Invertebrate Survey of Hakalau National Wildlife Refuge, Hawaii

Hawaii Biological Survey

Final Report

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Invertebrate Survey of Hakalau Forest National Wildlife Refuge, Hawaii

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The essential role that invertebrate species (snails, insects, and other arthropods) play in supporting native Hawaiian ecosystems has long been recognized, especially given the large biomass and numbers of species represented by these groups. However, both the distributions of invertebrate species in Hawaii and their precise ecological relationships are not well-understood. Hakalau Forest National Wildlife Refuge was established to protect and manage native forest birds and their rainforest habitat, including plants and invertebrates. It is essential to the refuge's ecosystem preservation program to have a rigorous list of invertebrate species and an understanding of the role they play in ecosystem dynamics Thus, knowledge of the invertebrate species present in The Refuge and the ecosystem role that they perform was identified by the U.S. Fish and Wildlife Service as essential to fulfilling the Refuge's goal of preservation of native Hawaiian rain forest. This project was undertaken to address these lacunae by:

- (1) Developing taxonomic lists of species potentially occurring in the Refuge; and
- (2) Conducting a baseline invertebrate field survey of the Refuge.

The goals of the project are consistent with the overall goals of the Invertebrate Conservation Program of the Ecological Services section of the USFWS Hawaii office and their strategic plan for conservation of native invertebrates in the Hawaiian Islands.

The 32,733-acre Hakalau Forest NWR, which was established in 1985, is located on the windward slopes of Mauna Kea, Island of Hawai`i and contains some of the finest remaining stands of native montane rainforest in Hawaii. The elevation ranges between about 3,000 feet in the east to over 6,500 feet in the west. The slopes below 4,000 feet are very wet, receiving 250 inches of rain annually. Rainfall diminishes with elevation with the upper boundary receiving 100 inches or less. The vegetation changes accordingly from bogs, fern patches and scrubby forest below 4,000 feet to very wet ohia forest between 4,000 and 5,000 feet, then a narrow strip of wet ohia koa forest, which gives way to mesic then drier koa forest. Above 5,000 feet the native forest is in various stages of recovery from its former use as cattle pasture. The Refuge supports a great diversity of native plants and animals, many of which are endangered and some which are unique to the Refuge.

The invertebrate fauna (especially insects) of the Refuge is undoubtedly enormous and a comprehensive inventory of all species was beyond the scope of the proposed project. We therefore focused on the small number of species listed as candidates for endangered or threatened status and on the much larger number listed as "species of concern." Among the latter group, the land snails (Gastropoda), beetles (Coleoptera), true bugs (Heteroptera), moths (Lepidoptera), damselflies (*Megalagrion* spp.), and endemic picture-winged flies (*Drosophila* spp.) were emphasized. The presence and distribution of notable harmful aliens, such as ants, the two-spotted leafhopper, and the invasive yellowjacket wasp was also emphasized.

The Hawaiian Islands are the most isolated group of oceanic islands in the world. Because of this isolation, the plants and animals that originally colonized the islands have been able to evolve into a myriad of different species that are unique to the islands and found nowhere else on earth. For example, there are about 750 endemic species of land snails (Cowie et al., 1995a; Cowie, 1996), 1,000 or so endemic species of flowering

plants (Wagner et al., 1999), and over 5,000 endemic insect species (Nishida, 2002). The native birds radiated evolutionarily from a small number of colonizers into a spectacular array of diverse species that have attracted great interest among evolutionary biologists (Freed et al., 1987).

Many of these native species are already extinct; most of the others are seriously threatened and often confined to small pockets of their former ranges, usually high in the mountains (e.g., Hadfield, 1986; Loope, 1998). The Hawaiian Islands have therefore been dubbed the "extinction capital of the United States" (Loope, 1998). For example, over 50 % of the endemic birds are now extinct (Loope, 1998), as are probably about 90 % of the endemic land snails (R.H. Cowie, unpublished). The islands contain one third of the species listed in the U.S. as endangered under the federal Endangered Species Act. Probably, many more deserve listing.

Island species are extremely vulnerable to extinction (Simberloff, 2000). Because of the isolation of the Hawaiian Islands and because of the uniqueness of its biodiversity, the plants and animals of Hawaii provide probably the most dramatic example of the vulnerability of island ecosystems. The twin paramount threats to biodiversity—habitat destruction and alien species introductions (Cox, 1999)—are exhibited in Hawaii more dramatically than anywhere else on earth. Hawaii is a microcosm illustrating in graphic style the destruction of the entire world's natural legacy. As such, they offer a natural laboratory to study endangered species and especially to develop management approaches for their conservation.

This report is divided into two main sections: Part 1 concerns the mollusks, and Part 2 treats the terrestrial arthropods. Part 2 is further subdivided into separate sections prepared by collaborators, specifically a main section on terrestrial arthropods by Hawaii Biological Survey staff; a chapter on the status of the true bugs (Heteroptera) by Dr. Dan Polhemus of the Smithsonian Institution; and a chapter on the status of native Drosophila and distribution of selected harmful alien species by Dr. David Foote of USGS/BRD, Volcano, Hawaii.

Part 1

Survey of the land snails and slugs of the Hakalau Forest National Wildlife Refuge, Island of Hawaii

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Introduction

The Hakalau Forest National Wildlife Refuge was established to conserve native forest birds, their rainforest habitats, and the plants and invertebrates occurring within. It's essential to the Refuge's ecosystem preservation program to have a rigorous list of invertebrate species and an understanding of the role they play in ecosystem dynamics. These are poorly known for invertebrates in general in the Hawaiian Islands, but virtually unknown in the Refuge aside from limited studies on invertebrates as critical food resources for native birds. There is a lack of inventory of invertebrates in the Refuge, and this survey addresses this problem.

The goals of this project are to conduct a baseline survey of the molluscan fauna at the Hakalau Forest NWR, and the compilation of a taxonomic list of the mollusks potentially occurring in the Hakalau Forest NWR, both considered important to the success of the conservation of the Refuge.

Land snails of Hawaii
Of the over 750 recognized species of native land snails in the Hawaiian Islands all but four or fewer are endemic to the archipelago (Cowie et al., 1995a; Cowie, 1996). The great majority of these species are either extinct or close to extinction (Solem, 1990). Causes of this dramatic decline, which is predominantly a 20th century phenomenon, include destruction or modification of habitat, shell collecting, and impacts of alien species (especially rats and predatory snails) (Hadfield, 1986; Solem, 1990; Hadfield *et al*., 1993). Native species are being replaced by a relatively small number of widespread, mostly synanthropic, introduced species (Cowie, 1998). A total of 60 nonindigenous land snail or slug species has been reported as having been introduced to the Hawaiian Islands, with 21 established (Cowie, 1997, 1998). New species are continuing to be introduced and continue to spread around the archipelago (e.g., Cowie, 2000).

The Island of Hawaii had 126 recognized native land snail species (Cowie, 1996; Cowie et al., 1995a). Many of these are probably extinct. An additional 34 or more introduced species have been reported from the island (Cowie, 1997, 2000). Many of these alien species appear associated with the horticultural trade (Cowie, 2000).

Land snails—endangered status
The entire land snail genus *Achatinella* (41 species), which is endemic to the island of Oahu, is listed as extinct or endangered. A few others are listed as candidates, but almost the entire remaining land snail species in the fauna are listed as species of concern.

Four species of land snails from the Island of Hawaii were formerly listed by the U.S. Fish and Wildlife Service (USFWS) as category 2 candidate species under the Endangered Species Act. Since the change in USFWS procedures, these taxa are now listed as species of concern. They are *Partulina confusa*, *P. horneri*, *P. physa* (all tree snails) and *Leptachatina lepida* (ground-dwelling). Although these four species are the only species from the Island of Hawaii that were ever formally listed as candidate species, it is widely acknowledged that the majority of the native land snails of the Hawaiian Islands are severely threatened (if not already extinct) (e.g., Solem, 1990). Probably almost all native Hawaiian land snail species should be listed as species of concern. This is the approach taken by the FWS, which currently lists 93 other taxa from the Island of Hawaii, almost the entire land snail fauna of the island, as species of concern. This list does not include any species of Achatinellidae other than the three *Partulina* species. This omission is a result of an oversight, as at least some of the other achatinellids (e.g., *Auriculella* spp., *Tornatellaria* spp.) should undoubtedly be included (Stephen E. Miller, FWS, personal communication).

Methods

This survey is part of a larger study that included the terrestrial arthropods. Some mollusks were collected during the arthropod sampling. The present survey of the terrestrial land snails and slugs of the Hakalau Forest NWR was conducted by David Preston and Fabio Moretzsohn, of the Hawaii Biological Survey (HBS), Bishop Museum, between 10-15 March, 2003.

Sampling was done along two elevational transects already established within the Hakalau Forest NWR, the Pua Akala, in the southern part, and the Maulua tract, in the northern part (Fig. 1). Additional sampling was conducted in the Hakalau tract, along the dry gulch and surrounding areas near the University of Hawai‘i Hakalau Forest Biological Field Station.

Surveys were undertaken in the Hakalau Forest NWR using standard sampling techniques for snails and arthropods. These techniques have been used extensively by HBS personnel in multi-taxon biodiversity surveys elsewhere on the Island of Hawaii (e.g., Cowie & Nishida, 1993; Cowie *et al.*, 1995b; Evenhuis *et al.*, 1996; Cowie *et al.*, 1999a, b; Howarth *et al.*, 1999), as well as at other locations in the Hawaiian Islands (e.g., Evenhuis & Cowie, 1994; Cowie *et al.*, 1999c), and the islands of the Pacific (Cowie *et al.*, 1996; Cowie & Cook, 1999, 2001; Cowie, 2001).

At each of the survey stations, separate samples were taken from vegetation and from the ground. Randomized quadrat sampling, that is, collecting all snails in a pre-determined,

randomly identified fixed area, is inappropriate for this kind of inventory survey of land snails, especially for small species such as many of those that constitute the Hawaiian fauna (e.g. Solem, 1976), because of their extremely localized micro-distribution patterns (Cowie, *et al.*, 1995b). Instead, timed sampling (collecting all snails found in a fixed time period at a number of places identified by an experienced individual as likely to harbor snails, such as rotting logs, the bark of large trees, the undersides of leaves and inside the hollow stem of ferns within a relatively broadly circumscribed area) has generally been found to be more appropriate (e.g., Cowie *et al.*, 1995b; Emberton *et al.*, 1996) and was the approach adopted in this survey. Over an area approximately 30 m in diameter, two people searched the vegetation for 20 minutes and the ground and leaf litter for 20 minutes. All snails, including dead shells, and slugs were collected. Additional specimens were collected incidentally between stations (Schilthuizen & Rutjes, 2001).

Leaf litter samples were sieved with a ¼ inch mesh width in the field, until a volume of approximately one liter of sieved litter and soil was collected and stored in a large ZipLoc bag. Upon sieving the litter, large leaves, twigs and bark pieces were inspected for snails and slugs before being discarded, because slugs attach themselves to leaves and may not be easily dislodged during sieving. Litter samples were sorted in the lab under a dissecting microscope to look for minute snails that in the past were once common in Hawaii's forests.

Live specimens were drowned by immersion in water for 12 hours, rinsed in water to remove some of the mucus, and preserved in 95 % ethanol. All collected material were brought to the Bishop Museum for sorting and identification by comparison with the Museum's extensive malacological collections, and will be held as vouchers in the Hawaii Biological Survey malacological collections at the Bishop Museum.

A portable GPS (Global Positioning System) receiver and an altimeter were brought to record the coordinates and elevation, respectively, of collection sites. However, there were problems with the operation of the GPS in the field, and it was not possible to record the coordinates. Since the samples were collected along transects with known coordinates, elevations were used to find the coordinates for collection sites along the transects, using the software TOPO, by DeLorme, which is based on the USGS topographic maps (1: 24,000). Maps were produced in TOPO, and legends and composite inset map were created in Adobe Photoshop.

Identification of the snails and slugs collected was done by comparison with the material in the extensive malacological collection of the Bishop Museum, and by reference to the literature. In particular, Barker (1999) presented a detailed description of the external morphology and anatomy of the alien species in New Zealand, some of which also occur in Hawaii. The identifications were confirmed by Mr. Daniel Chung (Kapiolani Community College, and formerly Bishop Museum) who dissected some specimens to corroborate the identifications.

Results

Table 1 shows the summary of the species found at each station. A total of 231 live specimens and 111 empty shells were collected at 26 collection sites along two elevational transects, the vicinity of the Hakalau Field Station, and in a few sites ("Chopper site") in lower elevation (4200 ft.). An annotated checklist of the native and introduced non-marine snails and slugs to the Island of Hawaii is shown on Table 2. Figure 1 shows the boundaries of the Hakalau Forest NWR and the tracks surveyed for snails.

In the Maulua Tract (Fig. 2), the northern part of the Hakalau Forest NWR, 8 collection stations were made between 4640 and 5640 ft. elevation, resulting in 96 live specimens and 39 empty shells. Some snails were found in between stations on fallen banana poke fruits that had been partially eaten by birds.

In the Pua Akala Tract (Fig. 3), the southern part of the Hakalau Forest NWR, 12 collection stations were made between 5150 and 6240 ft. elevation, resulting in 48 live specimens (empty shells were not collected at Pua Akala).

The Hakalau Tract (Fig. 4) was surveyed along the dry gulch in the vicinity of the University of Hawai'i Hakalau Forest Biological Field Station, between 6335 and 6410 ft. elevation, resulting in 76 live specimens and 72 empty shells from 6 collection sites. *Oxychilus alliarius* was abundant in several stations. Because this was a qualitative study, only some specimens were collected.

The Chopper Site (Fig. 2.4), a site at elevation around 4200 ft. in the Pua Akala tract, was sampled during the arthropod survey by Howarth and Preston (October 2002 - Part 2 of this report). Five live specimens of snails and 5 live specimens of slugs were found in 4 out of 5 sites surveyed for arthropods.

Taxonomic account

Family Achatinellidae
Genus *Tornatellides* Pilsbry, 1910
***Tornatellides* sp.**

The family Achatinellidae had an incredible radiation in the Hawaiian Islands. Cooke and Kondo (1960) reviewed the Achatinellidae, and recognized 58 species in *Tornatellides*, 48 of which confined to Hawaii (83%). Only the anatomy and shell of a few species were listed and illustrated, therefore it was not possible to identify to the species level the *Tornatellides* sp. collected in this survey. Cowie and Nishida (1993) and Cowie *et al.* (1995) could not identify specimens of *Tornatellides* sp(p) found on the leeward slopes of Mauna Loa, at elevations similar to those at the Hakalau Forest NWR.

The specimens of *Tornatellides* sp. found at the Refuge have a small (less than 3 mm in length), translucent, conical shell. One specimen was collected at the Maulua Tract, and

the other in the Pua Akala Tract, both found among ohia (*Metrosideros polymorpha* Gaud.) leaf litter.

Previous reports of *Tornatellides* sp. in Hawaii include: Caum (1928), Cooke and Kondo (1960), Chung and Cowie (1991), Cowie and Nishida (1993), and Cowie *et al.* (1995).

Family Arionidae

Genus *Arion* Férussac

***Arion intermedius* Normand, 1852**

Recommended common name: Glade slug (Barker, 1999); Hedgehog slug (several sources in the gardening literature).

An undetermined species of *Arion* was found in the gut of the introduced Kalij Pheasant from the Island of Hawaii in 1981 (Cowie, 1997: 15-16). Cowie (1998: 48) reported *Arion intermedius* as a new state record, from the Upper Waiakea Forest Reserve, on the north side of the Stainback Highway, 2900-3100 ft, collected by R.H. Cowie and R.J. Rundell, Nov.-Dec. 1998.

The species may be more widely distributed in the Hawaiian Islands than previously suspected (Cowie, 1998). In this survey, a total of 93 small specimens (ranging from 5 to 18 mm) were found in almost all sites sampled, and were locally abundant. Dissection of one of the larger specimens showed that it was a subadult, suggesting that sexually mature adults are probably small for the family (D. Chung, pers. comm., Sept. 2003). Barker (1999) reported adults of this small slug as ranging from 10 to 25 mm in extended length in New Zealand.

Arion slugs are usually omnivorous, and have a life span of about one year. *A. intermedius* is known for having a predominantly uniparental, probably autogamic breeding system, and mating has never been observed (Barker, 1999; Chung, pers. comm., Sept. 2003). In New Zealand, *A. intermedius* is locally abundant in pastures, hedgerows, plantation forests and in native forests. It can penetrate deep into undisturbed forest from areas disturbed by man. This slug is active during most of the year, even during the coldest months (Barker, 1999).

Previous reports of *Arion* sp. in Hawaii include: Lewin & Lewin (1978) *in* Cowie (1997), and Cowie (1998).

Family Succineidae

Genus *Succinea* Draparnaud

***Succinea* cf. *cepulla* Gould, 1846**

This is another family with a great radiation in the Hawaiian Islands. Cowie *et al.* (1995) listed 42 species from Hawaii. Taxonomy in this family is difficult and in need of revision, and proper identification may not be achieved without dissection. Therefore, the species found in this survey is tentatively identified as *Succinea* cf. *cepulla*, by comparison with preserved specimens deposited in the Bishop.

Only two specimens of *Succinea* cf. *cepulla* were found during the arthropod survey done by Howarth and Preston (October 2002), at sites at about 4200 ft. elevation in Pua Akala.

Previous reports of *Succinea* spp. in Hawaii include: Cooke (1921), Caum (1928), Chung & Cowie (1991), Cowie & Nishida (1993), and Cowie *et al.* (1995).

Family Zonitidae

Genus *Oxychilus* Fitzinger

***Oxychilus alliarius* (Miller, 1822)**

Recommended common name: Garlic glass snail (Barker, 1999); gardening literature: Garlic snail.

Widespread as native in northern and western Europe. Introduced into Greenland, North America, St. Helena, South Africa, Juan Fernandez, Australia and New Zealand (Barker, 1999). First recorded in Hawaii in 1937, probably accidentally introduced (Cowie, 1998). It has been recorded at 6000 ft elevation on Maui, between 2600 and 7200 ft on Hawaii, and also on Kauai and Molokai.

When disturbed, the snail produces a strong garlic smell, hence the specific name (Latin: *allium* = garlic), and the vernacular name, Garlic snail. This garlic scent is a good diagnostic character for the species (Cowie, 1997). Barker (1999) reported that in experiments using hedgehogs (the mammal, not the hedgehog slug) as predators, *O. alliarius* was rejected while other species of *Oxychilus* which do not produce the strong odor were readily consumed. This predation avoidance strategy may have contributed to *O. alliarius*' success in colonizing high elevation areas in Hawaii.

Oxychilus alliarius was the most abundant mollusk found in the Hakalau Forest NWR, especially in the Maulua and Hakalau Tracts. It was found in large numbers in the leaf litter, on mossy rocks, fallen bark of trees, and under rocks. Live specimens of *O. alliarius* were often found eating fallen 'banana poka' (*Passiflora mollissima* (Khunt)) fruits on the ground. Sediments carried by the rain often had tens to hundreds of old shells in the Hakalau Tract. Fresh shells of this species are glossy, translucent yellowish brown, but old and decaying shells become dull and chalky near the umbilicus. Only some specimens were collected at sites with high abundance. A total of 100 live and 111 empty shells were collected in this survey.

