PU‘U WA‘AWA‘A BIOLOGICAL ASSESSMENT

PU‘UWA‘AWA‘A, NORTH KONA, HAWAII

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Revised: June 2021

STATE OF HAWAII
DEPARTMENT OF LAND AND NATURAL RESOURCES
DIVISION OF FORESTRY AND WILDLIFE

TITLE PAGE (Koa tree on Pu‘uwa‘awa‘a cone) © Rob Shallenberger 2004

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GENERAL SETTING

Introduction

Data presented in this biological assessment were collected over a 12-year period (1990 to 2002) by Division of Forestry and Wildlife (DOFAW) staff. This project was not conceived as a formal biological investigation, but rather evolved as an approach to document biological discoveries being made during routine management activities. The assessment was originally drafted and submitted to DOFAW in 2003. It was updated in 2009 to correct errors in text and tables and to add names for many new arthropod species. The present version (2021) was extensively revised to correct errors, present additional historical material, and incorporate new biological data from other investigators. Photographs of rare and unusual species were also added. These images were taken by me unless otherwise noted.

A plant species list for Pu‘uwa‘awa‘a (PWW) was initially compiled from botanical survey reports and published literature. Additional taxa were added to the list as they were encountered in the field. I used botanical keys published by Wagner et al. (1999) and Wagner et al. (1993) to confirm species identification. Botanists associated with DOFAW, U.S Fish and Wildlife Service (USFWS), National Park Service, The Nature Conservancy, Bishop Museum, and National Museum of Natural History provided taxonomic expertise for some difficult determinations.

Live land snails were collected by hand from forest vegetation and subfossil snail shells were identified whenever possible. Snail species lists were compiled from all taxa encountered and from various literature sources. Additionally, one full day was spent in Honolulu at Bishop Museum (Malacology Department) searching through the Hawai‘i Island land shell collection. All shells with PWW locality labels were recorded. A total of eight species were in the museum collection. Subfossil shells collected at PWW were identified by Dr. Robert Cowie, Bishop Museum Malacologist.

Terrestrial arthropods were routinely collected at PWW from 1993 to 2002 and voucher specimens were preserved. The objective was to produce a preliminary checklist of invertebrates and 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. The arthropod reference collection was donated to the University of Hawaii at Hilo, College of Agriculture, Forestry, and Natural Resource Management, on December 14, 2016.

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. 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.

Moths and other nocturnal insects were generally sampled at night using a sheet light trap illuminated by a generator-powered mercury vapor bulb. The light trap was operated at least one day per month over a two-year period. A Universal black light trap (BioQuip) was also employed to attract insects on several occasions. Moth species determinations were made by

reference to original descriptions, keys published by Zimmerman (1958a, 1958b, and1978), and direct comparison to specimens in existing collections at Hawai‘i Volcanoes National Park and other local arthropod repositories.

I made multiple trips from Hawai‘i Island to O‘ahu to access native arthropod collections at Bishop Museum and the Hawai‘i Department of Agriculture. Invertebrates collected at PWW were compared with those in collections to aid in identifying species. Specialists at both organizations were also consulted to help with difficult determinations.

Cave surveys for subfossil birds were conducted regularly from August 1992 to August 1993. Survey crews systematically searched lava tubes with battery-powered lights. Each passage was examined twice, first in one direction and then in the other. This system improved chances of detecting specimens partially concealed by rocks. Survey crews included experienced volunteer cavers, state biologists, and avian paleontologists. Subfossil bird remains were initially identified by me or by Bishop Museum specialists. Remains that could not be determined with certainty were submitted to Storrs Olson or Helen James, paleornithologists at the Smithsonian Institution. Comparisons were routinely made of bones taken from caves against specimens in reference collections.

Radiocarbon dating for aging subfossil bird bones was conducted 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. A funding grant, for radiocarbon dating studies, was graciously provided by First Hawaiian Bank.

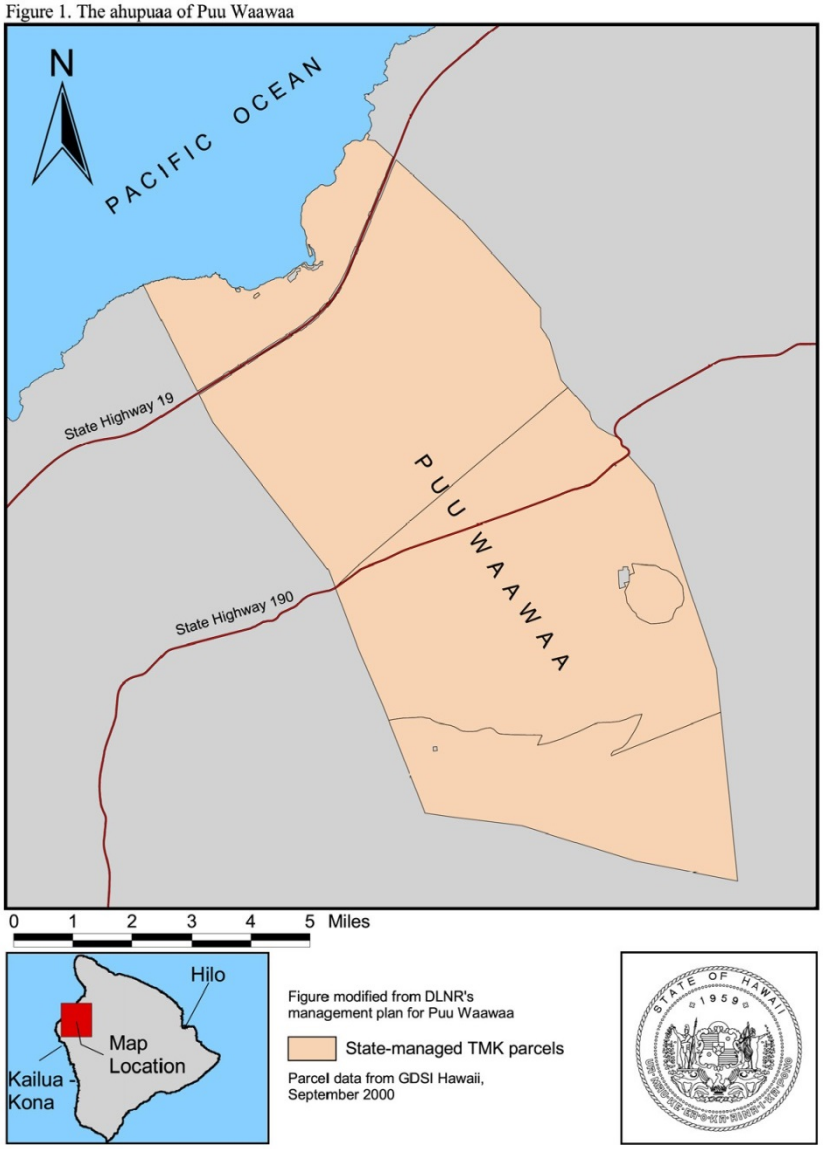
Land Use History

The land division or *ahupua‘a* of Pu‘uwa‘awa‘a (*lit.,* furrowed hill) is located on the western or leeward side of Hawai‘i Island (North Kona District). It lies on the northern flank of Hualalai volcano, extending from sea level to within a mile of the mountain summit (Figure 1). This area takes its name from the large volcanic cinder cone that prominently marks the landscape. The ahupua‘a is roughly bounded by the 1859 lava flow in the east and the Ka‘upulehu lava flows in the west. PWW is within Kekaha, which is the region of North Kona from Honokohau through Pu‘uanahulu. Kekaha means "a dry and barren place," a good description of the land below the hills or Napu‘u as they were originally called (Greenwell, 1991). 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 ahupua‘a of PWW 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 Ali‘i and Konohiki, which became known as "Konohiki Lands." A third class of land was given to the Government or Kingdom

and designated as “Government Lands.” This later division was set aside to support government activities and to provide additional lands for tenancy and leasehold interests.

Figure 1. The ahupuaa of Puu Waawaa



Native tenants could file claims for *kuleana* from these three classes of lands (approx. 1848-1855). Grants were later awarded by Royal Patent, and then lands were made available for homesteading purposes (by the 1880s). When the Monarchy was overthrown in 1893, both Crown and Government Lands were ceded to the United States and later to the State of Hawai‘i. These two land inventories make up the land base currently owned by the state at the present time.

In 1865, Francis Spencer obtained a lease for the entire ahupua‘a of Pu‘uanahulu “excepting the land rights of the native tenants thereon…” (Bureau of Conveyances Liber 19:333). Spencer was

a founder of Waimea Grazing and Agricultural Company based in nearby Waimea. By the time Spencer acquired the Pu‘uanahulu lease, he also had bases of operation at Humu‘ula in Hilo, and Ke‘amoku in Waikoloa. Cattle and sheep were the primary animals raised by the company. Spencer maintained his lease on Pu‘uanahulu through 1895. It is likely that Spencer’s grazing activities overflowed onto the lands of PWW because in 1891, Spencer made an application to lease acreage near PWW cone. However, it appears that no formal lease agreement was ever concluded between Spencer and the Commissioners of Crown Lands.

Prior to 1873, a native rancher named Kaukuna received a lease on the Crown Lands at PWW, primarily for harvesting goats. The lease was transferred to J.W. Punihaole in 1874. By the late 1880s, the aging Punihaole gave up his residence and lease at Kiholo and moved to Kohanaiki. It was not until March 1, 1893, that Robert Hind, Jr., and Eben Low obtained a long-term lease (25 years) at PWW from the Commissioners of Crown Lands. On June 1, 1898, Hind and Low acquired Spencer’s interest in Pu‘uanahulu and those lease-hold Government Lands were added to the holdings of Pu‘uwa‘awa‘a Ranch. Since 1917, the Territory or State of Hawai‘i has issued six different leases at PWW for pasture purposes.

Near the time of Hawaii’s annexation by America (1898), the Hawaiian Islands were investigated by the U. S. Government. A report of this investigation described the lands of PWW 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 PWW 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 ohia (area about 40,000 acres).” (Anon., 1903).

Domestic sheep were produced on the ranch in the early days. Circa 1922, a weed called Spanish needle (*Bidens pilosa)* became established at PWW. Seeds from this plant tangled the sheep's wool, making it impossible to card the fabric. As a result, the sheep operation was abandoned. Dairy heifers were bred at PWW for use in the Hind family dairy on O‘ahu. Turkeys were also raised, with as many as 700 being shipped to Honolulu during some years (Greenwell, 1991).

By 1960, Pu‘uwa‘awa‘a Ranch encompassed 105,831 acres of land, including portions of the PWW and Pu‘uanahulu ahupua‘a. All of this except 35 acres (2.75 acres at Halepiula rain shed and 32.54 acres in the headquarters area) was owned by the State of Hawai‘i and managed by its Land Division. The last 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 to Mr. F. Newell Bohnett, an O‘ahu resident. Pu‘uwa‘awa‘a Ranch was greatly reduced in size in 1984 when the Hawai‘i Board of Land and Natural Resources (BLNR) withdrew 84,434 acres from Bohnett’s lease. This action was taken to penalize Bohnett for illegally harvesting koa trees near the upper ranch boundary and for other lease violations. The remaining 21,434 acres remained under pasture lease to Bohnett until August 14, 2000, when all encumbered lands reverted to the State.

Lands withdrawn from the lease in 1984 were returned to the State Land Division's inventory for future disposition. The Hawai'i Division of Forestry and Wildlife (DOFAW) subsequently requested 3,806 acres of reverted PWW lands for protecting forest bird habitat and Hawaiian crows. The transfer of this acreage was approved by Board action on October 12, 1984. DOFAW immediately assumed responsibility for the parcel (TMK: (3) 7-1-01-007) and managed it as a native bird sanctuary for the next 18 years. During that time, DOFAW petitioned Governor Benjamin Cayetano to designate the area as an official state wildlife sanctuary. The Governor issued Executive Order No. 3932 on July 22, 2002 officially establishing the Pu'uwa'awa'a Forest Bird Sanctuary (PWWFBS) under Chapter 126, Hawai'i Administrative Rules.

On January 25, 2002, all remaining State lands within the ahupua'a of PWW were transferred from the State Land Division to DOFAW and State Parks for joint management. The BLNR directed both agencies to develop and implement management plans to 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.

At this point, DOFAW needed to decide which of its four administrative programs (Forestry, Wildlife, Natural Area Reserve, and Trails) could best manage the new unencumbered lands. Some Hawai'i Island staff wanted a new administrative program established and funded specifically for PWW. It was thought that the unusual requirement of combining cattle grazing and ecosystem restoration on the same parcel would be problematic. However, no new program was established, and the lands remained unencumbered for four more years under DOFAW's jurisdiction.

In June 2002, the BLNR directed DOFAW to form an advisory council to assist the State with management activities on public lands at PWW. The Council was then tasked with aiding the agency in developing and implementing a management plan for the area. That plan was completed in 2003 with input from local communities and the PWW Advisory Council (DLNR, 2003).

On September 27, 2006, at a special session of the PWW Advisory Council, members requested that the land designation at PWW be changed from unencumbered to forest reserve. The Governor signed executive Order No. 4203 on October 19, 2007 setting aside 37,901.30 acres at PWW as the Pu'uwa'awa'a Forest Reserve (TMK: (3) 7-1-01-001, 004 and 006; 7-1-02-001 and 013; 7-1-03-016; and 7-1-04-018). This area included most of the ahupua'a, except for the forest bird sanctuary, a few private inholdings, and a strip of coastline. A portion of Pu'uanahulu ahupua'a was also included in the forest reserve designation (fig. 2).

Prior to forest reserve designation (December 12, 2006), the Department of Land and Natural Resources (DLNR) and U. S. Forest Service (USFS) signed a 35-year Cooperative Agreement for the establishment and administration of the Hawai'i Experimental Tropical Forest at PWW. Under this agreement, the forest was to serve as a center for long-term research and a focal point for developing and transferring knowledge and expertise for the management of tropical forests. On January 26, 2007, the BLNR granted a non-exclusive permit to the USDA Forest Service to use State lands situated at PWW as a Hawai'i Experimental Tropical Forest Unit.

Geology

The Island of Hawai‘i is relatively young compared to other islands in the archipelago. 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 PWW. It is about 10 km long and 5 km wide.

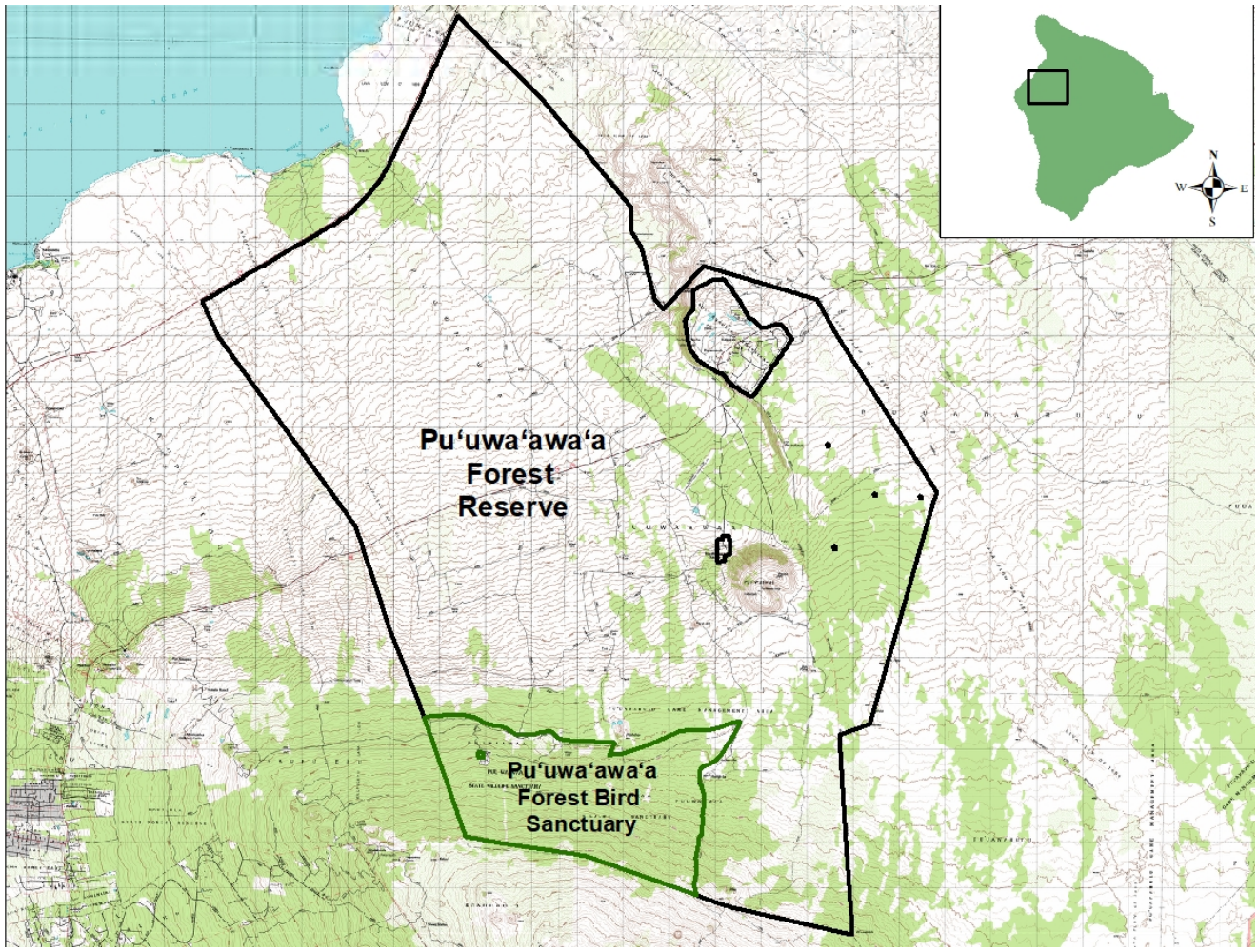


Figure 2. Pu‘uwa‘awa‘a Forest Reserve. Map by Edith Adkins.

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).

The last eruption of Hualalai occurred in 1801 creating the Huehue lava flow. Another eruption is highly probable 200 years from now 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. 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 earthquake at PWW 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 PWW. Several ranch buildings were moved from their foundations and rock walls collapsed.

Lava flows at PWW originated primarily on Hualalai volcano. They are chiefly Holocene in age but include deposits that are late Pleistocene (Moore and Clague, 1991). Lavas were mapped into general age classes by the above investigators. The oldest flows (5,000 to 10,000 years) only occur in a few, scattered patches. The next oldest age class (3,000 to 5,000 years) covers a wide strip in the central portion of the ahupua‘a with smaller units near PWW cone and at Kileo. Slightly younger flows (1,500 to 3,000 years) cover the greatest area. The very youngest flows (750 to 1,500 years) are restricted to a single area near the upper boundary of the ahupua‘a. A radiocarbon-dated charcoal sample collected near the Halepiula rain shed revealed that flows in that area were deposited 2,740$\pm$100 years before present (y.b.p.).

Basaltic lavas are generally classified as ‘a‘a (loose, cobbled lava) or pahoehoe (smooth, relatively unbroken material). ‘A‘a lavas have a rough, clinker like surface overlying a denser core. Pahoehoe usually has a smooth ropy surface with a hard basalt interior. The two forms can erupt from the same volcanic vent and differ primarily in heat and gas content. ‘A‘a is cooler, contains less trapped gasses, and flows more slowly than pahoehoe. The two lava types vary greatly in their ability to produce soils and support vegetation. The rough texture of ‘a‘a traps and holds soils better than the smoother pahoehoe. Lava substrates at PWW vary greatly in age and structure, intermingling to form a mosaic pattern in the lava bed. Vegetation that developed on these flows reflects the parent material. The most botanically diverse forests occur on the oldest a‘a flows while less floristically complex forests develop on younger pahoehoe flows.

Two historic lava flows dominate the PWW region. The 1859 flow from Mauna Loa is on the eastern side of the ahupua‘a while the 1800-1801 Ka‘upulehu flow from Hualalai lies to the west. These flows covered thousands of acres of native forest and destroyed several coastal Hawaiian villages and fishponds. Both flows are poorly vegetated and only slightly weathered.

Subterranean Features

Lava tube systems are of special scientific interest. They support significant flora and fauna assemblages and play an important role in maintaining biological diversity. Volcanic caves contain objects of archeological, cultural, paleontological, and geological significance. They are, however, intrinsically fragile, being susceptible to rapid deterioration through vandalism, siltation, flooding, agricultural development, indiscriminate forest clearing, quarrying, and recreational activities. Underground passages may be damaged or collapse by driving vehicles or heavy equipment over them. Hawaii’s cave protection law (2002) provides the legal basis for protecting lava tubes in the State of Hawai‘i.

Lava tubes are important geological features on Hawaiian volcanoes. These subterranean systems form almost exclusively in pahoehoe flows. Lava tubes often develop when the surface of lava, flowing in a channel, hardens and cools. As the eruption ceases, the molten lava drains from

the roofed channel 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.

PWW's lava tubes are a treasure chest of natural history information and contain preserved evidence of the past human use. They have significant biological, geological, cultural, aesthetic, recreational, and educational values. Cave entrances and passages provide important habitat for many kinds of plants and animals. Two species of tiny, pale white mushrooms (*Marasmiellus* spp.) were found on ʻohiʻa (*Metrosideros polymorpha*) roots in the dark zone of a few lava tubes. Mosses (*Homaliodendron flabellatum*), liverworts (*Dumortiera hirsuta*), ferns (various genera), mints (*Phyllostegia* & *Stenogyne*) and other rare plants flourish in cave openings where increased shade and moisture create a microhabitat conducive to their survival. Some subterranean bacteria and fungi can complete their entire life cycles in the dark zone of caves. These organisms are poorly known, but likely have considerable ecological importance. Microbial slimes sometimes cover the walls of lava tubes and fungi may grow on exposed plant roots and accumulated animal feces.

Volcanic sinkholes and skylights form natural exclosures where rare and endangered vascular plants are protected from damaged by wild and domestic herbivores. Several officially listed or proposed endangered plant taxa grow within lava tube entrances at PWW. Arthropods, snails, birds, bats, rats, and goats also inhabit lava tubes. Native forest birds, especially ʻapapane (*Himatione sanguinea)* and ʻomaʻo (*Myadestes obscurus),* nest on the floor or along ledges in lava tube openings. ʻOmaʻo are no longer present at PWW, but their remains are commonly preserved in lava tubes. Non-native barn owls (*Tyto alba)* and pigeons also roost and nest in cave entrances. In dry coastal areas, non-native finches were observed entering the twilight zone of lava tubes where they apparently obtained water pooling on passage floors.

Lava tubes in the Kileo and Henahena areas exhibit many unusual geological formations (speleothems) and mineral deposits. The ceiling and floor of some caves are decorated with lava lavacicles, stalactites, stalagmites, pillars, driblet spires, and triangular ceiling pendants, all composed of lava. Splattered lava formations are common on ceilings and walls. These are usually a shade of black but may be brightly colored by mineral oxidation (magenta, orange, or green). Gypsum crystals and other mineral precipitation may give passages a whitish cast.

Volcanic caves were important in ancient Hawaiian culture. Several names (ana, lua, pao, and ʻaʻaʻa) were associated with these formations, all of which had similar meanings. Handy and Handy (1972) described how Hawaiians living in the PWW area (Kekaha) obtained their drinng 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 cave ceilings. Kukui nut torches were said to be used as a light source while collecting water in dark cave interiors.

Native Hawaiians used lava tubes and rock caverns at PWW for various purposes, including shelter, water catchment, food storage, personal protection, and burials. Charcoal from torches was commonly found on the floor of lava tubes. Man-made structures such as rock platforms, trails paved with smooth stones, fire pits, stone cradles to support water collecting calabashes, and rock

walls were also present. Human remains were restricted to a few passages. Midden deposits in some shelter caves contained bird bones and marine invertebrate shells left by ancient Hawaiians. Live or freshly killed animals were apparently carried into caves where they were consumed, and their remains discarded on the floor. Bones of nene (*Branta sandvicensis*) and dark-rumped petrel (*Pterodroma phaeopygia sandwichensis*) were the primary bird species identified in shelter cave middens.

Lava tubes at PWW present a dangerous environment for people working or exploring underground. Hazards include total darkness, falling rocks, deep holes, sharp jagged rocks, and tight passages. Passage floors are generally rough, uneven, and strewn with lava breakdown. Huge boulders sometimes obstruct passages and abrupt lava falls impede travel underground. People can easily become lost in a maze of passages and rapidly suffer from hypothermia. European honeybees (*Apis mellifera*) habitually build hives in cave entrances and will attack intruders when disturbed. Western yellow-jacket wasps (*Paravespula pennsylvanica*) regularly nest in the ground, often near cave entrances. They will swarm from their nests when disturbed and attack anyone nearby. These insects are especially dangerous as they will pursue victims for long distances, repeatedly stinging them.

Umi‘i Manu Cave: An exceptionally large lava tube occurs between Kileo cone and the eastern boundary of the ahupua‘a. This underground formation developed in pahoehoe lava that flowed from an unnamed volcanic vent (hill 6383) about 3,000 to 5,000 years ago. The ancient pahoehoe flow is surrounded by younger ‘a‘a lava flows, estimated at 2,200 years old (David Clague, pers. comm.). This island of older lava with its associated forest is known as Kileo kipuka (500 acres). I was initially led to the cave site by Robin Hulce, a former resident of Pu‘uanahulu. In 1992, William “Buck” Cobb and I began exploring the lava tube and immediately realized it contained subfossil remains of prehistoric birds. I questioned area residents and PWW cowboys about a name for the lava tube, but none could be found. Kumu Hula Hulali Covington was then asked to create a name for the cave. She devised the term Umi‘i Manu (*lit*., bird trap) Cave for this subterranean system.

Umi‘i Manu Cave consists of a single, isolated tunnel which is sealed at both ends with lava. These blockages may have formed when more recent ‘a‘a lava filled previously open skylights. The lava tube originates at about 6,200 feet elevation and descends to almost 4,300 feet elevation, a vertical drop of 1,900 feet. This steep elevational gradient makes Umi‘i Manu one of the deepest caves (in terms of elevation) in the United States. Passage length at Umi‘i Manu is relatively long, extending for more than 12,751 linear feet (Schaefer et al., 2000). Most of this distance can be traversed underground. Sinkholes and skylights provide access to the lava tube at various locations. Walk-in entrances exist 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 (fig. 3).

