOFAW staff were identified by Dr. Robert Cowie, Bishop Museum Malacologist.

Insects and other terrestrial arthropods were collected at Pu‘u Wa‘awa‘a from 1993 to 2002 with the objectives of producing a preliminary checklist of invertebrates, and to assemble a reference collection for management purposes. Field work also provided incidental information on the abundance and distribution of insects as well as other ecological data.

Various techniques were employed to collect arthropods. Among the most frequently used methods were hand picking, and sweep netting. Pitfall traps baited with blue cheese were used to capture cave arthropods. Large insects were caught by hand, while smaller ones were aspirated into vials. A sheet light trap, illuminated by a generator-powered mercury vapor bulb, was operated at night at least one day per month over a two-year period. Universal black light traps (BioQuip) were also employed to capture insects after dark. Two malaise traps were operated at various locations before being stolen by vandals. This latter type of trap was used primarily for collecting Diptera and Hymenoptera. Most beetle species were reared from wood of dead trees utilizing cardboard hatching boxes to contain emerging specimens.

Cave surveys for fossil birds were conducted regularly from August 1992 to August 1993 by systematically searching lava tubes with battery-powered lights. Each known passage was

surveyed twice, first in one direction and then the other. This double survey system improved chances of detecting specimens partially concealed by rocks. Survey crews included experienced volunteer cavers, state biologists and avian paleontologists. Subfossil birds remains were identified by a DOFAW biologist or Bishop Museum specialist whenever possible. Those that could not be determined with certainty were submitted to Storrs Olson or Helen James at the Smithsonian Institution. Comparisons were routinely made of bones from caves with specimens in reference collections.

Radiocarbon dating for aging fossil bird bones was provided by Beta Analytic, Inc. (Miami, Florida) using the following procedure: Specimens were first physically cleaned and extraneous material removed. They were then crushed and put into dilute, cold acid. The acid was periodically renewed over the next few days as the mineral portion of the bones dissolved. After that, the collagen fractions remaining were washed in deionized water. The samples were then combusted in an enclosed system. The carbon dioxides collected were purified and reacted with hydrogen on cobalt catalysts to produce graphite. The Accelerator Mass Spectrometry (AMS) measurements were made in the Lawrence Livermore National Laboratory in California (CAMS). The chemical pre-treatments and target material conversions were done at Beta Analytic, Inc.

BIOLOGICAL RESOURCES

Hawaii is the most isolated archipelago in the world. The 2,000-mile water barrier between the islands and the nearest major land mass prevented natural colonization of many plants and animals. Plant families containing native gymnosperms and primitive flowering species are conspicuously absent. Many terrestrial animals are also missing from the native fauna. Reptiles, amphibians and mammals except for the bat were unable to reach the islands without the aid of man. As a result, Hawaii's native terrestrial fauna is dominated by only three groups of animals: molluscs, arthropods (especially insects), and birds. Hawaii's flora and fauna exhibits some of the planet's most remarkable examples of the evolutionary process called adaptive radiation. This is simply the evolution of different life forms from a single species. Conditions that favored rapid evolution in Hawaii were extreme geographic isolation, a tropical climate, and mountainous topography with extremes in rainfall and temperatures.

VEGETATION

The native flora of the Hawaiian Islands consists of approximately 956 species of flowering plants (Wagner et al., 1990) and 198 fern species (Wagner and Wagner, 1993). Most of these (89 and 78 percent, respectively) are endemic to Hawaii. In fact, no other place in the world has such a high level of endemism, not even the famous Galapagos Islands.

Hawaii has the highest number of threatened and endangered plant species (378) in the U.S. The natural communities that provide habitats for rare plant species are in danger as well. Scientists believe that more than half of the native plant communities in Hawaii are rare and most

will be severely degraded or lost in the next 25 years if they are not protected. The main threats to native plant species today are wildfire, habitat disturbance by non-native ungulates, damage or destruction of habitat from human action, rodents, pest insects, spread of invasive non-native plants, loss of native pollinators, and habitat fragmentation.

Botanical records for Pu‘u Wa‘awa‘a date back almost 100 years. Joseph Rock, a famous Hawaiian Botanist, conducted extensive surveys of vegetation on Pu‘u Wa‘awa‘a Ranch in 1909. At that time, he claimed that Pu‘u Wa‘awa‘a was "...the richest floral section of any in the whole Territory." (Rock, 1913). National Park Service botanist A.L. Mitchell (1944, 1945) conducted botanical surveys in the same area. His reports and field notes provide detailed descriptions of the region's botanical composition. More recent botanical surveys were completed by Takeuchi (1991) and The Nature Conservancy (1992). Even though Pu‘u Wa‘awa‘a's forests have been greatly altered over the past 100 years, remnants of this great botanical treasure still exist. At least 182 native vascular plant species in 69 families are known from the Pu‘u Wa‘awa‘a region (Appendix A). Several species occur nowhere else in the Hawaiian Islands.

Many factors have been responsible for forest degradation at Pu‘u Wa‘awa‘a: livestock grazing, tree clearing for pasture improvement, illegal harvesting of koa and other valuable native trees, introduction of non-native plants and animals and wildfires. Grazing by domestic and feral livestock has severely impacted native vegetation. An early observer (Prof. Koebele) noted that cattle were rapidly changing the forest in 1900. He reported that "The upper part of the ranch [presumably the forest bird sanctuary area] comprises some 12,000 acres of fertile Government land, covered with valuable forest trees, among them the famous koa. It is here where we have seen the sandalwood tree over eighteen inches in diameter. Five years since the present leaseholder had to hew a trail to see the condition of the land; today we find a handsome open park land, so to speak, where one can ride anywhere on horseback. I venture to say that at the expiration of the lease, twenty years hence, we will find an open pasture land, very much in want of moisture." (Koebele, 1900). Forest destruction occurred much as Koebele predicted, but at a slightly slower pace.

At the turn of the century, Waihou Forest (on Pu‘u Wa‘awa‘a Ranch) was one of the most botanically rich areas in the Hawaiian Islands. This mixed woodland was dominated primarily by koa (*Acacia koa*), mamane, naio, and akoko (*Chamaesyce olowaluana*) trees. Vegetation was said to be so thick in places that it was almost impossible to pass through the forest (Rock, 1912 & 1913). Even as late as 1959, the mamane canopy was still intact according to Billy Pairs (personal communication), a former ranch manager. Today, Waihou is an open pasture marked by standing skeletons of dead or dying trees. Drought is a common occurrence and non-native grasses and weeds have almost replaced native understory plants.

Wildfires have had a tremendous impact on the native ecosystem at Pu‘u Wa‘awa‘a. Much of the forest vegetation has repeatedly burned in the last few decades. Fires consumed hundreds of acres of dryland forest in 1986 and again in 1988. Fires have also scared the forest bird sanctuary. Several hundred acres of forest above Poohohoo cinder cone were set ablaze, probably by a lightening strike, about 1908. This event created a large open area that is still apparent today (B. Paris, personal communication). Charcoal from burned trees is buried more

than 8 inches deep in soil near the sanctuary cabin (4,000 feet elevation). This material may be from the 1908 fire or possibly an earlier one. In March 1995, campers set a fire in the Shangri-la area that burned from March 5 to May 5, 1995. At least 1,200 acres of vegetation were consumed by the blaze: 1,000 acres in the lower northeast corner of the forest bird sanctuary and 200 acres on Pu‘u Wa‘awa‘a Ranch.

Vegetation Zones and Associated Rare Plants

Several different ecological regions are present at Pu‘u Wa‘awa‘a. Starting on the upper slopes of Hualalai and proceeding downward the following zones can be recognized: subalpine (generally above 6,000 ft.), montane (2,500-6,000 ft.), lowland (below 2,500 ft.) and coastal (sea level). A variety of vegetation communities occur within each zone. At mid elevations, montane dry woodlands dominate the eastern side of Pu‘u Wa‘awa‘a while moister montane mesic forests lie to the west.

Rare plants are found in all vegetation zones at Pu‘u Wa‘awa‘a. At least 40 rare plant taxa have been reported from the area to date. Of these, 22 are officially listed as endangered or are proposed endangered species. Botanical surveys reveal that a great number of plants have been extirpated at Pu‘u Wa‘awa‘a in recent years. These include the endangered *Bonamia menziesii*, *Diellia erecta*, *Gardenia brighamii*, *Ochrosia kilaueaensis*, *Dissochondrus biflorus*, *Exocarpus gaudichaudii*, *Hesperocynide sandwicensis*, *Mariscus fauriei*, *Neraudia ovata*, *Nesoluma polynesicum*, *Zanthoxylum hawaiiense*, and *Solanum incompletum*. Many of these species still exist on adjacent lands, particularly at Pu‘u Anahulu and Ka‘upulehu. Some rare plants have only been found in lava tube openings where they are protected from wild herbivores. These include *Delissea undulata*, *Zanthoxylum kauaense*, *Stenogyne angustifolia*, *Phyllostegia ambigua* and *Asplenium fragile*.

Subalpine Zone: This zone is found at upper elevations on Hualalai and other high volcanoes in Hawaii. Plants growing here are adapted to relatively dry conditions and dramatic temperature fluctuations. Days are typically hot and nights cold. These forests at Pu‘u Wa‘awa‘a are characterized by open, low stature ‘ohi‘a trees *(Metrosideros polymorpha)* and scattered stands of native shrubs and grasses. Dominant understory species are pukiawe *(Styphelia tameiameiae)*, ‘ohelo (*Vaccinium spp.)*, a‘ali‘i, sedges and rushes. Native mints, lilies, and ferns often grow abundantly in shaded areas like lava tube openings.

One endangered plant is found in the subalpine zone at Pu‘u Wa‘awa‘a. Laukahi kuahiwi (*Plantago hawaiensis*) is a member of the plantain family (Plantaginaceae). This plant is a perennial herb with leathery leaves. It has only been seen near the upper boundary of the forest bird sanctuary. Very little is known about the abundance or distribution of this rare species. ‘Akala (*Rubus macraei*), mau‘u la ‘ili (*Sisyrinchium acre)*, and *Eragrostis deflexa* also grow in this zone. All three are species of concern (SOC).

Montane Dry Forest Zone: This zone is found directly below the subalpine zone on the eastern side of Pu‘u Wa‘awa‘a. Many rare and endangered plant species are found in this habitat type. Vegetation damage by feral ungulates, particularly goats and sheep, is widespread. These forests

are dominated by ʻohiʻa, naio and aʻaliʻi. Scattered stands of mamane, sandalwood *(Santalum paniculatum)* and akoko are also present. Non-native grasses, especially the invasive fountain grass, have replaced most native understory species.

Endangered plants of the montane dry forest are *Asplenium fragile, Portulaca sclerocarpa, Stenogyne angustifolia,* and *Zanthoxylum hawaiiense. Portulaca sclerocarpa* occurs on the 1859 lava flow while a few individuals of the mint (*Stenogyne angustifolia*) and aʻe (*Zanthoxylum hawaiiense*) grow on nearby aʻa lava flows. A native grass, *Eragrostis deflexa*, (SOC) is scattered throughout the Puʻu Waʻawaʻa area at above 4,000 feet elevation. This species is notable because the type specimen was collected by Hitchcock (1922) in August, 1916 "in open woods on hillside, Puʻu Waʻawaʻa, Hawaii".

Montane Mesic Forest Zone: This zone is relatively moist, but not as wet as rain forests. The mesic forest supports a rich assemblage of vascular plant species. It is best developed in the forest bird sanctuary. Koa and ʻohiʻa are the dominant tree species in the over story layer. Kolea (*Myrsine lessertiana*) dominates the mid-story layer while native short-stature trees and shrubs vegetate the understory. Introduced grasses, primarily Kikuyu (*Pennisetum clandestinum*) and native ferns, especially the shuttlecock shaped laukahi (*Dryopteris* spp.), cover the ground in forest openings. Other ferns such as hoio (*Athyrium sandwichianum*), akolea (*Athyrium microphyllum*) and palapalai (*Microlepia setosa*) are common in wetter, shaded areas. No tree fern stratum exists although hapuʻu (*Cibotium glaucum*) are scattered throughout the forest.

Endangered plants found in the upper mesic zone are *Vicia menziesii,* haha (*Cyanea stictophylla),* and *Phyllostegia velutina*. *Vicia menziesii* is a leguminous vine in the pea family (Fabaceae) that has the distinction of being Hawaii's first officially listed endangered species. Various common names have been used for *Vicia* including Hawaiian vetch and Hawaiian wild broad-bean. No native name is known for the plant (Warshauer and Jacobi, 1982). Natural populations of *Vicia* were thought to be restricted to Mauna Kea and Mauna Loa until 1985 when C. Kepler (USFWS) collected a single specimen on Hualalai. He found a colony of these plants at Puʻu Waʻawaʻa in an "open decadent Acacia koa-Myrsine forest with fern understory." The colony was said to cover an area of approx. 500 square feet. The location of the plants was never marked and subsequent attempts to relocated them were unsuccessful for many years.

On April 1, 1993, DOFAW staff rediscovered the same *Vicia* colony. It was found in the Halepiula mauka Waimea paddock at 5,250 feet elevation. The plants were found in a forest opening and occupied an area of approximately 3,750 square feet. *Vicia* vines were climbing on several ferns including hoio, hapuʻu and (*Pseudophegopteris keraudreniana*). Many of the plants were blooming at the time of their discovery. Recent field observations indicate a prolonged flowering period, extending from April to August. *Vicia menziesii* is a new record for Hualalai volcano and was not known to occur there prior to 1985.

Haha is an endangered shrub or tree in the bellflower family (Campanulaceae). This species has long lobed leaves that form an apical rosette. It bears tubular purple-black flowers and smooth orange fruits. Juvenile plants have thorn like prickles on stems and upper surface of leaves. These prickles diminish as the plant ages. Less than 10 individual plants are known to

exist in the wild. Only one wild plant has been found at Pu‘u Wa‘awa‘a and that individual exists in the forest bird sanctuary at 5,440 feet elevation. Blooming has been noted from December through March. Seedling planted in fenced exclosures first bloomed at four years of age.

At least four endangered plants occur in lower mesic forest. They are ‘aiea (*Nothocestrum breviflorum*), hau kuahiwi (*Hibiscadelphus hualalaiensis*), kawa‘u (*Zanthoxylum dipetalum* var. *tomentosum*), and *Delissea undulata* ssp. *undulata*. ‘aiea is a stout tree in the nightshade family (Solanaceae). This tomato relative is semi-deciduous, often dropping its leaves during dry periods. It produces tubular yellow flowers that have a pleasant fragrance and small orange fruits. Although classified as endangered, ‘aiea is locally common on ranch pastures at about 3,500 feet elevation. The last wild *Hibiscadelphus* died in January, 1992. However, seeds collected prior to its death were germinated and numerous seedlings were produced. Many of these were outplanted in enclosures beginning in 1990. Only seven wild kawa‘u trees remain, distributed from 3,100 to 3,600 feet elevation. The amount of seed produced is low as this species is dioecious and individuals are widely scattered.

Delissea undulata is one of the rarest plants on the Island of Hawaii. This unbranched, palm-like Hawaiian lobelioid has no common name. It produces a cluster of leaves on slender woody stems that sometimes reach up to 30 feet tall. *Delissea undulata* formerly existed on Mauna Loa and Hualalai volcanoes. Rock (1913) indicated that on Mauna Loa "The plants are exceedingly numerous, but especially on the crater bottoms of the numerous volcanic cones, where they form the main vegetation." On Hualalai, the plant was known to occur on Pu‘u Wa‘awa‘a cone (3,000 feet elevation) and in Waihou Forest (3,000-3,500 ft. elevation). Rock (1919) noted that these plants were numerous at Waihou, but did not attain the height of those seen on Mauna Loa. *Delissea* was last sighted at Pu‘u Wa‘awa‘a in 1922, but persisted elsewhere on Hualalai until 1971. It was thought to be extinct after that date (Wagner et al., 1990).

In April 1992, *Delissea undulata* was re-discovered at Pu‘u Wa‘awa‘a by DOFAW biologist, Jon Giffin. A single plant was located in the montane dry forest near Poohohoo cinder cone at 3,520 feet elevation. It was associated with mamane, ‘ohi‘a, koa, sandalwood, naio, ‘aiea and alani (*Melicope hawaiensis*). This rare lobelia was growing on the side of a collapsed lava tube, but had been knocked over by wind or animals and was dangling from its roots. The stem was immediately propped up with a stake and the entire plant fenced to prevent further injury. This individual flowered in July and produced its first fruit in August 1992. However, the fruit began dropping off the plant before reaching maturity. There was concern that no viable seeds would be produced without some immediate intervention. As a result, immature fruits were picked and sent to the tissue culture laboratory at Lyon Arboretum in Honolulu. Seeds were removed and allowed to mature on sterile media and then germinated by Gregory Koob, Research Assistant. Greg was successful in producing over 100 plants. Other seedlings were eventually germinated at the State Tree Nursery in Kamuela, Hawaii. The first of these were outplanted in May 1993 and flowered and produced fruit in June 1994 (at two years of age). In 1995, outplanted plants flowered from July through September. It is hoped that these young plants will provide the necessary stock to save this rare lobelioid from extinction.

Several sensitive species, which may be candidates for endangered species listing, are found in the lower mesic forest at Pu‘u Wa‘awa‘a. These include akoko, alani, ‘anunu (*Sicyos macrophyllus)* and ohe mauka (*Tetraplasandra oahuensis)*. Only about ten *Melicope hawaiensis* trees exist at Pu‘u Wa‘awa‘a. Their current distribution is restricted to a narrow band of forest between 3,220 and 3,760 feet in elevation.

The montane mesic forest at Pu‘u Wa‘awa‘a changes from a koa/‘ohi‘a community to an open-canopied ‘ohi‘a/mamane community at about 4,200 feet elevation. This latter woodland is a transitional vegetation type that descends to about 3,000 feet elevation. Although greatly altered, it is still an important conservation link between the moist montane and dry forest types. The ‘ohi‘a/mamane woodland supports many rare and unique plants and is still one of the most botanically diverse sections at Pu‘u Wa‘awa‘a. Trees that characterize this zone include koa, akoko, ‘iliahi (*Santalum paniculatum*), kopiko (*Psychotria hawaiiensis*), papala (*Charpentiera obovata*), papala kepau (*Pisonia brunoniana*), po‘ola (*Claoxylon sandwicense*), a‘ia‘i (*Streblus pendulinus*), olopua (*Nestegis sandwicensis*), and hoawa (*Pittosporum hosmeri*). The understory is composed primarily of non-native pasture grasses, but scattered stands of kulu‘i *(Nototrichium sandwicense)*, mint (*Stenogyne rugosa*), and ferns (*Dryopteris*, *Pteris*, *Asplenium*) still persist.

Lowland Dry Forest Zone: This zone occurs below the montane forests. Native plant communities in this zone are among the most diverse in Hawaii, containing many rare and endangered species. These woodlands have been greatly damaged by fire and feral animals during the past 150 years. Lama (*Diospyros sandwicensis*) and ‘ohi‘a are the dominant tree species and occur in both mixed and pure stands. Other less common trees include alahe‘e (*Canthium odoratum*), wiliwili (*Erythrina sandwicensis*), ohe makai (*Reynoldsia sandwicensis*), and kauila (*Colubrina oppositifolia*). The rare lama and lama/kauila plant communities are restricted to this zone at Pu‘u Wa‘awa‘a. Descriptions of Pu‘u Wa‘awa‘a’s lowland dry forests and information on their floristic composition were presented in detail by W. Takeuchi (1991) and The Nature Conservancy (l992).

Endangered plants of the lowland dry forest are ma‘o hau hele (*Hibiscus brackenridgei* ssp. *brackenridgei*, uhiuhi (*Caesalpinia kavaiensis*), koki‘o (*Kokia drynarioides*), kauila and halapepe (*Pleomele hawaiiensis*). Koai‘a (*Acacia koaia*) is a species of concern.

Coastal Zone: This zone extends from the high water mark for a short distance inland. Vegetation is strongly influenced by salt water from ocean spray and brackish springs. Non-native trees, especially coconut palms (*Cocos nucifera*) are commonly associated with this area. Native plants include ‘aki‘aki (*Sporobolus virginicus*), naupaka (*Scaevola sericea*), and pohuehue (*Ipomoea pes-caprae* spp. *brasiliensis*). A reconnaissance survey of coastal lands at Kiholo Bay was conducted by The Nature Conservancy (1993). No endangered plants have been found in the coastal zone.

Many rare plants are only represented by a few individuals or a single colony at Pu‘u Wa‘awa‘a. These include Kauai a‘e (*Zanthoxylum kauaense*), alani, ohe mauka, *Phyllostegia stachyoides*, *Phyllostegia ambigua*, *Stenogyne macrantha*, *Phytolacca sandwicensis*, and *Sicyos*

macrophyllus. All of these species are prime candidates for in situ germplasm conservation through cultivation and outplanting. This action is crucial in order to prevent their extirpation on Hualalai.

Other Notable Plant Taxa

Many taxa of plants are unnaturally rare at Pu‘u Wa‘awa‘a, but common elsewhere on the Island of Hawaii. Among these are hoi-kuahiwi (*Smilax melastomifolia*), olomea (*Perrottetia sandwicensis*), and ‘aiea (Nothocestreum longifolium). A few common plant species are noticeably absent at Pu‘u Wa‘awa‘a. These include ‘ie‘ie (*Freycinetia arborea*) and kanawao (*Broussaisia arguta*). ‘Ie‘ie was present in the Poohohoo paddock until about 1960. It was extirpated over a period of about 10 years after the area was opened for cattle grazing (D. Woodside, personal communication).

Many families of native plants are notable because they contain endemic genera or large numbers of endemic species. Some of the most famous are lobelioides, mints, sunflowers, and species in the rue family. A summary of the more important groups is as follows:

Campanulaceae (Lobelioides): Plants in the bellflower family (Campanulaceae, subfamily Lobelioideae) are shrubs or small trees with conspicuous flowers and fleshy fruit. They are of interest to botanists because species in the endemic genera, *Delissea Cyanea, Clermontia* and *Rollandia* are the largest group of Hawaiian plants to have evolved from a single immigrant ancestor (98 species). Growth form, leaf size and shape and floral morphology have also undergone extensive changes as these plants adapted to the Hawaiian environment (Givnish et al., 1995). Lobelioides are represented at Pu‘u Wa‘awa‘a by three genera. *Delissea* and *Cyanea* are rare while *Clermontia* is common. *Delissea* is found in dry montane or mesic habitats up to 5,600 feet elevation (Wagner et al., 1990). *Cyanea* prefers shadier, interior locations in mid elevation montane and wet forests. It shares this habitat with *Clermontia* although the latter species likes forest edges and openings. *Clermontia* is the most abundant lobelioid at Pu‘u Wa‘awa‘a, probably because it is best able to withstand habitat disturbance and is not palatable to introduced herbivores. Flowers of fleshy-fruited (baccate) lobelioides provide an important nectar source for long-billed honeycreepers (*Hemignathus, Vestiaria*) and fruits are eaten by other endemic forest birds (*Corvus, Psittirostra*).