Previous reports of *Oxychilus alliarius* in Hawaii include: Caum (1928), Cooke & Baker (1947), Lewin & Lewin (1984), Howarth (1985), Mountainspring *et al.* (1990), Chung & Cowie (1991), Cowie & Nishida (1993), and Cowie (1997).

Family Agriolimacidae

Genus *Deroceras* Rafinesque

***Deroceras laeve* (Müller, 1774)**

Recommended common name: Marsh slug (Barker, 1999).

D. laeve is a cosmopolitan terrestrial slug which has been generally assumed to be native to the Palearctic region, which has been introduced by man into most suitable areas worldwide (Barker, 1999). It was first recorded in Hawaii in 1897 (Cowie, 1997) or 1896 (Cowie, 1998). It has probably become established on all main Hawaiian Islands, including Lanai. It has been recorded at 2000 ft on Kauai, 2000 ft on Oahu, and 5000 ft on Maui (Cowie, 1998).

In this survey, it was common at the Halakau Tract, from 5350 to 6380 ft. elevation, under rocks and in the wet leaf litter under koa trees. A total of 15 specimens were collected.

Deroceras laeve is omnivorous, opportunistically predaceous on slow-moving animals such as earthworms, aphids, and insects caught on spider webs. It is highly aggressive towards other mollusks, and is cannibalistic. This species has been reared uniparentally for many generations in the lab, and its low heterozygosity suggests self-fertilization (Barker, 1999).

The family Agriolimacidae has recently been reinstated after having been grouped with Limacidae (Barker, 1999). Until recently, the name *Agriolimax* Mörch, 1865 was used in the literature, but *Deroceras* Rafinesque Schmaltz, 1820 has priority.

Family Limacidae

Genus *Limax* Linnaeus, 1758

***Limax maximus* Linnaeus, 1778**

Recommended common name: Tiger slug (Barker, 1999); gardening literature: Leopard slug.

Limax maximus is a large slug (reportedly up to 200 mm in length), probably introduced from Europe. Its distinct longitudinal dark markings give the slug its popular name, Leopard slug. This species was first recorded in Hawaii either in 1931 or 1949 (Cowie, 1997), depending on whether the first record does refer to this species or not. Its introduction was probably accidental (Cowie, 1998). The species is established in Hawaii. Ten small (15-40 mm) specimens, probably juveniles, were found during the survey at the Pua Akala and Hakalau Tracts.

In New Zealand, *Limax maximus* is common in gardens and buildings, and margins of native forests, but it does not seem to penetrate far into undisturbed forests, although it can be abundant in modified forest remnants and secondary forests (Barker, 1999). This nocturnal slug feeds primarily on decaying plant material and fungi, but because it shows aggressive behavior towards other slugs, it is often erroneously regarded as a predator (Barker, 1999). Therefore, although it may cause damage to the native flora, *L. maximus* probably does not present a problem to native fauna at the Hakalau Forest NWR.

Discussion

A total of 142 named species (and 20 subspecies) of native non-marine snails and 43 species of introduced snails and slugs have been reported from the Island of Hawaii (Table 2). There are no native slugs in the Hawaiian Islands. A number of native species remain unnamed. Solem (1976) estimated that 199-205 Hawaiian endodontoid species are represented in the Bishop Museum collections, of which only some 32 are described (31 Endodontidae and 1 Punctidae)(Cowie *et al*., 1995a).

The habitat and ecology of Hawaiian snails are poorly known, but most endodontids are believed to have inhabited forests. Habitat destruction and alien species are considered the two major problems faced by native species of plants and animals in Hawaii (e.g. Howarth, 1990). Among the most damaging alien species to native snails include: pigs, rats, alien predatory snails and ants (Hadfield, 1986; Solem, 1990). Cowie (unpublished) estimated that about 90% of the native snails may already be extinct.

Only a few specimens of two native species were found: *Succinea* cf. *cepulla*, and *Tornatellides* sp. Although an effort was made to sample representative habitats in the Hakalau Forest NWR, only part of the Refuge was surveyed, and other native snails may occur in the area. Subsequent surveys should look for snails in other areas of the Refuge not sampled in the current survey to complement the molluscan inventory.

In contrast, four introduced species, one a land snail (*Oxychilus alliarius*), and three slugs (*Arion intermedius, Limax maximus*, and *Deroceras laeve*) were found at the Hakalau Forest NWR. It should be noted that *O. alliarius* was abundant in many sites, especially in the Hakalau tract. *A. intermedius*, only recently reported from Hawaii (Cowie, 1998), was also very common in most sites, and is probably widespread in high elevations on the Island of Hawaii and perhaps Maui.

The montane rainforest of the Hakalau Forest NWR may have similar ecological characteristics (e.g. temperature, humidity, etc.) to parts of Europe where the four alien species of mollusks found in this survey are native. These four species have also been reported from other temperate habitats, such as New Zealand (Barker, 1999), northern continental USA and southern Canada, and have wide distribution in Europe. These are probably the result of accidental anthropogenic introductions (Cowie, 1998). In the Hakalau Forest NWR, these introduced mollusks were more abundant in regions more disturbed by pigs than those less disturbed by pigs. It is conceivable, then, that despite predation, pigs may contribute to the dispersal of alien snails and slugs. It is also possible that pigs are attracted to areas where snails and slugs are more abundant. Gagné (1983) reported the slug *Milax gagates* severely affected native greenswords on the slopes of Haleakala, Maui, and were an important attractant, encouraging rooting by pigs. Other slugs could be playing similar roles at the Hakalau Forest NWR (Howarth, pers. comm.).

Oxychilus alliarius is primarily a vegetarian snail, but it also predates on other snails and snail eggs (Barker, 1999). It has been suggested (Birding Hawaii, 2003) that *O. alliarius* may be a very effective food competitor for the endangered honeycreeper Po‘o-uli

(*Melamprosops phaeosoma* Casey and Jacobi, 1974) on the slopes of Haleakala, where the last three known birds live. The Po‘o-uli diet consists mostly of mollusks, and to a lesser degree, arthropods and fruits. Severns (1984) reported that *O. alliarius* was negatively correlated with populations of native snails on Maui, and believed that predation by *O. alliarius* is a factor in the decline of native snails. In the Hakalau Forest NWR, *O. alliarius* is locally abundant, and may be a competitor to other native and even endangered species, as well as a predator of native snails.

Hand sampling in the field is by far the most time-efficient for large scale surveys of land snails, yielding ten times as many specimens and seven times as many species per person-hour compared with litter sampling (Emberton *et al.*, 1995). Although the smallest species will be under-represented in terms of numbers of individuals if hand sampling in the field rather than a litter sampling approach is adopted, the far larger number of samples that can be analyzed means that these small species are still likely to be recorded (Cowie *et al.*, 1995b). Previous surveys by HBS staff confirm that it is possible to see and collect even the very small species, both litter-dwelling and arboreal, using hand sampling in the field. The advantages of the far greater number of samples possible and therefore, the greater geographic area covered outweigh the disadvantages of undersampling of very small species, especially if presence/ absence as opposed to relative abundance data at a particular station are required. Thus, hand sampling in the field was the approach adopted for this inventory survey. It permitted the collection of a larger number of samples and coverage of a larger area, and provided as complete a record of species presence/absence, as would the more precise but far more time-consuming litter sampling approach.

This first attempt to inventory of the native and alien snails and slugs, as well as other invertebrates (Part 2) of the Hakalau Forest NWR is a step towards a better understanding of the dynamics within the Refuge. More research is needed to ensure that the conservation plans are effective and to prevent further damage from habitat destruction and alien species introductions.

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Table 1. Location, method employed, date, elevation, coordinates and habitat of collection sites at the Hakalau Forest National Wildlife Refuge

No.	Transect/ Location	Method employed	Date	Elevation	Latitude	Longitude	Habitat/Vegetation
1	Hakalau Track Bird Res. Stn.	General, host searching	11.iii.03	6410’	19º49.212’N	155º19.903’W	Pasture, Koa, out-planted native plants.
2	Hakalau Tr.	Sieve of Koa litter	12.iii.03	6385’	19º49.176’N	155º19.898’W	Ohia, Koa, Akala, Ferns, grasses, in dry streambed.
3	Hakalau Tr.	Genera, host search	12.iii.03	6385’	19º49.172’N	155º19.854’W	Ohia, Koa, Akala, Ferns, grasses, in dry streambed.
4	Hakalau Tr.	General, host searching	12.iii.03	6360’	19º49.188’N	155º19.784’W	Pasture, Koa, small tree ferns.
5	Hakalau Tr.	Host search	12.iii.03	6360’	19º49.184’N	155º19.744’W	Pasture, Koa, small tree ferns.
6	Hakalau Tr.	Sweep net	12.iii.03	6360’	19º49.172’N	155º19.693’W	Talus slope in pasture with Koa, small tree ferns.
7	Hakalau Tr.	Fog	12.iii.03	6335’	19º49.201’N	155º19.724’W	Fern fronds on mossy rocks.
8	Hakalau Tr.	General, host searching	12.iii.03	6335’	19º49.201’N	155º19.724’W	Koa leaf litter
9	Maulua Tr. 13	General, Host searching	11.iii.03	5200’	19º52.204’N	155º17.967’W	Under ferns at base of large Ohia tree.
10	Maulua Tr. 13	General, Host searching	14.iii.03	5640’	19º51.874’N	155º19.157’W	Under fern near large Ohia tree.
11	Maulua Tr. 13	Sieving	14.iii.03	5640’	19º51.874’N	155º19.157’W	Fern leaf litter.
12	Maulua Tr. 13	Sieving	14.iii.03	5640’	19º51.874’N	155º19.157’W	Leaf litter under fern.
13	Maulua Tr. 13	General, Host searching	14.iii.03	5640’	19º51.874’N	155º19.157’W	Under Koa tree.
14	Maulua Tr. 13	General, Host searching	14.iii.03	5550’	19º51.954’N	155º18.787’W	Ferns, Koa, and bark.
15	Maulua Tr. 13	General, Host searching	14.iii.03	5550’	19º51.954’N	155º18.787’W	Under ferns, Koa leaves, & rocks.
16	Maulua Tr. 13	Sieving	14.iii.03	5550’	19º51.954’N	155º18.787’W	Fern leaf litter nr. Koa.
16A	Maulua Tr. 13	General, Host searching	14.iii.03	5540’	19º51.954’N	155º18.807’W	Ferns, Koa, and bark.
17	Maulua Tr. 13	General, Host searching	11.iii.03	4910’	19º52.575’N	155º17.578’W	Ohia leaf litter
18	Maulua Tr. 13	General, Host searching	11.iii.03	4700’	19º52.605’N	155º17.102’W	Under dead Ohia bark.
19	Maulua Tr. 13	Leaf litter sieve	11.iii.03	4700’	19º52.605’N	155º17.102’W	Ohia leaf litter.
20	Maulua Tr. 13	Sieving	11.iii.03	4700’	19º52.605’N	155º17.102’W	Ohia leaf litter nr. Large sedges.

No.	Transect/ Location	Method employed	Date	Elevation	Latitude	Longitude	Habitat/Vegetation
21	Maulua Tr. 13	General, Host searching	11.iii.03	4700’	19º52.605’N	155º17.102’W	Moss on tree trunks.
22	Maulua Tr. 13	General, host searching	11.iii.03	4640’	19º52.624’N	155º16.897’W	Lg. feaf Myrsine, boggy w/lg. Sedges, ferns.
23	Maulua Tr. 13	Sieving	11.iii.03	4640’	19º52.624’N	155º16.897’W	Lg. feaf Myrsine, boggy w/lg. Sedges, ferns.
24	Maulua Tr. 13	Sieving	11.iii.03	4640’	19º52.624’N	155º16.897’W	Mosses.
25	Maulua Tr. 13	Leaf litter sieve	11.iii.03	4910’	19º52.575’N	155º17.578’W	Ohia leaf litter.
26	Pua Akala Tr.	General host searching	13.iii.03	6240’	19º47.484’N	155º19.647’W	Ohia, Koa, Akala, Ferns, grasses.
27	Pua Akala Tr.	General, host searching	13.iii.03	6080’	19º47.364’N	155º18.367’W	Under bark of dead Koa branch.
28	Pua Akala Tr.	Sieving	13.iii.03	6080’	19º47.364’N	155º18.367’W	Fern leaf litter with Ohia and Akala over story.
29	Pua Akala Tr.	Sieving	13.iii.03	6080’	19º47.364’N	155º18.367’W	Koa and fern leaf litter.
30	Pua Akala Tr.	General host searching	13.iii.03	6080’	19º47.364’N	155º18.367’W	Ohia, Koa, Akala, Ferns, grasses.
31	Pua Akala Tr.	General, host searching	13.iii.03	6070’	19º47.364’N	155º19.355’W	“Big Koa”, under bark of dead branches.
32	Pua Akala Tr.	Sieving	13.iii.03	5300’	19º47.064’N	155º17.905’W	Ohia and moss litter.
33	Pua Akala Tr.	General, Host searching	13.iii.03	5290’	19º47.067’N	155º17.885’W	*Astelia* leaf litter and roots.
34	Pua Akala Tr.	General, Host searching	13.iii.03	5290’	19º47.271’N	155º17.902’W	Leaf litter.
35	Pua Akala Tr.	General, Host searching	13.iii.03	5290’	19º47.271’N	155º17.902’W	Leaf litter, (Ohia ?).
36	Pua Akala Tr.	Sieving Ohia leaf litter.	10.iii.03	5460’	19º47.030’N	155º18.414’W	Ohia, Koa, Akala, Ferns, grasses.
37	Pua Akala Tr.	General host searching	10.iii.03	5470’	19º47.030’N	155º18.414’W	Ohia, Koa, Akala, Ferns, grasses.
40	Pua Akala Tr.	General, host searching	13.iii.03	5150’	19º47.035’N	155º17.645’W	Mossy base of large Ohia tree, under dead tree bark.
41	Pua Akala Tr.	Fog	13.iii.03	5160’	19º47.051’N	155º17.642’W	Mossy base of large Ohia tree.
42	Pua Akala Tr.	Fog	13.iii.03	5160’	19º47.067’N	155º17.643’W	Mossy base of large Ohia tree.
43	Pua Akala Tr.	General	13.iii.03	5160’	19º47.081’N	155º17.653’W	Under large Koa tree, leaf and soil litter.
44	Pua Akala Tr.	Seiving	13.iii.03	5160’	19º47.095’N	155º17.663’W	Fern litter
45	Pua Akala Tr.	Sieving	13.iii.03	5160’	19º47.068’N	155º17.666’W	Leaf litter under ferns.

No.	Transect/ Location	Method employed	Date	Elevation	Latitude	Longitude	Habitat/Vegetation
32	Pua Akala/ Tr.1A; stn. 6	2 fogs and host searches	2.x.02	5295’	19º47.074’N	155º17.885’W	
35	Chopper site	Fog 1	3.x.02	4190’	19º46.358’N	155º16.001’W	
36	Chopper site	Fog 1 & 2	3.x.02	4180’	19º46.347’N	155º15.992’W	
37A	Chopper site	Fog & host search	3.x.04	4160’	19º46.304’N	155º15.947’W	Wet cliff above stream bank
37	Chopper site	Fog and host search	4.x.02	4225’	19º46.473’N	155º15.924’W	*Cibotium* fronds
11	Maulua Tr. 13	Malaise trap #2	6.x.02	5150’	19º52.229’N	155º16.987’W	
40	Maulua Tr. 13	Fog	6.x.02	4960’	19º52.373’N	155º17.705’W	

Table 2. List of native and introduced snails and slugs of the Island of Hawaii

This list follows Cowie *et al.* (1995a) and Cowie (1997). The known distribution of the species in the Hawaiian Islands follows the author of the species (in parenthesis); localities on the Island of Hawaii are listed when available. All remarks, except where noted otherwise, are from Cowie *et al.* (1995a). The species in **bold** are those found at the Hakalau Forest National Wildlife Refuge in this survey. For more localities on other islands and more details on the taxonomy, refer to Cowie *et al.* (1995). An asterisk (*) indicates species that potentially occur in the Refuge (Hadway, pers. comm.).