Cave walls inside Umi‘i Manu are generally damp with water from ceiling drip pooling in depressions on the floor. Passages are cool and drafty, especially in sections between large skylights. Air temperature, measured in the cave (4,300 feet), was 57.4° F in July 1995. Relative humidity on the same date was 92.0 percent.

Umi‘i Manu Cave is the most significant fossil bird deposit site ever found on Hawai‘i Island. Skeletal remains of more than 226 endemic and indigenous birds were preserved in the lava tube. This number comprises 19 species, seven of which were new to science. Avian families represented were Anatidae, Fringillidae, Accipitridae, Corvidae, Mohoidae, Muscicapidae, Procellariidae, Rallidae, and Strigidae (Giffin, 2018).

Several species of endemic cave-adapted arthropods inhabit the dark zone of Umi‘i Manu Cave. Most of these are rare and secretive. Obligate cave species in the following taxonomic Orders were collected in the lava tube and identified by specialists: Coleoptera (beetles), Diptera (true flies), Orthoptera (crickets), Amphipoda (scuds/sandhoppers), Araneae (spider, Chilopoda (centipedes), and Diplopoda (millipedes) (Giffin, 2018)

The entire Umi‘i Manu system lies within a montane dry forest consisting of mixed native trees and shrubs. Surface vegetation is dominated by scattered stands of ‘ohi‘a, naio (*Myoporum sandwicense*), mamane (*Sophora chrysophylla*), and a‘ali‘i (*Dodonaea viscosa*). A few clusters of kolea (*Myrsine lanaiensis*) occur in moist depressions. Understory vegetation is composed primarily of non-native grasses especially Kikuyu (*Pennisetum clandestinum*).

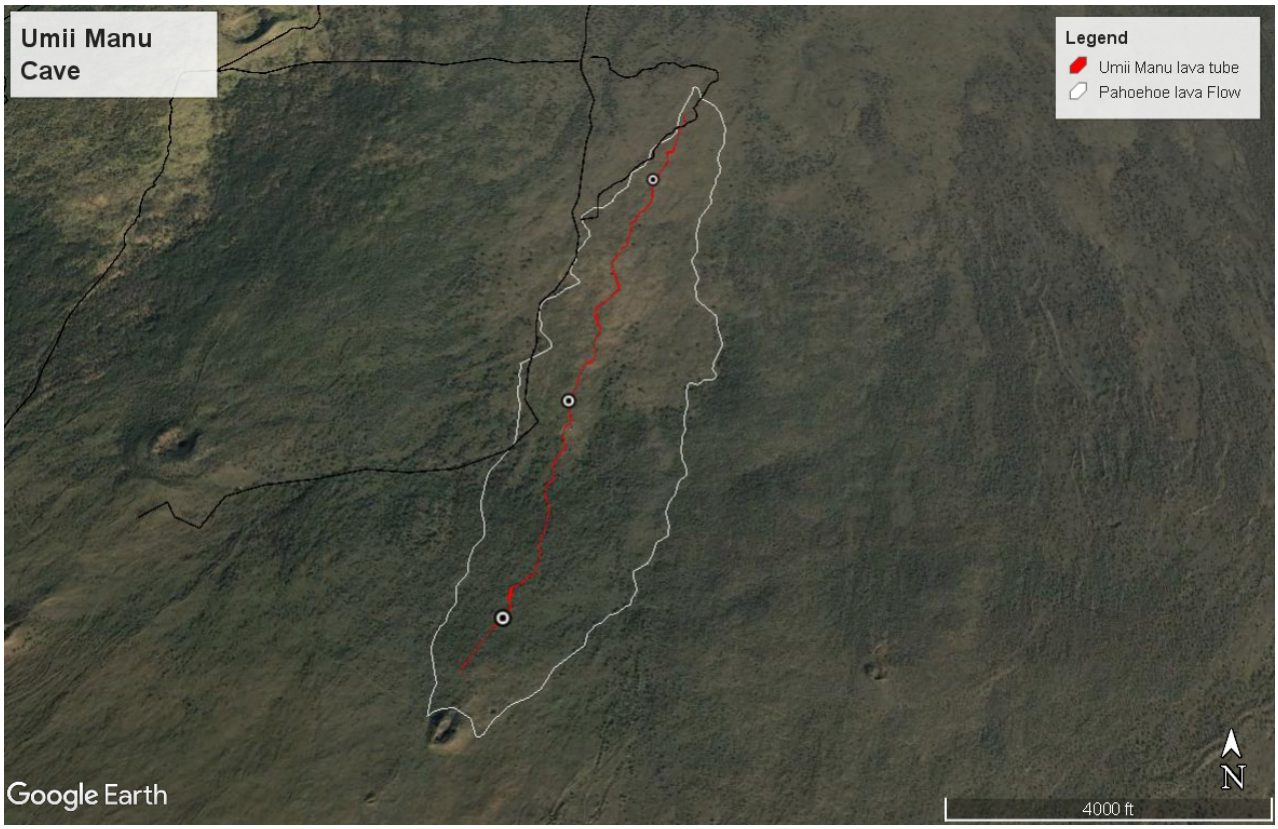


Figure. 3. Umi‘i Manu lava tube system on the eastern boundary of PWW ahupua‘a. White dots mark the location of three major entrances.

Henahena Lava Tube System: A complex system of lava tubes exists in the region between Poohohoo cone and Potato hill. This group of passages formed in pahoehoe that erupted from Hualalai volcano about 1,500 to 3,000 years ago. Two major systems dominate the area and

several secondary ones are present. The Delissea system lies to the west and Shangri-la to the east (fig. 4). These lava tubes begin above the ahupua‘a and extend downslope with some reaching the coast.

The Henahena area contains one of the most complex lava tube systems in the Hawaiian Islands. Passages are extensively braided and interconnected, often forming two or three levels. They are occasionally segmented, with sections blocked by rock piles, boulders, and lava plugs. Lava tubes in this area vary from small tunnels to huge caverns. Over 60 miles of Henahena lava tubes have been mapped to date and many uncharted passages still exist (Peter Bosted, pers. comm.). Henahena caves were generally named for geographic areas or plant and bird species observed at passage entrances.

The landscape at Henahena is riddled with volcanic openings. Over 600 lava tube skylights have been documented in the area between Poohohoo crater and Potato Hill (Peter Bosted, pers. comm.). These cavities range in size from tiny holes to gaping pits. Other types of volcanic openings found in the area include tree molds, cracks, trenches, and pit craters. Many skylights are concealed by dense forest vegetation, making foot travel extremely hazardous. Hikers are acutely reminded of this danger by the presence of cattle and pig bones, visible at the bottom of many skylights. Adjacent skylights are often divided by a thin land bridge which can collapse under light loads.

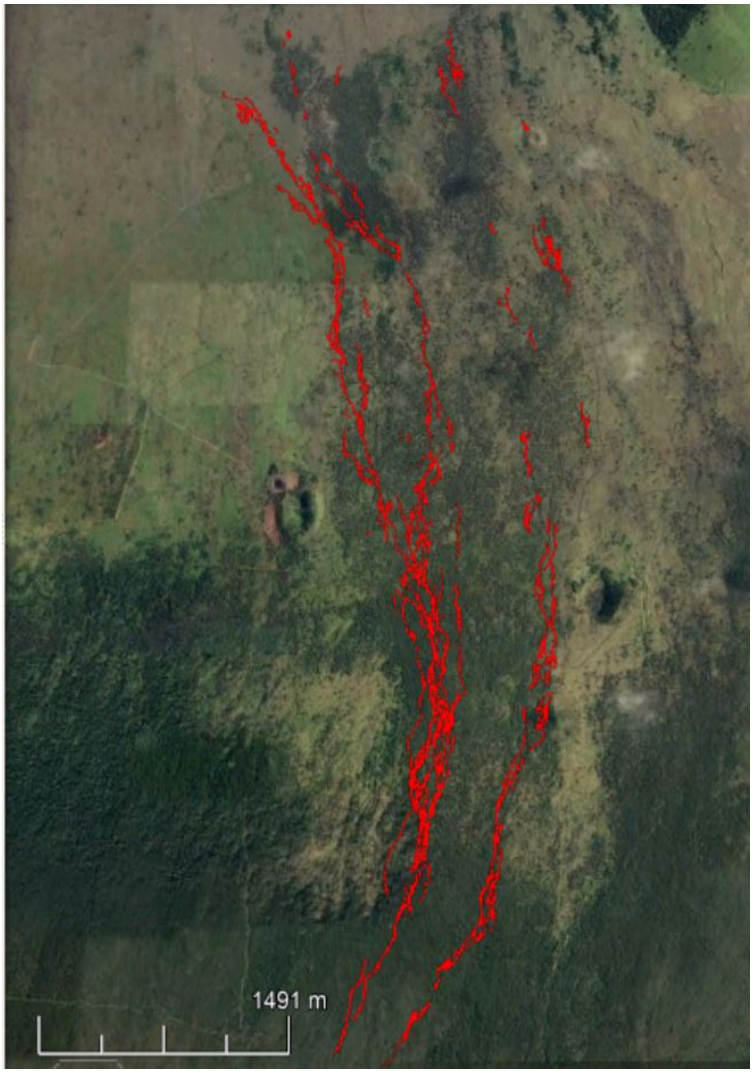


Figure 4. Lava tube systems in the Poohohoo/Potato hill region. The Delissea System is on the left and Shangri-la on the right. Map by Peter Bosted.

Henahena lava tubes provide habitats for many species of cave-adapted invertebrates. At least 11 species of obligate cave arthropods inhabit the dark zone of these passages. Other species likely await discovery. Rare plant species also thrive in the moist, protected environment created by skylights and other volcanic openings. Bird bones, land snail shells, and other paleontological deposits are preserved in some of the passages. Subfossil remains of 15 avian species have been recovered from Henahena caves.

The Henahena lava tube system occurs within a montane forest that ranges from dry to mesic, depending on elevation. Forest vegetation is more botanically diverse than that found in the Umi‘i Manu Cave area. Rare and endangered plant species are scattered throughout the region. Medium stature ‘ohi‘a, mamane, naio, and sandalwood (*Santalum paniculatum*) trees dominate the forest overstory. Common subcanopy shrubs include ‘a‘ali‘i, pilo (*Coprosma* sp.), and kolea. Non-native pasture grasses and native ferns cover the ground.

In arid sections of Henahena, native tree growth and survival are greatly increased where plants are growing above large lava tube systems. This phenomenon is very apparent in pastures where long, narrow stands of mature ‘ohi‘a trees exist in otherwise open grasslands. Upon close inspection, it becomes apparent that these stands are associated with and generally follow lava tube systems. Increased availability of moisture in subterranean passages likely provides improved growing conditions for plants that can extend their roots into this underground environment.

Cinder Cones

Cinder cones are prominent volcanic features at PWW. The most distinctive volcanic vent in the ahupua‘a is Pu‘uwa‘awa‘a cone. It rises 1,220 feet above the surrounding landscape to a height of 3,967 feet elevation with a base diameter of approximately one mile. Erosion, following a radial drainage pattern, has cut many gullies and ridges on the cone’s surface. Slope gradients range from 2 to 70 percent, depending on location. The cone and its associated lava flow, Pu‘uanahulu ridge, are the oldest geological formations on Hualalai (100,000 + years old).These unique landforms are composed of trachyte pumice and contain scattered blocks of trachyte obsidian (black volcanic glass). Trachyte is one of the most silicic lavas known in Hawai‘i (Walker, 1990). Unfortunately, Pu‘uwa‘awa‘a cone was commercially mined for cinders between 1968 and 1988 by Volcanite, Ltd. This operation resulted in extensive damage to the north-eastern slope of the cone. When the company closed, they left behind an eroded hillside and a gaping pit at the base of the cone. Additionally, the site was contaminated with diesel fuel and heavy equipment was buried nearby. Abandoned buildings still contain asbestos building materials (Jon Giffin, pers. obs.).

Ancient Hawaiians likely utilized Pu‘uwa‘awa‘a cinder cone and surrounding forests for extracting specialized resources. Harvested items included rock for tools, bird feathers for adornment, hardwoods for various purposes, and plants for traditional and medicinal usage. Burial sites are also hidden in the hill’s furrows and burial caves are found on Pu‘uanahulu ridge. Volcanic glass was quarried from Pu‘uwa‘awa‘a cone by people of old and made into small but extremely sharp cutting tools. Artifacts made from flakes of this natural Hawaiian glass have been excavated from fields at Amy B. H. Greenwell Ethnobotanical Garden in south Kona.

Several other prominent cinder cones mark the PWW region. The oldest of these are Potato hill and Pu‘u paha. Both are over 10,000 years old (D. Clague, pers. comm.). Potato hill may have been a sweet potato (*Ipomoea batatas*) cultivation site in the past and possibly derived its name from that plant. No Hawaiian name is recorded for the hill, but some evidence suggests that it was also known as Pu‘u Henahena. Location labels, for arthropods and molluscs collected at PWW in the early 1900s, were often marked “Puu Henahena” or “Puu Hinahina”. Geologic maps indicate that Pu‘u iki and Poohohoo are the next oldest vents (5-10,000 and 3-5,000 years, respectively). Kileo and Kalamalu cones are 2,200 years old (D. Clague, pers. comm.). Several smaller,

unnamed cinder and spatter cones are scattered throughout the ahupuaʻa. Delissea spatter cone in the Waihou Conservation Unit is a good example. This hill rises to an estimated 75 feet from its base, but the vent is not even plotted on USGS maps.

Soils

The soil classification system used worldwide distinguishes soils based on their measurable physical and chemical properties and the primary environmental factors that influenced their formation. These characteristics include fertility, climate zone, degree of weathering, composition, arrangement of soil layers, and the soil's developmental history. Eleven of the 12 classified soil orders have been reported in Hawaiʻi. Nine these occur on Hawaiʻi Island (Gavenda, et al., 1998). Andisols and Histosols are the primary soil orders occurring at PWW.

Andisols are soils that developed from volcanic ejecta such as ash, pumice, and cinder. They contain large amounts of organic matter in the soil surface layer (horizon). Andisols are generally highly productive soils. However, their aluminum and iron clay contents have a great capacity to absorb phosphorus, making this element unavailable for plants. With proper fertilization, this soil type can be made productive for a wide range of food crops (Deenik and McCellan, 2007).

Histosols are generally called bogs, moors, peats, and mucks. These soils develop from organic materials with the surface horizons comprising more than 50 percent of this matter. Histosols typically occur in cool, moist environments where anaerobic conditions exit in the soil profile. In Kona, Histosols formed on recent lava flows where organic matter accumulated from decaying vegetation. If these soils formed on ʻaʻa lava, the organic matter is mixed with the ʻaʻa fragments, making them very stony (up to 80 percent rock fragments). If they formed on pahoehoe, the organic matter accumulated above pahoehoe bedrock. ʻOhiʻa trees and various native fern species dominate the natural vegetation growing on Histosol soils (Deenik and McCellan, 2007).

Soil series further define characteristics of soils. These assemblages are typically delineated by parent material, rainfall, soil depth, slope, drainage, and permeability. In Hawaiʻi, soil series are generally given geographic place names, but written without diacritical marks. The most recent comprehensive soil survey of Hawaii Island was completed in 2013 by the U. S. Department of Agriculture. Current soil maps (NRCS, 2021) show 44 different soil mapping units at PWW. Soils classified as Napuu series cover the greatest area (17.9%). These are extremely cobbly, highly organic, medial sandy loams. They occur at upper elevations, generally between 1,000 to 3,500 feet elevation. Additionally, non-soil strata such as lava flows, ash, cinder land, badland, and sand/gravel alluvium cover many areas.

Soils classified as Waawaa medial silt loams occur on Puʻuwaʻawaʻa cone. These are the deepest soils in the ahupuaʻa. Depth to bedrock is more than 60 inches (152 cm). The Waawaa series consist of very deep, well-drained soils that formed in basic volcanic ash and cinders. Runoff is low to high depending on slope. Permeability is moderately rapid (USDA, 2017).

Climate

The climate at PWW can generally be classified as subtropical in nature. Mornings tend to be 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. The rising air mass draws in moist marine air that condenses as it moves upward, creating 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 were highest in September (71.6° F) and lowest in February (41.7° F). (Kevin Grace, pers. comm.). Winter frost is not uncommon above 4,000 feet elevation.

Northeasterly trade winds have little influence at PWW because of the region's leeward aspect. Winds are generally light, but velocity increases slightly during winter months. Strong western 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 Hawai‘i 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 PWW. Volcanic haze usually persists until winds shift and cause it to be blown out to sea.

PWW'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 had shifted by 1992 and 1993. The wettest period occurred from late fall to early winter based on data collected at the forest bird sanctuary cabin (4,000 feet elevation). Rainfall patterns also decrease from west to east. The Shangri-la is much drier than the same elevation at Halepiula. Differences in moisture also occur with elevation. Moist zones at mid-elevations become dryer at upper and lower elevations.

Water Storage

A five-million-gallon freshwater reservoir was constructed at Hauaina (2,375 ft.) by Pu‘uwa‘awa‘a Ranch sometime after 1972. It was supplied with water from a private well. The primary purposed of the reservoir was to store water for livestock operations. However, this impoundment provided important habitat for wildlife. The ranch also developed water collection and storage systems at Poohohoo (4,047 ft.) and Halepiula (4,600 ft.). Water from these rain catchment units was piped to various ranch paddocks. In 2019, the old water collection systems were completely refurbished, and new pipelines were installed to carry water from *mauka* storage tanks to the reservoir.

BIOLOGICAL RESOURCES

Hawai‘i is the most isolated archipelago in the world. The 2,000-mile-wide 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 from the native flora. Many common mainland terrestrial animals are also missing from the native fauna. Reptiles, amphibians, and mammals (except for bats) 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 Hawai‘i were extreme geographic isolation, a tropical climate, and mountainous topography with extremes in rainfall and temperatures.

Vegetation

Botanical records for PWW date back more than a century. Joseph Rock, a prominent territorial botanist, first explored the flora of PWW in 1909. At that time, he claimed that PWW was "...the richest floral section of any in the whole Territory." Rock collected and identified numerous plants growing in the area called Waihou. He remarked that "….Waihou is composed of a semi-wet forest and is situated at an elevation of 3,000 feet." According to Rock, Waihou forest was dominated primarily by ‘ohi‘a, koa, mamane, naio, and ‘akoko (*Chamaesyce* [*lorifolia*] *olowaluana*) trees. Rock further noted that ‘akoko .... "reaches a height of 20 to 25 feet and a diameter of often more than 10 inches." Opuhe (*Urera sandwicensis*) "…. is not uncommon in Waihou forest (elevation 3000 feet), where trees 35 feet in height can be found. It is here that the writer met with the biggest trees; some had trunks of one foot in diameter."[1] Manena (*Pelea* [*cinerea*] *hawaiensis*) "occurs quite plentifully." Other trees reported at Waihou were olapa (*Cheirodendron trigynum*), kolea (*Myrsine lanaiensis*), and kawa‘u (*Ilex anomala*) (Rock 1913).

Rock visited PWW again in 1911. His trip report mentioned that ‘akoko "was an especially significant component of Waihou Forest." He observed that, "In certain localities the plants are so thick that it is impossible to ride through them. The ground is covered densely with the young seedlings and thousands upon thousands of plants cover that area." (Rock, 1912).

W. A. Anderson, an employee of the Hawai‘i Agricultural Experiment Station, visited PWW in 1912. The purpose of his trip was to document the occurrence of ‘akoko and secure latex samples from the trees. He hoped to determine the adaptability of this species for tapping, cultivation, and rubber production. Anderson reported that, "The trees are growing among other forest growth on several thousand acres of Government land under lease to the Puuwaawaa Ranch." ...."They were found at an elevation of about 3,000 feet, in very thin a-a soil with frequent out-croppings of pahoehoe. The trees large enough for tapping are distributed at irregular intervals among other trees. The ground is covered with seedlings one to six or eight feet high, mostly of the Euphorbia trees, forming an immense nursery. There is very little undergrowth beside these seedlings. Many of these have been eaten off at the top by cattle, and have started growing again from eyes along the stems." ...."In the portions visited, there are about 50-75 mature trees per acre..." (McGeorge and Anderson, 1912).

A. L. Mitchell, a National Park Service botanist, conducted botanical surveys at PWW in 1944 and again in 1945. His reports and field notes provide detailed descriptions of the region's botanical composition at that time. Mr. Thomas Lindsey, Pu‘uwa‘awa‘a Ranch foreman, guided Mitchell on both of his field trips. The 1944 trip included "the area from 2,800 feet to the summit of Hualalai." In 1945, he surveyed "the area from the government road at about 1,900 feet to an elevation of 2,800 feet." On his second trip, Mitchell was able to meet with Isaac Sanford, a

[1] Less than one dozen opuhe trees were known to exist at PWW in 2002, all within the forest bird sanctuary.

former Pu‘uwa‘awa‘a Ranch employee and discuss identification of rare plants. Mitchell remarked that Sanford was Dr. Rock’s guide when he botanized PWW. Tom Lindsey told Mitchell that “probably no other man knew the forest of Puuwaawaa as well as does Sanford.”

Tom Lindsey guided Mitchell to several rare plants at PWW, including one called wahine noho kula. Lindsey stated, “….that at one time this tree was more numerous but he has never seen it fruit or flower because of the fondness of the goats for it.” He also noted that “the leaves are edible and a good medicine” (Mitchell, 1944, 1945).

Colin G. Lennox, Commissioner, Territorial Board of Agriculture and Forestry, visited Pu‘uwa‘awa‘a Ranch on May 24-25, 1945. The purpose of his visit was “to survey native trees and take measures to protect those which are in danger of extinction.” Lennox reported results of his 1945 field trip at a meeting of the Commissioners of the Territorial Board of Agriculture and Forestry. Thos. Lindsay and Isaac Sanford and others were part of his survey party. Tree species recorded in his report included ‘ohe mauka (*Tetraplasandra meiandra*) (3,500 ft.), hau kuahiwi (*Hibiscadelphus hualalaiensis*), (no elevation given) and a single wahine noho kula at 2,300 ft. In his report, Lennox recommended that several trees at PWW be protected by fencing to exclude animals. These included a “Small shrub of unknown genus called Wahine noho kula. Eaten down to a bare stump by animals. Said to be only one in existence by Sanford and Lindsey (Elev. 2300’).” (Lennox, 1945).

Wahine noho kula (*lit.,* woman dwelling on the plains) is a shrub or small tree in the Violet family (Violaceae). Plants in this family are collectively known as aupaka. Wahine noho kula (*Isodendrion pyrifolium*) formerly grew in dry shrub lands at low elevations (1,191 to 3,162 ft.). The above references by Mitchell and Lennox are notable because the species was not seen by botanists after 1870 and was presumed extinct. It appears that this plant was present at PWW at least until 1945.

In 1991, a small population of *I. pyrifolium* was rediscovered at Kealakehe near Kailua-Kona on the Island of Hawai‘i. However, only nine mature plants still existed by 2003 and all except one died by 2018. Seeds were banked from three mature trees before their death and a small number of seedlings were propagated in nurseries (USFWS, 2018). In 2006, 20 nursery propagated aupaka seedlings were outplanted at PWW in the Kipuka Oweowe exclosure. However, none of these became established (Nick Agorastos, pers. comm.).

Surveys of PWW flora were conducted by several botanists after 1945. Most notable were those completed by Takeuchi (1991) and The Nature Conservancy (1992). Even though PWW's forests have been greatly altered over the past 100 years, remnants of this great botanical treasure still exist. At least 200 native vascular plant species in 78 families have been recorded at PWW since 1909 (Appendix A). Several species occur nowhere else in the Hawaiian Islands.

Forest Decline

Territorial officials began reporting forest destruction at PWW as early as 1900. Professor Koebele visited Pu‘uwa‘awa‘a Ranch sometime between 1899 and 1900. He reported that cattle were rapidly changing the forest at that time. The report also notes 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 decline did occur much as Koebele predicted, but over a slightly longer time. Native understory vegetation was gradually replaced by non-native pasture grasses. However, native tree canopy cover persisted for many years. In 1959, the mamane canopy was still intact according to Billy Pairs, a former Pu‘uwa‘awa‘a Ranch manager (pers. comm.). Blackmore and Vitousek (2000) used aerial photos to measure the long-term loss of forest cover at Waihou. They found that the aerial extent of dense forest decreased 62 percent between 1954 and 1994 and that the area covered by grassland increased by 237 percent. By 2003, Waihou was an open pasture marked by standing skeletons of dead or dying mamane trees and ‘akoko was almost extirpated. Droughts were common and invasive grasses and weeds had almost completely replaced native understory plants.

PWW also has a long history of forest damage by wildfires. Several hundred acres of forest above Poohohoo cinder cone were set ablaze about 1908, probably by a lightning strike (B. Paris, pers. comm.). This event created a large opening in the forest that was apparent for several decades. Wildfires burned hundreds of acres in 1986 and again in 1988. In March 1995, campers accidently started a fire at Shangri-la cabin. This blaze destroyed the building and burned forest vegetation for two months (March 5 to May 5) before it was completely extinguished. At least 1,200 acres of native trees were consumed by that blaze: 1,000 acres in the lower northeast corner of the forest bird sanctuary and 200 acres in the adjacent Henahena paddock.

Many other factors have adversely impacted native flora and fauna at PWW. These include grazing by domestic and feral livestock, tree clearing for pasture improvement, illegal harvesting of koa and other valuable trees, and the purposeful introduction of non-native plants and animals. Koa, mamane, and ‘akoko trees were damaged where cattle, sheep, and goats had access to them. These animals browsed foliage, branches, bark, and seedlings. Rare trees were also girdled by feral pigs, especially ‘ohe mauka (*T. oahuensis*) and a‘e (*Z. hawaiiense*).

Forest Restoration

A major trend in forest restoration began in 1984 when 3,806 acres of koa/‘ohi‘a forest, near the upper boundary of Pu‘uwa‘awa‘a Ranch, were withdrawn from the master lease and transferred to DOFAW for management. Cattle were removed from most of that parcel in 1985, but a small herd remained in the Potato Hill area until 1989. In 2009, wildlife sanctuary management responsibility shifted from DOFAW’s Wildlife program to the Natural Area Reserve System program. Feral animal control activities (trapping, shooting, and snaring) increased significantly about that time. All goats have now been eradicated in the sanctuary, but a few sheep and pigs remain. Over 4,000 feral pigs have been removed by DOFAW staff to date. Seeds of rare plants are routinely collected and seedlings outplanted in ungulate free sections of the sanctuary. Over 15,000 common native trees have been planted to date, primarily koa, mamane, a‘ali‘i, and kolea. (Nick Agorastos, pers. comm.). Additionally, a natural resources management plan was completed for the wildlife sanctuary in 2010 (Giffin, 2010).

