Native and Exotic Organism Study
Lower Wailoa River, Waipi‘o Valley
County of Hawai‘i

November 2001

Hawaii
Biological
Survey

Final Report

Native and Exotic Organism Study

Lower Wailoa River, Waipi‘o Valley, County of Hawai‘i

Prepared for:

USDA Natural Resources Conservation Service

300 Ala Moana Blvd., Room 4316

Honolulu, Hawai‘i 96813

Prepared by:

R.A. Englund, C. Imada, D.J. Preston, N.L Evenhuis,

R.H. Cowie, C. Puttock, K. Arakaki, and J. Dockall

Hawaii Biological Survey

Bishop Museum

Honolulu, Hawai‘i 96817

November 2001

Contribution No. 2001-014 to the Hawaii Biological Survey

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

The Hawaii Biological Survey of the Bishop Museum conducted assessments of the aquatic fauna found in the lower Wailoa River, Waipi‘o Valley, Hawai‘i. The results of these assessments will be used for the preparation of a Comprehensive Stream Management Plan for the Wailoa River that will be prepared by the USDA Natural Resources Conservation Service. The objectives of these assessments were to 1) describe baseline distribution and abundance of native and introduced fish, amphibians, crustaceans, mollusks, aquatic insects, and aquatic plants (including macroalgae), in the Wailoa River and associated *kalo lo‘i* and *‘auwai*, and 2) assess various stream management options that can be used to improve stream habitat and populations of native aquatic species in the lower Waipi‘o Valley stream system.

A total of 69 aquatic macrofauna species were collected in the lower Wailoa River during this study, with aquatic insects being the most species-rich group found and also the numerically most abundant group. Overall, nonindigenous aquatic animal species dominated the lowest sections of the lower Wailoa River, with higher percentages and densities of native taxa occurring as elevations increased further upstream. A total of thirty native species, most of which were aquatic insects, two species of unknown status, and thirty-six introduced species were found in the lower Wailoa River study area. For all collection stations combined, 53% of the aquatic taxa found during this study were introduced species and 44% were native (either endemic or indigenous). Fish species recorded consisted of six native and four nonindigenous species. A sizable population of both native and nonindigenous fish species was found in the lower reaches of Wailoa River (and the Hi‘ilawe Stream tributary), while both native and nonindigenous fish densities were low above the highest *kalo ‘auwai* at the 37 m elevation level. It is quite likely that predation impacts from introduced fishes in the lowest reaches of the Wailoa River are the reason for low fish densities above the *kalo ‘auwai*. Seven mollusk species (six snails, one clam) were collected, of which six (five snails, one clam) were introduced alien species and only one (*hīhīwai* - a snail) was native.

A total of 45 aquatic insect species representing 64% of the aquatic macrofauna were collected in the lower Wailoa River during the study. It was beyond the scope of this study to provide a quantitative measure of aquatic insect densities as these methodologies are still in the developmental stage for Hawaiian aquatic systems. Aquatic insects represented a major component of biodiversity of the aquatic fauna found during this study, and when all stations were combined 47% were native species, 49% were introductions, and 4% were of currently unknown status. At least one species new to Hawai‘i, and a potentially harmful species of nonindigenous aquatic insect, the caddisfly *Hydroptila icona* was collected. Of particular concern is the ability of this species to tolerate the high water velocities found in the V-shaped area at the beginning or upstream end of cascades in riffles; these areas contain the greatest water volume and the highest water velocities. Two native crustacean species, the generally low elevation *‘ōpae ‘ōeha‘a* (*Macrobrachium*

grandimanus) and the more mountain-dwelling *ʻōpae kuahiwi* (*Atyoida bisulcata*), and two widespread introduced species (*Macrobrachium lar* and *Procambarus clarkii*), were found.

Riparian plant taxa including wetland, riparian, and aquatic macrophytes such as algae were recorded during surveys of six wetland and stream sites in the lower part of Wailoa River, Waipiʻo Valley. A total of 99 vascular plants and 4 algae species were found, including one new Hawaiʻi Island introduced plant record (*Cyperus papyrus*).

No Federally Threatened, Endangered, rare, or imminently threatened species of aquatic animals, or aquatic or terrestrial plants were found in or around the areas of the lower Wailoa River assessed during the present study. Because any impacts from restoring *kalo loʻi* or *ʻauwai* would only be short-term sedimentation inputs, no greater than produced by the many large rainstorms that often occur in this wet valley, and because no endangered species would be impacted, it is recommend that current and past cultural practices such as the repair and maintenance of *ʻauwai* and the restoration of *kalo loʻi* be allowed to proceed.

D.J. Preston measuring stream flow at the Wailoa River mouth.

INTRODUCTION

The Hawaii Biological Survey of the Bishop Museum was contracted by the Natural Resources Conservation Service to conduct biological surveys as part of an overall environmental assessment of lower Waipiʻo Valley. These surveys were specifically conducted to assess native and exotic aquatic organisms, and particularly to determine if sensitive, rare, or Candidate Endangered Species were found in the lower reaches of the Wailoa River. The objectives of these assessments were to 1) describe baseline distribution and abundance of native and introduced fish species, crustaceans, mollusks, aquatic insects, and aquatic plants (including macroalgae) in the Wailoa River and associated *kalo loʻi* and *ʻauwai*, and 2) assess various stream management options that can be used to improve stream habitat and populations of native aquatic species in the lower Waipiʻo Valley stream system.

STUDY AREA

Waipiʻo Valley is on the northeastern windward tip of the island of Hawaiʻi and drains the extinct volcanic dome of the Kohala Mountains. Mean annual rainfall in upper Waipiʻo Valley exceeds 160 inches and decreases to 80 inches in the lower reaches near the ocean (USGS 1995). The lower Wailoa River has five major tributaries located in the nearly inaccessible mountainous upper reaches of Waipiʻo Valley, respectively from downstream to upstream: Waimā, Koʻiawe, Alakahi, and Kawai Nui Streams. The major tributary closest to the ocean is Hiʻilawe Stream, and this was the only tributary assessed during the present study. The highest point in the Waipiʻo watershed is a tributary to Kawai Nui Stream that originates at nearly 1,524 m (5,000 ft), just below the Kohala Mountain summit of 1,604 m (5,260 ft).

The canyons of Waipiʻo Stream and its tributaries have cut deeply into the Kohala Mountains, and are separated by a narrow divide from Waimanu Stream. Kawai Nui Stream formerly drained into Waimanu Stream, but the greater perennial flow in Waipiʻo Stream cut a canyon deeper inland with a steeper gradient (Stearns and Macdonald 1946). Consequently, Waipiʻo Stream cut into more dikes and gained more water as the stream progressed headward, eventually stealing the main tributary of Waimanu Stream (Stearns and Macdonald 1946). Most flow from the Waipiʻo Valley tributaries results from springs issuing from erosion cut dike swarms (Stearns and Macdonald 1946).

Two major irrigation systems, the Upper and Lower Hāmākua Ditches, divert stream flow from the wet, windward side of the Kohala Mountains to areas of the Hāmākua coast formerly used for sugarcane cultivation. The Upper Hāmākua Ditch begins at an elevation of 1232 m (4,042 ft), just before Kawai Nui Stream descends into the steep canyon area. Prior to the demise of sugarcane agriculture, the Upper Hāmākua Ditch diverted an average of 0.43 m^3/sec (10 million gallons/day (mgd)) for irrigation (Hawaii

Stream Assessment 1990). The Lower Hāmākua Ditch originates on Kawainui Stream at 316 m (1,037 ft) and also currently diverts flow from Kawai Nui, Alakahi, and Ko'iawe Streams. Historically, water diversions on the Lower Hāmākua Ditch averaged 1.4 m^3/sec (32 mgd) (HSA 1990).

Beginning at the ocean, lower Wailoa Stream in Waipi'o Valley was sampled from the ocean mouth to the most upstream *kalo 'auwai* or taro irrigation diversion, a distance of approximately 3.2 km (2 miles). The study area was divided into 6 sampling sites (Figure 1). A general description and GPS coordinates (using Old Hawaiian datum) for each sampling station are given below.

