U.S. FISH AND WILDLIFE SERVICE
Pacific Islands Office, Ecological Services

SURVEYS OF ARTHROPOD AND GASTROPOD DIVERSITY IN THE GEOTHERMAL RESOURCE SUBZONES, PUNA, HAWAI'I.

submitted to:

Andrea Campbell
Department of Energy
Oak Ridge National Laboratory
P.O. Box 2001
Oak Ridge, Tennessee 37831-8600

by:

Stephen E. Miller, Jeff Burgett, and Marie Bruegmann
United States Fish and Wildlife Service
Pacific Islands Office
Ecological Services
P.O. Box 50167
Honolulu, Hawaii 96850

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SUMMARY

The invertebrate surveys reported here were carried out as part of ecological studies funded by the Department of Energy in support of their environmental impact statement (EIS) for the Hawai'i Geothermal Project. Currently, preparation of the EIS has been suspended, and all supporting information is being archived and made available to the public. The invertebrate surveys reported here assessed diversity and abundance of the arthropod and gastropod fauna in forested habitat and lava tubes in or near the three geothermal resource subzones. Recommendations for conservation of these organisms are given in this report.

Surveys were conducted along three 100-m transect lines at each of the six forested locations. Malaise traps, baited pitfall traps, yellow pan traps, baited sponge lures, and visual examination of vegetation were used to assess invertebrate diversity along each transect line. Three of these locations were adjacent to roads, and three were adjacent to lava flows. Two of these lava-forest locations (Keauohana Forest Reserve and Pu'u 'O'o) were relatively remote from direct human impacts. The third location (Southeast Kula) was near a low-density residential area. Two lava tubes were surveyed. The forest over one of these tubes (Keokea tube) had recently been burned away. This tube was used to assess the effects of loss of forest habitat on the subterranean fauna. An undisturbed tube (Pahoa tube) was used as a control. Over 26,000 arthropod and gastropod individuals in more than 100 families were evaluated in these surveys. Approximately 20% of these invertebrate specimens belonged to endemic (see Table 4, footnote a, for a definition of endemic) taxa (in 36 families). Approximately 70% were individuals belonging to alien taxa (in 44 families). The remaining 10% were specimens belonged to taxa of uncertain status (in 34 families).

These surveys showed that the diversity of endemic arthropod and gastropod taxa is greatest in the relatively intact forest associated with the higher elevations of the Middle East Rift (upper) geothermal resource subzone. This area also supports the greatest number of native plant species. While endemic diversity was lower in more disturbed lower elevation locations associated with the Kamaili (mid-elevation) and Kapoho (lower elevation) geothermal resource subzones, abundances of alien and endemic arthropods were highest in these areas. For the lava-tube fauna endemic diversity and abundance was highest in undisturbed Pahoa tube. Living roots that penetrate into the tubes and form the base of the food chain were five times more abundant in the Pahoa tube, as compared to the Keokea tube. Thus, loss of forest habitat is directly related to subterranean ecosystem vitality.

Recommendations offered in this report direct geothermal development away from areas of high endemic diversity and abundance, and toward areas where natural Hawaiian biotic communities have already been greatly disturbed. These disturbed areas are mainly found in the lower half of the Kamaili (middle) geothermal subzone and throughout most of the Kapoho (lower) geothermal subzone. These recommendation may also generally apply to other development projects in the Puna District.

INTRODUCTION AND OBJECTIVES

In 1993, the U.S. Department of Energy (DOE) contracted the U.S. Fish and Wildlife Service, Pacific Islands Ecoregion (Service) to conduct biological surveys of the geothermal resource subzones on the Island of Hawai'i (Fig. 1). These subzones were designated by the State of Hawai'i in 1989. Reports from these surveys were to be included in an environmental impact statement (EIS) being prepared by DOE for the Hawaii Geothermal Project. However, the DOE has suspended the completion of the EIS (Department of Energy, 1994) following a declaration by the State of Hawai'i (State of Hawai'i, 1993) that it no longer supported the Hawai'i Geothermal Project. Currently, the State of Hawai'i supports geothermal development to meet the energy needs of the Island of Hawai'i only. This report (and the bird and plant reports prepared by the Service) will be archived by the DOE and will be made available to the public in public reading rooms in Hawai'i and the mainland. Presented in this report are new field data on the current status of terrestrial invertebrates in or near the geothermal resource subzones, and an assessment of the potential impacts of geothermal development on these invertebrates.

The terrestrial invertebrate fauna of Hawai'i is characterized by its great diversity and its disharmonic composition. Terrestrial pulmonate and prosobranch snails number about 1000 species (Solem, 1990). The terrestrial arthropod fauna is even more diverse, composed of an estimated 10,000 (5,312 described) species of insects, arachnids, myriapods and crustaceans (Howarth and Mull, 1992; Nishida, 1994). Included in the arthropod fauna is a unique assemblage of cave taxa (Howarth, 1987) that is well represented in the geothermal resource subzones. This great diversity is disharmonic, being derived from only 15% of the families of terrestrial insects and 15% of the families of terrestrial snails. Endemism in Hawaiian snails and arthropods is greater than 95%, and most species have limited distributions, being found on single islands and often in a single valley or watershed.

The high extinction rate of Hawai'i`s terrestrial invertebrates is attributed to loss of habitat and the introduction of alien predators and competitors. Solem (1990) estimated that between 65-75% of the terrestrial snails of Hawai'i are extinct, with some groups (e.g. Entodontidae and Amastridae) being 90+% extinct. These high levels of extinction have resulted from direct or indirect human activities coupled with some or all of the following biological traits: high endemism, small geographic distributions, low dispersal capacity, slow growth rates, late age at first reproduction, and low fecundity (Hadfield and Miller, 1989; Hadfield *et al.*, 1993).

Similar levels of extinction may also apply to native Hawaiian arthropods, although extensive documentation is not presently available. For instance, of the 35 species of *Rhyncogonus* weevils, 69% (24) have been identified by the Service as species that may be in need of protection under the Endangered Species Act (U.S. Fish and Wildlife Service, 1994). Many other groups of Hawaiian arthropods are similarly listed by the Service: 53% of the 60 species of *Hylaeus* yellow-faced bees, 52% of the 33 species of *Eopenthes* click beetles, 48% of the 23

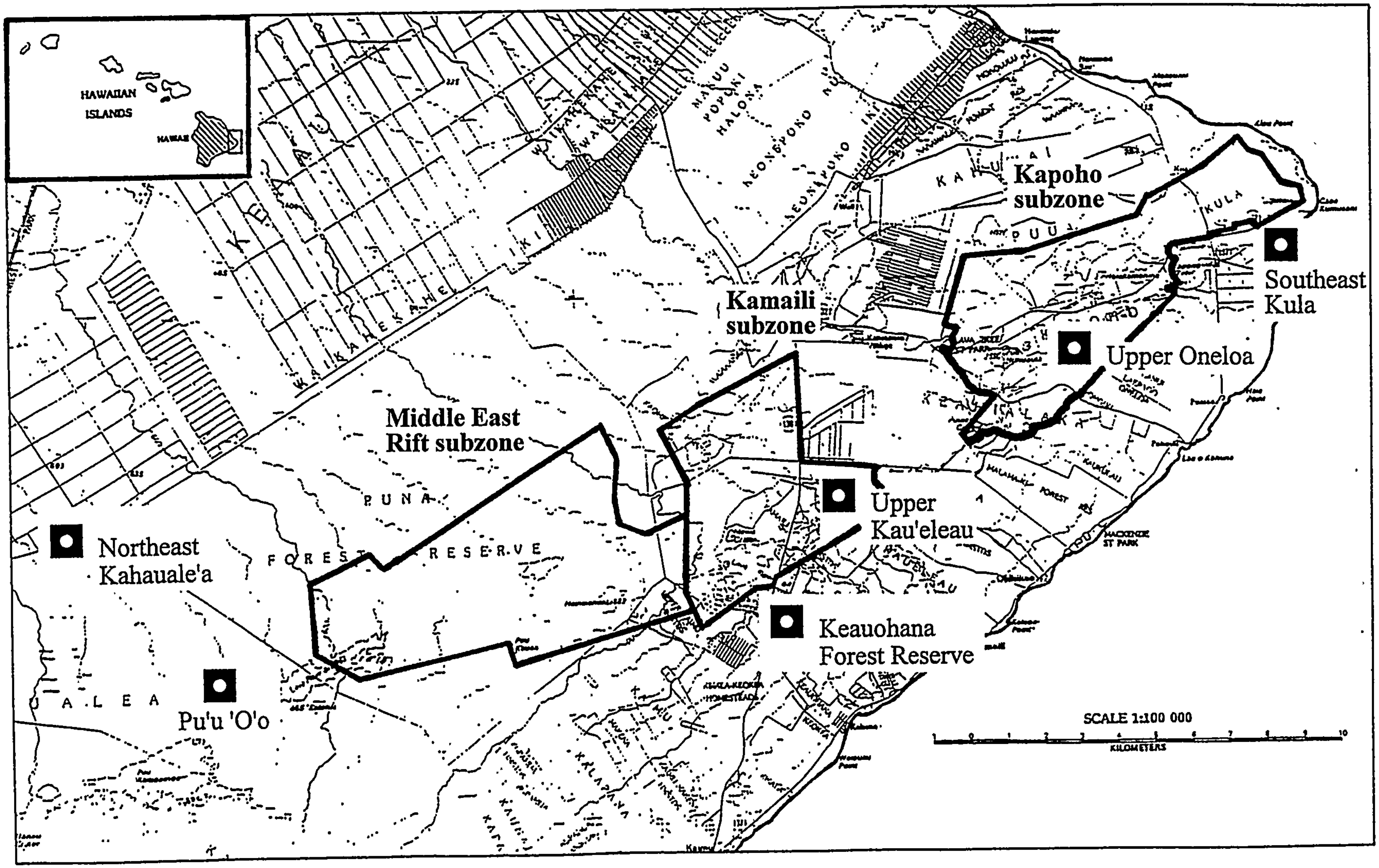

Figure 1. Surveyed locations in or near the three geothermal subzones; Puna District, Hawai'i, 1994. See Table 2 for locations of the surveyed lava tubes.

species of *Omiodes* moths, 46% of the 24 species of *Megalagrion* damselflies, 44% of the 162 species of Hawaiian *Proterhinus* beetles, and 32% of the 129 species of *Plagithmysus* long-horned beetles. Of the 351 Hawaiian arthropod taxa currently listed as candidates for protection under the Endangered Species Act, 75 (21%) are considered to be rare or possibly extinct. This is especially true for Lepidoptera and Hymenoptera, with 65% (22 taxa) and 64% (34 taxa), respectively, being rare or possibly extinct. As with Hawaiian snails, extinctions among these and other groups of Hawaiian arthropods are attributed to loss of habitat and alien predators and competitors (Asquith and Messing, 1993; Asquith and Miramontes, 1994; Gagné and Howarth, 1985).

Terrestrial invertebrates are represented on the Island of Hawai'i by approximately 128 snail species (Cowie, 1994), 1,700 insect species, and 100 other arthropod species (Nishida, 1992). These invertebrates make a significant contribution to ecosystem stability by recycling nutrients, pollinating native plants, and serving as a major food source for birds, bats, and other invertebrates. Despite the obvious need to study these fauna, only one brief systematic survey of terrestrial invertebrates has been done in the vicinity of the geothermal subzones (Nishida and Gagné, 1987). The fauna of Hawaiian lava-tubes (see Materials and Methods for a brief description of Hawaiian lava tubes) in the Puna District has been well sampled for taxonomic studies (Howarth, 1973), but surveys of this fauna in the geothermal subzones are few (McEldowney and Stone, 1991). Studies of invertebrates should be a fundamental part of assessing habitat vitality and biodiversity.

The objectives of this study were to:

1. evaluate arthropod and gastropod diversity and abundance in the geothermal subzones, including the composition of lava-tube fauna;
2. assess the impact of road cuts and lava flows on the abundance and diversity of native and non-native arthropods and gastropods;
3. assess the impact of forest removal on the abundance and diversity of native and non-native subterranean arthropods;
4. present recommendations for geothermal development that will minimize impacts on arthropod and gastropod fauna in the geothermal resource subzones.

Quantitative surveys of gastropods and arthropods in the 21,984 acres of the geothermal resource subzones would require several years of sampling across seasons, elevations, and habitats. The more limited invertebrate surveys presented here focus on arthropods and gastropods sampled from eight locations within or near the geothermal resource subzones. Six forested locations covered the elevation range of the subzones, and two additional locations are representative of mid-elevation lava-tube communities in the Puna area. Limits on funding, field time, and data analysis plus restricted land access represented significant constraints in surveying the invertebrate fauna in these subzones. However, this study provides important data needed to assess the biological impact of geothermal development, and will add to our understanding of the composition and dynamics of rift-zone invertebrate species.

MATERIALS AND METHODS

Sampling strategy and definitions

To accomplish the objectives of this study, invertebrate species were sampled from pairs of locations (disturbed/undisturbed) in or near each of the lower, middle and upper geothermal subzones (Fig. 1) and at two mid-elevation lava tubes (locations confidential). Survey locations were placed at several elevations ranging from 16 m to approximately 700 m, allowing comparisons along an elevation gradient. The types of human-caused disturbances selected for study were road cuts and removal of forest over a lava tube. These disturbances were meant to provide information on the potential effects on invertebrate diversity and abundance that might result from construction of roads and well pads associated with geothermal development. Paired locations for the forest surveys consisted of two forested areas, one adjacent to a road and the other adjacent to a lava flow. Thus, invertebrate diversity and abundance associated with a man-made disturbance (*i.e.*, a road cut) could be compared to that associated with a natural disturbance (*i.e.*, a lava flow). The single pair of subterranean locations were selected to compare invertebrate diversity and abundance in a disturbed lava tube (*i.e.*, overstory forest removed) to an undisturbed tube (*i.e.*, overstory forest intact).

For the purposes of this study, a "disturbed" forest location was defined by the presence of a road-cut next to an otherwise unmanipulated forest. An "undisturbed" location was defined by the presence of a recent lava flow (1955 or later) next to unmanipulated forest. Three locations were selected as undisturbed and three locations were selected as disturbed. For surveys of the subterranean lava-tube fauna, a disturbed location was defined as a lava tube in which the root system from the overlying forest had been destroyed by removal of the forest. The forest overlying the single disturbed lava tube selected for study had been burned away in March 1992. The single undisturbed lava tube selected for study had a well developed root system from a forest of mixed alien and native plants.

Selection of sampling locations

Access to all of the lands in the geothermal resource subzones was not available. Permission for access was requested from over 370 landowners in the geothermal subzones. Sixty percent of these landowners responded to our letters of access. Of these respondents, approximately 79% granted access for biological surveys. However, the Middle East Rift (upper elevation) geothermal subzone was almost entirely held by a single landowner, who denied access to this land. Table 1 gives the approximate composition of each subzone and of the areas available for surveys.

Table 1. Approximate composition of geothermal resource subzones and the areas available for field surveys; Puna District, Hawai'i, 1994. Areas (hectares) were estimated from aerial photographs taken during January-March 1992 and January-March 1993.

Coverage	Geothermal resource subzones (percent of total area)		
	Kapoho (lower)	Kamaili (middle)	Middle East Rift (upper)
Total subzone area[a]	2,977	2,242	3,689
Unforested lava flows	750 (25%)	250 (11%)	130 (4%)
Native forest	140 (5%)	1,322 (59%)	3,550 (96%)
Agricultural, urban, etc.	2,087 (70%)	670 (30%)	9 (0.2%)
Area available for surveys[b]	2,288 (77%)	730 (33%)	35 (1%)
Unforested lava flows	755 (25%)	7 (1%)	0 (0%)
Native forest	46 (2%)	540 (24%)	2 (0.1%)
Agricultural, urban, etc.	1,487 (50%)	183 (8%)	33 (0.9%)

a. Total areas for each geothermal subzone were obtained from the State of Hawaii (1989).

b. Access to land was dependent on written permission from the landowner.

Much of the land available for surveys did not meet criteria set for disturbed and undisturbed study locations. In order to meet these criteria, several locations were near to, but outside the boundaries for geothermal development (Fig. 1). Specifically, Pu'u 'O'o (a lava-forest location) and Northeast Kahauale'a (a road-forest location) were outside of the Middle East Rift (upper elevation) subzone because almost all of this subzone was unavailable for surveys. These two survey locations are probably ecologically similar to the forest along the upper boundary of the Middle East Rift subzone. Upper Kau'eleau (a road-forest location) was within the Kamaili (mid-elevation) subzone, but Keauohana Forest Reserve (a lava-forest location) was outside of this subzone; land within this subzone that supported an unmanipulated forest next to a lava flow was not available for surveys. Similarly, Upper Oneloa (a road-forest location) was within the Kapoho (lower elevation) subzone boundary, but Southeast Kula (a lava-forest location) was outside the boundary. The disturbed lava-tube location at Keokea was outside the geothermal boundary, being located south of the boundary common to the Middle East Rift and Kamaili subzones. The Pahoa tube (undisturbed) was the most distance from the geothermal subzone, being located approximately 3.5 km north of the northern boundary of the Kamaili (mid-elevation) subzone. This lava tube extends up into the Middle East Rift subzone. This upper section of the lava tube was not available for surveys. Table 2 gives precise location information on the placement of transect lines within each of the surveyed locations. Botanical characterization of each location is covered in the discussion.

Table 2. Coordinates of locations sampled in the invertebrate surveys; Puna District, Hawai'i, 1994.

Location	Transect	Coordinates for the 0-meter site		Elevation	Compass heading
		Latitude/Longitude	UTM[a]		
Southeast Kula	A	19° 30' 40.0" N 154° 49' 25.1" W	2158269.9 Northing 308627.5 Easting	0-meter site: 18 m 100-meter site: 17 m	105° N
	B	19° 30' 42.4" N 154° 49' 23.0" W	2158342.6 Northing 308690.7 Easting	0-meter site: 18 m 100-meter site: 17 m	105° N
	C	19° 30' 45.3" N 154° 49' 10.3" W	2158429.8 Northing 309059.6 Easting	0-meter site: 12 m 100-meter site: 14 m	258° N
Upper Oneloa	A	19° 28' 44.8" N 154° 52' 07.1" W	2154778.6 Northing 303866.6 Easting	0-meter site: 105 m 100-meter site: 108 m	300° N
	B	19° 28' 41.2" N 154° 52' 08.8" W	2154617.0 Northing 303815.1 Easting	0-meter site: 107 m 100-meter site: 111 m	300° N
	C	19° 28' 37.5" N 154° 52' 10.7" W	2154555.2 Northing 303759.5 Easting	0-meter site: 107 m 100-meter site: 111 m	300° N
Keauohana Forest Reserve	A	19° 25' 14.4" N 154° 57' 02.8" W	2148406.4 Northing 295166.8 Easting	0-meter site: 219 m 100-meter site: 226 m	255° N
	B	19° 25' 15.4" N 154° 57' 04.1" W	2148448.0 Northing 295130.0 Easting	0-meter site: 226 m 100-meter site: 232 m	255° N
	C	19° 25' 16.5" N 154° 57' 04.3" W	2148470.3 Northing 295124.3 Easting	0-meter site: 229 m 100-meter site: 232 m	255° N
Upper Kau'eleau	A	19° 27' 07.0" N 154° 55' 58.1" W	2151847.5 Northing 297095.6 Easting	0-meter site: 317 m 100-meter site: 311 m	60° N
	B	19° 27' 06.0" N 154° 55' 57.2" W	2151816.4 Northing 297119.6 Easting	0-meter site: 311 m 100-meter site: 305 m	60° N
	C	19° 27' 04.2" N 154° 55' 55.6" W	2151758.5 Northing 297166.6 Easting	0-meter site: 323 m 100-meter site: 317 m	60° N

continued

Table 2. Continued.