The ahupua‘a management plan, developed by DOFAW in 2003, designates eleven areas at PWW for special protection of native plants and animals. These conservation units were delineated on maps, but boundaries were not established on the ground or fenced. Since 2003, a total of five conservation units have been enclosed by ungulate-proof fencing. Most ungulates have been removed and forest restoration activities are now underway. Fenced conservation units include Kipuka Oweowe (2 subunits), Pu‘uwa‘awa‘a cone (5 subunits), Waihou, ‘Aiea, and Henahena. Unit size and fence construction dates are summarized below:

Kipuka Oweowe: Over 4,751 native seedlings have been outplanted in the subunits to date.
Subunit 1 (10.21 acres): Fencing completed in 2005.
Subunit 2 (16.04 acres): Fencing completed in 2015.

Pu‘uwa‘awa‘a Cone: The initial cone subunit was fenced in 2005 and all ungulates were removed the same year (subunit #1). This subunit contains the most intact section of native forest. Additional fenced units were constructed as funds became available. DOFAW plans to construct at least two more units in the future. Fenced units are as follows:

Subunit 1 (74.1 acres) Fencing completed in 2005.
Subunit 2 (3.2 acres) Fencing completed in 2011.
Subunit 3 (16.4 acres) Fencing completed in 2014.
Subunit 5 (3.5 acres) Fencing completed in 2016.
Subunit 7 (83.7 acres) Fencing completed in 2020.

Plans for fencing subunits #4 and #6 are delayed pending acquisition of funding and resolving management issues. Subunit #7 is the “Pu‘uwa‘awa‘a Community Based Subsistence Forest Area”. This 84-acre exclosure will be reforested, managed, and utilized by the Pu‘uanahulu community.

More than 75,000 seedlings have been planted in cone units since 2005. These trees and shrubs have experienced high survival rates. Natural regeneration of mamane, olopua (*Nestegis sandwicensis*), papala kepau (*Pisonia brunoniana*), po‘ola (*Claoxylon sandwicense*), *Neraudia ovata*, koa, manele (*Sapindus saponaria*), a‘ali‘i, and hoawa (*Pittosporum hosmeri*) has been documented in the units. Native ferns are also beginning to colonize the exclosures (Nick Agorastos, pers. comm.).

Waihou: This 211 acre unit was fenced and domestic livestock removed in 2003. Efforts to remove feral sheep and pigs started at the same time, but several animals remained inside the unit until 2012. From 2012 to 2017, more than 11,738 native tree and shrub seedlings, consisting of 32 species, were outplanted in the unit.

‘Aiea: This 286 acre unit was fenced in January 2018. Cattle were removed and feral pig control efforts began the same year. These actions protected another section of the former Waihou forest. A detailed natural resources management plan for the combined Waihou and ‘Aiea Conservation Units was completed in 2018 (Giffin, 2018).

Henahena: This 730 acre unit is adjacent to the Aiea Conservation Unit. It includes portions of the former Waihou forest and supports similar plant communities. Sections of the Henahena unit

were previously fenced to control livestock, but these fence lines were in poor condition did not exclude feral animals. Fencing of this unit with ungulate proof wire began in 2014. However, archeological surveys and funding issues delayed construction work for a few more years. The ungulate proof fence was not completed until May 2021 (Elliott Parsons, pers. comm.). Ungulate removal and forest restoration efforts are scheduled to begin soon. A natural resources management plan for the unit was completed in 2013 (Giffin, 2013).

The total area of protected forest in 2021 was 5,240 acres. This figure includes the forest bird sanctuary (3,806 acres) and all five plant exclosures. Additionally, several smaller rare plant exclosures have been established to protect critically imperiled species. These included the Hauaina, Delissea, and Sanctuary Cabin units. The Hauaina exclosure (49.03 acres) was fenced in 2009. It encloses the meeting house area and the freshwater reservoir. Over 14,941 seeding have been planted in that unit to date.

Existing Plant Species

Native flora of the Hawaiian Islands consists of approximately 956 species of flowering plants (Wagner et al., 1999) and 198 fern species (Wagner and Wagner, 1993). Most of these (89 and 78 percent, respectively) are endemic to Hawai‘i. In fact, no other place in the world has such a high level of endemism, not even the famous Galapagos Islands. Hawai‘i has the highest number of threatened and endangered plant species in the United States. 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 Hawai‘i 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 damage by non-native ungulates, destruction of forest vegetation by humans, predation by rodents, pest insects, spread of invasive non-native plants, loss of native pollinators, and habitat fragmentation.

Upland vegetation types in Hawai‘i were mapped by Jacobi (1989) during the period 1976-1981. Vegetation boundaries were initially delineated on aerial photographs and then overlaid on 1:24,000-scale orthophoto quad sheets. These units were then verified in the field and by aerial reconnaissance. The final product delineates vegetation types and describes tree canopy crown cover, tree height, tree species composition, and understory species composition. Jacobi’s maps show at least 13 different upland vegetation types at PWW. Detailed vegetation maps for the forest bird sanctuary and Henahena Conservation Unit were prepared based on Jacobi’s data. These maps are presented in the management plans developed for those two units (Giffin 2010, 2013).

Vegetation Zones and Associated Plants

PWW vegetation can be separated into five ecological regions based on the classification system presented by Gagne and Cuddihy (1999). These zones are based on elevation, moisture regimes and physiognomy. Starting at the upper boundary of the ahupua‘a and continuing downward, the following forest zones are recognized: subalpine dry, montane mesic, montane dry, lowland dry, and coastal. A variety of plant communities occur within each zone.

Subalpine Dry Forest: A narrow band of subalpine vegetation occurs from the upper boundary down to about 6,000 feet elevation. Plants growing here are adapted to relatively dry conditions and dramatic temperature fluctuations. Days are typically hot and nights cold. These forests

are characterized by open, low stature ʻohiʻa trees and scattered stands of native shrubs and grasses. Dominant understory species are pukiawe (*Leptecophylla* [*Styphelia*] *tameiameiae*], ʻohelo (*Vaccinium* spp.), aʻaliʻi, sedges, and rushes. Native mints, lilies, and ferns often grow abundantly in shaded areas and lava tube openings.

One endangered plant was found in the subalpine zone. Laukahi kuahiwi (*Plantago hawaiensis*) is a member of the plantain family (Plantaginaceae). This species is a perennial herb with leathery leaves. It was only encountered near the upper boundary of the forest bird sanctuary (6,300 ft.) Very little is known about the abundance or distribution of this endangered plant. ʻAkala (*Rubus macraei*), mauʻu laʻili (*Sisyrinchium acre*), and *Eragrostis deflexa* also grew in this zone. All three species are officially listed as species of concern (SOC) by the USFWS. *E. deflexa* 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: This vegetation zone begins directly below the subalpine zone and extends down to about 4,200 feet elevation. It reaches it best development in the central portions of the forest bird sanctuary. This forest is relatively moist, but not as wet as a rain forest. It supports a rich assemblage of vascular plant species and is notable for its diversity of tree species and relative abundance of rare plants. Koa and ʻohiʻa were the dominant tree species in the canopy layer. Kolea (*Myrsine lessertiana*) dominated the mid-story layer while the understory was comprised of native short-stature trees and shrubs. Introduced grasses, primarily Kikuyu (*Pennisetum clandestinum*), and native ferns, especially the shuttlecock shaped laukahi (*Dryopteris* spp.), covered the ground in forest openings. Other ferns such as hoʻiʻo (*Athyrium sandwichianum*), akolea (*Athyrium microphyllum*), and palapalai (*Microlepia setosa*) were common in wetter, shaded areas. No tree fern stratum exists although hapuʻu (*Cibotium glaucum*) was scattered throughout the forest.

The most botanically intact and diverse section of the montane mesic forest occurs in the Halepiula mauka Waimea paddock, generally above the sanctuary cabin (5,100 to 6,000 feet elevation). This area also supports a great number of threatened and endangered plant species. Maps prepared by Moore Clague (1991) show that lava flows in this paddock are among the oldest in the ahupuaʻa (3,000 to 5,000 years old).

Endangered plants documented in the montane mesic forest were *Asplenium fragile* var. *insulare* (5,800 ft.), *Vicia menziesii* (5,250 ft.) (fig. 5), haha (*Cyanea stictophylla*) (5,100 ft.) (fig. 6), and *Phyllostegia velutina* (5,200 ft.), *Phyllostegia warshaueri* (5,350 ft.), and *Phyllostegia stachyoides* (5,470 ft.). A native grass, *Eragrostis deflexa,* (SOC) was scattered throughout the area above 4,000 feet elevation. Other rare plants growing in this area were *Phyllostegia ambigua* (4,600 ft.), *Ranunculas mauiensis* (5,750 ft.) and *Sanicula sandwicensis* (5,860 ft.).

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 Cameron Kepler (USFWS) collected a

single specimen on Hualalai. He found a colony of these plants at PWW 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 relocate them were unsuccessful for many years.

I relocated the same *Vicia* colony in April 1993 and recorded GPS coordinates for the site. The colony was found in the Halepiula mauka Waimea paddock at 5,250 feet elevation. Plants were growing in a forest opening and occupied an area of approximately 3,750 square feet. *Vicia* vines were covering several species of ferns including hoio, hapu‘u, and *Pseudophegopteris keraudreniana.* Many of the plants were blooming at that time of year. Later observations of *vicia* indicated a prolonged flowering period, extending from April to August. *Vicia menziesii* is a new record for Hualalai volcano and was not known to occur on the mountain prior to 1985.

Haha is an endangered shrub or tree in the bellflower family (Campanulaceae). This lobeliod 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 PWW and that individual was in the forest bird sanctuary at 5,440 feet elevation. Blooming was noted from December through March. Seedlings obtained from the wild haha were outplanted in several fenced exclosures. These seedlings first bloomed at four years of age.

Figure 5. *Vicia menziesii* (no common name) growing in the forest bird sanctuary.

Figure 6. Haha (*Cyanea stictophylla*) growing in the forest bird sanctuary.

A distinctive montane mesic forest community exists on Pu‘uwa‘awa‘a cinder cone. The extreme age of the cone (100,000 + years), along with its high degree of soil development and complex topography, produced a unique assemblage of native plants. In 1909, Rock (1911) remarked that the cone was “like an oasis in a desert.” He goes on to say that “Rough a‘a surrounds its base, while on its slopes luxurious vegetation grows in the rich, dark soil, bearing some resemblance to the plant covering of Waihou and the middle forest belt of Mt. Hualalai.” Wagner et al. (1999) classified this plant community as an olopua (*Nestegis*) montane forest. It is characterized by trees such as olopua, papala kepau, po‘ola, manele or soapberry, and other woody species. Soapberry trees are found nowhere else on the island, except Hawaii Volcanoes National Park (HVNP).

At least 26 species of native trees were historically present on the cone slopes (Appendix B). Many of these plants are now extirpated or endangered. These include (*Eragrostis deflexa*), kawa‘u (*Zanthoxylum dipetalum* var. *tomentosum*), a‘e (*Zanthoxylum kauaense*), and (*Delissea undulata*). In 1912, Rock (1913) reported finding “numerous individuals (*Z. kauaense*) on Puuwaawaa hill proper.” The endangered kawa‘u still exists on the hill today.

Montane Dry Forest: This vegetation zone begins at about 4,200 feet and extends down to approximately 3,000 feet elevation. Many rare and endangered plant species are found here. These communities are dominated by ‘ohi‘a, naio, and a‘ali‘i. Scattered stands of mamane, sandalwood, and akoko were also present. Non-native grasses, especially the invasive fountain grass, have replaced most native understory species. Vegetation damage by feral ungulates, particularly goats and sheep, has been widespread.

The montane dry forest changes from a koa/‘ohi‘a community in the uppermost portion of the zone to an open canopy ‘ohi‘a/mamane community at lower elevations. Although greatly altered by decades of ranching activity, this woodland is an important conservation link between the montane mesic forest above and lowland dry forest below. The ‘ohi‘a/mamane woodland supports many rare and unique plant species and is highly diverse botanically. Trees that characterize this zone included koa, mamane, ‘akoko, ‘iliahi, kopiko (*Psychotria hawaiiensis*), papala (*Charpentiera obovata*), papala kepau, po‘ola, a‘ia‘i (*Streblus pendulinus*), olopua (*Nestegis sandwicensis*), hoawa, and manena (*Pelea hawaiensis*). Understory plants consist primarily of non-native pasture grasses, but scattered stands of kulu‘i (*Nototrichium sandwicense*), ma‘ohi‘ohi (*Stenogyne rugosa*), and native ferns (*Dryopteris, Pteris, Asplenium*) still persist.

Endangered plants found in the montane dry forest were ‘aiea (*Nothocestrum breviflorum*) (3,400 to 5,600 ft.), hau kuahiwi (*Hibiscadelphus hualalaiensis*) (3,350 ft.), kawa‘u (*Zanthoxylum dipetalum* var. *tomentosum*) (3,100 to 3,600 ft.), and *Delissea undulata* ssp. *undulata* (3,520 ft.). A few individuals of *Stenogyne angustifolia*, an endangered mint, occurred on the eastern boundary of PWW, near Pu‘u Hainoa (3,800 ft.). 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 seedlings were outplanted in enclosures beginning in 1990.

‘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 give off a pleasant fragrance and develop into pea-sized orange fruit. Although classified as endangered, ‘aiea was locally common in the Henahena Conservation Unit at about 3,500 feet elevation. These trees were generally restricted to lava tube openings and rough ‘a‘a lava flows where they were somewhat protected from ungulate damage. In 1909, Rock (1913) noted that ‘aiea were “exceedingly common” at Pu‘uwa‘awa‘a.

Only 20 wild kawa‘u (*Z. dipetalum tomentosum*) trees were known to exist during the survey period. This number dwindled to eleven by 2011. Individual trees were widely scattered across the entire ahupua‘a. This species is dioecious, having male and female flowers on separate trees. The number of seeds produced during the survey period was extremely low.

Delissea undulata is one of the rarest plants on the Island of Hawai‘i. 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 PWW 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 PWW in 1922 but persisted elsewhere on Hualalai until 1971. It was thought to be extinct after that date (Wagner et al., 1999).

In April 1992, I rediscovered a single *Delissea undulata* plant at PWW while searching for lava tube entrances. This individual was growing in the montane dry forest zone near Poohohoo cinder cone (3,520 ft.). It was associated with mamane, ʻohiʻa, koa, sandalwood, naio, ʻaiea, and alani (*Pelea hawaiensis*). The plant was clinging to the side of a collapsed lava tube where it was somewhat safe from herbivores. The stem was immediately propped up with a stake and the entire plant fenced to prevent further injury.

The protected plant flowered in July and produced its first fruit in August 1992. However, fruit began dropping from 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, Hawaiʻi. The first of these were outplanted in May 1993. They flowered and produced fruit in June 1994 (two years of age). In 1995, outplanted plants flowered from July through September. It was hoped that these young plants would provide the necessary stock to save this rare lobelia from extinction. The *Delissea* discovery site was photographed by Chris Johns, National Geographic photographer, and published in the September 1995 issue of National Geographic Magazine (Royte, 1995).

Manena and akoko grew in the montane dry forest zone, but in limited numbers. Both are designated as species of concern (SOC) by the USFWS. Only 11 manena trees were known to exist during the survey period. Their distribution was restricted to a narrow band of forest in the Waihou area, generally between 3,220-3,760 feet elevation. An undetermined number of akoko trees were scattered across the ahupuaʻa, generally below 4,200 feet elevation. The largest individuals were restricted to elevations above 4,000 feet, particularly around Potato Hill.

Lowland Dry Forest: Lowland mesic and dry forests in leeward locations were considered by Rock (1913) to be the richest of all Hawaiian forests in terms of tree species. At PWW, this zone begins at about 3,000 feet and extends down to about 1,000 feet elevation. Lama (*Diospyros sandwicensis*) and ʻohiʻa were the dominant tree species, occurring in both mixed and pure stands. Other less common trees included alaheʻe (*Psydrax* [*Canthium*] *odoratum*), wiliwili (*Erythrina sandwicensis*), and ʻohe makai (*Reynoldsia sandwicensis*). The rare lama and lama/kauila plant communities were restricted to this zone. These woodlands have been greatly damaged by fire, cattle, and feral animals during the past 150 years.

Endangered plants found in the lowland dry forest were kauila (*Colubrina oppositifolia*), ma‘o hau hele (*Hibiscus brackenridgei* ssp. b*rackenridgei*), uhiuhi (*Caesalpinia kavaiensis*), koki‘o (*Kokia drynarioides*), and halapepe (*Pleomele hawaiiensis*). The rare koai‘a (*Acacia koaia*), was also present. Descriptions of PWW’s lowland dry forests and information on their floristic composition were presented in detail by W. Takeuchi (1991) and The Nature Conservancy (l992).

Coastal Zone: This zone extends from the high-water mark inland to about 1,000 feet elevation. Introduced trees have replaced most native vegetation in this zone. Plants like coconut palms (*Cocos nucifera*) are strongly influenced by salt water, ocean spray, and brackish springs. Native plants found here 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 in 1993 by The Nature Conservancy (1993). No endangered plants were found in the coastal zone.

Rare Plant Taxa

At least 40 rare plant taxa have been reported from the PWW region to date. Of these, 23 are officially listed as endangered or are proposed for listing as endangered. A great many plants were extirpated from the *ahupua‘a* in the early 1900s. These included *Bonamia menziesii, Diellia erecta, Gardenia brighamii, Ochrosia kilaueaensis, Dissochondrus biflorus, Exocarpus gaudichaudii*, *Mariscus fauriei*, *Neraudia ovata*, *Nesoluma polynesicum*, and *Isodendrion pyrifolium.* Other rare species were extirpated in the last 30 years. The very last wild haha, *Delissea undulata*, hau kuahiwi , ‘ohe mauka (*Tetraplasandra* [*meiandra*] *oahuensis*), and a‘e (*Zanthoxylum kauaense*) were in this group. Propagated seedlings for most species have been outplanted in exclosures.

A few rare species only grew in lava tube openings (skylights) where they were protected from wild and domestic herbivores. This group included *Delissea undulata, Zanthoxylum kauaense*, *Stenogyne angustifolia, Phyllostegia ambigua, and Phyllostegia warshaueri.*

Some rare plants were only represented by a few individuals or a single living colony. These included a‘e (*Zanthoxylum kauaense*) and a‘e (*Z. dipetalum* var. *tomentosum*), akoko, manena (*Pelea hawaiensis*), ‘ohe mauka, opuhe, *Phyllostegia stachyoides*, *P. ambigua*, *P. warshaueri, Stenogyne macrantha*, *Phytolacca sandwicensis*, *Sicyos macrophyllus* and *Vicia menziesii*. These species are prime candidates for in situ germplasm conservation through propagation and outplanting. This action is crucial to prevent their extirpation on Hualalai.

In the early 1900s, ‘ohe mauka was widespread across the ahupua‘a, but not abundant anywhere. Rock (1913) found “a few specimens” in 1909. Mitchell recorded one tree at Waihou (3,700 feet elevation) in 1944. Lennox (1945) observed another individual in 1945 at 3,500 feet elevation. He noted that this tree was nearly girdled by pigs. There are no reported sightings of this tree after 1945. In 1991, I discovered a single ohe mauka tree along the western boundary of the ahupua‘a at 3,900 feet elevation. Over 100 seeds were collected from this tree before it died and planted in containers at the Kamuela Tree Nursery. Only three seedlings successfully germinated. These were outplanted in the rare plant exclosure at the wildlife sanctuary cabin. Only two of these trees survived. Both were fruiting in February 2018.

Other Notable Plants

A few taxa of native plants were unnaturally rare at PWW, but common elsewhere on the island of Hawai‘i. Among these were hoi-kuahiwi (*Smilax melastomifolia*), olomea (*Perrottetia sandwicensis*), ‘aiea (*Nothocestreum longifolium*), ‘ie‘ie (*Freycinetia arborea*), and kanawao (*Broussaisia arguta*). Rock (2013) reported that kanawao was present in 1909 and Mitchell saw it there in 1945. ‘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 (David Woodside, pers. comm.).

Many families of native plants are notable because they contain endemic genera or large numbers of endemic species. Some of the most well-known are lobeliads, mints, sunflowers, and species in the Rue family. Some of the more important groups are summarized below:

Campanulaceae (Lobeliads): Plants in the bellflower family (Campanulaceae, subfamily Lobelioideae) are shrubs or small trees with conspicuous flowers and fleshy fruit. Lobeliads are of interest to botanists because they are the largest group (6 genera, 126 species) of endemic Hawaiian plants to have evolved from a single immigrant ancestor (Givnish et al., 2008). This family includes species in the genera *Brighamia, Clermontia, Cyanea*, *Delissea, Lobelia*, and *Trematolobelia*. Growth form, leaf size and shape, and floral morphology have also undergone extensive changes as these plants adapted to the Hawaiian environment.

Three genera of Lobeliads were represented at PWW: *Delissea*, *Cyanea*, and *Clermontia*. The first two were rare while the latter was common. *Delissea* inhabits 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 prefers forest edges and openings. *Clermontia* was the most abundant lobeliad at PWW, probably because it is best able to withstand habitat disturbance and was apparently unpalatable to introduced herbivores. Flowers of fleshy-fruited (baccate) lobeliads 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 herbs or climbing vines that lack the strong fragrance of mainland species. Members of the mint family were especially well represented at PWW. At least four species of the endemic genera *Stenogyne* (*macrantha, rugosa, sessilis*, and *angustifolia*) and four species of the nearly endemic genera *Phyllostegia* (*ambigua, stachyoides*, *velutina, warshaueri*) were present during the survey period. Two other mints, *P. racemosa* (W. Giffard, 1918) and *S. microphylla* (Rick Warshauer, pers. comm.) were observed at PWW in the past but have not been recorded in recent years. *Phyllostegia ambigua* is a new record for Hualalai and was not known to exist on the mountain before 1993.

Rutaceae (Rue Family): The rue family (Rutaceae) is best known for the edible citrus fruits such as lemons, oranges, and limes. In Hawai‘i, the family is represented by 55 endemic species in three genera: *Pelea, Zanthoxylum*, and *Platydesma.* All have capsular fruit. Three endemic species of *Pelea* were present at PWW (*clusiifolia, hawaiensis*, and *volcanica*). Endemic *Zanthoxylum* species were kawa‘u and a‘e. *Platydesma* was not represented in the PWW flora.

Non-native Plants
Non-native plants readily invade disturbed ecosystems. PWW'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 were fountain grass (*Pennisetum setaceum*), banana poka (*Passiflora mollissima*), silk oak (G*revillea robusta*), daisy fleabane (*Erigeron karvinskianus*), and German ivy (*Delairea odorata*). Weedy plants often formed monotypic stands that displaced native vegetation over large areas. If not controlled, these species can rapidly change native forest structure and composition, resulting 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). Pore (polypores) and gill mushrooms (agarics) attain the greatest size.

Several kinds of pore mushrooms were found at PWW. An exceptionally large species of polypore fungus (*Laetiporus sulphureus*) was common on the trunks of koa and ʻohiʻa trees, primarily in the forest bird sanctuary. These orange colored, stalkless brackets are often called Sulphur shelf mushrooms or chicken of the woods (fig. 7). They are highly edible. Sulphur shelf fungi cause brown rot in 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*), a shelf fungus (*Phaeolus schweinitzii*), and the colorful turkey-tail (*Trametes versicolor*) were also present on branches and logs. Some of these species cause white rot in wood.

Molluscs
Hawaiʻi had 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 the islands (Solem, 1990). Very few malacological surveys have taken place in the islands since the 1930s. The most comprehensive Hawaiian land snail assessment in the last 60 years was reported by Yeung and Hayes (2018). An estimated 752 species of terrestrial gastropods once inhabited the Hawaiian Islands, but many of these are now extinct (Ibid.). Many surviving taxa are threatened or endangered.

The native land snail fauna of Hawaiʻi (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. These are represented by Achatinellidae, Amastridae, Ellobiidae, Endodontidae, Helicarionidae, Punctidae, Pupillidae, Succineidae, and Zonitidae. The smaller group or prosobranchs lack a lung, have only two tentacles, possess a hard or soft operculum and sexes are separate. The latter group is represented by snails in the families Helicinidae and Hydrocenidae (Cowie et al., 1995b).

Ancient Hawaiians had many names for land shells, including kahuli, pupu kuahiwi, and pupu kanioe. There was a widespread belief among these people that tree snails (Achatinellidae) were

able to sing or produce musical sounds (Perkins, 1913). Howarth and Mull (1992) provided an explanation for this belief. They noted that swordtail crickets (*Trigonidium* sp.) sing both day and night from hidden perches and provide the voices for the fabled "singing" tree snails of Hawai'i.

Subfossil Land Snails

PWW 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 mollusc families not represented in the list are Ellobiidae and Punctidae.

Figure 7. Sulphur shelf mushrooms (*Laetiporus sulphureus*) on a koa tree in the forest bird sanctuary.

Deposits of subfossil land snails were encountered in a variety of geological settings. Lava tubes were an unexpected place to find shells of tree snails and other surface-dwelling molluscs. Vegetation harboring these creatures probably fell into skylights or snails may have been washed into cave openings during storms. Subfossil shells were usually found on the floors of lava tubes, and generally near skylights. Greater numbers of preserved shells occurred in surface 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 individuals were Pohooho, Pu'u iki, and an unnamed cone inside *Delissea* exclosure.

Shells of 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 (fig. 8).