Lamiaceae (Mints): Hawaiian mints are climbing vines that lack the strong fragrance of mainland species. Members of the mint family are especially well represented at Pu‘u Wa‘awa‘a. At least four species of the endemic genera *Stenogyne* (*macrantha, rugosa, sessilis* and *angustifolia*) and three species of the nearly endemic genera *Phyllostegia* (*ambigua, stachyoides* and *velutina*) are still extant. Two other mints, *P. racemosa* (W. Giffard, 1918) and *S. microphylla* (Rick Warshauer, personal commuication) were observed at Pu‘u Wa‘awa‘a in the past, but have not been found in recent years. *Phyllostegia ambigua* is a new record for Hualalai and was not known to exist there before 1993.

Rutaceae (Rue Family): The rue family (Rutaceae) is best known for the edible citrus fruits such as lemons, oranges and limes. In Hawaii the family is represented by 55 endemic species in three

genera: *Melicope*, *Zanthoxylum* and *Platydesma*. All have capsular fruit. At Pu‘u Wa‘awa‘a, there are three endemic species of *Melicope* (*clusiifolia*, *hawaiensis*, and *volcanica*) and three endemic species of *Zanthoxylum* (*dipetalum* var. *tomentosum*, *hawaiiense* and *kauaense*).

Non-native Plants

Non-native plants readily invade disturbed ecosystems. Pu‘u Wa‘awa‘a's long history of land abuse has encouraged a major shift in vegetation composition. More than 60 non-native species were identified in the forest bird sanctuary alone. Many of these seriously disrupt native forest ecosystems. Species presenting the greatest threat to forest recovery are fountain grass (*Pennisetum setaceum*), banana poka (*Passiflora mollissima*), silk oak (*grevillea robusta*), daisy fleabane (*Erigeron karvinskianus*) and German ivy (*Senecio mikanioides*). Weedy plants often form monotypic stands that displace native vegetation over large areas. If not controlled, weed species will rapidly alter the native forest composition and structure and result in the extirpation of rare or endangered species.

Fleshy Fungi (Thallophytes)

Fleshy fungi are an interesting component of Hawaii's flora. All major taxonomic groups of thallophytic plants are found in the islands. Of these, the club fungi or basidium bearers (basidiomycetes) are the most conspicuous. These include the jelly fungi, rusts, smuts and mushrooms (Baker and Goos, 1980). Several types of fungi are present at Pu‘u Wa‘awa‘a. Pore (polypores) and gill mushrooms (agarics) attain the greatest size.

A very large polypore fungus grows on living or dead koa and ‘ohi‘a trees. These orange colored, stalkless brackets (Laetiporus sulphureus) are commonly called sulphur shelf mushrooms or chicken of the woods and are highly edible. Sulphur shelf fungi cause brown rot in the wood, a process that dissolves cellulose, but leaves lignin. Trees decayed by shelf fungi play an important role in soil formation. A small spring polypore (*Polyporus arcularius*) grows on sticks and logs and cause white rot. Others that grow on wood are a shelf fungi (*Phaeolus schweinitzii*) and the colorful turkey-tail (*Trametes versicolor*).

Several species of gill mushrooms have been identified at Pu‘u Wa‘awa‘a. The largest, an oyster mushroom (*Pleurotus cystidiosus*), grows on living ‘ohi‘a trees. Some parasol mushrooms like the large *Lepiota naucina* appear in pastures after heavy rains. This particular species is edible, but other similar appearing *Lepiota* are toxic and have the potential to make certain individuals violently ill. Field mushrooms (*Agaricus* spp.) are also well represented. This group contains both edible and mildly poisonous species (Don Hemmes, personal communication).

INVERTEBRATES

Mollusks

The native land snail fauna of Hawaii (class Gastropoda) can be separated into two unrelated subclasses, Pulmonata (lung-bearers) and Prosobranchia (gill-bearers). The largest group, the pulmonate snails have a lung for breathing air, four tentacles on the head, lack an operculum or trap door on the shell and are hermaphroditic. The smaller group or prosobranchs lack a lung, have only two tentacles, posses a hard or soft operculum and sexes are separate. The latter group is represented in Hawaii by snails in the families Helicinidae and Hydrocenidae (Cowie et al., 1995b).

Hawaii supported the most extensive and spectacular radiation of endemic land snails found anywhere in the world. However, only ten of the more than 65 land snail families have native representatives in Hawaii (Solem, 1990). Of the estimated 1,000 species of terrestrial gastropods that once inhabited the islands, over half are probably now extinct (Hadfield and Miller, 1989). Hawaiians have many names for native land shells. Two of the most common are kahuli and pupu kuahiwi. Only a few malacological surveys have taken place on the Island of Hawaii in recent years. As a result, little is known about the present status of the island's land shell fauna.

Subfossil Land Snails

Pu‘u Wa‘awa‘a had a particularly rich land snail fauna. The list of native taxa collected to date (both dead and alive) includes more than 30 species in nine families. The only native mollusk families not represented in the list are Ellobiidae and Punctidae. Unfortunately, most land snail taxa are now extinct. Deposits of subfossil land snails were recently encountered at Pu‘u Wa‘awa‘a in a variety of geological settings. Snail shells were often collected in lava tubes. Vegetation harboring these creatures probably fell into skylights or snails may have been washed into cave passages during heavy rains. Thousands more were found buried in soil strata, often at the base of lava rock outcrops. Subfossil shell deposits were particularly abundant on the slopes of cinder cones. Sites producing the most shells were Puu Poohohoo, Puu Iki and an unnamed cone inside *Delissea* exclosure. Shells of presumably extinct land snails collected by DOFAW staff in 1995 comprise species in several families: Achatinellidae (*Partulina, Tornatellaria*), Amastridae (*Amastra*, *Leptachatina*), Endodontidae (*Endodonta, Cookeconcha*), Helicarionidae (*Euconulus*), Helicinidae (*Pleuropoma*), Pupillidae (*Lyropupa*), and Succineidae (*Succinea*). At least two species of *Amastra* and four species of *Leptachatina* were identified in the deposits.

The agate or tree snail (*Partulina confusa*) was the largest and most conspicuous endemic land snail found at Pu‘u Wa‘awa‘a. Hawaiians knew this species as pupu kolea uka (Literal: inland plover shell). *P. confusa* was historically known from several areas on the big island, but is now presumed extinct. Preserved shells of *P. confusa* were found in several lava tubes (Delissea, Opuhi and Umi’i Manu caves and on Puu Iki cone) at Pu‘u Wa‘awa‘a. Based on these remains, it appears that tree snails were distributed along a narrow band of forest (presently

ʻohiʻa, mamane, naio and koa) from 3,340 to 4,400 feet elevation. The primary plant host for this species was said to be olopua, but ʻilima (*Sida* sp.) and mamane also supported this species.

Current Land Snail Fauna

A few taxa of native land snails still exist at Puʻu Waʻawaʻa, but are restricted to upper elevations, primarily in the forest bird sanctuary. Three species of tiny arboreal snails in the family Achatinellidae were collected in the Halepiula mauka Waimea paddock (5,100 to 5,450 feet elevation) in October 1992. These included species in the genera *Tornatellaria,* and *Lamellidea* as well as *Elasmias fuscum*. Snails were collected from the leaves of *Ilex anomala, Phyllostegia velutina, Clermontia clermontioides* and *Peperomia macraeana*.

A review of malacological records at Bishop Museum indicates that live specimens of land snails were collected at Puʻu Waʻawaʻa between 1919 and 1937. These included species in the genera *Endodonta*, *Leptachatina*, *Lyropupa*, and *Philonesia*. No intensive efforts have been made to search for live land snails at Puʻu Waʻawaʻa since the 1930's. It is possible that land snails in these and other genera are still present. Land snails in the genera *Leptachatina*, *Succinea*, *Striatura, Philonesia, Euconulus*, *Nesopupa, Pronesopupa* and *Nesovitrea* were recently live-collected in similar habitats at the nearby Pohakuloa Training Area. Live specimens of the presumed extinct *Leptachatina lepida* were among this group (Cowie et al., 1995a). This species may also persist at Puʻu Waʻawaʻa.

The introduced European garlic snail (*Oxychilus alliarius*) is extremely abundant at Puʻu Waʻawaʻa. These ground-dwelling, omnivorous mollusks are said to be a threat to native snails. They are often found on forest vegetation and below skylights in caves. Empty shells of the non-native *Bradybaenea similaris*, a common garden pest, were also found in caves and occasionally under rocks in the forest. This species is probably of little significance to native mollusks. The herbaceous European brown snail (*Helix aspersa*), carnivorous *Euglandina rosea*, giant African snail (*Achatina fulica*) and tiny *Subulina octona* have not been found at Puʻu Waʻawaʻa to date (Appendix B).

Crustaceans

A finding of interest was the discovery of terrestrial crab remains in Puʻu Waʻawaʻa lava tubes. These crustaceans were only recently recognized as a former component of Hawaii's native ecosystem (Howarth, 1990). Preserved exoskeletons (usually a chelae or carapace) of land-dwelling crabs were found from 120 to 3,160 feet elevation. Remains were most numerous, however, at about 500 feet elevation. The carapace of the largest specimen measured was 5.5 cm in breadth. Crab remains were typically associated with cave openings that contained subfossil bones of indigenous seabirds. In the past, seabirds apparently roosted or nested near cave openings, even at low elevations. Carcasses of dead seabirds, eggs, chicks and fish brought to nestlings probably washed into caves. This material certainly provided a rich food supply for scavenging crabs. Native terrestrial crustaceans may have gone extinct when lowland seabird nesting colonies were extirpated by introduced predators.

There is some confusion regarding the identification of extinct land crabs at Pu‘u Wa‘awa‘a. One specimen, collected by DOFAW staff members at 3,160 feet elevation, was tentatively identified as *Geograpsus crinipes*, a member of the Grapsidae family (F. Howarth, personal communication). However, this crab is supposedly a marine littoral species and it is surprising to find it at such a high elevation. Edmondson, (1962) noted that land crabs (Gecarcinidae) identified as *Cardisoma hirtipes* were formerly present on Oahu. They were last collected in 1864, but are probably extinct now. This later species looks similar to the Pu‘u Wa‘awa‘a specimens. Further study of the Big Island crustaceans is warranted before any conclusions can be made regarding their taxonomic classification.

Forest Arthropods.

Arthropods are the largest group of organisms in the world. In fact, three-quarters of all living species are insects. Hawaii's native arthropod fauna is estimated to exceed 10,000 species. Approximately half of these have been named by entomologists (Howarth and Mull, 1992). Arthropod evolution has been explosive in Hawaii. Several genera contain more than 100 species. Pomace flies in the family *Drosophila* are perhaps the most famous with over 1,000 species.

Native forest arthropods have been studied at Pu‘u Wa‘awa‘a for many years. Several individuals conducted entomological investigations in the area after the turn of the century. Koebele (1900, 1901) reported on several species of long-horned beetles (Cerambycidae) while Giffard (1918, 1919) surveyed the Delphacid planthopper fauna. Swezey (1946, 1954) listed the host plants for several Pu‘u Wa‘awa‘a insects and described new cerambycids from that area.

Pu‘u Wa‘awa‘a still supports a rich array of native (Appendix C) and non-native (Appendix D) insect taxa. Native species diversity is greatest in Lepidoptera follow by Heteroptera and Coleoptera. Some insect groups are striking in coloration and/or form such as giant dragonflies (*Anax strenuus*), Kamehameha butterflies (*Vanessa tameamea*), Hawk moths (*Hyles* and *Manudca* spp.), iridescent green koa bugs (*Coleotichus blackburniae*), cricket-like long-horned beetles (*Plagithmysus* spp.), delicate lacewings (*Anomalochrysa* spp.) and predatory Ichneumon wasps. All except the first two are obscure and seldom seen. Most have limited distributions, secretive habits or are rare. Other less showy species are more numerous and widespread, but go unnoticed because of their small size. These include the damsel bugs (Nabidae), mirid leaf bugs (Miridae), Lygaeid seed bugs (Lygaeidae) cixiid and delphacid planthoppers (Cixiidae and Delphacidae), leafhoppers (Cicadellidae) and spiders (Aranae). A summary of major arthropod orders at Pu‘u Wa‘awa‘a follows:

Araneae: Spiders in the families Linyphiidae, Lycosidae, Philodromidae, Saltcidae, Tetragnathidae, Thomisidae and Theridiidae have been collected at Pu‘u Wa‘awa‘a. The best-known species is the comb-footed or happy-face spider (*Theridion grallator*). These tiny (3-4 mm body length) arachnids exhibit a "happy- face" design on the dorsal surface of their abdomen. They occur in the mesic forest zone at Pu‘u Wa‘awa‘a, but are uncommon. Comb-footed spiders live under plant leaves where they wait for their prey. When a small fly or other

insect is detected, the spider will move to the edge of the leaf and snare its prey with a sticky web.

Crab spiders (Thomisidae) are an interesting group of arthropods that use adaptive coloration to ambush their prey while evading bird predation. These small arachnids are sometimes known as flower spiders on the mainland because they often mimic the coloration of flowers to catch pollinating insects. In Hawaii, Thomisid spiders are specialists on leaf, moss, and lichens. They often employ adaptive coloration to match their preferred host plant. At least 11 species are known from the island of Hawaii.

Four species of Thomisid crab spiders have been identified at Puʻu Waʻawaʻa to date. All are rare with the exception of *Misumenops anguliventris* which is common on ʻohiʻa foliage near the upper boundary of the forest bird sanctuary. Other species are found among the filamentous lichens (*Usnea* sp.*)* that grow on koa bark. The most surprising discovery was that of *M. aridus* on koa lichens. This species was assumed to be confined to Auwahi on Maui (J. Garb, personal communication).

Coleoptera: The endemic beetle fauna is well represented at Puʻu Waʻawaʻa. Families with native species are Aglycyderidae, Alleculidae, Anobiidae, Anthribidae, Carabidae, Cerambycidae, Ciidae, Curculionidae, Dermestidae and Nitidulidae. Most are wood-borers that live under the bark or in the wood of native trees. Dying mamane, koa, akoko and lama are often riddled with holes made by emerging longhorn beetles (*Plagithmysus* spp.). Kolea and sandalwood are bored by death-watch beetles (*Holcobius* spp.). Plagithmysines are diurnal while some Anobiids are nocturnal. Both are primary decomposers of dead forest trees.

Long-horned Cerambycid beetles in the endemic genus *Plagithmysus* have evolved to fill a variety of niches in Hawaii. At least 136 species and subspecies are currently recognized and all members of this complex group evolved from a single immigrant ancestor. These beetles are seldom seen and many species are considered rare (Samuelson and Gressitt, 1981). The island of Hawaii supports 46 species, the greatest number known from any island. Adult Plagithmysines oviposit their eggs on the branches and stems of dead or dying woody plants. The larvae hatch and bore under the bark to feed, leaving distinctive trails in the wood. At maturity, they excavate a cell (usually in the heartwood) and remain there to pupate. Emerging adult beetles bore through the bark to escape, leaving numerous exit holes in the dead tree. The five most important host plants for long-horned beetles are koa, alani, ʻohiʻa, mamane and mamake *(Pipturus albidus),* respectively (Gressitt, 1980). Larvae of Cerambycid beetles are a major source of food for forest birds, particularly the honeycreepers (Perkins, 1913).

At least twelve endemic species of *Plagithmysus* beetles are known from Puʻu Waʻawaʻa. The following ten species were collected from associated host plants by DOFAW staff in 1993:

Species	Hosts
1. *Plagithmysus debilis*	*Acacia koa*
2. *Plagithmysus nodifer*	*Acacia koa*
3. *Plagithmysus montgomeryi*	*Chamaesyce olowaluana*
4. *Plagithmysus blackburni*	*Sophora chrysophylla & Santalum paniculatum*
5. *Plagithmysus filipes*	*Sophora chrysophylla, Diospyros sandwicensis, Clermontia clermontioides, and Hibiscadelphus hualalaiensis*
6. *Plagithmysus darwinianus*	*Sophora chrysophylla and Sapindus saponaria*
7. *Plagithmysus davisi*	*Diospyros sandwicensis*
8. *Plagithmysus elegans (decorus)*	*Charpentiera obovata*
9. *Plagithmysus simplicicollis*	*Nothocestrum breviflorum*
10. *Plagithmysus perkinsi*	*Myoporum sandwicense*

Plagithmysus blackburni and *P. filipes* were the most abundant and widespread species at Puʻu Waʻawaʻa. Both were reared from wood of several different native trees, but sandalwood was a new host record for *P. blackburni. P. elegans* and *P. simplicicollis* are considered rare by the USFWS (SOC). *P. elegans* is only found on papala, a species that is almost extirpated at Puʻu Waʻawaʻa. The natural host plant for *P. simplicicollis* was not known until 1995 when DOFAW personnel reared this species from dying wood of the endangered ʻaiea tree. Only 13 individuals were collected. These rare beetles were taken at Puʻu Waʻawaʻa between 3,400 and 3,750 feet elevation in mesic forest habitat. Two endemic long-horned beetles were historically collected at Puʻu Waʻawaʻa, but have not been seen in recent years. These are *P. bishopi* from alani (*Pelea* spp.) and *P. mezoneuri* from uhiuhi (Swezey, 1946). Both species are considered rare.

Non-native long-horned beetles attack several species of endemic trees at Puʻu Waʻawaʻa. These introduced Cerambycids have been reared from the wood of ʻohiʻa, papala, akoko and kauila. Beetle species found on the respective trees were *Phoracantha semipunctata*, *Sybra alternans, Lagocheirus undatus* and *Curtomerus flavus*. ʻOhiʻa is a new host record for *Phoracantha semipunctata*. This beetle generally associates with *Eucalyptus* trees which are in the same family as ʻohiʻa (Myrtaceae). Some native trees are probably killed by exotic wood boring beetles.

The endemic beetle genus *Rhynchogonus* is represented by a single species (*R. giffardi*) on the Island of Hawaii. This rare weevil was originally described from specimens collected at Puʻu Waʻawaʻa by Giffard (1918 & 1919). It was found on koa. In 1937, specimens were also found on an *Osmanthus* tree in the crater of Puʻu Waʻawaʻa cone (A. Asquith, personal communication). Today, the beetle's range is restricted to a short section of dry gulch in the Waikii area with a known range of no more than one acre in size (Howarth, personal communication).

Diptera: Pomace flies (Drosophilidae) represent one of the most spectacular examples of adaptive radiation known in any group of animals. It is estimated that as many as 1,000 species exist in Hawaii. At least 111 of these comprise the picture-winged group (Kaneshiro et al.,

1995). This interesting group consists of large-bodied flies that have striking maculations on otherwise clear wings.

At least nine picture-winged species have been collected at Pu‘u Wa‘awa‘a since 1969. The most recent surveys were conducted in the PWWFBS (4,200 to 5,500 feet elevation) in February, March, and April 2002. David Foote and Jon Giffin collected five picture-winged species at sponge-baits. These included *D. hawaiiensis, D. silvestris, D. formella, D. murphyi,* and *D. sproati*. All picture-winged species were found to be uncommon and their range appears to have contracted since 1969. Our limited surveys indicate that picture-winged flies are restricted to forests between 4,500 and 5,100 feet elevation. *D. hawaiiensis* was the most widespread species, but was not common anywhere. D. silvestris was the most uncommon species with only 2 individuals observed (one collected), both at 5,100 feet elevation. Fly species diversity was greatest along the western boundary of the PWWFBS where remnant stands of ‘olapa (*Cheirodendron trigynum)* and oha wai (*Clermontia clermontoides)* still exist. Both host plants were uncommon and localized.

At least one fly species at Pu‘u Wa‘awa‘a is considered rare by the USFWS. *D. heteroneura* was proposed for endangered status on January 17, 2001, but the listing is still pending. This species was last collected near Halepiula rain shed (4,300 ft. elevation) in 1969 (K. Kaneshiro, personal communication). *D. heteroneura* is known to breed in the bark and stems of *Clermontia, Cheirodendron,* and *Delissea undulata.* All three of these plants currently occur in the PWWFBS. However, they are widely scattered and are being adversely impacted by slugs, rats, non-native insects, feral ungulates, and competition from invasive weeds.

Drosophila rearing records are available for five picture-winged species at Pu‘u Wa‘awa‘a. Flies have been reared from the following plants: *D. ciliaticrus, Dracaena* stem; *D. hawaiiensis, Myoporum* and *Myrsine lessertiana* sap fluxes; *D. murphyi, Cheirodendron* bark; *D. setosifrons, Cheirodendron trigynum* bark; and *D. silvarentis, Myoporum* sap flux (Montgomery, 1975).

Heteroptera: Pu‘u Wa‘awa‘a supports a great number of heteropteran species. Unusually large species complexes occur in Lygaeidae (*Neseis* & *Nysius*) and Miridae (*Orthotylus* & *Sarona*). Several rare bugs are found on rare host plants. These include *Orthotylus xylosmae* (new species) on *Xylosma hawaiiense, Sarona* sp. on *Phyllostegia velutina*, *Sulamita* nr. *dryas* on *Claoxylon sandwicense*, and *Oechalia* spp. on various hosts.

Koa bugs are the largest and most conspicuous Hawaiian members of the true bug family (Scutelleridae). Nymphs are often found clustered on koa seed pods and adults fly from the green foliage when disturbed. Specimens of both the green and red color morphs have been collected at Pu‘u Wa‘awa‘a on koa trees between 3,800 and 5,100 feet elevation. These endemic bugs are considered rare (SOC) and are disappearing at an alarming rate. Parasitism by biological agents introduced to control the southern green stink bug is thought to be the major cause of their decline (Howarth, 1990).

Endemic stink bugs in the family Pentatomidae are rarely observed at Pu‘u Wa‘awa‘a. Only two individuals have been collected in the past 10 years. *Oechalia virgula* is the only species identified to date. This bug is notable in that the male holotype was collected at Pu‘u Wa‘awa‘a (3,700 ft.) in August 1917 (Van Duzee, 1936). The species has been recorded on various hosts including koa, ‘a‘ali‘i, and naio (Swezey, 1954).

Homoptera: Pu‘u Wa‘awa‘a has a particularly well-developed homopterous fauna. Groups represented by endemic species are leafhoppers (Cicadellidae: *Nesophrosyne*), cixiid planthoppers (Cixiidae: *Oliarus*), and delphacid planthoppers (Delphacidae: *Aloha*, *Nesosydne* and *Nesothoe*). Cixiid planthoppers are one of the most common forest insects. Nymphs are light in color and lack wings. They live in the soil, feeding on the sap of plant roots. Adults have large compound eyes, long wings and dark pigmentation. They commonly inhabit trees, feeding on the leaves of a wide variety of species including koa, ‘ohi‘a, naio, sandalwood and akoko. A few species of planthoppers are obligate cave dwellers that are restricted to dark, underground habitats.

Hymenoptera: This import group of endemic insects includes yellow-faced bees (Colletidae), ichneumon wasps (Ichneuonidae), square-headed wasps (Specidae), and potter wasps (Vespidae). Yellow-faced bee (*Hylaeus* sp.) diversity is exceptional at Pu‘u Wa‘awa‘a with 15 species identified to date. This number is more than half of the total species (28) known from the big island. At least six Pu‘u Wa‘awa‘a bees are listed as Species of Concern by the USFWS (November, 1999). However, this listing does not reflect the true status of *Hyaleus*. The rarest species at Pu‘u Wa‘awa‘a are *H. paradoxicus, H. hula, H. dimidiatus, H. filicum*, and a new species, *H. akoko* (K. Magnacca, personal communication). Females of *H. paradoxicus* are the largest Hawaiian species and can be easily identified by their mahogany red abdomen. *H. akoko* is only known from Pu‘u Wa‘awa‘a (Daly and Magnacca, 2003).