Abbreviations for the islands:

H	Hawaii
K	Kauai
Kah	Kahoolawe
L	Lanai
M	Maui
Mo	Molokai
N	Niihau
O	Oahu
HI	Hawaiian Islands (no island was specified)

Family Neritidae (Remarks – both species below occur in freshwater (but perhaps not at the elevation of the Hakalau Forest NWR))

1. *Neritina* (*Neripteron*) *vespertina* Sowerby, 1849 (HI)
2. *Neritina* (*Neritona*) *granosa* Martens, 1869 (HI)

Family Helicinidae

3. *Pleuropoma* (*Aphanoconia*) *sulculosa* (Ancey, 1904) (H: “Olaa”)
4. *Pleuropoma* (*Pleuropoma*) *bronniana* (Philippi, 1847) (HI)
5. * *Pleuropoma* (*Pleuropoma*) *laciniosa konaensis* Neal, 1934 (H: “Puuwaawaa, Mawai, near Puu Henahena”)

Family Lymnaeidae

6. *Erinna aulacospira* (Ancey, 1889) (K, Mo, M, H – Hawaii: “in small streams in the mountains on the Hilo side”)
7. *Fossaria viridis* (Quoy & Gaimard, 1832) (N, K, O, Mo, M, H; introduced) (Remarks – this species is a major intermediate host of cattle liver flukes in the Hawaiian Islands, and is the subject of intensive efforts at biological control (Cowie, 1997))
8. *Lymnaea* (*Pseudisidora*) *producta* (Mighels, 1845) (N, K, O, ?H)
9. *Lymnaea* (*Pseudisidora*) *rubella* Lea, 1841 (N, K, O, Mo, M, H)

Family Ancylidae (Remarks – freshwater limpets)

10. *Ferrisia* (*Pettancylus*) *sharpi* (Sykes, 1900) (K, O, H, ?introduced)

Family Thiaridae

11. *Tarebia granifera* (Lamarck, 1816) (K, O, Mo, M, H; introduced)
12. *Tarebia lateritia* (Lea & Lea, 1851) (HI; introduced)
13. *Thiara indefinita* (Lea & Lea, 1851) (K, O, Mo, M, H; introduced)
14. *Thiara verrauiana* (Lea, 1856) (HI; introduced)

Family Viviparidae

15. *Cipangopaludina chinensis* (Griffith & Pidgeon, 1834) (K, O, Mo, M, H; introduced)

Family Achatinellidae

16. * *Auriculella armata* (Mighels, 1845) (H)
17. *Auriculella chamissoi* (Pfeiffer, 1855) (O, H)
18. * *Elasmias fuscum* (Ancey, 1903) (O, Mo, M, H – Hawaii: "Puna")
19. *Lamellidea* (*Lamellidea*) *gracilis* (Pease, 1871) (Kure, Laysan, Lisianski, Nihoa, N, K, O, Mo, M, L, Ka, H)
20. *Lamellidea* (*Lamellidea*) *oblonga* (Pease, 1865) (K, O, Mo, M, H ("Hilo"); introduced)
21. * *Lamellidea* (*Lamellidea*) *peponum* (Gould, 1847) (O, M, H)
22. *Pacificella baldwini* (Ancey, 1889) (K, O, M, H)
23. *Pacificella mcgregori* (Pilsbry & Cooke, 1915) (H: "Hilo")
24. *Partulina* (*Baldwinia*) *confusa* (Sykes, 1900) (H)
25. *Partulina* (*Baldwinia*) *horneri* (Baldwin, 1895) (H: "Hamakua")
26. *Partulina* (*Baldwinia*) *horneri candida* Pilsbry & Cooke, 1914 (H: "Above Kukuihaele, Hamakua")
27. *Partulina* (*Baldwinia*) *horneri fuscospira* Pilsbry & Cooke, 1914 (H: "Above Kukuihaele")
28. *Partulina* (*Baldwinia*) *horneri fuscozonata* Pilsbry & Cooke, 1914 (H)
29. *Partulina* (*Baldwinia*) *horneri kapuana* Gouveia & Gouveia, 1920 (H: "Waiahole, Kapua, South Kona, Hawaii: about one-half mile above Government Road")
30. *Partulina* (*Baldwinia*) *horneri konana* Pilsbry & Cooke, 1914 (H: "North Kona at Honoula")
31. * *Partulina* (*Baldwinia*) *physa* (Newcomb, 1845) (H: "Mouna [= Mauna] Kea")
32. *Partulina* (*Baldwinia*) *physa errans* Pilsbry & Cooke, 1913 (H: "Near Pahoa, Puna")
33. *Tornatellaria abbreviata hawaiiensis* Pilsbry & Cooke, 1916 (H: "Kukuihaele")
34. *Tornatellaria cincta* (Ancey, 1903) (?O, Mo, M, ?L, ?H)
35. *Tornatellaria convexior* Pilsbry & Cooke, 1916 (H: "Olaa")
36. * *Tornatellaria henshawi* (Ancey, 1903) (H: "Hamakua")
37. *Tornatellaria sharpi* Pilsbry & Cooke, 1916 (H: "Crest of Kilawea [= Kilauea] crater, about half a mile south of the Volcano House")
38. * *Tornatellaria smithi* Cooke & Pilsbry *in* Pilsbry & Cooke, 1916 (H: "Kaiwiki")
39. *Tornatellaria sykesii* Cooke & Pilsbry *in* Pilsbry & Cooke, 1916 (H: "Olaa")
40. *Tornatellaria trochoides* (Sykes, 1900) (Mo, L, H)

41. *Tornatellides* (*Tornatellides*) *compactus* (Sykes, 1900) (H: “Mauna Loa at 2000 feet”)
42. * *Tornatellides* (*Tornatellides*) *confusus* (Sykes, 1900) (?K, H: “Hilo”)
43. *Tornatellides* (*Tornatellides*) *cyphostyla* (Ancey, 1904) (H: “Palihoukapapa, on the Hamakua slope of Mauna-Kea, Kawaii [= Hawaii], at an elevation of 4,000 feet”)
44. *Tornatellides* (*Tornatellides*) *forbesi nanus* Cooke & Pilsbry *in* Pilsbry & Cooke, 1915 (H: “Reed’s Island”)
45. *Tornatellides* (*Tornatellides*) *kilauea* Pilsbry & Cooke, 1915 (H: “crest of Kilauea crater, about half a mile south of the Volcano House”)
46. * *Tornatellides* (*Tornatellides*) *konaensis* Cooke & Pilsbry *in* Pilsbry & Cooke, 1915 (H: “Kona”)
47. * *Tornatellides* (*Tornatellides*) *macromphala* (K, O, Mo, M, L, Kah, H)
48. * *Tornatellides* (*Tornatellides*) *oncospira* Cooke & Pilsbry *in* Pilsbry & Cooke, 1915 (H: “Kaiwiki”)
49. * *Tornatellides* (*Tornatellides*) *procerulus* (Ancey, 1903) (N, K, O, Mo, M, L, H)
50. *Tornatellides* (*Tornatellides*) *pyramidatus* (Ancey, 1903) (H: “Olaa”)
51. *Tornatellides* (*Tornatellides*) *terebra* (Ancey, 1903) (Mo, M, L, H)
52. *Tornatellides* (*Tornatellides*) *vitreus* (Dohrn, 1863) (?HI)
53. *Tornatellides* (*Waimea*) *rudicostatus* (Ancey, 1904) (H: “Palihoukapapa, on the Hamakua slope of Mauna-Kea, Kawaii [= Hawaii], at an elevation of 4,000 feet”)

***Tornatellides* sp.** Collected at the Hakalau Forest NWR in this survey.

Family Amastridae

54. *Amastra* (*Amastra*) *lineolata* (Newcomb, 1853) (?M, ?H)
55. *Amastra* (*Amastrella*) *conica* Baldwin, 1906 (H: “Hamakua”)
56. *Amastra* (*Amastrella*) *conica gentilis* Cooke, 1917 (H: “Waikii station, land of Waikoloa about 6,000 feet elevation”)
57. *Amastra* (*Amastrella*) *conica gyrans* Hyatt *in* Hyatt & Pilsbry, 1911 (H)
58. *Amastra* (*Amastrella*) *conica kohalensis* Hyatt & Pilsbry, 1911 (H: “Hokala Mts.”)
59. *Amastra* (*Amastrella*) *flavescens* (Newcomb, 1854) (H)
60. *Amastra* (*Amastrella*) *flavescens emortua* Cooke, 1917 (H: “Huehue in the district of North Kona, on the northwestern slopes of Hualalai about 1,700 feet elevation”)
61. *Amastra* (*Amastrella*) *flavescens saxicola* Baldwin, 1903 (H: “Kau”)
62. *Amastra* (*Amastrella*) *fossilis* Baldwin, 1903 (H: “Palihoukapapa, on the Hamakua slope of Maunakea, at an elevation of 4,000 feet”)
63. *Amastra* (*Amastrella*) *fragosa* Cooke, 1917 (H: “Kapulehu, about three miles north of Huehue and nearly the same elevation”)
64. *Amastra* (*Amastrella*) *hawaiiensis* Hyatt & Pilsbry, 1911 (H: “Waimanu, in the northeastern part of the island”)
65. *Amastra* (*Amastrella*) *henshawi* Baldwin, 1903 (H: “South Kona”)
66. *Amastra* (*Amastrella*) *melanosis* (Newcomb, 1854) (H) (Remarks: According to Pilsbry & Cooke (1915a: 49), Newcomb received his shells from Baldwin,

labeled “Hamakua”, but Newcomb’s labels says “Mauna Loa”. Verification of the exact type locality requires further research (Cowie *et al.*, 1995))

67. *Amastra* (*Amastrella*) *melanosis kauensis* Pilsbry & Cooke, 1915 (H: “Waiohinu, Kau, near the southern end of Hawaii”)
68. *Amastra* (*Amastrella*) *pagodula* Cooke, 1917 (H: “Huehue about 1,800 feet elevation)
69. *Amastra* (*Amastrella*) *senilis* Baldwin, 1903 (H: “Palihoukapapa on the Hamakua slope of Maunakea, at an elevation of 4,000 feet)
70. *Amastra* (*Cyclamastra*) *extincta* (Pfeiffer, 1856) (?K, ?O, ?H)
71. *Amastra* (*Cyclamastra*) *modicella* Hyatt & Pilsbry, 1911 (H: “Waikii station, in the land of Waikoloa, about 6,000 feet elevation”)
72. *Amastra* (*Cyclamastra*) *ultima* Pilsbry & Cooke, 1914 (H: “Kahuku, Kau, under lava slabs on a nearly naked flow”)
73. *Amastra* (*Cyclamastra*) *umbilicata pluscula* Cooke, 1917 (H: “Kapulehu, in the district of North Kona, about 18,000 feet elevation [elevation incorrect; no point on the island of Hawaii is that high])
74. *Amastra* (*Heteramastra*) *sinistrorsa* Baldwin, 1906 (H: “Hamakua”)
75. *Amastra* [*Incertae sedis* in the genus *Amastra*] *amicta* Smith *in* Gulick & Smith, 1873 (HI)
76. *Amastra* [*Incertae sedis* in the genus *Amastra*] *luteola* Férussac *in* Quoy & Gaimard, 1825 (?H – “probable qu’elle vient des îles Mariannes”) [Remarks: Newcomb (1858: 308) and Hyatt & Pilsbry (1911b: 138) considered the Marianas locality incorrect]
77. *Leptachatina* (*Angulidens*) *anceyana* Cooke *in* Hyatt & Pilsbry, 1910 (H: “Mana”)
78. * *Leptachatina* (*Leptachatina*) *arborea* Sykes, 1900 (H: “Kona at 4000 feet; Olaa, Hilo”)
79. *Leptachatina* (*Leptachatina*) *defuncta* Cooke *in* Hyatt & Pilsbry, 1910 (H: “Mana”)
80. *Leptachatina* (*Leptachatina*) *imitatrix* Sykes, 1900 (H: “Mauna Loa at 4000 feet”)
81. *Leptachatina* (*Leptachatina*) *konaensis olaaensis* Cooke *in* Hyatt & Pilsbry, 1910 (H: “Olaa”)
82. *Leptachatina* (*Leptachatina*) *konaensis* Sykes, 1900 (H: “Mauna Loa at 4000 feet”)
83. *Leptachatina* (*Leptachatina*) *lepida* Cooke *in* Hyatt & Pilsbry, 1910 (H: “Mana”)
84. *Leptachatina* (*Leptachatina*) *saccula* (Hartman, 1888) (HI)
85. * *Leptachatina* (*Leptachatina*) *simplex* (Pease, 1869) (H)
86. *Leptachatina* (*Leptachatina*) *tenuicostata* (Pease, 1869) (H)
87. *Leptachatina* (*Thaanumia*) *henshawi* Sykes, 1903 (H: “Bucholtz, Kona, 1,800 feet”)
88. *Planamastra peaseana* Pilsbry *in* Hyatt & Pilsbry, 1911 (HI)

<u>Family Pupillidae</u>

89. *Columella olaaensis* Pilsbry, 1926 (H: “Olaa”)
90. *Columella sharpi* Pilsbry & Cooke, 1906 (H: “Crest of the Kilauea crater, about a half mile south of the hotel”)

91. *Gastrocopta* (*Gastrocopta*) *nacca* (Gould, 1862) (O, H; introduced)
92. *Gastrocopta* (?*Gastrocopta*) *pediculus* (Shuttleworth, 1852) (H; introduced)
93. *Gastrocopta* (?*Gastrocopta*) *servilis* (Gould, 1843) (K, O, Mo, M, H, Midway, Pearl & Hermes, Laysan; introduced) (Remarks – Now a dominant member of land snail communities in many lowland areas (Christensen, 1983, *in* Cowie, 1997))
94. *Lyropupa* (*Lyropupa*) *clathratula* Ancey, 1904 (H: "Olaa")
95. *Lyropupa* (*Lyropupa*) *prisca* Ancey, 1904 (H: "Palihoukapapa, on the Hamakua slope of Mauna Kea, Kawaii [= Hawaii], at an elevation of 4,000 feet") [?error = Mana (Pilsbry & Cooke, 1920: 244)]
96. *Lyropupa* (*Lyropupa*) *striatula* (Pease, 1871) (H)
97. *Lyropupa* (*Lyropupa*) *truncata* Cooke, 1908 (H: "Kohaka Mts.")
98. *Lyropupa* (*Lyropupilla*) *anceyana* Cooke & Pilsbry *in* Pilsbry & Cooke, 1920 (H: "Olaa")
99. *Lyropupa* (*Lyropupilla*) *hawaiiensis* Ancey, 1904 (H: "Palihoukapapa, on the Hamakua slope of Mauna Kea, Kawaii [= Hawaii], at an elevation of 4,000 feet")
100. *Lyropupa* (*Mirapupa*) *costata* (Pease, 1871) (Mo, L, Kah, H)
101. *Lyropupa* (*Mirapupa*) *cubana* (Dall, 1890) (? HI)
102. *Lyropupa* (*Mirapupa*) *cyrta* Cooke & Pilsbry *in* Pilsbry & Cooke, 1920 (H: "Mana")
103. *Lyropupa* (*Mirapupa*) *ovatula kona* Pilsbry & Cooke, 1920 (Mo, ?M, H: "North Kona at Huehue")
104. * *Nesopupa* (*Infranesopupa*) *anceyana* Cooke & Pilsbry *in* Pilsbry & Cooke, 1920 (H: "Humuula")
105. * *Nesopupa* (*Infranesopupa*) *forbesi* Cooke & Pilsbry *in* Pilsbry & Cooke, 1920 (H: "Huumula … in a large *kipuka* in the 1855 Flow, about half way between Halealoha and Ainahou, at about 5,000 ft. elevation")
106. *Nesopupa* (*Infranesopupa*) *subcentralis* Cooke & Pilsbry *in* Pilsbry & Cooke, 1920 (H: "Palihoukapapa")
107. *Nesopupa* (*Limbatipupa*) *newcombi* (Pfeiffer, 1853) (O, Mo, L, H)
108. *Nesopupa* (*Limbatipupa*) *newcombi interrupta* Cooke & Pilsbry *in* Pilsbry & Cooke, 1920 (H: "Waiaha")
109. *Nesopupa* (*Limbatipupa*) *newcombi seminulum* Boettger, 1881 (K, O, Mo, M, H)
110. *Nesopupa* (*Nesodagys*) *thaanumi* Ancey, 1904 (O, M, L, H – Hawaii: "Olaa")
111. *Nesopupa* (*Nesodagys*) *wesleyana* Ancey, 1904 (O, M, Kah, H – Hawaii: "Hilo, 4 miles Olaa road")
112. *Nesopupa* (*Nesodagys*) *wesleyana gouveiae* Cooke & Pilsbry *in* Pilsbry & Cooke, 1920 (H: "Hookena")
113. *Nesopupa* (*Nesopupilla*) *bacca* (Pease, 1871) (H: "Kalapana")
114. *Nesopupa* (*Nesopupilla*) *baldwini* Ancey, 1904 (Mo, M, L, H)
115. *Nesopupa* (*Nesopupilla*) *baldwini centralis* Ancey, 1904 (H: "Olaa")
116. *Nesopupa* (*Nesopupilla*) *dispersa* Cooke & Pilsbry *in* Pilsbry & Cooke, 1920 (O, Mo, M, L, Kah, H)
117. *Prosenopupa* (*Edentulopupa*) *admodesta* (Mighels, 1845) (K, O, Mo, H)
118. * *Prosenopupa* (*Prosenopupa*) *acanthinula* (Ancey, 1892) (O, Mo, M, H)

119. *Prosenopupa* (*Prosenopupa*) *boettgeri* Cooke & Pilsbry *in* Pilsbry, 1920 (K, O, Mo, M, L, H)
120. *Prosenopupa* (*Prosenopupa*) *boettgeri spinigera* Cooke & Pilsbry *in* Pilsbry, 1920 (K, O, Mo, M, H)
121. *Prosenopupa* (*Prosenopupa*) *hystricella* Cooke & Pilsbry *in* Pilsbry, 1920 (K, O, Mo, M, L, H – Hawaii: "Hilo, Reed's Island")
122. *Prosenopupa* (*Sericipupa*) *lymaniana* Cooke & Pilsbry *in* Pilsbry, 1920 (H: "28 ½ miles Olaa road")
123. *Prosenopupa* (*Sericipupa*) *orycta* Cooke & Pilsbry *in* Pilsbry, 1920 (H: "Palihoukapapa")
124. * *Prosenopupa* (*Sericipupa*) *sericata* Cooke & Pilsbry *in* Pilsbry, 1920 (H: "Piihonua, (a hill) in the flow of 1855, about 5,000 feet elevation")
125. *Pupisoma orcula* (Benson, 1850) (K, O, Mo, M, H; introduced)

Family Spiraxidae
126. *Euglandina rosea* (Férussac, 1821) (K, O, Mo, M, H; introduced) (Remarks – This is the most significant of the predatory snail introduced deliberately during the 1950's as potential biological control agents against *Achatina fulica*. While there are no convincing evidence that *E. rosea* is successful in controlling *A. fulica*, the latter has declined for unknown but probably unrelated reasons. There is, however, ample evidence of its effects on the native Hawaiian land snail faunas (Cowie, 1997))

Family Streptaxidae
127. *Gonaxis quadrilateralis* (Preston, 1910) (K, O, M, H; introduced) (Remarks – one of the many predatory snails introduced into the wild as potential biological control agent of *Achatina fulica*. It has become established but apparently not widespread or abundant (Cowie, 1997))
128. *Gulella bicolor* (Hutton, 1834) (O, H; introduced) (Remarks – First recorded in 1940, possibly due to an accidental introduction. Subsequently deliberately introduced for control of *Achatina fulica* and *Subulina octona* but apparently not established. This species has been introduced widely and is now circum-tropical in distribution (Cowie, 1997))

Family Ferussaciidae (Remarks – The Ferussaciidae are not native to the Hawaiian Islands, but *C. baldwini* has been described from Hawaiian material)
129. *Cecilioides aperta* (Swainson, 1840) (O, H; introduced)
130. *Cecilioides baldwini* (Ancey, 1892) (K, O, M, H; introduced) (Remarks - It is probably a synonym of the widely distributed synanthropic *Cecilioides aperta* Swainson, 1840 (Cowie et al, 1995))

Family Subulinidae
131. *Allopeas clavulinum* (Potiez & Michaud, 1838) (H; introduced)
132. *Allopeas gracile* (Hutton, 1834) (N, K, O, Mo, M, H; introduced) (Remarks – probably introduced by Polynesian travelers prior to the arrival of westerners in the Hawaiian Islands (Christensen & Kirch, 1986 I Cowie, 1997))

133. *Allopeas prestoni hawaiiense* (Sykes, 1904) (K, O, Mo, M, H - Hawaii: "Kawailoa, Mauna Loa at 1,500 feet … Hilo"; introduced)
134. *Opeas hannense* (Rang, 1831) (N, K, O, H; introduced)
135. *Opeas mauritianum* (Pfeiffer, 1854) (O, M, H; introduced)
136. *Opeas mauritianum prestoni* Sykes, 1898 (H; introduced) (Remarks – This is probably synonymous with *mauritianum* s.s. but has not been formally synonymized, following Pilsbry (1906-1907) and pending further research (Cowie, 1997))
137. *Opeas opella* Pilsbry & Vanatta, 1906 (K, O, Mo, M, H: "Hilo"; introduced)
138. *Paropeas achatinaceum* (Pfeiffer, 1846) (K, O, Mo, M, H; introduced)
139. *Subulina octona* (Bruguièrre, [1789]-1792) (K, O, Mo, H, Midway; introduced) (Remarks – one of the most common snails of disturbed (especially urban and suburban) areas in the Hawaiian Islands; reported as prey of *Gonaxis* spp. (Cowie, 1997))