Location	Transect	Coordinates for the 0-meter site: Latitude/Longitude	Coordinates for the 0-meter site: UTM[a]	Elevation	Compass heading
Pu'u 'O'o	A	19° 24' 57.0" N 155° 06' 31.2" W	2148056.6 Northing 278597.7 Easting	0-meter site: 719 m 100-meter site: 719 m	285° N
	B	19° 24' 54.3" N 155° 06' 31.4" W	2147982.5 Northing 278571.2 Easting	0-meter site: 725 m 100-meter site: 725 m	285° N
	C	19° 24' 52.1" N 155° 06' 31.7" W	2147910.2 Northing 278561.9 Easting	0-meter site: 725 m 100-meter site: 727 m	285° N
Northeast Kahauale'a	A	19° 26' 59.5" N 155° 07' 58.3" W	2151865.1 Northing 276083.1 Easting	0-meter site: 722 m 100-meter site: 727 m	230° N
	B	19° 26' 57.0" N 155° 07' 56.9" W	2151787.7 Northing 276122.7 Easting	0-meter site: 722 m 100-meter site: 727 m	230° N
	C	19° 26' 54.1" N 155° 07' 55.0" W	2151698.8 Northing 276177.0 Easting	0-meter site: 722 m 100-meter site: 727 m	230° N
Pahoa lava tube	---	In order to protect the biological, geological and archaeological features of the lava tubes, specific information on location will be made available to interested parties only after special consideration by the U.S. Fish and Wildlife Service			
Keokea lava tube	---				

a. UTM, Universal Transmercator; grid system mapped onto 1:24,000 U.S.G.S. contour maps, Old Hawaiian Datum.

These selected survey locations correspond to the major habitats identified in the Scope of Work outlined for the Department of Energy. The 'ohi'a woodland habitat is represented by Upper Oneloa (lowland wet 'ohi'a/uluhe forest). The 'ohi'a forest habitat, the most common habitat in the geothermal subzones, is represented by the upper (Pu'u 'O'o and Northeast Kahauale'a) and mid-elevation (Keauohana Forest Reserve and Upper Kau'eleau) locations. This habitat is more commonly called lowland wet 'ohi'a forest. The Southeast Kula location (lowland mesic 'ohi'a forest) represents the mixed lowland forest habitat listed in the Scope of Work. Lava flows were sampled at the edge of the lava-forest interface at Pu'u 'O'o, Keauohana Forest Reserve and Southeast Kula, and lava tubes were samples at Pahoa and Keokea.

In selecting undisturbed locations, we attempted to find unmanipulated forest that was isolated from roads that might otherwise influence the composition of the invertebrate fauna. Unfortunately, extensive human activities in the Kapoho (lower elevation) and Kamaili (mid-elevation) subzones combined with limited access virtually excluded the "best" areas within the subzones from being surveyed. Consequently, the undisturbed locations in or near these geothermal subzones were significantly affected by alien species typically associated with agricultural and residential areas. The undisturbed Pu'u 'O'o location, west of the Middle East Rift (upper elevation) geothermal subzone, was the most intact section of forest surveyed and was approximately 2 km north of the most recently active vent (Pu'u 'O'o) of the ongoing Kilauea eruption.

Disturbed locations were readily found within or near all of the geothermal subzones. The roads associated with these locations carried light to moderate traffic associated with agricultural (Upper Oneloa; Kapoho subzone), industrial (cinder quarry; Upper Kau'eleau; Kamaili subzone), or residential (Northeast Kahauale'a; Middle East Rift subzone) activities.

For surveys of subterranean invertebrate fauna, two lava tube systems relatively near the geothermal subzones were studied. Hawaiian lava tubes are formed during an eruptive phase of an active volcano that produces sustained pahoehoe lava flows. Fluid, pahoehoe lava often forms river-like flows. The sides and upper surfaces of a pahoehoe flow can cool and harden, forming a tube through which the hotter, fluid lava can be transported for several kilometers. As the volcanic eruptive phase subsides, the pahoehoe lava within the lava tube empties out. The tube eventually cools and solidify into stable, elongate geological feature. Lava tubes are typically several meters in radius with a flat floor that is the remains of the flowing lava river. For those lava tubes near the surface, roots from 'ohi'a trees and other native vegetation penetrate into the tube. These roots provide the nutrient base to support a subterranean community of endemic Hawaiian arthropods. The Keokea lava tube was located during a helicopter scouting trip that was part of pre-survey activities. This tube most likely originates in the vicinity of Heiheiahulu, which is located within the lower part of the Middle East Rift subzone. The Pahoa lava tube is well known. It is estimated to be at least 10 km in length and extends up into the Middle East Rift (upper elevation) geothermal subzone. Interior sections of these tubes were used for the subterranean surveys. Lava tubes have traditionally been used by Hawaiians as burial sites and are important cultural and archaeological resources. Consequently, the specific locations of the lava tubes surveyed in this study are available only upon special request to the U.S. Fish and Wildlife Service and the State of Hawai'i Historic Preservation Division.

Sampling design

Assessing the diversity and abundance of arthropods and gastropods in the geothermal subzones required a variety of sampling techniques. The major sampling effort was expended on arthropods. For each of the six forest locations, three 100-m transect lines were extended from the edge of the adjacent road or lava flow into the forest. The transect lines were parallel and separated from each other by approximately 50 m, except at Southeast Kula where one transect line (C) was set 154^{o} from parallel with the other two transect lines. This lack of parallel design was necessitated by topographic features.

For each transect line, four types of arthropod traps (malaise, pitfall, yellow pan, and baited sponges) were set at the 0 m and 100 m sites; these traps are described below. In addition, a pair of pitfall traps was set up every ten meters along each transect line. Except for the baited sponges, the arthropod traps were allowed to operate continuously for approximately 54 hours. The first transect line was set up by 10-11 am the first day of sampling and taken down by 4-5 pm on the third day. Similarly, the second transect line was set up on the second day of sampling and taken down on the fourth day; the third transect line was set up on the third day of sampling and taken down on the fifth day. Baited sponges were sampled every morning on days 2-4.

Arboreal snails and slugs were sampled by counting the number of individuals seen on vegetation along the length of each transect line and within 3 meters of either side of the transect line. The leaf surfaces and stems of native and alien tree and bushes were examined, extending up as high as could be reached from the ground. Each transect line was surveyed for two hours by two biologists experienced in finding terrestrial and arboreal snails.

Arthropods were sampled in each of the two lava tubes surveyed in this study. Eight sites were established along a section of each lava tube at locations where root systems penetrated into the tube. The distance between each site within a tube varied, depending on the occurrence of roots. In the Pahoa tube, the sites were separated by an average of 58 m (range of 38-102 m) and covered a total distance of 1,110 m. The average area of each site was 62 m^2 (range of 52-78 m^2), totaling 520 m^2. In the Keokea tube, the sites were separated by an average of 140 m (range of 30-400 m) and covered a total distance of 408 m. The average area of each site was 68 m^2 (range of 42-95 m^2), totaling 544 m^2. Each lava tube was surveyed twice. The first survey was done on the first visit to each tube. Following the first count at each site, bean and alfalfa sprouts, rolled oats, and blue cheese were placed at 9-12 places within a site. In addition, four pit-fall traps (see below) were set at each of sites 1, 5, and 8 in the Keokea tube and sites 1, 6, and 8 in the Pahoa tube. Each site was surveyed a second time 72 hours later.

On each of the visits to the lava tubes, timed counts were conducted by a biologist experienced in the identification of Hawaiian lava tube fauna. Each site was surveyed for 20 minutes, during which time all accessible surfaces, including roots, were examined and the number of individuals of each observed species were recorded.

Arthropod trapping methods

Terrestrial insects were sampled at the 0 and 100 m sites using four different methods. Standard **malaise traps** were used to intercept flying insects; these preferentially sampled Lepidoptera, Diptera, and Hymenoptera. Two **yellow pan traps** (22 x 27 x 7 cm) were set under each of the malaise traps. The yellow color of the trap attracted flying insects into water/surfactant (*i.e.,* Photoflow) held within the trap. **Pitfall traps** were made of plastic cups (0.5 liter) one-third filled with water/surfactant and baited with a smear of blue cheese on the inside wall of the cup. These were set into and flush with the ground or set among the lava at the 0 m sites and in the lava tubes. These traps captured ground dwelling arthropods and were set every ten meters along each transect line or at the first, last, and middle sites in each lava tube. **Sponges** (15 x 9 x 2.5 cm) were baited for drosophilid flies and tacked up on the north face of trees. Two sponges were set at each of the 0 m and 100 m sites. Each sponge received two baits, one on the left half and the other on the right half of the sponge. The banana bait, meant to attract introduced fruit flies, was a mixture of banana-tapioca baby food and baker's yeast that had ripened overnight. The other bait, meant to attract Hawaiian picture-wing drosophilids, was a mixture of chopped mushrooms, water, and baker's yeast that had ripened for 5-7 days. Flies attracted to these baits were counted each morning, after which the baits were refreshed. Two additional trapping methods identified in the Scope or Work (baited bucket traps and hand netting) were not employed due to lack of time and the large sample sizes obtained from the other trapping methods.

Sample preservation and identification of taxa

Samples from each type of trap at each site were maintained separately. For each of the 0-m and 100-m sites, there were one malaise sample, one yellow pan sample (from two yellow pan traps) and one pitfall sample (from two pitfall traps). Additionally, there was one pitfall sample (from two pitfall traps) every ten meters between the 0-m and 100-m sites. Additional miscellaneous specimens were taken, when needed, from the sponges. All snails and slugs that were encountered were identified in the field. Samples were initially preserved in the field with 70% methanol. Upon return to the laboratory, the samples were rinsed with freshwater, and leaves, stems and other extraneous material were removed. Each sample was preserved in 70% ethanol. All collected specimens were curated by the entomological staff at the B. P. Bishop Museum, Honolulu, Hawai'i.

All arthropod specimens were identified by the entomological staff of the Bishop Museum, Honolulu. Terrestrial arthropods were mainly identified from collected specimens by D. Preston. Cave arthropods were identified by F. Howarth during field surveys and from a few collected specimens. Limited funding prevented the identification of all the large number of arthropod specimens collected during these surveys. Several groups of samples have not been included in this report or the analysis of the data. These include all of the malaise, yellow pan, and pitfall samples from two of the disturbed locations (Upper Kau'eleau and Northeast Kahauale'a), and the pitfall samples from the 10-90 m transect line sites at the four additional forest locations (southeast Kula, Upper Oneloa, Keauohana Forest Reserve, and Pu'u 'O'o). Completion of the analyses of these data depends on additional funding.

Botanical characterization of the surveyed locations

Each of the six forest locations and the area overlying the two lava tubes were characterized by their plant assemblage. Plants within a five meter radius of each 10 m sampling site were identified by a botanist (M. Bruegmann of the U.S. Fish and Wildlife Service) along each of the 100 m transect lines. A qualitative assessment of species dominance was made at each site. Visual estimates were also made for canopy height and percent canopy cover. Plant species and relative abundance for each transect line are given in Appendix 1.

Plants growing in the vicinity of the lava tubes were identified and percent cover was estimated for the more common species. In the area of the Keokea tube, the composition of three 440 m^2 quadrats of the burned forest was contrasted with the composition of three 440 m^2 quadrats from a nearby (400 m to the north) unburned area of the same tract of forest.

RESULTS

Botanical characterization of the forested survey locations

Alien plant species were found at all locations, and accounted for more that half of the plants seen at the lowest (16 m, Southeast Kula) elevation examined (Table 3). Higher elevation locations contained more native species, which accounted for 60-70% of all plant species at the highest elevations surveyed. The diversity of native species increased from 14 species up to 32 species with increasing elevation. Alien species decreased from 20 species down to 17 species with increasing elevation. For all plants species, the greatest diversity (54 taxa) was observed at a mid-elevation location (Upper Kau'eleau, 314 m).

Lava-forest locations (Southeast Kula, Keauohana Forest Reserve, and Pu'u 'O'o) were not richer in native species than the three road-forest locations (Table 3). However, middle (Keauohana Forest Reserve) and upper (Pu'u 'O'o) elevation lava-forest locations did have fewer alien plant species than the road-forest locations at similar elevations (Upper Kau'eleau and Northeast Kahauale'a).

Table 3. Botanical characterization of locations used in the invertebrate surveys; Puna District, Hawai`i, 1994.

Location (characterization)	Canopy height, % cover[a]	Number of native species (number common[b])			Number of alien species (number common)			% native (most common species)
		Canopy	Subcanopy	Total	Canopy	Subcanopy	Total	
Southeast Kula (elevation 16 m, lava-forest location, lowland mesic 'ohi'a forest)								
	3-5 m, 46%	1 (1)	-----[c]	14 (5)	5 (3)	-----	20 (7)	41.2 (41.7)
Upper Oneloa (elevation 108 m, road-forest location, lowland wet 'ohi'a/uluhe forest)								
	3-5 m, 23%	1 (1)	-----[c]	16 (4)	1 (1)	-----	20 (4)	44.4 (50.0)
Keauohana Forest Reserve (elevation 227 m, lava-forest location, lowland wet 'ohi'a forest)								
	24-32 m, 79%	1 (1)	6 (3)	25 (7)	0 (0)	2 (1)	15 (5)	62.5 (58.3)
Upper Kau'eleau (elevation 314 m, road-forest location, lowland wet 'ohi'a forest)								
	12-16 m, 86%	1 (1)	8 (3)	24 (5)	2 (0)	3 (1)	30 (4)	44.4 (55.6)
Pu'u 'O'o (elevation 723 m, lava-forest location, lowland wet 'ohi'a forest)								
	7-10 m, 84%	2 (2)	4 (2)	29 (8)	0 (0)	0 (0)	13 (2)	69.0 (80.0)
Northeast Kahauale'a (elevation 725 m, road-forest location, lowland wet 'ohi'a forest)								
	7-10 m, 76%	2 (2)	6 (3)	32 (8)	0 (0)	1 (1)	17 (1)	65.3 (75.0)

a. Canopy height was visually estimated for the locale of the transect lines. Percent cover was visually estimated at 33 sites on 3 transect lines; the reported value is an average of these estimates (the first site on each transect line was on the lava flow or road and was not included in the estimate of % cover).

b. Plant species seen at more than half of the 33 sites sampled or plant species that were dominant at more that one quarter of the sites were considered to be common (*i.e.*, a dominance value > 16.5, which equal half of 33; see Appendix 1).

c. The short stature forests (3-5 m canopy height) at Southeast Kula and Upper Oneloa do not have a subcanopy.

The two low elevation locations were low stature (3-5 m), open (23-46% cover) forests that lacked a subcanopy (Table 3). The lowest of these, Southeast Kula (lava-forest location), was characterized as a lowland mesic 'ohi'a forest with 59% alien plant species. The other low elevation location, Upper Oneloa (road-forest location), was a lowland wet 'ohi'a/uluhe forest with 56% alien plant species. In both these forests, 'ohi'a (*Metrosideros polymorpha*) is the only native canopy species (Table 4). At Southeast Kula three alien trees (*Clusia rosea*, *Schefflera actinophylla*, and *Schinus terebinthifolius*) also occupy canopy space. At Upper Oneloa strawberry guava (*Psidium cattleianum*) holds canopy space.

The four remaining forested locations were all characterized as lowland wet 'ohi'a forests with a medium to high (7-32 m), closed (76-86% cover) canopy and a low subcanopy (Table 3). The mid-elevation road-forest location at Upper Kau'eleau was comprised of 56% alien plant species. The highest elevation road-forest location, Northeast Kahauale'a, contained 35% alien plant species. This difference between these two locations was due to an increase in native species and an decrease in alien species at the higher elevation location. The two remaining lava-forest locations were comprised of mostly native plants; 63% native at the mid-elevation Keauohana Forest Reserve, and 65% native at the higher elevation Pu'u 'O'o.

The forest canopy at the four lowland wet 'ohi'a forest locations has not be invaded by alien trees; 'ohi'a dominates at all four locations and is accompanied by 'olapa (*Cheirodendron trigynum*) at the two upper elevation locations (Table 4). Diversity at these forest locations is greatly enhanced by a rich assemblage of subcanopy (4-8 species) and understory (16-26 species) plants at a given location.

Pulmonate gastropods observed during the surveys

The native arboreal snail fauna was completely absent at low (Southeast Kula, Upper Oneloa) and mid-elevation (Keauohana Forest Reserve, Upper Kau'eleau) locations. Four alien slugs (two *Deroceras* sp., two *Limax maximus*) and two alien snails, both *Euglandina rosea*, were found at Upper Kau'eleau, and an third specimen of *E. rosea* was found at Southeast Kula. *Euglandina rosea* is a predator of snails and slugs.

At the two upper elevation locations some native arboreal snails were encountered. The road-forest location at Northeast Kahauale'a had low numbers of *Succinea* sp., mainly on the endemic plant *Broussaisia arguta* (kanawao); a total of 9 specimens were counted along the three 100-m transect lines. Numerous alien slugs were also seen at this location and several were taken in the pitfall traps; eight *Deroceras* spp. (either *laeve*, the marsh slug, or *reticulatum*, the gray garden slug), four *Limax maximus* (spotted garden slug), and seven *Veronicella cubensis* (2-lined slug) were seen along the three transect lines.

No alien snails or slugs were seen or collected in pitfall traps at the lava-forest Pu'u 'O'o location, which is the most isolated of the six forest locations. The abundance of *Succinea* sp. at this location was 40 times higher than that at Northeast Kahauale'a, with a total of 120

Table 4. Most common plants found along transect lines sampled for invertebrates; Puna District, Hawai`i, 1994. Plant species seen at more than half of the 33 sites or plant species that were dominant at more than a quarter of the sites were considered to be common (dominance value ≥ 17; see Appendix 1).

Scientific name	Common name (canopy = c, subcanopy = sc)	Status[a]	Species occurrence (transect; number of sites occupied; number of sites as dominant)			Dominance value[b]
S.E. Kula (elevation 16 m, lava-forest location, lowland mesic 'ohi'a forest)						
Cocculus triloba	Huehue	indigenous	A; 11; --	B; 5; --	C; 4; --	20
Metrosideros polymorpha	'Ohi'a (c)	endemic	A; 11; 1	B; 11; 7	C; 11; 5	46
Nephrolepis cordifolia	fern	indigenous	A; 10; 2	B; 11; 5	C; 9; 1	38
Phymatosorus scolopendemicrium	fern	indigenous	A; 9; 2	B; 8; --	C; 4; --	23
Wikstroemia sp.	'Akia	endemic	A; 10; 2	B; 8; 3	C; 8; 1	32
Andropogon virginicus	Broomsedge	alien	A; 10; 1	B; 6; 1	C; 2; --	20
Clusia rosea	Autograph tree (c)	alien	A; 7; --	B; 7; --	C; 5; --	19
Schefflera actinophylla	Octopus tree (c)	alien	A; 6; --	B; 9; --	C; 2; --	17
Schinus terebinthifolius	Christmas berry (c)	alien	A; 10; 1	B; 9; 1	C; 11; --	32
Spathoglottis plicata	Phillipine ground orchid	alien	A; 6; --	B; 7; --	C; 6; --	19
Stachytarpheta urticifolia	none	alien	A; 9; 1	B; 3; 2	C; 2; --	17
Thunbergia fragrans	White thunbergia	alien	A; 7; --	B; 7; --	C; 8; --	22
Upper Oneloa (elevation 108 m, road-forest location, lowland wet `ohi`a/uluhe forest)						
Dicranopteris linearis	Uluhe	indigenous	A; 11; 6	B; 10; 10	C; 8; 8	53
Machaerina angustifolia	'Uki'uki	indigenous	A; 7; --	B; 7; --	C; 9; 3	26
Metrosideros polymorpha	'Ohi'a (c)	endemic	A; 11; 5	B; 9; 2	C; 11; 2	40
Nephrolepis cordifolia	fern	indigenous	A; 6; --	B; 8; --	C; 10; --	24
Andropogon virginicus	Broomsedge	alien	A; 9; 2	B; 7; 1	C; 7; 3	29
Arundina graminifolia	Bamboo orchid	alien	A; 11; 3	B; 11; 2	C; 9; 3	39
Psidium cattleianum	Strawberry guava (c)	alien	A; 11; --	B; 6; --	C; 6; --	23
Spathoglottis plicata	Phillipine ground orchid	alien	A; 10; --	B; 7; --	C; 9; --	26

continued

Table 4. Continued.