Akoko is an important host plant for native bees and wasps. When flowering, this tree can support great diversity of hymenopterian species. For example, nine species of yellow-faced bees and two species of native potter wasps (*Odynerus* spp.) were collected by K. Magnacca from a single akoko tree at Shangri-la (4,300 feet elevation) on August 1, 2002. Native bees also forage on several other community-dominant plants at Pu‘u Wa‘awa‘a including ‘ohi‘a, koa, olapa, naio, mamane, pukiawe, a‘ali‘i, and rare species like poola.

The most serious threat to Pu‘u Wa‘awa‘a’s native bees, other than habitat loss, is the introduced honey bee (*Apis mellifera*). These highly social bees aggressively displace native bees (Staples and Cowie, 2001) and compete with them for nectar and pollen resources (Daly and Magnacca, 2003). DLNR’s practice of issuing right-of-entry permits for commercial bee keeping (colony sites) in native forests is detrimental to yellow-faced bee populations. Commercial hives should be prohibited from any area where native bee protection is an objective.

Lepidoptera: At least 15 species of butterflies are found in Hawaii, but only two of these, the Kamehameha (*Vanessa tameamea*) and Blackburn (*Udara blackburni*) butterflies are native. These are members of the brushfooted (Nymphalidae) and a gossamer-winged (Lycaenidae) butterfly families, respectively. Both are common in the forest bird sanctuary, usually above

5,000 feet elevation. Mamaki is the preferred host plant for the Kamehameha butterfly while koa and aʻaliʻi are favored by Blackburn's butterfly. The largest and most showy non-native butterfly at Puʻu Waʻawaʻa is the monarch (*Danaus plexippus*). This species is extremely abundant, breeding and feeding on balloon plants (*Gomphocarpus physocarpus*), an introduced milkweed. Monarchs are migratory on the U.S. mainland, but are year-round residents in Hawaii.

The small number of endemic butterfly species in Hawaii contrasts sharply with the great species diversity of moths. This latter group is represented by almost 1,000 species in 17 families (Howarth and Mull, 1992). At Puʻu Waʻawaʻa, over 100 species of moths in 12 families have been collected and identified to date. Native species account for almost half of these taxa. Flight seasons of adult native moths at Puʻu Waʻawaʻa appeared to reflect plant phenology. Numerical and species abundance increased as mamane and ʻohiʻa flowers bloomed. The greatest numbers of moths were captured at traps during March and April, while August, September and October were usually poor trapping months.

Many endemic moths have narrow habitat requirements and are vulnerable to habitat disturbances. Larvae of some feed exclusively on the leaves, seeds pollen and wood of native plants. They often restrict their activities to a single plant species and, therefore, associate with specific forest types. Certain species of native Hawaiian cutworm, moths in the Noctuid genera *Agrotis* and *Peridroma* would be good indicator organisms for monitoring the changes and/or regeneration progress in Hawaiian forests (Howarth, 1990). Caterpillars of moths are important food items for many native forest birds.

Three major groups of Hawaiian moths were recognized by Zimmerman (1958a, 1958b & 1978). They are macrolepidoptera, pyraloidea and microlepidoptera. These groupings are based somewhat on size, but also on certain morphological characteristics. Macrolepidopterans are generally large moths, pyralids are medium to small sized moths and microlepidopterans are smaller to minute species. However, not all microlepidoptera species are small. A *Thryocopa* moth reared from *Clermontia* wood collected at Puʻu Waʻawaʻa has a wing span of 40 mm.

Macrolepidoptera species generally dominate the Puʻu Waʻawaʻa moth fauna. This group is represented by genera in the families Geometridae or measuring worm moths (*Eupithecia* and *Scotorythra*), Noctuidae or owlet moths (*Agrotis, Anomis, Haliophyle, Hypocala, Peridroma, Schrankia*) and Sphingidae or hawk moths (*Manduca* and *Hyles*). Moths in this group are generally conspicuous and some of the easiest to identify.

Native pyralids identified at Puʻu Waʻawaʻa all belong to the family Crambidae (*Eudonia, Mestolobes, Omiodes, Orthemecyna, Udea,* and *Uresiphita*). Many of these are common moths that are associated with native and introduced grasses.

Microlepidopterans are represented by genera in the families Carposinidae (*Carposina*), Cosmopterigidae (*Hyposmocoma*), Oecophoridae (*Thryocopa*) and Tortriacidae (*Cydia, Pararrhaptica, Spheterista*). This latter group is more difficult to identify and many specimens of tiny moths collected at Puʻu Waʻawaʻa await species determination.

Endemic moths in the genus *Eupithecia* are unique among Lepidoptera in that the larvae of some species are carnivorous and ambush their prey. These unusual inchworms obtain their food by perching erect and motionless on a leaf or twig. When an unsuspecting insects touches sensory bristles on the caterpillar's rump, it instantly lashes backwards to strike and seize the insect with its claws. The caterpillar returns to a straightened position to feed on its prey. Only live struggling arthropods are eaten, usually flies, crickets, cixiid leafhoppers and spiders (Montgomery, 1983). Carnivorous caterpillars identified as *Eupithecia craterias* were commonly collected in the forest bird sanctuary (5,100 to 5,500 feet elevation). Moths of the same species have also been drawn to light at the sanctuary cabin (4,000 feet). Larvae of *E. craterias* wait on various ferns to ambush their prey. Perches include hoio (*Diplazium sandwichianum*), lo‘ulu (*Coniogramme pilosa*), waimakanui (*Pteris excelsa*) and palapalai (*Microlepia strigosa*). Two other small moths in the genus *Eupithecia* are also present in the sanctuary. One of these, *E. staurophragma*, is notable because its larvae are also carnivorous ambush predators.

Some of the most impressive moths at Pu‘u Wa‘awa‘a are non-native species. The black witch (*Ascalapha odorata*) is notable because of it size. This species is said to be the largest moth in Hawaii with a wing expanse of over 4 inches. It often roosts in cave openings and can be mistaken for a bat while in flight. Several species of large, colorful sphinx or hawk moths have been captured at Pu‘u Wa‘awa‘a. These include the yam hawk month (*Theretra nessus*), sweet potato hornworm moth (*Agrius cingulata*) and white-lined sphinx (*Hyles lineata*). Sphingids resemble hummingbirds or large bees in flight because of their rapid wing beat.

A number of rare moths have been documented at Pu‘u Wa‘awa‘a. One of the rarest species on the Island of Hawaii is the red anomis noctuid (*Anomis vulpicolor*). This beautiful pink species is listed as a Species of Concern (SOC) and thought to be “possibly extinct” by the USFWS. A single individual was attracted to a mercury vapor light at the PWWFBS cabin on March 16, 2002. This species also occurs at Kau Forest Reserve, but in very low numbers. The larvae of red *Anomis* moths have been collected and reared from ‘ulei (*Osteomeles anthyllidifolis*) according to the literature (Meyrick, 1928). The black-veined A*grotis* (*Agrotis melanoneura*) is considered rare by the USFWS (SOC). However, this species is known to have a wide distribution on the big island and is sometimes locally common in the forest bird sanctuary. Its host plant is unknown. The endemic underwing moth (*Hypocala velans*) was thought to be extinct until a single specimen was collected at Pu‘u Wa‘awa‘a in April 1995. Two others have been collected since then. The host plant for *H. velans* caterpillars is Hawaiian ebony or lama. Adults of this species were known to roost in caves.

A geometrid moth species belonging to the endemic genus *Progonostola* was collected at the sanctuary cabin in 1995 (4,000 ft. elevation). Two specimens were taken, one in April and another in May. This moth is an extremely rare insect. Frank Howarth, entomologist with Bishop Museum, indicated (personal communication) that only three specimens of *Progonostola* were collected on the Island of Hawaii prior to 1999.

Blackburn’s sphinx moth (*Manduca blackburni)* was considered to be extirpated on the Big Island until recently. In December 1998, this species was rediscovered in the dry forest at Pu‘u Wa‘awa‘a (1,800 ft. elevation) by two professional photographers. They photographed a

few immature caterpillars feeding on two trees - an introduced Argentinean tree tobacco (*Nicotiana glauca*) and the endangered ʻaiea. Both trees are in the nightshade family. A few years latter (February 18, 2001) an adult moth in excellent condition was captured at the PWWFBS cabin (4,000 ft. elevation). This individual was attracted to a light trap at 8:10 pm. It was photographed and released. On May 22, 2002, a DOFAW botanist found several mature caterpillars feeding on five-year old outplanted ʻaiea trees in the forest bird sanctuary. This sighting is significant as it is the first record of *Manduca* reproducing on outplanted ʻaiea. No detailed information is available on the current distribution or abundance of *Manduca*. It appears, however, that numbers have increase in the past few years due to the recent invasion of tree tobacco, a favored food plant. *Manduca blackburni* was listed as endangered by the USFWS on February 1, 2000.

Neuroptera: These predaceous, and highly attractive insects are represented by endemic lacewings (Chrysopidae and Hemerobiidae) and antlions (Myrmeleontidae). The large green lacewings (*Anomalochrysa* spp.) are fairly common in wetter sections of the forest. Smaller, brown lacewings (*Micromus* spp.) are less common, and prefer dryer habitats above and below the koa belt. The rarest (SOC) and most unusual lacewing at Puʻu Waʻawaʻa is a flightless hemerobiid (*Micromus usingeri*). It inhabits the subalpine zone, in the vicinity of Kileo cone. Only two specimens have been collected in recent years (Maurice & Catherine Tauber, personal communication). The antlion (*Distolen wilsoni*) is uncommon, and appears to be restricted to the dry forest zone. Specimen have been collected between the 1859 lava flow and Kileo cone road (4,000-4,400 feet elevation).

Odonata: Endemic Hawaiian dragonflies or pinao are distributed from coastal wetlands to mountain forests. One species (*Anax strenuus*) has the distinction of being Hawaii's largest native insect. It is also the largest dragonfly in North America with a wingspan of up to six inches. Nymphs of *A. strennus* were collected at Puʻu Waʻawaʻa from a small reservoir in Poohohoo crater (3,860 ft. elevation). Adults are often seen darting about the forest in search of prey. Native damselflies (*Megalagrion*) are generally common in Hawaiian forests, but they appear to be absent at Puʻu Waʻawaʻa. The lack of suitable habitat (streams and ponds) is probably the limiting factor.

Orthoptera: Hawaii has at least twice as many endemic cricket (Gryllidae) species as the U.S. mainland (Otte, 1994). Native crickets are placed in three basic subfamilies (Howarth and Mull, 1992): Oecanthinae or tree crickets (*Prognathogryllus*, *Leptogryllus* and *Thaumatogryllus*); Trigonidiinae or sword-tails *(Anaxipha, Prolaupala* and *Laupala*); and Nemobiinae or ground crickets (*Caconemobius*, and *Thetella*). Endemic tree and sword-tail crickets are abundant in wet forests on the western slope of Hualalai volcano, but are uncommon at Puʻu Waʻawaʻa. No terrestrial tree crickets and only one species of sword-tail cricket (*Laupala* sp.) have been found to date. However, at least three species of endemic crickets have adapted to life in Puʻu Waʻawaʻa lava tubes; a tree cricket (*Thaumatogryllus cavicola),* a ground cricket (*Caconemobius varius*), and the barren lava flow cricket (*Caconemobius fori).* The subterranean tree cricket apparently evolved from surface-dwelling ancestors that are no longer present.

Insect/Host Relationships

Pu‘u Wa‘awa‘a presents a remarkable mosaic of forest communities ranging from dry to mesic to wet, on diverse substrate types, and arrayed across an impressive elevation gradient. Although many of the natural communities are badly damaged due to past fires, grazing, and invasive species, the remnant plants within them still harbor viable and significant arthropod populations. Many of these 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 obvious.

Several native arthropod species at Pu‘u Wa‘awa‘a are facing local extirpation or extinction due to the loss of their host plants. Those insects most at risk and their associated host plants are as follows:

Species	Hosts
1. *Plagithmysus simplicicollis* & *Manduca blackburni*	‘aiea
2. *Plagithmysus davisi* & *Hypocala velans*	lama
3. *Drosophila heteroneura*	olapa, oha wai
4. *Plagithmysus elegans*	papala
5. *Plagithmysus mezoneuri*	uhiuhi
6. *Hylaeus* spp. & *Plagithmysus montgomeryi*	akoko
7. *Sarona* & *Nysius* spp.	na‘ena‘e (*Dubautia plantaginea*)
8. *Sulamita* nr. *dryas*	poola

Arthropod restoration efforts at Pu‘u Wa‘awa‘a should focus on the protection and outplanting of the associated host plant species. This is the best and most effective method for conserving the region’s rare entomofauna. Insect host plants should be outplanted in protected plots and interspersed among existing host plants. This will allow natural colonization of the new plants and prevent extirpation of target insects.

Cave Arthropods

Surface ecosystems are not the only terrestrial habitats utilized by invertebrates. Almost 50 species of cave arthropods have been discovered to date, with 26 species known from Hawaii Island (Howarth, 1991). Until recently, scientists thought that animals took millions of years to evolve into cave-adapted forms. In 1971, scientists were quite surprised when obligate cave insects and spiders were discovered in lava tubes on the Island of Hawaii. It is now believed that cave adaptation occurs in a relatively short time, less than 500,000 years (Howarth, 1991). Caves are high-stress environments for insects. Obligate cave species are adapted to perpetual darkness, high humidity, lack of important environmental cues, complex mazelike living space, stressful or even lethal gas mixtures, patchy food resources, barren rocky substrates, wet and slippery vertical surfaces and occasional flooding (Howarth, 1993).

Cave animals are fascinating because of their amazing evolutionary history and interesting morphological and behavioral adaptations to life underground. Cave biologists

generally classify this group into four ecological categories: troglobites, troglophiles, trogloxenes and accidentals. Troglobites have the highest degree of specialization for subterranean life. They are so highly modified that they cannot survive above ground. This group of arthropods is characterized by reduced pigment, small eyes (or none at all) elongate antennae and legs and flightlessness (Howarth, 1993). They live in the dark zone of lava tubes, feeding on bacteria, fungi, cave debris, plant roots, slimes and dead animals. Troglophiles are able to live in subterranean habitats, but are not especially modified for cave life. Members of the same species may also occur above-ground in damp habitats. Trogloxene species often occur in caves, but cannot complete their entire life cycle there. Accidentals are surface species that occasionally fall, wander or are washed into caves. These temporary visitors can only exist underground for a short period of time and often serve as food sources for other cave inhabitants.

The cavernicolous fauna of Puʻu Waʻawaʻa includes species in all four ecological groups (Appendix E). At least 11 troglobitic or obligate arthropod species have colonized Puʻu Waʻawaʻa's lava tubes. Cave moths (*Schrankia* sp.) are the most abundant and conspicuous group of insects. Their larvae feed on roots and other cave vegetation. Females of highly cave-adapted species are flightless while males are weak flyers (Howarth and Mull, 1992). Pale colored cave millipedes (*Nannolene* sp.) and centipedes (*Lithobius* sp.) are common on the walls and floors of many caves. Millipedes feed on plant material and fungi while centipedes are carnivorous. The non-native garden millipede (*Oxidus gracillis*) outnumbers the endemic forms at Puʻu Waʻawaʻa, but these are heavily preyed upon by a red and black reduviid bug (*Haematoloecha rubescens*). Other common cave invertebrates are small wingless springtails (Collembola), crickets (Gryllidae) and humpback flies (*Megaselia* sp.). Springtails graze extensively on fungi growing underground on rat droppings. Crickets are secretive in caves, but readily come to traps baited with blue cheese. Species captured to date include an underground tree cricket (*Thaumatogryllus cavicola*) and a ground cricket (*Caconemobius* sp.). These insects have reduced eyes, and pale colored exoskeletons. They are mute and flightless and live on roots that penetrate cave ceilings. Both species are considered rare by the USFWS (SOC). The barren lava flow cricket (*Caconemobius fori*) also occurs at lower elevations. This species has been collected in the entrance and interior of Barnabys Cave near the coast at Kiholo Bay (The Nature Conservancy, 1993). Some obligate cave species appear to be very rare at Puʻu Waʻawaʻa. These include two species of blind Cixiid planthoppers (*Oliarus* spp.), an eyeless thread-legged bug with raptorial fore legs (*Nesidiolestes* cf. *ana*), and a hunting spider (*Lycosa* sp.). The predatory thread-legged bug is known only from Yellow-jacket Cave and is considered rare by the USFWS (SOC). This species stalks it prey in piles of lava breakdown. Lycosid spiders are at the top of the food chain and are the largest arthropod predator in subterranean habitats at Puʻu Waʻawaʻa.

Cixiid planthoppers are probably the most wide-spread obligate cave species in Hawaii. These insects are smaller and less pigmented than their terrestrial congeners. They are also flightless and blind. Cave-adapted planthoppers complete their entire life cycle underground with nymphs and adults feeding on plant roots. These insects locate mates by transmitting species specific substrate-borne vibrations along plant roots (Hoch and Howarth, 1993). At least seven species of obligate cave planthoppers occur on the Island (H. Hoch, personal communication). In July 1995, two species were found in Puʻu Waʻawaʻa lava tubes. The

smallest species was identified as *Oliarus polyphemus*, a pale, eyeless, short-winged form that is also known from other caves on the Island of Hawaii. Most significant was the discovery of a new, undescribed *Oliarus* species that was sharing the same cave with *O. polyphemus*. This slightly larger, yellowish-brown species has intermediate length wings and vestigial eyes. It is similar in appearance to *O. lorettae*, a very rare and recently discovered species known only from a coastal cave at Kiholo Bay (The Nature Conservancy, 1993). The new planthopper was described as *Oliarus makaiki* in reference to its small eyes (Hoch and Howarth, 1999). Only six individuals were obtained during two collecting trips. Both species of cave-adapted planthoppers were found on ʻohiʻa tree roots that were growing along cave walls. Examination of the new planthopper's genitalia indicated that it is closely related to a surface species, *Oliarus koan*oa. This latter planthopper is common on trees and shrubs at Puʻu Waʻawaʻa. *Oliarus makaiki* may have evolved directly from *O. koanoa* or possibly they share a common ancestor (H. Hoch, personal communication). The presence of two obligate planthopper species in the same lava tube in unusual and has not been reported elsewhere (H. Hoch, personal communication). All species of cave-adapted planthoppers are considered rare at Puʻu Waʻawaʻa even though a considerable amount of apparently suitable habitat exists. *O. makaiki* is only known from a single cave at the present time (Yellow-jacket Cave, Henahena paddock, 4,000 feet elevation).

Hawaii has an exceptionally rich amphipod fauna, consisting of more than 30 endemic species (Howarth and Mull, 1992). Most of these crustaceans are aquatic, but two Orders (Amphipoda and Isopoda) have successfully colonized terrestrial habitats. In July 1995, a troglobitic species of amphipod was discovered at Puʻu Waʻawaʻa (Henahena paddock, 3,900 ft. elevation). Specimens were found on wet lava rocks in the dark zone of two different lava tubes. These slender-bodied, shrimp-like crustaceans lack eyes and are pure white in color. This new, un-described species (family Talitridae) is significant because endemic amphipods were not known from the Island of Hawaii until now. Additionally, only one species of cave-adapted amphipod (*Spelaeorchestia koloana*) was known prior to this discovery and that species was restricted to caves on the island of Kauai (Howarth and Mull, 1992). Two specimens of the Puʻu Waʻawaʻa cave amphipod were provided to Bishop Museum for identification and taxonomic classification. Results of this work are not available yet.

Troglophile species are poorly known at Puʻu Waʻawaʻa, but an interesting ground beetle was recently discovered in two different lava tubes. This new and undescribed reddish-brown carabid (*Mecyclothorax* n. sp.) has only been captured in caves, but shows little morphological adaptation for subterranean existence (F. Howarth, personal communication). Strangely, this flightless species can be readily collected in pit fall traps, but has never been observed underground by any collector.

Trogloxene insects at Puʻu Waʻawaʻa include a second species of humpbacked fly (*Megaselia* sp.), pommace flies (*Drosophila* sp.), cixiid planthoppers (*Oliarus* sp.), springtails (Collembola), fungus gnats (*Tylparua* sp.), rove beetles (Staphylinidae), and a small linyphiid spider (*Meioneta* sp.). The spider is a new, undescribed species. Linyphiid spiders build finely woven horizontal sheet webs to capture prey.

Many epigean arthropods are accidental inhabitants of caves. Terrestrial planthopper are commonly found underground. These insects probably do not breed there and likely perish once they reach the adult stage. Nymphs and adults of surface planthoppers (*Oliarus koanoa*) were recently collected from caves at Puʻu Waʻawaʻa. Nymphs were found on roots and cave walls and also in wax cocoons attached to roots and lava rocks. Adults were perched on roots or lava rocks. This same species is abundant on ʻohiʻa, aʻaliʻi and naio trees growing above the caves.

VERTEBRATES

Birds

Hawaii's native avifauna originally consisted of more than 140 species of birds. At least 70 of these are now extinct and 30 more are endangered. Many of the endangered species are close to extinction. The progenitors of Hawaiian birds evolved and adapted to successfully occupy a variety of niches from mountain tops to coastlines. The Hawaiian honeycreepers, a group in the finch family (Fringillidae, subfamily Drepanidini), underwent extensive adaptive radiation producing more than 50 species with varied bill shapes and specialized food habits. Montane rain forests support the bulk of today's endemic bird life.

Avian Paleontology

Bones of extinct island animals have accumulated in lava tubes, sand dunes, limestone sinkholes, archeological middens, and crater lake beds since ancient times. These remains were often preserved in their original form with little or no chemical or physical alteration. Hawaiian fossil bones are not permineralized like traditional fossils and, therefore, are correctly called "subfossils" (S. Olson, 1991). Subfossil bird remains are valuable for a wide range of ecological and evolutionary studies. Recent advances in molecular biology offer exceptional opportunities for investigating the systematic relationships of animals by comparing ancient DNA from bones and tissue of preserved specimens with genetic material obtained from more modern forms (Cooper, 1993). Avian fossils also aid in the reconstruction of extinct bird species assemblages. They can reveal the natural distribution and range of living species and provide a sound biogeographic basis for the re-introduction and translocation of extirpated species.

Bird fossils are a very recent and unexpected source of information about Hawaii's natural history. Discoveries of extinct bird remains double the number of historically known species that inhabited the Hawaiian Islands. The first Hawaiian subfossil bird was discovered in 1926 at Pahala on the Island of Hawaii. It was buried 100 feet below the surface in a layer of volcanic ash. The remains consisted of some very fragmentary bones from a large, extinct terrestrial goose. This bird showed no close relationship to the modern nene and was named *Geochen rhuax* (Wetmore, 1943). Ash containing the fossil bones is now thought to between 9,000 and 10,500 years old (S. Olson, personal communication). Avian paleontology in Hawaii was inactive from the 1940's until the early 1970's when Joan Aidem uncovered deposits of subfossil bird bones in sand dunes on the Island of Molokai.