The most notable deposit of subfossil land shells was discovered in a shallow pahoehoe cave at the base of Poohohoo cinder cone (3,800 ft.). Loose soil containing several hundred well-preserved land snails had accumulated there. Snails in the families Amastridae, Endodontidae, Helicarionidae, and Succineidae were identified in this deposit. The death of these snails may have resulted from the sudden destruction of native vegetation and associated snail fauna. Deposition may have occurred when a widespread wildfire was followed by heavy rains and flooding, causing alluvial material containing snails to flow into the cave. In fact, a large wildfire consumed several hundred acres of koa and 'ohi'a forest above Poohohoo cone about 1908. The scar left on the land can readily be seen on satellite photos dating back to 1984 or earlier. This wildfire event may have caused the sudden death

Figure 8. Subfossil land snail shells collected at PWW. Top row pair (L. to R.): *Partulina confusa*, *Succinea* sp., *Amastra* sp.1. Bottom row pair (L. to R.): *Amastra* sp. 2, *Amastra* sp. 3, *Leptachatina* sp., *Philonesia* sp., *Endodonta* sp.

of an entire snail population and subsequent accumulation of soil and shells in the cave below Poohohoo.

Henshaw (1904) noted similar deposits of subfossil shells at Palihoukapapa, near Mana on Hawai'i Island. He remarked that an extensive forest fire had occurred in the region some 50 years prior to his investigations. Henshaw believed that a probable explanation for the formation of subfossil shell deposits was the sudden destruction of the native vegetation and associated land snails due to fire or another catastrophe. The dead shells then accumulated in low places before being buried by subsequent soil deposition.

A large, endemic tree snail (*Partulina confusa*) was historically known from several areas on Hawai‘i Island. Hawaiians knew it as pupu kolea uka (*lit.*, inland plover shell). H. W. Henshaw (1913) (*in* Pilsbry and Cooke, [1912-1914]) referred to a colony of *Partulina confusa* that existed on Hawai‘i Island (Waimea plains) in 1903. He remarked that this colony had an estimated population size of 75,000 individuals. Henshaw and others harvested 10,000 shells from the colony in just three months.

P. confusa was said to live chiefly upon olopua (*Nestegis sandwichensis*) although in some localities it was abundant on ilima (*Sida* sp.) (Ibid.). Other host plants recorded for this snail

included mamane, ‘ohi‘a, kolea, and kopiko (Hadway and Hadfield, 1999). The color of *P. confusa* shells varied greatly from uniform light gray or distinct brownish gray with or without brown marking on apical whorls. Some individuals were chestnut brown, banded with white or brown (Henshaw, 1913).

P. confusa was apparently common at PWW in the past. There are many of these shells in the Bishop Museum collection on O‘ahu labeled “Puuwaawaa”. Subfossil shells of this species were also frequently found at PWW during the project period. They were collected from several lava tubes (Delissea, Opuhi, and Umi’i Manu) and from under rocks on the slopes of Pu‘u iki cone. Shells were also found in soil and cinder deposits at Waihou, Henahena, and Kileo. Elevation records indicate that shells were distributed within a narrow band of forest (presently ‘ohi‘a, mamane, naio, and koa) from 3,440 to 4,260 feet elevation. Henshaw’s observations confirm that live *P. confusa* snails existed in the Waimea area until at least 1903. It is likely that the species persisted at PWW until about the same time. *P. confusa* is now presumed extinct.

Existing Land Snail Fauna

A few native taxa of living land snails were encountered at PWW, but these were restricted to higher 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 ft.) in October 1992. They included species in the genera *Tornatellaria*, *Lamellidea*, and *Elasmias.* Snails were collected from the leaves of *Ilex anomala*, *Phyllostegia velutina*, *Clermontia clermontioides*, and *Peperomia macraeana.*

A review of malacological records at Bishop Museum revealed numerous accounts of land snails which were collected alive at PWW between 1919 and 1937. These collections included species in the genera *Endodonta, Leptachatina, Lyropupa,* and *Philonesia.* No organized searches for live land snails have been made at PWW 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. Living specimens of the presumed extinct *Leptachatina lepida* were among that group (Cowie et al., 1995a). This species may also persist at PWW.

The introduced European garlic snail (*Oxychilus alliarius*) was extremely abundant at PWW. These ground-dwelling, omnivorous molluscs are said to be a threat to native snails. They were often found on forest vegetation and below skylights in caves. Some passages contained hundreds of individuals. Shells of native snails were generally restricted to cave openings, but garlic snail shells extended far into the dark zone of lava tubes. It is unlikely that they crawled this distance. Garlic snails must have entered passages from above by following tree roots through cracks in the lava. Once inside the lava tube, they died and dropped to the floor.

Empty shells of the nonnative *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 molluscs. The herbaceous European brown snail (*Helix aspersa*), carnivorous *Euglandina rosea*, giant African snail (*Achatina fulica*), and tiny *Subulina octona* were not found during the project period (Appendix C).

Crustaceans

The discovery of terrestrial crab remains in PWW lava tube passages was unexpected. 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 a land-dwelling crab species, were encountered at various elevations (120 to 3,160 ft.) but they were most numerous at about 500 feet. 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 roosted or nested near cave openings, even at low elevations. Carcasses of dead seabirds, eggs, chicks, and fish brought to nestlings were probably introduced into lava tubes. This material certainly provided a rich food supply for scavenging crabs. Native terrestrial crustaceans may have vanished when lowland seabird nesting colonies were extirpated by introduced predators.

There is some confusion regarding the identification of extinct PWW land crabs. One specimen, collected at 3,160 feet elevation, was tentatively identified as *Geograpsus crinipes*, a member of the Grapsidae family (F. Howarth, pers. comm.). However, this crab is supposedly a marine littoral species, so it is unlikely to find one at such a high elevation. Edmondson, (1962) noted that land crabs (Gecarcinidae) identified as *Cardisoma hirtipes* were formerly present on O‘ahu. They were last collected in 1864 but are probably extinct now. This later species looks like the PWW specimens. Further study of Hawai‘i Island crustaceans is warranted before any conclusions can be made regarding their taxonomic classification.

Native 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 the islands. Several genera contain more than 100 species. A remarkable variety of arthropod habitats exists at PWW. These ecological units have moisture regimes ranging from dry to wet and are arrayed across an impressive elevation gradient. Although many of the habitats are degraded due to wildfires, grazing, and invasive species, the forest remnants within them still harbor viable and significant arthropod populations. Most PWW invertebrates are obscure and seldom seen due to their limited distribution, secretive habits, or low population numbers. Others are more numerous and widespread but go unnoticed because of their small size.

Professional entomologists began collecting arthropods at PWW before 1900. Results of their activities were often documented in reports, dissertations, and entomological journals. The following authors contributed information about the region’s arthropod fauna: Koebele (1900 & 1901), Giffard (1918, 1919, & 1925), Fullaway (1920), van Duzee (1936), Swezey (1946 & 1954), Montgomery (1975), Hardy et al. (1980), Asquith (1994), Hoch et al. (1999), Gillespie (2002), Polhemus (2002 & 2004), Daly et al. (2003), Heddle (2003), Liebheer (2008), Tauber et al. (2008), Garb et al. (2009), Percy (2017) and Gillett, et al., (2019). Despite the long history of entomological work in the region, many endemic species still await identification and descriptions.

The exceptional botanical diversity at PWW is complemented by an equally rich endemic arthropod fauna. At least 291 native arthropod species in 65 families were recorded during the

survey period (Appendix D). Species diversity was greatest in Lepidoptera followed by Heteroptera and Coleoptera. Twelve arthropod species collected at PWW were new to science and have not been found elsewhere (PWW endemics). Another five species were new Hawai‘i Island endemics, and one species was a new Hawai‘i Island record, previously known only from the Island of Maui. New species of arthropods collected and identified at PWW are summarized below:

New Species	Family	Status
Hylaeus akoko Magnacca	Colletidae	PWW endemic
Mecyclothorax aa Leibheer	Carabidae	PWW endemic
Mecyclothorax giffini Liebherr	Carabidae	PWW endemic
Nesophrosyne mabae Polhemus	Cicadellidae	PWW endemic
Orthotylus diospyri Polhemus	Miridae	PWW endemic
Orthotylus hedyoticola Polhemus,	Miridae	PWW endemic
Orthotylus nestegiae Polhemus	Miridae	PWW endemic
Orthotylus neopsychotriae Polhemus	Miridae	PWW endemic
Orthotylus xylosmae Polhemus	Miridae	PWW endemic
Oliarus makaiki Hoch	Cixiidae	PWW endemic
Pariaconus pyramidalis Percy	Psyllidae	Hawaii Island endemic
Swezeyana sp. (undescribed)	Psyllidae	PWW endemic
Tetragnatha kukuhaa Gillespie	Tetragnathidae	PWW endemic
Schrankia h*owarthi* Davis&Medeiros	Noctuidae	Hawaii Island endemic
Scotorythra giffini Heddle	Geometridae	Hawaii Island endemic
Scotorythra prestoni Heddle	Geometridae	Hawaii Island endemic
S*cotorythra rivera* Heddle	Geometridae	Hawaii Island endemic
Misumenops aridus Suman	Thomisidae	New island record

Some native arthropods are notable for their rarity, adaptive coloration, unusual behavior, unique host plant associations, spectacular adaptive radiation, strange feeding behavior, or flightless condition. Selected examples are as follows:

Araneae: Spiders in the families of Linyphiidae, Lycosidae, Philodromidae, Saltcidae, Tetragnathidae, Thomisidae, and Theridiidae were common at PWW. The best-known of these species is the comb-footed or happy-face spider (*Theridion grallator*), which was present in the forest bird sanctuary. These tiny (3-4 mm body length) arachnids exhibit a "happy-face" design on the dorsal surface of their abdomen. They were found in the montane mesic and montane dry forest zones. Comb-footed spiders live under plant leaves and 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 victim with a sticky web.

Long-jawed spiders in the genus *Tetragnatha* are common in Hawaiian forests. This group includes web-building (elongate clade) and non-web-building (spiny leg clade) taxa. Spiny leg species are nocturnal hunters that actively move around vegetation in search of prey. Four species of spiny leg *Tetragnatha* were collected during the survey period, including *T. kukuhaa*

which was new to science. This spider is only found at PWW, inhabiting the montane dry forest zone (Gillespie, 2002). A single orb weaver in the acuta clade (*T. kea*) was also collected.

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 Hawai‘i, Thomisid spiders are specialists on leaves, moss, and lichens. They often employ adaptive coloration to match their preferred host plant. At least 11 species are known from the Island of Hawai‘i.

Figure 9. Crab spider (*Misumenops arida*) on koa lichens. Photo by Jessica Garb.

Four species of Thomisid crab spiders were identified at PWW. All were rarely encountered except for *Misumenops anguliventris* which was frequently collected from ‘ohi‘a foliage near the upper boundary of the forest bird sanctuary. Other species were found among the filamentous lichens (*Usnea* sp.) that grow on koa bark (Jessica Garb, pers. comm.). The most surprising discovery was that of *M. aridus* which lives on koa lichens (fig. 9). This species was a new island record, previously known only from Auwahi, Maui (Garb, et. al, 2009).

Coleoptera: The endemic beetle fauna is well represented at PWW. Families with native species were Aglycyderidae, Alleculidae, Anobiidae, Anthribidae, Carabidae, Cerambycidae, Ciidae, Cucujidae, Curculionidae, Dermestidae, Nitidulidae, Scolytidae, and Staphylinidae. Most are wood borers that live under the bark or in the wood of native trees. Dying mamane, koa, akoko, and lama trees were often riddled with holes made by emerging long-horn beetles (*Plagithmysus* spp.) These insects usually do not attack living trees but are attracted to dying individuals. Kolea and sandalwood were often bored by death-watch beetles (*Holcobius* spp.). Long-horn beetles are diurnal while some death-watch species 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 Hawai‘i. 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 observed, and many species are considered rare (Samuelson and Gressitt, 1981). The island of Hawai‘i supports 46 species, the greatest number known from any island. Female plagithmysines oviposit their eggs on the branches and stems of dead or dying woody plants. 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, ‘ohi‘a, mamane, and mamake *(Pipturus albidus*), respectively (Gressitt, 1980). Larvae of Cerambycid beetles are a major source of food for forest birds, particularly honeycreepers (Perkins, 1913). At least twelve

endemic species of *Plagithmysus* beetles have been recorded at PWW. Ten species were collected from associated host plants by DOFAW staff in 1993:

Species	Host
Plagithmysus debilis	*Acacia koa*
Plagithmysus nodifer	*Acacia koa*
Plagithmysus montgomeryi	*Chamaesyce olowaluana*
Plagithmysus blackburni	*Sophora chrysophylla & Santalum paniculatum*
Plagithmysus filipes	*Sophora, Diospyros, Clermontia, & Hibiscadelphus*
Plagithmysus darwinianus	*Sophora chrysophylla and Sapindus saponaria*
Plagithmysus davisi	*Diospyros sandwicensis*
Plagithmysus elegans (*decorus*)	*Charpentiera obovata*
Plagithmysus simplicicollis	*Nothocestrum breviflorum*
Plagithmysus perkinsi	*Myoporum sandwicense*

Plagithmysus blackburni (fig. 10) and *P. filipes* were the most abundant and widespread long-horn beetles. Both species were reared from wood of various native trees, but sandalwood was a new host record for *P. blackburni*. *Plagithmysus davisi* (fig. 11) was uncommon and restricted to lama trees (*Diospyros sandwicensis*). *P. elegans* was only found on papala trees, a species that is almost extirpated at PWW. The natural host plant for *P. simplicicollis* (fig. 12) was not known until 1995 when I reared 13 individuals from dying wood of the endangered ‘aiea tree. These beetles were found from 3,400 to 3,750 feet elevation in montane dry forest habitat. *Plagithmysus elegans* and *P. simplicicollis* are considered rare by the USFWS (SOC). *Plagithmyus bishopi* and *P. mezoneuri* were historically present at PWW but have not been collected in recent years. Their host plants were recorded as alani (*Pelea* spp.) and uhiuhi (*Caesalpinia* [*Mezoneuron*] *kavaiensis*), respectively (Swezey, 1946).

Figure 10. *P. blackburni*

Figure 11. *P. davisi*

Figure 12. *P. simplicicollis*

Weevils in the genus *Rhynchogonus* are represented by two species on the Island of Hawai‘i: *R. giffardi* and *R .stellaris*. Only two specimens of *R. giffardi* are known to exist. The type specimen was collected by W.M. Giffard in 1917 (Giffard, 1918, 1919). It was labeled “N. Kona: Puuwaawaa, 3,700 ft. on *Acacia koa.*” The holotype specimen was collected by D. Anderson in 1937, labeled “Puuwaawaa crater, 3,700 ft on *Osmanthus* or *Pteris*” (Samuelson, 2003). Today, the range of this rare beetle is restricted to a short section of dry gulch (one acre) in the Waikii area (Howarth, pers. comm.). A closely related species (*Rhynchogonus stellaris* Samuelson) occurs in

the Pohakuloa Training Area (PTA), but in exceptionally low numbers. Both species are extremely rare and threatened with extinction.

Ground beetles in the family Carabidae are relatively uncommon at PWW. However, four species were recorded during the survey period. Most notable was the discovery of a new species that inhabits mossy logs in the forest bird sanctuary. This beetle (*Mecyclothorax giffini*) is restricted to montane mesic forests on Hualalai volcano (Liebheer, 2008).

Diptera: True flies were represented by nine families at PWW: Asteiidae, Calliphoridae, Dolichopodidae, Drosophilidae, Muscidae, Phoridae, Pipunculidae, Tephritidae, and Tipulidae. 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 Hawai‘i. At least 111 of these comprise the picture-winged group (Kaneshiro et al., 1995). This interesting assemblage consists of large-bodied flies that have striking maculations on otherwise clear wings.

Nine species of picture-winged flies were recorded at PWW prior to 1969. Surveys conducted in the forest bird sanctuary (4,200 to 5,500 feet elevation) in February, March, and April of 2002 produced only five species of these insects, all observed at sponge-baits. They 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 indicated that picture-winged flies are restricted to the montane mesic forest zone ranging from 4,500 to 5,100 feet elevation. *D. hawaiiensis* was the most abundant species but was not common anywhere. *D. silvestris* was scarce with only two 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.

One picture-wing fly found at PWW (*D. heteroneura*) is considered rare by the USFWS and was listed as endangered on May 9, 2006. This species was last collected near Halepiula rain shed (4,300 ft.) in 1969 (K. Kaneshiro, pers comm.). *D. heteroneura* is known to breed in the bark and stems of *Clermontia*, *Cheirodendron*, and *Delissea undulata.* All three of these plants occurred in the PWWFBS. However, individual plants were widely scattered and were 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 captured at PWW. Flies were reared from the indicated 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 fluxes) (Montgomery, 1975).

Heteroptera: A great number of true bug (heteropteran) species occur at PWW. Families represented were: Anthocoridae, Lygaeidae, Miridae, Nabidae, Pentatomidae, and Scutelleridae. Unusually large species complexes occurred in Lygaeidae (*Neseis* & *Nysius*) and Miridae (*Orthotylus* & *Sarona*). Several rare bugs were found on rare host plants. These included

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 (Scutelleridae) are the largest and most conspicuous Hawaiian members of the true bug family. Nymphs were often found clustered on koa seed pods and adults inhabited green foliage. Specimens of both the green and red color morphs were collected on koa trees from 3,800 to 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 (Pentatomidae) are rarely collected on the Island of Hawai‘i. One species (*Oechalia virgule*) is notable because the male holotype was collected at PWW (3,700 ft.) in August 1917 (Van Duzee, 1936). *O. virgule* has been recorded on various host plants including koa, ‘a‘ali‘i, and naio (Swezey, 1954). Native stinkbugs were collected in the forest bird sanctuary on two occasions during the survey period. One individual (*Oechalia* sp.) was taken on the wing during a wildfire event and the other was beaten from ‘ohi‘a foliage. These bugs are difficult to place at the species level so determinations must await future taxonomic revisions (Dan Polhemus, pers. comm.).

Homoptera: A particularly well-developed homopterous fauna exists at PWW. Families represented by these endemic leafhoppers, planthoppers and plant lice were Cicadellidae, Cixiidae, Delphacidae, and Psyllidae. 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, restricted to dark, underground habitats.

Hymenoptera: This important group of endemic insects is represented at PWW by the following bee and wasp families: Bethylidae, Colletidae, Diapriidae, Eucoilidae, Eulophidae, Ichneuonidae Specidae, and Vespidae. Yellow-faced bee (*Hylaeus* sp.) diversity was exceptional at with 15 species identified to date. This number is more than half of the total species (28) known from Hawai‘i Island. At least six *Hylaeus* species are listed as Species of Concern by the USFWS (November 1999). However, this listing does not reflect the true status of the genus. *H. paradoxicus, H. hula, H. dimidiatus, H. filicum,* and *H. akoko* are considered rare (Karl Magnacca, pers. comm.). *H. paradoxicus* females are the largest native bees and can be easily identified by their size and mahogany red abdomen. *H. akoko* is a new species, only known from PWW (Daly and Magnacca, 2003).

‘Akoko is an important host plant for native bees and wasps. When flowering, this tree can support a great diversity of hymenopterian species. For example, K. Magnacca collected nine species of yellow-faced bees and two species of native potter wasps (*Odynerus* spp.) from a single ‘akoko tree at PWW on August 1, 2002. The host tree was an exceptionally large individual growing below the old Shangri-la cabin at 4,300 feet elevation. Native bees also forage on several other community-dominant plants at PWW including ‘ohi‘a, koa, ‘olapa, naio, mamane, pukiawe, a‘ali‘i, and the po‘ola.

The most serious threat to PWW's native bees, other than habitat loss, is the introduced honeybee (*Apis mellifera*). These highly social insects aggressively displace native bees (Staples and Cowie, 2001) and compete with them for nectar and pollen resources (Daly and Magnacca, 2003). Honeybees are known to travel up to five miles from their hives to forage on a food source (Tripplehorn and Johnson, 2005). 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 Hawai'i, but only two of these, the Kamehameha (*Vanessa tameamea*) and Blackburn (*Udara blackburni*) butterflies are native. Both species were 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 a'ali'i are favored by Blackburn's butterfly. The largest and most showy butterfly at PWW was the non-native monarch (*Danaus plexippus*). This species was 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 Hawai'i.

The small number of endemic butterfly species in Hawai'i 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). 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 (Noctuidae: *Agrotis* and *Peridroma*) may 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 somewhat based on size, but more correctly on relationships. Microlepidoptera refer to all the primitive families, Macrolepidoptera are the advanced families, and Pyraloidea are a distinct superfamily somewhere between the other two. A total of 346 endemic moth species are recorded from the Island of Hawai'i (Nishida, 2002). This number includes taxa that are certainly extinct but does not account for some undescribed and undocumented resident species present in collections.

Moth surveys at PWW documented 92 species of endemic moths in 10 families. This is approximately 27 percent of the island-wide species total. Native Microlepidopterans were represented by genera in the families Batrachedridae (*Batrachedrodes*), Carposinidae (*Carposina*), Cosmopterigidae (*Hyposmocoma*), Oecophoridae (*Thryocopa*), and Tortriacidae (*Cydia*, *Pararrhaptica*, *Spheterista*). Moths in this taxonomic group are particularly difficult to identify and published keys are unavailable for many of the species.

Native macrolepidoptera species generally dominated the PWW moth fauna. This group was 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*). Many of these moths are generally conspicuous and some of the easiest to identify.

Native pyralid moths were represented by a single family (Crambidae). Genera included *Eudonia, Mestolobes, Omiodes, Orthomecyna, Udea,* and *Uresiphita*. Many of these moths are common and primarily associate with native and introduced grasses.

Flight seasons of adult native moths 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 in March and April, while August, September, and October were usually poor trapping months.

Night-flying species of noctuid moths in the genus *Hypocala* exhibit unusual cave-roosting behavior. Perkins (1913) noted that the endemic underwing moth (*Hypocala velans*) commonly hid in caves and crevices of rock walls during the daytime and emerged in great numbers at sunset. Lowland colonies of *Hypocala velans* have now disappeared and this species is extremely rare. I collected a single specimen at PWW in April 1995. The host plant for *H. velans* caterpillars was Hawaiian ebony or lama according to Swezey (1954).

Peridroma albiorbis, another cave-roosting noctuid, is still common in upland forests at PWW and at other locations on the island. In the 1980s, Frank Howarth, a Bishop Museum entomologist, witnessed a huge living colony of undescribed *Peridroma* moths at a high-elevation lava tube on Mauna Loa (about 4,000 meters). He described how moths "darkened the sky" with a large funnel-shaped cloud as they emerged at dusk and flew downslope (Ziegler et al. 2016). In 2000, Dave Bunnell and I found large numbers of mummified *P. albiorbis* scattered throughout the dark zone of Big Red Cave (7,600 ft.) on Mauna Loa (Bunnell et. al, 2000).

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 victim 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 ft.). They perched on various ferns to ambush their prey including hoio (*Diplazium sandwichianum*), loʻulu (*Coniogramme pilosa*), waimakanui (*Pteris excelsa*), and palapalai (*Microlepia strigosa*). Five other species of small moths in the genus *Eupithecia* were also present in the sanctuary. Larvae of all, except *E. monticolens*, are carnivorous ambush predators.

Several uncommon moths were documented at PWW. One of the rarest species on the Island of Hawaiʻi is the red anomis (*Anomis vulpicolor*). This beautiful pink noctuid is listed as a Species of Concern (SOC) and was 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 Kaʻu Forest Reserve, but in exceptionally low numbers. The larvae of red *Anomis*

moths have been collected and reared from ʻulei (*Osteomeles anthyllidifolis*) according to 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 Hawaiʻi Island and was sometimes locally common in the forest bird sanctuary. Its host plant is unknown.

An extremely rare and undescribed geometrid moth, in the endemic genus *Progonostola*, occurs at PWW. In 1995, I collected two individuals at the forest bird sanctuary cabin (4,000 ft.), one was taken in April and another in May. Prior to this, only three other specimens in this genus were collected on the Island of Hawaiʻi.

Blackburn's sphinx moth (*Manduca blackburni*) was considered extinct in the late 1970's (Gagne and Howarth, 1985). In December 1998, this species was rediscovered in the dry forest at PWW (1,800 ft.) by two professional photographers. They found several immature caterpillars feeding on Argentinean tree tobacco (*Nicotiana glauca*) and native ʻaiea leaves. Both trees are in the nightshade family. A few years latter (February 18, 2001), I captured an adult moth in excellent condition at the forest bird sanctuary cabin (4,000 ft.). This individual was attracted to a light trap on the cabin porch.

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 since it is the first record of *Manduca* reproducing on outplanted ʻaiea. No detailed information is available on the current distribution or abundance of *Manduca* at PWW. 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 and critical habitat for this species was designated on June 10, 2003. The Critical Habitat Unit at PWW encompasses 24,597 acres of forest.

Some of the most impressive moths at PWW were non-native species. The black witch (*Ascalapha odorata*) is notable because of its size. This species is said to be the largest moth in Hawaiʻi 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 were captured at PWW. These included 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.

Neuroptera: These predaceous and highly attractive insects are represented at PWW by endemic lacewings and antlions (Chrysopidae: Hemerobiidae, and Myrmeleontidae). The large green lacewings (*Anomalochrysa* spp.) are common in wetter sections of the forest bird sanctuary. Smaller, brown lacewings (*Micromus* spp.) are less abundant, and prefer dryer habitats above and below the koa belt. The rarest and most unusual lacewing on Hawaiʻi Island is a flightless hemerobiid (*Micromus usingeri*). Only four specimens of this unusual insect have been collected since 1935. Two of these were taken at PWW during the survey period. Both were captured in the subalpine zone near Kileo cone. A closely related and rare flightless form of *Micromus longispinosus* was also discovered in the forest bird sanctuary (Tauber et al., 2008). The antlion (*Distolen wilsoni*) was uncommon and appeared to be restricted to the montane dry forest

zone. Specimens were 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. strenuus* were collected in the small reservoir at Poohohoo crater (3,860 ft.) and adults were often seen darting about the forest in search of prey. Native damselflies (*Megalagrion)* are generally common in Hawaiian rain forests, but they appear to be absent at PWW. The lack of suitable habitat (streams and ponds) is probably a limiting factor.

Orthoptera: Hawai‘i 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). Trigonidiinae or sword-tails (*Trigonidium, Prolaupala*, and *Laupala*); Oecanthinae or tree crickets (*Prognathogryllus, Leptogryllus*, and *Thaumatogryllus*); and Nemobiinae or ground crickets (*Caconemobius* and *Thetella*). Terrestrial tree crickets are common in wet forests on the western slope of Hualalai volcano but were rarely encountered at PWW. Sword-tail cricket songs were occasionally heard in and around the forest bird sanctuary. However, a survey conducted by Kerry L. Shaw, a cricket specialist, only collected one unidentified species of *Trigonidium* during the project period. This species was found on PWW cone where they inhabited the olopua (*Nestegis*) montane forest (K. L. Shaw, pers. comm.).