Scientific name	Common name (canopy = c, subcanopy = sc)	Status[a]	Species occurrence (transect; number of sites occupied; number of sites as dominant)			Dominance value[b]
Keauohana Forest Reserve (elevation 227 m, lava-forest location, lowland wet 'ohi'a forest)						
Cibotium glaucum	Hapu'u (sc)	endemic	A; 8; --	B; 7; 1	C; 8; 3	27
Cocculus triloba	Huehue	indigenous	A; 7; --	B; 6; --	C; 7; --	20
Freycinetia arborea	'Ie'ie (sc)	indigenous	A; 6; 1	B; 6; 2	C; 6; 1	22
Leucobryum sp.	moss	indigenous	A; 5; --	B; 3; --	C; 5; --	13
Metrosideros polymorpha	'Ohi'a (c)	endemic	A; 11; 3	B; 11; 2	C; 9; 3	37
Nephrolepis exaltata var. *hawaiiensis*	fern	endemic	A; 9; 2	B; 10; 2	C; 10; 6	39
Psychotria hawaiiensis	\`Opiko (sc)	endemic	A; 10; --	B; 8; 1	C; 6; --	25
Wikstroemia sp.	\`Akia	endemic	A; 8; 2	B; 7; 2	C; 2; --	21
Arundina graminifolia	Bamboo orchid	alien	A; 9; --	B; 5; --	C; 4; --	18
Psidium cattleianum	Strawberry guava (sc)	alien	A; 8; 2	B; 7; 1	C; 6; 1	25
Rubus rosifolius	Thimbleberry	alien	A; 9; --	B; 4; --	C; 7; --	20
Spathoglottis plicata	Phillipine ground orchid	alien	A; 9; --	B; 9; --	C; 2; --	20
Thelypteris parasitica	fern	alien			C; 5; --	55
Upper Kau'eleau (elevation 314 m, road-forest location, lowland wet 'ohi'a forest)						
Cibotium glaucum	Hapu'u (sc)	endemic	A; 8; --	B; 8; --	C; 7; --	23
Freycinetia arborea	'Ie'ie	indigenous	A; 7; --	B; 11; --	C; 6; --	24
Metrosideros polymorpha	'Ohi'a (c)	endemic	A; 11; 1	B; 11; --	C; 11; --	34
Nephrolepis exaltata var. *hawaiiensis*	fern	endemic	A; 10; --	B; 11; --	C; 11; --	32
Psychotria hawaiiensis	'Opiko (sc)	endemic	A; 11; --	B; 11; --	C; 11; --	33
Melastoma candidum	shrub melastome	alien	A; 9; --	B; 9; --	C; 8; --	26
Oplismenus hirtellus	Basket grass	alien	A; 8; --	B; 10; --	C; 9; --	27
Psidium cattleianum	Strawberry guava (sc)	alien	A; 10; --	B; 10; --	C; 9; --	29
Spathoglottis plicata	Phillipine ground orchid	alien	A; 4; --	B; 5; --	C; 5; --	19

continued

Table 4. Continued.

Scientific name	Common name (canopy = c, subcanopy = sc)	Status[a]	Species occurrence (transect; number of sites occupied; number of sites as dominant)			Dominance value[b]
Pu'u 'O'o (elevation 723 m, lava-forest location, lowland wet 'ohi'a forest)						
Broussaisia arguta	Kanawao	endemic	A; 8; 0	B; 10; 1	C; 9; 0	28
Cheirodendron trigynum	'Olapa (c)	endemic	A; 6; 0	B; 8; 0	C; 10; 0	24
Cibotium glaucum	Hapu'u (sc)	endemic	A; 8; 3	B; 6; 0	C; 10; 0	27
Clermontia parviflora	'Oha wai	endemic	A; 9 ; 0	B; 6; 0	C; 4; 0	19
Dicranopteris linearis	Uluhe	indigenous	A; 9; 6	B; 8; 6	C; 8; 6	43
Melicope clusiifolia	Kolokolo mokihana (sc)	endemic	A; 6; 0	B; 8; 0	C; 4; 0	18
Metrosideros polymorpha	'Ohi'a (c)	endemic	A; 11; 3	B; 11; 8	C; 11; 6	50
Nephrolepis cordifolia	fern	indigenous	A; 6; 1	B; 8; 1	C; 6; 1	23
Paspalum conjugatum	Hilo grass	alien	A; 6; 0	B; 8; 1	C; 5;.1	21
Deparia petersenii		alien	A; 7; 0	B; 6; 0	C; 5; 0	18
N.E. Kahauale'a (elevation 725 m, road-forest location, lowland wet 'ohi'a forest)						
Broussaisia argutar	Kanawao	endemic	A; 8; --	B; 8; --	C; 9; --	24
Cheirodendron trigynum	'Olapa (c)	endemic	A; 7; --	B; 9; --	C; 7; --	23
Cibotium glaucum	Hapu'u (sc)	endemic	A; 11; --	B; 7; --	C; 10; 1	19
Dicranopteris linearis	Uluhe	indigenous	A; 8; 2	B; 10; 5	C; 4; 2	31
Freycinetia arborea	'Ie'ie (sc)	indigenous	A; 7; --	B; 9; --	C; 10; --	26
Isachne distichophylla	`Ohe	endemic	A; 8; --	B; 9; --	C; 9; --	26
Metrosideros polymorpha	'Ohi'a (c)	endemic	A; 11; 1	B; 11; 11	C; 11; 3	48
Psychotria hawaiiensis	'Opiko (sc)	endemic	A; 6; --	B; 8; --	C; 10; --	24
Psidium cattleianum	Strawberry guava (sc)	alien	A; 11; --	B; 9; --	C; 10; 10	40

a. Endemic species are species found only in the Hawaiian Islands. Indigenous species are found in the Hawaiian Islands and in other areas (mostly Pacific islands) outside of the Hawaiian Islands. For both endemic and indigenous Hawaiian species, they have either evolved in Hawai'i or arrived in Hawai'i without human assistance.

b. From "Species occurrence" column: number of sites + number of sites as dominant.

snails observed along the three transect lines. Three small native snails belonging to the genus *Auriculella* sp. were also observed. As at Northeast Kahauale'a, almost all of these native snails were living on *Broussaisia arguta*.

Arthropods sampled during the surveys

Arthropods identified from the six sample locations totaled 25,899 individuals in 94 families (Table 5). Twenty percent of these specimens (5,110 in 36 families) are from species that are endemic to Hawai'i. Specimens of alien species accounted for 69% (17,863; 44 families) of the total, and specimens of uncertain status accounted for the remaining 11% (2,926; 34 families). For all samples combined, the abundance of individuals was inversely correlated with the elevation of the sampled location (Table 5); 42% of all specimens were from Southeast Kula (elevation 16 m), 31% were from Upper Oneloa (elevation 108 m), 12% were from Keauohana Forest Reserve (elevation 227 m), and 11% were from Pu'u 'O'o (elevation 723 m). The remaining 4% of specimens were native and alien drosophilid flies sampled at Upper Kau'eleau and Northeast Kahauale'a (see below). The diversity of arthropods was fairly uniform across the sampled locations (Table 5 and Appendix 2). Southeast Kula had 81 taxa in 57 families, Upper Oneloa had 77 taxa in 62 families, Keauohana Forest Reserve had 66 taxa in 49 families and Pu'u 'O'o had 87 taxa in 60 families.

The greatest numbers of endemic arthropod individuals were seen at the two lower elevation locations (Appendix 2). Samples from Southeast Kula had 1,437 individuals (17 taxa, 16 families), and samples form Upper Oneloa had 1,713 individuals (25 taxa, 22 families). *Mestelobes* spp. moths (Lepidoptera, Crambidae) accounted for 47% (676 individuals) of the endemic Kula species; 32% (465 individuals) belonged to the dipteran family Sciaridae; total Diptera accounted for 44% (in 9 taxa) of the all the endemic specimens from Kula (Table 6). At Upper Oneloa, 82% (1,406 individuals in 10 taxa) of the endemic specimens were Diptera (Appendix 2). Forty-one percent (704 specimens; Table 6) of the endemic Oneloa sample were from a single species of ceratopogonid fly (*Forcipomyia*, probably *hardyi*). Sciarid flies represented 23% (388 individuals) of the endemic Oneloa sample.

Keauohana Forest Reserve (elevation 227 m) and Pu'u 'O'o (elevation 723 m) had fewer endemic individuals (951 and 868, respectively) but more endemic taxa (26 and 39, respectively) and families (23 and 29, respectively) than the lower elevation locations at Southeast Kula and Upper Oneloa. As for the lower elevation locations, endemic flies dominated the samples from Pu'u 'O'o and Keauohana. At Keauohana, 52% (10 taxa in 9 families) of the endemic sample were flies, mostly (37%) *Forcipomyia* sp. The hemipteran caseate *Alares* sp. was also commonly taken at Keauohana (21% of the endemic specimens), as were *Mestelobes* spp. (12% of the endemic specimens). At Pu'u 'O'o 15 taxa of endemic flies represented 60% (524 individuals) of the sample of endemic arthropods. However, unlike the four other locations, no single species dominated the sample; the most common fly (13% of the specimens) was *Forcipomyia* sp. (Table 6). Unidentified hemipteran psyllids were the largest group (26% of the endemic sample).

Table 5. Numbers of individuals and families of arthropods sampled during the invertebrate surveys; Puna District, Hawai`i, 1994.

Location taxon status	0-meter samples			100-meter samples			All samples		
	Individuals	%[a]	Families[b]	Individuals	%	Families	Individuals	%	Families
Southeast Kula (elevation 16 m, lava-forest location, lowland mesic 'ohi'a forest[c])									
endemic	600	5.4	13 (13)	837	7.6	13 (14	1,437	13.1	16 (17)
alien	6,081	55.4	29 (38)	2,079	18.9	18 (29	8,160	74.3	30 (42)
ants	5,470	49.8		1,151	10.4		6,621	60.3	
Drosophila spp.	291	2.7		717	6.5		1,008	9.2	
uncertain status	938	8.5	18 (18)	445	4.1	20 (20	1,383	12.6	22 (22)
site total	7,619	69.4	52 (69)	3,361	30.6	43 (63	**10,980**	-----	57 (81)
Upper Oneloa (elevation 108 m, road-forest location, lowland wet 'ohi'a/uluhe forest[d])									
endemic	993	12.3	20 (21)	720	9.0	16 (17	1,713	21.3	22 (25)
alien	2,746	34.2	24 (32)	2,926	36.3	23 (28	5,672	70.5	27 (39)
ants	594	7.4		1,077	13.4		1,671	20.8	
Drosophila spp.	1,785	22.2		1,634	20.3		3,419	42.5	
uncertain status	364	4.5	19 (20)	302	3.8	18 (20	666	8.3	24 (26)
site total	4,103	51.0	56 (73)	3,948	49.0	50 (57	**8,051**	-----	62 (77)
Keauohana Forest Reserve (elevation 227 m, lava-forest location, lowland wet 'ohi'a forest[c])									
endemic	801	26.7	22 (25)	150	5.0	11 (11	951	31.7	23 (26)
alien	1,076	35.9	17 (20)	676	22.5	13 (15	1,752	58.4	20 (25)
ants	444	14.8		343	11.4		787	26.2	
Drosophila spp.	301	10.0		229	7.6		530	18.0	
uncertain status	115	3.8	11 (11)	182	6.1	8 (8)	297	9.9	15 (15)
site total	1,992	66.4	42 (56)	1,008	33.6	28 (34	**3,000**	-----	49 (66)

continued

Table 5. Continued.

Location taxon status	0-meter samples			100-meter samples			All samples		
	Individuals	%[a]	Families[b]	Individuals	%	Families	Individuals	%	Families
Pu'u 'O'o (elevation 723 m, lava-forest location, lowland wet 'ohi'a forest[f])									
endemic	435	15.1	24 (31)	433	14.9	23 (30	868	30.2	29 (39)
alien	950	33.1	12 (15)	479	16.6	15 (16	1,429	49.7	20 (23)
ants	2	0.1		0	0		2	<0.1	
Drosophila spp.	863	30.0		323	11.2		1,186	41.2	
uncertain status	216	7.5	19 (18)	364	12.7	20 (21	580	20.2	24 (25)
site total	1,601	55.7	48 (65)	1,276	44.4	49 (67	**2,877**	-----	60 (87)
All locations combined[g]									
endemic	2,884	11.1	35	2,226	8.6	28	5,110	19.7	36
alien	11,443	44.2	39	6,420	24.8	36	17,863	69.0	44
ants	6,510	25.1		2,571	9.9		9,081	35.1	
Drosophila spp.	3,830	14.8		3,163	12.2		6,993	27.0	
uncertain status	1,633	6.3	30	1,293	5.0	31	2,926	11.3	34
grand total	15,960	61.7	89	9,939	38.4	82	**25,899**	-----	94

a. Percentage of the total number of individuals seen at a single location (**bold** numbers).
b. Values in parentheses are the number of taxa within a site and within a status group (endemic, alien, uncertain).
c. Southeast Kula plants: 5 m canopy, 46% closed, 41% native; near a very low density residential area.
d. Upper Oneloa plants: 5 m canopy, 23% closed, 44% native; adjacent to agricultural land.
e. Keauohana Forest Reserve plants: 31 m canopy, 79% closed, 63% native.
f. Pu'u 'Ō'ō plants: 16 m canopy, 84% closed, 69% native.
g. Includes drosophilid flies sampled on sponges at Upper Kau'eleau and Northeast Kahauale'a.

Table 6. Most common arthropods sampled at the surveyed location; Puna District, Hawai`i, 1994.

Order	Family	Scientific name	Number of individuals (percent[a]) 0-meter samples	100-meter samples	All samples
Southeast Kula (elevation 16 m, lava-forest location, lowland mesic 'ohi'a forest)					
Endemic taxa					
Diptera	Ceratopogonidae	*Forcipomyia* sp. prob. *hardyi*	50	7	57
Diptera	Sciaridae		144	321	465
Lepidoptera	Crambidae	*Mestelobes* spp.	304	372	676
Subtotal			498	700	1,198 (83.4)
Alien taxa					
Diptera	Drosophilidae	*Drosophila suzukii* group	291	717	1,008
Hymenoptera	Formicidae	*Anoplolepis longipes*	5,104	329	5,433
Hymenoptera	Formicidae	Red sp.	70	362	432
Subtotal			5,465	1,408	6,873 (84.2)
Taxa of uncertain status					
Diptera	Drosophilidae	*Drosophila* spp.	141	35	176
Diptera	Psychodidae		51	24	75
Hymenoptera	Agaonidae		205	61	266
Lepidoptera	undetermined		441	189	630
Subtotal			838	309	1,147 (82.9)
Location total			6,801	2,417	9,218 (84.0)
Upper Oneloa (elevation 108 m, road-forest location, lowland wet 'ohi'a/uluhe forest)					
Endemic taxa					
Diptera	Ceratopogonidae	*Forcipomyia* sp. prob. *hardyi*	450	254	704
Diptera	Chironomidae	*Orthocladius* sp.	192	26	218
Diptera	Sciaridae		121	267	388
Psocoptera	undetermined		78	77	155
Subtotal			841	624	1,464 (85.5)

continued

Table 6. Continued.

Order	Family	Scientific name	Number of individuals (percent[a])		
			0-meter samples	100-meter samples	All samples
Upper Oneloa - continued					
Alien taxa					
Diptera	Drosophilidae	*Drosophila suzukii* group	1,785	1,624	3,409
Diptera	Formicidae	*Anoplolepis longipes*	195	549	0744
Hymenoptera	Formicidae	Red sp.	292	500	0792
Subtotal			2,274	2,673	4,942 (87.1)
Taxa of uncertain status					
Coleoptera	Ptilidae		15	6	21
Collembola	Entomobryidae		132	105	237
Collembola	Sminthuridae		23	62	85
Diptera	Psychodidae		102	12	114
Hymenoptera	Chalcidoidea		45	46	91
Subtotal317			317	231	548 (82.3)
Location total			3,430	3,528	6,954 (86.4)
Keauohana Forest Reserve (elevation 227 m, lava-forest location, lowland wet 'ohi'a forest)					
Endemic taxa					
Diptera	Ceratopogonidae	*Forcipomyia* sp. prob. *hardyi*	284	66	350
Diptera	Phoridae	*Megaselia* spp.	419	17	66
Homoptera	Psyllidae		172	30	202
Lepidoptera	Crambidae	*Mestelobes* spp.	110	0	110
Psocoptera	undetermined		63	8	71
Subtotal			678	121	799 (84.0)
Alien taxa					
Blattaria	Blattidae	*Periplaneta americana*	130	0	130
Diptera	Drosophilidae	*Drosophila suzukii* group	301	229	530

continued

Table 6. Continued.

Order	Family	Scientific name	Number of individuals (percent[a])		
			0-meter samples	100-meter samples	All samples
Keauohana Forest Reserve - continued					
Alien taxa - continued					
Hymenoptera	Formicidae	*Anoplolepis longipes*	311	89	400
Hymenoptera	Formicidae	Black sp.	6	253	259
Hymenoptera	Formicidae	Red sp.	127	0	127
Subtotal			875	571	1,446 (82.5)
Taxa of uncertain status					
Acari	Oribatulidae		0	69	69
Amphipoda	Talitridae		23	0	23
Collembola	Entomobryidae		1	69	71
Diptera	Psychodidae		64	29	93
Subtotal			88	167	255 (85.9)
Location total			1,641	859	2,500 (83.3)
Pu`u O`o (elevation 723 m, lava-forest location, lowland wet 'ohi'a forest)					
Endemic taxa					
Diptera	Calliphoridae	*Dyscritomya* spp.	2	22	24
Diptera	Ceratopogonidae	*Forcipomyia* sp. prob. *hardyi*	7	105	112
Diptera	Dolichopodidae	*Eurynogaster* spp.	7	13	22
Diptera	Drosophilidae	*Drosophila tanythrix*	4	32	36
Diptera	Drosophilidae	*Scaptomyza* sp.	54	28	82
Diptera	Phoridae	*Megaselia* spp.	36	31	67
Diptera	Sciaridae		72	36	108
Homoptera	Cixiidae	*Iolania sp.*	10	12	22
Homoptera	Psyllidae		142	80	222
Subtotal			334	361	695 (80.1)

continued

Table 6. Continued.

Order	Family	Scientific name	Number of individuals (percent[a]) 0-meter samples	100-meter samples	All samples
Pu'u 'O'o - continued					
Alien taxa					
Diptera	Drosophilidae	*Drosophila suzukii* group	863	323	1,186
Subtotal	2 families (10.0% of 20 families[a])		863	323	1,186 (83.0)
Taxa of uncertain status					
Coleoptera	Elateridae		12	8	20
Coleoptera	Staphylinidae		24	153	177
Collembola	Entomobryidae		2	67	69
Diptera	Psychodidae		50	45	95
Hymenoptera	Diapriidae		0	20	20
Hymenoptera	Encyrtidae		18	2	20
Hymenoptera	Ichneumonidae		14	8	22
Lepidoptera	Tortricidae		54	0	54
Subtotal			174	303	477 (82.2)
Location total			1,371	987	2,358 (82.0)

a. Subtotal percentages are calculated within sites using the total number of individuals seen within a given status (*e.g.*, endemic, alien or uncertain; see Table 5 or Appendix 2 for totals); for instance, at Southeast Kula, 83.4% of the 1,437 endemic individuals sampled were from the four listed taxa. Percentages for location totals were calculated from all individuals (endemic + alien + uncertain) collected at a given location; for instance, at Southeast Kula, 84.0% of all sampled arthropod individuals (10,980) were in the taxa listed for that site.

For endemic drosophilid flies, all but 13 of the 267 individuals seen during the surveys were counted while they fed at mushroom-baited sponges. Over half (59%) of these endemic drosophilid flies belonged to the *Scaptomyza* group (157 individuals), and the remaining 110 individuals were picture wing *Drosophila*, including *tanythrix* (76 individuals), *ochracea* (29 individuals), and *sproati* (5 individuals). No native drosophilid flies were seen at the lowest elevation location, Southeast Kula (Appendix 2), and were seen in very low numbers (a total of 5 *Scaptomyza* spp.) at Upper Oneloa (elevation 108 m, road-forest) and the Keauohana Forest Reserve (227 m, lava-forest). Thirty-two flies were recorded at the Kau'eleau location and the remaining 230 individuals were almost equally divided between the two highest locations, Pu'u 'O'o (723 m, 120 flies) and Northeast Kahauale'a (725 m, 110 flies). At Kau'eleau and Northeast Kahauale'a, both road-forest locations, approximately two-thirds of the flies (69% and 66%, respectively) were seen at the 100-m sites. This contrasts with observations at Pu'u 'O'o, a lava-forest location, where flies were equally abundant at the 0-meter (59 flies) and 100-meter sites (61 flies).

The number of alien arthropods caught in the traps was greatest at the lower elevation locations (Table 5, Appendix 2). Southeast Kula yielded the largest alien sample with 8,160 individuals (42 taxa in 30 families) representing 74% of the entire Kula sample. The sample from Upper Oneloa had 5,672 individuals (39 taxa in 27 families) representing 71% of the total Oneloa sample. Most of these alien arthropods were ants (9 taxa, 81% of the alien Kula sample; 7 taxa, 29% of the alien Oneloa sample) and flies (12 taxa, 15% of the alien Kula sample; 10 taxa, 67% of the alien Oneloa sample). The abundance of alien arthropods was much lower at the Keauohana Forest Reserve and at the Pu'u 'O'o location. At Keauohana, the 1,752 alien individuals (25 taxa in 20 families) sampled were 40% ants and 45% flies. At Pu'u 'O'o, only two alien ants were taken, and the 1,429 alien individuals were predominately (93%) alien flies. At all locations where they occurred, ants were mainly represented by the long-legged ant (*Anoplolepis longipes*), and flies were mostly *Drosophila* belonging to the *suzukii* group.