Few attempts have been made to search for fossil birds on the Island of Hawaii. Avian paleontologists assumed that there was little chance of finding preserved remains of birds on such a geologically young island. In July 1992 scientists were amazed when an intact skeleton of an extinct flightless goose was discovered (Giffin, 1992). The remains were found in a lava tube at Pu‘u Wa‘awa‘a, North Kona, on the Island of Hawaii. Subsequent surveys of Pu‘u Wa‘awa‘a lava tubes uncovered additional bones of flightless geese and remains of other extinct birds. Many of these species were new to science.

Subfossil bird deposits at Pu‘u Wa‘awa‘a were found in lava tubes that formed from 1,500 to 5,000 years ago. Lava tube skylights and sinkholes formed natural pitfalls where flightless and volant birds were trapped over the ages. Associated skeletons of birds were generally found lying exposed on the floor of lava tubes. Some caves contained bones that were buried in alluvial deposits or under rock piles. It is not known why birds entered lava tubes. Those species that roosted or nested in cave entrances probably fell into lava tubes or were chased into them by predators. Others may have taken shelter in caves during storms or fires. Being unable or unwilling to fly or walk out, they probably wandered into the darken passages, became lost, and died. In New Zealand, Worthy (1993) found that the shape of cave openings had a noticeable influence on the type of birds that were trapped. Bones of flightless species were predominant in passages with small, narrow entrances. The larger, wider and presumably more obvious entrances (greater than 10 m in diameter) captured more flighted species. Similar trends have been observed in Hawaiian caves.

Prehistoric Avifauna

Waterfowl: The Hawaiian goose or nene, Laysan duck (*Anas laysanensis*) and Hawaiian duck or koloa (*Anas wyvilliana*) are the only species of waterfowl historically known from the Hawaiian Islands. However, the fossil record reveals surprising evidence of a spectacular evolutionary diversification of endemic Hawaiian waterfowl (Anatidae). More than 12 species of this aquatic group are now known to have existed prior to European contact. Prehistoric waterfowl included giant flightless geese and ponderous duck-like birds. The latter group was recently named moa-nalos. These flightless birds were the dominant herbivores in Hawaii and apparently filled the ecological role of missing native ungulates. Flightless geese and ducks were apparently forest dwellers. These woods-walkers grazed and browsed on grasses and fern fronds. Givnish et al. (1994) proposed that lobelioid plants in the endemic genus *Cyanea* evolved prickles to protect stems and leaves from browsing by large extinct birds like flightless geese and moa-nalos. All flightless species are now extinct.

The most interesting of the prehistoric waterfowl were moa-nalos. One species from Kauai (*Chelychelynechen quassus*) had a thick bill resembling the jaws of a land tortoise. Others, (*Thambetochen* and *Ptaichen* spp.) exhibited heavy bills lined with tooth-like projections. *Thambetochen* is known from the islands of Maui, Molokai and Oahu while *Ptaichen* has only been found on Maui. Extinct nene-like geese are also known to have existed on the Islands of Kauai, Oahu and Maui. The Maui form was flightless (Olson and James, 1991).

Geese: The giant flightless goose discovered at Pu‘u Wa‘awa‘a is the largest terrestrial vertebrate ever found on the Island of Hawaii. This extinct bird (*Branta* n. sp.) was over twice the size of the modern nene (*Branta sandvicensis*). It had a massive skull, heavy body, stocky legs, and wings too small for sustained flight. This large terrestrial goose was apparently very common in mesic montane forests at Pu‘u Wa‘awa‘a. Remains of over 100 giant flightless geese have been found in lava tubes to date. Distributional range of the subfossils varied from 3,000 to 6,000 feet in elevation. Subfossil goose bones have also been found at a few other locations on the Big Island: Kailua-Kona, Kahua Ranch, Honomalino (4,000 ft. elevation) and Manuka Natural Area Reserve (2,500 ft. elevation).

Bones of flightless geese found at Pu‘u Wa‘awa‘a are somewhat larger than those of the older *Geochen rhuax*, but have similar morphology. Because no other large flightless waterfowl were known from the Island of Hawaii, it can be assumed that *G. rhuax* simply increased in size over the past 10,000 years and evolved into the giant flightless goose. The latter species is morphologically distinct from modern *Branta* species. Structural differences in the wing, leg and skull bones are especially noticeable. Recent DNA studies indicate that the Big Island flightless goose is related to subspecies in the large Canada goose complex (E. Paxinos, personal communication). Canada geese are regular winter migrants in the Hawaiian Islands.

In 1992, preserved bones of two flightless geese were collected for radiocarbon dating. Remains of one bird came from Umi‘i Manu Cave and the other from Delissea Cave. A femur and tibiotarsus were selected from each skeleton for the analysis. Samples were sent to Beta Analytic, Inc. (Miami, Florida) for ^{14}C dating using the AMS (Accelerator mass Spectrometry) technique. Bone samples from Umi‘i Manu Cave yielded a conventional ^{14}C date of 510 ± 60 years before present while those from Delissea cave yielded a conventional ^{14}C date of 900 ± 60 years before present (before present = radiocarbon years before 1950 A.D.). The error represents one standard deviation (68 % probability). Using the Stuiver and Reimer (1993) age calibration computer program (CALIB 4.8), the ^{14}C age corresponds to corrected nominal calendar dates of 1421 (1330 to 1440 AD) and 1160 AD, (1030 to 1220 AD), respectively. Goose skeletal material not destroyed by the carbon dating process was deposited at Bishop Museum to serve as voucher specimens. Accession numbers assigned to these bones were BPBM catalog #178860 and #178861.

Paxinos (1998) aged subfossil bones from three additional flightless geese collected from Pu‘u Wa‘awa‘a lava tubes. These samples provided radiocarbon dates of 510, 870, and 900 years before present. Based on these results, it appears that flightless geese survived until fairly recent times, possibly a few hundred years before the islands were visited by Captain Cook in 1778.

Ancient Hawaiians were certainly aware of flightless geese and probably hunted them for food. Bird catchers must have encountered these large birds while collecting feathers in the forest. In fact, fragments of bone from a flightless goose were recently recovered from archaeological middens on the Island of Hawaii (H. James, personal communication). Flightless geese were a conspicuous component of the native avifauna, yet surprisingly, no legends remain about them. These birds shared the same habitat as the o‘o (*Moho nobilis*), i‘iwi (*Vestiaria*

coccinea), and other species prized for their brilliant feathers. The only Hawaiian word known for native geese is nene. This generally refers to the historically known flighted species (*Branta sandvicensis*). It is interesting to note, however, that there is a place on Hualalai (5,080 feet elevation), not far from where flightless goose subfossils were found, that is called "nenenui". This literally means "large goose". Perhaps two species of geese were recognized by ancient Hawaiians, nene and nenenui.

Reasons for the extinction of flightless geese can only be surmised. Kirch (1982) determined that Hawaii's prehistoric human population increased rapidly after A.D. 1200 and reached a peak about A.D. 1650. Human food resources must have been greatly stressed during the latter period and large birds like flightless geese were probably severely exploited. This along with increased predation from introduced rats may have resulted in the rapid demise of giant flightless geese.

Ducks and Gallinules: The discovery of preserved duck (*Anas* sp.) and gallinule (*Gallinula* sp.) remains in Puʻu Waʻawaʻa lava tubes was another unexpected event. The former presence of waterbirds in well-drained upland mesic forests was surprising, especially since all subfossil sites were several miles upslope of coastal wetlands. Historically known wild ducks typically inhabit upland ponds and streams. However, Puʻu Waʻawaʻa's forests grow on porous ʻaʻa lava flows that are devoid of running surface water or standing pools. The normal habitat of gallinules includes freshwater ponds, marshes, irrigation ditches, reservoirs, taro patches and rice fields (Berger, 1972). Both species are known to feed on mollusks. I am unsure why waterbirds were utilizing wooded uplands at Puʻu Waʻawaʻa or what they were doing in lava tubes. Perhaps ducks and gallinule moved up from coastal wetlands to forage on endemic land snails. Terrestrial mollusks were apparently very abundant at Puʻu Waʻawaʻa in the past judging by the large numbers of preserved shells found in some lava tubes.

Subfossil duck bones taken from caves at Puʻu Waʻawaʻa were originally thought to be those of the modern koloa (*Anas wyvilliana*). However, they were smaller than that species and morphologically indistinguishable from bones of the Laysan duck (*Anas laysanensis*), an endangered species (S. Olson, personal communication). Recent genetic studies using polymerase chain reaction and ancient DNA confirm morphological findings. This work shows that subfossil duck bones are indeed those of the Laysan duck. Additionally, Laysan ducks were determined to be a distinct species with no close genetic relationship to koloa or mallards. DNA results also indicated that koloa and mallards are closely related to each other (Cooper et al., 1996). Based on subfossil collections and DNA studies, we now know that Laysan ducks were once widespread in the Hawaiian archipelago and occupied all main Hawaiian Islands. These small ducks were probably more terrestrial than koloa, nesting and foraging on the forest floor. Bones of a single juvenile bird, found at Puʻu Waʻawaʻa (4,500 ft. elevation) confirm breeding activity at that site. Subfossil distribution indicates that Laysan ducks ranged from 3,440 to 5,880 feet elevation at Puʻu Waʻawaʻa. Wild Laysan ducks are no longer present on any of the main Hawaiian Islands, but a small population still persists on Laysan Island.

Fossil and historic records reveal that Puʻu Waʻawaʻa supported at least four endemic species of upland waterfowl. These included two geese (flightless goose and nene) and two

ducks (Laysan duck and koloa). The Laysan duck discovery poses several interesting management possibilities. We have evidence that Laysan ducks previously inhabited the main Hawaiian Islands and that the duck population on Laysan Island is only a remnant of a once wide-spread species. These waterfowl were extirpated from part of their range by forces yet unknown. If limiting factors can be found and controlled, Laysan ducks are likely candidates for reintroduction into protected environments on the main islands.

Passerines: Preserved remains of perching birds were scarce at all Pu‘u Wa‘awa‘a sites, but were among the most significant discoveries in the fossil record. It is interesting to note that most species found were those of extinct species. Remains of present-day birds were seldom encountered in caves. ‘Elepaio (*Chasiempis sandwichensis*), ‘apapane and ‘oma’o bones were the exceptions. Subfossil bones of all three species were found in caves. ‘Elepaio and ‘apapane still inhabit upland forests at Pu‘u Wa‘awa‘a.

Hawaiian honeycreepers (Fringillidae: Drepanidini) were among the subfossil remains at Pu‘u Wa‘awa‘a. Three extinct species were identified: a long-billed ‘akialoa (*Hemignathus* n. sp.), a giant nukupu‘u (*Hemignathus n. sp.),* and a form of Hawaiian finch *(Telespiza n. sp.)* resembling the Laysan finch (*Telespiza cantans*). All three species were new to science and represent important evolutionary records for this interesting group of birds.

The long-billed akialoa was much larger and had a longer beak than its historically known relative (*Hemignathus obscurus*). Four specimens of this bird were found in Umi‘i Manu Cave in 1992 (between 4,600 and 4,800 feet elevation). Today, the collection site is an upland dry forest dominated by mamane, naio, and ‘ohi‘a trees.

Remains of an unusual honeycreeper was found below a skylight in Petrel Cave (Henahena paddock, 3,840 ft. elevation) on January 8, 1993 (BPBM 179437). This bird was identified by Helen James (personal communication) as a giant Nukupu‘u. The new nukupu‘u had a long, scimitar-like maxillary rostrum with a much shorter mandibular rostrum, giving the bird an unusual appearance. It was much larger than the historically known nukupu‘u (*Hemignathus lucidus*), being about the size of a myna bird (S. Olson, personal communication). This species is thought to be the largest drepanidine yet known. Only a single skeleton of the giant nukupu‘u has been found to date. Paleoecology evidence indicates that the giant nukupu‘u preferred forest habitat like its relatives. The lava flow that created Petrel Cave covered an ancient forest that was vegetated by tall, large diameter trees. This fact is confirmed by the presence of numerous tree molds in that flow. The original forest was inundated by younger lava approximately 1,500-3,000 years ago, burying all existing vegetation. Another forest apparently colonized the site before the giant nukupu‘u died in Petrel Cave, probably less than 900 years ago. This date assumes that the specimen is in the same age class as radiocarbon dated goose bones collected from another cave in the same vicinity. Today, the area supports a mesic forest dominated by mamane and ‘ohi‘a.

Hawaiian finch remains were discovered in two different lava tubes at Pu‘u Wa‘awa‘a. These individuals were the first Big Island records for this species. Remains of two birds were found, one at 760 ft. (Owl Cave) and the other at 4,600 ft. elevation (Umi‘i Manu Cave). Both

lava tubes are situated in a montane dry forest setting. One additional *Telespiza* specimen was subsequently discovered at Puu Nanaha on Mauna Kea (8,800 ft. elevation) in 1995. The fact that the last two sets of remains were observed at elevation is notable for the genus. Other *Telespiza* species are only known from sites near sea level (H. James, personal communication).

Honeyeaters (Meliphagidae) are another important group of endemic Hawaiian forest birds represented in the Pu‘u Wa‘awa‘a fossil record. Remains of these large, historically extinct birds were recovered from several lava tubes. Two species were identified, the kioea (*Chaetoptila angustipluma*) and the Hawaii ‘o‘o (*Moho nobilis*). Neither species was documented at Pu‘u Wa‘awa‘a by early naturalists. These discoveries provide important new distributional records for both species.

The Hawaiian thrush or ‘oma‘o had a much wider distribution in the past than it does today. This solitaire was extirpated from Hualalai in historic times, but is still abundant elsewhere on the Island of Hawaii. At Pu‘u Wa‘awa‘a, numerous ‘oma‘o skeletal remains were recovered from caves in lowland dry and upland mesic forests. Elevational range of subfossil sites ranged from 700 to 5,880 feet on Hualalai volcano. The occurrence of these bones in lava tubes is was not surprising since ‘oma‘o are known to regularly nest in cave entrances.

Endemic crows (*Corvus* spp.) were a major component of Pu‘u Wa‘awa‘a’s ancient avifauna. The ‘alala or Hawaiian crow (*Corvus hawaiiensis*) persisted in upland forests until 1991, but has since been extirpated. Bones of this bird were not found as subfossils, but remains of two other highly unusual corvids were discovered. The latter species are extinct and known only from the fossil record. One species had a long slender-bill adapted for probing. The other had a skull and beak modified for hammering on hard surfaces, perhaps like a woodpecker. Subfossil crow remains were found from 760-5,300 feet elevation and in various habitat types ranging from dry lowland to wet mesic forests.

Rails: Subfossil records indicate that flightless rails were one of the most ubiquitous species on the Island of Hawaii. Remains of these small birds have been found from sea level on Hualalai volcano to 8,800 feet elevation on Mauna Kea. At Pu‘u Wa‘awa‘a, they were apparently abundant in dry and mesic montane forests. Skeletal components of rails were commonly found in caves from 760 to 5,880 feet elevation. The former existence of at least three species is suggested based on differences in bone sizes. Size forms were classified as large, medium and tiny. The largest and smallest types were thought to be prehistorically extinct species while the other was probably the historically extinct moho or Hawaiian rail (*Porzana sandwichensis*).

Seabirds: Seabirds have suffered fewer extinctions than other groups of Hawaii birds. A small petrel (*Pterodroma jugabilis*) is the only seabird thought to be extinct. Fossil records indicate that many kinds of seabirds formerly concentrated and probably nested in the uplands of Pu‘u Wa‘awa‘a. Preserved bones of the following species have been collected from caves and identified to date: dark-rumped petrel, Bonin petrel (*Pterodroma hypoleuca*), band-rumped storm petrel (*Oceanodroma castro*), Bulwer's petrel (Bulweria bulwerii) and *Pterodroma jugabilis*. Associated skeletons of seabirds have been found in lava tubes from 500 to 6,000 feet elevation indicating that these birds formerly utilized both lowland and upland habitats. Most bones were

concentrated around lava tube openings such as skylights and sinkholes. Birds may have nested on ledges and in lava cracks near these openings. Seabirds no longer breed on Hualalai. Nesting colonies were probably wiped out after rats, cats and mongooses became established. Breeding colonies of dark-rumped petrel were recently found on the summit area of Mauna Loa, but reproduction of Bonin, band-rumped and Bulwer's petrel is restricted to other islands in the archipelago.

Historical Bird Records

Written historical accounts of birds at Puʻu Waʻawaʻa supplement paleontological evidence. The ʻakiapolaʻau (*Hemignathus munroi*) exists only on the Island of Hawaii, with the largest population centered on the windward side (Scott et al., 1986). This species was formerly abundant in Kona and inhabited mixed koa-mamane-naio forests. A single specimen was collected at Puʻu Waʻawaʻa by Wilson in 1887 or 1888 (Banko, 1979). The most recent ʻakiapolaʻau sighting on Hualalai was reported by van Riper (1973). He found a single individual on the western side of the mountain. Scott et al. (1986) attributed the absence of ʻakiapolaʻau in north Kona to isolated and insufficient habitat.

Banko (1981) noted that Brigham saw three mamo (*Drepanis pacifica*) in a sandalwood tree at about 7,000 feet elevation on Hualalai volcano in 1890. Second-hand accounts suggest that the mamo may have occurred at Puʻu Waʻawaʻa and persisted until recently. In 1960, the Puʻu Waʻawaʻa Ranch owner (no name given) told Hanson (1960) that he "saw the Mamo in the forested area behind his ranch. He says that he has seen it several times. As the area is accessible by horseback only, we were unable to check on it."

Billy Paris, former Puʻu Waʻawaʻa Ranch Foreman, claims (personal communication) that ʻoʻo were present on the ranch until the 1950's. He further noted that the last ʻoʻo was observed at Poohohoo in 1957 by his uncle Robson Hind. Upon questioning, Billy appeared to be familiar with the species. Subfossil evidence mentioned above lends further support to this claim.

Waterbirds were sometimes observed or collected in the past at Puʻu Waʻawaʻa. Lewin (1971) noted that koloa ducks were occasionally seen in the central portion of Puʻu Waʻawaʻa Ranch. Sightings of this species have not been confirmed by fossil records or other observations. Banko (1979) documented the collection of a single ʻAlae-ʻula or Hawaiian gallinule (*Gallinula chloropus sandvicensis*) from Kiholo Bay about 1887. This species is no longer present on the Island of Hawaii.

Based on the above records and paleontological evidence, we now know that at least 26 taxa of endemic birds existed at Puʻu Waʻawaʻa (Appendix F). This total does not include seabirds and migratory species. Unfortunately, 17 taxa or 65 percent of the endemic species, including all flightless forms, are now extinct or have been locally extirpated. These include representatives in the following families: Anatidae, Rallidae, Corvidae, Meliphagidae, Muscicapidae, and Fringillidae. Only nine species of endemic birds still persist at Puʻu Waʻawaʻa. Half of these are rare and threatened with extinction.

Current Avifauna

Birds are the primary form of native wildlife found Pu‘u Wa‘awa‘a today (Appendix G). The endemic species consist of five honeycreepers, one monarchine flycatcher, two raptors and a goose. The honeycreepers, listed in order of abundance are ‘amakihi (*Hemignathus virens*), ‘apapane, i‘iwi, Hawaii ‘akepa (*Loxops coccineus*), and Hawaii creeper (*Oreomystis mana*). Other native birds are the ‘elepaio, nene, i‘o or Hawaiian hawk (*Buteo solitarius*), and pueo or owl (*Asio flammeus sandwichensis*). The ‘alala or Hawaiian crow was formerly present, but is probably extirpated on Hualalai. Five of the native birds are considered endangered: the Hawaii ‘akepa, Hawaii creeper, Hawaiian goose (nene), Hawaiian hawk (i‘o), and the Hawaiian crow (‘alala).

Endangered Species

Nene: Nene sightings have been made at Pu‘u Wa‘awa‘a Ranch 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 ranch also served as an important breeding site. Nene nested in the Waihou and Halekula paddocks between 2,300 and 4,000 feet elevation. Nests were also reported above Halekula in 1941 and at Poohohoo hill in 1942 (Baldwin, 1945). Recent nene nests have been confined to the Pu‘u Anahulu ridge and homesteads area, from 1,600 to 2,300 feet in elevation.

A total 46 nene was known to be present at Pu‘u Wa‘awa‘a Ranch in April 1991. Birds were distributed from 1,600 to 3,200 feet in elevation. Movement studies of banded birds were conducted from 1991 to 1992. Results indicated that at least 13 different individuals were flying between Pu‘u Wa‘awa‘a and hill 6677 on the northern slope of Mauna Loa. This is a straight-line distance of approximately 23 miles. Nene probably fly across the military impact area at Pohakuloa when moving between these two locations. This travel route exposes them to air traffic, artillery fire and other military hazards.

A fresh water reservoir near ranch headquarters is the single most important habitat feature for nene at Pu‘u Wa‘awa‘a. This 5 million gallon impoundment, situated at 3,055 feet elevation, is supplied with water from a private well. Portions of the shoreline are planted in grass (about ½ acre). Almost all nene in the area fly to the reservoir morning and evening to drink water and graze along the shore. Thousands of introduced finches and a few native bats also utilize this water source. The reservoir is most intensively used by nene each spring, however. Almost all geese in the area take up residency there to undergo their annual molt. Birds are flightless during this six week period and use the reservoir to escape from predators or human intruders. Green grass growing along the shore is the primary food source at this time.

‘Alala: 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 Pu‘u Anahulu in North Kona around to Kilauea crater in the Ka‘u district. ‘Alala were formerly abundant at Pu‘u

Waʻawaʻa. They occupied several habitat types including lowland dry, montane mesic and subalpine forests. In the 1950's, several pairs were often seen together at Puʻu Waʻawaʻa Ranch headquarters (B. Paris, personal communication). ʻAlala nested near Halepiula (5,100 ft. 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 Puʻu Waʻawaʻa on March 14, 1991. This lone individual was foraging on the western boundary of the forest bird sanctuary at 5,350 feet elevation. The decline of wild ʻalala on Hualalai volcano was documented by Giffin (1983, 1987).

Iʻo: The endangered Hawk or iʻo is relatively common at Puʻu Waʻawaʻa. 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 iʻo breeding habitat at Puʻu Waʻawaʻa is restricted to a narrow band of dry montane forest near the lower boundary of the forest bird sanctuary. All but one of the 13 nests found to date was situated in this forest type. Nests have been observed from 3,140 to 4,600 feet in elevation and were constructed in kolea, ʻohiʻa or 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, ʻamakihi and pig remains. Baseline surveys of native raptor abundance were initiated in December 1993. Results of these investigations are available from the USFWS.

Hawaii ʻAkepa: Hawaii ʻakepa 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 ʻakepa 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 ʻakepa sightings at Puʻu Waʻawaʻa has been documented since 1978. A total of 64 detections were obtained. This information indicates that ʻakepa were most abundant between 4,600 and 5,600 feet elevation. The upper and lower limits of distributed ranged from 6,000 to 4,400 feet elevation.

Old growth koa/ʻohiʻa forests have been identified as essential habitat for Hawaii ʻakepa. Key habitat components in this vegetation type are ground ferns and other native vegetation. Field studies conducted at the Hakalau National Wildlife Refuge indicate that akepa are tree cavities nesters and that lack of tree cavities may be a limiting factor. Large diameter trees (over 26 inches DBH) are usually selected for nest construction (L. Freed, personal communication).