Family Veronicellidae

140. *Laevicaulis alte* (Férussac, 1822) (O, Mo, H, Midway; introduced) (Remarks – the well-known black slug (Cowie, 1997))
141. *Vaginula plebeia* Fischer, 1868 (O, H; introduced) (Remarks – the common brown slug (Cowie, 1997))

Family Achatinidae

142. *Achatina fulica* Bowdich, 1822 (K, O, Mo, L, M, H; introduced) (Remarks – This species was widely introduced in the humid tropics, and is often an agricultural pest. In Hawaii, it was first recorded in 1936, and several predatory snails, notably *Euglandina rosea* (Férussac), were introduced as attempts at biological control. *A. fulica* is now declining in the Hawaiian Islands, but there is no convincing evidence that it is the result of predation (Cowie, 1997))

Family Arionidae

143. ***Arion intermedius*** Normand, 1852 (H; introduced) (Remarks – This species was found in most sites sampled in the Hakalau Forest NWR, suggesting that the species is established and more widely distributed than previously (Cowie, 1997, 1998) believed)

Family Bradybaenidae

144. *Bradybaena similaris* (Rang, 1831) (K, O, Mo, M, L, H, Midway; introduced) (Remarks – This species was widely introduced in tropical and subtropical regions, including many Pacific islands. This is one of the most widespread of the introduced species in the Hawaiian Islands (Cowie, 1997))

Family Helicidae

145. *Helix aspersa* Müller, 1774 (K, O, M, H; introduced) (Remarks – This species has been introduced and become established in the Hawaiian Islands. Although it has not achieved a wide distribution in the islands, nor become a serious agricultural pest, there are many records of *H. aspersa* in Hawaii, and the State Plant

Quarantine officials intercept it every so often. Cowie (1997) notes that this species is of temperate origin, and it may be restricted to high elevations in the Hawaiian Islands. This species is highly prized and cultivated by Europeans as an edible snail (the renown *escargot,* or *Petit-Gris*))

Family Endodontidae

146. *Cookeconcha elisae* (Ancey, 1889) (?HI)
147. *Cookeconcha henshawi* (Ancey, 1904) (H: "Palihoukapapa, on the Hamakua slope of Mauna Kea, Kawaii [= Hawaii], at an elevation of 4,000 feet")
148. *Cookeconcha lanaiensis* (Sykes, 1896) (?K, L, ?H)
149. *Cookeconcha nuda* (Ancey, 1899) (H: "Olaa, Central Hawaii")
150. *Cookeconcha paucilamellata* (Ancey, 1904) (H: "Palihoukapapa, on the Hamakua slope of Mauna Kea, Kawaii [= Hawaii], at an elevation of 4,000 feet")
151. * *Cookeconcha thaanumi* (Pilsbry & Vanatta, 1905) (Mo, M, H – Hawaii: "Kaiwiki, near Hilo")
152. *Cookeconcha thwingi* (Ancey, 1904) (H: "in an extinct crater on the Kona coast")
153. *Nesophila baldwini albina* (Ancey, 1889) (HI)

Family Punctidae

154. *Punctum horneri* (Ancey, 1904) (H, O – Hawaii: "Palihoukapapa, on the Hamakua slope of Mauna Kea, Kawaii [= Hawaii], at an elevation of 4,000 feet")

Family Succineidae

155. *Catinella rotundata* (Gould, 1846) (O, Mo, H)
156. *Succinea* (*Succinea*) *approximata* Sowerby *in* Reeve & Sowerby, 1872
157. *Succinea* (*Succinea*) *aurulenta* Ancey, 1889 (H)
158. *Succinea* (*Succinea*) *bicolorata* Ancey, 1899 (H: "Waimea")
159. *Succinea* (*Succinea*) *casta henshawi* Ancey, 1904 (H: "Olaa, Hawaii, 2,425 ped. Supra mare")
160. *Succinea* (*Succinea*) *casta orophila* Ancey, 1904 (H: "Kaiwiki, Hawaii, 2,500 ped. S.m. [= 2,500 feet above sea level]")
161. ***Succinea* (*Succinea*) *cepulla*** Gould, 1846 (O, Mo, H) (Remarks – collected at the Hakalau Forest NWR during the arthropod survey at Pua Akala tract at about 4200 ft. elevation)
162. * *Succinea* (*Succinea*) *garrettiana* Ancey, 1899 (H: "Rainbow Falls, Hilo")
163. *Succinea* (*Succinea*) *giba* Henshaw, 1904 (H: "Mana, Hamakua")
164. *Succinea* (*Succinea*) *inconspicua* Ancey, 1899 (H: "Waimea")
165. *Succinea* (*Succinea*) *konaensis* Sykes, 1897 (H: "Mt. Kona, Hawaii, at 4,000 feet")
166. * *Succinea* (*Succinea*) *kuhnsi* Ancey, 1904 (H: "Kaïwicki [= Kaiwiki], Hilo")
167. *Succinea* (*Succinea*) *lumbalis* Gould, 1846 (K, H)
168. *Succinea* (*Succinea*) *maxima* Henshaw, 1904 (H: "Mana, Hamakua")
169. *Succinea* (*Succinea*) *mirabilis* Henshaw, 1904 (H: "Palihoukapapa, Hamakua")
170. *Succinea* (*Succinea*) *newcombiana* Garrett, 1857 (H: "District of Waimea")
171. *Succinea* (*Succinea*) *pristina* Henshaw, 1904 (H: "Mana, Hamakua")
172. *Succinea* (*Succinea*) *protracta* Sykes, 1900 (H: "Kau")

173. *Succinea* (*Succinea*) *punctata* Pfeiffer, 1855 (?H)
174. * *Succinea* (*Succinea*) *quadrata* Ancey, 1904 (H: "Olaa, Kaiwiki … 2,550 ped. supra mare [= 2,550 feet above sea level]")
175. *Succinea* (*Succinea*) *tahitiensis* Pfeiffer, 1847 (HI) (remarks – Caum (1928: 60) listed *S. tahitiensis* as a Hawaiian species)
176. * *Succinea* (*Succinea*) *tenerrima* Ancey, 1904 (H: "Kawaiki, Hawaii, alt. 2500-2600 ped. s.m. [= feet above sea level]")
177. *Succinea* (*Succinea*) *tenerrima coccoglypta* Ancey, 1904 (H: "Hilo")
178. *Succinea* (*Succinea*) *thaanumi* Ancey, 1899 (H: "Olaa")
179. * *Succinea* (*Succinea*) *venusta* Gould, 1846 (H)
180. * *Succinea vesicalis* Gould, 1846 (H: "Mauna Kea")

Family Helicarionidae

181. *Euconulus* (*Chetosyna*) *thurstuni* Baker, 1941 (H: "North Kona … Puu Huluhulu (which?)") (Remarks – more than one location on the Island of Hawaii bears the name "Puu Huluhulu"; Baker was uncertain which Puu Huluhulu was the source of his specimens)
182. *Euconulus* (*Nesoconulus*) *gaetanoi* (Pilsbry & Vanatta, 1908) (H: "Palihoukapapa")
183. *Euconulus* (*Nesoconulus*) *gaetanoi vivens* Baker, 1941 (H: "South Hilo … large *kipuka* between Hilo and Kilauea trails from Humuula, alt. About 5,000 ft., 1855 flow")
184. *Euconulus* (*Nesoconulus*) *konaensis* (Sykes, 1897) (H: "Mt. Kona, Hawaii, at 3,000 feet")
185. *Euconulus* (*Nesoconulus*) *thaanumi* (Ancey, 1904) (H: "Olaa")
186. *Euconulus* (*Pellucidomus*) *lubricellus* (Ancey, 1904) (H: "Olaa")
187. *Hiona* (*Hionella*) *rufobrunnea* (Ancey, 1904) (H: "Olaa")
188. *Philonesia* (*Aa*) *gouveiana* Baker, 1940 (H: "South Kona … alt. 6,000 ft., Honomalino")
189. *Philonesia* (*Haleakala*) *turgida diducta* Baker, 1940 (K, O, Mo, M, L, H)
190. *Philonesia* (*Hiloaa*) *hiloi* Baker, 1940 (H: "South Hilo … 4 miles out along Olaa road from Hilo")
191. * *Philonesia* (*Hiloaa*) *piihonuae* Baker, 1940 (H: "South Hilo … *kipuka* 4, Piihonua")
192. * *Philonesia* (*Philonesia*) *cicercula* (Gould, 1846) (H: "Mountains of Hawaii")
193. *Philonesia* (*Philonesia*) *cicercula boettgeriana* (Ancey, 1889) (H: "Kona")
194. *Philonesia* (*Waihoua*) *kaliella* Baker, 1940 (H: "North Kona … inland of old branding pen along trail, Waihou, Puu Waawaa")

Family Zonitidae

195. *Hawaiia minuscula* (Binney, 1841) (K, O, Mo, L, M, H, Midway; introduced) (Remarks – despite the genus name, which was established for the junior synonym *kawaiensis* Reeve, this species is not native to Hawaii, but has been introduced since western contact (Cowie, 1997))
196. * *Nesovitrea hawaiiensis* (Ancey, 1904) (H: "Olaa")

197. ***Oxychilus alliarius*** (Miller, 1822) (K, Mo, M, H; introduced) (Remarks – The "garlic snail", so called because of the strong garlic smell it produced when handled (Cowie, 1997), was the widely distributed in most sites surveyed at the Hakalau Forest NWR. It was locally abundant, and it has been suggested as a potential competitor of native species such as the endangered bird, Puuoli (Birding Hawaii website, 2003))
198. *Striatura* (*Pseudohyalina*) *meniscus* (Ancey, 1904) (H: "Palihoukapapa, on the Hamakua slope of Mauna Kea, Kawaii [= Hawaii], at an elevation of 4,000 feet")
199. *Vitrina tenella* Gould, 1846 (K, M, H)
200. *Zonitoides arboreus* (Say, 1819) (O, M, H; introduced)

Family Milacidae
201. *Milax gagates* (Draparnaud, 1801) (M, H; introduced)

Family Agriolimacidae (Remarks – We follow Barker (1999), who recognizes the family Agriolimacidae as separate from Limacidae)
202. *Deroceras globosum* (Collinge, 1896) (H: "Mauna Loa"; introduced)
203. ***Deroceras laeve*** (Müller, 1774) (K, O, M, H; introduced) (Remarks – this species was found in the Hakalau Forest NWR in the present survey)
204. *Deroceras globosum* (Collinge, 1896) (H: "Mauna Loa, Hawaii"; introduced)
205. *Deroceras reticulatum* (Müller, 1774) (K, H; introduced) (Remarks – the name *reticulatum* may have been used to refer to *laeve* Müller, and vice-versa. This species is frequently intercepted by State Plant Quarantine officials (Cowie, 1997))

Family Limacidae
206. ***Limax maximus*** Linnaeus, 1758 (O, M, H; introduced) (Remarks – The "leopard slug", *L. maximus*, was found in the Hakalau Forest NWR in the present survey)
207. *Limax sandwichiensis* Souleyet, 1852 (HI; introduced)
208. *Limax tenellus* Müller, 1774 (HI; introduced)

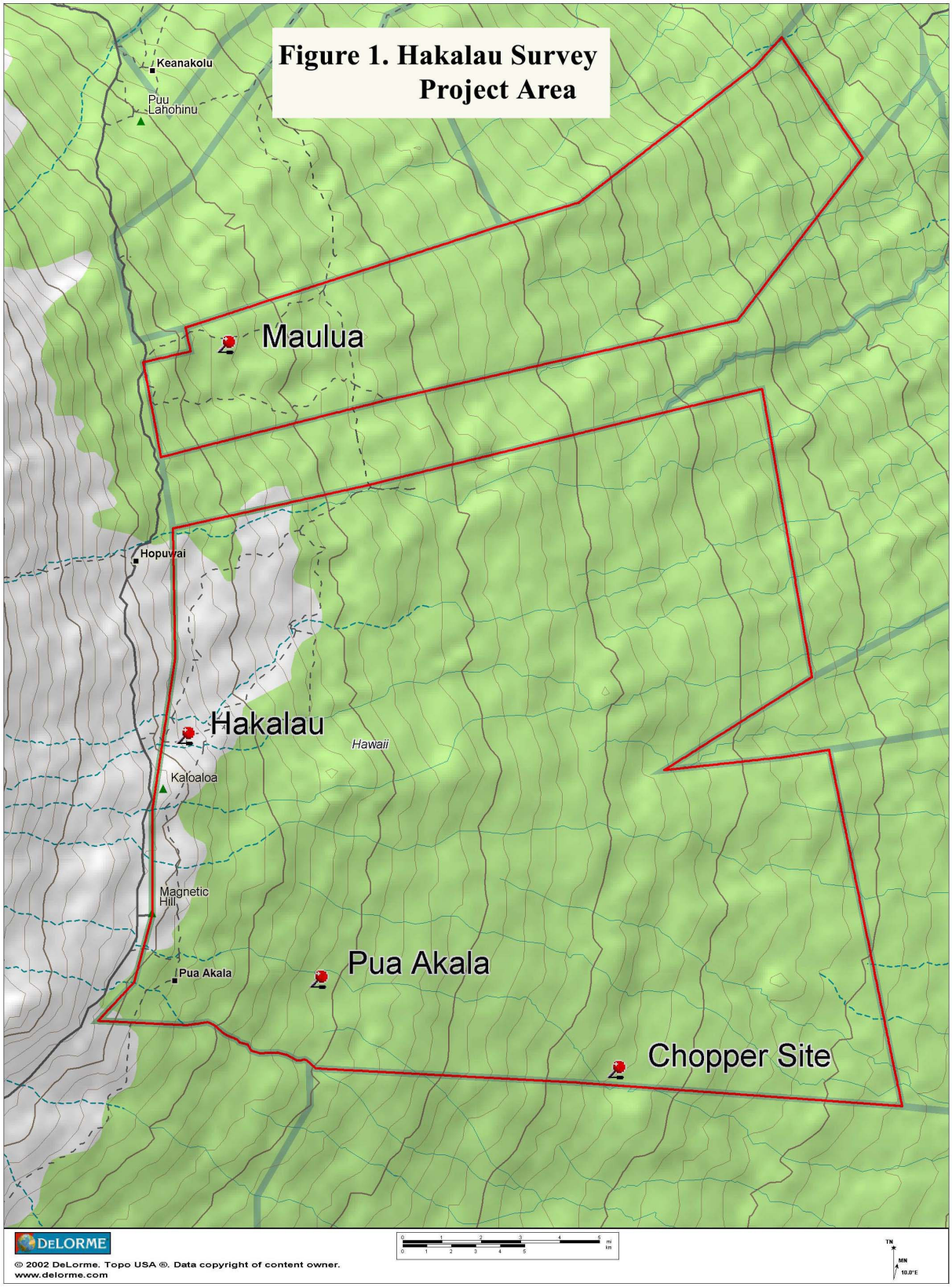
Figure 1. Hakalau Survey
Project Area
Keanakolu
Puu
Lahohinu
Maulua
Hopuwai
Hakalau
Hawaii
Kaloaloa
Magnetic
Hill
Pua Akala
Pua Akala
Chopper Site
DeLORME
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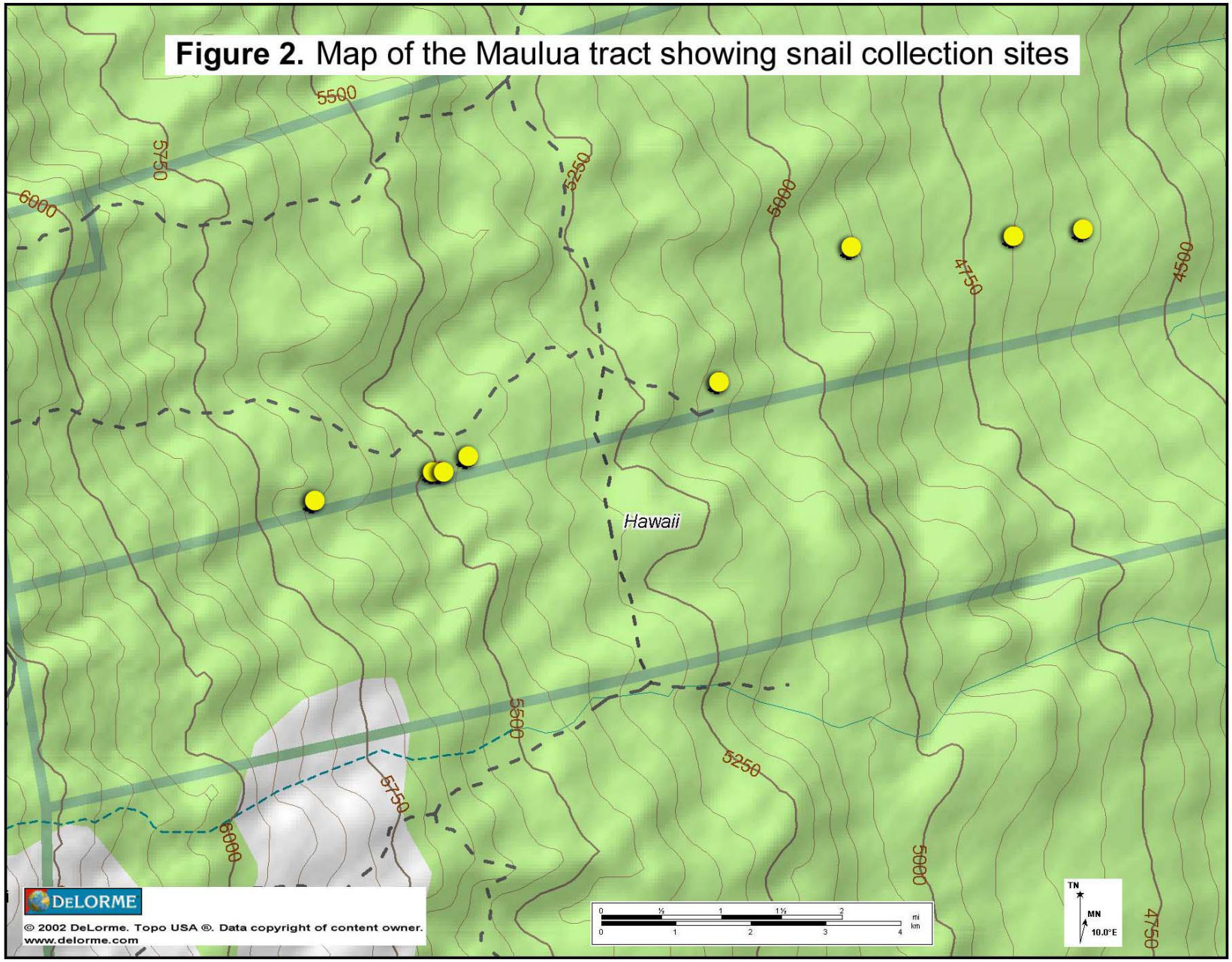
Figure 2. Map of the Maulua tract showing snail collection sites
5500
5750
6000
5250
5000
4750
4500
Hawaii
5500
5250
5750
6000
5000
4750
DeLORME
© 2002 DeLorme. Topo USA ®. Data copyright of content owner.
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TN
MN
10.0°E