Of the 17,853 alien specimens, 51% (9,081; 35% of the grand total) were ants and 39% (6,983; 27% of the grand total) were fruit flies (Table 5). Most (72%) of the ants observed in these surveys were long-legged ants (*Anoplolepis longipes*, Table 6), and most (91%) were found at the two lower elevation locations; 73% (6,621) were from Southeast Kula and 18% (1,671) were from Upper Oneloa. Although Southeast Kula is a lava-forest location, low density residential housing is common in the general vicinity area. Upper Oneloa is a road-forest location adjacent to agricultural land. The number of ants captured at the Southeast Kula forest edge (0-meter sites) was 4.75 times higher than the count form the 100-meter forest site (Table 6). This relationship did not hold for Upper Oneloa or Keauohana Forest Reserve (a lava-forest location). At Upper Oneloa, the 100-meter forest site yielded almost twice as many ants (1,077) as the 0-meter site. At Keauohana, the two sites had similar number of ants and total 787 specimens. The lava-forest location at Pu'u 'O'o was virtually free of ants (Table 5), yielding only two specimens from the forest edge.

Alien *Drosophila* fruit flies were the dominant fly at all of the surveyed locations. Overall, these flies were equally common at the 0-m and 100-m sites (Table 5). Almost all of these flies were counted when they came to feed at the banana-baited sponges; a small number were also taken in malaise traps. Approximately half of the 6,900+ specimens taken were from the Upper Oneloa (road-forest) location, which is adjacent to agricultural land; the flies were equally distributed between the 0-meter and 100-meter sites at this location and at the Keauohana Forest Reserve (530 specimens). The high (Pu'u 'O'o) and low (Southeast Kula) elevation lava-forest locations yielded similar numbers of flies (1,186 and 1,008, respectively). However, at the higher location 73% of the flies were from the 0-meter site, compared to 29% at the lower location. At the two remaining road-forest locations, alien flies were most abundant at the 0-meter road sites (Appendix 2), but were comparatively uncommon (Kau'eleau, 155 flies, 75%, at the 0-m site; Northeast Kahauale'a, 435 flies, 68%, at the 0-m site).

Species of uncertain status represented 8-20% of the arthropods sampled for each of the six forested locations (Table 5). Southeast Kula had the highest number of individuals of uncertain status (1,383; 22 taxa in 22 families), and most of these specimens were moths (46% of the uncertain status Kula sample). At Upper Oneloa, 666 specimens of uncertain status were represented by 26 taxa in 24 families; most were entomobryid collembola (36% of the uncertain status Oneloa sample). The lowest number of uncertain status arthropods were taken at the Keauohana Forest Reserve. The 297 individuals represented 15 taxa in 15 families. At the Pu'u 'O'o location, 31% of the 580 individuals (25 taxa in 24 families) were beetles belonging to the family Staphylinidae.

Botanical characterization of the lava-tube forests

The plant assemblage growing over the two surveyed lava tubes was mainly comprised of alien species with low diversity (Table 7). Root systems penetrating into the Pahoa lava tube were probably from three alien and two native tree species including 'ohi'a, which was once the dominant forest tree in this area. The main ground cover in this area of the lava tube was *Melastoma candidum*, which might also send roots into the lava tube. At the Keokea lava tube, the main ground cover was also an alien plant, the broomsedge *Andropogon virginicus*. This location was covered by an 'ohi'a/uluhe forest prior to a forest fire in March 1992. At this time, very few of the 'ohi'a remain alive; two live and 120 dead trees were found within a 440 m^2 quadrat (Table 7). However, an additional 65 'ohi'a within this quadrat were sprouting new growth from the base of the tree trunk.

The live 'ohi'a tree roots were the primary nutrient source for cave invertebrates in the Keokea lava tube; the death of these trees has greatly reduced the food base for this food web. A comparison of the root systems of the Pahoa and Keokea lava tubes (Table 8) shows that while the total abundance of roots in each of the tubes was very similar (28/100 m^2 at Keokea, 34/100 m^2 at Pahoa), 77% of the roots in the Keokea tube were dead versus <2% in the Pahoa tube.

Table 7. Most common plants found over the Pahoa (undisturbed) and Keokea (disturbed) lava tubes; Puna District, Hawai'i, 1994.

Scientific name	Common name	Status[a]	Percent cover[b]
Pahoa lava tube[c]			
Metrosideros polymorpha	'Ohi'a	endemic	1%
Psychotria hawaiiensis	'Opiko	endemic	1%
Melastoma candidum	none	alien	70%
Nephrolepis multiflora	fern	alien	1%
Psidium cattleianum	Strawberry guava	alien	10%
Keokea lava tube[d]			
Metrosideros polymorpha	'Ohi'a	endemic	2%
Albizia lebbeck	Siris Tree	alien	<1%
Arundina graminifolia	Bamboo orchid	alien	10%
Andropogon virginicus	Broomsedge	alien	70%
Psidium cattleianum	Strawberry guava	alien	1%
Unburned forest upslope of the Keokea lava tube[e]			
Dicranopteris linearis	Uluhe	indigenous	70%
Machaerina angustifolia	'Uki'uki	endemic	2%
Metrosideros polymorpha	'Ohi'a	endemic	15%

a. Endemic species are species found only in the Hawaiian islands.. Indigenous Hawaiian species are found in the Hawaiian Islands and in other areas (mostly Pacific islands) outside of the Hawaiian Islands. For both endemic and indigenous species, they have either evolved in Hawai'i or arrived in Hawai'i without human assistance.

b. Approximate value was visually determined.

c. Presently, a mixed exotic wet shrubland; historically, probably a lowland wet 'ohi'a/uluhe forest.

d. Presently, a mixed exotic wet shrubland; prior to a 1992 fire, this was a lowland wet 'ohi'a/uluhe forest. The main nutrient source for this cave fauna was live 'ohi'a roots. The present condition of these trees were assessed in three 440 m^2 quadrats. Of the 187 'ohi'a trees in these quadrats, 120 (64%) were dead, two were alive, and 65 (35%) had new shoots sprouting from the base of the dead tree trunk. These latter trees will require an extended period of growth before new roots can re-establish themselves in the lava tube.

e. This forest previously extended over the area of the Keokea lava tube. Presently, it is a lowland wet 'ohi'a/uluhe forest. The condition of the 'ohi'a trees that dominate this area were assessed in three 440 m^2 quadrats. Of the 199 'ohi'a trees in these quadrats, 198 (99%) were alive. A lava tube under this intact forest cover would be expected to have 3 times more roots (198 ÷ [65+2]) than the Keokea lava tube is expected to have after all of the live 'ohi'a trees remaining over it have re-grown deep roots. The Pahoa lava tube currently has 5 times more live roots than the Keokea lava tube in its current condition (see Table 8).

Table 8. Site location and subterranean root structure in the Pahoa (undisturbed) and Keokea (disturbed) lava tubes; Puna District, Hawai'i, 1994.

Site	Site location (meters from tube entrance; m² sampled)		Subterranean roots[a] (f=flushing roots, p=root patch, h=hanging roots, a=attached root; roots/100 m²)			
			Keokea tube		Pahoa tube	
	Keokea tube	Pahoa tube	Living	Dead	Living	Dead
1	230; 72	415; 52	0	12h, >30h; 58	10a, 5h; 29	0
2	660; 70	466; 75	3fh, 2ph; 7	12h, 1a; 19	5a, 14h; 25	0
3	1,020; 42	517; 52	1fh; 2	12h; 29	8h; 16	3a; 6
4	1,125; 60	555; 69	0	1a, >3pa; 7	11a, 4h; 22	0
5	1,250; 95	657; 70	12fh; 13	1h; 1	8h, 3fa; 16	0
6	1,280; 84	704; 69	12fh, 3fpa; 18	>10a; 12	18a, 27h, 3pa; 70	0
7	1,310; 63	777; 55	0	11h, >10a; 33	13a, 21h; 62	0
8	1,340; 58	823; 78	1fh, 1fa; 3	11h, 2a; 22	14a, 10h; 31	0
Total; average[b]	544 m²; 68 m²	520 m²; 62 m²	35; 5	>116; 23	174; 34	3; 1

a. Flushing root = new, white root that has not developed an outer bark; root patch = numerous short roots hanging from ceiling and wall cracks or spreading as a patch across a rock surface; hanging root = root emerges from the ceiling but does not reach the floor or wall and is less accessible to most cave invertebrates; attached root = root extends from ceiling to floor or wall, or lies along the ceiling or wall.

b. Total area of all sites; average area per site. Total number of roots at all sites; average root density (per 100 m²).

Arthropods sampled or observed in lava tubes

A list of the invertebrate taxa encountered during the lava-tube surveys is given in Table 9. A list of all known lava-tube species that have been observed in the Puna District is given in Appendix 3. Of the 24 taxa seen in the two lava tubes, 13 were endemic, nine were alien, and two were of uncertain status. Of the endemic taxa, nine were considered to be obligate lava-tube (*i.e.*, hypogean; troglobite) species. Four additional endemic taxa were troglophiles, living and reproducing in lava tubes but also found in surface (epigean) habitats. Only one of the alien taxa was classified as a troglobite (the spider *Nesticella mogera*). Seven of the remaining alien taxa were troglophiles and one (the snail *Subulina* sp.) was an accidental occurrence that is typically found in surface habitats.

Overall, diversity (Table 9) was highest in the undisturbed Pahoa tube, with 11 endemic taxa, eight alien taxa, and one taxon of uncertain status. Although diversity was 25% lower in the

Table 9. Invertebrates observed in the Pahoa (undisturbed) and Keokea (disturbed) lava tubes; Puna District, Hawai'i, 1994.

Scientific name	Lava tube affinity, taxon group, trophic niche[a]	Number of individuals (unbaited, baited[b])		Number of sites[c] (unbaited, baited[b])	
		Keokea	Pahoa	Keokea	Pahoa
Endemic taxa					
Caconemobius sp. A	TB, cricket, S	0, 4	11, 28	0, 4	5, 8
Caconemobius sp. B	TB, cricket, S	——	0, 1	——	0, 1
Cavaticovelia aaa	TB, water treader, P	4, 0	——	1, 0	——
Forcipomyia pholetor	TB/TP, midge, S	3, 6	18, 13	1, 2	6, 7
Limonia sp. near *jacobus*	TP, crane fly, B	18, 13	0, 1	3, 1	0, 1
Lycosa howarthi	TB, spider, P	——	1, 0	——	1, 0
Nannolene sp.	TP, millipede. S	0, 8	0, 2	0, 3	0, 2
Oliarus polyphemus	TB, planthopper, PHY	2, 0	244, 158	2, 0	8, 8
Phytosciara volcanata	TP, fly, S	0, 11	——	0, 1	——
Psychodidae	TP, moth fly, S	——	1, 0	——	1, 0
Sinella yosiia	TB, springtail, S	——	7, 20	——	5, 7
Schrankia sp. A	TB, moth, PHY	4, 3	9, 8	1, 3	3, 3
Tachys sp. near *arcanicola*	TB, beetle, P	0, 1	1, 2	0, 1	1, 2
Alien taxa					
Entomobryidae	TP, springtail, S	0, 4	0, 3	0, 3	3, 0
Geoplana septumlineata	TP, flatworm, S	——	0, 1	——	0, 1
Nesticella mogera	TB, spider, P	——	0, 2	——	0, 2
Nicoletia meinerti	TP, bristle tail, S	——	2, 2	——	2, 2
Onychiurus folsomi	TP, springtail, S	1, 5	——	1, 2	——
Oxidus gracilis	TP, millipede, S	1, 1	2, 1	1, 1	1, 1
Phoridae	TP, coffin fly, S	——	1, 12	——	1, 5
Porcellio sp.	TP, isopod, S	1, 72	2, 1	1, 7	2, 1
Subulina sp.	ACC, snail, S	——	0, 1	——	0, 1
Uncertain status					
Collembola spp.	?, springtail, S	47, 163	12, 9	4, 6	2, 1
Rhagidiidae	TB?, mite, P	0, 6	——	0, 3	——

a. ACC, accidental, animal that wanders into lava tubes but cannot survive there; B, scavenger that feeds on mineral precipitate/bacterial slime on the cave walls; P, predator; PHY, phytophage that sucks fluids from live plant roots hanging inside the lava tube; S, scavenger that feeds on dead plant and/or animal material; TB, troglobite, species that is obligate to hypogean lava-tube habitats; TP, troglophile, species that lives and reproduces in lava tubes but is also found in epigean (surface) habitats; TX, trogloxene, species that uses lava tubes for shelter but feeds in the epigean environment.

b. After the first of two visits per tube, each site was baited with blue cheese, bean sprouts and oatmeal.

c. Number of sites where each taxon was seen; there were eight sites sampled in each lava tube.

disturbed Keokea tube, most of this decline was due to a lack of alien species; nine endemic taxa, four alien taxa, and two taxa of uncertain status were seen in this tube.

More dramatic differences were seen in the abundance of endemic and alien lava-tube species. In the undisturbed Pahoa tube, 327 endemic and 27 alien individuals were seen; an additional 12 springtails were of uncertain status. In the disturbed Keokea tube, 58 endemic and 82 alien individuals were seen. Six mites and 163 springtails, both of uncertain status, were also seen in the Keokea tube. These uncertain taxa are comprised of very small individuals, and we estimate that they constitute much less than 1% of the total lava tube biomass. Thus, endemic abundance in the Pahoa tube 2.6 times greater than in the Keokea tube. Alien arthropods are three times more common in the disturbed Keokea tube than in the undisturbed Pahoa tube.

An assessment of the abundance of taxa and individuals in the lava tubes showed that the undisturbed Pahoa tube supported more taxa and individuals (Table 10). The disturbed Keokea tube supported 1.3 endemic taxa and 0.7 alien taxa per 100 m^2 of rooted substrate. This is compared to 1.7 endemic taxa and 1.3 alien taxa in the Pahoa tube. Abundance was 8.5 endemic and 15.1 alien individuals per 100 m^2 in the Keokea tube. In the Pahoa tube, 56.2 endemic and 4.0 alien individuals were seen per 100 m^2. Thus, in the Pahoa tube, the densities of endemic and alien taxa were 31% and 46% higher, respectively, that in the Keokea tube. The density of endemic individuals in the Pahoa tube was 6.6 times (561%) higher than in the Keokea tube. However, the density of alien individuals in the Pahoa tube was 74% lower than the density of alien individuals in the Keokea tube.

DISCUSSION

The data accumulated during these surveys can be used to assess arthropod and gastropod diversity and abundance in forested areas and lava tubes associated with the geothermal subzones. These data also allow for an assessment of the effects of loss of forest cover on lava-tube fauna. However, a full assessment of the impacts of roads on invertebrate diversity and abundance could not be completed for this report. To achieve this goal, data on invertebrate diversity and abundance was collected at paired locations at similar elevations; one location was adjacent to a road and one location was removed from the influence of roadways. Funding restrictions have prevented the analysis of the two locations (Northeast Kahauale'a and Upper Kau'eleau) that represented the road-forest samples. Consequently, a more definitive statement on the effects of roads on invertebrate diversity will have to await later analysis of this data. Nevertheless, an understanding of patterns of faunal (and floral) diversity and abundance presented in this report can help direct conservation actions and development activities in a manner that will optimize the preservation of natural resources. The following discussion further characterizes the distribution of terrestrial arthropod and gastropod diversity and abundance in the geothermal resource subzones of the Puna District, Hawai'i, and concludes with recommendations for the conservation of this diversity in the face of future growth and development.

Table 10. Diversity and abundance of invertebrates in the Pahoa (undisturbed) and Keokea (disturbed) lava tubes; Puna District, Hawai'i, 1994.

Site	Lava-tube fauna[a] (number of taxa; number of individuals)							
	Keokea tube[b]				Pahoa tube			
	Unbaited visit		Baited visit		Unbaited visit		Baited visit	
	Native	Alien	Native	Alien	Native	Alien	Native	Alien
1	2; 18	0; --	4; 30	1; 1	7; 33	1; 1	5; 28	3; 4
2	1; 1	1; 1	2; 2	1; 1	4; 79	1; 1	7; 57	2; 4
3	2; 5	0; --	0; --	1; 4	2; 14	0; --	4; 9	3; 5
4	1; 1	1; 1	2; 2	2; 12	3; 27	3; 4	4; 24	1; 1
5	0; --	1; 1	2; 4	2; 16	2; 14	0; --	4; 22	1; 1
6	2; 6	0; --	2; 3	2; 20	3; 15	3; 3	6; 24	0; --
7	0; --	0; --	2; 4	1; 20	5; 37	0; --	4; 24	2; 4
8	0; --	0; --	1; 1	3; 8	4; 73	1; 1	5; 45	1; 1
Totals[c]	5; 31	3; 3	7; 46	4; 82	8; 292	5; 10	9; 233	7; 20
per 100 m^2	0.9; 5.7	0.6; 0.6	1.3; 8.5	0.7; 15.1	1.5; 56.2	1.0; 1.9	1.7; 44.6	1.3; 4.0

a. Excludes rhagidiid mites (6 seen in the Keokea tube) and unidentified Collembola (63 seen during the unbaited visit and 163 seen during the baited visit in the Keokea tube; 12 seen during the unbaited visit and 9 seen during the baited visit in the Pahoa Tube) that are of uncertain native/alien status. These two groups have a minimal effect on overall animal biomass in the lava tube.

b. Includes crane flies, which found in dryer areas of lava tubes. Keokea tube: 18 crane flies seen during the unbaited visit and 13 seen during the baited visit, all at site 1. Pahoa tube: one crane fly was seen at site 8. The surveyed section of Pahoa tube lacks the drier conditions preferred by these crane flies.

c. The visit with the highest number of individuals at each site was used to determine the maximum number of individuals seen in each tube. For the Keokea tube, 58 endemic individuals, 82 alien individuals, and 169 individuals of uncertain status were seen. For the Pahoa tube, 327 endemic individuals, 27 alien individuals, and 12 individuals of uncertain status were seen.

Diversity and abundance of arthropod taxa

The data collected during this study indicate that the diversity of alien arthropod taxa increased with decreasing elevation (Table 11A). The greatest difference was between the lowest (Southeast Kula, 16 m elevation) and highest (Pu'u 'O'o, 723 m elevation) locations; alien taxa were almost twice as common at the lower elevation location (an increase of 83% over that of the higher elevation location). The decrease in alien diversity with elevation was paralleled by an increase in endemic diversity with elevation. Again, the greatest difference was between the lowest and highest locations; endemic taxa were more than twice as common at the upper elevation location (an increase of 129% over that of the lower elevation location). Total arthropod diversity (alien plus endemic taxa) was greatest at Pu'u 'O'o, the highest elevation

Table 11. Comparisons of arthropod diversity (number of taxa) and abundance (number of individuals) between pairs of surveyed locations; Puna District, Hawai`i, 1994. The 0-m and 100-m sites are summed. Values for columns are to the left of the slash; values for rows are to the right of the slash. Values above and below the blank diagonal (dashes) are for different subsets of arthropods, as indicated.