Hawaii Creeper. Hawaii creeper still exist on all major Hawaii Island volcanoes except Kohala Mountain. They are most common in mesic and wet forests above 4,900 feet elevation (Scott et al., 1986). These small green birds feed on insects, spiders and other invertebrates. Creepers glean arthropods from the trunk and larger branches of ʻohiʻa and koa trees. Both sexes are similar in coloration. In 1978, an estimated 220 creeper lived in the koa/ʻohiʻa forest on north Hualalai (Scott et al., 1986). The distribution of this species has been documented since 1978. A

total of 48 detections were obtained, all in the PWWFBS. Most birds were found between 4,900 and 5,800 feet in elevation. The upper and lower limits of distribution ranged from 6,300 to 4,000 feet elevation. At least 94 percent of the sightings occurred between 4,900 and 5,800 feet elevation (Figure 4).

Non-native Birds

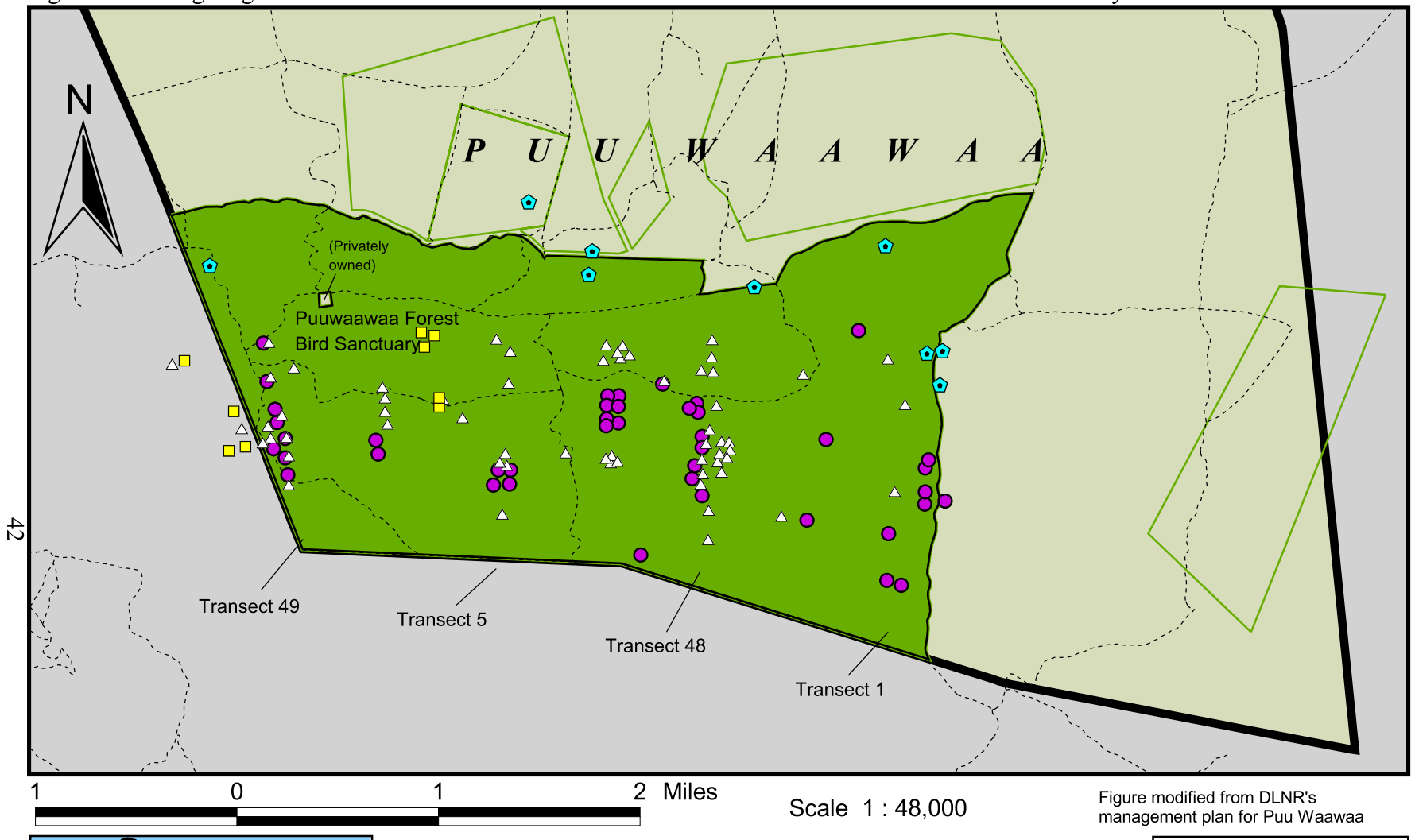
Game bird introductions were made many times at Puʻu Waʻawaʻa beginning in the late 1800's. An anonymous individual (1963) cited release dates for some species. They are as follows: California valley quail, prior to 1892; turkeys, 1890's; peacocks, 1908 or 1909 and again in the 1930's; guinea fowl, between 1910 and 1920; pheasants, including Japanese blue (*Phasianus colchicus versicolor*), Chinese (*Phasianus colchicus torquatus*) and Golden (*Chrysolophus pictus*), mid 1930's. Quail were said to be already present when the ranch began in 1892. Turkey introductions were credited to Robert Hind and Eben Low. It is believed that these birds were of domestic ancestry. Pheasants were thought to have been imported from a Territorial Game Farm on Oahu. Only the quail, turkey, peacock and probably the Chinese pheasant have persisted until the present time.

A second and more extensive game bird release program took place at Puʻu Waʻawaʻa Ranch from 1959 to 1972. At least 33 species of wild fowl were imported and liberated at that time (Lewin, 1971). Some of these became established and have spread throughout the island. Bird congregating units were constructed in conjunction with the release program. These fenced plots were provided with food and water to increase survival of released birds as well as those already established. Predator control activities including trapping and poisoning were carried out at each bird sanctuary. A review of helminths collected from Puʻu Waʻawaʻa game birds was reported by Lewin and Holmes (1971).

Many kinds of songbirds were imported, and propagated by the owners of Puʻu Waʻawaʻa Ranch. Aviaries for these birds were maintained near ranch headquarters by Mr. L. S. Dillingham. A former ranch employee, Mr. Sunchiro Yano (personal communication) indicated 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.

Few records could be found listing the species of songbirds escaped or released at Puʻu Waʻawaʻa Ranch. It is suspected, however, that the following were set free: yellow cardinal (*Gubernatrix cristata*), red-cheeked cordon-bleu (*Uraeginthus bengalus*), lavender waxbill (*Estrilda caerulescens*), saffron finch (*Sicalis flaveola*), warbling silverbill (*Lonchura malabarica*), and yellow-fronted canary (*Serinus mozambicus*). Many of these plus other exotic songbirds have become established. The most abundant non-native species in the forest bird sanctuary are Japanese white-eye, house finch, northern cardinal and red-billed leiothrix, respectively.

Figure 4. Field sightings and nest observations for selected native birds in the Puu Waawaa Forest Bird Sanctuary.



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 forest bird sanctuary at 5,200 feet 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, Personal communication). Up to 13 burrowing parrots (*Cyanoliseus patagonus*) have also been observed at Halepiula rain shed. The distribution and abundance of birds in the PWWFBS was summarized by Giffin (1990, 1991).

Native Mammals

The ‘ope‘ape‘a or Hawaiian hoary bat (*Lasiurus cinereus semotus*) is Hawaii's only native land mammal. This animal was originally considered to be a distinct species, but is now classified as a subspecies of the American mainland hoary bat (Tomich, 1986). The Hawaiian bat is officially listed as an endangered species by the USFWS. Local bats appear to prefer coastal areas for feeding and roosting, but they are not uncommon in upland forests. Trees are generally chosen as roost sites, but a few bats have been found in caves.

Small numbers of bats (1-3 individuals) are frequently observed at Pu‘u Wa‘awa‘a and particularly in the forest bird sanctuary. Recent sightings were made at the sanctuary cabin (4,000 ft. elevation) and above Poohohoo hill (4,250 ft. elevation). Both of these animals were actively feeding on flying insects. Bats have also been observed to the east, west and below the PWWFBS at 4,500, 4,600, and 3,055 ft. elevations, respectively. Bats can be seen at Pu‘u Wa‘awa‘a almost any time of year, but are most commonly encountered in August. No roost sites have been located to date, but bats are frequently seen emerging from the sanctuary forest at dusk. Evidence of cave use has also been documented at Pu‘u Wa‘awa‘a. On April 11, 1994, Helen James, a Smithsonian Institution Zoologist, accidentally flushed a single bat from it roost inside Delissea Cave (4,500 feet elevation). Additional surveys are needed to document the abundance and distribution of these rare animals.

Fossil records indicate that a smaller, undescribed bat species formerly inhabited Pu‘u Wa‘awa‘a. Remains of two individuals have been collected in Umi‘i Manu Cave (4,400 and 6,200 ft. elevations), one in 1993 and another in 2000. This new fossil bat is thought to be an extinct Vespertilionidae species (H. James, personal communication). Nothing is known about its distribution or habits.

Non-native Mammals

Three species of exotic game mammals inhabit the Pu‘u Wa‘awa‘a region: feral sheep (*Ovis aries*), feral goats (*Capra hircus*) and feral pigs (*Sus scrofa*). Feral sheep are most abundant in upland forests, primarily above highway 190. Feral goats occur throughout Pu‘u Wa‘awa‘a, but are most abundant at lower elevations, generally below highway 190. Prior to 1922, an estimated 21,000 wild goats was present on Pu‘u Wa‘awa‘a Ranch. The territorial

government assisted Pu‘u Wa‘awa‘a Ranch with goat drives from 1922 to 1926. Over 7,000 goats were driven from the uplands to Kiholo Bay and killed over a two-day period in 1922 (Judd, 1922). Feral pigs are widely distributed, but most abundant in wetter, dense forest regions. No population estimates are available for feral animal herds. All three species are potentially detrimental to native forest ecosystems.

Exotic non-game animals present at Pu‘u Wa‘awa‘a are the small Indian mongoose (*Herpestes auropunctatus*), Polynesian rat (*Rattus exulans*), roof rat (*Rattus rattus*), house mouse (*Mus domesticus*), feral cats, and wild dogs. All of these are also considered detrimental to native ecosystems.

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REFERENCES

Anon. 1903. Hawaiian Investigation, Part 3, Page 1,332 (source: Kona Historical Society).

Anon. 1963. Imported Birds of Pu‘u Wa‘awa‘a. Unpublished handwritten report by a Pu‘u Wa‘awa‘a Ranch employee. 22pp.

Baker, G.E. and R.D. Goos. 1980. Endemism and Evolution in the Hawaiian Biota: Fungi. in: E.A. Kay (ed.), A Natural History of the Hawaiian Islands. Univ. Press of Hawaii.

Baldwin, Paul H. 1945. The Hawaiian Goose, its Distribution and Reduction in Numbers. The Condor 47(1):27-37.

Banko, W.E. 1979. History of Endemic Hawaiian Birds Specimens in Museum Collections. CPSU/UH Avian History Report 2. Univ. of Hawaii. Dept. of Botany. Honolulu.

Banko, W.E. 1981. History of Endemic Hawaiian Birds. Part I. Population Histories--Species Accounts. Forest Birds: *Vestiaria coccinea, Drepanis funerea, Drepanis pacifica*. CPSU/UH Avian History Report 11 A & B. Univ. of Hawaii. Dept. of Botany. Honolulu.

Berger, Andrew J. 1972. Hawaiian Birdlife. The University Press of Hawaii, Honolulu.

Clague, D.A. and G.B. Dalrymple. 1987. The Hawaiian-Emperor Volcanic Chain, Part 1, Geologic Evolution. pp. 5-54 In: R.W. Decker, T.L. Wright and P.H. Staufefer (Eds.), Volcanism in Hawaii. U.S. Geol. Surv. Prof. Pap. 1350. Washington, D.C.

Cooper, A. 1993. Unknown Title. Pages 149-165 in B. Herrmann and S. Hummel (Eds.), Ancient DNA. Springer Verlag. New York.

Cooper, A., J. Rhymer, H.F. James, S.L. Olson, C.E. McIntosh, M.D. Sorenson and R.C. Fleischer. 1996. Ancient DNA and Island Endemics [*Anas Laysanensis* in the Main Hawaiian Islands]. Nature 381:484.

Cowie, R.H., G.M. Nishida, Y. Basset and S.M. Gon, III. 1995a. Patterns of Land Snail Distribution in a Montane Habitat on the Island of Hawaii. Malacologia, 36(1-2): 155-169.

Cowie, R.H., N.L. Evenhuis and C.C. Christensen. 1995b. Catalog of the Native Land and Freshwater Molluscs of the Hawaiian Islands. Backhuys Publishers, Leiden. 248 pp.

Daly, H. V. and K. N. Magnacca. 2003. Insects of Hawaii. Vol. 17. Hawaiian Hylaeus (Nesoprosopis) bees (Hymenoptera: Apoidea). University of Hawaii Press. Honolulu.

Division of Water Resource Management. 1991. Monthly and annual Rainfall Summary of the Hawaiian Islands. Unpublished Data. Department of Land and Natural Resources, State of Hawaii.

Edmondson, C.H. 1962. Hawaiian Crustacea: Goneplacidae, Pinnotheridae,Cymopoliidae, Ocypodidae, and Gecarcinidae. Occasional Papers of B.P. Bishop Mus. Vol. XXIII, No. 1. 17 pp.

Giffin, J.G. 1983. Alala Investigation. Hawaii Dept. of Land and Natural Resources, Div.of Forestry and Wildlife. Honolulu. 50 pp.

Giffin, J.G., J.M. Scott and S. Mountainspring. 1987. Habitat Selection and Management of the Hawaiian Crow. J. Wildl. Manage. 51(2):485-494.

Giffin, J.G. 1990. Limited Surveys of Forest Birds and Their Habitats in the State of Hawaii. Pu‘u Wa‘awa‘a Wildlife. Sanctuary Bird Survey. Pittman-Robertson Project W-18-R-15, Study R-II. Hawaii Dept. of Land & Nat. Res., Honolulu. 8pp.

Giffin, J.G. 1991. Limited Surveys of Forest Birds and Their Habitats in the State of Hawaii. Pu‘u Wa‘awa‘a Wildlife Sanctuary Bird Survey. Pittman-Robertson Project W-18-R-16, Study R-II. Hawaii Dept. Land & Nat. Res., Honolulu. 10pp.

Giffin, J.G. 1992. New Species of Fossil Birds Found at Pu‘u Wa‘awa‘a, Island of Hawaii. Elepaio. 53(1):1-3.

Giffard, W.M. 1918. Notes on Delphacids Collected on a Short Visit to Portions of the Intermediate Forest in Olaa and in North and South Kona, Island of Hawaii. Proc. Haw. Ent. Soc. III(5):407-412.

Giffard, W.M. 1919. Miscellaneous Notes and Exhibits of Insects Collected at Pu‘u Wa‘awa‘a, North Kona, and Kilauea, Hawaii. Proc. Haw. Ent. Soc. IV(1):232-233.

Givnish, T.J., K.J. Sytsma, J.F. Smith and W.J. Hahn. 1994. Thorn-like Prickles and Heterophylly in *Cyanea*: Adaptions to Extinct Avian Browsers on Hawaii. Proceedings of the National Academy of Sciences, USA 91:2810-2814.

Gressitt, J.L. 1980. The Endemic Hawaiian Cerambycid Beetles. Proceedings Third Conf. in Nat. Sci., Hawaii Volcanoes Nat. Park. pp.139-142.

Hadfield, M.G. and S.E. Miller. 1989. Demographic Studies on Hawaii's Endangered Tree Snails: *Partulina proxima*. Pacific Science 43(1):1-16. Univ. of Hawaii Press.

Handy, E.S. and E.G. Handy. 1972. Native Planters in Old Hawaii: Their Life, Lore , and Environment. Bernice P. Bishop Museum Bull. 233. Bishop Museum Press, Honolulu, HI.

Hanson, C. 1960. Easter vacation Trip to Maui and Hawaii. Elepaio 20(12):87-88.

Henke, L.A. 1929. A Survey of Livestock of Hawaii. Univ. Hawaii Res. Publ. 5. 82pp.

Hitchcock, A.S. 1922. The Grasses of Hawaii. Memoirs of the Bernice Pauahi Bishop Museum. Vol. VIII, No. 3. Honolulu, Hawaii.

Hoch, H. and F.G. Howarth. 1993. Evolutionary Dynamics of Behavioral Divergence Among Populations of the Hawaiian Cave-dwelling Planthopper *Oliarus polyphemus* (Homoptera: Fulgoroidea: Cixiidae). Pacific Science 47(4):303-318. Univ. of Hawaii Press.

Hoch, H. and F.G. Howarth. 1999. Multiple Cave Invasions by Species of the Planthopper Genius *Oliarus* in Hawaii (Homoptera: Fulgoroidea: cixiidae). Zoo. J. Linnean Soc., 127:453-475. [Desc. of new cave adapted planthopper from Pu‘u Wa‘awa‘a]

Howarth, F.G. 1990. Hawaiian Terrestrial Arthropods: An Overview. Bishop Museum Occasional Papers. 30:4-26.

Howarth, F.G. 1991. Hawaiian Cave Faunas: Macroevolution on Young Islands. pp. 285-295 in: E.C. Dudley (Ed.). The Unity of Evolutionary Biology. Dioscorides Press, Portland Or. Vol. 1, 588 pp.

Howarth, F.G. 1993. High-Stress Subterranean Habitats and Evolutionary Change in Cave-Inhabiting Arthropods. The American Naturalist. 142, Supplement:65-77.

Howarth, F.G. and W.P. Mull. 1992. Hawaiian Insects and Their Kin. Univ. of Hawaii Press. 160 pp.

Judd, C.S. 1922. The Hawaiian Forester and Agriculturist. 19 (11): 244-248.

Kirch, P.V. 1982. The Impact of the Prehistoric Polynesians on the Hawaii Ecosystem. Pacific Science 36:1-14. Univ. of Hawaii Press.

Koebele, A. 1900. Report of Prof. Koebele on Destruction of Forest Trees, Hawaii. Report of Commissioner of Agriculture and Forestry, pp. 50-60.

Koebele, A. 1901. Hawaii's Forest Foes. Thrum's Hawaiian Annual. pp. 90-97.

Lewin, L.A. 1971. Exotic Game Birds of the Pu‘u Wa‘awa‘a Ranch, Hawaii. Jour. Wildl. Mgmt. 35(1):141-155.

Lewin, V. and J.C. Holmes. 1971. Helminths from the Exotic Game Birds of the Pu‘u Wa‘awa‘a Ranch, Hawaii. Pacific Science 25:372-381.

MacDonald, G.A. and A.T. Abbott. 1970. Volcanoes in the Sea: The Geology of Hawaii. Univ. of Hawaii Press, Honolulu.

McDougall, I. and D.A. Swanson. 1972. Potassium-argon Ages from the Hawi and Pololu Volcanic Series, Kohala Volcano, Hawaii. Bull. of the Geological Society of America 83:3731-3738

Meyrick, E. 1928. Some New Species of Hawaiian Lepidoptera. Proc. Hawaii. Entomol. Soc. 7(1): 91-104.

Mitchell, A.L. 1945. Memoranda of December 11, 1944 and April 20, 1945 Concerning Pu‘u Wa‘awa‘a Field Trips for Nene and Botanical Study. National Park Report. Unpublished.

Montgomery, S.L. 1975. Comparative Breeding Site Ecology and the Adaptive Radiation of Picture-winged Drosophila in Hawaii. Proc. Hawaii. Entomol. Soc. 23(1): 65-103.

Montgomery, S. 1983. Carnivorous Caterpillars: the Behavior, Biogeography and Conservation of *Eupithecia* (Lepidoptera: Geometridae) in the Hawaiian Islands. GeoJournal (7.6):549-556.

Moore, R.B., D.A. Clague, M.Rubin and W.A. Bohrson. 1987. Hualalai Volcano: A Preliminary Summary of Geologic, Petrologic, and Geophysical Data. Pages 571-585 in R.W. Decker, T.L. Wright, and P.H. Stauffer (eds.). Volcanism in Hawaii. U. S. Geological Survey Professional Paper; 1350. U.S. Gov. Printing Office. 2 vols.

Moore, R.B. and David A. Clague. 1991. Geologic Map of Hualalai Volcano, Hawaii. U.S. Dept. of the Interior. Misc. Investigations Series. Map I-2213 (sheets 1 & 2). U.S. Geological Survey.

Moore, J.G. and D.A. Clague. 1992. Volcano Growth and Evolution of the Island of Hawaii. Bull. of the Geological Society of America 104:1471-1484.

Olson, S.L. and H.F. James. 1991. Descriptions of Thirty-two New Species of Birds from the Hawaiian Islands: Part I.. Non-Passeriformes. Part II. Passeriformes. Ornithological Monographs No. 45. The American Ornithologists' Union. Washington, D.C.

Otte, D. 1994. The Crickets of Hawaii: Origin, Systematics and Evolution. The Orthopterists' Society. Philadelphia, Penn.

Paxinos, E.E. 1998. Prehistoric Anseriform Diversity in the Hawaiian Islands: A Molecular Perspective from the Analysis of Subfossil DNA. Unpublished PhD. Dissertation. Brown University, Providence, Rhode Island. 175pp.

Perkins, R.C.L. 1913. Introduction in David Sharp (ed). Fauna Hawaiiensis. Cambridge Univ. Press.

Peterson, D.W. and R.B. Moore. 1987. Geologic History and Evolution of Geologic Concepts, Island of Hawaii. Pages 149-186 in R.W. Decker, T.L. Wright, and P.H. Stauffer (eds.). Volcanism in Hawaii. U. S. Geological Survey Professional Paper; 1350. U.S. Gov. Printing Office. 2 vols.

Rock, J.F. 1912. Report of the Consulting Botanist. The Board of Commissioners of Agriculture and Forestry, Honolulu, Hawaii.

Rock, J.F. [1913] 1974. The Indigenous Trees of the Hawaiian Islands. Reprint, with Introduction by S. Carlquist and addenda by D.R. Herbst. Privately Pub.

Rock, J.F. 1919. A Monographic Study of the Hawaiian Species of the Tribe *Lobelioideae*, Family Campanulaceae. Memoirs Bishop Museum 7(2): 1-395.

Samuelson, G.A. and J.L. Gressit. 1981. Wood-boring Cerambycid Beetles. Pages 133-138 in Mueller-Dombois et al. (eds.). Island Ecosystems. Hutchinson Ross Pub. Co., Woods Hole, Mass.

Scott, M.J., S. Mountainspring, F.L. Ramsey and C.B. Kepler. 1986. Forest Bird Communities of the Hawaiian Islands: Their Dynamics, Ecology and Conservation. Studies in Avian Biology No. 9. Cooper Ornithological Society.

Solem, A. 1990. How Many Hawaiian Land Snails Species Are Left? and What We Can Do for Them. Bishop Museum Occasional Papers 30:27-40.

Staples, G.W. and R.H. Cowie (eds.). 2001. Hawaii's Invasive Species. Mutual Publishing and Bishop Museum Press.