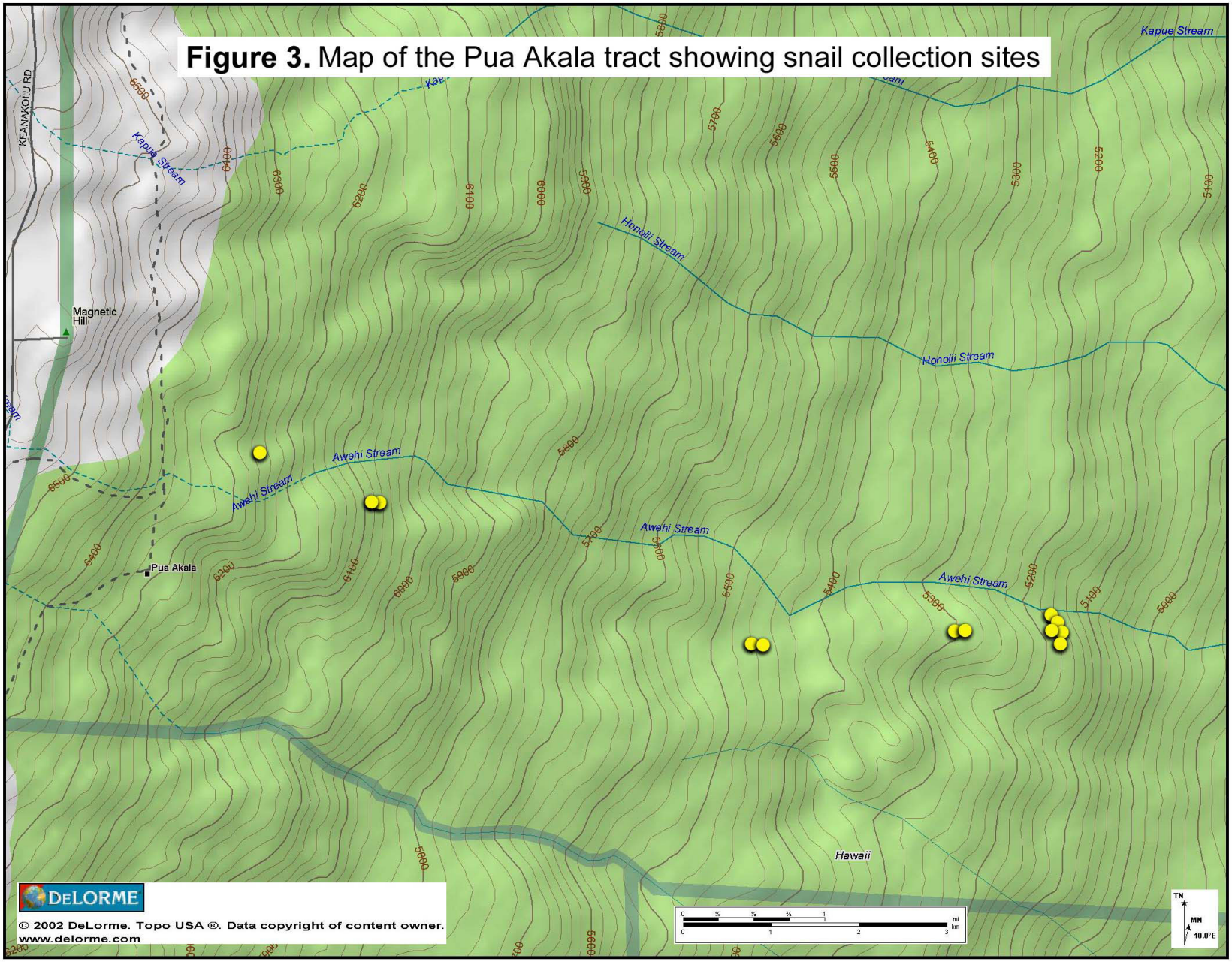

Figure 3. Map of the Pua Akala tract showing snail collection sites

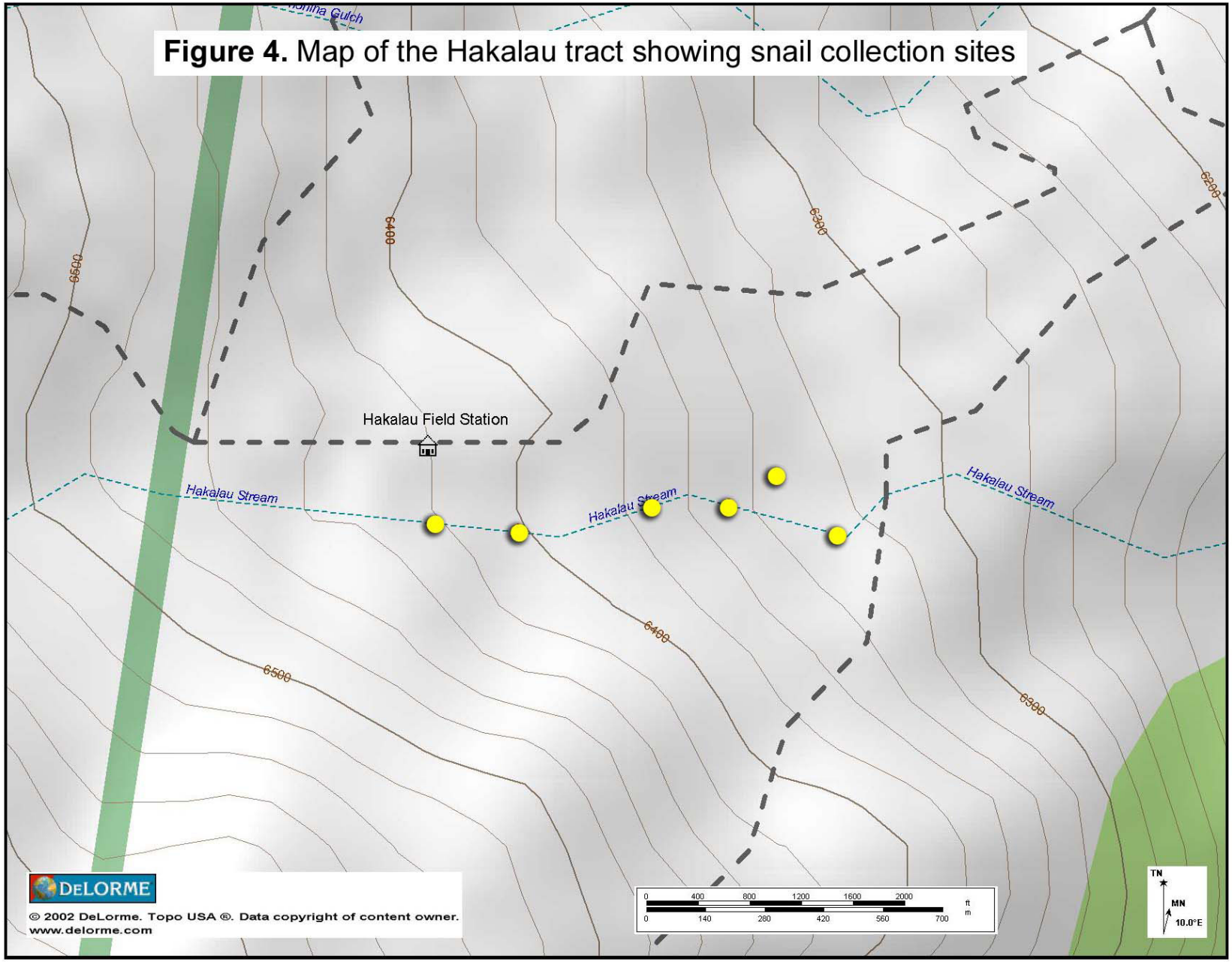

Figure 4. Map of the Hakalau tract showing snail collection sites

PART 2

Survey of the terrestrial arthropods (insects and their relatives) of the Hakalau Forest National Wildlife Refuge, Island of Hawaii

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Introduction

The terrestrial arthropod fauna of the Hawaiian Islands totals 9,897 species, of which 5,732 are endemic, 101 are indigenous (i.e., occur naturally in the Hawaiian Islands but also native elsewhere), and 3,432 are non-native; the remainder (631) are of unknown status (Nishida, 2002). The majority are insects, with 5,449 native and 2,697 non-native species recorded (Nishida, 2002). Over 1,700 species of native insects have been recorded from the Island of Hawaii (Howarth *et al*., 1995). Several hundred more species of other, non-insect native arthropods plus non-native species brings the total arthropod fauna of the island to well over 2,000. Populations of many native species have certainly undergone precipitous declines in recent years. The causes of the declines include habitat destruction, loss of host species, and invasions by introduced species (Howarth & Ramsay, 1991).

The status of most species is unknown—surveying for such a large number of species is a daunting task, but knowledge of the distribution and status of these arthropod species is of primary importance in managing natural areas such as the Hakalau NWR. For example, historical evidence and preliminary studies have suggested that food resources, especially invertebrates, limit the populations and distributions of native Hawaiian birds (Loope et al., 2001). Thus many previous ecological studies on invertebrates at Hakalau FNWR have focused on invertebrates as a prey resource for native birds (Peck, 1993; Fretz, 1996, 2000). Because these studies were limited by a lack of basic knowledge of what invertebrate species occurred in the Refuge, they categorized the invertebrates into only broad groups.

Preliminary work on the distribution of invasive yellowjacket wasps has also been undertaken in the refuge (D. Foote, personal communication), and a few recent revisions of taxonomic groups have included material from the Refuge (e.g., Gillespie 1991). Also, a few preliminary surveys have been done [e.g., carabid beetles (J. Liebherr, unpublished) and native damselflies (D. Polhemus, unpublished)]. However, no broad-based invertebrate surveys generating species-level inventories have been undertaken, yet such surveys are the only way to generate the necessary baseline data for understanding the overall role of invertebrates in the Refuge and for evaluating the conservation status of "species of concern".

The purposes of this study were two-fold: (1) to create a list of arthropod species, which are thought likely to occur within the Refuge that are potentially at risk of extinction or that could serve as indicator taxa for the health of the ecosystems within the Refuge; and (2) to conduct a baseline survey of the arthropods within the Refuge, focusing especially on species of concern.

Methods

Taxonomic lists of invertebrate species potentially occurring in the Refuge

Using relevant literature and specimen data contained in collections of the Hawaii Biological Survey (Bishop Museum), selected native arthropod species were evaluated in terms of whether their historic range encompassed the Refuge. The arthropod fauna of Hawaii Island (over 2,000 species) is too diverse to permit a comprehensive evaluation of all species at this time; therefore, only taxonomic groups containing species of concern or having the potential to serve as indicator taxa were evaluated.

Biological Survey

Three collecting trips each of about six days duration and involving three entomologists were conducted during 2002: one in March, one in July, and one in October. All field trips were scheduled the week before a new moon as a dark evening sky makes night collecting much more productive. An additional field trip in March 2003 focused on the mollusks (see part 1), but included some arthropod collecting.

Arthropod sampling was conducted primarily along two transects within the refuge: one transect was along an elevational gradient within the Pua Akala Tract and approximately coincided with the bird census Transect 1A. The other transect followed a similar elevational gradient along Transect 13 in the Maulua Tract. Arthropods were sampled at specific sites along each transect, with additional samples for specific taxa taken at suitable sites (e.g., significant host plants and damselfly breeding sites) between the main stations. Specific sampling sites were chosen to ensure that each of the accessible major vegetation zones within the reserve was sampled along each transect. Additional collecting was done in the vicinity of the University of Hawaii Hakalau Forest Biological Field Station in the Hakalau Tract. As part of the in-kind contribution from the Smithsonian Institution, a helicopter trip was arranged for a two-day collecting trip to the usually inaccessible bog habitats at mid-elevation. The general locations of the transects and 53 principal sites collecting sites are listed in Table 1 and illustrated in Figure 1.

Collecting Methods

Mercury vapor light (MV). Two night-time collections were made on each transect using a MV (mercury vapor) bulb shining on a white sheet. An additional sample was taken at the mid-elevation bog site. The locations are shown on Figures 2, 3, and 4. Arthropods attracted to the sheet were collected by hand. This is the standard method for obtaining specimens of moths and certain other nocturnal arthropods that either require special handling or are not otherwise commonly found.

Malaise traps. Malaise traps are large open-walled tent-like structures with baffles made of fine netting and about six feet high and eight feet long. They are stretched across suspected insect flyways. The traps act as interceptors; i.e., dispersing insects entering the open tent are guided into a collecting jar by the side and top panels. Two traps were set near the upper boundary of the ohia forest: one on Transect 1A in the Pua Akala Tract and the other on Transect 13 in the Maulua Tract. These were left in place from February to October 2002 and serviced about once every four weeks. The locations of these traps is shown on Figures 2 and 3.

Host searches and general collecting. Substrates and plant hosts were visually inspected for arthropods especially in conjunction with other survey methods or while walking between sites. An insect sweep net was used to capture specimens. Foliage was also sampled with a beating sheet, which is a 3X3-foot square of muslin stretched tight on a wooden frame. The sheet is held directly under foliage, like an umbrella, and the foliage shaken. Dislodged arthropods were collected from the sheet. The locations are shown of Figures 1, 2, 3 and 4.

Lindgren funnels. These special beetle traps consist of a set of about eight plastic funnels about 10 inches in diameter fastened to nest about one inch apart. The bottom funnel empties into a collecting jar. One trap was hung next to a tree trunk near each Malaise trap and left in place for circa three months. The locations are shown on Figures 2 and 3.

Fogging. Timed fogging samples were conducted at selected stations. Each sample involved spreading a 2 m x 2 m white plastic sheet under the most likely productive microhabitat in the vicinity of each sampling station, usually a mossy log or wall of thick vegetation, and fogging the substrate over the sheet with a quick knockdown biodegradable pesticide (pyrethrum). The arthropods of interest that fell to the sheet during 45 minutes were collected. Sample locations are shown on Figures 3, 4 and 5.

Gasoline-powered aspirator. These powerful vacuum pumps are often efficient for collecting a range of arthropods often missed by other means. However, attempts to use a portable gas-powered device at the Refuge gave unsatisfactory results because of the wet conditions.

Laboratory work

The collected specimens were returned to Bishop Museum and sorted to separate each morphologically similar form (usually species), and representative specimens of each morpho-species in selected taxa were appropriately mounted and labeled for identification, using standard entomological techniques. Names and status follow Nishida (1997 and 2002). Because of the huge amount of material collected by the techniques adopted, priority was given to identifying the species thought to be sensitive species or species of concern. Voucher specimens are deposited in the Hawaii Biological Survey entomology collections at the Bishop Museum. Where appropriate, duplicate voucher specimens were retained by the collaborating specialist who assisted with the determination.

RESULTS

Rare species potentially occurring in the Refuge

A search of the Hawaii Biological Survey collections and databases at Bishop Museum for records of species occurring within the Refuge was beyond the scope of this study, except for confirming identifications and assessing the relative rarity of the species captured. To plan the survey, an annotated list of taxonomic groups likely to be encountered and also likely to serve as indicators of the health of the ecosystem was prepared (Table 2).

Endangered species. Only one officially endangered arthropod [Blackburn's sphinx moth, *Manduca blackburni* (Butler, 1880)] occurs on Hawai'i Island. However, it is a denizen of drier habitats, and although potential host plants are found within Hakalau FNWR, the moth is not expected to occur there. The USFWS currently recognizes eight additional proposed or candidate endangered arthropod species on Hawaii Island (Table 3), some of which are expected to occur in the Refuge. More than 100 species of concern (88 species plus an unspecified number of the 22 *Proterhinus* endemic to Hawaii Island) are also listed from the Island of Hawai'i (Table 4). Not all of these species would be expected to occur at Hakalau, for example some of the cave species. However, the Refuge serves as an important haven for many of these and other rare species.

Biological Survey

Over 2,500 specimens were collected and curated, and about 50 species have been identified (Table 4). This represents less than 10% of the number of species expected to occur in the Refuge. Because of the time required and need to rely on systematic specialists who have the experience and expertise, many species remain to be identified. The list is dynamic and will grow as the current material is identified. The existence of the voucher collection and list of species will encourage ecologists and other researchers working in the Refuge to assist in expanding the list. The small number of species identified so far makes some generalizations difficult; however, a few conclusions can be made. These are elaborated below and concern the notable species collected, certain expected species that were conspicuously absent, and relative species diversity compared to other surveyed sites.

Notable species found:

DIPLOPODA: CAMBALIDAE

Nannolene species

Fifteen closely related endemic species of millipedes in the genus *Nannolene* have been described from the Hawaiian Islands, but none from Hawai'i Island. However, several distinct surface and blind cave populations on Hawai'i Island. Some surface populations of *Nannolene* have declined markedly in the past two decades, and finding these animals at several sites is noteworthy.

ODONATA: COENAGRIONIDAE

Megalagrion species **Species of Concern**

The 29 species of native Hawaiian damselflies all belong to the endemic genus *Megalagrion*. Nine species occur on Hawai‘i Island, but one of these, *M. nesiotes,* hasn't been seen for decades. It was a denizen of rain forests near Kīlauea and may survive in the Refuge. *M. pacificum*, which is a candidate endangered species, is a pool and stream breeder and may occur at the lowest elevations in the Refuge, as may the stream breeder, M. nigrohamatum, a SOC on Hawaii. The other, species of concern, *M. amaurodytum peles*, breeds in damp litter in axils of *Astelia* and *Freycinetia*. We found immatures in *Astelia* axils wherever we found suitable habitat.

COLEOPTERA: AGLYCYDERIDAE

Proterhinus species **Species of Concern**

Aglycyderids are small primitive weevils found almost exclusively on oceanic islands. Over 170 species, all in the genus *Proterhinus*, are endemic to the Hawaiian Islands. Twenty-two species are known from Hawai‘i Island, but many species remain to be discovered. Hawaiian species are twig-, stem-, and wood- borers, and a few are even leaf miners. Each species has a very narrow host range, but in concert the group attacks a wide range of woody plant species. One Hawai‘i Island species restricted to *Hibiscadelphus* is believed to be extinct, and surviving populations of the others are sensitive to extirpation, as their hosts become rarer. They are all flightless, and as their hosts become more scattered, they cannot survive. They were widespread on our transects but not common. Species identification is not currently possible. The use of fogging for collecting has greatly expanded our collection of these cryptic weevils.