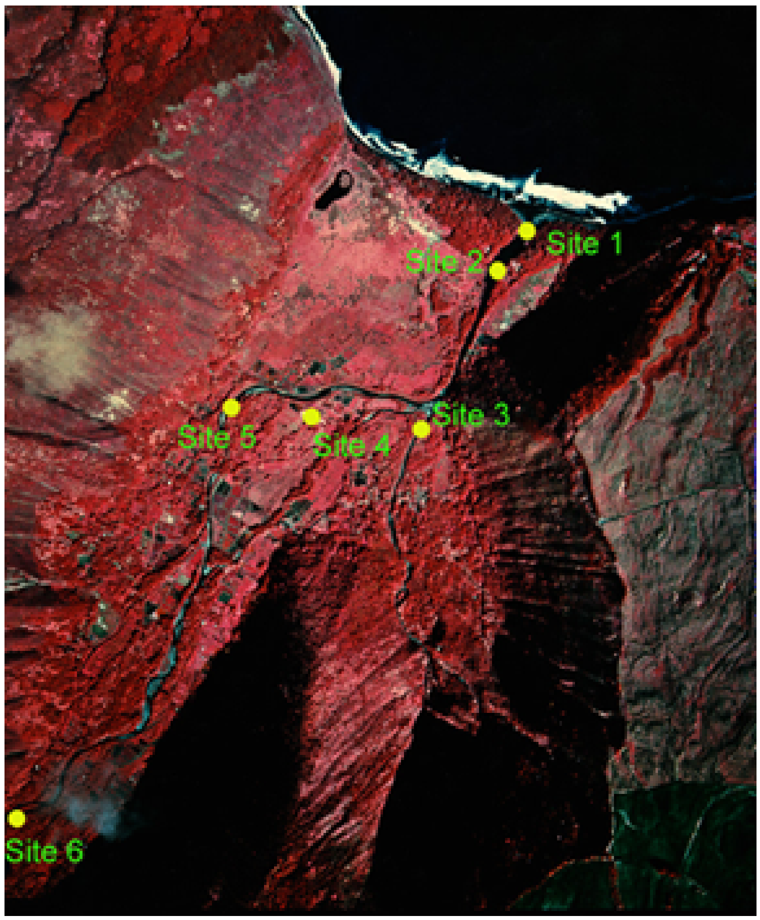


Figure 1. Study area and sampling sites in lower Wailoa Stream in Waipi'o Valley.

Station Descriptions and GPS Coordinates

Station 1: Wailoa River mouth

Station 1 began at the ocean and extended upstream through the cobble riffle formed at the mouth of Wailoa River. Both Station 1 and Station 2 are downstream of any *kalo lo'i* irrigation diversions. The river here was 29 m wide immediately upstream of the first riffle, with the stream channel meandering around the wave-formed ocean sand berm during high flows. Little riparian vegetation was found along the sandy banks lining the stream as it enters the ocean. The wide streambed here was composed of large cobbles; the banks are of sand grading into large cobbles streamward. Stream discharge measured on 12 March 2001, just above the first riffle was 2.9 m^3/sec (103.1 cfs). 20°05'32.9''N, 155°37'00.8"W.

Station 2: Large pool area above first riffle

This station began shortly upstream of the first riffle entering the ocean, and formed a large, deep pool that extends upstream almost to the confluence with Hi'ilawe Stream. Water flow was quite sluggish in this large terminal pool of the lower Wailoa River, and substrate consisted mainly of a thick layer of fine sediment overlying rocks and boulders in areas nearer the ocean. Many areas at this station contained stagnant and still water. Station 2A was approximately 300 m upstream from the main area sampled at Station 2 (above the first riffle near the stream mouth), in an area where the ocean access road is adjacent to the stream. An additional collection of mollusks was made at Station 2A, but this long, slow reach of stream has similar hydrologic and physical characteristics and is included in the overall Station 2 reach.

Station 3: Hi'ilawe Stream above confluence with lower Wailoa River

Hi'ilawe Stream flows over the most recent lava flows of Waipi'o Valley. Lava spilled into Hi'ilawe Canyon and reached the floor of Waipi'o Valley in the late Pleistocene (Stearns and Macdonald 1946). The other streams in Waipi'o Valley were unaffected by this lava flow. Hi'ilawe (Lālākea) Stream originates at approximately 853 m in the Kohala mountains, and according to USGS maps, two major diversions occur on this stream. A spring at the base of Hi'ilawe Falls provides much of the flow in Hi'ilawe Stream. During dry periods this spring contributes 0.35 m^3/sec (8 mgd) of flow into Hi'ilawe Stream and hence into lower Wailoa River (Stearns and Macdonald 1946).

The highest diversion in the Hi'ilawe watershed occurs where the Upper Hāmākua Ditch cuts across the uppermost drainage area and supplies water to the Pu'u Pūlehu (Pu'ukapu) Reservoir. Excess water in the Upper Hāmākua Ditch is also released at this location to contribute to streamflow in Hi'ilawe Stream. A second diversion located 915 m upstream of the canyon rim provides an average of 0.04 m^3/sec (1 mgd) to the Lālākea Reservoir. Although it is the same stream, the name changes from Lālākea Stream to Hi'ilawe Stream below the Waipi'o Canyon rim. The Lower Hāmākua Ditch passes just underneath Hi'ilawe Falls but does not actually divert water from the stream.

This site started immediately upstream of the concrete road crossing on the main Waipi'o Valley road that crosses Hi'ilawe Stream. There is an approximate 2 m retaining wall on the south bank of the stream at the beginning of this station, which extended several hundred meters upstream. Although no deep pools were found at this station, stream gradient was low. Habitat consisted mainly of runs and riffles. Underwater visibility was high--up to 5 m. 20°05'32.9''N, 155°37'00.8"W.

Station 4: Kawashima *kalo* (taro) farm wetlands

The Kawashima *kalo* farm is one of the larger remaining *kalo* growing areas and is located in the central lower portion of lower Waipi'o Valley, in a flat alluvial plain area. Several taro paddies were examined, ranging from flooded fields planted with *kalo* to those laying fallow and overgrown with weeds. Aquatic organisms were sampled within the *kalo* fields that were covered with 5–25 cm of water. 20°06'54.4''N, 155°36'03.4"W.

Station 5: Wailoa River adjacent to Kawashima *kalo* farm

Station 5 started at the road crossing Wailoa River near the Kawashima *kalo* farm and extended upstream in the main Wailoa River for approximately 200 m. The stream in this area picks up slightly in gradient, with a number of lower velocity riffles. Upstream of the road crossing past the Kawashima taro farm was a long, high-gradient riffle with larger cobbles extending for approximately 50 m. An evenly mixed substrate of sand, gravel, small and large cobbles, and a few small boulders were found at this site. Stream discharge taken at this station on 15 March 2001 was measured at 1.95 m^3/sec (69.0 cfs). 20°06'56.4''N, 155°36'15.0"W.

Station 6: Wailoa River above highest *kalo lo'i*

This area was the uppermost sampling point assessed during the present study, and started above the highest *kalo lo'i* (taro fields) at the beginning of the *kalo 'auwai* (taro irrigation diversion) and extended approximately 200 m upstream. The highest elevation sampled at this station was approximately 37 m (120 ft) above sea level. Several small side tributaries and spring areas were also sampled here. Stream gradient in this reach starts to substantially increase, and aquatic habitats consisted of mainly moderate-gradient riffles and runs, with some shallow pool habitats. Water clarity ranged from highly turbid after a rainstorm during the first day of sampling, to clear after several days of dry conditions. This upper reach represented the most pristine conditions found in the lower Wailoa River during this study. Stream discharge at Station 6 was measured on 15 March 2001, and was 2.7 m^3/sec (97.7 cfs). This station is above the uppermost limits of any irrigation diversions, thus flow taken at the uppermost Station 6 was substantially higher than the 1.95 m^3/sec (69.0 cfs) measured at Station 5, which lies downstream of many *kalo lo'i*. 20°05'32.9''N, 155°37'00.8"W.

METHODS

Biological assessments of lower Wailoa River in Waipi'o Valley, Hawai'i Island were conducted by staff from the Hawaii Biological Survey from 12–17 March 2001. With the exception of one day of rain on 12 March 2001, sampling took place during a period of dry and sunny weather, but just after a rainstorm had caused water levels and turbidity levels to increase. However, after several days of clear weather, stream flows returned to low, basal conditions.

Composition of the riparian vegetation, stream substrate, and habitat condition for native aquatic organisms were evaluated at each sampling station. Altitude was determined by using a combination of USGS topographic quad maps and a hand-held altimeter. Stream names were taken from USGS topographic quads.

Aquatic Insect Sampling

Aquatic insect sampling was conducted according to Englund *et al.* (2000) and Englund and Preston (1999). It was beyond the scope of this study to provide a quantitative measure of aquatic insect densities as these methodologies are still in the developmental stage for Hawaiian aquatic systems. Because most native Hawaiian aquatic insect species have been described from adults, the primary problem in establishing aquatic insect densities is larval identifications can currently only be made to the genus or family level. Collections of immature and adult specimens were conducted with MV (mercury vapor) light traps, Malaise traps, yellow pan traps, aerial nets, dip nets, and Surber (benthic) samplers. Visual observations of aquatic insects were also conducted as we traveled between sampling stations. Sampling effort was focused on habitat suitable for native insects: splash zones around riffles and cascades, wet rock faces associated with springs and seeps, waterfalls, wetland areas associated with *kalo lo‘i*, and stream substrates. All aquatic habitats were sampled, however.