Stuiver, M. and P.J. Reimer. 1993. Extended ^{14}C Data Base and Revised Calib 3.0 ^{14}C Age Calibration Program. Radiocarbon 35(1):215-230.

Swezey, Otto H. 1946. Some New Species of Cerambycidae from the Island of Hawaii (Coleoptera). Proc. Haw. Ent. Soc. Vol. XII, No. 3. pp. 621-623.

Swezey, Otto H. 1954. Forest Entomology in Hawaii. An Annotated Check-list of the Insect Faunas of the Various Components of the Hawaiian Forests. Bernice P. Bishop Museum Special Pub. 44. Honolulu Star-Bulletin.

Takeuchi, W. 1991. Botanical Survey of Pu‘u Wa‘awa‘a. Final Report. State of Hawaii. State of Hawaii. Division of Forestry and Wildlife. 32 pp.

The Nature Conservancy. 1992. Botanical Survey of Selected Portions of the Pu‘u Wa‘awa‘a Game Management and Lease Area, Island of Hawaii. State of Hawaii. Division of Forestry and Wildlife. 36 pp.

The Nature Conservancy. 1993. Biological Database & Reconnaissance Survey of the Coastal Lands of the Kiholo Bay Area, Island of Hawaii. State of Hawaii, Division of State Parks. 87 pp.

Tomich, P.Q. 1986. Mammals in Hawaii: A Synopsis and Notational Bibliography. Second Edition. Bishop Museum Press, Honolulu, Hawaii.

U.S.D.A. 1973. Soil Survey of Island of Hawaii, State of Hawaii. Map Sections 67 & 68. Soil Conservation Service in Cooperation with the Univ. of Hawaii, Agricultural Experiment Station. U. S. Government Printing Office.

van Duzee, E.P. 1936. A Report on Some Heteroptera from the Hawaiian Islands, with Descriptions of New Species. Proc. Haw. Ent. Soc. IX, No.2. April.

van Riper, C.III. 1973. Island of Hawaii Land Bird Distribution and Abundance. Elepaio 34:1-3.

Wagner, W.L., D.R. Herbst and S.H. Sohmer. 1990. Manual of the Flowering Plants of Hawaii. University of Hawaii Press and Bishop Museum Press. 1,853 pp.

Wagner, W.H. Jr. and F.S. Wagner. 1993. Revised Checklist of Hawaiian Pteridophytes. Unpublished.

Walker, G.P. 1990. Geology and Volcanology of the Hawaiian Islands. Pacific Science 44:315-347.

Warshauer, F.R. and J.D. Jacobi. 1982. Distribution and Status of *Vicia menziesii* Spreng. (Leguminosae): Hawaii's First Officially Listed Endangered Plant Species. Biological Conservation 23 111-126. Applied Science Publishers Ltd, England.

Wetmore, A. 1943. An Extinct Goose from the Island of Hawaii. Condor 45(4):146-148.

Worthy, T. 1993. Fossils of Honeycomb Hill. Museum of New Zealand Te Papa Tongarewa, Wellington. 56 pp.

Zimmerman, E.C. 1958a. Insects of Hawaii. Vol. 7, Macrolepidoptera. Univ. of Hawaii Press. Honolulu.

Zimmerman, E.C. 1958b. Insects of Hawaii. Vol. 8, Lepidoptera:Pyraloidea. Univ. of Hawaii Press. Honolulu.

Zimmerman, E.C. 1978. Insects of Hawaii. Volume 9, Microlepidoptera, Parts I & II. Univ. of Hawaii Press. Honolulu.

ADDITIONAL PU‘U WA‘AWA‘A REFERENCES

Blackmore, M. and P.M. Vitousek. 2000. Cattle Grazing, Forest Loss, and Fuel Loading in a Dry Forest Ecosystem at Pu‘u Wa‘awa‘a Ranch, Hawaii. Biotropica 32(4a): 626-632.

Carlquist, S. 1970. Hawaii A Natural History: Geology, Climate, Native Flora and Fauna Above the Shoreline. The Natural History Press, Garden City, New York. 463 pp.

Christensen, Carl C. 1983. Analysis of Land Snails. In: J.T. Clark and P.V. Kirch (Eds.), Archaeological Investigations of the Mudlane-Waimea-Kawaihae Road Corridor, Island of Hawaii. pp.449-471.

Fancy, S.G., J.T. Nelson, P. Harrity, J. Kuhn, M. Kuhn, C. Kuehler and J.G. Giffin. 2001. Reintroduction and Translocation of ‘Oma‘o: A Comparison of Methods. Studies in Avian Biology NO. 22:347-353

Judd, C.S. 1932. Botanical Bonanzas. Thrum's Hawaiian Annual.

Kelly, M. 1996. A Brief History of the Ahupua‘a of Pu‘uwa‘awa‘a and its Neighbors in North Kona, Island of Hawaii. Privately printed by Earl E. Bakken. 40pp.

Kuehler, C. et al. 2000. Development of Restoration Techniques for Hawaiian Thrushes: Collection of Wild Eggs, Artificial Incubation, Hand-rearing, Captive-breeding, and Re-introduction to the Wild. Zoo Biology 19:263-277.

Rock, J.F. 1911. Botanical Explorations, North Kona, Hawaii. Report of the Board of Commissioners of Agriculture and Forestry. pp. 71-88.

Rock, J.F. 1920. The Leguminous Plants of Hawaii: Being an Account of the Native, Introduced and Naturalized Trees, Shrubs, Vines and Herbs Belonging to the Family Leguminosae. Experiment Station of the Hawaiian Sugar Planters' Association. Honolulu, Hawaii. 234 pp.

Trujillo, E.E., C. Kadooka, V. Tanimoto, S. Bergfeld, G. Shishido, G. Kawakami. 2001. Effective Biomass Reduction of the Invasive Weed Species Banana Poka by Septoria Leaf Spot. Plant Dis. 85:357-361.

Zimmerman, E.C. 1948. Insects of Hawaii. Vol. 1, Introduction. Univ. of Hawaii Press. Honolulu.

APPENDIX A. NATIVE PLANTS OF PU‘U WA‘AWA‘A

Plants are listed in groups and then alphabetically by family, genus and species. Taxonomy follows the Manual of the Flowering Plants of Hawaii by Wagner et al. (1990) and Revised Checklist of Hawaiian Pteridophytes by Wagner and Wagner (1993).

STATUS CODES:
E = endangered species
S = species of concern
R = rare species with no formal listing
X = extirpated
I = indigenous
* = endemic

TAXON	COMMON NAME	STATUS
THALLOPHYTES (Algae, Fungi & Lichens)		
SPONGE MUSHROOMS (Morels)		
MORCHELLACEAE		
Morchella esculenta	common morel	I?
PORE FUNGI (Polypores)		
POLYPORACEAE		
Laetiporus sulphureus	sulphur shelf	I?
Trametes versicolor	turkey-tail fungi	I?
GILL FUNGI (Agarics)		
TRICHOLOMATACEAE		
Pleurotus cystidiosus	oyster mushrooms	I?
Marasmiellus spp.	pinwheel mushrooms	I?
BRYOPHYTES (Mosses & Liverworts)		
NECTARACEAE		
Homaliodendron flabellatum	moss	I?
MARCHANTIACEAE		
Dumortiera hirsuta	thallose liverwort	I?

TAXON	COMMON NAME	STATUS
PTERIDOPHYTES (Ferns & Fern Allies)		
ADIANTACEAE		
Coniogramme pilosa	loʻulu	*
Doryopteris decora		*
Pellaea ternifolia	lau-kahi, cliffbrake	I
Pteris cretica	owali	I
Pteris excelsa	waimakanui	I
Pteris irregularis		*
ASPLENIACEAE		
Asplenium adiantum-nigrum	iwaʻiwa	I
Asplenium contiguum		*
Asplenium cookii (A. polyodon)		*
Asplenium fragile		E*
Asplenium trichomanes	owali	I
Asplenium unilaterale	pamoho	I
Asplenium praemorsum		I
Diellia erecta		X*
BLECHNACEAE		
Sadleria cyatheoides	amaʻu	*
CYATHEACEAE		
Cibotium glaucum	hapuʻu	*
Pteridium decompositum		*
DENNSTAEDTIACEAE		
Hypolepis punctata ssp. hawaiiensis		*
Microlepia strigosa	palapalai	I
Pteridium decompositum (P. aquilinum)	kilau, bracken fern	*
DRYOPTERIDACEAE		
Athyrium microphyllum	ʻakolea	*
Athyrium sandwichianum		*
Cyrtomium caryotideum	kaʻapeʻape	I
Cyrtomium falcatum		?
Diplazium sandwichianum (Athyrium)	hoʻiʻo	*
Dryopteris fusco-atra		*
Dryopteris glabra	kilau	*
Dryopteris hawaiiensis		*
Dryopteris unidentata	ʻakole	*
Dryopteris wallichiana	laukahi	I
Elaphoglossum paleaceum (E.hirtum)	ʻekaha-ula	I
Elaphoglossum wawrae	ʻekaha-ula	*
Nothoperanema rubiginosa (Ctenitis rubiginosa)		*

TAXON	COMMON NAME	STATUS
DRYOPTERIDACEAE (continued)		
Polystichum hillebrandii		R*
Tectaria cicutaria ssp. *gaudichaudii*		*
GLEICHENIACEAE		
Dicranopteris linearis	uluhe	I
GRAMMITIDACEAE		
Grammitis hookeri		I
LINDSAEACEAE		
Sphenomeris chinensis	pala‘a	I
POLYPODIACEAE		
Lepisorus thunbergianus (Pleopeltis)	‘ekaha, akolea	I
Polypodium pellucidum	‘ae	*
PSILOTACEAE		
Psilotum nudum	moa	I
THELYPTERIDACEAE		
Pseudophegopteris keraudreniana	waimaka-nui	*
Thelypteris stegnogrammoides (Pneumatopteris sandwicensis)		*
SPERMATOPHYTES (Flowering Plants)		
MONOCOTYLEDONS		
AGAVACEAE (Agave Family)		
Pleomele hawaiiensis	halapepe	E*
CYPERACEAE (Sedge Family)		
Carex alligata	alligator sedge	*
Carex macloviana		I
Carex wahuensis		*
Gahnia gahniiformis		I
Mariscus fauriei		X*
Mariscus hillebrandii ssp. hillebrandii		*
Uncinia uncinata		I
IRIDACEAE (Iris Family)		
Sisyrinchium acre	mau‘u la‘ili	S*

TAXON	COMMON NAME	STATUS
JUNCACEAE (Rush Family)		
Luzula hawaiiensis	wood rush	*
LILIACEAE (Lily Family)		
Astelia menziesiana	pa‘iniu, kaluaha	*
PANDANACEAE (Screwpine Family)		
Freycinetia arborea	‘ie‘ie	IX
POACEAE (Grass Family)		
Agrostis sandwicensis	grass	*
Deschampsia nubigena	grass	*
Dissochondrus biflorus		X*
Eragrostis deflexa	grass	S*
Sporobolus virginicus	‘aki‘aki	I
SMILACACEAE (Catbrier Family)		
Smilax melastomifolia	hoi kuahiwi	*
DICOTYLEDONS		
AMARANTHACEAE (Amaranth Family)		
Charpentiera obovata	papala	*
Nototrichium sandwicense	kulu‘i	*
APOCYNACEAE (Dogbane Family)		
Alyxia oliviformis	maile	*
Ochrosia kilaueaensis	holei	EX*
AQUIFOLIACEAE (Holly Family)		
Ilex anomala	kawa‘u	I
ARALIACEAE (Ginseng Family)		
Cheirodendron trigynum	‘olapa	*
Reynoldsia sandwicensis	ohe makai	S*
Tetraplasandra oahuensis	ohe mauka	*
ASTERACEAE (Sunflower Family)		
Bidens menziesii	ko‘okoolau, ko‘olau	*
Bidens menziesii ssp. filiformis x Bidens micrantha ssp. ctenophylla		R*
Dubautia ciliolata	na‘ena‘e, kupaoa	*
Dubautia linearis	na‘ene‘e, kupaoa	*
Dubautia plantaginea	na‘ene‘e, kupaoa	*
Dubautia scabra	na‘ena‘e, kupaoa	*

TAXON	COMMON NAME	STATUS
ASTERACEAE (continued)		
Gnaphalium sandwicensium	‘ena‘ena	*
Lipochaeta subcordata	nehe	*
Tetramolopium humile		*
CAMPANULACEAE (Bellflower Family)		
Clermontia clermontioides	oha wai	*
Cyanea stictophylla	haha	E*
Delissea undulata ssp. undulata		E*
CAPPARACEAE (Caper family)		
Capparis sandwichiana	caper bush	*
CELASTRACEAE (Bittersweet Family)		
Perrottetia sandwicensis	olomea	*
CHENOPODIACEAE (Goosefoot Family)		
Chenopodium oahuense	‘aheahea	*
CONVOLVULACEAE (Morning Glory Family)		
Bonamia menziesii		EX*
Ipomoea indica	morning glory	I
Ipomoea pes-caprae subsp. brasiliensis	pohuehue	I
Ipomoea tuboides	Hawaiian moon flower	*
CUCURBITACEAE (Gourd Family)		
Sicyos lasiocephalus		*
Sicyos macrophyllus	‘anunu	S*
Sicyos pachycarpus		*
EBENACEAE (Ebony Family)		
Diospyros sandwicensis	lama	*
EPACRIDACEAE (Epacris Family)		
Styphelia tameiameiae	pukiawe	I
ERICACEAE (Heath Family)		
Vaccinium calycinum	‘ohelo, ‘ohelo kau la‘au	*
Vaccinium reticulatum	‘ohelo, ‘ohelo ‘ai	*
EUPHORBIACEAE (Spurge Family)		
Chamaesyce olowaluana	‘akoko, koko, kokomalei	S*
Chamaesyce sp.	‘akoka, koko, kokomalei	*
Claoxylon sandwicense	po‘ola	*

TAXON	COMMON NAME	STATUS
FABACEAE (Pea Family)		
Acacia koa	koa	*
Acacia koaia	koai‘a	S*
Caesalpinia kavaiensis	uhiuhi	E*
Canavalia hawaiiensis		*
Erythrina sandwicensis	wiliwili	E
Senna gaudichaudii	kolomona	I
Sophora chrysophylla	mamane	*
Vicia menziesii	Hawaiian vetch	E*
FLACOURTIACEAE (Flacourtia Family)		
Xylosma hawaiiense	maua	*
GERANIACEAE (Geranium Family)		
Geranium cuneatum	nohoanu, hinahina	*
GESNERIACEAE (African Violet Family)		
Cyrtandra menziesii	ha‘iwale	S*
GOODENIACEAE (Goodenia Family)		
Scaevola sericea	naupaka	I
LAMIACEAE (Mint Family)		
Phyllostegia ambigua	mint	*
Phyllostegia stachyoides	mint	*
Phyllostegia racemosa	kiponapona	EX*
Phyllostegia velutina	mint	E*
Plectranthus parviflorus	‘ala‘ala wai nui	I
Stenogyne angustifolia	mint	E*
Stenogyne macrantha	mint	S*
Stenogyne microphylla		EX
Stenogyne rugosama	‘ohi‘ohi	*
Stenogyne sessilis	mint	*
MALVACEAE (Mallow Family)		
Hibiscus brackenridgei	ma‘o hau hele	E*
Hibiscadelphus hualalaiensis	hau kuahiwi	E*
Kokia drynarioides	kokio	E*
Sida fallax	ilima	I
MENISPERMACEAE (Moonseed Family)		
Cocculus trilobus	huehue	I
MORACEAE (Mulberry Family)		
Streblus pendulinus	a‘ia‘i	I

TAXON	COMMON NAME	STATUS
MYOPORACEAE (Myoporum Family)		
Myoporum sandwicense	naio, bastard sandalwood	I
MYRSINACEAE (Myrsine Family)		
Myrsine lanaiensis	kolea	*
Myrsine lessertiana	kolea lau nui	*
MYRTACEAE (Myrtle Family)		
Metrosideros polymorpha	‘ohi‘a, ‘ohi‘a lehua	*
NYCTAGINACEAE (Four-O'Clock Family)		
Pisonia brunoniana	papala kepau	I
Pisonia sandwicensis	papala	*
OLEACEAE (Olive Family)		
Nestegis sandwicensis	olopua	*
PAPAVERACEAE (Poppy Family)		
Argemone glauca	pua kala	*
PHYTOLACCACEAE (Pokeweed Family)		
Phytolacca sandwicensis	popolo, pokeberry	S*
PIPERACEAE (Pepper Family)		
Peperomia cookiana	‘ala‘ala wai nui	*
Peperomia leptostachya	‘ala‘ala wai nui	I
Peperomia macraeana	‘ala‘ala wai nui	*
PITTOSPORACEAE (Pittosporum Family)		
Pittosporum hosmeri	ho‘awa	*
Pittosporum terminalioides	ho‘awa	*
PLANTAGINACEAE (Plantain Family)		
Plantago hawaiensis	laukahi kuahiwi	E*
PLUMBAGINACEAE (Plumbago or Leadwort Family)		
Plumbago zeylanica	‘ilie‘e	I
POLYGONACEAE (Buckwheat Family)		
Rumex giganteus	pawale	*
PORTULACACEAE (Purslane Family)		
Portulaca sclerocarpa	‘ihi	EX*

TAXON	COMMON NAME	STATUS
RHAMNACEAE (Buckthorn Family)		
Alphitonia ponderosa	kauila	S*
Colubrina oppositifolia	kauila	E*
ROSACEAE (Rose Family)		
Fragaria chiloensis	‘ohelo papa	I
Osteomeles anthyllidifolia	‘ulei	I
Rubus hawaiensis	‘akala	*
Rubus macraei	‘akala	S*
RUBIACEAE (Coffee Family)		
Canthium odoratum	alahe‘e	I
Coprosma ernodeoides	kukaenene	*
Coprosma menziesii	pilo	*
Coprosma montana	pilo	*
Coprosma rhynchocarpa	pilo	*
Gardenia brighamii	na‘u	EX*
Hedyotis terminalis (Gouldia)	manono	*
Psychotria hawaiiensis	kopiko ‘ula, ‘opiko	*
RUTACEAE (Rue Family)		
Melicope clusiifolia	alani	*
Melicope hawaiensis	alani	S*
Melicope volcanica	alani	*
Zanthoxylum dipetalum var. tomentosum	kawa‘u	E*
Zanthoxylum hawaiiense	a‘e	EX*
Zanthoxylum kauaense	a‘e	RX*
SANTALACEAE (Sandalwood Family)		
Exocarpus gaudichaudii	hulumoa	RX*
Santalum paniculatum	‘iliahi, sandalwood	*
SAPINDACEAE (Soapberry Family)		
Dodonaea viscosa	‘a‘ali‘i	I
Sapindus saponaria	a‘e, manele	I
SAPOTACEAE (Sapodilla Family)		
Nesoluma polynesicum	keahi	IRX
Pouteria sandwicensis	ala‘a	*
SOLANACEAE (Nightshade Family)		
Nothocestrum breviflorum	‘aiea	E*
Nothocestrum longifolium	‘aiea	*
Solanum americanum	popolo	I?
Solanum incompletum	popolo ku mai	EX*

TAXON	COMMON NAME	STATUS
STERCULIACEAE (Cacao Family)		
Waltheria indica	‘uhaloa	I?
THYMELAEACEAE (Akia Family)		
Wikstroemia sandwicensis	‘akia	*
Wikstroemia phillyreifolia	‘akia	
URTICACEAE (Nettle Family)		
Pipturus albidus	mamaki	*
Urera glabra	opuhe	*
VISCACEAE (Mistletoe Family)		
Korthalsella complanata	hulumoa	I
Korthalsella cylindrica		*
Korthalsella remyana		*

LITERATURE CITED:

Wagner, W.L., D.R. Herbst and S.H. Sohmer. 1990. Manual of the Flowering Plants of Hawaii. University of Hawaii Press and Bishop M:useum Press. 1,853 pp.

Wagner, W.H. Jr. and F.S. Wagner. 1993. Revised Checklist of Hawaiian Pteridophytes. Unpublished.

APPENDIX B. LAND SNAILS OF PU‘U WA‘AWA‘A

Code Data Source

1 C.C. Christensen. 1983. Analysis of land snails. In J.T. Clark and P.V. Kirsh (eds.). Archaeological investigations of the Mudland-Waimea-Kawaihae road corridor, Island of Hawaii. B.P. Bishop Museum. Honolulu, HI.

2 Subfossils collected by J. Giffin and R. Covington and identified by Robert Cowie.

3 Snails live-collected by J. Giffin, identified by Robert Cowie.

4 Chung D.J.D. and R.H. Cowie, 1991. An archival inventory of the land snails of the state of Hawaii natural area reserves system. B. P. Bishop Museum. Honolulu, HI.

5 Specimens in B.P. Bishop Museum Collection.

* Pu‘u Wa‘awa‘a is the type locality for these species.

Taxonomy follows R.H. Cowie, N.L. Evenhuis and C.C. Christensen. 1995. Catalog of the native land and freshwater molluscs of the Hawaiian islands. Backhuys Publishers, Leiden. 248 pp.

NATIVE SPECIES

TAXON	SOURCE	LOCATION and ELEVATION (feet)
ACHATINELLIDAE		
Partulina confusa	2	Henahena, Waihou, Kileo, Puu Iki: 3,440-4,260
Tornatellaria abbreviata hawaiiensis	1	Open forest in Pu‘u Wa‘awa‘a region
Tornatellides sp.	3	Halepiula Waimea paddock: 5,200
Elasmias fuscum	3	Halepiula Waimea paddock: 5,200.
Lamellidea sp.	3	Halepiula Waimea paddock: 5,200
AMASTRIDAE		
Amastra sp.	2	Henahena paddock: 3,600-4,260
Amastra conica	5	
Amastra flavescens	5	
Amastra fragosa	5	
Amastra modicella	5	
Amastra umbilicata pluscula	5	
Amastra viriosa	5	
Amastra pagodula	2	Kileo and Henahena paddocks: 3,800-4,500
Leptachatina (Angulidens) anceyyana	1	Pu‘u Wa‘awa‘a region

AMASTRIDAE (continued)		
Leptachatina spp. (at least 4 species)	2	Kileo and Henahena paddocks: 3,440-4,500
Leptachatina konaensis	5	
ENDODONTIDAE		
Endodonta sp.	2	Inside Poohohoo crater
Cookeconcha sp.	2	Inside Poohohoo crater
HELICARIONIDAE		
Euconulus sp.	2	
Philonesia cicercula	4	
Philonesia sp.	1	Summit of Puʻu Waʻawaʻa cone
Philonesia (Waihoua) kaliella	1*	Puʻu Waʻawaʻa region
HELICINIDAE		
Pleuropoma laciniosa konaense	1*	Puʻu Waʻawaʻa near Puʻu Hinahina (Potato Hill)
PUPILLIDAE		
Lyropupa (Lyropupilla) Hawaiiensis	1	Inside Poohohoo crater
Lyropupa (Mirapupa) ovatula kona	1	Puu Iki crater & Puʻu Waʻawaʻa cone: 3,100
Lyropupa sp.	2	Inside Delissea exclosure
Nesopupa (Nesopupilla) dispersa	1	Puʻu Waʻawaʻa cone: 3,100-3,350
Nesopupa (Infranesopupa) subcentralis	1	Mt. Hualalai: 6,000-7,000
Nesopua (Nesodagys) wesleyana	1	Puʻu Waʻawaʻa region
Nesopua (Limbatipupa) newcombi	1	Puʻu Waʻawaʻa region: 3,200
SUCCINEIDAE		
Succinea spp.	2	Kileo and Henahena paddocks: 3,340-4,500
Succinea konaensis	5	
ZONITIDAE		
Striatura meniscus	1	Near Puʻu Waʻawaʻa cone: 3,250
Nesovitrea hawaiiensis	1	Near Puʻu Waʻawaʻa cone

INTRODUCED SPECIES

ZONITIDAE		
Oxychilus alliarius (garlic snail)	3	Puʻu Waʻawaʻa forests: 3,440-5,400
BRADYBAENIDAE		
Bradybaenea similaris	2	Kileo and Henahena Paddocks: 3,440-4,500

APPENDIX C. NATIVE ARTHROPODS OF PU‘U WA‘AWA‘A

Taxonomy follows the Hawaiian Terrestrial Arthropod Checklist (second edition) by G.M Nishida (ed.). Bishop Museum, 1994. Taxonomic expertise for identifying arthropods was provided by the following individuals: Al Samuelson (Coleoptera), James Liebherr (Carabidae), David Foote (Drosophila), Dan Polhemus (Heteroptera), Hannelore Hoch and Manfred Asche (Homoptera), Karl Magnacca (Colletidae), Mandy Heddle, Steven Montgomery and Francis Howarth (Lepidoptera), Maurice and Catherine Tauber (Neuroptera), Jonathan Brown (Tephritidae), Rosemary Gillespie and Jessica Garb (Araneae), Diana Percy (Psyllidae), and Francis Howarth and Keri Williamson (cave species).