Three species of endemic PWW crickets have adapted to life underground: a tree cricket (*Thaumatogryllus cavicola*), a ground cricket (*Caconemobius varius*), and the barren lava flow cricket (*Caconemobius fori*). Cave-adapted tree crickets (*T. cavicola*) were common in PWW lava tubes. They were easily trapped using baited pit fall traps. Subterranean tree crickets have surprisingly lost the ability to sing and climb trees. They apparently evolved from surface-dwelling species, but their arboreal ancestors are no longer present at PWW.

Non-native Arthropods

Non-native arthropods collected during field work were identified and recorded whenever possible. However, no attempt was made to systematically list all species present. Moths and butterflies were the exception. All lepidoptera species encountered were recorded (Appendix E) .

Non-native arthropods have a profound adverse effect on native ecosystems at PWW. Introduced beetles, thrips, and parasitic gall wasps attack a variety host of plants. Ants, wasps, and other Hymenoptera species prey on endemic invertebrates.

Exotic long-horned beetles (Cerambycidae) were responsible for damage to several species of native trees at PWW. These pests bored holes in the wood of affected plants. The following beetles were reared from the wood of their host trees: *Phoracantha semipunctata* from ‘ohi‘a, *Sybra alternans* from papala, *Lagocheirus undatus* from ‘akoko, and *Curtomerus flavus* from kauila. ‘Ohi‘a is a new host record for *Phoracantha semipunctata.* This beetle generally associates with *Eucalyptus* trees which belong in the same family as ‘ohi‘a (Myrtaceae). Some native trees are likely killed by exotic wood boring beetles.

Other species of invasive insects have infested entire stands of native trees. The naio thrip (*Klambothrips myopori*) was first discovered on Hawai‘i Island in 2009. It rapidly spread to PWW and began attacking naio trees there. In 1992, dense stands of naio were present in Kileo kipuka, especially in the vicinity of Umi‘i Manu Cave. By 2018, thrips had killed most of these trees.

Wiliwili gall wasps (*Quadrastichus erythrinea*) were first seen in Hawai‘i in 2005 and rapidly spread to Hawai‘i Island. These insects produce galls on the leaves and stems of wiliwili, often defoliating trees. A gall wasp parasitoid (*Eurytoma erythrinae*) was released in the Waikoloa Village Dry Forest Unit in 2009 to control the wiliwili gall wasp. Long-term effects of this natural gall wasp predator are yet to be determined.
Ants (Hymenoptera: Formicidae) are capable of decimating entire populations of native Hawaiian invertebrates. Endemic flightless species are especially vulnerable to attack. I sometimes observed ants preying on long-horned beetles (*Plagithmysus* spp.) at PWW. Ants would attack a beetle as it emerged from a wooden pupation cell on the host tree. Multiple ants would grab the beetle by its legs and antennae, biting or stinging the victim until it died.

Yellow-jacket wasps are generalist predators that prey on a wide range of native invertebrates. They are likely responsible for widespread ecological disruption at PWW. Gambino et al., (1987) studied the feeding behavior of adult wasps in Hawai‘i. They observed wasps preying on arthropods in several taxonomic orders. The highest instance of predation was on Araneae, Lepidoptera, Homoptera, Coleoptera, Hymenoptera, and Diptera, respectively.

I vividly remember one incident involving yellow-jacked wasps during a period of prolonged drought at PWW. The wasp population had increased dramatically rainfall declined. I was driving up a road in the forest bird sanctuary (4,500 ft.) and encountered a densely packed stream of yellow-jackets, flying at a high rate of speed, up and down the roadside. There were probably thousands of wasps in this swarm. They were apparently flying between their nest and a plentiful food source in the sanctuary. Any prey insect within the range of this horde would not have had a chance of survival.

Insect-Plant Associations
Many native invertebrates are obligate specialists living on rare host plants. Since some of these plants are, in turn, threatened or endangered, their importance in terms of Hawaiian invertebrate conservation is considerable.

Pollination is a well-known example of an insect-plant association. Arthropods in the orders Coleoptera, Hymenoptera, Diptera, and Lepidoptera are responsible for pollinating many species of plants (Tripplehorn and Johnson, 2005). In Hawai‘i, pollination studies have generally focused on bird/plant associations. The extent of plant fertilization by native insects is poorly known.

Yellow-face bees (*Hylaeus*) are important pollinators of native Hawaiian plants. However, little is known about their role in the process. This is partly due to the bees’ habit of carrying pollen internally. Magnacca (2002) removed the pollen loads from the crops of female yellow-face bees and identified the grains. He found that nearly 70% came from seven community-dominant plants: ‘ohi‘a, ‘olapa, pukiawe, a‘ali‘i, naupaka (*Scaevola* spp.), naio, and mamane. The potential

dependence of common forest plants on bee pollination is a concern because many of the once-common native bee species have declined in recent decades.

Koa supports more endemic arthropod species than any other generic group of Hawaiian trees. Over 100 species of native arthropods utilize koa for various stages of their life cycle. These include the Kamehameha butterfly, Blackburn's butterfly, and koa bug (Swezey, 1954). Koa was widespread at PWW and hosted 19 arthropod species in 14 families. Native species were collected from sap, bark, wood, foliage, flowers, seedpods, and parasitic plants (*Korsalla* sp.) growing on trees. The ecologically dominant ʻohiʻa hosted 16 arthropod species in 10 families. Invertebrates were collected from all parts of the tree. Naio trees were considerably less common than koa and ʻohiʻa but yielded 15 species of arthropods in 11 families.

Several native arthropod species are currently facing local extirpation or extinction at PWW due to the loss of their host plants. Long-horned beetles (*Plagithmysus* spp.) are probably the most impacted as they are highly specialized feeders and many of their host trees are rare or endangered. *Drosophila heteroneura* flies are dependent on lobelias to complete their life cycle, but these plants have been nearly extirpated by wild sheep and domestic cattle. Yellow-faced bees show a marked preference for ʻakoko flowers and may be adversely affected by the loss of these trees. Arthropods most at risk and their associated host plants are as follows:

Species	Hosts
Plagithmysus simplicicollis & *Manduca blackburni*	ʻaiea
Plagithmysus davisi & *Hypocala velans*	lama
Drosophila heteroneura	olapa, ʻoha wai
Plagithmysus elegans	papala
Plagithmysus mezoneuri	uhiuhi
Hylaeus spp. & *Plagithmysus montgomeryi*	ʻakoko
Nesosydne n. sp.	*Cyanea stictophylla*
Nysius sp. (undet.)	*Dubautia plantaginea*
Sarona n. sp.	*Phyllostegia velutina*
Sulamita nr. *dryas*	poʻola

The best and most effective method for conserving PWW's rare arthropod fauna is to focus on protecting and outplanting host plant species that support rare insect associations. Outplanted seedlings should be placed near existing wild individuals and interspersed among them. This will allow natural colonization of the new plants and increase habitat availability for target arthropods. It is also best to avoid application of pesticides on host plants unless necessary. The presence or absence of rare host-dependent insects on new plant communities should be monitored to determine the effectiveness of management actions.

Cave Arthropods

Surface ecosystems are not the only terrestrial habitats utilized by invertebrates. Almost 50 species of cave arthropods have been discovered in Hawaiʻi to date. At least 26 of these are known from the Island of Hawaiʻi (Howarth, 1991). Until recently, scientists thought that animals took millions of years to evolve into cave-adapted forms. In 1971, entomologists were quite surprised

when obligate cave insects and spiders were discovered in lava tubes on the Island of Hawai‘i. 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 arthropods 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. Cave-adapted arthropods are characterized by reduced pigment, small eyes (or eyeless), 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 can 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 PWW includes arthropods in all four ecological groups. At least 11 troglobitic or obligate species have colonized PWW's lava tubes (Appendix F).

Pale colored cave millipedes (*Nannolene* sp.) and centipedes (*Lithobius* sp.) were commonly encountered on the walls and floors of many PWW lava tubes. Millipedes feed on plant material and fungi while centipedes are carnivorous. The non-native garden millipede (*Oxidus gracillis*) outnumbered endemic forms, but these were heavily preyed upon by an introduced red and black reduviid bug (*Haematoloecha rubescens*). Other common cave invertebrates observed were 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 at PWW include a cave-adapted tree cricket (*Thaumatogryllus cavicola*) (fig. 13) and a ground cricket (*Caconemobius* sp.). These insects have reduced eyes and pale colored exoskeletons. They are mute and flightless, living on roots that penetrate cave from above. Both cricket species are considered rare by the USFWS (SOC). The barren lava flow cricket (*Caconemobius fori*) occurs at lower elevations. This species has been collected in the entrance and interior of Barnaby’s Cave near the coast at Kiholo Bay (The Nature Conservancy, 1993).

Some obligate cave species appear to be rare at PWW. 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 its prey in piles of lava breakdown. Lycosid spiders are at the top of the food

Figure 13. Cave tree cricket Thaumatogryllus cavicola). Photo by Bill Mull.

chain and are the largest arthropod predator in subterranean habitats at PWW.

Moths are an abundant and conspicuous group of cave insects at PWW. Their larvae feed on roots and other plant material. A small cave-adapted species (*Schrankia howarthi*) was recently named and described by Medeiros et al. (2009). The unusual aspect of this moth is that it exhibits three different morpho-types. Two types inhabit lava tubes. A small form with greatly reduced pigmentation occurs in the dark zone while a slightly larger variety with moderate pigmentation and weak rhomboid-like markings on the forewings lives in the twilight zone. The lava tube varieties are weak flyers or may be flightless. A slightly larger dark colored morph, with yellow antemedial and postmedial lines on the forewings, occurs above-ground. This surface variety is a strong flyer and is attracted to lights at night. Even though size and pigmentation vary greatly between the three morphs, all males have identical genitalia, and they form a monophyletic group (Matt Medeiros, pers. comm.).

Beetles with morphological adaptations for subterranean existence are relatively uncommon in Hawaiian lava tubes. However, a new species of cave-adapted ground beetle (Carabidae) was discovered in two different lava tubes at PWW. *Mecyclothorax a'a* is a reddish-brown carabid that has pallid cuticle and reduced eyes (Liebheer, 2008). Strangely, specimens can be readily collected in pit fall traps, but are rarely observed underground by collectors.

Cixiid planthoppers are probably the most wide-spread obligate cave species in Hawai'i. At least seven species of cave planthoppers occur on Hawai'i Island (H. Hoch, personal comm.) These insects are smaller and less pigmented than their surface 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).

In July 1995, two cave-adapted planthopper species were found in lava tubes at PWW. The smallest was identified as *Oliarus polyphemus,* a pale, eyeless, short-winged form which is also known from other caves on the island. 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,* an exceedingly rare and recently discovered species known only from a coastal cave at Kiholo Bay (The Nature Conservancy, 1993). The new planthopper was described and named *Oliarus makaiki.* The species epithet refers to the insect's small eyes (Hoch and Howarth, 1999). Only six individuals were obtained during two collecting trips. 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 PWW. *Oliarus makaiki* may have evolved directly from *O. koanoa* or possibly they share a common ancestor (H. Hoch, pers.

comm.). The presence of two obligate planthopper species in the same lava tube is unusual and has not been reported elsewhere (H. Hoch, per. comm.). All species of cave-adapted planthoppers are considered rare even though a considerable amount of apparently suitable habitat exists at PWW. *O. makaiki* is only known from a single cave at the present time (Yellow-jacket Cave, Henahena paddock, 4,000 feet elevation). It was found on ʻohiʻa tree roots growing along cave walls.

Hawaiʻi 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 PWW. Two individuals were collected, one at Umiʻi Manu Cave and another in a cave at Henahena (3,900 ft.). They were found on wet lava rocks in the dark zone of the passages. These slender-bodied, shrimp-like crustaceans lack eyes and are pure white in color. The new, undescribed amphipod (family Talitridae) is significant because it was only the second cave-adapted species to be found in Hawaiʻi. The other species (*Spelaeorchestia koloana*) is restricted to caves on the Island of Kauaʻi (Howarth and Mull, 1992). Both specimens of the PWW cave amphipod were sent to Frank Howarth at Bishop Museum for identification and taxonomic classification. No results were ever received.

Trogloxene insects at PWW include a second species of humpbacked fly (*Megaselia* sp.), pomace 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 intricately woven horizontal sheet webs to capture prey.

Many epigean arthropods are accidental inhabitants of caves. Surface planthopper species are commonly found underground. These insects probably do not breed there, and any nymphs likely perish before reaching the adult stage. *Oliarus koanoa* a, surface planthopper species, was often collected in caves at PWW. Nymphs were found on roots, in wax cocoons attached to roots, and on cave walls and lava rocks. Adults were perched on roots or lava rocks. This same species is abundant on ʻohiʻa, aʻaliʻi, and naio trees growing on the surface.

Avifauna

The first avian species to arrive in Hawaiʻi encountered environmental conditions of extreme geographic isolation, a tropical climate, mountainous topography, and extremes in rainfall and temperature. These conditions encouraged the process known as adaptive radiation and reduced the value of flight. Over time, wing size was reduced, as compared to continental relatives, and a few species became flightless. Several kinds of flightless birds roamed PWW's forests in ancient times. These included large herbivorous geese (*Branta* sp.) and small ubiquitous rails (*Porzana* spp.). The flightless goose was Hawaii's largest land animal, standing about three feet (0.91 m) tall. This species existed until at least 500 years ago, probably grazing on grasses and fern fronds. Flightless rails survived until the 1800s and a few live specimens were collected by early naturalists. All of Hawaii's flightless birds are now extinct, but preserved bones of these animals can still be found in lava tubes scattered throughout the PWW area.

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" (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 subfossils 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.

Avian subfossils 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 Hawai‘i. Some very fragmentary bones of a large, extinct terrestrial goose were found 100 feet below the surface in a water tunnel. The bird showed no close relationship to the modern nene and was named *Geochen rhuax* (Wetmore, 1943). Ash containing the subfossil bones was estimated at 9,000 to 10,500 years old (S. Olson, pers. comm.). Avian paleontology in Hawai‘i 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 Moloka‘i.

Few attempts were made to search for subfossil bird remains on the Island of Hawai‘i prior to 1992. Avian paleontologists assumed that there was little chance of finding preserved birds on such a geologically young island. In July 1992, scientists were amazed when Buck Cobb and I discovered an intact skeleton of an extinct flightless goose in a PWW lava tube. Subsequent surveys uncovered additional bones of flightless geese and remains of other extinct birds. Many of these species were new to science (Giffin, 1993).

Subfossil bird deposits at PWW occur in lava tubes that formed 1,500 to 5,000 years ago. Lava tube skylights and sinkholes created natural pitfalls where flightless and volant birds were trapped over the ages (fig. 14). Perpetual darkness and stable temperature conditions allowed remains to persist in caves for long periods of time, thus facilitating their preservation. Most bird remains were deposited long before rodents or ungulates were introduced to the islands. They probably remained undisturbed for hundreds of years, except for occasional trampling by other victims. Erosion from dripping water, dispersal by flood waters, falling rocks and earthquakes eventually scattered or buried some remains.

During the Polynesian period, rats invaded underground ecosystems and began scavenging on the tissues and bones of freshly trapped animals. This greatly reduced the number of

individuals available for preservation and may be one reason why so few modern birds are found as subfossils. Older bones are leached of most organic matter and are probably of little interest to foraging rodents (Worthy, 1993). Today, subfossil remains may be damaged when large, introduced herbivores like cattle and pigs fall through lava tube openings. Those that survive the fall often roam underground passages, trampling preserved bones on cave floors.

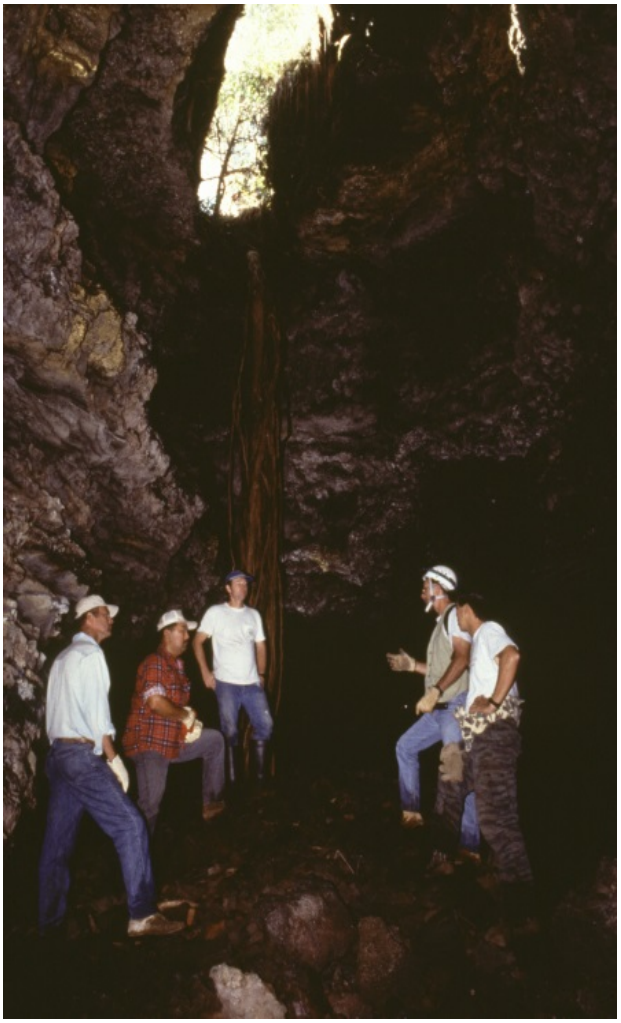


Figure 14. Interior view of a lava tube with overhead skylight that trapped flightless birds. DLNR photo.

It is not known why birds entered lava tubes. Those species that roosted or nested in cave entrances probably fell into passages or were chased into them by predators. Others may have taken shelter in caves during storm or wildfire events. Being unable or unwilling to fly or walk out, they probably wandered into the darken passages, became lost, and died. Subfossil bird remains often consisted of complete skeletons laying exposed on bare rock. However, some bones were found buried in alluvial deposits, or concealed under rock piles. Scattered bones were not uncommon.

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. I observed similar tendencies in Hawaiian caves.

Prehistoric Avifauna

Based on paleontological evidence and modern bird observations, we know that at least 34 taxa of endemic birds existed at PWW (Appendix G). This total does not include seabirds and migratory species. Nine avian species are new to science and only known from the subfossil record. Unfortunately, 10 taxa or 29 percent of the endemic species, including all flightless forms, are now extinct. Families no longer represented in the PWW avifauna include Corvidae, Meliphagidae, and Railidae. Only 12 species of endemic birds are still extant at PWW and more than half of these are rare and threatened with extinction.

Waterfowl: The Hawaiian goose or nene, Laysan duck (*Anas laysanensis*), and Hawaiian duck or koloa (*Anas wyvilliana)* are the only species of waterfowl (Anatidae) historically known from the Hawaiian Islands. However, the subfossil record reveals surprising evidence of a spectacular

evolutionary diversification of endemic Hawaiian waterfowl. 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 (moa-nalos). These flightless birds were the dominant herbivores in Hawai‘i and apparently filled the ecological role of missing native ungulates. Flightless geese and ducks were apparently forest dwellers, grazing and browsing on grasses and fern fronds. Givnish et al. (1994) proposed that lobeliad 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 Hawaiian birds 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, Moloka‘i, and O‘ahu while *Ptaichen* has only been found on Maui. Extinct nene-like geese are also known to have existed on the Islands of Kaua‘i, O‘ahu, and Maui. The Maui form was flightless (Olson and James, 1991).

Geese: Subfossil records reveal that two endemic species of geese inhabited PWW, a flightless species and the nene. Bones of flightless geese found at PWW 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 Hawai‘i, it can be assumed that *G. rhuax* simply increased in size over the past 10,000 years and evolved into the giant flightless goose now known as *Branta rhuax*. Hawai‘i Island flightless geese are morphologically distinct from modern *Branta* species (Olson, 2013). Structural differences in the wing, leg, and skull bones are especially noticeable. Recent DNA studies indicate that these terrestrial birds are related to a subspecies in the large Canada goose complex (E. Paxinos, pers. comm.). Canada geese are regular winter migrants in the Hawaiian Islands.

Extinct flightless geese are the largest terrestrial vertebrates ever found on the Island of Hawai‘i. These birds were over twice the size of the modern nene (*Branta sandvicensis*). They had massive skulls, heavy bodies, stocky legs, and wings too small for sustained flight (fig. 15). Flightless geese were apparently quite common in montane mesic forests at PWW. Remains of over 100 birds were found in lava tubes during the survey period. Distributional of subfossils ranged from 3,000 to 6,000 feet elevation. I also found subfossil goose bones at two other locations on Hawai‘i Island: Honomalino (4,000 ft.) and Manuka Natural Area Reserve (2,500 ft.).

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 y.b.p. while those from Delissea cave yielded a conventional ^{14}C date of 900 + 60 y.b.p. (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.

Figure 15. Comparison of flightless goose and subfossil nene skulls from Ambigua Cave.

Paxinos (1998) aged subfossil bones from three additional flightless geese collected from PWW lava tubes. These samples yielded radiocarbon dates of 510, 870, and 900 y.b.p. Based on these results, it appears that flightless geese survived until 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 recovered from archaeological middens on the Island of Hawai‘i (H. James, pers. comm.).

Flightless geese were a conspicuous component of the native avifauna, yet surprisingly, no legends remain about them. They shared the same habitat with ‘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. Interestingly, there is a locality on Mauna Loa (5,080 ft.), near flightless goose subfossils sites, called Nene nui (*lit*., large goose). Perhaps two species of geese were recognized by ancient Hawaiians, nene nui and nene iki (*lit.*, small goose).

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 birds.

Ducks and Gallinules: The discovery of ancient duck (*Anas* sp.) and gallinule (*Gallinula* sp.) bones in PWW lava tubes was another unexpected event. All subfossil sites were situated in well-drained upland mesic forests, several miles from coastal wetlands. These forests grow on porous ‘a‘a lava flows which are devoid of running surface water or standing pools. Historically known wild ducks like koloa typically feed in ponds and streams. The normal habitat of gallinules includes freshwater ponds, marshes, irrigation ditches, reservoirs, taro patches, and rice fields (Berger,

1972). I am unsure why water birds were utilizing wooded uplands at PWW or what they were doing in lava tubes. Perhaps they flew up from coastal wetlands to forage on endemic land snails. Terrestrial molluscs were extremely abundant at PWW in the past judging by the large number of preserved shells deposited at various sites.

Subfossil duck bones taken from PWW lava tubes were originally thought to be those of the modern koloa. However, they were smaller than that species and morphologically indistinguishable from Laysan duck (*Anas laysanensis*) bones (S. Olson, pers. comm.). Genetic studies using polymerase chain reaction and ancient DNA confirmed that subfossil duck bones were indeed those of the endangered 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 the main Hawaiian Islands. These small ducks were likely nesting and foraging on the forest floor at PWW. Bones of a juvenile bird found at 4,500 ft. elevation confirm breeding activity at that site. Subfossil distribution of PWW Laysan ducks indicates that the range of these birds extended from 3,440 to 5,880 feet elevation. Wild Laysan ducks are no longer present on any of the main Hawaiian Islands, but a small population persists on Laysan Island. These birds have also been translocated to Midway Atoll.

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 passerine birds were among the most significant discoveries in the subfossil record at PWW. It is notable that most songbird bones found were those of extinct species. Remains of present-day birds were seldom encountered as subfossils. Bones of ‘elepaio (*Chasiempis sandwichensis sandwichensis*), ‘apapane, and ‘oma’o were the exceptions. Subfossil remains of all three species were found in PWW lava tubes. ‘Elepaio and ‘apapane still inhabit upland forests in the ahupua‘a, but ‘oma’o are no longer present.

Hawaiian honeycreepers (Fringillidae: Drepanidini) were among the most interesting subfossils discovered in PWW lava tubes. Bones of three extinct species were collected and identified: long billed ‘akialoa (*Hemignathus* n. sp.), giant nukupu‘u (*Hemignathus vorpalis*), and Hawaiian finch (*Telespiza* n. sp.). This later species resembled the modern Laysan finch (*Telespiza cantans*). All three species were new to science and represent important evolutionary records for this interesting group of birds.

In 1992, I discovered several remains of an undescribed long-billed ‘akialoa in Umi‘i Manu Cave (4,600 to 4,800 ft.). This new ‘akialoa was much larger than its historically known relative (*Hemignathus obscurus*) and had a longer beak. Bones of four individuals were collected and

transferred to Storrs Olson and Helen James at the Smithsonian Institution to confirm identification. This interesting species still awaits an original description and naming. Today, the ʻakialoa site supports a montane dry forest dominated by mamane, naio, and ʻohiʻa trees.

In 1993, I discovered the remains of a single giant nukupuʻu in Petrel Cave (Henahena paddock, 3,840 ft.). A partial skeleton was scattered on the lava tube floor, directly below an overhead skylight. These bones were collected and transferred to Bishop Museum in Honolulu (BPBM 179437). The nukupuʻu had a long, scimitar-like maxillary rostrum with a much shorter mandibular rostrum, giving the bird an unusual appearance. The maxilla appears to be adapted for probing in cracks or crevices to obtain invertebrate prey. The bird was much larger than the historically known nukupuʻu (*Hemignathus lucidus),* being about the size of a myna bird (S. Olson, pers. comm.). It is thought to be the largest drepanidine yet known. This new subfossil bird was described and named *Hemignathus vorpalis* by James and Olson (2003).

Paleoecology evidence indicates that *H. vorpalis* preferred forest habitats like its modern relatives. Age of the giant nukupuʻu bones is not known, but radiocarbon dated goose remains found in a nearby cave were 900 years old. Tree molds in the lava surrounding Petrel Cave provide evidence that an ancient forest, consisting of large diameter trees, covered the site just prior to an eruption that formed the lava tube. The original tall forest was inundated by a lava flow approximately 1,500-3,000 years ago, burying all existing vegetation. A secondary forest probably colonized the site before the giant nukupuʻu died in Petrel Cave. Today, the subfossil site supports a montane dry forest dominated by mamane and ʻohiʻa.