General collections were conducted in prime native aquatic insect habitats, with numerous aerial net sweeps taken around riffle splash-zones, cascades, seeps, and waterfalls . Repeated benthic sampling was conducted at each sampling station by one person holding an aquatic dip net, while another person disturbed rocks upstream of the net. Benthic sampling also included collecting individual rocks and using a toothbrush to sweep off immature aquatic insects and other aquatic invertebrates from the stream rocks. Night-time surveys using light traps located on the river bank at Station 5 were employed to comprehensively sample aquatic insects that are only nocturnally active. This area was sampled using an MV (mercury vapor) light shining on a white sheet. Arthropods attracted to the light were collected for later identification. All insect specimens were stored in 75% ethanol and subsequently transported to the Bishop Museum Entomology laboratory for curation and identification. Voucher specimens are currently housed in the Bishop Museum collection.

Aquatic and Riparian Vegetation Sampling Methods

The botanical inventory was conducted by the walk-through method. At each sampling station, notes were taken on the vegetation structure—the main canopy trees (if any), mid-layer trees and shrubs, and herb and groundcover species. General habitat descriptions were based on these notes, and taxa not common enough to be mentioned in these summaries were included in a comprehensive species list. The stream bottoms and other wetland sites were observed for floating or submerged vascular plants and algae. Mosses, liverworts, lichens, and fungi were excluded from the scope of the survey.

Because this was a survey of riparian and wetland sites, an attempt was made to restrict the inventory to plant communities directly influenced by saturated soil conditions. In flooded wetland sites (e.g., Kawashima *kalo lo'i*, Lālākea Fishpond) every vascular plant and alga seen was recorded. In streamside settings, generally only the vegetation within the high-water mark was recorded, although some of the larger canopy trees noted may have been further inland. Thus, the comprehensive species list may include species that do not necessarily have an affinity to wet soils.

Specimens were generally collected only if positive identification could not be made in the field, or if the record represented a little-collected or new naturalized species for the island or the state. Collected vouchers were pressed in the field, then identified, labeled, and deposited in the Bishop Museum Botany Department herbarium (BISH). Algae specimens were collected with their rock substrates. We thank Jack Fisher, collections technician at BISH, for processing and preliminary identification of the algae specimens.

Fish and Crustacean Sampling

Fish and crustacean underwater sampling conformed with Hawaii Division of Aquatic Resources (HDAR) native fish sampling guidelines (Baker and Foster 1992). Densities of *'o'opu (*native gobiids), crustaceans, and *hīhīwai* (native neritid snails) were assessed by snorkeling and using the HDAR standard quadrat point-count method (Baker and Foster 1992). This method consists of randomly selecting quadrats along the stream channel and performing total counts of aquatic macrofauna within these quadrats. Sampling points were selected by using a random number table, with the sampling beginning at the downstream end of each sampling station. A snorkeler used a combination of two random numbers to determine a longitudinal (distance upstream) and transverse (distance from the left bank) position in the stream. For example, if the random numbers were 12 and 6, the snorkeler would walk 12 paces upstream and conduct the count at 0.6 the distance from the left stream bank. The second snorkeler would determine the position of his point-count by beginning the pacing at the location of the previous snorkeler's point count. This method would be continued by 'leap-frogging' upstream until all counts were completed for a given station. This method reduces bias in selecting sampling locations, and with a sufficient number of counts, habitats are sampled in proportion to their abundance.

Depending upon habitat and substrate characteristics, the sampling quadrats ranged in size from about 0.2 to 0.8 m^2. Data collected at each sample point included the name of the snorkeler, substrate composition, habitat type, quadrat size, water column depth, date, and observation time; underwater point count data sheets were based on HDAR data sheets. Point counts were conducted at Stations 3, 5, and 6, the only stations with suitable conditions for this type of sampling, but not in the lower reaches of Wailoa River due to poor underwater visibility and deep water. Because this survey was only a one time ‘snapshot’ survey, the usefulness of these point counts is low; point counts are mainly useful for longer-term monitoring of fish populations (Baker and Foster 1992).

Because of poor visibility, transect snorkeling was used to assess fish species composition in the lowest reaches (Stations 1 and 2) of Wailoa River. This involved snorkeling through an entire habitat or large section of stream and visually assessing fish species composition. Seine netting and dip netting were also used to collect fish in areas unsuitable for snorkeling, such as in the Kawashima *kalo lo‘i*.

Mollusk Survey Methods

The survey took place 13–14 March 2001. At each of the seven survey sites searches were made in the water by visual inspection from the bank, by wading, and by snorkeling. Searches were not quantified but generally took 0.5–1 hr. In most cases, all specimens seen were collected. However, where a species was especially abundant, representative specimens only were collected. All collected specimens were returned to the Bishop Museum for sorting and identification by reference to the extensive Hawaiian and Pacific collections already held at the Museum and by reference to pertinent literature also available at the Museum. Live specimens were preserved in 75% ethanol (ethyl alcohol). All the collected mollusks have been deposited in the Bishop Museum collections (accession number 2001.073; Mollusk Collection catalog numbers BPBM 262071–262087).

Also, see Fish and Crustacean Sampling Methods (above) for a description of quantitative efforts to count *hīhīwai* (*Neritina granosa*) during fish point-count sampling. Because of the very localized distribution of *hīhīwai*, none were observed during point-count sampling.

RESULTS AND DISCUSSION

Overall, nonindigenous aquatic animal species dominated the lowest sections of the lower Wailoa River, with higher percentages and densities of native taxa occurring as elevations increased further upstream. For this report we have separated the aquatic animal totals from the aquatic and riparian plant species totals, and the following results section discusses aquatic animals. A total of 30 native species, most of which were aquatic insects, two unknown, and 37 introduced aquatic species were found in the lower Wailoa River study area (Table 1). For all stations combined, 54% of the aquatic taxa found during this study were introduced species and 44% were native (either endemic or indigenous) (Table 1).

For all aquatic animal species combined, the percentage of native species found just above the ocean (Station 1) was 30%, and increased to 53% at Station 6, which was approximately 37 m above sea level and 3.2 km inland (Figure 2). Areas of still water, such as the extensive *kalo lo'i* wetlands found in

Table 1. Summary of the native or nonindigenous status and total number (percent) of aquatic species found in all reaches combined in lower Wailoa Stream, Waipi'o Valley, Hawai'i Island.

Geographic Status	All Aquatic Species	Amphibians	Fishes	Mollusks	Leeches	Aquatic Insects	Crustaceans
Introduced	37 (54%)	2 (100%)	4 (40%)	6 (86%)	1 (100%)	22 (47%)	2 (50%)
Native	30 (43%)	-	6 (60%)	1 (14%)	-	21 (49%)	2 (50%)
Unknown	2 (3%)	-	-	-	-	2 (4%)	-
Total	69	2	10	7	1	45	4

Waipi'o Valley were heavily impacted by alien aquatic species, with a very low 9% native aquatic species at the Kawashima *kalo lo'i*. With the exception of a probable hybridized *Koloa* duck (*Anas wyvilliana*), no Federally Threatened or Endangered aquatic species, or candidate species for listing, were observed in the lower Wailoa River area. Instead, the aquatic species composition in this area reflected a mix of a wide range of introduced aquatic animals and plants, but also contained a substantial native fish population. Distributions, numbers of species, and abundances of endangered Hawaiian waterbirds in the lower Wailoa River were not examined during this study, and are not included in the following graphs and tables.

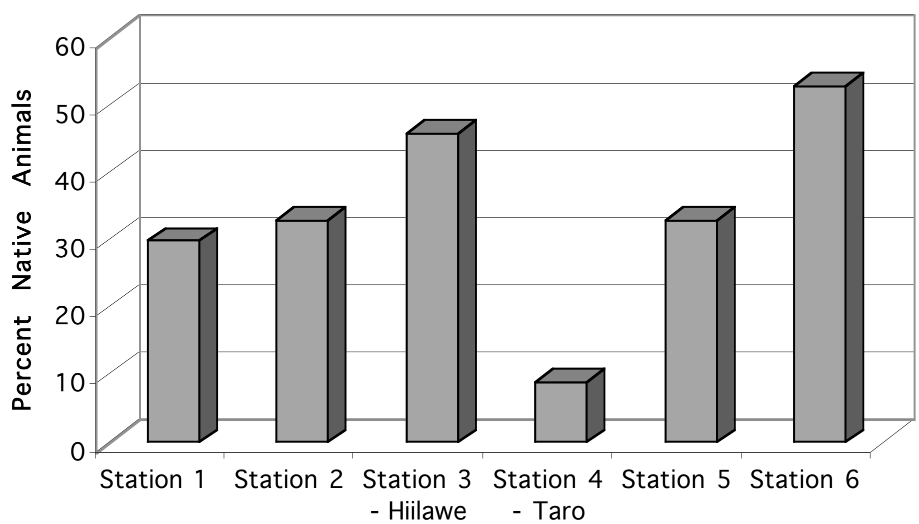


Figure 2. Overall percent of native aquatic species (excluding aquatic plants) found in sampling stations during this study in the lower Wailoa River, Waipi'o Valley, Hawai'i Island.