Location (elevation)	S.E. Kula[a] (16 m)	U. Oneloa[b] (108 m)	Keauohana F.R.[c] (227 m)	Pu'u 'O'o[d] (723 m)
A. Location diversity			endemic taxa	
Southeast Kula (16 m)	------	25 / 17	26 / 17	39 / 17
Upper Oneloa (108 m)	42 / 39	------	26 / 25	39 / 25
Keauohana F. R. (227 m)	42 / 25	39 / 25	------	39 / 26
Pu'u 'O'o (723 m)	42 / 23	39 / 23	25 / 23	------
		alien taxa		
B. Total location diversity (all taxa[e])				
Upper Oneloa	81 / 77	------		
Keauohana F. R.	81 / 66	77 / 66	------	
Pu'u 'O'o	81 / 87	77 / 87	66 / 87	------
C. Location abundance			endemic taxa	
Southeast Kula	------	1,713 / 1,437	951 / 1,437	868 / 1,437
Upper Oneloa	8,160 / 5,672	------	951 / 1,713	868 / 1,713
Keauohana F. R.	8,160 / 1,752	5,672 / 1,752	------	868 / 951
Pu'u 'O'o	8,160 / 1,429	5,672 / 1,429	1,752 / 1,429	------
		alien taxa		
D. Location abundance: alien taxa without ants and alien *Drosophila* flies			alien taxa without ants and *Drosophila* flies	
Southeast Kula	------	582 / 531	435 / 531	241 / 531
Upper Oneloa	1,539 / 4,001	------	435 / 582	241 / 582
Keauohana F. R.	1,539 / 965	4,001 / 965	------	241 / 435
Pu'u 'O'o	1,539 / 1,429	4,001 / 1,427	965 / 1,427	------
		alien taxa without ants		
E. Total location abundance (all individuals[f], all sites)				
Upper Oneloa	10,980 / 8,051	------		
Keauohana F. R.	10,980 / 3,000	8,051 / 3,000	------	
Pu'u 'O'o	10,980 / 2,877	8,051 / 2,877	3,000 / 2,877	------

a. Southeast Kula: lava-forest location, lowland mesic 'ohi'a forest; residential area nearby.
b. Upper Oneloa: road-forest location, lowland wet 'ohi'a/uluhe forest; adjacent agriculture.
c. Keauohana Forest Reserve: lava-forest location, lowland wet 'ohi'a forest.
d. Pu'u 'Ō'ō: lava-forest location, lowland wet 'ohi'a forest.
e. Includes all endemic taxa, alien taxa, and taxa of uncertain status.
f. Includes all individuals from endemic taxa, alien taxa, and taxa of uncertain status.

location (Table 11B). Intermediate elevation locations (Keauohana Forest Reserve and Upper Oneloa) had the lowest diversity of taxa, and Southeast Kula, the lowest location surveyed, had a taxon diversity almost as high as that observed at Pu'u 'O'o.

Diversity of arthropods along an altitudinal gradient have been studied on the Island of Hawai'i by Gagné (1979, 1980), Mueller-Dombois *et al.* (1981), and Gon (1978). The report presented in Mueller-Dombois *et al.* (1981) is the same as Gagné (1979); the latter only will be referenced below. Most of the data in these studies are not directly comparable to the data presented in this report; the Gagné and Gon surveys were conducted at higher elevations than the current surveys, were in distinctly different forest types, and focused on more limited or distinct assemblages of arthropods. Nevertheless, general trends in these studies are useful in gaining a broader view of overall trends in species diversity and abundance in the Puna District, Island of Hawai'i.

Gon (1978) reported an overall decrease in the numbers of endemic families of night-flying insects with increasing elevation (585 m up to 1690 m) in a south Kona forest; there was a small but consistent increase in diversity at the 1440-m site where the mesophytic forest abruptly changes to a xerophytic scrub forest. By contrast, Gagné (1979, 1980) reported an increase in the number of endemic canopy-associated arthropod species with increasing elevation (15 m up to 2440 m). This was accompanied by a decrease in the diversity of alien canopy-associated species. Two peaks in total species diversity were observed at mid-elevation sites (1195 m and 1280 m) and were associated with the only closed canopy 'ohi'a forest in the survey. Gagné attributed these peak abundances to canopy closure, which ameliorated the effects of persistent rain-bearing trade winds and offered more sheltered microhabitats. Gagné's study was in the vicinity of the geothermal surveys but focused at a much higher elevation fauna.

The trends that Gagné observed for endemic and alien species diversity are similar to those observed in our geothermal surveys of the geothermal subzones. In our surveys, total abundance (*i.e.*, the total number of individuals sampled) of arthropods decreased with an increase in elevation (Table 11E). As with arthropod diversity, the greatest difference in total abundance was between the lowest (Southeast Kula, 16 m elevation) and the highest (Pu'u 'O'o, 723 m elevation); Southeast Kula had an abundance that was more than 3.5 times higher (282% higher) than the abundance at the Pu'u 'O'o location. The most similar locations were the two most isolated lava-forest locations; abundance at the Keauohana Forest Reserve was 4% higher than the Pu'u 'O'o..

These general trends in abundance also held for endemic arthropods and for alien arthropods (Table 11C). For the latter group, Southeast Kula (the lowest location) had the highest alien abundance and exceeded the least abundant location (Pu'u 'O'o) by more than 5.5 times (471%). The highest endemic abundance was seen at Upper Oneloa (108 m elevation), which is a road-forest location adjacent to an agricultural area. Endemic arthropods were 49% more abundant at Oneloa than at Pu'u 'O'o, which had the lowest abundance of endemic taxa. As with total abundance, the locations most similar in abundance of alien or endemic arthropods were the two most isolated lava-forest locations (Keauohana Forest Reserve and Pu'u 'O'o).

Based on these observations, geothermal development would have lesser impacts on native species diversity and abundance in low elevation areas where endemic diversity is lowest. Lower elevation forested areas, such as Upper Oneloa, Kau'eleau, Keauohana Forest Reserve, and, to a lesser extent, Southeast Kula, should be excluded from development since these relatively small tracts of forest can still support significant native arthropod communities. For instance, Nishida and Gagné (1987) surveyed terrestrial arthropods in the vicinity of Pahoa and Kea'au in the lower Puna District. During these brief surveys, they reported 44 native species, three of which were new endemic species, and 73 alien species, eight of which were new to Hawai'i. These lower elevation forests derive additional value from two other facts: they represent an increasingly rare Hawaiian ecosystem, and they are the only remaining habitat for invertebrates that are restricted to low elevation locations.

Impacts of ants on arthropod diversity and abundance

The high abundance of a few taxa of ants (all of which are alien in Hawai'i) and alien *Drosophila* flies at lower elevations in the Puna District added a significant bias to the interpretation of the data on alien abundance. These two groups accounted for approximately 90% (51% ants and 39% *Drosophila* flies) of the alien arthropod individuals seen during the surveys. Table 11D shows how alien abundance is affected when these two groups are excluded from the data. Exclusion of individuals in these taxa leads to nearly even alien abundances at the lower (Southeast Kula and Upper Oneloa) and mid-elevation (Keauohana Forest Reserve) locations. Exclusion of alien *Drosophila* flies greatly reduced the estimate of alien abundance at the high elevation Pu'u 'O'o location (83% reduction). This reduction resulted in an estimate of alien abundance that was approximately two times (45-69%) lower than that observed at the lower and mid-elevation locations (Table 11D).

While the impact of alien *Drosophila* flies on native Hawaiian biota appears to be minimal, ants, all of which are alien to Hawai'i, have been implicated as a major cause for decreased native abundance and diversity (Howarth, 1985; Howarth and Medeiros, 1989). Cole *et al.* (1992) showed that the presence of the Argentine ant (*Iridomyrmex humilis*) was associated with a loss of endemic arthropod diversity in a high-elevation (2000 m) shrubland. This negative impact was demonstrated for a wide range native arthropod taxa, including key predator species and native species that are major pollinators of native shrubs and herbaceous plants. A significant aspect of the Cole *et al.* (1992) study was the distribution of the Argentine ant. Ant populations were adjacent to the only road leading into the study area (Haleakala National Park).

Gillespie and Reimer (1993) showed that the presence of three ant species was associated with a reduction or complete absence of endemic Hawaiian *Tetragnatha* spiders. They also demonstrated that two of these ants, *Pheidole megacephala* and *Anoplolepis longipes*, are highly effective at attacking, dismembering, and killing native spiders. Alien spiders tolerate the presence of ants by using a variety of behaviors that are not used by native spiders to fend off ant attacks (Gillespie and Reimer, 1993). *Anoplolepis longipes* is the major ant species in the geothermal resource subzones.

Observations that establish a significant relationship between roadways and the occurrence or dispersal of ants or other alien organisms are particularly relevant to geothermal development or other development projects. Roadways, whether temporary or permanent, can provide routes of access for alien taxa that would otherwise be far less likely to disperse into these areas. Trails into native forest can also be avenues of dispersal. An example of this near the Middle East Rift (upper elevation) geothermal subzone can be seen along the Captain's Trail into the Kahauale'a Natural Area Reserve. Alien plants occur along the beginning of this trail, decreasing in numbers as the trail penetrates further into the Reserve. Deep in the Reserve, these alien plants occur in numbers at pig wallows where seeds dispersed by the pigs can get established along the disturbed edges of the wallows.

In some cases, preventing dispersal or controlling population sizes of particularly devastating alien species, such as ants and wasps, may protect the native arthropod fauna in a given area. These actions would have to be long term because it is unlikely that the alien species of concern would ever be permanently extirpated from an area; remaining populations will continue to disperse along roads and trails and attempt to repopulate protected areas. Where roadways are an unavoidable component of development, actions that control dispersal and population sizes of destructive alien species could represent a significant mitigation effort. This may be especially effective for development projects in which the roads would carry limited traffic, as would be anticipated for a geothermal development project.

Diversity and abundance of lava-tube fauna

Lava tubes are one of the unique subterranean habitats in the Hawaiian Islands (Howarth, 1987). An assessment of the trophic niches occupied by the lava-tube taxa indicates that a breakdown in ecosystem structure can result from a loss of root nutrients to support the food web. The major nutrient source for Hawaiian lava-tube ecosystems is derived mostly from the roots of 'ohi'a trees (*Metrosideros polymorpha*) that penetrate into the lava tubes (Howarth, 1973). Phytophagous cave arthropods extract nutrients from the living roots. Scavenger arthropods utilize the dead tree roots or feed on other dead organisms. These phytophagous and scavenger arthropods in turn support a small assemblage of arthropod predators (Howarth, 1981).

In the disturbed Keokea lava tube, the death of approximately 77% of the living roots (Table 8) has greatly shifted the trophic structure away from that observed in the undisturbed Pahoa tube. At Pahoa, phytophagous insects are represented by two endemic species (no alien phytophagous species occur the either lava tube). This is less than 11% of the total diversity of this lava tube (Table 9). However, these same two species represent more than 71% of the observed individuals in the tube. In the Keokea tube, only six phytophagous individuals were seen, representing 4% of the observed fauna. Scavengers in the Keokea tube were more abundant than at the Pahoa tube, and were mostly (64%) alien troglophile species; endemic scavengers were more abundant and more diverse in the undisturbed Pahoa tube. Predator abundance and diversity were almost identical in both tubes.

It is apparent that the trophic structure of the disturbed Keokea lava tube no long utilizes live roots and phytophagous arthropods, but instead relies on the next trophic level, the scavengers, as the base of energy into the ecosystem. The immediate consequences of this shift in the base trophic web are apparent in the loss of total abundance (down by 60%) and diversity (down by 31%), and especially in the loss of endemic abundance (down by 82%) and diversity (down by 18%).

Recovery of the Keokea tube fauna may occur if new growth can re-establish roots into the lava tube. Not all of the Keokea overstory of 'ohi'a was killed by the March 1992 fire; 35% of the burned trees had new shoots growing from their bases. However, the presence of alien plants will greatly slow the recovery of this area of burned forest. This, in turn, will curtail the recovery of the lava-tube fauna. A lava tube under an adjacent area of unburned forest would be expected to have 3 times more roots than the Keokea lava tube is expected to have after all of the live `ohi`a trees remaining over it have re-grown deep roots (see Table 7). The fauna of the Pahoa tube is currently supported by 5 times more live roots than are presently found in the Keokea lava tube.

Pulmonate gastropods and the native flora

The surveys for native snails in the Puna District were limited to arboreal species. These surveys showed that the remaining native snail fauna are confined to upper elevation locations (Northeast Kahauale'a and Pu'u 'O'o). Lower elevation locations were complete devoid of arboreal snails, but did support the alien predatory snail *Euglandina rosea*, and other alien snails and slugs. *Euglandina* has been shown to be a major causative agent in the continuing loss of native snail populations and species (Hadfield *et al.*, 1993), and has undoubtedly played a major role in the decline of native snails in the lower Puna District. Loss of native plant species used by arboreal snails has also significantly contributed to the loss of native snails at the low and mid-elevation locations. Changes in microclimatic conditions associated with the dissection and removal of large tracts of native forest may also contribute to the long term degradation of native snail habitat. Comparatively large, intact tracts of predominantly native forest, along with the absence of alien snail predators, appear to be required in order to sustain native snail populations. Appropriate tracts of forest are found in the wet 'ohi'a forest of the upper elevation locations (Upper Kahauelea̅'a and Pu'u 'O'o). These areas are still composed of older, species-rich vegetation with a closed canopy and diverse native subcanopy. The flora composition of the upper elevation locations was approximately 70% native taxa and thus forms better habitat for native arboreal snails. Much of the area in the Kapoho (lower elevation) and Kamaili (mid-elevation) geothermal subzones has been tranformed from forest to agricultural or residential uses (Table 1). Historically, these subzones were mesic to wet 'ohi'a forests growing on relatively young lava flows. These forests were mostly open-canopied, with widely spaced trees of fairly uniform size and an uluhe fern carpet between the trees. Extensive development in the Puna District has converted these native woodlands into mixed lowland forests composed of highly fragmented stands of exotic canopy and understory plant species mixed with native 'ōhi'a, lama and hala trees. Alien plant species constitute about 60% of the plants in the surveyed locations (Table 3).

RECOMMENDATIONS

The following recommendations for geothermal development are based on observations and data collected during the invertebrate surveys; they may also apply to other industrial, residential, or agricultural development in the area. Impacts that are unique to geothermal development, such as emissions from wells and electromagnetic field effects associated with transmission lines, were not addressed by these surveys. However, if the following recommendations are followed, these impacts on invertebrate organisms will be minimized.

In general, it is recommended that any geothermal development in the Puna District be directed away from areas of high endemic diversity and abundance, and toward areas where unique Hawaiian natural resources have already been greatly disturbed. These disturbed areas are mainly found in the lower half of the Kamaili (mid-elevation) geothermal subzone and throughout most of the Kapoho (lower elevation) geothermal subzone.

1. The Middle East Rift (upper elevation) geothermal subzone should be excluded from geothermal development until biological surveys can be completed within this area. Field data from locations near the upper boundary of this subzone indicate that native invertebrate species may still dominate the higher elevations of this subzone. Helicopter overflights and vegetation mapping (see the geothermal botanical report) indicate that these high elevation areas are still largely covered by intact native forest. Importantly, the upper elevation locations surveyed in this study were the only locations that retained a native assemblage of snails. These snail populations may also occur in the upper section of the Middle East Rift geothermal subzone. If future surveys show that these native arthropod and gastropod species are present in the upper geothernal subzone, then this area should be excluded from future development.

Previous botanical surveys have shown that lower elevation areas of this subzone have been significantly affected by alien plants. Despite the disturbance to native flora, the invertebrate surveys indicate that a substantial native arthropod fauna may remain in these less-than-pristine areas. The lower elevation sections of this subzone should also be left intact to serve as an important buffer zone to further invasion of the more native upper sections of forest. This will help maintain the natural composition and integrity of the upper forest ecosystem.

2. Remaining stands of 'ohi'a forest in the Kapoho (lower elevation) and Kamaili (mid-elevation) geothermal subzones should be excluded from plans for geothermal development. As discussed in this report and in the previous recommendation, these areas still support substantial populations of endemic invertebrates.

3. Where geothermal development is near a stand of forest, mitigation for roadways, well pads, and transmission corridors should be part of the development project. These associated structures are avenues for dispersal of alien organisms including ants, which are especially destructive to endemic invertebrates. The fact that there are no native ant species in Hawai'i and the unique social behavior of ants may lead to effective local control of these aliens. These actions should be ongoing for the life of the project, should include frequent assessment and, when necessary, modification of mitigation actions, and should extend into post-project rehabilitation of geothermal project sites.

4. Areas that are developed for geothermal resources and then abandoned as the resource is depleted should be recovered to their natural condition. This applies to roadways, well pads, transmission corridors and other areas disturbed by development activities. These restoration efforts will help prevent further long-term loss of native biodiversity.

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Appendix 1. Plant taxa found within five meters of the invertebrate transect lines; Puna District, Hawai'i, 1994.

Scientific name	Common name (c = canopy; sc = subcanopy)	Status	Species occurrence (transect; number of sites occupied; number of sites as dominant)			Dominance value[a]
S.E. Kula (elevation 16 m, lava-forest location, lowland mesic 'ohi'a [*Metrosideros*] forest)						
Alyxia oliviformis	Maile	endemic		B; 1; 0		1
Cocculus trilobus	Huehue	indigenous	A; 11; 0	B; 5; 0	C; 4; 0	20
Cuscuta sandwichiana	Kauna'oa	endemic	A; 5; 0	B; 2; 0		7
Metrosideros polymorpha	'Ohi'a (c)	endemic	A; 11; 1	B; 11; 7	C; 11; 5	46
Nephrolepis cordifolia	fern	indigenous	A; 10; 2	B; 11; 5	C; 9; 1	38
Osteomeles anthyllidifolia	'Ulei	indigenous	A; 3; 0	B; 1; 0		4
Peperomia leptostachya	'Ala'ala wai nui	indigenous		B; 3; 0	C; 2; 0	5
Phymatosorus scolopendrium	fern	indigenous	A; 9; 2	B; 8; 0	C; 4; 0	23
Plectranthus parviflorus	'Ala'ala wai nui	indigenous		B; 1; 0	C; 3; 0	4
Psilotum nudum	Moa	indigenous	A; 1; 0	B; 5; 0	C; 2; 0	8
Stereocaulon volcanica	lichen	endemic	A; 1; 0			1
Styphelia tameiameiae	Pukiawe	indigenous	A; 1; 0			1
Waltheria indica	'Uhaloa	indigenous?		B; 1; 0		1
Wikstroemia sp.	'Akia	endemic	A; 10; 2	B; 8; 3	C; 8; 1	32
Ageratum conizioides	Maile hohono	alien	A; 1; 0	B; 4; 0	C; 6; 0	11
Andropogon virginicus	Broomsedge	alien	A; 10; 1	B; 6; 1	C; 2; 0	20
Arundina graminifolia	Bamboo orchid	alien	A; 7; 0	B; 4; 0	C; 1; 0	12
Begonia foliosa	begonia	alien	A; 4; 0	B; 6; 0	C; 5; 0	15
Chamaecrista nictitans	Partridge pea	alien	A; 7; 0	B; 2; 0		9
Clusia rosea	Autograph tree (c)	alien	A; 7; 0	B; 7; 0	C; 5; 0	19
Commelina diffusa	Honohono	alien			C; 1; 0	1
Dioscorea pentaphylla	Pi'a	Polynesian			C; 2; 0	2
Emelia fosbergii	herb	alien	A; 2; 0			2
Lantana camara	Lantana	alien	A; 1; 0			1
Melinis minutiflora	Molasses grass	alien			C; 1; 0	1
Passiflora foetida	Love-in-a-mist	alien	A; 1; 0			1
Pluchea symphytifolia	Sourbush	alien	A; 3; 0	B; 2; 0	C; 4; 0	9

continued

Appendix 1. Continued.

Scientific name	Common name (c = canopy; sc = subcanopy)	Status	Species occurrence (transect; number of sites occupied; number of sites as dominant)			Dominance value[a]
S.E. Kula - continued						
Psidium cattleianum	Strawberry guava (c)	alien	A; 1; 0	B; 3; 0	C; 8; 0	12
Psidium guajava	Common guava (c)	alien	A; 1; 0		C; 2; 0	3
Schefflera actinophylla	Octopus tree (c)	alien	A; 6; 0	B; 9; 0	C; 2; 0	17
Schinus terebinthifolius	Christmas berry (c)	alien	A; 10; 1	B; 9; 1	C; 11; 0	32
Spathoglottis plicata	Phillipine ground orchid	alien	A; 6; 0	B; 7; 0	C; 6; 0	19
Stachytarpheta urticifolia	herb	alien	A; 9; 1	B; 3; 2	C; 2; 0	17
Thunbergia fragrans	White thunbergia	alien	A; 7; 0	B; 7; 0	C; 8; 0	22
Upper Oneloa (elevation 108 m, road-forest location, lowland wet 'ohi'a/uluhe [*Metrosideros/Dicranopteris*] forest)						
Cladina sp.	British soldiers	indigenous	A; 4; 0	B; 1; 0	C; 2; 0	7
Cocculus trilobus	Huehue	indigenous	A; 2; 0	B; 2; 0	C; 2; 0	6
Cuscuta sandwichiana	Kauna'oa	endemic	A; 2; 0	B; 1; 0		3
Dicranopteris linearis	Uluhe	indigenous	A; 11; 6	B; 10; 10	C; 8; 8	53
Diplazium microphyllum	fern	endemic	A; 5; 0	B; 3; 0		8
Leucobryum sp.	moss	indigenous	A; 4; 0	B; 5; 0	C; 5; 0	14
Machaerina angustifolia	'Uki'uki	indigenous	A; 7; 0	B; 7; 0	C; 9; 3	26
Metrosideros polymorpha	'Ohi'a (c)	endemic	A; 11; 5	B; 9; 2	C; 11; 2	40
Nephrolepis cordifolia	fern	indigenous	A; 6; 0	B; 8; 0	C; 10; 0	24
Palhinhaea cernua	fern ally	indigenous		B; 1; 0		1
Psilotum nudum	Moa	indigenous	A; 4; 0	B; 3; 0	C; 4; 0	11
Psychotria hawaiiensis	'Opiko	endemic			C; 1; 0	1
Rhyncogonium sp.	moss	indigenous	A; 4; 0	B; 1; 0	C; 1; 0	6
Sadleria cyatheoides	'Amau	endemic	A; 3; 0	B; 1; 0	C; 1; 0	5
Styphelia tameiameiae	Pukiawe	indigenous	A; 2; 0	B; 3; 0	C; 4; 0	9
Wikstroemia sp.	'Akia	endemic	A; 3; 0	B; 4; 0	C; 2; 0	9
Andropogon virginicus	Broomsedge	alien	A; 9; 2	B; 7; 1	C; 7; 3	29
Arundina graminifolia	Bamboo orchid	alien	A; 11; 3	B; 11; 2	C; 9; 3	39

continued

Appendix 1. Continued.