Hawaiian finch remains (*Telespiza* n. sp.) were discovered in two different lava tubes at PWW. These were the first Hawaiʻi Island records for the species. Skeletons of two birds were found, one in Owl Cave (760 feet elevation) and the other in Umiʻi Manu Cave (4,600 feet elevation). Lava tubes are situated in lowland dry and montane mesic forests, respectively. I subsequently collected a third *Telespiza* specimen in a subalpine forest on Mauna Kea (Puʻunanaha, 8,800 ft.). The fact that this species was occupying high elevation woodlands is unusual for the genus. Other *Telespiza* species are only known from sites near sea level (H. James, pers. comm.).

Honeyeaters (Meliphagidae) were another group of Hawaiian songbirds recorded in the subfossil record at PWW. Remains of these large, historically extinct birds were recovered from several lava tubes. Two species were identified, the kioea (*Chaetoptila angustipluma*) and Hawaiʻi ʻoʻo (*Moho nobilis*). Neither bird was documented at PWW by early naturalists. These discoveries provide important new distributional records for native honeyeaters. All historically known Hawaiian honeyeaters were thought to have died out between the 1850s and 1890s (Fleischer et al., 2008).

The Hawaiian thrush or ʻomaʻo had a much wider distribution on Hawaiʻi Island in the past. This solitaire was extirpated from Hualalai in historic times but is still present elsewhere on the island. Numerous ʻomaʻo skeletal remains were recovered from PWW lava tubes in lowland dry and montane mesic forests. Elevational range of subfossil sites varied from 700 to 5,880 feet. The occurrence of these bones in lava tubes was not surprising because ʻomaʻo are known to regularly nest in cave entrances.

Endemic crows (*Corvus* spp.) were a major component of PWW's avifauna. The ʻalala or Hawaiian crow (*Corvus hawaiiensis*) persisted in upland forests until 1991 but has since been extirpated. Bones of this bird were not found in lava tubes. However, preserved remains of two other highly unusual corvids were discovered as subfossils in caves. 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 in various habitat types ranging from dry lowland to montane mesic forests. Both new corvid species are extinct and known only from the subfossil record. Neither has been described or named to date (H. James, pers. comm.).

Rails: Subfossil records indicate that flightless rails were one of the most ubiquitous species on the Island of Hawaiʻi. Remains of these small birds have been found from sea level on Hualalai volcano to 8,800 feet elevation on Mauna Kea. At PWW, they inhabited 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 known moho or Hawaiian rail (*Porzana sandwichensis*). Causes of rail extinctions are unknown but may be attributed to a combination of human predation, habitat destruction, and predation by the introduced Polynesian rats (Olson, 1999).

Moho survived into the historic period and were thought to exist until about 1864. These small birds were probably generalized, opportunistic omnivores and may have relied to a considerable extent on land snails for food (Olson, 1999). Perkins (1903) remarked that rails were "formerly a common bird, and on Hawaiʻi widely distributed, since it certainly inhabited both sides of the large island, and was well known to some of the oldest natives on the lee side as to those on the windward." He goes on to say, "Both on Hawaii and Molokai the Moho frequented the open country below the continuous forest, and the open country covered with scrub that lies within the forest belt."

Seabirds: Subfossil records indicate that many kinds of seabirds formerly nested at PWW. Preserved bones of dark-rumped petrel were abundant and wide-spread in lava tubes. Remains of Bonin petrel (*Pterodroma hypoleuca*), band-rumped storm petrel (*Oceanodroma castro*), and Bulwer's petrel (*Bulweria bulwerii* were also present, but in reduced numbers. All four species still exist in Hawaiʻi, but in greatly reduced numbers. 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 may be restricted to other islands in the archipelago.

Seabird populations have suffered less from extinctions than other groups of Hawaiian birds. A small, extinct petrel (*Pterodroma jugabilis*) is the only seabird thought to be extirpated from the native avifauna. Subfossil remains of this bird were found in PWW lava tubes at elevations between 500 and 6,000 feet. Bones were most abundant in passages below lava tube skylights and sink holes. Birds probably nested on ledges and lava cracks in these openings before dying and falling into the passages.

Historic Bird Records
Recorded accounts of bird sightings were reviewed to develop a complete record of the PWW avifauna. Records were found of several species that are no longer present in the ahupua‘a.

‘Akiapola‘au (*Hemignathus wilsoni*) are medium-sized honeycreepers closely related to the extinct *Hemignathus vorpalis*. This species only occurs on the island of Hawai‘i, with the largest population centered on the windward side (Scott et al., 1986). ‘Akiapola‘au were formerly abundant in Kona and inhabited mixed koa-mamane-naio forests. A single specimen was collected at PWW by Wilson in 1887 or 1888, according to Banko (1979). The most recent ‘akiapola‘au sighting on Hualalai was reported by van Riper (1973). He observed a single male on the western side of the mountain (5,500 ft.) in August 1971. Scott et al. (1986) attributed the relative absence of ‘akiapola‘au 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 PWW and persisted until recently. In 1960, the Pu‘uwa‘awa‘a 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.”

George Munro reported that Hawai‘i ‘o‘o were common above Kawa‘aloa, South Kona, in 1891 and 1892. However, the birds disappeared from there by 1894. Munro also mentions that an ‘o‘o “had been heard on the slopes of Mauna Loa near the Hawaii National Park about 1934 but had disappeared after that date” (Munro [1944] 1960). This second party record may indicate that ‘o‘o existed on the island until the early 1900s.

Billy Paris, Pu‘uwa‘awa‘a Ranch foreman, claimed that Hawaii ‘o‘o were present on the ranch until the 1950's. He further noted that the last ‘o‘o was observed at Poohohoo by his uncle Robson Hind in 1957 (pers. comm.). When questioned by me, Billy appeared to be familiar with this conspicuous honeyeater. Hawaii ‘o‘o subfossils collected at PWW lend further support to Paris’ claim. The species may have persisted at PWW long after they were considered extinct.

Water birds were sometimes observed or collected at PWW in the past. Lewin (1971) noted that koloa ducks were occasionally seen in the central portion of Pu‘uwa‘awa‘a Ranch. The occurrence of this species has not been documented by subfossil records, but I can confirm intermittent use of the area by these ducks. Banko (1979) documented the collection of a single ‘Alae-‘ula or Hawaiian gallinule (*Gallinula chloropus sandvicensis*) from Kiholo Bay about 1887. This species is no longer present on the Island of Hawai‘i.

Existing Avifauna
Birds are the dominant form of wildlife found at PWW today. At least 53 native and non-native avian species inhabited the ahupua‘a in 1991 (Appendix H). Thirty of these were passerine species. The endemic birds included five species of honeycreepers, a monarchine flycatcher, nene or Hawaiian geese, i‘o or Hawaiian hawks (*Buteo solitarius*), pueo (*Asio flammeus sandwichensis*), and three species of water birds. The ‘alala or Hawaiian crow was formerly present but is now extirpated from the wild. The Hawaiian thrush or ‘oma‘o (*Phaeornis obscurus*) is noticeably

absent from the area. It occurs in windward forests on the island but has not been recorded on Hualalai for many years.

The five-million-gallon Hauaina reservoir (2,375 ft.) provides suitable habitat for numerous introduced, native, and migratory birds. I have observed thousands of non-native cardueline and estrellid finches flocking to the reservoir for water during periods of drought. Red avadavats (*Amandava amandava*) were especially numerous. Waterfowl and water birds are also attracted the site. Native species recorded by biologists and volunteer bird counters between 1990 and 2021 included nene, Hawaiian coots (*Fulica alai*), and Hawaiian stilts (*Himantopus mexicanus knudseni*), all of which are endangered. Migratory waterfowl and water birds visiting the area included ring-necked ducks (*Aythya collaris*), lesser scaup (*Aythya affins*), pacific golden plovers (*Pluvialis dominica*), wandering tattlers (*Tringa incana*), and ruddy turnstones (*Arenaria interpres*). The indigenous, black-crowned night heron (*Nycticorax nycticorax hoactli*) was also a frequent visitor.

Threatened and Endangered Species

Nene: Hawaiian geese have been recorded at Pu‘uwa‘awa‘a Ranch since the early 1900’s. Flocks of up to 33 birds were sometimes observed near PWW cinder cone in the early 1940's. Ranch lands served as important feeding and breeding sites for these birds. In the past, nene nested in the Waihou and Halekula paddocks from 2,300 to 4,000 feet elevation. Nests were also reported above Halekula in 1941 and at Poohohoo hill in 1942 (Baldwin, 1945). During the survey period, nene nests were often observed at Hauaina reservoir, Pu‘uanahulu ridge, and the adjacent homesteads (1,600 to 2,300 feet elevation).

A total 46 nene were known to be present at Pu‘uwa‘awa‘a Ranch in April 1991. Birds were distributed from 1,600 to 3,200 feet in elevation. DOFAW conducted movement studies of banded birds from 1991 to 1992. Results indicated that at least 13 different individuals were flying between PWW and Hill 6677 on the northern slope of Mauna Loa. That is a straight-line distance of approximately 23 miles. Nene apparently 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.

The Hauaina reservoir provides important habitat for nene. Sometime after 1972, portions of the reservoir shoreline (about 1/2 acre) were planted with Kikuyu grass and mowed regularly by Pu‘uwa‘awa‘a Ranch employees. During the project period, flocks of nene flew to the reservoir morning and evening to drink water and graze on grass along the shoreline. The standing water provided important habitat for nene each spring. Almost all geese in the area took up residency at the reservoir to undergo their annual molt. Birds are flightless at this time of year and used the reservoir to escape from predators and human intruders. Green shoreline grass was the primary food source available to birds during the molting period.

‘Alala: The endangered ‘alala or Hawaiian crow is the only corvid presently found in the Hawaiian archipelago. It is one of the rarest birds in Hawai‘i today. Historically, crows were only known from the Island of Hawai‘i, with the entire breeding population being restricted to the forested slopes of Hualalai and Mauna Loa. Their range extended south from Pu‘uanahulu in North Kona around to Kilauea crater in Ka‘u district. ‘Alala were formerly abundant at PWW. They occupied several habitat types including lowland dry, montane dry, montane mesic, and

subalpine forests. In the 1950's, several pairs were often seen together at Pu‘uwa‘awa‘a Ranch headquarters (B. Paris, pers. comm.). ‘Alala 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 PWW on March 14, 1991. This lone individual was foraging along the western boundary of the forest bird sanctuary at 5,350 feet elevation. The decline of wild ‘alala on Hualalai volcano was documented by Giffin (1983, 1987).

I‘o: Hawaiian hawks were common at PWW during the project period. These birds of prey were often seen hunting in the sanctuary forest and adjacent pasture lands. The population consisted almost entirely of light phase color morphs. The best i‘o breeding habitat at PWW was restricted to a narrow band of montane dry forest near the lower boundary of the forest bird sanctuary. All but one of the 13 nests found during the survey period was situated in that forest and pasture interface. Nests were observed from 3,140 to 4,600 feet in elevation and were constructed in kolea, ‘ohi‘a, or koa trees. Females were noted incubating eggs in April and most young were fledged by mid-July. Little is known about the food habits of adult birds, but they were observed feeding on rodents, game birds, myna birds, ‘amakihi, and pig remains. The Hawaiian Hawk was formerly listed as endangered, but in January 2020 the USFWS published a final rule removing this bird from the list of endangered species. The agency determined that the hawk was no longer threatened or endangered.

Bird Surveys

The Hawaiian Forest Bird Survey (HFBS) was Hawaii’s most important effort to inventory native birds in modern times. This project was sponsored by the USFWS and covered a seven-year period from 1976 to 1983. Surveys were focused on native forest habitats above 3,200 feet elevation on all the main islands, except O‘ahu. Biologists sampled and recorded the occurrence of all bird species detected along transects using the Variable Circular-plot Method (Scott et al., 1986).

In 1978, HFBS transects were established on Hualalai to mark survey routes. Two transects (#48 and #49) passed through the upper portion of Pu‘uwa‘awa‘a Ranch, primarily in the forest bird sanctuary area. Birds were counted along these transects from May 25-28, 1978. In 1990, DOFAW biologists reestablished those two transects and then added two more in 1991 (#1 and #5). Sampling stations were marked at 440 feet (134 m) intervals using hip chains to measure distances.

Bird counts were made on two transects in 1978 (32 sampling stations), the same transects in 1990, and four transects in 1991 (74 sampling stations). Observers walked down the flagged lines, stopping for 8 minutes at each marked station to count birds. All individuals seen or heard were recorded and their detection distances estimated. Bird density estimates were only computed for species which had 30 or more detections. Standard error and variance of counts with less than that number are too high for reliable density estimates (E. Garton and M. Scott, pers. comm.). Forest bird counts were conducted by biologists from various government agencies, including DOFAW, USFWS, HVNP, and a few qualified volunteers.

A total of 14 passerine species were recorded during the 1990 and 1991 forest bird surveys. Of these, six were native and eight were non-native. The endemic passerines, listed in order of abundance were ‘amakihi (*Hemignathus virens*), ‘apapane (*Himatione sanguinea*), ‘i‘iwi

(*Vestiaria coccinea*), Hawai‘i ‘akepa (*Loxops coccineus*), ‘elepaio, and Hawai‘i creeper (*Oreomystis mana*). House finches (*Carpodacus mexicanus*) were the most abundant non-native bird encountered (Giffin, 1990, 1991).

Hawaii ‘amakihi: This small honeycreeper is the most abundant native forest bird at PWW. Amakihi often congregate in small flocks, foraging on fruit and flower nectar. Birds also search for invertebrates while clinging to the bark of trees. These birds are particularly fond of banana poka (*Passiflora mollissima*) flower nectar. ‘Amakihi pierce flower receptacles to obtain the sweet liquid. In fact, most poka flowers in the forest bird sanctuary were damaged by foraging ‘amakihi.

‘Amakihi occurred on all four survey transects in 1991, with 708 birds detected. They were recorded at all elevations but were most abundant from 5,200 to 6,100 feet. Population numbers more than tripled between 1978 and 1990. Estimated density of ‘amakihi in 1978 was 672 birds/km^2. That figure increased to 2,184 birds/km^2 in 1990. This population surge was probably triggered by several events. Cattle were removed from the western side of the sanctuary in 1985 but remained in the eastern side until 1989 when a new section of boundary fence was completed. Cattle removal set the stage for widespread koa regeneration and allowed the dramatic proliferation of banana poka. Improved habitat conditions and increased food supplies likely triggered the dramatic ‘amakihi population increase noted after 1978.

‘Apapane: This nectarivorous honeycreeper feeds primarily on ‘ohi‘a flower nectar, but foliage insects are also taken. These gregarious birds are often seen feeding and flying in small flocks.
‘Apapane occurred on all four survey transects in 1991with 420 birds detected. Estimated density in 1990 was 630 birds/km^2. This figure was 18 percent higher than in 1978. ‘Apapane were detected at all elevations surveyed but were most common from 5,000 to 6,360 feet elevation.

‘I‘iwi: This medium-sized honeycreeper has a sharply decurved orange bill. These birds are primarily nectarivorous, feeding on flower nectar, but they also take foliage insects.

Survey results between 1978 and 1990 indicated that ‘i‘iwi were uncommon in the forest bird sanctuary and population density was declining. Estimated population density in 1978 was 384 birds/km$_2$, but this figure declined to 206 birds/km^2 in 1990. ‘I‘iwi occurred on all four survey transects in 1991 with 118 detections. They exhibited an elevational range from 4,560 to 6,400 feet but were most abundant between 5,000 and 6,100 feet. ‘I‘iwi are of special concern to the USFWS because of declining numbers. On October 20, 2017, the Service determined Threatened status for this species under the Endangered Species Act of 1973.

Hawai‘i ‘akepa: ‘Akepa are insectivorous honeycreepers that glean insects from tree foliage, especially ‘ohi‘a leaf buds and koa phyllodes. They often move about the forest in small flocks. Old growth koa/‘ohi‘a forests are considered essential habitat for Hawai‘i ‘akepa. Field studies conducted at the Hakalau National Wildlife Refuge indicated that ‘akepa are tree cavities nesters. The lack of suitable holes may be a limiting factor for the species. Large diameter trees (over 26

inches DBH) are usually selected for nest construction (L. Freed, pers. comm.). In 1978, 16 Hawaii ʻakepa were counted on the two survey transects. Birds were detected on all four survey transect in 1991 with 22 birds recorded. Bird detections were distributed from 4,700 to 5,580 feet elevation.

ʻAkepa sightings, obtained over a 17-year period (1978 to 1994), were mapped based on incidental observations and survey detections (fig. 16). A total of 64 records were available for mapping. The data indicated that ʻakepa were most abundant from 4,600 to 5,600 feet elevation. The upper and lower limits of distribution ranged from 6,000 to 4,400 feet elevation.

Hawaii ʻelepaio: This small flycatcher inhabits a variety of forest types. ʻElepaio feed on insects and other invertebrates, often capturing them in the air. These bold and curious birds can easily be attracted by imitating their calls. Ancient Hawaiian canoe makers considered ʻelepaio to be a friendly guardian spirit.

ʻElepaio were rarely encountered on forest bird surveys. Ten birds were counted on the two survey transects in 1978, but only 14 were detected on the four transects in 1991. Birds were distributed between 4,620 to 6,100 feet elevation.

Hawaiʻi creeper: This olive-green honeycreeper feeds on insects, spiders, and other invertebrates. They glean arthropods from the trunk and larger branches of ʻohiʻa and koa.

Creepers were the rarest endemic species at PWW. Only nine birds were counted on the two survey transects in 1978. Six birds were counted on three of the four transects in 1991. Creepers were distributed along transects from 5,120 to 5,840 feet elevation.

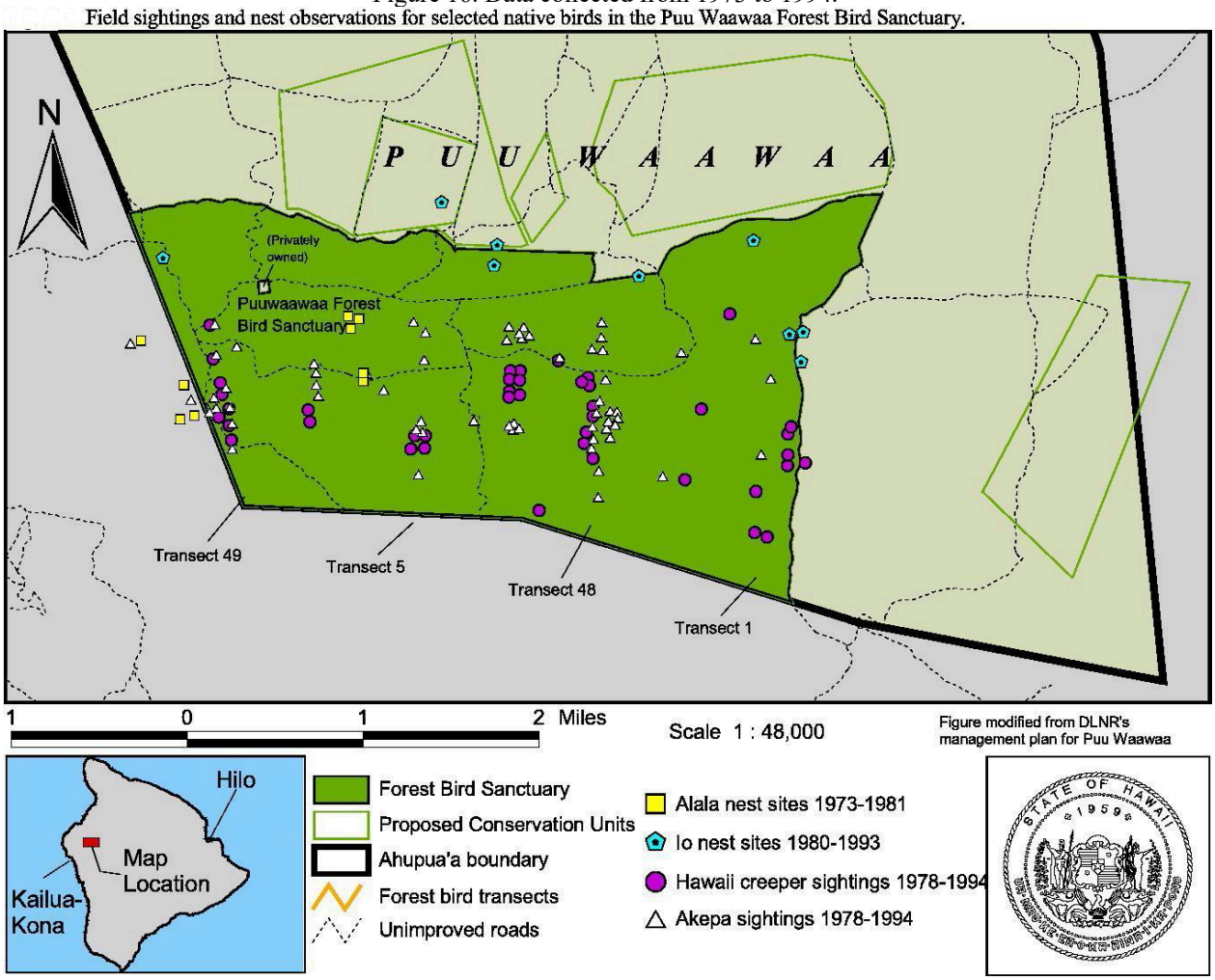
The distribution of creeper sightings from 1978 to 1994 was mapped based on incidental observations and survey detections. A total of 48 creeper detections was available for mapping. These data indicated that creepers were distributed from 4,400 to 6,300 feet elevation. Population density was greatest between 5,000 and 5,700 feet (fig. 16).

Forest bird survey data, for the period 1978 to 1991, indicated an alarming trend in native bird populations. Declining bird numbers were suggested for Hawaiʻi creeper, ʻiʻiwi, and ʻelepaio. Most other species exhibited only small fluctuations in population size during the 14-year bird survey period.

PWW forest bird surveys were repeated in 1996, 2003, and 2009 by Pratt et al. (2010). Their analysis of survey data for the 1978 to 2009 period indicated a declining trend in rare bird detections. By 2009, Hawaiʻi ʻakepa, Hawaiʻi creeper, and elepaio densities had diminished to the point where those species were localized and very rarely detected. Additionally, ʻiʻiwi densities showed a steady decline from 384 birds/km_2 in 1978 to196 birds/km^2 in 2003. Apapane densities changed little, but the Hawaiʻi ʻamakihi population essentially doubled over the same period. The authors believed that populations of Hawaiʻi akepa, Hawaiʻi creeper, elepaio, and ʻiʻiwi were shrinking. They remarked that Hawaiʻi ʻakepa were so rare they “seemed about to disappear altogether.” Additional forest bird surveys were conducted at PWW after 2009.

However, data from these more recent counts have not been analyzed or reported by investigators (Rick Camp, pers. comm., Feb. 22, 2021).

Figure 16. Data collected from 1973 to 1994.



Bird Introductions

Non-native birds: Exotic Game birds have a long history of introductions at PWW. An anonymous Pu‘uwa‘awa‘a Ranch employee reported release dates for the following species: 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 was established in1893. 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 O‘ahu (Anon., 1963)[2]. Only quail, turkeys, peacocks, and Chinese pheasants have persisted until the present time.

[2] Report provided by Chizu Nakamura, Dillingham Corp.

An extensive game bird release program took place at Pu‘uwa‘awa‘a Ranch from 1959 to 1972. At least 33 species of upland game birds were imported from various locations around the world and liberated at that time (Lewin, 1971). Pu‘uwa‘awa‘a Ranch constructed bird congregating units in conjunction with their release program. These fenced plots were supplied 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 record of helminths collected from those birds was reported by Lewin and Holmes (1971).

Some of the liberated game birds became established and rapidly spread around the island. A notable example was the kalij pheasant (*Lophura leucomelana*). Lewin et al. (1984) noted that 67 birds were released at ranch headquarters in 1962. This species dispersed at a rate of 8 km/year and colonized a major portion of mid-elevation forests on the island in 14 years.

Many kinds of songbirds were imported and propagated by Mr. Lowell S. Dillingham, owner of Pu‘uwa‘awa‘a Ranch. Aviaries for these birds were located behind the main ranch house known as Pihanakalani. Cages and birds were maintained by ranch personnel. A former employee, Mr. Sunchiro Yano (pers. comm.), indicated that there was never a deliberate release program for songbirds. He noted, however, that some individuals escaped from their cages in the 1960’s. The entire collection was released when the ranch property was sold to F. Newell Bohnett in 1972. Some of these birds became established in the wild.

No records could be found listing the species of songbirds imported or released at Pu‘uwa‘awa‘a Ranch. However, I suspect that the following species were liberated because early sighting were often restricted to the PWW area: yellow-billed cardinal (*Paroaria capitata*), red-cheeked cordon-bleu (*Uraeginthus bengalus*), lavender waxbill (*Estrilda caerulescens*), saffron finch (*Sicalis flaveola*), warbling silverbill (*Lonchura malabarica*), and yellow-fronted canary (*Serinus mozambicus*). Most of these bird species are now widespread on the island.

Other species of exotic birds became established at PWW over the years. In the 1990s, the most abundant non-native species in the forest bird sanctuary were Japanese white-eyes, house finches, northern cardinals, and red-billed leiothrix, respectively. Japanese bush-warblers (*Cettia diaphone*) were first detected at PWW in 1998. This bird is of interest because it is rapidly spreading on Hawai‘i Island (Pratt et al., 2010). Parakeets and parrots were a minor component of PWW's exotic avifauna. On September 29, 1993, I sighted a flock of 31 parakeets (conures) feeding in the forest bird sanctuary at 5,200 feet elevation. These birds were 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 Kailua-Kona (Kaloko Subdivision). The former owner of the birds indicated that they were imported from South America in 1989 and escaped the same year. These wild parakeets were said to be breeding in deep sinkholes on the western slope of Hualalai (T.L.C. Casey, pers. comm.). I also observed a flock of 13 burrowing parrots (*Cyanoliseus patagonus*) at Halepiula rain shed about 1995.

‘Oma‘o Reintroduction: An experimental translocation of Hawaiian thrush or ‘oma‘o was initiated at PWW in September 1996. This project was a cooperative effort between the Peregrine Fund, USGS Biological Resources Division, and Hawai‘i DOFAW. The primary

objectives of the introduction were to develop and refine recovery procedures for the critically-endangered small Kaua‘i thrush or puaiohi (*Myadestes palmeri*). Puaiohi are the nearest relative of ‘oma‘o. Further, it was hoped that the project would re-establish ‘oma‘o in leeward Hawai‘i where the birds were extirpated sometime after the turn of the century.