A total of 69 aquatic macrofauna species were collected in the lower Wailoa River during this study, and a complete list of species including their geographic origin can be found in Table 2. Aquatic insects were by far the most species-rich group found (Figure 3) and were also numerically the most abundant group. Nonindigenous aquatic species have been brought into Hawaiʻi both accidentally and intentionally. The native or nonindigenous status of arthropods was ascertained from Nishida (1997). Species of undetermined geographic origin are termed cryptogenic (Carlton 1996); however, no cryptogenic

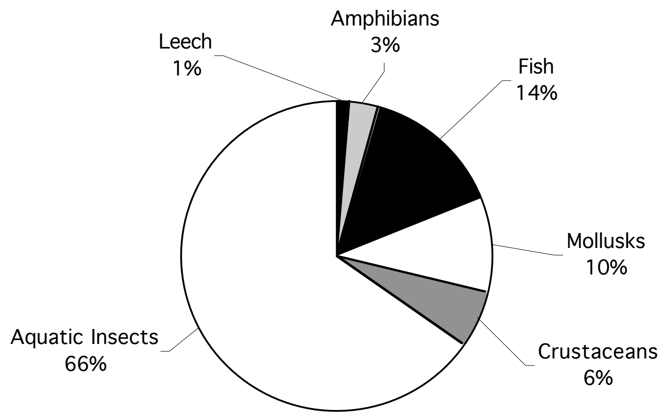


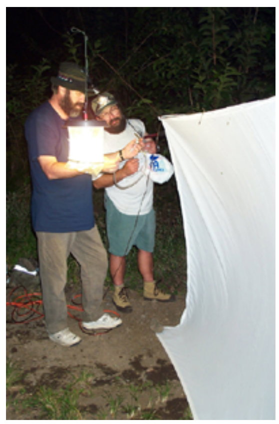
Figure 3. Percent composition of introduced and native aquatic macrofauna taxa found in the lower Wailoa River, Waipiʻo Valley, Hawaiʻi Island, in March 2001.

animal species were found during this study. It is uncertain whether the two species of aquatic flies could not be identified to the species level these species are cryptogenic until specific determinations can be made, and these, and their geographic and cryptogenic origin will remain unknown until further species determinations can be made.

Fish

Six native and four nonindigenous species of fish were found during the survey (Table 1). Sizable populations of both native and nonindigenous fish species were found in the lower reaches of Wailoa River (and the Hiʻilawe Stream tributary), while both native and nonindigenous fish densities were low above the highest *kalo ʻauwai* at Station 6. It is quite likely that impacts from introduced fishes (e.g., predation on post-larvae as they attempt to ascend the river) in the lower reaches of the Wailoa River are the primary reason for low fish densities above the *kalo ʻauwai* (also, see Conclusions section). Measurements of fish densities could not be taken in the lowest reaches (Stations 1 and 2) because poor water visibility and excessive water depths created unsuitable quantitative snorkeling conditions in these areas. Full-blown fishery population estimates were beyond the scope of this study as they are time intensive and costly, and provide little information if only conducted at one point in time. However, general observations were made on the relative densities of the introduced and native fish fauna that may be of some interest. Although not a new observation, leeches, presumably *Myzobdella lugubris*, were observed on both native and introduced fishes throughout the study area, and even up to the uppermost Station 6 on *Awaous guamensis*. Introduced fish were relatively uncommon at this upper station, except in backwater areas.

Chironomus hawaiiensis, from Waipi'o Valley



N.L. Evenhuis and D.J. Preston night trapping for aquatic insects

Oreochromis mossambicus (Tilapia) from Waipi'o Valley

Table 2. Results of Hawaii Biological Survey, Bishop Museum surveys conducted in March 2001 of aquatic species in lower Wailoa Stream, Waipi‘o Valley, Hawai‘i Island.

Taxon	Station 1	Station 2	Station 3- Hi‘ilawe	Station 4 - Taro	Station 5	Station 6	Geographic Status
Amphibians							
Bufo marinus	X	X	X	X	X	X	Introduced
Rana catesbeiana		X	X	X	X	X	Introduced
Fish							
Awaous guamensis	X	X	X		X	X	Indigenous
Eleotris sandwicensis	X	X	X		X	X	Endemic
Stenogobius hawaiiensis	X	X	X		X		Endemic
Sicyopterus stimpsoni		X	X		X	X	Endemic
Kuhlia xenura	X	X	X		X		Endemic
Mugil cephalus	X	X					Indigenous
Gambusia affinis	X	X	X	X	X		Introduced
Poecilia mexicana (complex)	X	X	X	X	X		Introduced
Xiphophorus helleri	X	X	X		X	X	Introduced
Oreochromis mossambicus	X	X	X	X	X		Introduced
Mollusks							
Neritina granosa					X		Endemic
Corbicula fluminea	X	X		X	X		Introduced
Pseudosuccinea columella			X			X	**New Island Introduction**
Planorbella duryi				X			Introduced
Pomacea canaliculata	X	X		X	X		Introduced
Tarebia granifera				X	X	X	Introduced
Physidae sp.				X			Introduced
Crustaceans							
Atyoida bisulcata			X				Endemic
Macrobrachium grandimanus	X	X	X				Endemic
Macrobrachium lar	X	X	X		X	X	Introduced
Procambarus clarkii				X			Introduced
Hirudinea (leeches)							
Myzobdella lugubris		X	X		X	X	Introduced
Aquatic Insects							
Anisoptera (Dragonflies)							
Aeschnidae							
Anax junius	X	X		X	X		Indigenous
Anax strenuus						X	Endemic
Libellulidae							
Orthemis ferruginea	X	X		X			Introduced
Pantala flavescens	X	X		X	X	X	Indigenous

Table 1 (cont.). Results of Hawaii Biological Survey, Bishop Museum surveys conducted in March 2001 of aquatic species in lower Wailoa Stream, Waipiʻo Valley, Hawaiʻi Island.

Taxon	Station 1	Station 2	Station 3- Hiilawe	Station 4- Taro	Station 5	Station 6	Geographic Status
Zygoptera (Damselflies)							
Coenagrionidae							
Enallagma civile		X					Introduced
Ischnura ramburii	X	X	X	X	X	X	Introduced
Ischnura posita	X	X	X	X	X	X	Introduced
Megalagrion blackburni						X	Endemic
Megalagrion hawaiiense						X	Endemic
Heteroptera (True Bugs)							
Mesoveliidae							
Mesovelia amoena				X			Introduced
Saldidae							
Saldula exulans			X			X	Endemic
Diptera (Flies, gnats)							
Canacidae							
Procanace acuminata						X	Endemic
Ceratopogonidae							
Dasyhelea hawaiiensis						X	Endemic
Forcipomyia sp.						X	Endemic
Chironomidae							
Chironomus hawaiiensis					X	X	Endemic
Cricotopus bicinctus	X	X	X	X	X	X	Introduced
Orthocladius new sp.		X				X	Endemic
Micropsectra sp.						X	Endemic
Telmatogeton torrenticola			X				Endemic
Chloropidae							
Cadrema pallida	X	X					Introduced
Monochaetoscinella anonyma				X			Introduced
Dolichopodidae							
Chrysosoma globiferum					X		Introduced
Chrysotus longipalpus						X	Introduced
Chrysotus sp. 1	X	X					Introduced
Syntormon flexible	X	X					Introduced
Tachytrechus angustipennis	X	X			X	X	Introduced
Ephydridae							
Hecamede granifera	X						Introduced
Hydrellia williamsi	X						Introduced
Octhera circularis						X	Introduced
Scatella clavipes			X			X	Endemic
Scatella mauiensis			X				Endemic
Scatella oahuense			X				Endemic

Table 1 (cont.). Results of Hawaii Biological Survey, Bishop Museum surveys conducted in March 2001 of aquatic species in lower Wailoa Stream, Waipi'o Valley, Hawai'i Island.

Taxon	Station 1	Station 2	Station 3- Hiilawe	Station 4- Taro	Station 5	Station 6	Geographic Status
Scatella warreni						X	Endemic
Muscidae							
Lispe assimilis					X		**New State Introduction**
Psychodidae							
Psychoda sp.						X	Unknown
Trichomyia sp.						X	Endemic
Sciaridae							
Genus sp. 1		X					Unknown
Sciomyzidae							
Sepedon aenescens					X		Purposeful Intro.
Tethinidae							
Dasyrhicnoessa vockerothi	X						Indigenous
Tethina variseta	X						Introduced
Tipulidae							
Limonia advena			X			X	Introduced
Limonia jacoba			X		X		Endemic
Trichoptera (Caddisflies)							
Hydropsychidae							
Cheumatopsyche pettiti	X	X	X	X	X	X	Introduction
Hydroptilidae							
Hydroptila icona	X		X	X	X	X	Introduction
Lepidoptera (Aquatic Moths)							
Hyposmocoma sp. 1						X	Endemic
Total: Intro. + Native + Unknown Spp.	30	31	28	22	30	35	
Total Native Aquatic Species	9	10	13	2	10	18	
Percent Native Aquatic Species[1] (%)	30	33	46	9	33	53	