COLEOPTERA: CERAMBYCIDAE

Plagithmysus vicinus **Species of concern**

There are about 140 species in the endemic genus of long-horned wood-borers in Hawaii. Most species are extremely host-specific, but in concert most woody plant groups in Hawaii are attacked. Thirteen species on Hawaii Island are considered species of concern, one of which, *P. vicinus*, was collected at Maulua. Some species remain common and along with the wood-boring moth *Thyrocopa* species, are believed to be an important food resource for the Akiapola`au

COLEOPTERA: CURCULIONIDAE

Achalles species **Extremely local and rare**

There are 22 endemic Hawaiian species of *Achalles* weevils, five of which occur on Hawai‘i Island. They are small (2–3 mm long), cryptically colored weevils living on tree branches and leaf litter. Their camouflage is enhanced by fungi and algae that grow on large specialized scale-like spines on the weevils' backs and elytra. They are flightless and sensitive to habitat disturbance and invading species, and all species have become rare in the past 100 years.

Oodemus species

These small (3–5 mm long) egg-shaped weevils characteristically have a metallic sheen. There are 64 known species, 13 of which occur on Hawai‘i Island. Populations have declined significantly during the past 30 years (Howarth unpublished).

LEPIDOPTERA: CRAMBIDAE

Omiodes species **Species of Concern**

The 23 species of endemic *Omiodes* leaf rollers are unusual in including both native agricultural pests as well as locally endemic rare species. Ten Hawaii Island species are listed as species of concern. One of these, *O. pritchardii*, is restricted to *Pritchardia* palms and was thought to be endemic to the Stainback Highway. It was present at the lower elevation site in Pua Akala and not far from its host palms.

LEPIDOPTERA: GEOMETRIDAE

Progonostola cremnopis

Progonostola is an endemic genus. It is rarely collected, and the group is poorly known. *P. cremnopis* was collected at only one site.

Scotorythra species

This endemic inchworm genus contains 38 named species, of which 20 occur on Hawai‘i Island. The group is currently being reviewed, and some species will soon be considered for listing. Eight species were collected, which makes the Refuge an important area for the group. The larvae of some species are one of the most important food items of nestling and fledgling native forest birds (Perkins, 1913). Introduced parasites and predators have greatly reduced their numbers, which probably has reduced breeding success of some endangered birds.

DIPTERA: CALLIPHORIDAE

Dyscritomyia species

Twenty-five species are known in this endemic Hawaiian genus, 12 of which occur on Hawai‘i Island. These flies, related to the blue- and green-bottle flies, have declined precipitously in numbers of both species and individuals in recent years. The immature stages are carrion feeders and were no doubt an important component of Hawaiian ecosystems before the arrival of Europeans. Loss of their natural carrion hosts (especially land snails [Perkins, 1913]) and introduction of predators and parasites have probably led to some species becoming extinct. Adults feed on snail slime trails and other liquid protein foods. Some species have dispensed with a feeding larval stage; the female gives birth to a fully-grown larva that transforms to a pupa and adult without feeding. Native *Dyscritomyia* are now largely confined to high elevation wet habitats. Only one species was found during the survey.

Missing species

Because of the difficulties of sampling the great diversity of arthropods, not finding a species is not proof that it is not present. Many of the missing species would be found by continuing the survey. This is especially true for the cryptic species, those active during only certain times of the year, and those living in habitats (such as the canopy) where it was not possible to sample. Among the missing native taxa that should be found at the site with more sampling are the long-horned wood-boring beetles (*Plagithmysus*), click beetles (*Eopenthes*), long-nosed *Nesotochus* weevils, yellow-faced bees (*Hylaeus*) and potter wasps (*Odynerus*).

Some species may be absent because of the ravages of introduced species, for example, the stink bugs and shield bugs (Pentatomidae). *Coleotichus blackburniae*, the koa bug, is the largest and most conspicuous native true bug. It is nearly an inch long and iridescent blue, green, maroon, and yellow. Once common on koa and ʻaʻaliʻi on all of the main islands, it has become rare. The 14 native species of related predatory stink bugs in the genus *Oechalia* also declined at the same time, following the introduction, beginning in the 1960s, of several parasites for biological control of the pestiferous southern green stink bug, *Nezara viridula* (Howarth, 2000). Another group important in the ecology of the Refuge is the native cutworm moths (*Agrotis and Peridroma*). Only two species were found. Several upland species fed on grasses and until about 20 years ago, were often abundant on the upper slopes of Mauna Kea. Several predators and parasites were purposefully introduced to control them, and some members of the group are now very rare (Gagne and Howarth, 1985).

The endemic seed bug, *Nesomartis psammophila* Kirkaldy, 1907, was last collected in the early 1970s from a high-elevation wetland on Mauna Loa, a habitat similar to parts of the Refuge. Until about 50 years ago, it was one of the most abundant true bugs in Hawaii, and the reason for its demise is unknown.

Overall, the diversity seemed lower than expected and increased at lower elevation sites. These results agree with the conclusions of a study on Kilauea by Gagne (1981), who found a clear correlation of native arthropod distribution with altitude with the highest biodiversity occurring between 3,500 and 4,000 feet elevation. Most of the study sites sampled at Hakalau were at or above the upper limit of range for many native arthropod species

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Table 1. Location, method employed, date, elevation, coordinates and habitat of arthropod collection sites at the Hakalau Forest National Wildlife Refuge.

No.	Transect/ Location	Method	Date	Elevation	Latitude WGS 84	Longitude WGS 84	Habitat/Vegetation
1	Pua Akala	Malaise # 1	13.ii.-5.x.02	5490’	19º47.152’N	155º18.463’W	Open ohia forest with native understory
2	Pua Akala Tr. 1A	Gressitt’s malaise	7-11. vii.02	5465’	19º47.061’N	155º18.441’W	Across stream in open ohia forest
3	Pua Akala	Lindgren Funnels	7.vii.02-5.x.02	5490’	19º47.147’N	155º18.468’W	Open ohia forest with native understory
4	Pua Akala	MV-light	12.iii.02	5480’	19º47.084’N	155º18.471’W	Open ohia forest with native understory
5	Pua Akala	MV-light	7.vii.02	6070’	19º47.356’N	155º19.351’W	Open ohia koa forest
6	Pua Akala /1A	Fog	12.iii.02	5470’	19º47.037’N	155º18.452’W	Fallen ohia log at forest margin
7	Pua Akala	2 fogs	12.iii.02	6250’	19º47.484’N	155º19.647’W	Ohia buttresses in recovering pasture
8	Pua Akala	fog & search	12.iii.02	5475’	19º47.064’N	155º18.462’W	Open ohia forest with native understory
9	Pua Akala	day fogs	7.vii.02	6070’	19º47.356’N	155º19.351’W	Open ohia koa forest
10	Puu Akala	fogging koa log	8.vii.02	5490’	19º47.149’N	155º18.463’W	Open ohia forest
11	Pua Akala Tr. 1A	Fogging	11.vii.02	5465’	19º47.061’N	155º18.441’W	Open ohia forest with native understory
12	Pua Akala Tr. 1A	3+ Fogging	11.iii.02	5465’	19º47.023’N	155º18.425’W	Open ohia forest with native understory
13	Pua Akala/ tr1A; stn 6	2 fogs	2.x.02	5295’	19º47.074’N	155º17.885’W	Wet ohia forest
14	Pua Akala	host searches [Rubus,etc.]	7.vii.02	6070’	19º47.356’N	155º19.351’W	Wet gulch with native trees and shrubs
15	Puu Akala	beating, ohia	8.vii.02	5490’	19º47.149’N	155º18.463’W	Open ohia forest
16	Puu Akala	General/	8.vii.02	5480’	19º47.074’N	155º18.467’W	Open ohia forest
17	Puu Akala	General/	8.vii.02	5700’	19º47.215’N	155º18.851’W	Roadside pool in open ohia forest
18	Pua Akala/ tr1A	General/	2.x.02	5350’	19º47.052’N	155º18.06’W	Bog in wet ohia forest
19	Pua Akala/ tr1A; stn 6	Host searches	2.x.02	5295’	19º47.074’N	155º17.885’W	Wet ohia forest
20	Pua Akala/ tr1A	Fog	2.x.02	5370’	19º47.046’N	155º18.132’W	Wet ohia forest
21	Pua Akala/ tr1A	Fogs	13.iii.03	5160’	19º47.05’N	155º18.64’W	Wet ohia forest

Table 1. (Continued)

No.	Transect/ Location	Method	Date	Elevation	Latitude WGS 84	Longitude WGS 84	Habitat/Vegetation
22	Maulua Tr. 13	Malaise trap #2	13.ii.02 to 6.x.02	5150’	19º52.299’N	155º17.987’W	Ohia forest with native understory
23	Maulua Tr. 13	Lindgren funnels	9.vii.02 to 6.x.02	5150’	19º52.299’N	155º17.987’W	Ohia forest with native understory
24	Maulua Tr. 13	MV Bulb	14.iii.02	5910’	19º51.89’N	155º19.62’W	Recovering pasture, koa savanna.
25	Maulua	MV Bulb	9.vii.02	6010’	19º52.023’N	155º19.891’W	Open koa woodland
26	Maulua Tr. 13	fog	14.iii.02	5910’	19º51.93’N	155º19.66’W	Fallen log in recovering pasture, koa savanna.
27	Maulua Tr. 13	fog	14.iii.02	5920’	19º52.0’N	155º19.75’W	*Myrsine* sp. in recovering pasture, koa savanna.
28	Maulua Tr. 13	fog	14.iii.02	5904’	19º51.97’N	155º19.70’W	*Rubus hawaiiensis* in recovering pasture, koa savanna.
29	Maulua Tr. 13	Fogging	9.vii.02	5010’	19º52.347’N	155º17.792’W	Ohia forest with native understory
30	Maulua Tr. 13	Fogging	9.vii.02	5010’	19º52.347’N	155º17.792’W	Ohia forest with native understory
31	Maulua	Fog koa & lichens	10.vii.02	5825’	19º51.975’N	155º19.48’W	koa, ohia, ferns, akala, grasses
32	Maulua	Fog ohia folliage	10.vii.02	5805’	19º52.005’N	155º19.457’W	Ohia koa woodland
33	Maulua	Fog fallen koa tree	10.vii.02	5690’	19º51.897’N	155º19.214’W	Koa
34	Maulua/ tr13	Fog	6.x.02	4970’	19º52.939’N	155º17.721’W	Ohia forest with native understory
35	Maulua/ tr13	Fog	6.x.02	4970’	19º52.394’N	155º17.725’W	Ohia forest with native understory
36	Maulua/ tr13	Fog	6.x.02	4960’	19º52.373’N	155º17.705’W	Ohia forest with native understory
37	Maulua	Rotting wood General	9.vii.02	5260’	19º52.314’N	155º18.337’W	Grassland
38	Maulua	Fallen koa & Ohia General	9.vii.02	5155’	19º52.652’N	155º18.037’W	Open ohia koa woodland.
39	Maulua Tr. 13	host searches General	9.vii.02	5010’	19º52.347’N	155º17.792’W	Recovering pasture, koa savanna.
40	Maulua	General	10.vii.02	5830’	19º51.958’N	155º19.479’W	koa, ohia, ferns, akala, grasses
41	Maulua	Fog large koa butt.	10.vii.02	5820’	19º51.985’N	155º19.47’W	Ohia koa woodland
42	Maulua/ tr13	sweeping *Sadleria* General	6.x.02	4960’	19º52.373’N	155º17.705’W	Ohia forest with native understory
43	Maulua Spring Water Camp	sweeping sedges General	6.x.02	5045’	19º52.105’N	155º17.823’W	Disturbed wetland

Table 1. (Continued)

No.	Transect/ Location	Method	Date	Elevation	Latitude WGS 84	Longitude WGS 84	Habitat/Vegetation
44	Pua Akala Awehi Stream	MV light &searches	3-4.x.02	4210’	19º46.386’N	155º16.025’W	Bog
45	Pua Akala Awehi Stream	Fog	3.x.02	4190’	19º46.358’N	155º16.001’W	Very wet ohia forest
46	Pua Akala Awehi Stream	2 Fogs	3.x.02	4180’	19º46.347’N	155º15.992’W	Very wet ohia forest
47	Pua Akala Awehi Stream	Fog	3.x.04	4160’	19º46.304’N	155º15.947’W	wet cliff above stream bank
48	Pua Akala Awehi Stream	Fog	4.x.04	4225’	19º46.473’N	155º15.924’W	Cibotium fronds in wet ohia tree fern forest
49	Pua Akala Awehi Stream	Host search	4.x.04	4225’	19º46.473’N	155º15.924’W	Cibotium fronds in wet ohia tree fern forest
50	Pua Akala Awehi Stream	Host search	3.x.04	4160’	19º46.304’N	155º15.947’W	wet cliff above stream bank
52	Hakalau Tract Bird Res. Stn	Fogs	12.iii.02 to 6.x.03	6385’	19º49.18’N	155º19.90’W	Ohia, koa, akala, ferns, in stream bed.
53	Hakalau Tract Bird Res. Stn	General	12.iii.02 to 6.x.03	6415’	19º49.212’N	155º19.903’W	Pasture, koa.

Table 2. **List of potentially sensitive species of insects and other arthropods likely to occur in the Hakalau Forest National Wildlife Refuge and well enough known and conspicuous enough to serve as indicator taxa.**

Scientific Name	Rarity
ARANEAE: LINYPHIIDAE	
Orsonwelles species	Large conspicuous webs
ARANEAE: TETRAGNATHIDAE	
Tetragnatha species	Many species, in diverse habits
COLEOPTERA: AGLYCYDERIDAE	
Proterhinus species	Many species, sparse or on rare host
COLEOPTERA: CARABIDAE	
Several genera	Many species, in diverse habitats
COLEOPTERA: CERAMBYCIDAE	
Plagithmysus species	Many rare species, on rare hosts, important food for birds
COLEOPTERA: CURCULIONIDAE	
Achalles species	Flightless weevils, rarely seen
Oodemus species	Flightless weevils, rarely seen
Nesotocus species	Rare species
COLEOPTERA: ELATERIDAE	
Eopenthes species	Many rare species
COLEOPTERA: NITIDULIDAE	
Several genera	Many species on rare hosts
DIPTERA: CALLIPHORIDAE	
Dyscritomyia species	Many species recently declining
DIPTERA: DOLICHOPODIDAE	
Emperoptera hawaiiensis (Hardy & Delfinado)	flightless fly. Possibly extinct,
DIPTERA: DROSOPHILIDAE	
Drosophila species and related forms	45 species possible, some very rare
DIPTERA: MUSCIDAE	
Lispocephala species	Many species, some rare, predators
DIPTERA: PIPUNCULIDAE	
Cephalops species	Many species rarely collected, parasites
HETEROPTERA: LYGAEIDAE	
Several genera	Many species, on rare hosts
HETEROPTERA: MIRIDAE	
Several genera	Many species, on rare hosts
HETEROPTERA: NABIDAE	
Nabis species	Many species rarely collected
HETEROPTERA: PENTATOMIDAE	
Oechalia species	Many species, all species in serious decline
HETEROPTERA: REDUVIIDAE	
Nesidiolestes ana Gagné & Howarth	Rare, specialized habitat (cave)
Nesidiolestes selium Kirkaldy	Rare, rain forest predator
Saicella mulli Polhemus, 2000	Rare, rain forest predator
HETEROPTERA: SCUTELLERIDAE	
Coleotichus blackburniae White	Common in 1970s now rarely collected
HOMOPTERA: CIXIIDAE	
Oliarus species	Many species, diverse hosts

Table 2. (Continued)

Scientific Name	Rarity
HYMENOPTERA: COLLETIDAE	
Hylaeus species	Many species rare, important pollinators
HYMENOPTERA: ICHNEUMONIDAE	
Enicospilus species	Many species rare, parasites
HYMENOPTERA: SPHECIDAE	
Ectemnius species	Many species rare, predatory wasps
HYMENOPTERA: VESPIDAE	
Odynerus species	Many species rare, predatory wasps
LEPIDOPTERA: CARPOSINIDAE	
Carposina species	Many species rare, fruit moths
LEPIDOPTERA: COSMOPTERIGIDAE	
Hyposmocoma species	> 40 species in Refuge, diverse habits
LEPIDOPTERA: CRAMBIDAE	
Omiodes species	rare species, on rare hosts, leafrollers
Udea species	Many species rare
LEPIDOPTERA: GEOMETRIDAE	
Eupithecia species	rare species, predatory caterpillars many species declining
Scotorythra species	Many rare species, on rare hosts, important food for native birds
LEPIDOPTERA: LYCAENIDAE	
Udara blackburni (Tuely)	Common, 1 of 2 native butterflies
LEPIDOPTERA: NOCTUIDAE	
Agrotis species	rare species, on rare hosts, some common species in serious decline
Haliophyle species	rare, on ferns
Hypena species	all native species apparently extinct
Lophoplusia species	Rare on rare hosts
Schrankia species	Rare, forest and cave species
LEPIDOPTERA: NYMPHALIDAE	
Vanessa tameamea Esc.	Common, 1 of 2 endemic butterflies
LEPIDOPTERA: OECOPHORIDAE	
Thyrocopa species	Many species, diverse habits; important food for birds
LEPIDOPTERA: SPHINGIDAE	
Hyles callida hawaiiensis Roths.&Jord.	Possibly extinct
NEUROPTERA: CHRYSOPIDAE	
Anomalochrysa species	Many species, predators, very rare
NEUROPTERA: HEMEROBIIDAE	
Micromus species	Many species, predators, very rare
ODONATA: COENAGRIONIDAE	
Megalagrion amaurodytum peles (Perkins)	Sparse
Megalagrion nesiotes (Perkins)	possibly extinct
ORTHOPTERA: GRYLLIDAE	
Caconemobius varius Gurney & Rentz	Rare, specialized habitat (cave)
Thaumatogryllus cavicola Gurney & Rentz	Rare, specialized habitat (cave)
DIPLOPODA: CAMBALIDAE	
Nannolene species	Millipedes, leaf litter and caves, rare

Table 3. Proposed and candidate species of arthropods known to occur (or to have historically occurred) on Hawai'i Island (updated by USFWS October 30, 2001).

Scientific Name *	Common Name
PROPOSED SPECIES	
**Drosophila mulli* Perreira & Kaneshiro, 1990	pomace fly (no common name)
**Drosophila heteroneura* (Perkins, 1910)	pomace fly (no common name)
Drosophila ochrobasis Hardy & Kaneshiro, 1968	pomace fly (no common name)
CANDIDATE SPECIES	
ODONATA: COENAGRIONIDAE	
**Megalagrion nesiotes* (Perkins, 1899)	Nesiotes megalagrion damselfly
**Megalagrion pacificum* (McLachlan, 1883)	Pacific megalagrion damselfly
Megalagrion xanthomelas (Selys-Longchamps, 1876)	Orangeblack megalagrion damselfly
HETEROPTERA: LYGAEIDAE	
Nysius wekiuicola Ashlock & Gagne, 1985	Wekiu bug
DIPTERA: DROSOPHILIDAE	
**Drosophila digressa* Hardy & Kaneshiro, 1968	pomace fly (no common name)

* Potentially occurs in the Refuge.

Table 4. Arthropod species of concern known to occur (or to have historically occurred) on Hawai'i Island (updated by USFWS August 31, 2000).