A total of 25 captive-reared and 16 wild caught ‘oma‘o were released at PWW during the translocation project. Birds were set free from two hack towers located at 5,400 feet elevation in the central portion of the forest bird sanctuary. Released birds persisted for a few years, and there was some evidence of reproduction, but the species did not become established (Fancy et al, 2001).

Native Mammals

The ‘ope‘ape‘a or Hawaiian hoary bat (*Lasiurus cinereus semotus*) is Hawaii's only historically known native land mammal. This cryptic foliage-roosting creature was originally considered to be a distinct species but is now classified as a subspecies of the U. S. mainland hoary bat (Tomich, 1986). Hawaiian bats are officially listed as an endangered by the USFWS. They occur from sea level to the highest volcanic peaks on Hawai‘i Island.

Sightings of native bats are especially common in the Kona region. These animals tend to concentrate in coastal lowlands during the breeding season (May through October) and migrate to interior highlands during the winter non-breeding season. There is a significant association between bat occupancy and prevalence of mature forest cover (Gorresen et al., 2013). Trees are generally chosen as roost sites, but a few bats have been found in caves.

I frequently observed small numbers of bats (1-3 individuals) at PWW, especially in the forest bird sanctuary. Sightings were made at the sanctuary cabin (4,000 ft.) and above Poohohoo hill (4,250 ft.). These animals were actively feeding on flying insects. Bats were also observed to the east, west and below the PWWFBS from 3,055 to 4,600 feet elevation. These mammals were present almost all year but were most abundant in August. I occasionally saw bats at the Hauaina reservoir (2,375 ft.) They were observed skimming the water surface in mid-day, apparently feeding on low flying insects, or possibly drinking water. No roost sites were ever located, but bats were frequently seen emerging from the sanctuary forest at dusk. Evidence of cave use was also documented at PWW. On April 11, 1994, Helen James (pers. comm.) accidentally flushed a single bat from its roost inside Delissea Cave (4,500 feet elevation). Additional surveys are needed to document the abundance and distribution of these cryptic animals.

Subfossil records confirm that a second, smaller bat species *Synemporion keana* (Vespertilionidae) formerly inhabited the PWW region. Remains of this extinct mammal were collected by researchers at Umi‘i Manu Cave. A single specimen was obtained in 1993 and another in 2000 (4,400 & 6,200 ft., respectively). *S. keana* was apparently present in the Hawaiian Islands by 320,000 years y.b.p. and survived until at least 1,100 years ago and possibly much later. Even though a fair number of fossilized individuals have been found in caves, there is no evidence that this species roosted underground. They may have accidently entered subterranean caverns and became trapped in narrow passages. Bats may have also followed cave-roosting moths and other food sources underground where they became disoriented and lost. The cause of their extinction is unknown (Ziegler et al., 2016).

Non-native Mammals
Prior to 1922, an estimated 21,000 wild goats were present on Pu‘uwa‘awa‘a Ranch. The territorial government assisted the 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).

Three species of game mammals presently inhabit the PWW region: feral sheep (*Ovis aries*), feral goats (*Capra hircus*), and feral pigs (*Sus scrofa*). In 2003, feral sheep were most abundant in upland forests, primarily above Highway 190. Feral goats occurred throughout the PWW region but were most plentiful at lower elevations. Feral pigs were widely distributed, attaining high population numbers in the forest bird sanctuary. All three game species are potentially detrimental to native forest ecosystems. Additionally, feral pigs at PWW are known to carry several pathogenic parasites and diseases, creating a public health hazard. Serological evidence collected by DOFAW in 1971 indicated that brucellosis (*Brucella suis*) was infecting 38 percent of the 16 animals tested. Feral pigs in the forest bird sanctuary are also infected by Pseudorabies (Nick Agorastos, per. com.).

Non-game animals were also widespread at PWW. These included small Indian mongooses (*Herpestes auropunctatus*), Polynesian rats (*Rattus exulans*), roof rats (*Rattus rattus*), house mice (*Mus domesticus*), feral cats, and feral dogs. All species are considered detrimental to native ecosystems. Wild dogs were widespread in early 2003. Packs of these animals are considered dangerous as they sometimes attack livestock and humans. A pack of three wild dogs attacked a DOFAW employee near Umi‘i Manu Cave during the project period. He escaped injury by shooting one the dogs.

Final Comments
I hope that the information presented in this document conveys some sense of appreciation for the extraordinary natural history treasure that PWW offers the people of Hawai‘i. The ahupua‘a provides important habitats for the protection and survival of endemic plant and wildlife species, presents opportunities for the restoration of rare natural communities; and offers significant scientific, cultural, recreational, and historic resources. The same attributes which make PWW suitable for scientific research also make it appropriate for structured environmental education. These lands certainly deserve protection, rehabilitation, and study for the benefit of future generations.

ACKNOWLEDGMENTS

Numerous individuals contributed their time and expertise to this project. Those who played a major role in botanical surveys and plant identification were Jim Jacobi, Linda Cuddihy Pratt, Rick Warshauer, Carolyn Corn, and Derral Herbst, Joel Lau, Warren Herb Wagner, Jr., and Nick Agorastos.

Taxonomic expertise for identifying arthropods was provided by the following individuals: Al Samuelson (Coleoptera), James Liebherr (Carabidae), David Foote (Drosophila), Robert Peck (Ichneumonidae), Dan Polhemus (Heteroptera), Hannelore Hoch and Manfred Asche (Homoptera), Karl Magnacca (Colletidae), Mandy Heddle, Steven Montgomery, Francis Howarth, Will Haines, and Matt Mederios (Lepidoptera), Maurice & Catherine Tauber (Neuroptera), Jonathan Brown

(Tephritidae), Rosemary Gillespie and Jessica Garb (Araneae), and Diana Percy (Psyllidae). Francis Howarth, Keri (Williamson) Shingleton, Hannelore Hoch, Manfred Asche, and Fred Stone aided in the identification of cave-adapted arthropods.

Michael Scott, Paul Banko, Thane Pratt, Stephen Mountainspring, Steven Fancy, Cameron Kepler, Reginald David, and Tim Burr were instrumental in organizing and conducting forest bird surveys. Michael Scott, Stephen Mountainspring, and Steven Fancy assisted with data analysis and other technical aspects of forest bird surveys.

Biological surveys of lava tubes and identification subfossil bird remains would not have been possible without the help of Robin Hulce, Barbara Schaefer, William “Buck” Cobb, Bern Szukalski, Nevin and Judy Davis, Storrs Olson, Helen James, Carla Kishinami, and Robert Covington. Lava tube systems were mapped and photographed by Doug and Hazel Medville, Don Coons, Peter and Anne Bosted, and other members of the Hawai‘i Speleological Society.

Robert Covington assisted with all aspects of the field work. Michael Constantinides, Mike Donoho, Edith Adkins, and Elliott Parsons generously provided editorial expertise and assisted in preparing maps and figures for this document. My special thanks to all of you.

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

Plants are listed in taxonomic groups and then alphabetically by family, genus, and species. Taxonomy follows the Manual of the Flowering Plants of Hawaii by Wagner et al. (1999) and Revised Checklist of Hawaiian Pteridophytes by Wagner and Wagner (1993). All plant species listed here were present during the 1990 to 2002 survey period, except for underlined taxa. Those were reported from earlier surveys.

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	lo‘ulu	*
Doryopteris decora	kumunlu	*
Pellaea ternifolia	lau-kahi, cliffbrake	I
Pteris cretica	owali	I
Pteris excelsa	waimakanui	I
Pteris irregularis		*
ASPLENIACEAE		
Asplenium adiantum-nigrum	iwa‘iwa	I
Asplenium contiguum		*
Asplenium cookii (*A. polyodon*)		*
Asplenium fragile var. *insulare*		E*
Asplenium trichomanes	owali	I
Asplenium unilaterale	pamoho	I
Asplenium praemorsum		I
Diellia erecta (TNC, 1992)		X*
BLECHNACEAE		
Sadleria cyatheoides	ama‘u	*
CYATHEACEAE		
Cibotium glaucum	hapu‘u	*
Pteridium decompositum		*
DENNSTAEDTIACEAE		
Hypolepis punctata ssp. hawaiiensis		*
Microlepia strigosa	palapalai	I
Pteridium decompositum (P. aquilinum)	kilau, bracken fern	*
DRYOPTERIDACEAE		
Athyrium microphyllum	‘akolea	*
Athyrium sandwichianum		*
Cyrtomium caryotideum	ka‘ape‘ape	I
Cyrtomium falcatum		*?*
Diplazium sandwichianum (Athyrium)	ho‘i‘o	*
Dryopteris fusco-atra		*
Dryopteris glabra	kilau	*
Dryopteris hawaiiensis		*
Dryopteris unidentata	‘akole	*
Dryopteris wallichiana	laukahi	I
Elaphoglossum paleaceum (E. hirtum)	‘ekaha-ula	I
Elaphoglossum wawrae	‘ekaha-ula	*

TAXON	COMMON NAME	STATUS
Nothoperanema rubiginosa (Ctenitis rubiginosa)		*
Polystichum hillebrandii		R*
Tectaria cicutaria ssp. *gaudichaudii*		*
GLEICHENIACEAE		
Dicranopteris linearis	uluhe	I
GRAMMITIDACEAE		
Grammitis hookeri		I
LINDSAEACEAE		
Sphenomeris chinensis	pala‘a	I
NEPHROLEPIDACEAE		
Nephrolepis *exaltata*	kupukupu	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 (TNC, 1992)		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 (David Woodside)	‘ie‘ ie	IX
POACEAE (Grass Family)		
Agrostis sandwicensis	grass	*
Deschampsia nubigena	grass	*
Dissochondrus biflorus (TNC, 1992)	grass	X*
Eragrostis deflexa (TNC, 1992)	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	*
APIACEAE (Parsley Family		
Sanicula sandwicensis (N. Agorastos)	snake root	*
APOCYNACEAE (Dogbane Family)		
Alyxia oliviformis	maile	*
Ochrosia kilaueaensis (TNC,1992)	holei	EX*
AQUIFOLIACEAE (Holly Family)		
Ilex anomala	kawa‘u	I
ARALIACEAE (Ginseng Family)		
Cheirodendron trigynum	‘olapa	*
Reynoldsia sandwicensis	‘ohe makai	S*
Tetraplasandra [meiandra] *oahuensis*	‘ohe mauka	*
Tetraplasandra hawaiiensis (Rock, 1913)	‘ohe	*
T. [*Pterotropis*] *kavaiensis* (Mitchell, 1945)	‘ohe‘ohe	*
(The above species noted as “Rare, at 3,800 ft., Waihou”)		
ASTERACEAE (Sunflower Family)		
Bidens menziesii ssp. *filiformis*	ko‘okoolau, ko‘olau	*
Bidens micrantha ssp. ctenophylla (TNC, 1992)		R*
Dubautia ciliolata	na‘ena‘e, kupaoa	*

TAXON	COMMON NAME	STATUS
Dubautia linearis	na‘ene‘e, kupaoa	*
Dubautia plantaginea	na‘ene‘e, kupaoa	*
Dubautia scabra	na‘ena‘e, kupaoa	*
Gnaphalium sandwicensium	‘ena‘ ena	*
Lipochaeta subcordata	nehe	*
Tetramolopium humile		*
CAMPANULACEAE (Bellflower Family)		
Clermontia clermontioides	‘oha wai	*
Cyanea stictophylla	haha	E*
Delissea undulata ssp. undulata	no common name	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 (TNC, 1992)		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)		
Leptecophylla 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	*
Antidesma pulvinatum (Mitchell, 1945)	hame	*
Antidesma platyphyllum (Rock, 1913)	hame	*

TAXON	COMMON NAME	STATUS
FABACEAE (Pea Family)		
Acacia koa	koa	*
Acacia koaia	koai‘a	S*
Caesalpinia kavaiensis	uhiuhi	E*
Canavalia galeata (Rock, 1913)	‘awikiwiki	*
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
HYDRANGEACEAE (Hydrangea Family)		
Broussaisia arguta (Rock, 1913; Mitchell, 1945)	kanawao	*
LAMIACEAE (Mint Family)		
Phyllostegia ambigua	mint	*
Phyllostegia stachyoides (N. Agorastos)	mint	*
Phyllostegia racemosa (R. Warshauer)	kiponapona	EX*
Phyllostegia velutina	mint	E*
Phyllostegia warshaueri (N. Agorastos)	mint	E*
Plectranthus parviflorus	‘ala‘ ala wai nui	I
Stenogyne angustifolia	mint	E*
Stenogyne macrantha	mint	S*
Stenogyne microphylla (R. Warshauer)	mint	X*
Stenogyne rugosa	ma‘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

TAXON	COMMON NAME	STATUS
MENISPERMACEAE (Moonseed Family)		
Cocculus trilobus	huehue	I
MORACEAE (Mulberry Family)		
Streblus pendulinus	a‘ia‘i	I
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	*
Peperomia tetraphylla	`ala`ala wai nui	I
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	*

TAXON	COMMON NAME	STATUS
PORTULACACEAE (Purslane Family)		
Portulaca sclerocarpa	ʻihi	EX*
RANUNCULACEAE (Buttercup Family)		
Ranunculus mauiensis (N. Agorastos)	makou	R*
RHAMNACEAE (Buckthorn Family)		
Alphitonia ponderosa	kauila	S*
Colubrina oppositifolia	kauila	E*
ROSACEAE (Rose Family)		
Fragaria chiloensis ssp. *sandwicensis*	ʻohelo papa	S*
Osteomeles anthyllidifolia	ʻulei	I
Rubus hawaiensis	ʻakala	*
Rubus macraei	ʻakala	S*
RUBIACEAE (Coffee Family)		
Psydrax odoratum	alaheʻe	I
Coprosma ernodeoides	kukaenene	*
Coprosma menziesii	pilo	*
Coprosma montana	pilo	*
Coprosma rhynchocarpa	pilo	*
Gardenia brighamii (TNC, 1992)	naʻu	EX*
Hedyotis terminalis (Gouldia)	manono	*
Psychotria hawaiiensis	kopiko ʻula, ʻopiko	*
RUTACEAE (Rue Family)		
Pelea clusiifolia	alani	*
Pelea hawaiensis	manena	S*
Pelea volcanica	alani	*
Zanthoxylum dipetalum var. *tomentosum*	kawaʻu	E*
Zanthoxylum hawaiiense (Rock, 1913, TNC, 1992)	heaʻe, aʻe	E*
Zanthoxylum kauaense	aʻe	R*
SANTALACEAE (Sandalwood Family)		
Exocarpus gaudichaudii (TNC, 1992)	hulumoa	RX*
Santalum paniculatum	ʻiliahi, sandalwood	*
SAPINDACEAE (Soapberry Family)		
Dodonaea viscosa	ʻaʻaliʻi	I
Sapindus saponaria	aʻe, manele	I
SAPOTACEAE (Sapodilla Family)		
Nesoluma polynesicum (Rock, 1913)	keahi	IRX
Pouteria sandwicensis	alaʻa	*

TAXON	COMMON NAME	STATUS
SOLANACEAE (Nightshade Family)		
Nothocestrum breviflorum	ʻaiea	E*
Nothocestrum longifolium	ʻaiea	*
Solanum americanum	popolo	I?
Solanum incompletum (TNC, 1992)	popolo ku mai	E*
STERCULIACEAE (Cacao Family)		
Waltheria indica	ʻuhaloa	I?
THYMELAEACEAE (Akia Family)		
Wikstroemia sandwicensis	ʻakia	*
Wikstroemia phillyreifolia	ʻakia	
URTICACEAE (Nettle Family)		
Neraudia ovata (TNC, 1992)	maʻaloa	X
Pipturus albidus	mamaki	*
Urera glabra	opuhe	*
VIOLACEAE (Violet Family)		
Isodendrion pyrifolium	aupaka	EX
VISCACEAE (Mistletoe Family)		
Korthalsella complanata	hulumoa	I
Korthalsella cylindrica		*
Korthalsella remyana		*

APPENDIX B. PU‘UWA‘AWA‘ CONE PLANT LIST

Data source: Rock, (1911, 1913, 1919), Mitchell (1945), Takeuchi (1991), The Nature Conservancy (1992), and Cornell University Tree Survey (2005).

COMMON NAME	SPECIES	STATUS
Koa	*Acacia koa*	present
‘Ohi‘a	*Metrosideros polymorpha*	present
Mamane	*Sophora chrysophylla*	present
Kopiko	*Psychotria hawaiiensis*	present
Po`ola	*Claoxylon sandwicense*	present
Papala	*Charpentiera obovata*	present
Olopua	*Nestegis sandwicensis*	present
Manele	*Sapindus saponaria*	present
Papala kepau	*Pisonia brunoniana*	present
Pilo	*Coprosma menziesii*	present
Alani	*Melicope hawaiensis*	present
Olopua	*Nestegis sandwicensis*	present
Hoawa	*Pittosporum hosmeri*	present
Kolea	*Myrsine lanaiensis*	present
Kolea	*Myrsine lesertiana*	present
Nehe	*Lipochaeta subcordata*	present
A‘e	*Zanthoxylum dipetalum dipetalum*	present
Halapepe	*Pleomele hawaiensis*	present
‘Ala‘a	*Pouteria sandwicensis*	present
Ili‘ahi	*Santalum paniculatum*	present
Naio	*Myoporum sandwicense*	present
Lobelia	*Delissea undulata*) Rock,1913, 1919	extirpated
Mau‘u	*Eragrostis deflexa* TNC, 1992	extirpated
A‘e	*Zanthoxylum kauaense* Rock, 1913	extirpated
Kului	*Nototrichium sandwicense* (Rock, 1913)	extirpated
Hame	*Antidesma platyphyllum* (Mitchell, 1945)	extirpated

APPENDIX C. NATIVE LAND SNAILS OF PU‘UWA‘AWA‘A

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.

Data Source Codes

CR: Christensen (1983)
JG-F: Subfossil shells collected by J. Giffin - identified by Robert Cowie.
JG-L: Snails live-collected by J. Giffin - identified by Robert Cowie.
CC: Chung and Cowie (1991)
CO: Cowie et al. (1995b)
BM: Bernice Pauahi Bishop Museum Collection.
* Pu‘uwa‘awa‘a is the type locality for these species.

TAXON	SOURCE	LOCATION/ ELEVATION (feet)
ACHATINELLIDAE		
Partulina confusa	BM/JG-F:	Various sites 3,440-4,260
Tornatellaria abbreviata hawaiiensis	CR:	Open forest in PWW region
Tornatellides sp.	JG-L:	Halepiula Waimea paddock 5,200
Elasmias fuscum	JG-L:	Halepiula Waimea paddock 5,200
Lamellidea sp.	JG-L:	Halepiula Waimea paddock 5,200
AMASTRIDAE		
Amastra sp.	JG-F:	Henahena paddock 3,600-4,260
Amastra conica	BM:	
Amastra flavescens	BM:	
Amastra fragosa	BM:	
Amastra modicella	BM:	
Amastra umbilicata pluscula	BM:	
Amastra viriosa	BM:	
Amastra pagodula	JG-F:	Kileo & Henahena 3,800-4,500
Leptachatina (*Angulidens*) *anceyyan*	CR:	PWW found under pua trees
Leptachatina spp. (4+ species)	JG-F:	Kileo/Henahena 3,440-4,500
Leptachatina konaensis	BM:	
ENDODONTIDAE		
Endodonta sp.	CR/JG-F:	Inside Poohohoo crater/shallow cave
Cookeconcha sp.	JG-F:	Inside Poohohoo crater
HELICARIONIDAE		
Euconulus sp.	JG-F:	
Philonesia cicercula	CC:	
Philonesia sp.	CR:	Summit of PWW cone
Philonesia (*Waihoua*) *kaliella**	CR:	PWW region/Waihou (Cowie et al. 1995b)

TAXON	SOURCE	LOCATION/ELEVATION (feet)
HELICINIDAE		
Pleuropoma laciniosa var. *konaense**	CR/ CO:	"PWW near Pu'u Hinahina"/ "PWW Mawai, near Puu Henahena"
PUPILLIDAE		
Lyropupa (*Lyropupilla*) *hawaiiensis*	CR:	Inside Poohohoo crater
Lyropupa (*Mirapupa*) *ovatula kona*	CR:	Puu Iki crater & PWW cone: 3,100
Lyropupa sp.	JG-F:	Inside Delissea exclosure
Nesopupa (*Nesopupilla*) *dispersa*	CR:	PWW cone: 3,100-3,3 50
Nesopupa (*Infranesopupa*) *subcentralis*	CR:	Mt. Hualalai: 6,000-7,000
Nesopua (*Nesodagys*) *wesleyana*	CR:	PWW region
Nesopua (*Limbatipupa*) *newcombi*	CR:	PWW region: 3,200
SUCCINEIDAE		
Succinea spp.	JG-F:	Kileo & Henahena 3,340-4,500
Succinea konaensis	BM:	
ZONITIDAE		
Striatura meniscus	CR:	Near PWW cone: 3,250
Nesovitrea hawaiiensis	CR:	No location given

APPENDIX D. NATIVE ARTHROPODS OF PU‘UWA‘AWA‘A (Except Cave-Adapted Species)

Taxonomy follows the Hawaiian Terrestrial Arthropod Checklist (fourth edition) by G.M. Nishida (ed.). Bishop Museum, 2002.

STATUS CODES:
(E) = endangered species
(C) = candidate for endangered listing
(S) = species of concern
(N) = new Hawai‘i Island record
(R) = rare species with no formal listing
(NS) = new species

INSECTS

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

TAXON	STATUS	COMMON NAME	NOTE/HOST PLANT/CITATION
ANTHRIBIDAE			
Araecerus varians		fungus weevil	reared from *Clermontia clermontioides* wood
CARABIDAE			
Blackburnia kilauea		ground beetle	
Mecyclothorax giffini Liebherr	(NS)	ground beetle	on mossy logs, rare
Mecyclothorax konanus		ground beetle	
Mecyclothorax pele		ground beetle	
CERAMBYCIDAE			
Plagithmysus bishopi	(R)	long-horned beetle	*Pelea* sp. (Koebele, 1901)
P. blackburni		long-horned beetle	*Sophora chrysophylla* & *Santalum paniculatum*
P. darwinianus		long-horned beetle	*Sophora chrysophylla*
P. davisi		long-horned beetle	*Diospyros sandwicensis*
P. debilis		long-horned beetle	*Acacia koa* foliage
P. elegans (*P. decorus*)	(S)	long-horned beetle	*Charpentiera obovata*
P. (Neoclytarlus) filipes		long-horned beetle	*Sophora, Diospyros*, & *Hibiscadelphus*
P. mezoneuri	(S)	long-horned beetle	*Caesalpinia kavaiensis* (Swezey, 1946)
P. (*Neoclytarlus*) *montgomeryi*		long-horned beetle	*Chamaesyce olowaluana*
P. (*Neoclytarlus*) *nodifer*		long-horned beetle	*Acacia koa*
P. perkinsi		long-horned beetle	*Myoporum sandwicense*
P. simplicicollis	(S)	long-horned beetle	*Nothocestrum brevifolium*
CIIDAE			
Cis sp.		minute tree-fungus beetle	*Myoporum*, *Cheirodendron*, & *Myrsine* bark
Cis sp.		minute tree-fungus beetle	*Acacia koa*
CUCUJIDAE			
Parandrita sp.	(R)	flat bark beetles	*Myrsine lessertiana* bark

TAXON	STATUS	COMMON NAME	NOTE/HOST PLANT/CITATION
CURCULIONIDAE			
Dryophthorus squalidus		true weevil	*Cheirodendron trigynum* wood
Oodemus sp. undet. #1		true weevil	mossy log
Rhynchogonus giffardi	(S)	true weevil	koa & olopua (Giffard, 1918)
DERMESTIDAE			
Labrocerus sp.		dermestid beetle	*Hibiscadelphus hualalaiensis* & Acacia koa
NITIDULIDAE			
Nesopetinus spp.		souring beetle	*Acacia koa* seed pods, *Clermontia*
SCOLYTIDAE			
Xyleborus dubiosus		bark beetles	Trapped (Gillett, et al., 2019)
Xyleborus nubilus		bark beetles	Trapped (Gillett, et al., 2019)
STAPHYLINIDAE			
Undet. taxa #1		rove beetle	
DIPTERA (True flies)			
ASTEIIDAE (Asteiid flies)			
Asteia montgomeryi		fly	*Erythrina sandwicensis* (Hardy et al., 1980)
Asteia sabrosky		fly	*Pisonia, Charpentiera*, *Urera* (Hardy et al., 1980)
CALLIPHORIDAE			
Dyscritomyia spp.		native blow fly	
DOLICHOPODIDAE			
Campsicnemus spp.		long-legged fly	
DROSOPHILIDAE			
Drosophila ciliaticrus		picture-wing pomace fly	reared from *Dracaena*

TAXON	STATUS	COMMON NAME	NOTE/HOST PLANT/CITATION
Drosophila clara		pomice fly	
Drosophila formella		picture-wing pomace fly	
Drosophila hawaiiensis		picture-wing pomace fly	reared from *Myoporum* & *Myrsine lessertiana*
Drosophila heteroneura	(E)	picture-wing pomace fly	
Drosophila iki		pomace fly	
Drosophila imparisetae		pomace fly	
Drosophila multiciliata		pomice fly	
Drosophila murphyi		picture-wing pomace fly	reared from *Cheirodendron*
Drosophila ochropleura		pomice fly	
Drosophila setosifrons		picture-wing pomace fly	reared from *Cheirodendron*
Drosophila silvarentis		picture-wing pomace fly	reared from *Myoporum*
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	*Pelea volcanica* foliage
TEPHRITIDAE			
Trupanea apicalis		fruit fly	*Dubautia linearis*
Trupanea arboreae		fruit fly	*Dubautia linearis*
Trupanea crassipes		fruit fly	light trap
TIPULIDAE			
Linonia spp.		crane fly	