[1]Unknown spp. not included in % native calculations

Tilapia (*Oreochromis mossambicus* although likely hybridized), green swordtails (*Xiphophorus helleri*), western mosquitofish (*Gambusia affinis*), and Mexican mollies (*Poecilia mexicana*) were found in high densities throughout the lower reaches of the lower Wailoa River. The backwater areas of Station 2 were especially dominated by these introduced species. Additionally, these four introduced fish species were the only fish observed in any Waipi'o Valley *kalo lo'i*, although it is possible that long-term monitoring might find low densities of some adult native *'o'opu* in these areas. It is likely that native *'o'opu* were not observed in *kalo lo'i* areas because of the short duration of the present study. Recruitment peaks of post-larval *'o'opu* (*hinana*) are seasonal in nature, with peaks observed in March and October (Nishimoto and Kuamo'o 1997). Recruiting post-larvae *hinana* have been observed by the thousands in Waipi'o Valley *kalo* *lo'i* (Dr. R. Nishimoto, HDAR, pers. comm.), however, none was observed during the present study perhaps because of yearly variation in recruitment peaks and the limited sampling time available. For whatever the reason, no *hinana* were observed in the *kalo lo'i* during the present study. It is clear that from both the present study and previous studies conducted since 1997 (Englund and Filbert 1997, Englund and Preston 1999) that very few *'o'opu* are able to colonize Wailoa Stream above the *kalo lo'i* area. Green swordtails were the only introduced fish species found at Station 6, the uppermost site sampled, and these fish penetrate high gradient areas of the mainstem Wailoa River to at least 77 m in elevation (Englund and Filbert 1997).

Random Point Counts – Fish

Random point counts were not conducted at Stations 1 and 2 because reduced visibility would have made them ineffective. Additionally, because of very shallow water the random point counts could not be made in *kalo lo'i* wetlands around the Kawashima farm at Station 4. Because this was a biodiversity survey rather than an exhaustive fish population study, a relatively small number (10 per station) of random point counts were conducted at each sampling station with adequate water depth and visibility. Random point counts were taken just at one point in time and are only one snapshot in time of native fish densities; long-term monitoring would be required to gain a better understanding of fish populations. Sample effort reflected the predominant aquatic habitats found within each station where random point counts were conducted (Table 3). A relatively even mix of run, riffle, and pool habitats was found at Station 3 (Hi'ilawe Stream), while slightly higher gradient runs dominated at Station 5, and riffles dominated at the most upstream Station 6 (Table 3). The lower Wailoa River changes character at Station 6, where stream gradient rapidly increases and the only introduced fish able to inhabit this higher gradient area are green swordtails.

In stations (3, 5, 6) where visibilities allowed point counts to be conducted, densities of native species were relatively low for *'o'opu akupa* (*Eleotris sandwicensis*), *'o'opu nākea* (*Awaous guamensis*), *'o'opu nōpili* (*Sicyopterus stimpsoni*), and *āholehole* (*Kuhlia xenura*) (Table 4). Higher densities of native fish at Stations 1 and 2 were recorded during qualitative observations made while snorkeling, and *'o'opu naniha* (*Stenogobius hawaiiensis*) was especially common just above the first riffle at Station 2. Relatively low native fish densities should be interpreted with caution, however, as this is only one factor when considering the importance and health of an aquatic ecosystem. Several species of fish were not counted during the random point counts because the fish were outside of the predetermined point-count area. However, fish species outside the count area were noted, and all fish species observed at a particular station but not necessarily during random point counts are shown in Table 1.

Although densities for native *'o'opu* were not measured at Stations 1 and 2 near the ocean, relatively large numbers of three *'o'opu* species (*A. guamensis*, *E. sandwicensis*, and *S. hawaiiensis*) were observed during snorkeling at these stations. Additionally, large numbers of *Mugil cephalus* and *Kuhlia xenura* were also observed at Stations 1 and 2, with *K. xenura* observed or collected as high as Station 5 during this study. This contrasts with far fewer numbers of *A. guamensis* and *E. sandwicensis* being observed upstream of Station 6 at the beginning of the *kalo ʻauwai*. There appears to be very little recruitment of native *ʻoʻopu* upstream of the highest *kalo ʻauwai*, although water clarity and aquatic habitats are excellent from Station 6 and continuing upstream.

Table 3. Snorkeling effort in Waipiʻo Stream (main channel), Hawaiʻi, during March 2001.

			Random Points	
Station	**Elevation (m)**	**Habitat**	**No.**	**Area (m²)**
3 (Hiʻilawe)	12	Run	4	1.09
		Riffle	4	0.85
		Pool	2	0.56
		Total	10	2.5
5	18	Run	8	3.1
		Pool	1	0.7
		Side Pool	1	0.59
		Total	10	4.3
6	37	Run	3	1.5
		Riffle	6	3.2
		Plunge Pool	1	0.9
		Total	10	5.5

Table 4. Mean density of fish (per/m^2) in lower Wailoa River (main channel), Hawaiʻi, found during random point counts conducted in March 2001.

Station	Elevation (ft)	*ʻoʻopu akupa*	*ʻoʻopu nākea*	*ʻoʻopu nōpili*	*āholehole*	green swordtail
3	12 (Hiʻilawe)	0	0	0.04	0.007	0.004
5	18	0.003	0	0.005	0.015	0.016
6	37	0	0.002	0	0	0

Aquatic Insects

A total of 45 aquatic insect species representing 64% of the aquatic species were collected in the lower Wailoa River during the present study. Aquatic insects represented a major component of the biodiversity found during this study, and when data from all stations were combined 47% were native species, 49% were introductions, and 4% were of currently unknown status (Table 5). No federally listed Candidate aquatic insects or other rare species were observed in the area of lower Wailoa River sampled during this study. However, three endemic aquatic insect species considered sensitive to environmental disturbance were found: two species of damselfly (*Megalagrion blackburni* and *Megalagrion hawaiiense*) and the giant Hawaiian chironomid (*Telmatogeton torrenticola*). Adults of two native damselfly species were collected in a small spring area lacking introduced fish, found upstream of the first *kalo 'auwai* at Station 6 (elevation 37 m). Several adult *M. blackburni* were also observed landing on stream boulders and patrolling the main channel of Wailoa River immediately upstream of the *kalo 'auwai*. Immature damselflies were not collected during numerous benthic samples taken in this area, indicating that these adults may possibly have flown down from higher elevation areas. Adult *Megalagrion* damselflies are frequently found considerable distances away from habitats where the immatures aquatic stages are found. *Telmatogeton torrenticola*, the other species considered sensitive to disturbance, was found in low numbers at Station 3 in Hi'ilawe Stream above the road crossing, although this species becomes much more common in high gradient riffle areas more upstream and closer to Hi'ilawe Falls.

Introduced aquatic insects dominated the aquatic insect fauna in Wailoa River at stations nearest the ocean, and percentages of native species increased as elevations increased (Table 5). The *kalo lo'i* wetlands and lower reaches of Wailoa River were dominated by introduced aquatic insects. Only four native aquatic insect species were found in the lowest reaches, and included the highly mobile native *pinao* (dragonflies) *Anax junius* and *Pantala flavescens*, and two aquatic flies *Orthocladius* new sp. and *Dasyrhicnoessa vockerothi*. As elevations increased the numbers and percentages of native aquatic insect species increased, with only 19% native species at Station 1 near the ocean to a high of 58% native species found at Station 6 (37 m elevation).

A new, undescribed species of aquatic chironomid fly in the endemic genus *Orthocladius* is of interest and was found both in the lowest reaches of Wailoa River and in the uppermost Station 6 habitats, indicating that it has the unusual ability to tolerate somewhat disturbed and excellent aquatic habitats. The new *Orthocladius* sp. is known only from the lower elevations of the lower Wailoa River, as it was not found in the upper elevation areas during the previous two Waipi'o surveys. *Lispe assimilis*, a large introduced aquatic muscid, was collected on the mudflats of Station 5 and is a new state record. This species appears to be a relatively recent introduction and was not collected during previous Waipi'o Valley surveys.

At least one new and potentially harmful species of nonindigenous aquatic insect, the caddisfly *Hydroptila icona* was collected during the March 2001 surveys. This caddisfly was absent during the recent previous surveys conducted in Waipi'o Valley (Englund and Filbert 1997, Englund and Preston 1999) and is presumed to have been introduced subsequent to those studies. This small case-building caddisfly was collected in stream habitats just above the ocean to Station 6 at the 37 m elevation level. The center area of the main channel was the primary habitat preferred by this species, in areas on top of rocks in heavily flowing water. Of particular concern is the ability of *H. icona* to tolerate the high water velocities found in the V-shaped area at the beginning or upstream end of cascades in riffles; these areas that contain the greatest water volume and the highest water velocities, and are preferentially used by native aquatic insect species. Thus, this new caddisfly species has a potential to harm sensitive and rare native aquatic insect taxa, especially if it is able to colonize upper elevation and higher gradient sections of the Waipi‘o watershed. Unfortunately, there is nothing that can be done to stop the spread of these highly dispersible and adaptable species of insect.