Scientific Name	Common Name
ARCHAEOGNATHA: MACHILIDAE	
Neomachilis heteropus (Silvestri, 1904)	Hawaiian long-palp bristletail
COLEOPTERA: AGLYCYDERIDAE	
Proterhinus species: 72 spp. (not specified)	Primitive broad-nose weevils
COLEOPTERA: CERAMBYCIDAE	
Plagithmysus claviger (Sharp, 1900)	Hawai'i clubbed long-horned beetle
Plagithmysus decorus Perkins, 1921	Hawai'i decorus long-horned beetle
Plagithmysus elegans Sharp, 1910	Hawai'i elegant long-horned beetle
Plagithmysus greenwelli Gressitt & Davis, 1971	Greenwell's long-horned beetle
Plagithmysus kohalae Perkins, 1927	Kohala long-horned beetle
Plagithmysus kraussi Gressitt & Davis, 1970	Krauss' long-horned beetle
Plagithmysus mezoneuri (Swezey, 1946)	Hawai'i uhiuhi long-horned beetle
Plagithmysus platydesmae Perkins, 1920	Pilo kea long-horned beetle
Plagithmysus podagricus (Perkins, 1927)	Podagricus long-horned beetle
Plagithmysus simplicollis Sharp, 1910	Simple-necked long-horned beetle
Plagithmysus sulphurescens Sharp, 1896	Hawai'i opuhe long-horned beetle
Plagithmysus swezeyi Perkins, 1920	Swezey's long-horned beetle
Plagithmysus vicinus Sharp, 1896	Hawai'i alani long-horned beetle
COLEOPTERA: CURCULIONIDAE	
Nesotocus giffardi Perkins, 1910	Giffard's nesotocus weevil
Nesotocus munroi Perkins, 1900	Munro's nesotocus weevil
COLEOPTERA: CURCULIONIDAE	
Rhyncogonus giffardi Sharp, 1919	Giffard's rhyncogonus weevil
COLEOPTERA: ELATERIDAE	
Eopenthes cognatus Sharp, 1908	Cognatus eopenthes click beetle
Eopenthes tinctus Sharp, 1908	Tinged eopenthes click beetle
HETEROPTERA: LYGAEIDAE	
Metrarga obscura Blackburn, 1888	Mauna Loa seed bug
Nesocryptias villosa (White, 1878)	Villosan flightless seed bug
Oceanides bryani Usinger, 1942	Bryan's oceanides seed bug
HETEROPTERA: MESOVELIIDAE	
Cavaticovelia aaa (Gagné & Howarth, 1975)	Aaa water treader bug
HETEROPTERA: MIRIDAE	
Engytatus species 2	'Ānunu plant bug,
Kalania hawaiiensis (Kirkaldy, 1902)	Lana'i kalanian leaf bug
HETEROPTERA: PENTATOMIDAE	
Oechalia grisea (Burmeister, 1834)	Gray oechalia stink bug
Oechalia patruelis (Stal, 1859)	Patruelis oechalia stink bug

continued...

Table 4. (Continued)

Scientific Name	Common Name
HETEROPTERA:REDUVIIDAE	
Empicoris pulcher (Blackburn, 1888)	Pulchrus thread-legged bug
Nesidiolestes ana Gagné & Howarth, 1975	Cave thread-legged bug
Nesidiolestes selium Kirkaldy, 1902	Rain forest thread-legged bug
HETEROPTERA: RHOPALIDAE	
Ithamar annectans Van Duzee, 1936	Annectans rhopalid bug
Ithamar hawaiiensis Kirkaldy, 1902	Hawaiian rhopalid bug
HETEROPTERA: SCUTELLARIDAE	
Coleotichus blackburniae White, 1881	Koa bug
HOMOPTERA: CIXIIDAE	
Oliarus "lorettae"	Loretta Lynn's cave planthopper
Oliarus species 1	Doc Bellou cave planthopper
Oliarus species 2	Pahoa cave planthopper
HOMOPTERA: DELPHACIDAE	
Nesosydne cyrtandricola Muir, 1918	Glenwood nesosydne planthopper
HYMENOPTERA: COLLETIDAE	
Hylaeus anthracina (F. Smith, 1853)	Anthracinan yellow-faced bee
Hylaeus assimulans (Perkins, 1899)	Assimulans yellow-faced bee
Hylaeus comes (Perkins, 1899)	Comes yellow-faced bee
Hylaeus coniceps (Blackburn, 1886)	Conehead yellow-faced bee
Hylaeus crabronoides (Perkins, 1899)	Crabronoid yellow-faced bee
Hylaeus difficilis (Perkins, 1899)	Difficult yellow-faced bee
Hylaeus dimidiata (Perkins, 1899)	Dimidiatan yellow-faced bee
Hylaeus facilis (F. Smith, 1879)	Easy yellow-faced bee
Hylaeus filicum (Perkins, 1912)	Fern yellow-faced bee*Hylaeus*
Hylaeus flavipes (F. Smith, 1853)	Yellow-foot yellow-faced bee
Hylaeus hula (Perkins, 1912)	Hulan yellow-faced bee
Hylaeus insignis (Perkins, 1899)	Insignis yellow-faced bee
Hylaeus kona (Blackburn, 1886)	Kona yellow-faced bee
Hylaeus laeta (Perkins, 1899)	Laetan yellow-faced bee
Hylaeus obscurata (Perkins, 1899)	Obscuratan yellow-faced bee
Hylaeus ombrias (Perkins, 1910)	Ombrias yellow-faced bee
Hylaeus pubescens (Perkins, 1899)	Furry yellow-faced bee
Hylaeus simplex (Perkins, 1899)	Simple yellow-faced bee
Hylaeus specularis (Perkins, 1899)	Specular yellow-faced bee
Hylaeus sphecodoides (Perkins, 1899)	Sphecodoid yellow-faced bee
Hylaeus vicina (Perkins)	Vicinan yellow-faced bee

continued...

Table 4. (Continued)

Scientific Name	Common Name
HYMENOPTERA: SPHECIDAE	
Deinomimesa hawaiiensis Perkins, 1899	Hawaiian deinomimesan wasp
Deinomimesa punae Perkins, 1899	Puna deinomimesan sphecid wasp
Ectemnius bidecoratus (Perkins, 1899)	Bidecoratus sphecid wasp
Ectemnius curtipes (Perkins, 1899)	Short-foot ecteminus sphecid wasp
Ectemnius fulvicrus (Perkins, 1899)	Brown cross ectemnius sphecid wasp
Ectemnius rubrocaudatus (Blackburn, 1886)	Red-tail ectemnius sphecid wasp
Ectemnius yoshimotoi Bohart, 1976	Yoshimoto's ectemnius wasp
HYMENOPTERA: VESPIDAE	
Odynerus nigripennis (Holmgren, 1869)	Black-winged odynerus vespid wasp
LEPIDOPTERA: CRAMBIDAE	
Glyphodes cyanomichla (Meyrick, 1899)	Blue margaronian moth
Omiodes anastrepta Meyrick, 1899	Moloka‘i sedge hedyleptan moth
Omiodes anastreptoides Swezey, 1913	Kohala sedge hedyleptan moth
Omiodes asaphombra Meyrick, 1899	‘Ohe omiodes moth
Omiodes euryprora Meyrick, 1899	‘Ōla‘a banana hedyleptan moth
Omiodes fullawayi Swezey, 1913	Fullaway's banana hedyleptan moth
Omiodes giffardi Swezey, 1921	Giffard's ‘ohe hedyleptan moth
Omiodes iridias Meyrick, 1899	Kilauea pa‘iniu hedyleptan moth
Omiodes meyricki Swezey, 1907	Meyrick's banana hedyleptan moth
Omiodes monogona Meyrick, 1888	Hawaiian bean leafroller (moth)
Omiodes pritchardii Swezey, 1948	Hawaiian lo‘ulu hedyleptan moth
Stemorrhages exaula (Meyrick, 1888)	Green margaronian moth
Udea dryadopa (Meyrick, 1899)	‘Ohenaupaka udean moth
LEPIDOPTERA: NOCTUIDAE	
Agrotis melanoneura Meyrick, 1899	Black-veined agrotis noctuid moth
Agrotis microreas Meyrick, 1899	Microreas agrotis noctuid moth
Anomis vulpicolor Meyrick, 1928	Red anomis noctuid moth
Helicoverpa confusa Hardwick, 1965	Confused helicoverpan noctuid moth
NEUROPTERA: HEMEROBIIDAE	
Micromus usingeri (Zimmerman, 1940)	Usinger's brown lacewing
ODONATA: COENAGRIONIDAE	
Megalagrion amaurodytum peles (Perkins, 1899)	Pele ‘ie‘ie damselfly
Megalagrion nigrohamatum (Blackburn, 1884)	Black-knees damselfly
ORTHOPTERA: GRYLLIDAE	
Caconemobius varius Gurney & Rentz, 1978	Kaumana cave cricket
Thaumatogryllus cavicola Gurney & Rentz, 1978	Volcanoes cave cricket

TABLE 5. List of species of terrestrial arthropods collected within the Hakalau Forest National Wildlife Refuge Environs during the period from 12 February to 6 October 2002. Names and arrangement follows Nishida (1997 and 2002).

ARTHROPOD FAUNA	Status and Distribution within the Hakalau Forest National Wildlife Refuge									
SCIENTIFIC NAME	Relative bundance	Collection method	Maulua, Mesic: Koa/Ohia Pasture >5500 ft.	Maulua, Mesic: Koa/Ohia Pasture 5500 – 5200 ft.	Maulua, Mesic: Ohia/Koa <5200 ft. Closed canopy	Hakalau, Dry: Koa/Ohia 6500 – 6200 ft.	Pua Akala, Mesic: Koa/Ohia, old Pasture >5600 ft.	Pua Akala, Mesic: Koa/Ohia 5600 – 5300 ft. Closed canopy	Pua Akala, Wet, Ohia/Koa <5300 ft. Closed canopy	Pua Akala: Awehi Stream Wet: Ohia Tree fern, + Bog, ~ 4200 ft.
CLASS: ARACHNIDA ORDER: ARANEAE FAMILY: Tetragnathidae										
Tetragnatha quasimodo Gillespie	C	G		X	X			X		X
Tetragnatha sp. 1	S	G, F	X	X	X			X		X
Tetragnatha sp. 2	R	G, F			X					X
CLASS: INSECTA ORDER: ODONATA FAMILY: Aeshnidae										
Anax strenuous Hagen, 1867	S									X
Coenagrionidae										
Megalagrion calliphya calliphya (McLachlan, 1883)	R	G						X		X
Megalagrion hawaiiense (McLachlan, 1883)	R	G						X		XX
Megalagrion amaurodytum peles (Perkins, 1899)	S	H		X	X			X	X	X
Megalagrion blackburni McLachlan, 1883	R	G						X		X
ORDER: ORTHOPTERA FAMILY: Gryllidae										
Laupala sp. 1	C	G, F	X	X	X	X	X	X		X
Leptogryllus sp. 1	S	F				X		X		X
Trigonidium spp.	C	F		X	X	X	X	X		X
ORDER: DIPTERA FAMILY: Calliphoridae										
Dyscritomyia sp. 1	R	G	X	X	X			X		X
Muscidae										
Lispocephala sp. 1	R	G			X			X		X

Table 5. (Continued)

ARTHROPOD FAUNA	Status and Distribution within the Hakalau Forest National Wildlife Refuge									
SCIENTIFIC NAME	**Relative bundance**	**Collection method**	**Maulua, Mesic: Koa/Ohia Pasture >5500 ft.**	**Maulua, Mesic: Koa/Ohia Pasture 5500 – 5200 ft.**	**Maulua, Mesic: Ohia/Koa <5200 ft. Closed canopy**	**Hakalau, Dry: Koa/Ohia 6500 – 6200 ft.**	**Pua Akala, Mesic: Koa/Ohia, old Pasture >5600 ft.**	**Pua Akala, Mesic: Koa/Ohia 5600 – 5300 ft. Closed canopy**	**Pua Akala, Wet, Ohia/Koa <5300 ft. Closed canopy**	**Pua Akala: Awehi Stream Wet: Ohia Tree fern, + Bog, ~ 4200 ft.**
Pipunculidae										
Cephalops sp.	R	M		X						
Tipulidae										
Gonomyia hawaiiensis Alexander, 1919	R	MV		X	X			X	X	X
ORDER: HETEROPTERA FAMILY: Miridae (Leaf bugs)										
Kamehameha lunalilo Kirkaldy, 1902	R	F								X
Koanoa hawaiiensis (Kirkaldy, 1902)		F								
Orthotylus sp. 1	S	F								
Nabidae: (damselbugs)										
Nabis lusciosus White, 1877	C	F	X	X	X	X	X	X	X	X
Nabis oscillans Blackburn, 1888	S	F		X			X			
Reduviidae (Assassin bugs)										
Nesidiolestes selium Kirkaldy, 1902	R	F		X				X	X	X
Saicella mulli Polhemus, 2000	R	F						X	X	X
ORDER: LEPIDOPTERA FAMILY: Crambidae										
Omiodes (=Hedylepta) prichardii	R	MV								X
Geometridae										
Prognostola cremnopsis Meyrick, 1899	S	MV		X						
Scotorythra arboricolens Butler, 1883	C	MV	X	X	X			X	X	
Scotorythra artemidora Meyritc, 1899	C	MV		X	X			X	X	
Scotorythra epixantha (Perkins, 1901)	R	MV						X		
Scotorythra goniastis Meyrick, 1899	R	MV						X		
Scotorythra paludicola, (Butler, 1879)	R	MV		X						

Table 5. (Continued)

ARTHROPOD FAUNA	Status and Distribution within the Hakalau Forest National Wildlife Refuge									
SCIENTIFIC NAME	**Relative bundance**	**Collection method**	**Maulua, Mesic: Koa/Ohia Pasture >5500 ft.**	**Maulua, Mesic: Koa/Ohia Pasture 5500 – 5200 ft.**	**Maulua, Mesic: Ohia/Koa <5200 ft. Closed canopy**	**Hakalau, Dry: Koa/Ohia 6500 – 6200 ft.**	**Pua Akala, Mesic: Koa/Ohia, old Pasture >5600 ft.**	**Pua Akala, Mesic: Koa/Ohia 5600 – 5300 ft. Closed canopy**	**Pua Akala, Wet, Ohia/Koa <5300 ft. Closed canopy**	**Pua Akala: Awehi Stream Wet: Ohia Tree fern, + Bog, ~ 4200 ft.**
Scotorythra rara, (Butler, 1879)	C	MV	X	X	X		X	X	X	X
Scotorythra new sp. 7, Heddle, in press.	R	MV		X				X		
Scotorythra new sp. 13, Heddle, in press.	R	MV		X				X		
ORDER: LEPIDOPTERA FAMILY: Noctuidae										
Agrotis epicremna Meyrick, 1899	R	MV		X						
Haliophyle euclidias (Meyrick, 1899)	C	MV		X				X		
Haliophyle flavistigma (Warren, 1913)	R	MV						X		
Haliophyle ignita Warren, 1912	R	MV		X				X		
Pseudaletia macrosaris (Meyrick, 1899)	R	MV		X				X		
Pseudaletia sp. A ("big red") undescribed	R	MV		X						
Oecophoridae										
Thyrocopa sp.	C	MV		X						
ORDER: COLEOPTERA FAMILY: Aglycyderidae										
Proterhinus spp.	S	F	X	X	X		X	X	X	X
Anobiidae										
Xyletobius sp. 1	S	F		X	X		X	X	X	X
Carabidae										
Bembidion spp.	S	F		X				X	X	X
Blackburnia sp. 1	S	F		X			X	X	X	X
Blackburnia sp. 2	S	F	X	X			X	X	X	X
Blackburnia sp. 3	S	F		X			X	X	X	X
Mecyclothorax sp. 1	R	F						X	X	X

Table 5. (Continued)

ARTHROPOD FAUNA	Status and Distribution within the Hakalau Forest National Wildlife Refuge									
SCIENTIFIC NAME	**Relative bundance**	**Collection method**	**Maulua, Mesic: Koa/Ohia Pasture >5500 ft.**	**Maulua, Mesic: Koa/Ohia Pasture 5500 – 5200 ft.**	**Maulua, Mesic: Ohia/Koa <5200 ft. Closed canopy**	**Hakalau, Dry: Koa/Ohia 6500 – 6200 ft.**	**Pua Akala, Mesic: Koa/Ohia, old Pasture >5600 ft.**	**Pua Akala, Mesic: Koa/Ohia 5600 – 5300 ft. Closed canopy**	**Pua Akala, Wet, Ohia/Koa <5300 ft. Closed canopy**	**Pua Akala: Awehi Stream Wet: Ohia Tree fern, + Bog, ~ 4200 ft.**
Cerambycidae										
Plagithmysus vicinus vicinus Sharp, 1896	C	G		X						
Curculionidae										
Achalles sp. 1	S	F		X	X		X	X	X	
Oodemas sp. 1		F					X			
ORDER: HYMENOPTERA FAMILY: Ichneumonidae										
Enicospilus sp. A	S	MV		X	X			X	X	X
Enicospilus sp. B	S	MV		X	X			X	X	X
Enicospilus sp. C	S	MV		X	X			X	X	X
Sphecidae										
Ectemnius sp. A	R	G	X				X	X		
ORDER: NEUROPTERA FAMILY: Chrysopidae										
Anomalochrysa sp. A	R	G								
Hemerobiidae										
Micromus spp.	S	MV								
CLASS: DIPLOPODA ORDER: Spirostrepida FAMILY: Cambalidae										
Nannolene sp. 1	S	F		X	X	X		X	X	X

Abundance: R=rare, S=scarce, C=common. Collection method: B=beating sheet, F=water based pyrethrum fog, G=general collecting, H=host search, M=Malaise trap, MV=mercury vapor bulb.