STATUS CODES:
E = endangered species
C = candidate for endangered listing
S = species of concern
N = new Big Island record
R = rare species with no formal listing

INSECTS

TAXON	COMMON NAME	NOTE / HOST PLANT / CITATION	STATUS
COLEOPTERA (Beetles)			
AGLYCYDERIDAE			
Proterhinus spp.	primitive weevils	reared from *Sophora, Clermontia*	
ALLECULIDAE			
Labetis hawaiiensis	comb-clawed beetle	*Sicyos macrophyllus* foliage (plant in flower)	R

TAXON	COMMON NAME	NOTE / HOST PLANT / CITATION	STATUS
ANOBIIDAE			
Holcobius granulatus	death-watch beetle	*Acacia koa*	
Holcobius cf. *hawaiiensis*	death-watch beetle	*Myrsine lessertiana*	
Holcobius sp. undet. #1	death-watch beetle	*Santalum paniculatum*	
Holcobius sp. undet. #2	death-watch beetle	*Sophora chrysophylla*	
Mirosternus sp. undet. #1	death-watch beetle	*Ilex anomala bark*	
Xyletobius sp. undet. #1	death-watch beetle	*Myoporum, Pittosporum, Myrsine, Acacia,* and *Ilex*	
ANTHRIBIDAE			
Araecerus varians	fungus weevil	reared from *Clermontia clermontioides* wood	
CARABIDAE			
Blackburnia kilauea	ground beetle	small species	
Mecyclothorax gracilis	ground beetle		
Mecyclothorax pele	ground beetle		
Mecyclothorax proximus	ground beetle		
Mecyclothorax sp. nr. *Proximus*	ground beetle	new sp. (reddish) from lava tubes	
CERAMBYCIDAE			
Plagithmysus bishopi	long-horned beetles	*Melicope* sp. (Koebele, 1901)	
P. blackburni	long-horned beetles	*Sophora chrysophylla, Santalum paniculatum*	
P. darwinianus	long-horned beetles	*Sophora chrysophylla*	
P. davisi	long-horned beetles	*Diospyros sandwicensis*	
P. debilis	long-horned beetles	*Acacia koa* foliage	
P. elegans (P. decorus)	long-horned beetles	*Charpentiera obovata*	S
P. (Neoclytarlus) filipes	long-horned beetles	*Sophora, Diospyros, Hibiscadelphus*	
P. mezoneuri	long-horned beetles	*Caesalpinia kavaiensis* (Swezey, 1946)	S
P. (Neoclytarlus) montgomeryi	long-horned beetles	*Chamaesyce olowaluana*	
P. (Neoclytarlus) nodifer	long-horned beetles	*Acacia koa*	
P. perkinsi	long-horned beetles	*Myoporum sandwicense*	
P. simplicicollis	long-horned beetles	*Nothocestrum brevifolium*	S

TAXON	COMMON NAME	NOTE / HOST PLANT / CITATION	STATUS
CIIDAE			
Cis sp.	minute tree-fungus beetle	*Myoporum, Cheirodendron, Myrsine* bark	
Cis sp.	minute tree-fungus beetle	*Acacia koa*	
CUCUJIDAE			
Parandrita sp.	flat bark beetles	*Myrsine lessertiana* bark	R
CURCULIONIDAE			
Dryophthorus squalidus	true weevil	*Cheirodendron trigynum* wood	
Oodemus sp. undet. #1	true weevil	mossy log	
Rhynchogonus giffardi	true weevil	*Acacia koa, Nestegis sandwicensis* (Giffard, 1918)	S
DERMESTIDAE			
Labrocerus sp.	dermestid beetle	*Hibiscadelphus hualalaiensis, Acacia koa*	
NITIDULIDAE			
Nesopetinus spp.	souring beetle	*Acacia koa* seed pods, *Clermontia*	
DIPTERA (True flies)			
ASTEIIDAE (Asteiid flies)			
Asteia Montgomeryi	fly	*Erythrina sandwicensis* (Hardy & Delfinado, 1980)	
Asteia sabrosky	fly	*Pisonia, Charpentiera, Urera* (Hardy & Delfinado, 1980)	
CALLIPHORIDAE			
Dyscritomyia spp.	native blow fly		
DOLICHOPODIDAE			
Campsicnemus spp.	long-legged fly		

TAXON	COMMON NAME	NOTE / HOST PLANT / CITATION	STATUS
DROSOPHILIDAE			
Drosophila ciliaticrus	picture-wing pomace fly		
Drosophila clara	pomice fly		
Drosophila formella	picture-wing pomace fly		
Drosophila hawaiiensis	picture-wing pomace fly		
Drosophila heteroneura	picture-wing pomace fly		C
Drosophila iki	pomace fly		
Drosophila imparisetae	pomace fly		
Drosophila multiciliata	pomice fly		
Drosophila murphyi	picture-wing pomace fly		
Drosophila ochropleura	pomice fly		
Drosophila setosifrons	picture-wing pomace fly		
Drosophila silvarentis	picture-wing pomace fly		
Drosophila silvestris	picture-wing pomace fly		
Drosophila sproati	picture-wing pomace fly		
MUSCIDAE			
Lispocephala spp.	predatory fly		
PHORIDAE			
Megaselia sp.	humpbacked fly		
PIPUNCULIDAE			
Cephalops sp.	big-headed fly	*Melicope volcanica* foliage	
TEPHRITIDAE			
Trupanea apicalis	fruit fly	*Dubautia linearis*	
Trupanea arboreae	fruit fly	*Dubautia linearis*	
Trupanea crassipes	fruit fly	light trap	

TAXON	COMMON NAME	NOTE / HOST PLANT / CITATION	STATUS
TIPULIDAE			
Linonia spp.	crane fly		
HETEROPTERA (True bugs)			
ANTHOCORIDAE			
Lasiochilus sp. undet. #1	minute pirate bug	*Acacia koa* bark	
LYGAEIDAE			
Neseis fasciata fasciata	lygaeid seed bug	*Coprosma rhynchocarpa*	
Nesius ochriasis maculiceps	lygaeid seed bug	*Sophora chrysophylla*	
Neseis sp. undet. #1	lygaeid seed bug	*Pipturus albidus* foliage	
Neseis sp. undet. #2	lygaeid seed bug	*Hedyotis terminalis* foliage	
Nysius coenosulus	lygaeid seed bug	*Chamaesyce olowaluana*	
Nysius delectus	lygaeid seed bug	*Dubautia plantaginea*	
Nysius terrestris	lygaeid seed bug	*Nototrichium sandwicense*	
Nysius sp. undet. #1	lygaeid seed bug	*Dubautia* sp. (hybrid plant)	
Oceanides nubicola	lygaeid seed bug	*Myoporum sandwicense* foliage	
Oceanides pteridicola	lygaeid seed bug	*Metrosideros polymorpha* flowers	
MIRIDAE			
Engytatus sp.	mirid leaf bug	*Dubautia linearis*	
Koanoa sp.undet.	mirid leaf bug	various shrubs & trees	
Hyalopeplus pellucidus	mirid leaf bug	*Metrosideros, Nestegis, Claoxylon*	
Nesiomiris sp. undet. #1	mirid leaf bug	*Cheirodendron trigynum*	
Nesiomiris timberlakei	mirid leaf bug	*Reynoldsia sandwicensis*	
Nesiomiris hawaiiensis	mirid leaf bug	*Ilex anomala*	
Opuna sp. undet. #1	mirid leaf bug	*Acacia koa*	
Opuna sp. undet. #2	mirid leaf bug	*Metrosideros polymorpha* flowers	

TAXON	COMMON NAME	NOTE / HOST PLANT / CITATION	STATUS
MIRIDAE (continued)			
Opuna sp. undet. #3	mirid leaf bug	*Chamaesyce olowaluana*	
Orthotylus azalais	mirid leaf bug	*Metrosideros polymorpha* flowers	
Orthotylus diospyri n. sp.	mirid leaf bug	*Diospyros sandwicensis* foliage	
Orthotylus hedyoticola n. sp.	mirid leaf bug	*Hedyotis terminalis* foliage	
Orthotylus kanakanus	mirid leaf bug	*Coprosma rhynchocarpa* foliage	
Orthotylus xylosmae n. sp.	mirid leaf bug	*Xylosma hawaiiense* foliage	R
Orthotylus n. sp. #1 nr. *azalais*	mirid leaf bug	black / *Metrosideros polymorpha*	
Orthotylus n. sp. #2	mirid leaf bug	green / *Sophora chrysophylla* foliage	
Orthotylus n. sp. #3	mirid leaf bug	black and white / *Nestegis sandwicensis*	
Orthotylus n. sp. #4	mirid leaf bug	green / *Nestegis sandwicensis*	
Orthotylus n. sp. #5	mirid leaf bug	black male, green female / *Psychotria hawaiiensis*	
Sarona adonias	mirid leaf bug	*Metrosideros polymorpha* foliage	
Sarona flavidorsum	mirid leaf bug	*Korsalla* sp. (on *acacia koa*)	
Sarona hamakua	mirid leaf bug	*Myrsine lessertiana* foliage	
Sarona kau (?)	mirid leaf bug	*Dubautia* sp. (hybrid plant)	
Sarona mamaki	mirid leaf bug	*Pipturus albidus*	
Sarona myoporicola	mirid leaf bug	*Myoporum sandwicense* foliage	
Sarona pittospori	mirid leaf bug	*Pittosporum hosmeri* foliage (Asquith, 1994)	
Sarona n. sp. #1	mirid leaf bug	*Ilex anomala* foliage	
Sarona n. sp. #2	mirid leaf bug	*Phyllostegia velutina* foliage	R
Sarona n. sp. #3	mirid leaf bug	*Melicope volcanica* foliage	
Sarona undet. sp. #4	mirid leaf bug	*Korsalla* sp. (on *Nestegis sandwicensis*)	
Sulamita nr. *dryas*	mirid leaf bug	*Claoxylon sandwicense*	R
NABIDAE			
Nabis blackburni	damsel bug	*Dryopteris wellichiana*	
Nabis kahavalu	damsel bug	*Sophora chrysophylla* (Van Duzee, 1936)	
Nabis oscillans	damsel bug	*Metrosideros polymorpha* leaves	
Nabis tarai	damsel bug	*Styphelia tameiameiae*	

TAXON	COMMON NAME	NOTE / HOST PLANT / CITATION	STATUS
PENTATOMIDAE			
Oechalia virgula	stink bug	*Dodonaea, Myoporum* (Van Duzee, 1936)	R
Oechalia sp. undet. #1	stink bug	*Metrosideros polymorpha*	R
SCUTELLERIDAE			
Coleotichus blackburniae	koa bug, shield bug	*Acacia koa* foliage	S
HOMOPTERA (Hoppers, whiteflies, aphids & scale insects)			
CICADELLIDAE			
Nesophrosyne eburneola	leafhoppers	*Claoxylon sandwicense, Psychotria hawaiiensis*	
Nesophrosyne mabae n. sp.	leafhoppers	*Diospyros sandwicensis*	
Nesophrosyne pluvialis	leafhoppers	*Coprosma rhynchocarpa*	
Nesophrosyne sp. undet. #1	leafhoppers	grey */ Reynoldsia sandwicensis*	
Nesophrosyne sp. undet. #3	leafhoppers	*Lipochaeta subcordata*	R
Nesophrosyne sp. undet. #4	leafhoppers	*Myrsine lessertiana*	
Nesophrosyne sp. undet. #5	leafhoppers	black */ Cyanea stictophylla*	R
Nesophrosyne sp. undet. #6	leafhoppers	grey / *Coprosma rhynchocarpa*	
Nesophrosyne sp. undet. #7	leafhoppers	*Hedyotis terminalis*	
Nesophrosyne sp. undet. #8	leafhoppers	*Coprosma menziesii (?)*	
Nesophrosyne sp. undet. #9	leafhoppers	*Phyllostegia velutina*	R
Nesophrosyne sp. undet. #10	leafhoppers	*Dodonaea viscosa*	
Nesophrosyne sp. undet. #11	leafhoppers	*Myoporum sandwicense*	
Nesophrosyne sp. undet. #12	leafhoppers	*Clermontia clermontioides*	
Nesophrosyne sp. undet. #13	leafhoppers	*Ilex anomala*	
CIXIIDAE			
Oliarus hevaheva	cixiid planthopper	unknown host	
Oliarus inaequalis	cixiid planthopper	unknown host (Giffard, 1925)	
Oliarus koanoa	cixiid planthopper	*Dodonaea viscosa*	

TAXON	COMMON NAME	NOTE / HOST PLANT / CITATION	STATUS
DELPHACIDAE			
Aloha myoporicola	delphacid planthopper	*Myoporum sandwicense* (Giffard, 1918)	
Aloha swezeyi	delphacid planthopper	various plants (Giffard, 1918)	
Nesothoe sp.	delphacid planthopper	*Dodonaea viscosa*	
Nesosydne ipomoeicola	delphacid planthopper	*Lythrum maritinum* (Giffard, 1918)	
Nesosydne koae	delphacid planthopper	*Acacia koa* (Giffard, 1918)	
Nesosydne phyllostegiae	delphacid planthopper	*Phyllostegia racemosa* (Giffard, 1918)	
Nesosydne rubescens	delphacid planthopper	*Acacia koa* (Giffard, 1918)	
Nesosydne sp. undet. #1	delphacid planthopper	*Cyanea stictophylla*	R
Nesosydne sp. undet. #2	delphacid planthopper	*Nototrichium sandwicense*	
PSYLLIDAE			
Trioza sp. undet. #1	psyllids, plant lice	*Metrosideros polymorpha*	
Swezeyana elongena	psyllids, plant lice	*Pouteria sandwicensis*	
Swezeyana n. sp. undet. #2	psyllids, plant lice	*Pouteria sandwicensis*	
HYMENOPTERA (Bees, wasps & ants)			
BETHYLIDAE			
Sierola aucta	bethylid wasp	unknown host (Fullaway, 1920)	
Sierola konana	bethylid wasp	unknown host (Fullaway, 1920)	
Sierola laticeps	bethylid wasp	unknown host (Fullaway, 1920)	
Sierola megalognatha	bethylid wasp	unknown host (Fullaway, 1920)	
Sierola puuwaawaa	bethylid wasp	unknown host (Fullaway, 1920)	
Sierola quadriceps	bethylid wasp	unknown host (Fullaway, 1920)	
Sierola spicata hawaiiensis	bethylid wasp	unknown host (Fullaway, 1920)	
Sierola streblognatha	bethylid wasp	unknown host (Fullaway, 1920)	

TAXON	COMMON NAME	NOTE / HOST PLANT / CITATION	STATUS
COLLETIDAE			
Hylaeus akoko (n. sp.)	yellow-faced bee	*Chamaesyce, Metrosideros, Myoporum*	R
Hylaeus coniceps	yellow-faced bee	*Chamaesyce, Metrosideros, Cheirodendron, Acacia*	S
Hylaeus connectens	yellow-faced bee	C*laoxylon sandwicense*	
Hylaeus dimidiatus	yellow-faced bee	C*hamaesyce olowaluana*	R
Hylaeus difficilis	yellow-faced bee	C*hamaesyce olowaluana*	S
Hylaeus filicum	yellow-faced bee	C*hamaesyce olowaluana*	S
Hylaeus hula	yellow-faced bee	C*hamaesyce olowaluana*	S
Hylaeus inquilina	yellow-faced bee	Cleptoparasitic species from pahoehoe lava	
Hylaeus kona	yellow-faced bee	*Myoporum sandwicense*	S
Hylaeus laetus	yellow-faced bee	*Chamaesyce olowaluana*, volcanic cinder	S
Hylaeus ombrias	yellow-faced bee	*Chamaesyce olowaluana*	
Hylaeus paradoxicus	yellow-faced bee	*Chamaesyce, Myoporum, Cheirodendron, Metrosideros*	R
Hylaeus pele	yellow-faced bee	*Chamaesyce olowaluana, Sophora chrysophylla*	
Hylaeus pubescens	yellow-faced bee	*Chamaesyce, Myoporum, Metrosideros*	S
Hylaeus volcanicus	yellow-faced bee	volcanic cinder	
EUPELMIDAE			
Eupelmus sp.	wasp		
ICHNEUONIDAE			
Echthromorpha sp.	ichneumon wasp	*Cibotium glaucum*, dead fern fronds	
SPHECIDAE			
Ectemnius polynesialis	square-headed wasp	volcanic cinder	
Ectemnius rubrocaudatus	square-headed wasp	*Metrosideros, Cheirodendron*	S
VESPIDAE			
Odynerus sp. undet. #1	potter wasp	black abdomen / *Chamaesyce olowaluana*	
Odynerus sp. undet. #2	potter wasp	red abdomen / *Chamaesyce olowaluana*	

TAXON	COMMON NAME	NOTE / HOST PLANT / CITATION	STATUS
LEPIDOPTERA (moths and butterflies)			
CARPOSINIDAE			
Carposina nigronotata	moth	light trap	
Carposina olivaceonitens	moth	light trap	
Carposina sp. undet. #1	moth	black & white, light trap	
Carposina sp. undet. #2	moth	small, light trap	
COSMOPTERIGIDAE			
Hyposmocoma spp.	moth	light trap	
CRAMBIDAE			
Eudonia (*scoparia*) spp.	moth	light trap	
Mestolobes minuscule	moth	light trap	
Mestolobes sp. undet. #1	moth	light trap	
Omiodes (Hedylepta) accepta	sugarcane leafroller	light trap	
Omiodes anastreptoides	moth	light trap	S
Omiodes blackburni	coconut leafroller	light trap	
Omiodes continualtalis	moth	light trap	
Omiodes localis	moth	light trap	
Omiodes monogona	moth	light trap	C
Orthomecyna epicausta	moth	light trap	
Orthomecyna heterodryas	moth	light trap	
Orthomecyna metalycia	moth	light trap	
Orthomecyna sp. undet. #1	moth	light trap	
Udea calliastra	moth	light trap	
Udea endopyra	moth	light trap	
Udea micacea (?)	moth	light trap	
Udea pyranthes	moth	light trap	
Uresiphita polygonalis virescens		light trap	

TAXON	COMMON NAME	NOTE / HOST PLANT / CITATION	STATUS
GEOMETRIDAE			
Eupithecia craterias	pug moth	ferns	
Eupithecia monticolens	pug moth	*Metrosideros polymorpha* flowers, ferns	
Eupithecia staurophragma	pug moth	light trap	
Prognostola cremnopis	pug moth	trap	R
Scotorythra arboricolans	pug moth	light trap	
Scotorythra artemidora	pug moth	light trap	
Scotorythra corticea	pug moth	reared from *Santalum paniculatum*	
Scotorythra demetrias	pug moth	light trap (M. Heddle, personal communication)	
Scotorythra nr. *kuschie*	pug moth	light trap	
Scotorythra ortharcha	pug moth	light trap (M. Heddle, personal communication)	R
Scotorythra paludicola	pug moth	light trap	
Scotorythra rara	pug moth	light trap	
LYCAENIDAE			
Udara blackburni	Blackburn butterfly	flying	
NOCTUIDAE			
Agrotis aulacias	cutworm moth	light trap	
Agrotis baliopa	cutworm moth	light trap	
Agrotis ceramophaea	cutworm moth	light trap	
Agrotis diplosticata	cutworm moth	light trap	
Agrotis dislocata	cutworm moth	light trap	
Agrotis melanoneura	cutworm moth	light trap	S
Agrotis mesotoxa (?)	cutworm moth	light trap	S
Agrotis perigramma	cutworm moth	light trap	
Agrotis psammophaea	cutworm moth	light trap	
Agrotis xiphias	cutworm moth	light trap	
Agrotis sp. (undescribed)	cutworm moth	light trap	
Anomis vulpicolor	red anomis noctuid	light trap	

TAXON	COMMON NAME	NOTE / HOST PLANT / CITATION	STATUS
NOCTUIDAE (continued)			
Haliophyle connexa	fern moth	light trap	
Haliophyle nr.euclidias	fern moth	light trap	
Haliophyle niphadopa	fern moth	light trap	
Haliophyle sp. undet. #1	fern moth	light trap	
Haliophyle sp. undet. #2	fern moth	light trap	
Helicoverpa hawaiiensis	moth	light trap	
Hypocala velans	moth	light trap	R
Peridroma albiorbis	moth	light trap	
Peridroma cintipennis	moth	light trap	
Peridroma coniotis	moth	light trap	
Peridroma selenias	moth	light trap	
Pseudaletia sp.	moth (undescribed)	light trap	
Pseudaletia macrosaris	moth	light trap	
Schrankia sp. undet. #1	cave moths	on roots	
Schrankia sp. undet. #2	terrestrial moth	light trap	
NYMPHALIDAE			
Vanessa tameame	Kamehameha butterfly	*Pipturus albidus*	
OECOPHORIDAE			
Thyrocopa sp. undet. #1	moth	hand caught	
Thryocopa sp. undet. #2	moth	reared from *Clermontia clermontioides*	
PYRALIDAE			
Homoeosoma albosparsum??	moth	light trap	
SPHINGIDAE			
Hyles wilsoni	sphinx or hawk moth	light trap	
Manduca Blackburni	Blackburn hawk moth	light trap / *Nothocestrum brevifolium* foliage	E

TAXON	COMMON NAME	NOTE / HOST PLANT / CITATION	STATUS
TORTRICIDAE			
Cydia sp.	moth	light trap	
Mantua sp.		light trap	
Spheterista sp.	leaf roller moth	light trap	
Pararrhaptica sp.		light trap	
NEUROPTERA (lacewings and antlions)			
CHRYSOPIDAE			
Anomalochrysa hepatica	green lacewing	*Cheirodendron trigynum, Acacia koa*	
Anomalochrysa debilis	green lacewing		
HEMEROBIIDAE			
Micromus vagus	brown lacewing	light trap	
Micromus usingeri	flightless brown lacewing	unknown host (M. Tauber, personnal communication)	S
Micromus longispinosus	flightless form	*Ilex, Melicope, Metrosideros*	R
MYRMELEONTIDAE			
Distolen wilsoni	antlion	light trap	
ODONATA (Damselflies & dragonflies)			
AESHNIDAE			
Anax strenuous	dragonfly or pinao	breeding in reservoir	

TAXON	COMMON NAME	NOTE / HOST PLANT / CITATION	STATUS
ORTHORPTERA (grasshoppers, katydids, crickets)			
GRYLLIDAE			
Laupala sp.	sword-tail cricket	*Sophora, Claoxylon*	
PSOCOPTERA (barklice and booklice)			
PSOCIDAE			
Ptycta sp. (?)	psocids	various trees	

NON-INSECT ARTHROPODS

ARANEAE (spiders)

LYCOSIDAE			
Lycosa sp.	wolf spider	lava flows	
PHILODROMIDAE			
Pagiopalus spp.(?)	philodromid crab spider	tree bark	
SALTICIDAE			
Sandalodes sp.(?)	jumping spiders	tree bark	
THOMISIDAE			
Misumenops anguliventris	thomisid crab spider	*Metrosideros polymorpha*	
Misumenops aridus	thomisid crab spider	lichens on Acacia koa	N
Misumenops nigrofrenatus	thomisid crab spider	*Myoporum sandwicense, Melicope volcanica* foliage	
Synaema naevigerum	thomisid crab spider	unknown host	

TAXON	COMMON NAME	NOTE / HOST PLANT / CITATION	STATUS
TETRAGNATHIDAE			
Tetragnatha anuenue	long-jawed spider	unknown host	
Tetragnatha kea	long-jawed spider	unknown host	
Tetragnatha kukuhaa	long-jawed spider	unknown host	
Tetragnatha quasimoto (?)	long-jawed spider	unknown host	
Tetragnatha sp.	long-jawed spider	green body, spine on abdomen / unknown host	
THERIDIIDAE			
Theridion grallator	happy-face spiders	leaves	

PSEUDOSCORPIONES (Pseudoscorpions)

Undetermined Taxon	Pseudoscorpion	*Claoxylon sandwicense* foliage	
Undetermined Taxon	Pseudoscorpion	*Acacia koa* bark	

LITERATURE CITED:

Asquith, A. 1994. Revision of the Endemic Hawaiian Genus *Sarona* Kirkaldy (Heteroptera: Miridae: Orthotylinae). Bishop Museum Occasional Papersonal No. 40. Bishop Museum Press. 81 pp,

Fullaway, D.T. 1920. New Species of Sierola with Explanatory Notes. Occasional Papers of the Bernice Pauahi Bishop Museum of Polynesian Ethnology and Natural History. Vol. VII, No. 7. Bishop Museum Press. 144 pp.