Table 5. Numbers of native and introduced aquatic insect species found during surveys conducted in March 2001 of aquatic species in lower Wailoa Stream, Waipi‘o Valley, Hawai‘i Island.

Station	Number (%) Native spp.	Number (%) Introduced spp.	Unknown (%) geographic origin spp.
1	3 (19%)	13 (81%)	-
2	3 (22%)	10 (72%)	1 (6%)
3	5 (45%)	6 (55%)	-
4	2 (20%)	8 (80%)	-
5	3 (25%)	9 (75%)	-
6	15 (58%)	10 (38%)	1 (4%)
All Stations Combined:	21 (47%)	22 (49%)	2 (4%)

To determine if the trend of increasing native aquatic insect diversity at higher elevations held on a larger scale in Waipi‘o Valley, it is of interest to present data from studies conducted recently (1997–1999) (Englund and Filbert 1997; Englund and Preston 1999) at higher elevations (Figure 4). Because Kawai Nui Stream is the largest of the five major tributaries in Waipi‘o Valley, it was used in the elevational comparisons with the lower Wailoa River assessed in this study. The trend was quite visible and dramatic, with higher percentages of native aquatic insect species found as elevations increased, with a maximum of 86% native aquatic insect species found in the highest reaches of Kawai Nui Stream.

Blackburn’s Hawaiian Damselfly (*Megalagrion blackburni*) from Waipi‘o Valley.

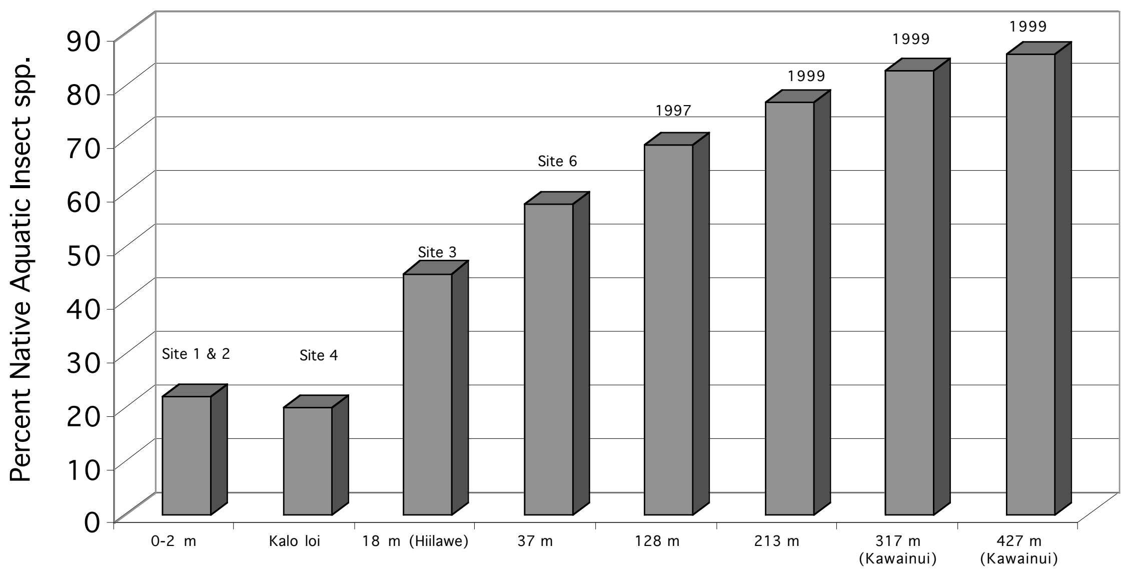


Figure 4. Native aquatic insect diversity in Waipi'o Valley habitats from sea level to 1400 ft. Data from the present study: 0–1.5 m = Stations 1 and 2 combined, *kalo lo'i* = Station 4, 18 m elevation = Station 3, 37 m = Station 6; 128-426 m elevation data from Englund and Filbert (1997) and Englund and Preston (1999).

In over ten plus years of studying Hawaiian streams, staff from the Hawaii Biological Survey of the Bishop Museum have found aquatic insect species assemblages in nearly pristine streams to be quite stable. For example, the aquatic insect fauna of Pelekunu Stream, Moloka'i, has been monitored between 1991 to 2001. Englund (2001) found that percentages of native aquatic insect species ranged from 79 to 83% between 1991 and 2001, and the numbers of native species found at Pelekunu Stream ranged from 15 to 17. This indicates that native species diversity not only provides a good indication of the overall aquatic ecosystem health, but that when done by using similar methods, these surveys are comparable over relatively long time periods.

Crustaceans

Two native species, the generally low elevation inhabiting *'ōpae 'ōeha'a* (*Macrobrachium grandimanus*) and the more mountain-dwelling *'ōpae kuahiwi* (*Atyoida bisulcata*), and two widespread introduced species (*Macrobrachium lar* and *Procambarus clarkii*) were found within the study area. While exceptionally high densities of *'ōpae 'ōeha'a* have been found in the upper tributaries of Waipi'o Valley (Englund and Filbert 1997; Englund and Preston 1999), Station 3 at Hi'ilawe Stream was the only station where this species was collected. Because of their amphidromous nature, the mountainous *'ōpae kuahiwi* must pass through the lower reaches of Wailoa River in great numbers to remain so abundant in the upper Waipi'o Valley tributaries. Unlike native *‘o‘opu*, the lower reaches of Wailoa River apparently pose little or no obstacle for *‘ōpae kuahiwi* during their upstream migration from the ocean. The highly aggressive grass shrimp (*Neocaridina denticulata sinensis*) has not yet been introduced into the Waipi‘o Valley watersheds; this introduced species would undoubtedly have highly negative impacts and displace the native *‘ōpae kuahiwi* as has occurred on O‘ahu (Englund and Cai 1999).

The introduced crayfish *P. clarkii* was abundant in the warm, still waters of the *kalo lo‘i*, but was less common in the main flowing sections of lower Wailoa River, and this species was not observed upstream of *kalo lo‘i*, or at Station 6. The introduced Tahitian prawn (*M. lar*) was common throughout the study area, as was the native shrimp *‘ōpae ‘ōeha‘a* in the lower stations. *‘Ōpae ‘ōeha‘a* was relatively common except in the uppermost Station 6, and also was absent from the *kalo lo‘i.*

Mollusks

The native freshwater mollusk fauna of the Hawaiian Islands includes very few species, most in the families Lymnaeidae and Neritidae (Cowie *et al.* 1995). However, a greater number of alien species has been introduced to the Islands (Cowie 1997, 1998) and these species now dominate the mollusk fauna of most freshwater ecosystems, especially those that have been modified for human use.

The purpose of the mollusk survey of Waipi‘o Valley was to develop an inventory of aquatic mollusk species present in the Valley and to assess the status of the fauna from conservation and agricultural perspectives.

Mollusks recorded

A total of 127 specimens belonging to seven species (six snails, one clam) was collected during the survey. Of these species, six (five snails, one clam) are introduced alien species and only one (a snail) is native. The species recorded during the survey are listed in Table 6, with the numbers of each species collected at each Station and their status as alien or native.

R.H. Cowie collecting snails at Station 6, Wailoa River

Table 6**.** Mollusk species collected in lower Wailoa River, Waipi‘o Valley, March 2001.

		Number of specimens collected		Geographic
Station	Species	Live animals	Dead shells	Status
1	*Pomacea canaliculata*	1	-	Introduced
	Corbicula fluminea	-	2	Introduced
2	*Pomacea canaliculata*	6	1	Introduced
	Corbicula fluminea	1	7	Introduced
2A[1]	*Pomacea canaliculata*	14	-	Introduced
3	*Pseudosuccinea columella*	24	3	Introduced
4	*Pomacea canaliculata*	5	-	Introduced
	Tarebia granifera	19	-	Introduced
	Unidentified Physidae	1	-	Introduced
	Planorbella duryi	5	-	Introduced
	Corbicula fluminea	2	6	Introduced
5	*Neritina granosa*	11	-	Native
	Pomacea canaliculata	2	-	Introduced
	Tarebia granifera	3	-	Introduced
	Corbicula fluminea	-	7	Introduced
6	*Tarebia granifera*	-	1	Introduced
	Pseudosuccinea columella	6	-	Introduced

[1]This site is a part of Station 2, but was located upstream 300 m from the main sampling area

Brief details of each of the mollusk species collected during the survey are now given below:

FAMILY AMPULLARIIDAE

Pomacea canaliculata (Lamarck, 1822)—golden apple snail, channeled apple snail, Alien

Four species of apple snails have been reported in the Hawaiian Islands. All are alien, late twentieth century introductions. Two of them, *Pomacea canaliculata* and *Pomacea bridgesii*, have been recorded on the Island of Hawai‘i, both from Waipi‘o Valley. *Pomacea canaliculata* was first reported from Waipi‘o Valley in 1992, but *P. bridgesii* has been recorded from the Valley since 1965 (Cowie 1995, 1997). During the survey, however, only *Pomacea canaliculata* was found, at Stations 1, 2, 2A, 4, and 5.