Scientific name	Common name (c = canopy; sc = subcanopy)	Status	Species occurrence (transect; number of sites occupied; number of sites as dominant)			Dominance value[a]
Upper Oneloa - continued						
Buddleia asiatica	Butterfly bush	alien	A; 1; 0	B; 1; 0		2
Chamaecrista nictitans	Partridge pea	alien	A; 1; 0	B; 1; 0	C; 1; 0	3
Crotalaria pallida	Smooth rattlepod	alien		B; 1; 0		1
Desmodium triflorum	Tick clover	alien	A; 1; 0			1
Emelia fosbergii	herb	alien	A; 2; 0			2
Erechtites valerianifolia	Fireweed	alien	A; 1; 0			1
Heterocentron subtriplinervium	Pearl flower	alien	A; 8; 0	B; 3; 0		11
Hyptis pectinata	Comb hyptis	alien	A; 1; 0			1
Mangifer indica	Mango (c)	alien		B; 1; 0		1
Melinis minutiflora	Molasses grass	alien	A; 1; 0	B; 1; 0		2
Melochia umbellata	shrub	alien	A; 1; 0	B; 1; 0		2
Nephrolepis multiflora	fern	alien	A; 4; 0		C; 1; 0	5
Pluchea symphytifolia	Sourbush	alien	A; 1; 0	B; 2; 0		3
Polygala paniculata	Milkwort	alien	A; 1; 0	B; 1; 0		2
Psidium cattleianum	Strawberry guava (c)	alien	A; 11; 0	B; 6; 0	C; 6; 0	23
Rubus rosifolius	Thimbleberry	alien		B; 1; 0		1
Spathoglottis plicata	Phillipine ground orchid	alien	A; 10; 0	B; 7; 0	C; 9; 0	26
Stachytarpheta urticifolia	herb	alien	A; 1; 0			1
Keauohana Forest Reserve (elevation 227 m, lava-forest location, lowland wet 'ohi'a [*Metrosideros*] forest)						
Alyxia oliviformis	Maile	endemic	A; 2; 0	B; 2; 0		4
Asplenium nidus	Bird's nest fern (sc)	indigenous	A; 5; 0	B; 5; 0	C; 5; 0	15
Cibotium glaucum	Hapu'u (sc)	endemic	A; 8; 0	B; 7; 1	C; 8; 3	27
Cocculus trilobus	Huehue	indigenous	A; 7; 0	B; 6; 0	C; 7; 0	20
Diplazium microphyllum	fern	endemic	A; 1; 0			1
Diplazium sandwichianum	fern	endemic			C; 2; 0	2
Elaphoglossum crassifolium	fern	endemic	A; 1; 0			1
Freycinetia arborea	'Ie'ie (sc)	indigenous	A; 6; 1	B; 6; 2	C; 6; 1	22

continued

Appendix 1. Continued.

Scientific name	Common name (c = canopy; sc = subcanopy)	Status	Species occurrence (transect; number of sites occupied; number of sites as dominant)			Dominance value[a]
Keauohana Forest Reserve - continued						
Leucobryum sp.	moss	indigenous	A; 5; 0	B; 3; 0	C; 5; 0	13
Mecodium recurvatum	Filmy fern	indigenous			C; 3; 0	3
Metrosideros polymorpha	'Ohi'a (c)	endemic	A; 11; 3	B; 11; 2	C; 9; 3	37
Myrsine lanaiensis	Kolea (sc)	endemic	A; 2; 0	B; 2; 0	C; 2; 0	6
Nephrolepis cordifolia	fern	indigenous	A; 9; 1	B; 1; 0	C; 1; 0	12
Nephrolepis exaltata var. *hawaiiensis*	fern	endemic	A; 9; 2	B; 10; 2	C; 10; 6	39
Peperomia hypoleuca	Ala'ala wai nui	endemic	A; 1; 0	B; 1; 0	C; 1; 0	3
Phymatosorus scolopendrium	fern	indigenous	A; 3; 0	B; 4; 0		7
Pipturus albidus	Mamaki	endemic			C; 3; 0	3
Psilotum nudum	Moa	indigenous	A; 3; 0	B; 3; 0	C; 2; 0	8
Pseudophegopteris keraudreniana	fern	endemic			C; 1; 0	1
Psychotria hawaiiensis	'Opiko (sc)	endemic	A; 10; 0	B; 8; 1	C; 6; 0	25
Rhachomytrium sp.	moss	endemic		B; 2; 0		2
Rhyncogonium sp.	moss	indigenous	A; 6; 0	B; 5; 0	C; 2; 0	13
Stereocaulon volcanica	lichen	endemic	A; 1; 1	B; 1; 1	C; 1; 1	6
Vittaria elongata	fern	indigenous	A; 6; 0	B; 1; 0	C; 2; 0	9
Wikstroemia sp.	'Akia	endemic	A; 8; 2	B; 7; 2	C; 2; 0	21
Andropogon virginicus	Broomsedge	alien	A; 1; 0			1
Arundina graminifolia	Bamboo orchid	alien	A; 9; 0	B; 5; 0	C; 4; 0	18
Cordyline fruticosa	Ti	Polynesian	A; 2; 0			2
Erechtites valerianifolia	Fireweed	alien	A; 1; 0		C; 2; 0	3
Lantana camara	Lantana	alien	A; 1; 0		C; 1; 0	2
Melastoma candidum	shrub melastome	alien		B; 1; 0		1
Ophioglossum pendula	fern	alien	A; 3; 0		C; 1; 0	4
Oplismenus hirtellus	Basket grass	alien	A; 6; 0	B; 1; 0	C; 7; 0	14
Plectranthus scutellarioides	Coleus	alien	A; 7; 1	B; 2; 1	C; 3; 1	15
Pluchea symphytifolia	Sourbush	alien	A; 2; 0	B; 1; 0	C; 1; 0	4

continued

Appendix 1. Continued.

Scientific name	Common name (c = canopy; sc = subcanopy)	Status	Species occurrence (transect; number of sites occupied; number of sites as dominant)			Dominance value[a]
Keauohana Forest Reserve - continued						
Psidium cattleianum	Strawberry guava (sc)	alien	A; 8; 2	B; 7; 1	C; 6; 1	25
Psidium guajava	Common guava (sc)	alien		B; 1; 0	C; 2; 0	3
Rubus rosifolius	Thimbleberry	alien	A; 9; 0	B; 4; 0	C; 7; 0	20
Spathoglottis plicata	Phillipine ground orchid	alien	A; 9; 0	B; 9; 0	C; 2; 0	20
Thelypteris parasitica	fern	alien			C; 5; 0	55
Upper Kau'eleau (elevation 314 m, road-forest location, lowland wet 'ohi'a [*Metrosideros*] forest)						
Adenophorus tamariscinus	fern	endemic	A; 1; 0	B; 1; 0	C; 1; 0	3
Asplenium nidus	Bird's nest fern (sc)	indigenous		B; 1; 0	C; 5; 0	6
Cibotium glaucum	Hapu'u (sc)	endemic	A; 8; 0	B; 8; 0	C; 7; 0	23
Cibotium menziesii	Hapu'u (sc)	endemic		B; 1; 0		1
Diplazium sandwichianum	fern	endemic		B; 1; 0		1
Elaphoglossum spp.	fern	endemic	A; 2; 0	B; 6; 0	C; 8; 0	16
Freycinetia arborea	'Ie'ie (sc)	indigenous	A; 7; 0	B; 11; 0	C; 6; 0	24
Grammitis tenella	fern	endemic		B; 1; 0	C; 2; 0	3
Isachne distichophylla	'Ohe	endemic	A; 1; 0			1
Lepisorus thunbergianus	fern	indigenous	A; 1; 0			1
Machaerina angustifolia	'Uki'uki	indigenous			C; 1; 0	1
Mecodium recurvatum	Filmy fern	indigenous		B; 2; 0	C; 1; 0	3
Metrosideros polymorpha	'Ohi'a (c)	endemic	A; 11; 1	B; 11; 0	C; 11; 0	34
Myrsine lanaiensis	Kolea (sc)	endemic		B; 2; 0	C; 1; 0	3
Nephrolepis exaltata var. *hawaiiensis*	fern	endemic	A; 10; 0	B; 11; 0	C; 11; 0	32
Peperomia spp.	'Ala'ala wai nui	indigenous		B; 1; 0	C; 3; 0	4
Phlegmariurus filiformis	club moss	indigenous			C; 1; 0	1
Phymatosorus scolopendrium	fern	indigenous		B; 1; 0		1
Pipturus albidus	Mamaki	endemic		B; 1; 0		1
Psilotum nudum	Moa	indigenous			C; 1; 0	1
Psychotria hawaiiensis	'Opiko (sc)	endemic	A; 11; 0	B; 11; 0	C; 11; 0	33

continued

Appendix 1. Continued.

Scientific name	Common name (c = canopy; sc = subcanopy)	Status	Species occurrence (transect; number of sites occupied; number of sites as dominant)			Dominance value[a]
Upper Kau'eleau - continued						
Sadleria cyatheoides	'Amau	endemic	A; 1; 0			1
Tetraplasandra oahuensis	'Ohe (sc)	endemic		B; 4; 0	C; 1; 0	5
Wikstroemia sp.	\`Akia	endemic		B; 1; 0		1
Ageratum conizioides	Maile hohono	alien	A; 2; 0	B; 1; 0	C; 1; 0	4
Aleurites moluccana	Kukui (c)	Polynesian	A; 1; 0			1
Buddleia asiatica	Butterfly bush	alien	A; 1; 0		C; 1; 0	2
Castilleja arvensis	Indian paintbrush	alien			C; 1; 0	1
Cecropia obtusifolia	Guarumo (c)	alien	A; 6; 0	B; 2; 0		8
Centella asiatica	Pennywort	alien	A; 1; 0			1
Cordyline fruticosa	Ti	Polynesian	A; 2; 0			2
Cuphea carthagenensis	Tarweed	alien	A; 1; 0	B; 1; 0	C; 1; 0	3
Cyperus halpan	Umbrella sedge	alien			C; 1; 0	1
Cyperus spp.	sedge	alien			C; 1; 0	1
Desmodium triflorum	Tick clover	alien	A; 2; 0		C; 1; 0	3
Digitaria ciliaris	Henry's crabgrass	alien			C; 1; 0	1
Dioscorea pentaphylla	Pi'a	Polynesian	A; 9; 0	B; 3; 0	C; 1; 0	13
Hedychium flavescens	Yellow ginger	alien	A; 2; 0			2
Melastoma candidum	shrub melatome	alien	A; 9; 0	B; 9; 0	C; 8; 0	26
Melochia umbellata	shrub	alien			C; 1; 0	1
Mimosa pudica	Sleeping grass	alien	A; 1; 0		C; 1; 0	2
Ophioglossum pendula	fern	alien	A; 1; 0	B; 5; 0	C; 1; 0	7
Oplismenus hirtellus	Basket grass	alien	A; 8; 0	B; 10; 0	C; 9; 0	27
Pityrogramma calomelanos	Silver fern	alien	A; 1; 0		C; 1; 0	2
Pluchea symphytifolia	Sourbush	alien	A; 2; 0	B; 1; 0	C; 1; 0	4
Polygala paniculata	Milkwort	alien	A; 1; 0	B; 1; 0	C; 1; 0	3
Psidium cattleianum	Strawberry guava (sc)	alien	A; 10; 0	B; 10; 0	C; 9; 0	29
Psidium guajava	Common guava (sc)	alien	A; 3; 0		C; 1; 0	4

continued

Appendix 1. Continued.

Scientific name	Common name (c = canopy; sc = subcanopy)	Status	Species occurrence (transect; number of sites occupied; number of sites as dominant)			Dominance value[a]
Upper Kau'eleau - continued						
Rubus rosifolius	Thimbleberry	alien	A; 2; 0	B; 2; 0	C; 1; 0	5
Schizostachyum glaucifolium	Bamboo (sc)	Polynesian?	A; 5; 0			5
Spathoglottis plicata	Phillipine ground orchid	alien	A; 4; 0	B; 5; 0	C; 5; 0	19
Stachytarpheta urticifolia	herb	alien	A; 2; 0			2
Thelypteris parasitica	fern	alien	A; 2; 0		C; 1; 0	2
Toona ciliata	Austrailian red cedar	alien		B; 1; 0		1
Pu'u 'Ō'ō (elevation 723 m, lava-forest location, lowland wet 'ohi'a[*Metrosideros*] forest)						
Adenophorus tamariscinus	fern	endemic	A; 5; 0	B; 3; 0	C; 2; 0	10
Broussaisia arguta	Kanawao	endemic	A; 8; 0	B; 10; 1	C; 9; 0	28
Cheirodendron trigynum	'Olapa (c)	endemic	A; 6; 0	B; 8; 0	C; 10; 0	24
Cibotium glaucum	Hapu'u (sc)	endemic	A; 8; 3	B; 6; 0	C; 10; 0	27
Clermontia parviflora	'Oha wai	endemic	A; 9 ; 0	B; 6; 0	C; 4; 0	19
Coprosma sp.	Pilo	endemic			C; 1; 0	1
Cyrtandra hawaiensis	Ha'iwale	endemic	A; 1; 0			1
Cyrtandra platyphylla	Ha'iwale	endemic	A; 1; 0	B; 2; 0		3
Dicranopteris linearis	Uluhe	indigenous	A; 9; 6	B; 8; 6	C; 8; 6	43
Diplazium microphyllum	fern	endemic	A; 2; 0	B; 2; 0	C; 2; 0	6
Dubautia scabra	Na'ena'e	endemic			C; 1; 0	1
Elaphoglossum crassifolium	fern	endemic	A; 6; 0	B; 4; 0	C; 5; 0	15
Freycinetia arborea	'Ie'ie (sc)	indigenous	A; 5; 0	B; 4; 0	C; 1; 0	10
Grammitis tenella	fern	endemic	A; 1; 0	B; 3; 0		4
Ilex anomala	Kawa'u (sc)	indigenous			C; 1; 0	1
Machaerina angustifolia	'Ūki'uki	indigenous	A; 1; 0			1
Mecodium recurvatum	Filmy fern	indigenous	A; 4; 0	B; 3; 0		7
Melicope clusiifolia	Kolokolo mokihana	endemic	A; 6; 0	B; 8; 0	C; 4; 0	18
Metrosideros polymorpha	'Ohi'a (c)	endemic	A; 11; 3	B; 11; 8	C; 11; 6	50
Microlepia strigosa	Palapalai	indigenous		B; 1; 0		1

continued

Appendix 1. Continued.

Scientific name	Common name (c = canopy; sc = subcanopy)	Status	Species occurrence (transect; number of sites occupied; number of sites as dominant)			Dominance value[a]
Pu'u 'Ō'ō - continued						
Nephrolepis cordifolia	fern	indigenous	A; 6; 1	B; 8; 1	C; 6; 1	23
Palhinhaea cernua	club moss	indigenous	A; 1; 0			1
Peperomia sp.	'Ala'ala wai nui	endemic	A; 4; 0	B; 3; 0	C; 6; 0	13
Phlegmariurus filiformis	club moss	indigenous		B; 1; 0		1
Pipturus albidus	Mamaki	endemic		B; 1; 0		1
Psilotum complenatum	Moa	indigenous			C; 1; 0	1
Psychotria hawaiiensis	'Opiko (sc)	endemic	A; 7; 0	B; 4; 0	C; 5; 0	16
Thelypteris cyatheoides	fern	endemic	A; 1; 0	B; 4; 0	C; 1; 0	6
Vaccinium calycinum	'Ohelo	endemic	A; 5; 0	B; 3; 0	C; 5; 0	13
Ageratum conizioides	Maile hohono	alien		B; 1; 0	C; 1; 0	2
Andropogon virginicus	Broomsedge	alien			C; 1; 0	1
Arundina graminifolia	Bamboo orchid	alien	A; 2; 0	B; 3; 0	C; 3; 0	8
Buddleia asiatica	Butterfly bush	alien		B; 1; 0		1
Cuphea carthagenensis	Tarweed	alien	A; 2; 0	B; 1; 0		3
Cyperus halpan	Umbrella sedge	alien	A; 2; 0	B; 1; 0	C; 2; 0	5
Deparia petersenii	fern	alien	A; 7; 0	B; 6; 0	C; 5; 0	18
Erechtites valerianifolia	Fireweed	alien	A; 2; 0		C; 1; 0	1
Melastoma candidum	shrub melostome	alien	A; 2; 0	B; 3; 0	C; 2; 0	7
Paspalum conjugatum	Hilo grass	alien	A; 6; 0	B; 8; 1	C; 5; 1	21
Rubus rosifolius	Thimbleberry	alien	A; 4; 0		C; 2; 0	6
Spathoglottis plicata	Phillipine ground orchid	alien		B; 1; 0	C; 1; 0	2
Torenia asiatica	Ola'a beauty	alien	A; 1; 0	B; 2; 0		3
N.E. Kahauale'a (elevation 725 m, road-forest location, lowland wet 'ohi'a [*Metrosideros*] forest)						
Adenophorus tamariscinus	fern	endemic	A; 2; 0	B; 2; 0	C; 7; 0	10
Broussaisia arguta	Kanawao	endemic	A; 8; 0	B; 8; 0	C; 9; 0	24
Cheirodendron trigynum	'Olapa (c)	endemic	A; 7; 0	B; 9; 0	C; 7; 0	23

continued

Appendix 1. Continued.

Scientific name	Common name (c = canopy; sc = subcanopy)	Status	Species occurrence (transect; number of sites occupied; number of sites as dominant)			Dominance value[a]
N.E. Kahauale'a - continuned						
Clermontia parviflora	'Oha wai	endemic	A; 1; 0	B; 3; 0	C; 3; 0	7
Cibotium glaucum	Hapu'u (sc)	endemic	A; 11; 0	B; 7; 0	C; 10; 1	19
Cibotium menziesii	Hapu'u (sc)	endemic		B; 4; 0	C; 1; 0	5
Coprosma spp.	Pilo	endemic	A; 2; 0	B; 7; 0	C; 4; 0	13
Cyanea sp.	Haha	endemic			C; 1; 0	1
Dicranopteris linearis	Uluhe	indigenous	A; 8; 2	B; 10; 5	C; 4; 2	31
Diplazium microphyllum	fern	endemic	A; 2; 0	B; 2; 0		4
Diplazium sandwichianum	fern	endemic	A; 5; 0	B; 3; 0	C; 3; 0	11
Elaphoglossum spp.	fern	endemic	A; 1; 0	B; 3; 0	C; 5; 0	9
Freycinetia arborea	'Ie'ie (sc)	indigenous	A; 7; 0	B; 9; 0	C; 10; 0	26
Grammitis tenella	fern	endemic		B; 1; 0	C; 2; 0	3
Ilex anomala	Kawa'u (sc)	indigenous	A; 2; 0	B; 2; 0	C; 1; 0	5
Isachne distichophylla	'Ohe	endemic	A; 8; 0	B; 9; 0	C; 9; 0	26
Machaerina angustifolia	'Uki'uki	indigenous	A; 4; 0	B; 4; 0		8
Mecodium recurvatum	Filmy fern	indigenous	A; 1; 0		C; 2; 0	3
Melicope radiata	Alani (sc)	endemic	A; 1; 0	B; 3; 0	C; 5; 0	9
Metrosideros polymorpha	'Ohi'a (c)	endemic	A; 11; 1	B; 11; 11	C; 11; 3	48
Nephrolepis cordifolia	fern	indigenous	A; 1; 0			1
Nephrolepis exaltata var. *hawaiiensis*	fern	endemic	A; 3; 0	B; 2; 0	C; 1; 0	6
Oligadenus pinnatifidus	fern	endemic		B; 1; 0		1
Palhinhaea cernua	club moss	indigenous	A; 6; 0	B; 3; 0	C; 1; 0	10
Peperomia spp.	'Ala'ala wai nui	indigenous	A; 5; 0	B; 2; 0	C; 5; 0	12
Phlegmariurus filiformis	club moss	indigenous			C; 1; 0	1
Pipturus albidus	Mamaki	endemic		B; 2; 0		2
Psilotum complenatum	Moa	indigenous	A; 1; 0		C; 1; 0	2
Psilotum nudum	Moa	indigenous		B; 1; 0	C; 1; 0	2
Psychotria hawaiiensis	'Opiko (sc)	endemic	A; 6; 0	B; 8; 0	C; 10; 0	24
Scaevola gaudichaudii	Nnaupaka kuahiwi	endemic		B; 2; 0		2

continued

Appendix 1. Continued.