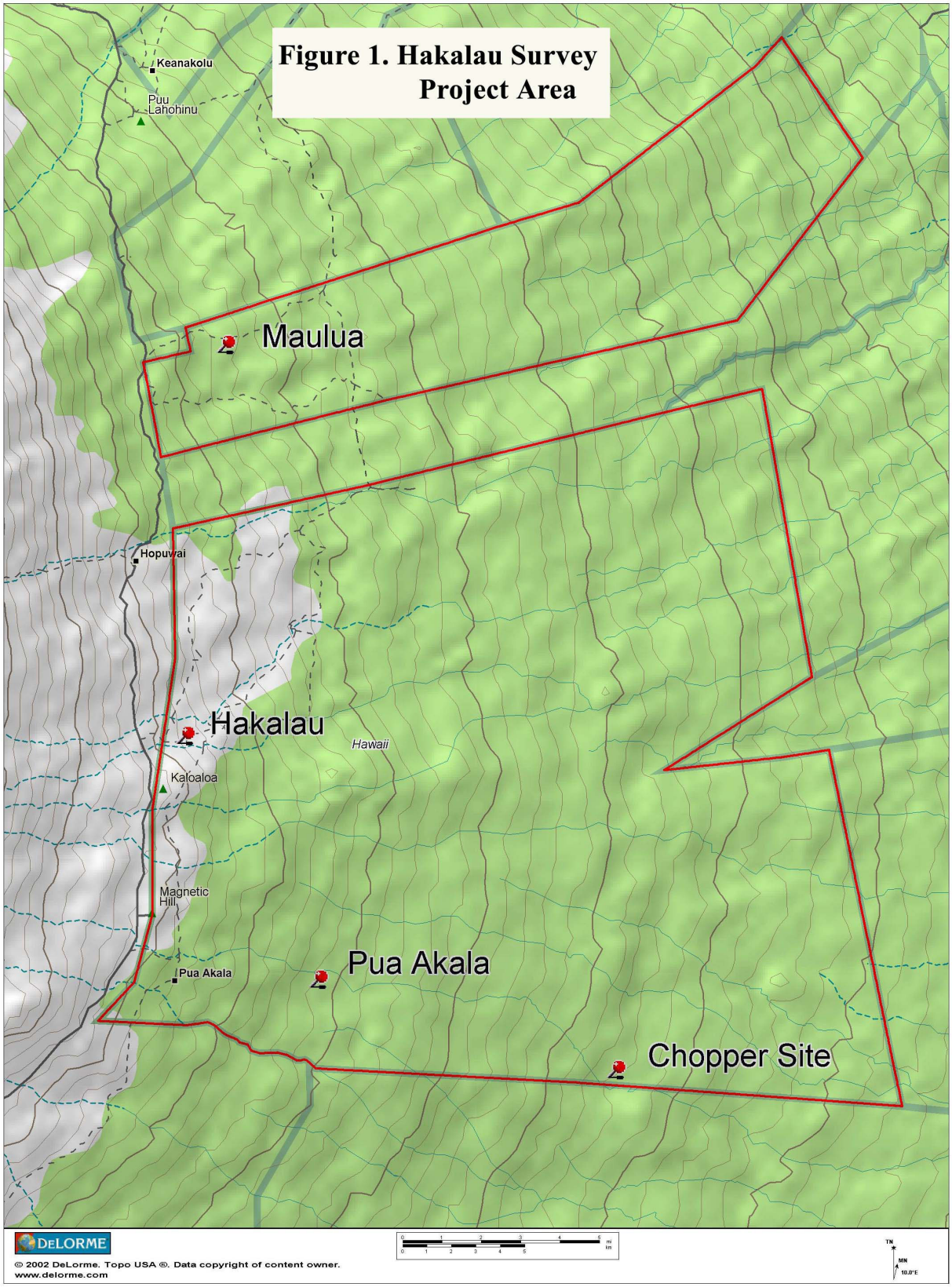
Figure 1. Hakalau Survey
Project Area
Keanakolu
Puu
Lahohinu
Maulua
Hopuwai
Hakalau
Hawaii
Kaloaloa
Magnetic
Hill
Pua Akala
Pua Akala
Chopper Site
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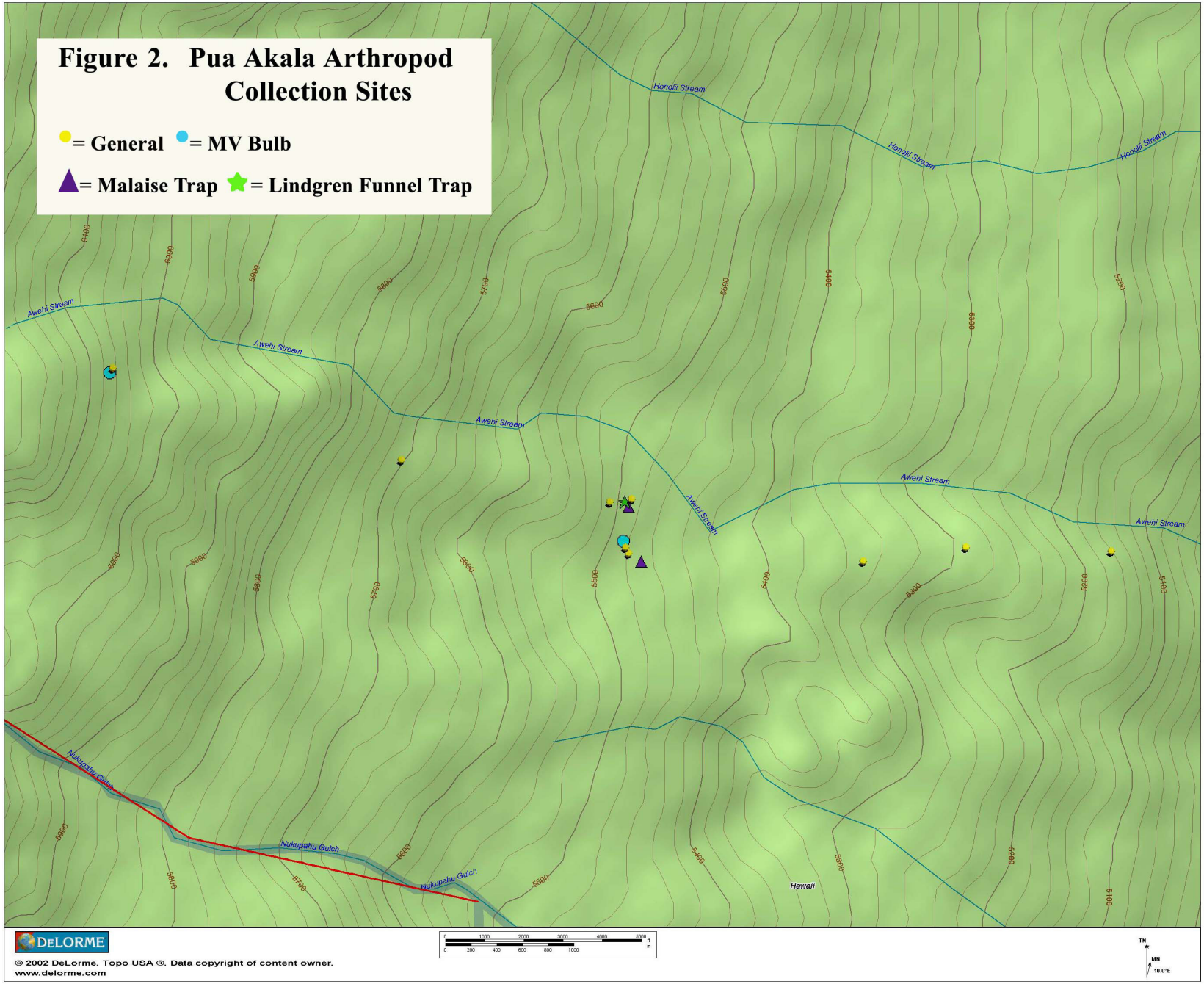
Figure 2. Pua Akala Arthropod Collection Sites
= General
= MV Bulb
= Malaise Trap
= Lindgren Funnel Trap
Honolii Stream
Awehi Stream
Nukupahu Gulch
Hawaii
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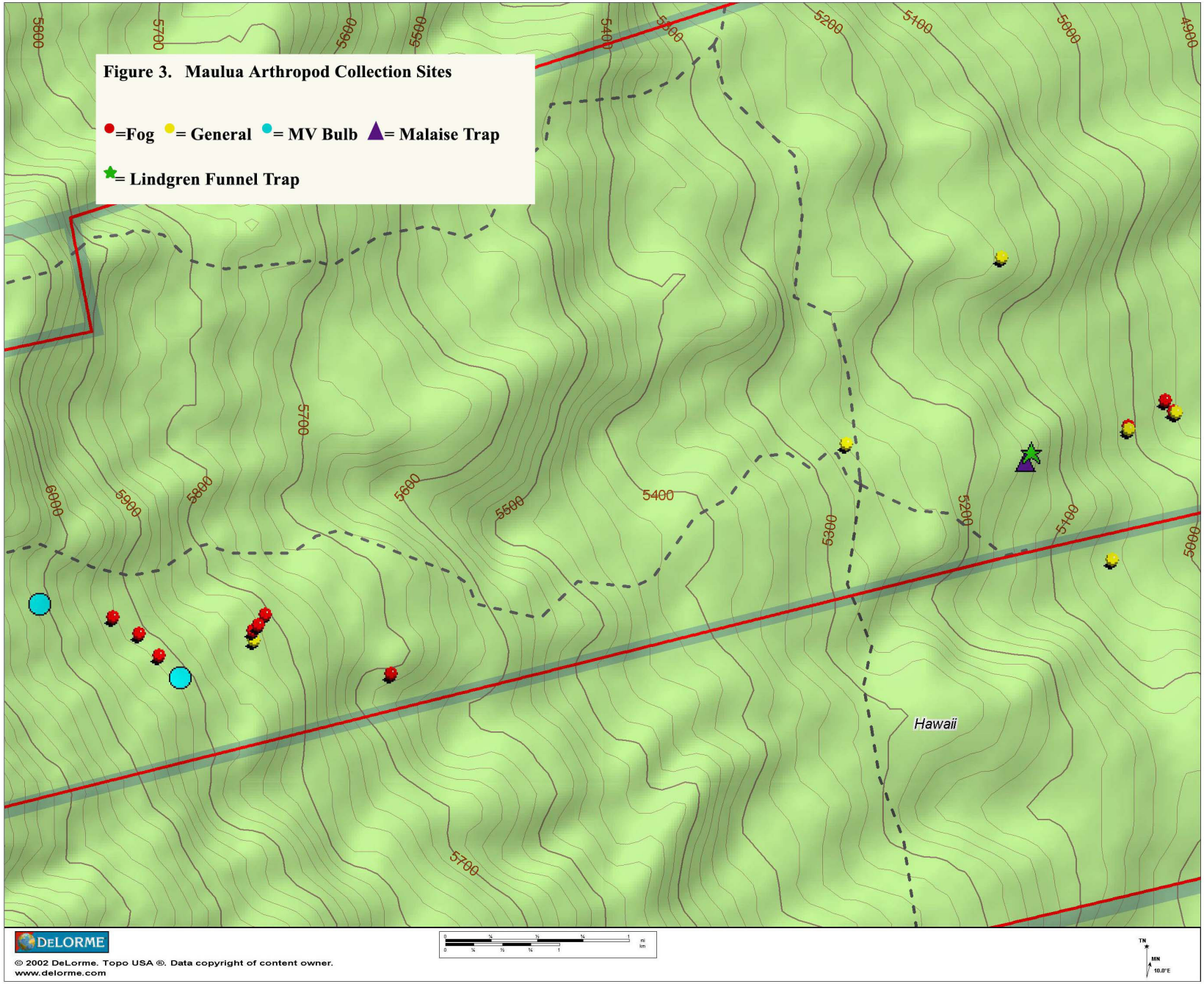
Figure 3. Maulua Arthropod Collection Sites
=Fog = General = MV Bulb = Malaise Trap
= Lindgren Funnel Trap
Hawaii
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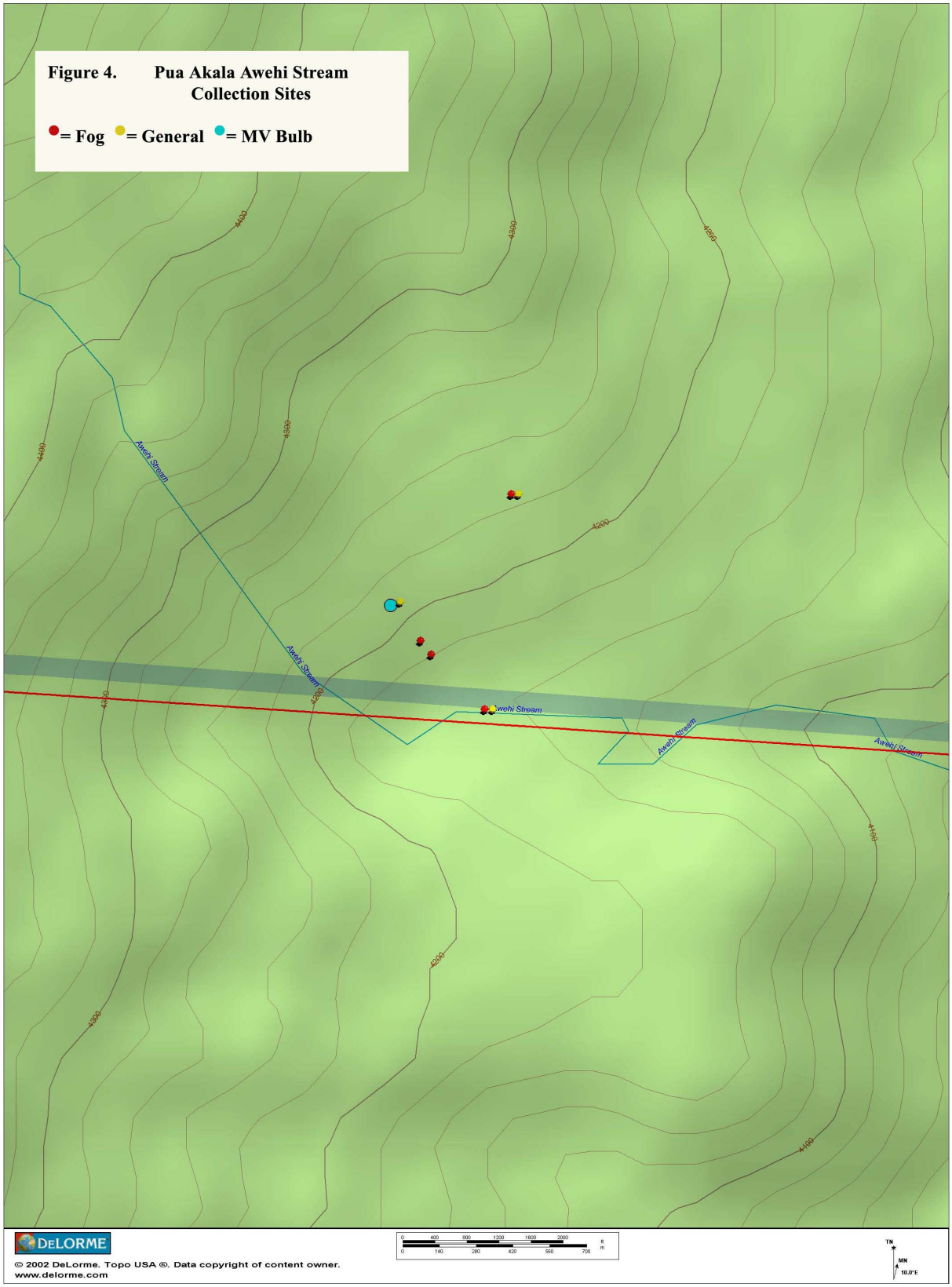
Figure 4. Pua Akala Awehi Stream Collection Sites
= Fog = General = MV Bulb
Awehi Stream
Awehi Stream
Awehi Stream
Awehi Stream
Awehi Stream
4400
4500
4600
4700
4800
4900
5000
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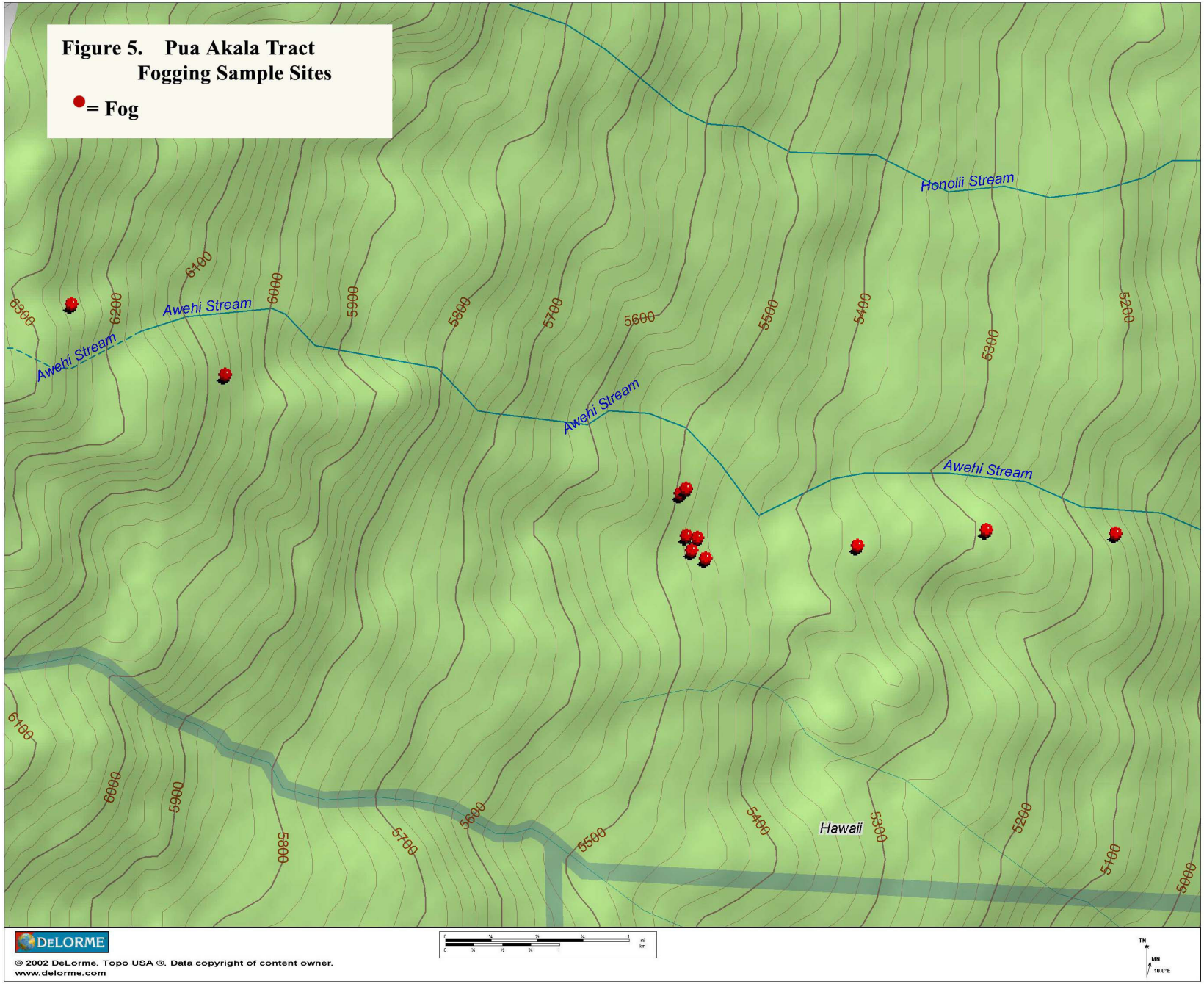
Figure 5. Pua Akala Tract
Fogging Sample Sites
= Fog
Honolii Stream
Awehi Stream
Awehi Stream
Awehi Stream
Awehi Stream
Hawaii
6300
6200
6100
6000
5900
5800
5700
5600
5500
5400
5300
5200
5100
5000
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