Apple snails are large snails with big, round shells that are usually dark brown but may also be golden or yellowish, sometimes with darker-colored bands running spirally around the shell. Distinguishing the various species is difficult but the two species known from Waipio can be told apart with practice: the shell of *Pomacea canaliculata* has very rounded whorls with deeply channeled sutures (the junction between successive whorls); *Pomacea bridgesii* has a shell with a more “stepped” appearance and sutures that are not so deeply channeled (Glover and Campbell 1994, Yamamoto and Tagawa 2000). Both species lay conspicuous egg masses (usually about 200 eggs per egg mass) on emergent vegetation, rocks, or other hard surfaces above the water surface. Those of *Pomacea canaliculata* are very bright, rosy pink; those of *P. bridgesii* are also pink but not usually so bright. These highly visible egg masses may be the first sign that apple snails are present.

Apple snails, especially *Pomacea canaliculata*, have become major pests of *kalo* in the Hawaiian Islands (Cowie 1997, in press, Lach *et al.* 2001), as well as major rice pests throughout much of south east Asia (Naylor 1996, Vitousek *et al.* 1996, Cowie in press). As well as eating the crops, dead shells can cut the feet of farmers (Yamamoto and Tagawa 2000). Efforts to control them include application of chemical pesticides, hand-picking, and biological control using ducks to eat the snails, but control has been generally not very successful and eradication appears not to be possible (Cowie in press). Hand-picking, though tedious and labor-intensive, has proven most successful in the Hawaiian Islands, but clean maintenance of *lo'i* and other practices may also help in keeping snail numbers down (Kobayashi *et al.* 1993, Glover and Campbell 1994).

Apple snails were introduced to the Hawaiian Islands as domestic aquarium snails and as a potential human food resource (Cowie 1995). However, the damage they cause to *kalo*, as well as their potential impacts on natural ecosystems and their ability to spread extremely rapidly (Lach and Cowie 1999, Lach *et al.* 2001) mean that every effort should be made to prevent their introduction to localities as yet free of them.

FAMILY CORBICULIDAE

Corbicula fluminea (Müller, 1774)—Asiatic freshwater clam, Alien

Clams are bivalve mollusks, meaning they have two shells. A small number of freshwater bivalves have been introduced to the Hawaiian Islands and most are inconspicuous. However, *Corbicula fluminea*, first reported in the Islands in 1977 and well established by the late 1980s and early 1990s (Eldredge 1994, Burch 1995, Cowie 2000, Yamamoto and Tagawa 2000), is extremely invasive and has rapidly become widespread (Yamamoto and Tagawa 2000, Cowie 2000, 2001). During the survey it was found at Stations 1, 2, 4, and 5.

This clam is the only freshwater bivalve known from Waipi'o Valley. It can reach 6 cm in size but is usually much smaller, often only reaching 1-2 cm. It ranges in color from dark blackish-brown to pale yellowish-brown, although the inside of the shells are white or pale grayish, and dead shells often become white with age and exposure (Yamamoto and Tagawa 2000 , Cowie 2001).

Corbicula fluminea is now widespread in *kalo*-growing areas and in streams, irrigation ditches and most other bodies of fresh water throughout the Hawaiian Islands. Large numbers of empty, white shells may be the first sign of its presence (Yamamoto and Tagawa 2000, Cowie 2001).

This species causes serious problems. Because it can achieve huge numbers, it can cause clogging of irrigation lines and pipes; and broken shells in *kalo lo'i* can cut the feet of farmers (Yamamoto and Tagawa 2000, Cowie 2000, 2001).

FAMILY LYMNAEIDAE

Pseudosuccinea columella (Say, 1817), Alien

The family Lymnaeidae, along with the Neritidae (see above), contains the only native Hawaiian freshwater snails. There are four native species of Lymnaeidae (Cowie *et al.* 1995). However, their identification is difficult and in the past they have probably been confused with the small number of alien lymnaeids that have been introduced to the Islands (Cowie 1997). The collected material all belongs to a single species that is tentatively identified as the alien North American species *Pseudosuccinea columella*. It was found at two sites (Stations 3 and 6), and at least at Station 3 it was common. This is the first record of *Pseudosuccinea columella* from the Island of Hawai'i.

Lymnaeid shells are dextral (coil to the right), with the single exception of the native Hawaiian species *Lymnaea reticulata*, which coils to the left (sinistral). In contrast, physids (see below) are sinistral (for explanation of these terms see Yamamoto and Tagawa 2000). Most lymnaeids have thin yellowish-brown shells that are generally taller than they are broad and with a relatively sharply-pointed apex, as do most physids. Under a microscope, shells of *Pseudosuccinea columella* exhibit fine spiral sculpturing that distinguishes the species from other lymnaeids in the Hawaiian Islands. Most specimens collected were small, less than 0.5 cm, but a few were up to about 1 cm tall.

Pseudosuccinea columella is a vector of the cattle liver fluke and has in the past been targeted for biological control because of this (Alicata 1969). This species has been in the Hawaiian Islands since about 1950 (Cowie 1997). It was probably introduced accidentally with domestic aquarium plants.

FAMILY NERITIDAE

Neritina granosa Sowerby, 1825—hīhīwai, Endemic

There are three native Hawaiian stream snails in the family Neritidae but only *Neritina granosa* is an entirely freshwater species, the others (*Neritina vespertina*, *Theodoxus cariosus*) inhabiting brackish waters near stream mouths (Cowie *et al.* 1995, Yamamoto and Tagawa 2000). These snails lay their eggs in the streams but the larvae are washed out into the ocean, where they spend up to a year before returning to the streams to mature and reproduce. During the survey *Neritina granosa* was found at one site (Station 5). Hīhīwai were not common enough to be detected during the underwater snorkel point counts conducted at Station 5, but were observed during the snorkel longitudinal transects determining overall aquatic macrofauna species composition at this Station 5. The population found at Station 5 did not appear to have frequent or recent recruitment as all individuals observed or collected at Station 5 were larger individuals (50 mm or more in length). Additionally, this population was restricted to one relatively small riffle area approximately 50 m long.

Neritina granosa may reach sizes of over 55 mm. The upper, exposed surface of the shell is black, while the underside (visible if the snail is removed from the substrate) is white and orange (Yamamoto and Tagawa 2000). The shell of *Neritina granosa* is thick and strong. These snails are valued by people as natural delicacies, but they are now much more rare than they once were and generally only found in the upper reaches of more remote streams. *Neritina granosa* is endemic to the Hawaiian Islands, that is, it does not occur anywhere else (Kay 1979).

FAMILY PHYSIDAE

Unidentified physid—pouch snails, Alien

Physidae occur in most parts of the world but those in the Hawaiian Islands are very poorly documented and their identifications are uncertain. At least three species have been reported, all alien: *Physa compacta*, *Physa elliptica*, *Physa virgata*. However, the identity of the single snail collected during the survey (at Station 4) is not known, although it may belong to one of these species. To determine its correct identity would require research beyond the scope of this report.

Physids are characterized by having sinistral shells (shells that coil to the left); most other snails, including lymnaeids (see above) have dextral shells (shells that coil to the right). Physid shells are generally taller than they are broad and have a relatively sharply-pointed apex; they are similar to lymnaeids in this feature. The single specimen collected was small, less than 1 cm tall.

There are no native Hawaiian Physidae. Physids were almost certainly introduced to the Islands via the domestic aquarium trade, either deliberately as aquarium snails or inadvertently in association with aquarium plants (Yamamoto and Tagawa 2000). One or more species of Physidae may have been in the Islands since the nineteenth century (Cowie 1997).

FAMILY PLANORBIDAE

Planorbella duryi (Wetherby, 1879)—ramshorn snail, Alien

Planorbid snails, commonly known as ramshorn snails, are popular in domestic aquariums and were probably introduced to the Hawaiian Islands by the aquarium trade from North America. Planorbids occur throughout most parts of the world. Identification of planorbids is difficult and the identification of the survey specimens as *Planorbella duryi* is somewhat tentative. *Planorbella duryi* was found at only one Station (Station 4), but this is the first documented record of a planorbid from the Island of Hawai'i.

Shells of planorbids are typically flattened spirals, which gives them their common name (ramshorn snails). Those of *Planorbella duryi* generally reach about 2 cm in maximum diameter. These snails feed on a range of plant and animal resources. They can also act as vectors of the parasites causing human schistosomiasis, although these parasites are not present in the Islands (Yamamoto and Tagawa, 2000). *Planorbella duryi* was first formally recorded from the Hawaiian Islands in the literature in 1969 (see Cowie 1997, 1998) but may well have been present in the Islands long before this.

FAMILY THIARIDAE

Tarebia granifera (Lamarck, 1816)—quilted melania, Alien

Two species of Thiaridae are common in the Hawaiian Islands, *Tarebia granifera* and *Melanoides tuberculata*. Both have probably been in the Islands for a long time (Cowie 1997, Yamamoto and Tagawa 2000). Only *Tarebia granifera* was found during the survey, at three sites (Stations 4, 5, and 6).