Scientific name	Common name (c = canopy; sc = subcanopy)	Status	Species occurrence (transect; number of sites occupied; number of sites as dominant)			Dominance value[a]
N.E. Kahauale'a - continuned						
Vaccinium calycinum	'Ohelo	endemic	A; 3; 0	B; 2; 0	C; 4; 0	9
Arundina graminifolia	Bamboo orchid	alien	A; 9; 0	B; 4; 0	C; 2; 0	15
Asplenium lobulatum	fern	alien			C; 1; 0	1
Cardamine flexuosa	Bittercress	alien		B; 1; 0		1
Centella asiatica	Pennywort	alien	A; 1; 0		C; 1; 0	2
Crotalaria pallida	Smooth rattlepod	alien	A; 1; 0			1
Cuphea carthagenensis	Tarweed	alien	A; 1; 0	B; 1; 0		2
Cyperus halpan	Umbrella sedge	alien	A; 6; 0	B; 3; 0	C; 2; 0	11
Desmodium triflorum	Tick clover	alien	A; 1; 0			1
Erechtites valerianifolia	Fireweed	alien	A; 4; 0	B; 4; 0	C; 1; 0	9
Hedychium flavescens	Yellow ginger	alien	A; 1; 0	B; 2; 0	C; 6; 0	9
Impatiens wallerana	Busy Lizzy	alien	A; 1; 0	B; 3; 0	C; 4; 0	8
Melastoma candidum	shrub melastome	alien	A; 3; 0	B; 1; 0	C; 2; 0	6
Nephrolepis multiflora	fern	alien			C; 1; 0	1
Ophioglossum pendula	fern	alien			C; 1; 0	1
Oplismenus hirtellus	Basket grass	alien			C; 1; 0	1
Psidium cattleianum	Strawberry guava (sc)	alien	A; 11; 0	B; 9; 0	C; 10; 10	40
Rubus rosifolius	Thimbleberry	alien	A; 1; 0	B; 4; 0	C; 1; 0	6

a. From "Species occurrence" column: number of sites + number of sites as dominant.

Appendix 2. Arthropod taxa observed or sampled during the invertebrate surveys; Puna District, Hawai`i, 1994.

Order[1]	Family[2]	Scientific name	Number of individuals seen[3]								
			0-meter samples				100-meter samples				Grand
			A	B	C	total	A	B	C	total	total
Southeast Kula (elevation 16 m, lava-forest location, lowland mesic 'ohi'a forest)											
Endemic tax († = mostly likely native)											
Diptera	Calliphoridae	*Dyscritomyia* spp.	5			5		3		3	8
	Ceratopogonidae	*Forcipomyia* sp. prob.	10		40	50	5		2	7	57
	Chironomidae	*Orthocladius* sp.	7	2		9	1	18	5	24	33
	Dolichopodidae	*Campsicnemus* spp.				0	7	16	5	28	28
	Muscidae	*Lispocephala* sp.		3		3				0	3
	Phoridae	*Megaselia* spp. (†)	1	4		5	9		5	14	19
	Sciaridae	(†)	7	114	23	144	9	112	>200	321	465
	Tipulidae	*Limonia grimshawi*		6	1	7			1	1	8
	Tipulidae	*Limonia* sp.				0		4	5	9	9
Heteroptera	Lygaeidae	*Neseis* sp.		1		1				0	1
Homoptera	Cicadellidae	(†)				0		1		1	1
	Psyllidae	(†)	3	10	8	21	6	2	23	31	52
Hymenoptera	Cynipidae	(†)	1	5	4	10		1	2	3	13
Lepidoptera	Crambidae	*Mestelobes* spp.	94	68	142	304	57	110	205	372	676
	Noctuidae	*Schrankia* sp.				0			6	6	6
Orthoptera	Gryllidae	*Paratrigonidium* sp.	1		1	2				0	2
Psocoptera	undetermined	(†)	11	16	12	39	5		12	17	56
Subtotal	16 families		140	229	231	600	99	267	471	837	1,437
Alien taxa											
Coleoptera	Coccinellidae	*Scymnus* ? sp.		1		1		1	1	2	3
	Coccinellidae		1			1				0	1
	Silvanidae	*Psammoechus insularis*	1			1				0	1
Diptera	Ceratopogonidae	*Atrichopogon jacobsoni*	1	2		3	1	1		2	5
	Chloropidae	*Rhodesiella* sp.		13	3	16	23	10	11	44	60
	Culicidae				1	1		1	1	2	3

continued

Appendix 2. Continued.

Order[1]	Family[2]	Scientific name	Number of individuals seen[3]								
			0-meter samples				100-meter samples				Grand
			A	B	C	total	A	B	C	total	total
Southeast Kula - continued											
Alien taxa - continued											
Diptera	Dixidae				1	1				0	1
	Drosophilidae	*Drosophila suzukii* group	156	76	59	291	>430	112	175	717	1,008
	Neriidae	*Telostylinus lineolatus*		2		2		1		1	3
	Sphaeroceridae	*Leptocera* sp. (†)	13	9		22	24	28	5	57	79
	Stratiomyidae		1			1				0	1
	Syrphidae			2		2				0	2
	Tachinidae		6	6	2	14	1	3		4	18
	Tipulidae	*Limonia perkinsi*		2	15	17	12	1	21	34	51
	Tipulidae	*Limnotes* sp.			3	3			1	1	4
Heteroptera	Anthocoridae				2	2		2	2	4	6
	Cydnidae		1	1	1	3				0	3
	Reduviidae	*Hematoloecha rubescens*		1		1				0	1
Homoptera	Aphididae	*Greenidea formosana*	8	23	17	48			2	2	50
	Aphididae		3		2	5			1	1	6
	Cicadellidae	2-spotted leafhopper	1	6	1	8			5	5	13
	Flatidae	*Siphanta aucta*			1	1				0	1
	Membracidae	*Vanduzeea segmentata*	1		1	2				0	2
Hymenoptera	Aphelinidae	*Aphytis* spp.	3	1		4	1	1		2	6
	Braconidae	*Meteorus* sp.		1		1				0	1
	Chalcididae			2		2				0	2
	Evaniidae	*Evania appendigaster*				0		2	1	3	3
	Formicidae	*Anoplolepis longipes*	>5,00	104		604	11	18	>300	329	933
	Formicidae	*Monomorium* sp.				0		114	11	125	125
	Formicidae	*Paratrechina* sp.		30	134	164		90	67	157	321
	Formicidae	*Ponera* sp.			4	4		1	3	4	8
	Formicidae	*Strumigenys* sp.				0	1		1	2	2
	Formicidae	*Tapinoma*	5	3		8		49		49	57

continued

Appendix 2. Continued.

Order[1]	Family[2]	Scientific name	Number of individuals seen[3]								
			0-meter samples				100-meter samples				Grand total
			A	B	C	total	A	B	C	total	
Southeast Kula - continued											
	Alien taxa - continued										
Hymenoptera	Formicidae	Black sp.		50		50		43		43	93
	Formicidae	Red sp.			70	70	139	179	44	362	432
	Formicidae		12	55	3	70	13	50	17	80	150
Lepidoptera	Noctuidae	*Bocana manifestalis*				0	1	7		8	8
	Noctuidae	*Elaphria nucicolora*	1			1		2		2	3
	Oecophoridae	*Stoeberhinus testaceus*	34	83	20	137	14	12	7	33	170
Mantodea	Mantidae	*Tenodera australasiae*		1		1				0	1
Orthoptera	Gryllidae	*Gryllodes sigillatus*	4	14		18				0	18
	Tettigoniidae	*Elimaea punctifera*		1		1			4	4	5
Subtotal	30 families		5251	489	340	6,081	671	728	680	2,079	8,160
	Taxa of uncertain status										
Acari	Oribatulidae				24	24	3		6	9	33
Araneae	undetermined		1	1		2			2	2	4
Coleoptera	Elateridae			1		1				0	1
	Ptilidae		2			2	2	2		4	6
Collembola	Entomobryidae			1	2	3	37			37	40
	Sminthuridae				8	8	11	1	7	19	27
Diptera	Dolichopodidae		4	1	1	6		2	2	4	10
	Drosophilidae	*Drosophila* spp.	36	98	7	141	9	14	12	35	176
	Muscidae			3		3		1	1	2	5
	Psychodidae		9	37	5	51	1		23	24	75
	Tipulidae			2	1	3		1		1	4
	Tephritidae					0		1		1	1
Hymenoptera	Agaonidae		4	4	197	205	2		59	61	266
	Chalcidoidea		2	12	15	29	6	4	4	14	43

continued

Appendix 2. Continued.

Order[1]	Family[2]	Scientific name	Number of individuals seen[3]								
			0-meter samples				100-meter samples				Grand
			A	B	C	total	A	B	C	total	total
Southeast Kula - continued											
	Taxa of uncertain status - continued										
Hymenoptera	Encyrtidae					0			17	17	17
	Ichneumonidae		2			2				0	2
	Mymaridae					0			10	10	10
	Platygasteridae			2	3	5			6	6	11
	Pteromalidae				11	11		2		2	13
	Sphecidae				1	1		5		5	6
Lepidoptera	undetermined		>35	305	101	441	6	62	121	189	630
Thysanoptera	undetermined					0		3		3	3
Subtotal	22 families		95	467	376	938	77	98	270	445	1,383
Site total	57 families		5,487	1,185	947	7,619	847	1,093	1,421	3,361	10,980
Upper Oneloa (elevation 108 m, road-forest location, lowland wet 'ohi'a/uluhe											
	Endemic taxa († = most likely endemic)										
Coleoptera	Nitidulidae			5		5		1		1	6
Diptera	Calliphoridae	*Dyscritomyia* spp.				0	14			14	14
	Ceratopogonidae	*Forcipomyia* sp. prob.	>200	200	50	450	54		200	254	704
	Chironomidae	*Orthocladius* sp.	55	60	77	192	15		11	26	218
	Dolichopodidae	*Campsicnemus* spp.			1	1	14	8	3	25	26
	Drosophilidae	*Scaptomyza* sp.	1	2		3				0	3
	Phoridae	*Chonocephalus* sp. (†)		10		10				0	10
	Phoridae	*Megaselia* spp. (†)	2	8	8	18	1			1	19
	Sciaridae		40	>66	15	121	25	186	56	267	388
	Tipulidae	*Limonia* sp.		6	7	13	10		1	11	24
Heteroptera	Lygaeidae	*Neseis* sp.			2	2				0	2
Homoptera	Cicadellidae	*Iolania* sp.				0	1			1	1
	Cicadellidae		5		1	6		3		3	9

continued

Appendix 2. Continued.

Order[1]	Family[2]	Scientific name	Number of individuals seen[3]								
			0-meter samples				100-meter samples				Grand
			A	B	C	total	A	B	C	total	total
Upper Oneloa - continued											
	Endemic taxa († = most likely endemic) - continued										
Homoptera	Cixiidae	*Iolania* sp.				0	1			1	1
	Cixiidae	*Oliarus* sp.		1		1				0	1
	Psyllidae		14	10	16	40	3	5	11	19	59
Hymenoptera	Dryinidae			1	1	2				0	2
	Encyrtidae		1			1				0	1
Lepidoptera	Carposinidae	*Carposina* sp.	2			2				0	2
	Cosmopteridgidae	*Hyposmocoma* spp.			11	11			4	4	15
Lepidoptera	Crambidae	*Mestelobes* spp.	2	24	3	29			2	2	31
	Noctuidae	*Schrankia* sp.		1	1	2	3		9	12	14
	Tortricidae	*Cydia* spp.		6		6				0	6
Neuroptera	Hemerobiidae	*Micromus* 2 spp.				0		2		2	2
Psocoptera	undetermined		33	34	11	78	19	43	15	77	155
Subtotal	22 families		355	434	204	993	160	248	312	720	1,713
	Alien taxa										
Araneae	Araneidae	*Gasteracantha* sp.			2	2				0	2
Blatteria	undetermined				14	14				0	14
Chilopoda	Scolopendridae	*Scolopendra subspinipes*			1	1				0	1
Coleoptera	Cerambycidae	*Curtomerus flavus*				0			1	1	1
	Coccinellidae	*Scymnus* ? sp.			1	1		1		1	2
	Hydrophilidae				1	1				0	1
	Phalacridae				4	4	2			2	6
Diptera	Ceratopogonidae	*Atrichopogon jacobsoni*	3	52	13	68			8	8	76
	Chloropidae	*Rhodesiella* sp.	2	1		3	4			4	7
	Dixidae		1		1	2			1	1	3
	Drosophilidae	*Drosophila suzukii* group	>402	>582	>801	1785	295	>809	>520	1,624	3,409

continued

Appendix 2. Continued.

Order[1]	Family[2]	Scientific name	Number of individuals seen[3]								
			0-meter samples				100-meter samples				Grand
			A	B	C	total	A	B	C	total	total
Upper Oneloa - continued											
	Alien taxa - continued										
Diptera	Drosophilidae	*Drosophila melanogaster* group				0			1	1	1
	Neriidae	*Telostylinus lineolatus*		1	1	2		1		1	3
	Otitidae		4	2		6	1			1	7
	Sphaeroceridae	*Leptocera* sp. (†)	71	98	23	192	48	25	44	117	309
	Syrphidae	*Allograpta* near *exotica*			1	1				0	1
	Syrphidae					0		1		1	1
Heteroptera	Anthocoridae				2	2		6		6	8
Homoptera	Aphididae	*Greenidea formosana*	2	1		3		6		6	9
Homoptera	Aphididae		3	6	5	14	1	2		3	17
	Cicadellidae	2-spotted leafhopper				0		2		2	2
	Flatidae	*Melormenis basalis*	2			2				0	2
	Flatidae	*Siphanta aucta*				0		2		2	2
Hymenoptera	Aphelinidae	*Aphytis* spp.	2			2	5			5	7
	Braconidae	*Apanteles* sp.	1			1				0	1
	Braconidae	*Meteorus* sp.				0		1		1	1
	Chalcididae				4	4				0	4
	Formicidae	*Anoplolepis longipes*	102	17	76	195	54	137	358	549	744
	Formicidae	*Paratrechina* sp.				0		1		1	1
	Formicidae	*Strumigenys* sp.			1	1				0	1
	Formicidae	*Tapinoma*			97	97				0	97
	Formicidae	Black sp.		2	6	8	2	1		3	11
	Formicidae	Red sp.	5	36	251	292		200	300	500	792
	Formicidae				1	1	20			20	21
	Scelionidae	*Baeus* ? sp.			5	5		1	1	2	7
Lepidoptera	Noctuidae	*Bocana manifestalis*	2	6		8		2	8	10	18
	Noctuidae	*Elaphria nucicolora*	5			5				0	5

continued

Appendix 2. Continued.

Order[1]	Family[2]	Scientific name	Number of individuals seen[3]								
			0-meter samples				100-meter samples				Grand total
			A	B	C	total	A	B	C	total	
Upper Oneloa - continued											
	Alien taxa - continued										
Lepidoptera	Oecophoridae	*Stoeberhinus testaceus*	11	8	5	24	4	30	3	37	61
	Sphingidae	*Macroglossum*		2		2			5	5	7
Subtotal	27 families		618	814	1,316	2,746	436	1,228	1,250	2,916	5,662
	Taxa of uncertain status										
Acari	Oribatulidae					0	2			2	2
	undetermined					0		1		1	1
Araneae	undetermined		2	5	1	8		1		1	9
Coleoptera	Curculionidae			1		1				0	1
	Elateridae			7		7		1		1	8
Coleoptera	Ptilidae		2	13		15	2	3	1	6	21
	Staphylinidae		1	8	2	11	2	2		4	15
Collembola	Entomobryidae		18	111	3	132	15	44	46	105	237
	Isotomidae			3		3		2	4	6	9
	Sminthuridae		1	19	3	23	8	37	17	62	85
Diptera	Drosophilidae	*Drosophila* spp.	2		2	4		2	8	10	14
	Muscidae		1			1	4			4	5
	Psychodidae		95	7		102	10		2	12	114
	Sphaeroceridae					0		7		7	7
	Tephritidae		1			1				0	1
Heteroptera	Miridae		1		1	2		5	1	6	8
Homoptera	Delphacidae					0	2	3		5	5
	Pseudococcidae				1	1				0	1
Hymenoptera	Chalcidoidea		34	1	10	45	39	7		46	91
	Encyrtidae			1	3	4		2	2	4	8
	Proctotrupoidea					0		1		1	1

continued

Appendix 2. Continued.

Order[1]	Family[2]	Scientific name	Number of individuals seen[3]								
			0-meter samples				100-meter samples				Grand total
			A	B	C	total	A	B	C	total	
Upper Oneloa - continued											
	Taxa of uncertain status - continued										
Lepidoptera	Noctuidae					0		2		2	2
	Tortricidae		1			1				0	1
	undetermined			1		1		17		17	18
Pseudoscorpioni	Pseudoscorpionida			1		1				0	1
Thysanoptera	undetermined		1			1				0	1
Subtotal	24 families		160	178	26	364	84	137	81	302	666
Site total	62 families		1,133	1,426	1,546	4,105	680	1,613	1,643	3,936	8,041
Keauohana Forest Reserve (elevation 227 m, lava-forest location, lowland wet 'ohi'a forest)											
	Endemic taxa († = most likely endemic)										
Diptera	Calliphoridae	*Dyscritomyia* spp.			2	2				0	2
	Ceratopogonidae	*Forcipomyia* sp. prob.	84		200	284	12	2	52	66	350
	Chironomidae	*Orthocladius* sp.	10		7	17	1	1	2	4	21
	Dolichopodidae	*Campsicnemus* spp.				0	1		1	2	2
	Drosophilidae	*Scaptomyza* sp.			2	2				0	2
	Muscidae	*Lispocephala* sp.	1	1		2				0	2
	Phoridae	*Megaselia* spp. (†)	4	10	35	49	3	4	10	17	66
	Sciaridae		8	4	10	22		4	7	11	33
	Tipulidae	*Limonia grimshawi*			5	5				0	5
	Tipulidae	*Limonia* sp.	2		6	8		1	1	2	10
Homoptera	Cicadellidae	*Nesophrosyne* sp.		1		1			1	1	2
	Cicadellidae				1	1				0	1
	Cixiidae	*Oliarus* sp.	1			1		2	1	3	4
	Psyllidae		46	89	37	172		4	26	30	202
Hymenoptera	Cynipidae			1		1				0	1
	Dryinidae			1		1				0	1
Lepidoptera	Carposinidae	*Carposina* sp.	1		1	2				0	2

continued

Appendix 2. Continued.