TAXON	STATUS	COMMON NAME	NOTE/HOST PLANT/CITATION
HETEROPTERA (True bugs)			
ANTHOCORIDAE			
Lasiochilus sp. undet. #1		minute pirate bug	*Acacia koa* bark
LYGAEIDAE			
Nesius (Icteronysius) ochriasis maculiceps		lygaeid seed bug	*Sophora chrysophylla*
Neseis fasciata fasciata		lygaeid seed bug	*Coprosma rhynchocarpa*
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?)
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*
Nesiomiris secularis (Gagne, 1997)		mirid leaf bug	*Reynoldsia sandwicensis & Tetraplasandra* sp.
Opuna sp. undet. #1		mirid leaf bug	*Acacia koa*
Opuna sp. undet. #2		mirid leaf bug	*Metrosideros polymorpha* flowers
Opuna sp. undet. #3		mirid leaf bug	*Chamaesyce olowaluana*
Orthotylus diospyri Polhemus	(NS)	mirid leaf bug	*Diospyros sandwicensis* foliage
Orthotylus hedyoticola Polhemus	(NS)	mirid leaf bug	*Hedyotis terminalis* foliage
Orthotylus kanakanus		mirid leaf bug	*Coprosma rhynchocarpa* foliage
Orthotylus metrosideri		mirid leaf bug	*Metrosideros polymorpha*

TAXON	STATUS	COMMON NAME	NOTE/HOST PLANT/CITATION
Orthotylus nestegiae Polhemus	(NS)	mirid leaf bug	*Nestegis sandwicensis*
Ortho. neopsychotriae Polhemus	(NS)	mirid leaf bug	*Psychotria hawaiiensis*
Orthotylus sophorae		mirid leaf bug	*Sophora chrysophylla* foliage
Orthotylus xylosmae Polhemus	(NS, R)	mirid leaf bug	*Xylosma hawaiiense* foliage
Sarona adonias		mirid leaf bug	*Metrosideros polymorpha* foliage
Sarona flavidorsum		mirid leaf bug	*Korsalla sp*. (growing on koa)
Sarona hamakua		mirid leaf bug	*Myrsine lessertiana* foliage
Sarona kau (?)		mirid leaf bug	*Dubautia* sp. (hybrid?)
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	(R)	mirid leaf bug	*Phyllostegia velutina* foliage
Sarona n. sp. #3		mirid leaf bug	*Pelea volcanica* foliage
Sarona undet. sp. #1		mirid leaf bug	*Korsalla* sp. (growing on *Nestegis sandwicensis*)
Sulamita nr. *dryas*	(R)	mirid leaf bug	*Claoxylon sandwicense*
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*
PENTATOMIDAE			
Oechalia virgule	(R)	stink bug	*Dodonaea* & *Myoporum* (Van Duzee, 1936)
Oechalia sp. undet. #1	(R)	stink bug	*Metrosideros polymorpha*
SCUTELLERIDAE			
Coleotichus blackburniae	(S)	koa bug, shield bug	*Acacia koa* foliage

TAXON	STATUS	COMMON NAME	NOTE/HOST PLANT/CITATION
HOMOPTERA (Hoppers, whiteflies, aphids & scale insects)			
CICADELLIDAE			
Nesophrosyne eburneola		leafhoppers	*Claoxylon sandwicense* & *Psychotria hawaiiensis*
Nesophrosyne mabae Polhemus	(NS)	leafhoppers	*Diospyros sandwicensis*
Nesophrosyne pluvialis		leafhoppers	*Coprosma rhynchocarpa*
Nesophrosyne sp. undet. #1		leafhoppers (grey)	*Reynoldsia sandwicensis*
Nesophrosyne sp. undet. #3	(R)	leafhoppers	*Lipochaeta subcordata*
Nesophrosyne sp. undet. #4		leafhoppers	*Myrsine lessertiana*
Nesophrosyne sp. undet. #5	(R)	leafhoppers (black)	*Cyanea stictophylla*
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	(R)	leafhoppers	*Phyllostegia velutina*
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*
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)

TAXON	STATUS	COMMON NAME	NOTE/HOST PLANT/CITATION
Nesosydne sp. undet. #1	(R)	delphacid planthopper	*Cyanea stictophylla*
Nesosydne sp. undet. #2		delphacid planthopper	*Nototrichium sandwicense*
PSYLLIDAE			
Swezeyana elongena		psyllids, plant lice	*Pouteria sandwicensis*
Swezeyana sp. (undescribed)	(NS)	psyllids, plant lice	*Pouteria sandwicensis*
Pariaconus pyramidalis Percy	(NS)	psyllids, plant lice	*Metrosideros polymorpha*
HYMENOPTERA (Bees, wasps & ants)			
BETHYLIDAE			
Sclerodermus sophorae		bethylid wasp	*Myrsine lessertiana* bark
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)
COLLETIDAE			
Hylaeus akoko Magnacca	(NS, R)	yellow-faced bee	*Chamaesuce, Metrosid., Myoporum*, & *Cheirod.*
Hylaeus coniceps	(S)	yellow-faced bee	*Chamaesyce olowaluana*
Hylaeus connectens		yellow-faced bee	*Cham.*, *Claoxylon*, *Metrosideros*, *Acacia*, *Cheirod.*
Hylaeus dimidiatus	(R)	yellow-faced bee	*Chamaesyce olowaluana* & *Acacia koa*
Hylaeus difficilis	(S)	yellow-faced bee	*Chamaesyce olowaluana* & *Myoporum sandwicense*
Hylaeus filicum	(S)	yellow-faced bee	*Chamaesyce olowaluana*, pahoehoe lava
Hylaeus hula	(S)	yellow-faced bee	*Chamaesyce olowaluana*
Hylaeus inquilina		yellow-faced bee	Cleptoparasitic species from pahoehoe lava
Hylaeus kona	(S)	yellow-faced bee	*Myoporum sandwicense*

TAXON	STATUS	COMMON NAME	NOTE/HOST PLANT/CITATION
Hylaeus laetus	(S)	yellow-faced bee	*Chamaesyce olowaluana*, volcanic cinder
Hylaeus ombrias		yellow-faced bee	*Chamaesyce olowaluana*
Hylaeus paradoxicus	(R)	yellow-faced bee	*Cham., Myoporum*, *Cheirodendron*, & *Metrosideros*
Hylaeus pele		yellow-faced bee	*Chamaesyce olowaluana*, *Sophora chrysophylla*
Hylaeus pubescens	(S)	yellow-faced bee	*Cham., Myoporum, Metrosideros, Cheirodendron*
Hylaeus volcanicus		yellow-faced bee	volcanic cinder
DIAPRIIDAE			
Trichopria soror		diapriid wasp	*Pelia volcanica*
EUCOILIDAE			
Hypodiranchis sp.		eucoilid wasp	*Pisonia brunoniana*
EULOPHIDAE		eulophid wasp	*Pisonia brunoniana*
Euderus metallicus			
EUPELMIDAE			
Eupelmus sp.		eupelmid wasp	unknown host
ICHNEUMONIDAE			
Enicospilus lineatus (I.D. by Bob Peck)		parasitoid wasp	*Cibotium glaucum* - dead fern fronds
SPHECIDAE			
Ectemnius polynesialis		square-headed wasp	volcanic cinder
Ectemnius rubrocaudatus	(S)	square-headed wasp	*Metrosideros* foliage
VESPIDAE			
Odynerus undet. #1		potter wasp	*Chamaesyce olowaluana*
Odynerus undet. #2		potter wasp	*Chamaesyce olowaluana*

TAXON	STATUS	COMMON NAME	NOTE/HOST PLANT/CITATION
LEPIDOPTERA (Moths and butterflies)			
BATRACHEDRIDAE			
Batrachedrodes sp.		moth	light trap
CARPOSINIDAE			
Carposina gemmata		moth	light trap
Carposina gracillima		moth	light trap
Carposina graminicolor		moth	light trap
Carposina inscripta		moth	light trap
Carposina nigronotata		moth	light trap
Carposina olivaceonitens		moth	light trap
COSMOPTERIGIDAE			
Hyposmocoma alliterate		moth	light trap
Hyposmocoma agromacha		moth	light trap
Hyposmocoma calva		moth	light trap
Hyposmocoma chilonella		moth	light trap
Hyposmocoma exornata		moth	light trap
Hyposmocoma lignivora		moth	light trap
Hyposmocoma liturata		moth	light trap
Hyposmocoma ossea		moth	light trap
Hyposmocoma subnitida		moth	light trap
Hyposmocoma trimelanota		moth	light trap
Hyposmocoma sp. undet. #1		moth	light trap
Hyposmocoma sp. undet. #2		moth	light trap
CRAMBIDAE			
Eudonia balanopis		moth	light trap
Eudonia platyscia		moth	light trap
Eudonia tetranesa		moth	light trap (new island record)

TAXON	STATUS	COMMON NAME	NOTE/HOST PLANT/CITATION
Mestolobes minuscule		moth	light trap
Mestolobes chlorolychna		moth	light trap
*Omiodes accepta*sugar		cane leafroller	light trap
Omiodes anastreptoides	(S)	moth	light trap
Omiodes Blackburni		coconut leafroller	light trap
Omiodes continualtalis		moth	light trap
Omiodes localis		moth	light trap
Omiodes monogona	(C)	moth	light trap
Orthomecyna sp.		moth	light trap
Orthomecyna epicausta		moth	light trap
Orthomecyna heterodryas		moth	light trap
Orthomecyna metalycia		moth	light trap
Udea calliastra synastra		moth	light trap
Udea endopyra		moth	light trap
Udea stellata (?)		moth	light trap
Udea pyranthes		moth	light trap
Uresiphita polygonalis virescens		moth	light trap
GEOMETRIDAE			
Eupithecia craterias		pug moth	ferns
Eupithecia monticolens		pug moth	*Metrosideros polymorpha* flowers and ferns
Eupithecia orichloris		pug moth	light trap
Eupithecia scoriodes	(R)	pug moth	light trap
Eupithecia staurophragma		pug moth	light trap
Eupithecia stypheliae		pug moth	light trap
Prognostola cremnopis	(R)	moth	light trap
Scotorythra arboricolans		moth	light trap
Scotorythra artemidora		moth	light trap
Scotorythra corticea		moth	reared from *Santalum paniculatum*
Scotorythra demetrias	(R)	moth (Heddle, pers. comm.)	light trap
Scotorythra giffini Heddle	(NS)	moth	light trap
Scotorythra goniastis		moth	light trap

TAXON	STATUS	COMMON NAME	NOTE/HOST PLANT/CITATION
Scotorythra ortharcha	(R)	moth (Heddle, pers. comm.)	light trap
Scotorythra prestoni Heddle	(NS)	moth	light trap
Scotorythra paludicola		moth	light trap
Scotorythra rara		moth	light trap
Scotorythra rivera Heddle	(NS)	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 dislocate		lesser native cutworm	light trap
Agrotis melanoneura	(S)	black-veined agrotis	light trap
Agrotis mesotoxa (?)	(S)	moth	light trap
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	(S)	red anomis noctuid	light trap (listed by USFWS as “possibly extinct”)
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	(R)	moth	light trap
Peridroma albiorbis		moth	light trap
Peridroma cintipennis		moth	light trap
Peridroma coniotis		moth	light trap

TAXON	STATUS	COMMON NAME	NOTE/HOST PLANT/CITATION
Peridroma selenias		moth	light trap
Pseudaletia sp.		moth (undescribed big red)	light trap
Pseudaletia macrosaris		moth	light trap
Schrankia sarothrura		terrestrial species	light trap
Schrankia howarthi		terrestrial morph	light trap
NYMPHALIDAE			
Vanessa tameamea		Kamehameha butterfly	*Pipturus albidus*
OECOPHORIDAE			
Thryocopa indecora		moth	light trap
Thyrocopa adumbrata		moth	light trap
Thryocopa sp.		moth	reared from *Clermontia clermontioides*
OLETHREUTIDAE			
Cydia walsinghami		moth	light trap
Cydia sp.		moth	light trap
PYRALIDAE			
Unadilla humeralis			
SPHINGIDAE			
Hyles wilsoni		sphinx or hawk moth	light trap
Manduca blackburni	(E)	Blackburn hawk moth	light trap & *Nothocestrum brevifolium* foliage
TORTRICIDAE			
Macraesthetica rubiginis		moth	light trap
Pararrhaptica sublichenoides		moth	light trap

TAXON	STATUS	COMMON NAME	NOTE/HOST PLANT/CITATION
NEUROPTERA (Lacewings and antlions)			
CHRYSOPIDAE			
Anomalochrysa hepatica		green lacewing	*Cheirodendron trigynum* & *Acacia koa*
Anomalochrysa debilis		green lacewing	light trap
HEMEROBIIDAE			
Micromus vagus		brown lacewing	light trap
Micromus usingeri	(S, R)	flightless brown lacewing	unknown host
Micromus longispinosus	(R)	flightless form	*Ilex*, *Pelea*, *Metrosideros*
MYRMELEONTIDAE			
Distolen wilsoni		antlion	light trap
ODONATA (Damselflies & dragonflies)			
AESHNIDAE			
Anax strenuous		dragonfly or pinao	breeding in reservoir
ORTHORPTERA (Grasshoppers, katydids, crickets)			
GRYLLIDAE			
Trigonidium sp. (Kerry L. Shaw, pers. comm.)		sword-tail cricket	*Sophora* and *Claoxylon*
PSOCOPTERA (Barklice and booklice)			
PSOCIDAE			
Ptycta sp. (?)		psocids	various trees

TAXON	STATUS	COMMON NAME	NOTE/HOST PLANT/CITATION
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
TETRAGNATHIDAE			
Tetragnatha anuenue		long-jawed spider	unknown host
Tetragnatha kea		long-jawed spider	unknown host
Tetragnatha kukuhaa Gillespie	(NS)	long-jawed spider	tree branches
Tetragnatha quasimoto		long-jawed spider	unknown host
THOMISIDAE			
Misumenops anguliventris		thomisid crab spider	*Metrosideros polymorpha*
Misumenops aridus	(N)	thomisid crab spider	lichens on *Acacia koa* (Garb et al., 2009)
Misumenops nigrofrenata		thomisid crab spider	*Myoporum, Pelea, lichens* (Garb et al., 2009)
Synaema naevigerum		thomisid crab spider	unknown host
THERIDIIDAE			
Theridion grallator		happy-face spiders	leaves
Tetragnatha brevignatha		long-jawed spider	unknown host (green body, spine on abdomen)
PSEUDOSCORPIONES (Pseudoscorpions)			
Undet. taxon		Pseudoscorpion	*Claoxylon sandwicense* foliage
Undet. taxon		Pseudoscorpion	*Acacia koa* bark

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

Taxonomy follows the Hawaiian Terrestrial Arthropod Checklist (fourth edition) by G.M. Nishida (ed.). Bishop Museum, 2002.

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*
CHRYSOMELIDAE	leaf beetles	
Diachus auratus	flea beetle	
Lema trilineata	three-lined potatoe beetle	
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	

TAXON	COMMON NAME	HOST
SCARABAEIDAE		
Copris incertus prociduus	dung beetle	cattle manure
Onthophagus nigriventris	dung beetle	cattle manure
Canthon humectus	bumblebug	cattle manure
SCOLYTIDAE		
Hypothenemus eruditus	bark beetle	*Chamaesyce* wood
Hypothenemus hampei	bark beetle	trap
Xyleborus ferrugineus	bark beetle	trap
Xyleborinus andrewesi	bark beetle	trap
Xyleborinus saxesenii	bark beetle	trap
Xylosandrus crassiusculus	bark beetle	trap
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 ustralis		
Graptostethus manillensis		
Nysius palor		
Pachybrachius vincta		

TAXON	COMMON NAME	HOST
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		
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 honeybee	
BRACONIDAE:		
Rhaconotus vagrans	parasitoid wasp	cerambycid larvae
Doryctinae: undet. taxa	Coleoptera ectoparasite	mamane wood
COLLETIDAE		
Hylaeus albonitens		*Chamaesyce*
ICHNEUMONIDAE		
Diadegma sp.	parasitoid wasp	lepidoptera larvae
Diplazon laetatorius	parasitoid wasp	syrphid fly larvae
Gelis tenellus	hyperparasitoid wasp	other wasps
Pimpla punicipes	parasitoid wasp	
Vulgichneumon diminutus	parasitoid wasp	

TAXON	COMMON NAME	HOST
POMPILIDAE		
Anoplius luctuosus	spider wasp	
SPECIDAE		
Ampulex compressa	emerald cockroach wasp	
VESPIDAE		
Paravespula pensylvanica	yellow-jacket wasp	
ISOPTERA (Termites)		
KALOTERMITIDAE		
Neotermes connexus	forest-tree termite	*Acacia koa, Sophora*
LEPIDOPTERA (Moths & butterflies)		
ALUCITIDAE		
Alucita objurgatella	many-plumed moth	
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	

TAXON	COMMON NAME	HOST
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	
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	

TAXON	COMMON NAME	HOST
NEUROPTERA (Lacewing and antlions)		
HEMERODIIDAE		
Hemerobius pacificus	brown lacewing	
Sympherobius barberi	brown lacewing	
ORTHOPTERA (Grasshoppers, Katydids & crickets)		
TETRIGIDAE		
Paratettix mexicanus	grouse or pigmy locust	
CYCLOPTILOIDES		
Trigonidomorpha sjostedti	sword-tail cricket	*Chamaesyce,* ferns

NON-INSECT ARTHROPODS

ARANEAE (spiders)

CLUBIONIDAE

Cheiracanthium diversum	pale leaf spider	

ISOPODA (isopods, sowbugs, woodlice & pilbugs)

no data

AMPHIPODA (scuds & sandhoppers)

TALIRIDAE

Talitroides sp.	amphipod	soil

DIPLOPODA (millipedes)

PARADOXOSOMATIDAE

Oxidus gracilis	garden millipede	leaf litter

APPENDIX F. CAVE ARTHROPODS OF PUUWAAWAA

Taxonomy follows the Hawaiian Terrestrial Arthropod Checklist (fourth edition) by G.M Nishida (ed.). Bishop Museum, 2002.

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.

TAXON	COMMON NAME	STATUS
INSECTS		
COLEOPTERA (Beetles)		
CARABIDAE		
Mecyclothorax aa Leibheer	ground beetle	TB*, n. sp.
ELATERIDAE		
Conoderus sp.	click beetle	AC, AD
STAPHYLINIDAE		
Nesomedon sp. (undescribed)	rove beetle	TB*
Nesomedon sp. (undescribed)	rove beetle	AC*
COLLEMBOLA (Springtails)		
UNIDENTIFIED FAMILY		
undet. genus/species	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*
KEROPLATIDAE		
Tylparua cf. *hawaiiensis*	fungus gnat	TP?*

TAXON	COMMON NAME	STATUS
MYCETOPHILIDAE		
Leia sp. (unidentified)	fungus gnat	TP? AD
PHORIDAE		
Megaselia sp. (undescribed)	humpbacked fly	TB*
Megaselia sp. (undescribed)	humpbacked fly	TP*
SCIARIDAE		
undet. genus/species	black fungus gnat	TP?*
TIPULIDAE		
Limonia 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 Hoch	planthopper	TB*, n. sp.
Oliarus polyphemus	planthopper	TB*
LEPIDOPTERA (Moths and Butterflies)		
NOCTUIDAE		
Schrankia howarthi	cave moth	TB* n. sp.
ORTHOPTERA (Grasshoppers, Katydids & Crickets)		
GRYLLIDAE: subfamily oeacanthinae		
Thaumatogryllus cavicola	cave cricket	TB*
GRYLLIDAE: subfamily nemobiinae		
Caconemobius varius	cave cricket	TB*

TAXON	COMMON NAME	STATUS

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 G. NATIVE BIRDS OF PU‘U WA‘AWA‘A: PAST AND PRESENT[4]

DATA SOURCE:	POP. STATUS		CONSERVATION STATUS	
F: subfossil record	n.sp.	new species	end	endangered
H: historic account	ext	extinct	thr	threatened
O: field observation	exp	extirpated		
	cur	currently present		

TAXON	COMMON NAME	STATUS
ACCIPITRIDAE (hawks, old world vultures and harriers)		
Buteo solitarius	i‘o or Hawaiian hawk	O: cur
ANATIDAE (ducks, geese, and swans)		
Branta rhuax	giant flightless goose	F: ext, n.sp.
Branta sandvicensis	nene or Hawaiian goose	O: cur, end
Anas laysanensis	Laysan duck	F: exp, end
Anas wyvilliana	koloa duck	O: cur, end
ARDEIDAE (herons)		
Nycticorax nycticorax hoactli	black-crowned night heron	O: cur
CHARADRIIDAE (plovers, turnstones, and surfbirds)		
Pluvialis dominica	Pacific golden-plover	O: cur
CORVIDAE (crows, jays, and magpies)		
Corvus hawaiiensis	‘alala	H: exp, end
Corvus sp.	slender-billed crow	F: ext, n.sp.
Corvus sp.	hammer-billed crow	F: ext, n.sp.
FRINGILLIDAE (Hawaiian honeycreepers)		
Telespiza sp.	Hawaiian finch[5]	F: ext, n.sp.
Hemignathus sp.	long-billed ‘akialoa	F: ext, n.sp.
Hemignathus vorpalis.	giant nukupu‘u	F: ext, n. sp.
Hemignathus munroi	‘akiapola‘au	H: exp, end
Hemignathus virens	common ‘amakihi	O: cur
Himatione sanguinea	‘apapane	O: cur
Oreomystis mana	Hawaii creeper	O: cur, end
Loxops coccineus	‘akepa	O: cur, end
Vestiaria coccinea	‘i‘iwi	O: cur, thr
HYDROBATIDAE (storm-petrels)		
Oceanodroma castro	band-rumped storm petrel	F: exp

[4]All subfossil remains identified by Storrs Olson and Helen James

[5]This species was tentatively listed as palila in Giffin (1993).

TAXON	COMMON NAME	STATUS
MELIPHAGIDAE (honeyeaters)		
Moho nobilis	Hawaii ʻoʻo	F: ext
Chaetoptila angustipluma	kioea	F: ext
MUSCICAPIDAE (old world insect-eaters)		
Chasiempis sandwichensis	ʻelepaio	O: cur
Myadestes obscurus	ʻomaʻo or Hawaiian thrush	F: exp
PROCELLARIIDAE (shearwaters and petrels)		
Pterodroma phaeopygia sandwichensis	dark-rumped petrel	F: exp
Bulweria bulwerii	Bulwer's petrel	F: exp
Pterodroma jugabilis	Petrel	F: ext, n. sp.
Pterodroma hypoleuca	Bonin petrel	F: exp
RALLIDAE (rails, gallinules, and coots)		
Porzana sp.	large Hawaiian rail	F: ext, n. sp.
Porzana sandwichensis	moho or Hawaiian rail	F: ext
Porzana sp.	tiny Hawaiian rail	F: ext, n.sp.
Gallinula chloropus	ʻalae ʻula or gallinule	H: exp
Fulica alai	ʻalae keʻokeʻo or coot	O: cur, end
RECURVIROSTRIDAE (stilts)		
Himantopus mexicanus knudseni	aeʻo or Hawaiian stilt	O: cur, end
SCOLOPACIDAE (sandpipers and waders)		
Arenaria interpres	ruddy turnstone	O: cur
Tringa incana	wandering tattler	O: cur
STRIGIDAE (typical owls)		
Asio flammeus sandwichensis	Pueo or short-eared owl	O: cur

APPENDIX H. EXISTING AVIFAUNA OF PU‘U WA‘AWA‘A: NATIVE AND NON-NATIVE

The species listed below were observed in the PWW area from 1990 to 2002, except for some migratory waterfowl. Birds are listed alphabetically by family and then by genus and species.

STATUS CODES
E = endangered endemic
T = threatened endemic
* = endemic
I = indigenous
V = visitor
O = non-native

TAXON	COMMON NAME	STATUS
ACCIPITRIDAE (hawks and eagles)		
Buteo solitarius	i‘o or Hawaiian hawk	*
ALAUDIDAE (larks)		
Alauda arvensis	Eurasian skylark	O
ANATIDAE (ducks, geese and swans)		
Anas wyvilliana	koloa	E*
Aythya affins	lesser scaup	V
Aythya collaris	ring-necked duck	V
Branta sandvicensis	nene	E*
ARDEIDAE (herons)		
Nycticorax nyticorax hoactli	black-crowned night heron	I
CHARADRIIDAE (plovers and lapwings)		
Pluvialis fulva	Pacific golden plover	V
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*

TAXON	COMMON NAME	STATUS
DREPANIDIDAE (Hawaiian honeycreepers)		
Hemignathus virens virens	Hawai‘i ‘amakihi	*
Himatione sanguinea	‘Apapane	*
Loxops coccineus coccineus	Hawai‘i ‘akepa	E*
Oreomystis mana	Hawai‘i creeper	E*
Vestiaria coccinea	‘i‘iwi	T*
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	lavender waxbill	O
Estrilda troglodytes	black-rumped waxbill	O
Lonchura malabarica	warbling silverbill	O
Lonchura punctulata	nutmeg manikin	O
Padda oryzivora	Java sparrow	O
Uraeginthus bengalus	red-cheeked cordon blue	O
FRINGILLIDAE (cardueline finches)		
Carpodacus mexicanus	house finch	O
Serinus mozambicus	yellow-fronted canary	O
MIMIDAE (mimic thrushes and allies)		
Mimus polyglottos	northern mockingbird	O
MONARCHIDAE (monarch flycatchers)		
Chasiempis sandwichensis	‘elepaio	*
MUSCICAPIDAE (Insect-eaters)		
Cettoa diphone	Japanese bush-warbler	O
PASSERIDAE (old world sparrows)		
Passer domesticus	house sparrow	O
PHASIANIDAE (francolins, pheasants, and quail)		
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

TAXON	COMMON NAME	STATUS
Lophura leucomelana	kalij pheasant	O
Meleagris gallopavo	wild turkey	O
Pavo cristatus	common Peafowl	O
Phasianus colchicus	ring-necked pheasant	O
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
RAILLIDAE (rails, gallinules, coots)		
Fulica alai	Hawaiian coot	E*
RECURVIROSTRIDAE (Avocets and stilts)		
Himantopus mexicanus knudseni	Hawaiian stilt	E*
SCOLOPACIDAE (sandpipers, waders)		
Arenaria interpres	ruddy turnstone	V
Heteroscelus incanus	‘ulili or wandering tattler	V
STRIGIDAE (typical owls)		
Asio flammeus sandwichensis	pueo	*
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