Giffard, W.M. 1918. Notes on Delphacids Collected on a Short Visit to Portions of the Intermediate Forest in Olaa and in North and South Kona, Island of Hawaii. Proc. Haw. Ent. Soc. III(5):407-412.

Giffard, W.M. 1925. A Review of the Hawaiian Cixiidae, with Descriptions of Species (Homoptera). Proc. Haw. Ent. Soc., VI(1):51-157.

Hardy, D.E. and M.D. Delfinado, 1980. Insects of Hawaii. Volume 13, Diptera: Cyclorrhapha III. The University Press of Hawaii, Honolulu.451 pp.

Koebele, A. 1901. Hawaii's Forest Foes. Thrum's Hawaiian Annual. pp. 90-97.

Nishida, G.M. 1994. Hawaiian Terrestrial Arthropod Checklist. Second Edition. Bishop Museum Technical Report No. 4. Bishop Museum. 287 pp.

Swezey, O.H. 1946. Some New Species of Cerambycidae from the Island of Hawaii (Coleoptersa). Proc. Haw. Ent. Soc. Vol. XII, No. 3. Pp. 621-623.

Van Duzee, E.P. 1936. A Report on Some Heteroptera from the Hawaiian Islands, with Descriptions of New Species. Proc. Haw. Ent. Soc. IX,(2):219-229.

APPENDIX D. NON-NATIVE ARTHROPODS OF PU‘U WA‘AWA‘A

Taxonomy follows the Hawaiian Terrestrial Arthropod Checklist (second edition) by G.M. Nishida (ed.). Bishop Museum, 1994.

TAXON	COMMON NAME	HOST
INSECTS		
COLEOPTERA (Beetles)		
ANTHRIBIDAE		
Araecerua fasciclatus	coffee bean weevil	*Chamaesyce* wood
BOSTRYCHIDAE		
Amphicerus cornutus	branch and twig borer	*Charpentriera obovata*
CARABIDAE		
Colopodes buchanani	ground beetle (iridescent green)	
CERAMBYCIDAE		
Curtomerus flavus	long-horn beetle	*Colubrina opositifolia*
Lagocheirus undatus	long-horn beetle	*Chamaesyce, Streblus*
Phoracantha semipunctata	long-horn beetle	*Metrosideros*
Sybra alternans	long-horn beetle	*Charpentiera obovata*
COCCINELLIDAE		
undetermined genus/spp.	lady beetles	various plants
CURCULIONIDAE		
Oxydema fusiforme	weevil	*Charpentiera obovata*
Asynonychus godmanni	Fuller's rose beetle	*Myrsine lessertiana*
DERMESTIDAE		
Dermestes vulpinus	hide beetle	animal carcass
ELATERIDAE		
Conoderus sp.	click beetle	
SCARABAEIDAE		
Copris incertus prociduus	dung beetle	cattle manure
Onthophagus nigriventris	dung beetle	cattle manure
Canthon humectus	bumblebug	cattle manure
SCOLYTIDAE		
Hypothenemus eruditus		*Chamaesyce* wood

TAXON	COMMON NAME	HOST
DIPTERA (True flies)		
CULICIDAE		
Culex quinquefasciatus	night mosquito	
Aedes sp.	day mosquito	
STRATIOMYIDAE		
Stratiomyia sp.	soldier fly	*Cheirodendron* wood
TEPHRITIDAE		
Ceratitis capitata	Mediterranean fruit fly	*Coprosma*
Dioxyna sorcucula		*Bidens pilosa*
Eutreta xanthochaeta	biocontrol for lantana	
Procecidochares utilis		
HETEROPTERA (True bugs)		
MIRIDAE		
Coridromius variegatus		*Acacia koa*
Rhinacola forticornis		
Stenotus binotatus		
Taylorilygus pallidulus		
Taylorilygus apicalis		
NABIDAE		
Nabis capsiformis		
LYGAEIDAE		
Brentiscerus australis		
Graptostethus manillensis		
Nysius palor		
Pachybrachius vincta		
PENTATOMIDAE		
Brochymena sp.	brochymenas stink bug	*Xylosma hawaiiense*
Nezara viridula	southern green stink bug	
REDUVIIDAE		
Haematoloecha rubescens	assassin bug	
Empicoris rubromaculatus	thread-legged assassin bug	*Santalum, Metrosideros*
Oncocephalus pacificus	assassin bug	
RHOPALIDAE		
Niesthrea louisianica		

TAXON	COMMON NAME	HOST
TINGIDAE		
Teleonemia scrupulosa	lantana lace bug	
HOMOPTERA (Hopper, whiteflies, aphids & scale insects)		
CEROPIDAE		
Philaeenus spumarius	spittle bug	
CICADELLIDAE		
Sophonia rufofascia		
Acopsis sp.	sharpshooter	
FLATIDAE		
Siphanata acuta	torpedo bug	
HYMENOPTERA (Bees, wasps & ants)		
APIDAE		
Apis mellifera	European honey bee	
COLLETIDAE		
Hylaeus albonitens		*Chamaesyce*
POMPILIDAE		
Anoplius luctuosus	spider wasp	
SPECIDAE		
Ampulex compressa	emerald cockroach wasp	
VESPIDAE		
Paravespula pensylvanica	yellow-jacket wasp	
ISOPTERA (termites)		
no data		
KALOTERMITIDAE		
Neotermes connexus	forest-tree termite	*Acacia koa, Sophora*
LEPIDOPTERA (moths & butterflies)		
ALUCITIDAE		
Alucita objurgatella	many-plumed moth	

TAXON	COMMON NAME	HOST
CRAMBIDAE		
Maruca testulalis	bean pod borer moth	
Spoladae recurvalis	beet webworm moth	
Nomophila noctuella	moth	
Hellula undalis	cabbage webworm moth	
Herpetogramma licarsisalis	moth	
GEOMETRIDAE		
Anacamptodes testulslis	moth	
Cyclophora nanaria	moth	
Cryptophlebia illepida	koa seed borer	*Acacia koa* seed
Macaria infusata	moth	
Disclisioprocta stellata		moth
LYCAENIDAE		
Strymon bazochii	smaller lantana butterfly	
NOCTUIDAE		
Achaea junata	moth	
Agrotis ypsilon	black or greasy cutworm moth	
Amyna natalis	moth	
Ascalapha odorata	black witch moth	
Athetis thoracica	moth	
Callopistria maillardi	moth	
Condica dolorosa	moth	
Condica illecta	moth	
Elaphria nucicolora	moth	
Hypena laceratalis	lantana moth	
Hypocala deflorata	moth	
Leucania loreyimima?	moth	
Leucania striata	moth	
Lycophotia porphyrea	variegated cutworm moth	
Megalographa biloba	garden looper moth	
Melipotis indomita	kiawe or monkey pod moth	
Neogalea sunia	moth	
Ophiusa disjungens	guava moth	
Pandesma anysa	moth	
Polydesma boarmioides	moth	
Pseudaletia unipuncta	armyworm moth	
Spodoptera mauritia	nutgrass armyworm	
Targalla delatrix	eugenia caterpillar	
NOTODONTIDAE		
Cyanotricha necyria	biocontrol for banana poka	

TAXON	COMMON NAME	HOST
NYMPHALIDAE		
Agraulis vanillae	passion vine butterfly	
Danaus plexippus	monarch butterfly	
Vanessa virginiensis	painted beauty butterfly	
PIERIDAE		
Pieris rapae	cabbageworm butterfly	
PTEROPHORIDAE		
undetermined genus/species	plume moth	
SPHINGIDAE		
Theretra nessus	yam hawk moth	
Hyles lineata	white-lined sphinx	
Agrius cingulata	sweet potato hornworm moth	
TINEIDAE		
Opogona omoscopa	moth	
Decadarchis sp.	moth	*Chamaesyce* wood
TORTRICIDAE		
Amorbia emigratella	Mexican leaf-roller moth	

NEUROPTERA (Lacewing and antlions)

HEMERODIIDAE		
Hemerobius pacificus	brown lacewing	
Sympherobius barberi	brown lacewing	
ORTHOPTERA (Grasshoppers, Katydids & crickets)		
no data		
TETRIGIDAE		
Paratettix mexicanus	grouse or pigmy locust	
CYCLOPTILOIDES		
Trigonidomorpha sjostedti	cricket	*Chamaesyce*, ferns

TAXON	COMMON NAME	HOST

NON-INSECT ARTHROPODS

ARANEAE (spiders)

CLUBIONIDAE
Cheiracanthium diversum pale leaf spider

ISOPODA (isopods, sowbugs, woodlice & pilbugs)
no data

AMPHIPODA (scuds & sandhoppers)
no data

TALIRIDAE
Talitroides sp. amphipod soil

DIPLOPODA (millipedes)
no data

PARADOXOSOMATIDAE
Oxidus gracilis garden millipede leaf litter

APPENDIX E. CAVE ARTHROPODS OF PUUWAAWAA

STATUS CODES:
AC = Accidental; an organism that wanders into caves, but cannot survive there.
AD = Adventive; non-native, introduced by humans.
TB = Troglobite or obligate cave species; restricted to caves.
TP = Troglophile or facultative cave species; able to live in damp surface habitats.
TX = Trogloxene; species that commonly use caves for food or shelter.
* = endemic.

Taxonomy follows the Hawaiian Terrestrial Arthropod Checklist (second edition) by G.M Nishida (ed.). Bishop Museum, 1994.

TAXON	COMMON NAME	STATUS
INSECTS		
COLEOPTERA (Beetles)		
CARABIDAE		
Mecyclothorax sp. nr. *proximus*	ground beetle	TB*
ELATERIDAE		
Conoderus sp.	click beetle	AC, AD
STAPHYLINIDAE		
Nesomedon sp. (undescribed)	rove beetle	TB*
Nesomedon sp. (undescribed)	rove beetle	AC*
COLLEMBOLA (Springtails)		
UNIDENTIFIED FAMILY		
Unidentified	springtail	TP?*
DIPTERA (True Flies)		
CALLIPHORIDAE		
Calliphora vomitoria	flesh fly	AC, AD
DROSOPHILIDAE		
Drosophila sp. (unidentified)	pomace fly	AC?*
Drosophila sp. (unidentified)	pomace fly	TP*

TAXON	COMMON NAME	STATUS
KEROPLATIDAE		
Tylparua cf. *hawaiiensis*	fungus gnat	TP?*
MYCETOPHILLIDAE		
Leia sp. (unidentified)	fungus gnat	TP? AD
PHORIDAE		
Megaselia sp. (undescribed)	humpbacked fly	TB*
Megaselia sp. (undescribed)	humpbacked fly	TP*
SCARIDAE		
unidentified genus	black fungus gnat	TP?*
TIPULIDAE		
Linonia sp.	crane fly	TP?*
HETEROPTERA (True Bugs)		
REDUVIIDAE		
Haematoloecha rubescens	assassin bug	AC, AD
Scadra rufidens	assassin bug	AC, AD
Nesidiolestes sp.	thread-legged bug	TB*
HOMOPTERA (Hoppers, Whiteflies, Aphids & Scale Insects)		
APHIDIDAE		
Rhopalosiphoninus latysiphon	subterranean aphid	TP, AD
Cixiidae		
Oliarus spp.	planthoppers	AC*
Oliarus koanoa	planthopper	TP*
Oliarus makaiki	planthopper	TB*
Oliarus polyphemus	planthopper	TB*
LEPIDOPTERA (Moths and Butterflies)		
NOCTUIDAE		
Schrankia sp.	cave moth	TB*

TAXON	COMMON NAME	STATUS
ORTHOPTERA (Grasshoppers, Katydids & Crickets)		
GRYLLIDAE: subfamily oeacanthinae		
Thaumatogryllus cavicola	cave cricket	TB*
GRYLLIDAE: subfamily nemobiinae		
Caconemobius varius	cave cricket	TB*

NON-INSECT ARTHROPODS

AMPHIPODA (Scuds & Sandhoppers)		
TALITRIDAE		
Spelaeorchestia sp.??	cave amphipod	TB*
Talitroides sp.??	terrestrial amphipod	TP,AD
ARANEAE (Spiders)		
LINYPHIIDAE		
Meioneta sp.	sheet web spider	TB*
Erigone sp. (unidentified)	sheet web spider	TP*
LYCOSIDAE		
Lycosa howarthi	wolf spider	TB*
CHILOPODA (Centipedes)		
LITHOBIIDAE		
Lithobius sp.	rock centipede	TB*
Lithobius sp.	rock centipede	TP, AD
DIPLOPODA (Millipedes)		
CAMBALIDAE		
Nannolene (*Dimerogonus*) sp.	cave millipede	TB*
Nannolene sp. (unidentified)	surface millipede	TP*
PARADOXOSOMATIDAE		
Oxidus gracilis	garden millipede	TP,AD

APPENDIX F. NATIVE BIRDS OF PU‘U WA‘AWA‘A – PAST & PRESENT

(Derived from Current, Historical and Fossil Records)

STATUS CODES:
P = currently present
X = extirpated
Z = extinct
1 = historical record
2 = fossil record
3 = reintroduced

TAXON	COMMON NAME	STATUS
PROCELLARIIDAE (shearwaters and petrels)		
Pterodroma phaeopygia sandwichensis	dark-rumped petrel	X,2
Bulweria bulwerii	Bulwer’s petrel	X,2
Pterodroma jugabilis		Z,2
Pterodroma hypoleuca	Bonin petrel	X,2
HYDROBATIDAE (storm-petrels)		
Oceanodroma castro	band-rumped storm petrel	X,2
ANATIDAE (ducks, geese and swans)		
Branta sp.	giant flightless goose	Z,2
Branta sandvicensis	nene or Hawaiian goose	P,1,2
Anas laysanensis	Laysan duck	X,2
Anus wyvilliana	koloa duck	X,1
RALLIDAE (rails, gallinules and coots)		
Porzana sp.	large Hawaiian rail	Z,2
Porzana sandwichensis	moho or Hawaiian rail	Z,2
Porzana sp.	tiny Hawaiian rail	Z,2
Gallinula chloropus	‘alae ‘ula or gallinule	X,1,2
CHARADRIIDAE (plovers, turnstones and surfbirds)		
Pluvialis dominica	lesser Golden-plover	P,2
ACCIPITRIDAE (hawks, old world vultures & harriers)		
Buteo solitarius	i‘o or Hawaiian hawk	P,2
STRIGIDAE (typical owls)		
Asio flammeus sandwichensis	Pueo or short-eared owl	P,2

TAXON	COMMON NAME	STATUS
CORVIDAE (crows, jays and magpies)		
Corvus hawaiiensis	ʻalala	X1
Corvus sp.	slender-billed crow	Z,2
Corvus sp.	hammer-billed crow	Z,2
MUSCICAPIDAE (old world insect-eaters)		
Chasiempis sandwichensis	ʻelepaio	P,2
Myadestes obscurus	ʻomaʻo or Hawaiian thrush	X,2,3
MELIPHAGIDAE (honeyeaters)		
Moho nobilis	Hawaii ʻoʻo	Z,2
Chaetoptila angustipluma	kioea	Z,2
FRINGILLIDAE (Hawaiian honeycreepers)		
Telespiza sp.	Hawaiian finch	Z,2
Hemignathus sp.	long-billed ʻakialoa	Z,2
Hemignathus sp.	giant nukupuʻu	Z,2
Hemignathus munroi	ʻakiapolaʻau	X,1
Hemignathus virens	common ʻamakihi	P
Himatione sanguinea	ʻapapane	P,2
Oreomystis mana	Hawaii creeper	P
Loxops coccineus	ʻakepa	P
Vestiaria coccinea	ʻiʻiwi	P
ARDEIDAE (herons)		
Nycticorax nycticorax hoactli	Black-crowned night heron	P
LARIDAE	*(gulls and terns)*	
Sterna fuscata oahuensis	sotty tern	P
SCOLOPACIDAE (sandpipers and allies)		
Arenaria interpres	ruddy turnstone	P

APPENDIX G. BIRD SPECIES OF PU‘U WA‘AWA‘A

The birds listed below were observed in the Pu‘u Wa‘awa‘a area from 1990-2002. Birds are listed alphabetically by family and then by genus and species.

STATUS CODES
E = endangered species
I = indigenous
O = non-native
* = endemic

TAXON	COMMON NAME	STATUS
ACCIPITRIDAE (hawks and eagles)		
Buteo solitarius	i‘o or Hawaiian hawk	E*
ALAUDIDAE (larks)		
Alauda arvensis	Eurasian skylark	O
ANATIDAE (ducks, geese and swans)		
Branta sandvicensis	nene	E*
ARDEIDAE (herons)		
Nycticorax nyticorax hoactli	black-crowned night heron	I
CHARADRIIDAE (plovers and lapwings)		
Pluvialis fulva	Pacific golden plover	I
COLUMBIDAE (pigeons and doves)		
Columba livia	rock dove	O
Geopelia striata	zebra dove	O
Streptopelia chinensis	spotted dove	O
Zenaida macroura	mourning dove	O
CORVIDAE (jays, crows and magpies)		
Corvus hawaiiensis	‘alala or Hawaiian crow	E*
DREPANIDIDAE (Hawaiian honeycreepers)		
Hemignathus virens virens	Hawai‘i ‘amakihi	E
Himatione sanguinea	‘Apapane	E
Loxops coccineus coccineus	Hawai‘i ‘akepa	E*
Oreomystis mana	Hawai‘i creeper	E*
Vestiaria coccinea	‘i‘iwi	E

TAXON	COMMON NAME	STATUS
EMBERIZIDAE (emberizids)		
Cardinalis cardinalis	Northern cardinal	O
Paroaria capitata	Yellow-billed cardinal	O
Sicalis flaveola	Saffron finch	O
ESTRILDIDAE (waxbills and mannikins)		
Amandava amandava	red Avadavat	O
Estrilda caerulescans	lavendar waxbill	O
Estrilda troglodytes	black-rumped waxbill	O
Lonchura malabarica	warbling silverbill	O
Lonchura punctulata	nutmeg mannikin	O
Uraeginthus bengalus	red-cheeked cordon blue	O
Padda oryzivora	Java sparrow	O
FRINGILLIDAE (cardueline finches)		
Carpodacus mexicanus	house finch	O
Serinus mozambicus	yellow-fronted canary	O
LARIDAE (gulls and terns)		
Sterna fuscata oahuensis	sotty tern	I
MIMIDAE (mimic thrushes and allies)		
Mimus polyglottos	northern mockingbird	O
MONARCHIDAE (monarch flycatchers)		
Chasiempis sandwichensis	‘elepaio	E
MUSCICAPIDAE (Insect-eaters)		
Cettoa diphone	Japanese bush-warbler	O
PASSERIDAE (old world sparrows)		
Passer domesticus	house sparrow	O
PHASIANIDAE (francolins, pheasants and quails)		
Alectoris chukar	chukar	O
Callipepa californica	California Quail	O
Coturnix japonica	Japanese quail	O
Francolinus erckelii	Erckel's francolin	O
Francolinus francolinus	black francolin	O
Francolinus pondicerianus	grey francolin	O
Lophura leucomelana	kalij pheasant	O
Meleagris gallopavo	wild turkey	O
Pavo cristatus	common Peafowl	O
Phasianus colchicus	ring-necked pheasant	O

TAXON	COMMON NAME	STATUS
PSITTACIDAE (parrots and parakeets)		
Aratinga mitrata	mitred parakeet	O
Aratinga wagleri	Scarlet-fronted parakeet	O
Cyanoliseus patagonus	Burrowing parrot	O
PTEROCLIDIDAE (sandgrouse)		
Pterocles exustus	Chestnut-bellied sandgrouse	O
RECURVIROSTRIDAE (Avocets and stilts)		
Himantopus mexicanus knudseni	Hawaiian stilt	E*
SCOLOPACIDAE (sandpipers and allies)		
Arenaria interpres	Ruddy trunstone	I
STRIGIDAE (typical owls)		
Asio flammeus sandwichensis	Pueo	E
STURNIDAE (Starlings and mynas)		
Acridotheres tristis	Common myna	O
TIMALIIDAE (Babblers)		
Leiothrix lutea	Red-billed leiothrix	O
TYTONIDAE (barn owls)		
Tyto alba	Barn owl	O
ZOSTEROPIDAE (silvereyes)		
Zosterops japonicus	Japanese white-eye	O