Order[1]	Family[2]	Scientific name	Number of individuals seen[3]								
			0-meter samples				100-meter samples				Grand
			A	B	C	total	A	B	C	total	total
Keauohana Forest Reserve - continued											
	Endemic taxa - continued										
Lepidoptera	Cosmopteridgidae	*Hyposmocoma* spp.	1	27	10	38				0	38
	Crambidae	*Eudonia* spp.	1			1				0	1
	Crambidae	*Mestelobes* spp.	72	30	8	110				0	110
	Geometridae	*Scotorythra* sp.		1		1				0	1
	Noctuidae	*Schrankia* spp.	2		11	13				0	13
	Tortricidae	*Cydia* spp.		3		3			6	6	9
Neuroptera	Hemerobiidae	*Micromus* spp.			1	1				0	1
Orthoptera	Gryllidae	*Paratrigonidium* sp.			1	1				0	1
Psocoptera	undetermined		27	36		63		4	4	8	71
Subtotal	23 families		260	204	337	801	17	22	111	150	951
	Alien taxa										
Blattaria	Blattidae	*Periplaneta americana*	18	112		130				0	130
	undetermined		1			1				0	1
Diptera	Ceratopogonidae	*Atrichopogon jacobsoni*	1			1		21		21	22
	Drosophilidae	*Drosophila suzukii* group	78	13	210	301	125	50	54	229	530
	Neriidae	*Telostylinus lineolatus*			2	2	4			4	6
	Otitidae		19	8	4	31				0	31
	Sphaeroceridae	*Leptocera* sp. (†)	5	18	35	58	10	15	23	48	106
	Syrphidae	*Allograpta* near *exotica*		1	1	2				0	2
	Tipulidae	*Limonia perkinsi*	1	2	3	6		3		3	9
Heteroptera	Anthocoridae					0		1		1	1
Homoptera	Aphididae		4	8	5	17			3	3	20
	Cicadellidae		1			1				0	1
	Flatidae	*Syphanta acuta*	1	3	1	5				0	5
	Membracidae	*Vanduzeea segmentata*	2	1		3				0	3

continued

Appendix 2. Continued.

Order[1]	Family[2]	Scientific name	Number of individuals seen[3]								
			0-meter samples				100-meter samples				Grand
			A	B	C	total	A	B	C	total	total
Keauohana Forest Reserve - continued											
	Alien taxa - continued										
Hymenoptera	Apidae	*Apis melifera*			1	1			1	1	2
	Braconidae	*Meteorus* sp.				0			1	1	1
	Chalcididae					0			2	2	2
	Formicidae	*Anoplolepis longipes*	85	19	>207	311	>75	10	4	89	400
	Formicidae	Black sp.	1	1	4	6	>152	97	4	253	259
	Formicidae	Red sp.		127		127				0	127
	Formicidae					0			1	1	1
Isopoda	undetermined			63		63			2	2	65
Lepidoptera	Noctuidae	*Bocana manifestalis*				0	7	2	9	18	18
	Noctuidae	*Elaphria nucicolora*			1	1				0	1
	Oecophoridae	*Stoeberhinus testaceus*	6		3	9				0	9
Subtotal	20 families		223	376	477	1,076	373	199	104	676	1,752
	Taxa of uncertain status										
Acari	Oribatulidae					0	2	3	64	69	69
Amphipoda	Talitridae		2	21		23				0	23
Aranreae	undetermined					0	2			2	2
Coleoptera	Elateridae					0			1	1	1
Collembola	Entomobryidae				1	1	10	30	29	69	70[4]
	Sminthuridae					0		1	3	4	4
Diptera	Drosophilidae	*Drosophila* spp.		12		12			4	4	16
	Muscidae		2	1	1	4				0	4
	Psychodidae		14	46	4	64	1	6	22	29	93
	Tipulidae				3	3				0	3
Hymenoptera	Agaonidae			1	1	2				0	2
	Chalcidoidea		2			2		4		4	6

continued

Appendix 2. Continued.

Order[1]	Family[2]	Scientific name	Number of individuals seen[3]								
			0-meter samples				100-meter samples				Grand
			A	B	C	total	A	B	C	total	total
Keauohana Forest Reserve - continued											
	Taxa of uncertain status - continued										
Hymenoptera	Encyrtidae			2		2				0	2
	Ichneumonidae				1	1				0	1
	Mymaridae		1			1				0	1
Subtotal	15 families		21	83	11	115	15	44	123	182	297
Site total	49 families		504	663	825	1,992	405	265	338	1,008	3,000
Upper Kau'eleau (elevation 314 m, road-forest location, lowland wet 'ohi'a forest)											
	Endemic taxa										
Lepidoptera	Tortricidae		5	2		7				0	7
Diptera	Drosophilidae	*Drosophila ochracea*	1	2	1	4		3	1	4	8
	Drosophilidae	*Drosophila sproati*	1	1		2		2		2	4
	Drosophilidae	*Drosophila tanythrix*	2	2		4		2	6	8	12
	Alien taxa										
Diptera	Drosophilidae	*Drosophila suzukii* group	52	65	38	155	12	21	18	51	206
Pu'u 'O'o (elevation 723 m, lava-forest location, lowland wet 'ohi'a forest)											
	Endemic taxa († = most likely endemic)										
Araneae	Tetragnathidae	*Tetragnatha* sp.							2	2	2
Coleoptera	Carabidae		4	1	1	6	6	3		9	15
	Nitidulidae					0	5	2		7	7
	Scolytidae		1			1	1			1	2
Diptera	Calliphoridae	*Dyscritomyia* spp.			2	2	7	3	12	22	24
	Ceratopogonidae	*Forcipomyia* sp. prob.			7	7	5	50	50	105	112
	Chironomidae	*Orthocladius* sp.	2		15	17		1	3	4	21
	Dolichopodidae	*Campsicnemus* spp.	1	1	5	7	3	5	2	10	17
	Dolichopodidae	*Eurynogaster* spp.	7			7	4	4	7	15	22
	Drosophilidae	*Drosophila ochracea*	1			1	1	1	1	3	4

continued

Appendix 2. Continued.

Order[1]	Family[2]	Scientific name	0-meter samples A	0-meter samples B	0-meter samples C	0-meter samples total	100-meter samples A	100-meter samples B	100-meter samples C	100-meter samples total	Grand total
			Number of individuals seen[3]								
Pu'u 'O'o - continued											
	Endemic taxa († = most likely endemic) - continued										
Diptera	Drosophilidae	*Drosophila sproati*				0	1			1	1
	Drosophilidae	*Drosophila tanythrix*	2		2	4	11	18	3	32	36
	Drosophilidae	*Scaptomyza* sp.	21	1	32	54	7	17	4	28	82
	Muscidae	*Lispocephala* sp.		12		12				0	12
	Phoridae	*Chonocephalus* sp. (†)				0			1	1	1
	Phoridae	*Megaselia* spp. (†)	11	20	5	36		5	26	31	67
	Sciaridae		12	53	7	72	2	13	>21	36	108
	Tipulidae	*Limonia grimshawi*	3		5	8	2		1	3	11
	Tipulidae	*Limonia* sp.	2		1	3	1	1		2	5
Heteroptera	Miridae	*Orthotylus* sp.	1			1				0	1
	Nabidae	*Nabis* sp.	1		1	2	1		1	2	4
Homoptera	Cicadellidae	*Nesophrosyne* sp.		1	2	3	1			1	4
	Cicadellidae		1	1		2				0	2
	Cixiidae	*Iolania* sp.	3	4	3	10	11	1		12	22
	Cixiidae	*Oliarus* sp.	7		1	8		4	3	7	15
	Delphacidae	*Aloha* sp.	1			1				0	1
	Delphacidae	*Kelisia* sp.				0	3			3	3
	Delphacidae	*Leialoha* sp.			1	1				0	1
	Psyllidae		67	36	39	142	59	5	16	80	222
Hymenoptera	Bethylidae			1	3	4		1		1	5
	Colletidae	*Hylaeus* sp.	2			2				0	2
	Cynipidae		2			2				0	2
	Dryinidae		6			6			5	5	11
	Eucoilidae				2	2				0	2
	Vespidae	*Odynerus* sp.			7	7				0	7
Lepidoptera	Geometridae	*Scotorythra* sp.				0		1		1	1
	Tortricidae	*Cydia* spp.				0		1	3	4	4

continued

Appendix 2. Continued.

Order[1]	Family[2]	Scientific name	Number of individuals seen[3]								
			0-meter samples				100-meter samples				Grand
			A	B	C	total	A	B	C	total	total
Pu'u 'O'o - continued											
	Endemic taxa († = most likely endemic) - continued										
Orthoptera	Gryllidae	*Paratrigonidium* sp.	1	4		5	1	2		3	8
Psocoptera	undetermined					0		2		2	2
Subtotal	29 families		159	135	141	435	132	140	161	433	868
	Alien taxa										
Coleoptera	Phalacridae					0			1	1	1
	Scarabaeidae					0			1	1	1
	Silvanidae	*Psammoechus insularis*				0		2		2	2
Diptera	Chloropidae	*Rhodesiella* sp.	11			11				0	11
	Drosophilidae	*Drosophila suzukii* group	238	>315	>310	863	83	103	137	323	1,186
	Sphaeroceridae	*Leptocera* sp.	8	3	3	14	10	41	46	97	111
	Stratiomyidae					0			2	2	2
	Tipulidae	*Limonia perkinsi*	3		5	8	2		1	3	11
	Tipulidae	*Limnotes* sp.	2			2	1			1	3
Heteroptera	Anthocoridae					0		3		3	3
	Reduviidae	*Hematoloecha rubescens*	2		3	5	2			2	7
Homoptera	Aphididae	*Greenidea formosana*			1	1				0	1
	Aphididae			10	9	19		1		1	20
	Flatidae	*Melormenis basalis*	2	2	1	5				0	5
	Flatidae	*Syphanta acuta*	1	4	4	9				0	9
Hymenoptera	Aphelinidae	*Aphytis* spp.				0			31	31	31
	Apidae	*Apis mellilfera*		1		1				0	1
	Braconidae	*Apanteles* sp.	3	5		8		1	4	5	13
	Chalcididae					0			5	5	5
	Formicidae			2		2				0	2
	Scelionidae	*Baeus* ? sp.	1			1			1	1	2

continued

Appendix 2. Continued.

Order[1]	Family[2]	Scientific name	Number of individuals seen[3]								
			0-meter samples				100-meter samples				Grand
			A	B	C	total	A	B	C	total	total
Pu'u 'O'o - continued											
	Alien taxa - continued										
Hymenoptera	Vespidae	*Vespula pensylvanica*			1	1					1
Lepidoptera	Tortricidae	*Bactra* sp. (†)				0			1	1	1
Subtotal	20 families		271	342	337	950	98	151	230	479	1,429
	Taxa of uncertain status										
Acari	Oribatulidae					0		3	7	10	10
	undetermined					0			2	2	2
Amphipoda	Talitridae		4			4	1		2	3	7
Araneae	undetermined		1		1	2	1			1	3
Coleoptera	Curculionidae		3	1		4		1		1	5
	Elateridae		8	4		12	8			8	20
	Ptiliidae		1	1		2		2	3	5	7
	Staphylinidae		9	5	10	24	4	31	118	153	177
Collembola	Entomobryidae			2		2	2	13	52	67	69
	Isotomidae					0	2	2	2	6	6
Diptera	Dolichopodidae			1		1			1	1	2
	Drosophilidae	*Drosophila* spp.	3		9	12	2		1	3	15
	Muscidae					0		1	1	2	2
	Psychodidae				50	50	1	21	>23	45	95
	Sphaeroceridae					0	11			11	11
	Tipulidae				2	2	5	1		6	8
Heteroptera	Miridae		2	1		3	1		1	2	5
Hymenoptera	Chalcidoidea				6	6		2	6	8	14
	Diapriidae					0			20	20	20
	Encyrtidae		15	3		18		2		2	20
	Ichneumonidae		3	5	6	14		1	7	8	22

continued

Appendix 2. Continued.

Order[1]	Family[2]	Scientific name	0-meter samples A	0-meter samples B	0-meter samples C	0-meter samples total	100-meter samples A	100-meter samples B	100-meter samples C	100-meter samples total	Grand total
Pu'u 'O'o - continued											
	Taxa of uncertain status - continued										
Hymenoptera	Platygasteridae		3			3				0	3
	Proctotrupidae		2			2				0	2
	Sphecidae				1	1				0	1
Lepidoptera	Tortricidae				54	54				0	54
Subtotal	24 families		54	23	139	216	38	80	277	364	580
Site total	60 families		484	500	617	1,601	268	371	637	1,276	2,877
Northeast Kahauale`a (elevation 725 m, road-forest location, lowland wet 'ohi'a											
	Endemic taxa										
Diptera	Drosophilidae	*Drosophila ochracea*	3	1		4	4	1	8	13	17
	Drosophilidae	*Drosophila sproati*				0			1	1	1
	Drosophilidae	*Drosophila tanythrix*	5	5	1	11	4	3	9	16	27
	Drosophilidae	*Scaptomyza* sp.	8	8	6	22	5	5	34	44	66
	Alien taxa										
Diptera	Drosophilidae	*Drosophila suzukii* group	141	145	149	435	65	30	114	209	644

Number of individuals seen[3]

1. Includes Class Chilopoda. Taxonomy: class/order based on Borror *et al.* (1989); fased on Nishida (1994).
2. Includes superfamily Chalcidoidea and superfamily Proctotrupoidea, both under taxa of uncertain status.
3. Each count is the total of one malaise trap, two yellow pan traps, and two pitfall traps. Counts of drosophilid flies were the maximum number of flies seen during a single count of two baited sponges, plus flies collected in the malaise traps and yellow pan traps (see methods of details.)

Appendix 3. Invertebrates observed in the lava tubes of the Puna District, Hawai'i, 1994.

Scientific name	Affinity for lava tubes[a]	Status	Family
Arthropoda			
Agrotis spp.	TX moth	endemic	Noctuidae
Anisolabis howarthi	TB earwig	endemic	Carcinophoridae
Ageneta Meioneta sp.	TB spider	endemic	Linyphiidae
Astigmata - unidentified	TP mite	endemic?	
Caconemobius sp. A	TB cricket	endemic	Gryllidae
Caconemobius sp. B	TB cricket	endemic	Gryllidae
Caconemobius sp. C	TX cricket	endemic	Gryllidae
Caconemobiu fori	TX cricket	endemic	Gryllidae
Caconemobius varius	TB cricket	endemic	Gryllidae
Cavaticovelia aaa	TB water treader	endemic	Mesoveliidae
Cryptostigmata	TB/TP mite	endemic?	Cryptostigmatidae
Drosophila sp.	TB/TP fruit fly	endemic	Drosophilidae
Erigone stygius	TB spider	endemic	Linyphiidae
Forcipomyia pholetor	TB/TP midge	endemic	Ceratopogonidae
Foveacheles tenorioae	TB? mite	endemic?	Rhagidiidae
Hawinella lava	TB springtail	endemic	Entomobryidae
Hypocala velans	TX moth	endemic	Noctuidae
Ischnothyreus sp. A	TB spider	endemic	Oonopidae
Lepidoptera sp.	TB/TP crambid? moth	endemic	Crambidae ?
Limonia sp. near *jacobus*	TP crane fly	endemic	Tipulidae
Limonia sp.	TX/ACC crane fly	endemic	Tipulidae
Linyphiidae, Genus ? sp. A	TP spider	endemic	Linyphiidae
Linyphiidae, Genus ? sp. B	TB spider	endemic	Linyphiidae
Lithobius ? sp.	TB centipede	endemic	Lithobiidae
Lycosa howarthi	TB spider	endemic	Lycosidae
Megascelia sp.	TP coffin fly	endemic?	Phoridae
Nannolene sp.	TB millipede	endemic	Camballidae
Neanura hawaiiensis	TB springtail	endemic	Hypogastruridae
Nesidiolestes sp.	TB thread-legged bug	endemic	Reduviidae
Nesioneta ? sp. A	TB/TP spider	endemic	Linyphiidae
Nesioneta ? sp. B	TP spider	endemic	Linyphiidae
Nesomedon sp.	TB? rove beetle	endemic	Staphylinidae
Oliarus polyphemus	TB planthopper	endemic	Cixiidae
Oliarus spp.	ACC planthopper	endemic	Cixiidae
Oonopinus sp. A	TB? spider	endemic?	Oonopidae
Oonopinus sp. A	TB? spider	endemic?	Oonopidae
Oonops ? sp.	TB spider	endemic?	Oonopidae

continued

Appendix 3. Continued.

Scientific name	Affinity for lava tubes[a]	Status	Family
Arthropoda - continued			
Papuaphiloscia laevis	TB isopod	endemic	Philosciidae
Peridroma spp.	TX moth	endemic	Noctuidae
Phytosciara volcanata	. TP fly	endemic	Sciaridae
Psychodidae - unidentified	TP moth fly	endemic	Psychodidae
Sinella yosiia	TB springtail	endemic	Entomobryidae
Schrankia sp. A	TB moth	endemic	Noctuidae
Schrankia sp. B	TP moth	endemic	Noctuidae
Schrankia spp.	TP moth	endemic	Noctuidae
Sciaridae - unidentified	TP sciarid fly	endemic	Sciaridae
Tachys sp. near *arcanicola*	TB/TP? beetle	endemic	Carabidae
Thaumatogryllus cavicola	TB cricket	endemic	Gryllidae
Thaumatogryllus sp.	TB cricket	endemic	Gryllidae
Theridion sp.	TB spider	endemic	Theridiidae
Tylparua sp.	TP keroplatid fly	endemic	Keroplatidae
Tyrannochthonius howarthi	TB pseudoscorpion	endemic	Chthoniidae
Achaearanea tepidariorum	TP spider	alien	Theridiidae
Anoplolepis longipes	TX long legged ant	alien	Hymenoptera
Culex quinquefasciatus	TX mosquito	alien	Culicidae
Diplonevra peregrina	TP coffin fly	alien	Phoridae
Eidmanella pallida	TP spider	alien	Nesticidae
Entomobrya multifasciata	TP springtail	alien	Entomobryidae
Folsomia candida	TP springtail	alien	Isotomidae
Geococcus coffeae	TP coffee mealybug	alien	Pseudococcidae
Haematoloecha rubescens	ACC red and black bug	alien	Reduviidae
Indjapyx sharpi ?	TP Diplura	alien	Japygidae
Leptocera abdominiseta	TP fly	alien	Sphaeroceridae
Limonia Perkinsi	TX/ACC crane fly	alien	Tipulidae
Megascelia scalaris	TP coffin fly	alien	Phoridae
Nesticella mogera	TB spider	alien	Nesticidae
Nicoletia meinerti ?	TP bristle tail	alien	Nicoletidae
Onychiurus folsomi	TP springtail	alien	Onychiuridae
Oxidus gracilis	TP millipede	alien	Paradoxosomatida
Periplaneta americana	TP cockroach	alien	Blattidae
Pheidole megacephala	TX big headed ant	alien	Hymenoptera
Philoscia sp.	TP isopod	alien	Philosciidae
Phoridae sp.	TP coffin fly	alien	Phoridae
Porcellio dilatatus	TP isopod	alien	Porcellionidae

continued

Appendix 3. Continued.

Scientific name	Affinity for lava tubes[a]	Status	Family
Arthropoda - continued			
Porcellio laevis	TP isopod	alien	Porcellionidae
Porcellionides pruinosus	TP isopod	alien	Porcellionidae
Psocoptera - unidentified	TP barklice	alien?	
Rhopalosiphoninus	TP green root aphid	alien	Aphididae
Rhytidoporus indentatus	TP cydnid bug	alien	Cydnidae
Salina celebensis	ACC springtail	alien	Entomobryidae
Sciaridae - unidentified	TP sciarid fly	alien	Sciaridae
Scolopendra subspinipes	TP/ACC centipede	alien	Scolopendridae
Scytodes longipes	TP spider	alien	Scytodidae
Sinella caeca	TP springtail	alien	Entomobryidae
Smeringopus elongatus	TP spider	alien	Pholcidae
Smeringopus pallidus	TP spider	alien	Pholcidae
Styloniscus mauritiensis	TP isopod	alien	Styloniscidae
Symphyla - unidentified	TP symphylans	alien	
Synthesiomyia nudiseta	TX flesh fly	alien	Muscidae
Talitroides topitotum	Tp amphipod	alien	Talitroides
Annelida - unidentified	TX/ACC earthworms	alien	
Rhynchocoela (Nemertina)			
Argonemertes dendyi	TP/ACC ribbon worm	alien	Prosorhochmidae
Platyhelmenthes			
Bipalium kewense	TP flatworm	alien	
Geoplana septumlineata	TP flatworm	alien	
Mollusca			
Euglandina rosea	ACC snail	alien	Spiraxidae
Oxychilus alliarius	ACC snail	alien	Zonitidae
Subulina sp.	ACC snail	alien	Subulinidae

a. ACC, accidental, animal that wanders into lava tubes but cannot survive there; TB, troglobite, species that is obligate to hypogean lava-tube habitats; TP, troglophile, species that lives and reproduces in lava tubes but is also found in epigean (surface) habitats; TX, trogloxene, species that uses lava tubes for shelter but returns to the epigean environment for food.