Thiarid snails, including *Tarebia granifera*, bear tall, pointed shells. Large individuals of *T. granifera* may reach 2–3 cm in height, but many are smaller. The shells have a strongly granulated appearance, whereas those of *Melanoides tuberculata* tend to be more finely sculptured. These snails often occur in large numbers locally. They feed on algae and detritus, and themselves are fed upon by fish (Yamamoto and Tagawa 2000). *Tarebia granifera* has been in the Islands since at least 1856 (Cowie 1997, 1998). Because it is now so widely distributed around the world it is not possible to know where it originated. It is possible that it was introduced to the Islands by early Polynesian colonizers, prior to western discovery of the Islands (Cowie 1998). The Thiaridae appear to have been present in the Hawaiian Islands for many years, and *T. granifera* was recently found in archaeological sites in Kauai wetlands, but only in post-contact (after 1778) deposits (D. Burney, Fordham University, pers. comm).

Discussion-Mollusks

Almost all the freshwater mollusks recorded during the survey in the streams, *kalo lo‘i*, and other habitats in Waipi‘o Valley are alien. Only *Neritina granosa* (*hīhīwai*) is a native Hawaiian species. It was only found at a single site (Station 5) and has probably declined in abundance compared to its natural state because of the major modifications of aquatic systems within Waipi‘o Valley. It is possible that it, and perhaps other native freshwater snail species, still occur in good numbers at locations farther upstream towards the head of the valley. These areas were not within the scope of the survey, but have been thoroughly surveyed for hīhīwai during previous surveys (Englund and Filbert 1997, Englund and Preston 1999) up to an elevation of over 427 m (1400 ft). Aquatic habitat in upper stream sections of the Wailoa tributaries is highly suitable for *hīhīwai*, with clear, cool and well-oxygenated waters being found in these high quality tributaries (Yamamoto and Tagawa 2000).

The other species recorded during the survey are all common alien species in the Hawaiian Islands. Some have been in the Islands since the nineteenth century; others are more recent introductions. Two species

(*Planorbella duryi*, *Pseudosuccinea columella*) are recorded for the first time from the Island of Hawai‘i, although both may have been present long before this. The aquatic molluscan fauna of Waipi‘o Valley, with the exception of *Neritina granosa*, is thus dominated by alien species and is of no great concern from a conservation perspective. The presence of apple snails (notably *Pomacea canaliculata*) and Asian freshwater clams (*Corbicula fluminea*) poses significant agricultural problems.

Aquatic Vegetation

Introduction

A vegetation survey of selected riparian and wetland sites in Waipi‘o Valley was conducted on 13–14 March 2001. The goals of the survey were to inventory and briefly characterize the vegetation at six Stations (stream, freshwater wetland, cultivated wetland) selected for a biological assessment of aquatic habitats in the lower part of the valley. A walk-through method was used in conducting the survey. Vascular plants were surveyed by C. Imada, while the algae were handled by C. Puttock. Survey sites with obligate wetland vegetation (e.g., *kalo lo‘i,* sites that are flooded for at least part of the year) were thoroughly inventoried; streamside vegetation was generally inventoried only a few feet landward, dependent on bank slope and the influence of soil saturation on vegetation composition.

Vegetation History

Waipi‘o Valley has had a long and venerable history of habitation by man. In prehistoric times, the wide, flat, gently sloping valley floor and abundant fresh running water made it a superb site for the development of a thriving *kalo*-farming community that supported a sizable population, estimated at 2,600 at the end of prehistory (Cordy 1994). The valley was also the political and religious center of Hawai‘i Island. The Pili line of chiefs ruled on Hawai‘i out of Waipi‘o Valley, at least from the fifteenth century to the beginning of the seventeenth century. Among these chiefs, the most renowned were Līloa and his son ‘Umi. Paka‘alana Heiau, located just behind the coastal sand dunes (now occupied by a tall common ironwood grove) was regarded as one of the most sacred *heiau* on the Big Island and within its grounds was Hale o Līloa, a sacred royal mausoleum (Cordy 1994).

Because Waipi‘o Valley had such a prominent role in Hawaiian prehistory, a lengthy oral tradition was associated with it. Chants and mythology serve as the earliest form of documentation for the vegetation of the valley. Fornander (1916) tells of a great drought during which “great famine was experienced over all the lands from Hawai‘i to Kauai, all the wet lands were parched and the crops were dried up on account of the drought, so that nothing even remained in the mountains. Waipio was the only land where the water had not dried up, and it was the only land where food was in abundance; and the people from all parts of Hawai‘i and as far as Maui came to this place for food." Fornander also recounts that the great high chief 'Umi "built large taro patches in Waipio, and he tilled the soil in all places where he resided."

Visitors to the valley in the 1800s, such as William Ellis and Isabella Bird, provide tantalizing glimpses of the vegetation of Waipi'o at the time, primarily confirming that the valley floor was already largely cultivated. William Ellis (1827) in 1823 described the valley floor as "one continued garden, cultivated with taro, bananas, sugar-cane, and other productions of the islands, all growing luxuriantly." Isabella Bird (1964), viewing the valley from the *pali* above in 1873, described "a fertile region perfectly level…watered by a winding stream, and bright with fishponds, meadow lands, *kalo* patches, orange and coffee groves, figs, breadfruit, and palms." On a hike to a waterfall, her group pushed "with eyes shut through wet jungles of Indian shot *[Canna indica, ali'ipoe]*, guava, and a thorny vine." She describes seeing "some very fine fig trees and thickets of the castor-oil plant" and she "rode among most extensive *kalo* plantations, and large artificial fish-ponds…". From around 1880 to the 1920s, rice was intensively cultivated in the valley (Lennox 1954).

Colin Lennox, in a 1954 report classifying the vegetation of the valley floor, noted the "nearly complete removal of native vegetation from all areas suitable for cultivation or limited land use" (Lennox 1954). He defined four vegetation classes based on the dominant overstory tree: common guava *(Psidium guajava)*, *kukui (Aleurites moluccana)*, monkeypod *(Samanea saman)*, and *hala (Pandanus tectorius);* and three other classes with no dominating overstory, one for dune habitats, one for fallow fields, and another for wetland habitats. In the capsule descriptions provided for each vegetation type, only two species mentioned are native: the indigenous *hala* and beach morning-glory *(Ipomoea pes-caprae* ssp. *brasiliensis)*, making it readily apparent that the vegetation had already been profoundly altered. Lennox noted at the time that about 300 acres were in *kalo* cultivation, with ready archaeological evidence that at least 800 acres of the valley floor and walls up to 25 percent slope had been intensively worked in ancient times, at least up to the junction of Waimā and Waipi'o Streams. This is well upstream of the highest reach sampled during the current survey. The cultivated fishponds were "unproductive" and "filled with swamp vegetation or water hyacinth" (Lennox 1954). Lennox placed the population in 1954 at between 30 and 40 farmers. The current population is estimated at no more than 50–75 residents (J. Dockall, Bishop Museum, unpub. data).

It is difficult to imagine what the vegetation in Waipi'o Valley might have looked like in prehistoric times. Comparing the site to present-day vegetation communities can have some predictive value. One such vegetation classification system, published in the *Manual of the Flowering Plants of Hawai'i* (Wagner *et al.* 1999) describes 106 native and weedy Hawaiian communities based on a combination of elevation (coastal, lowland, upland, etc.), rainfall (dry, semi-wet, wet), and plant form (herbland, grassland, shrubland, forest), complete with a list of native and alien species typical of that vegetation type. Existing vegetation communities in Waipiʻo can be placed in various of these categories [e.g., Common Ironwood Coastal Forest (p. 64), *Kukui* Forest (p. 83)]. Likewise, remnant native plant species can sometimes be used as cues ("indicator species") to predict which of the native vegetation communities might once have inhabited the area. An *ʻUki* Sedgeland (p. 86) featuring *ʻuki (Cladium jamaicense),* a large indigenous sedge, occupies a portion of the floor of the adjoining Waimanu Valley, and may have been more common in Waipiʻo as well. Based on the environmental settings, other native communities that may have existed there in the past include the coastal *ʻAkaʻakai/Kaluha/Makaloa (Schoenoplectus/Bolboschoenus/Cyperus)* Sedgeland (p. 65), semi-wet and wet forests dominated by *ʻōhiʻa (Metrosideros polymorpha)* and *koa (Acacia koa), Pāpala kēpau/Pāpala (Pisonia/Charpentiera)* Riparian Forest (p. 83), and *Māmaki (Pipturus)* Riparian Shrubland (p. 89).

Palaeobotanical studies are one means of reconstructing the vegetation history of an area, both spatially and through time. Such work involves the identification of seeds, plant fragments, and wood from habitation sites, which can reveal economic plants used by the inhabitants; and identification of pollen in sediment cores, which can help reveal ancient vegetation patterns. Studies such as these conducted in other sites have often provided unexpected glimpses into an area's past (for example, see Athens and Ward (1993) for their results in Kawainui Marsh, Oʻahu). Because the best pollen sampling locations are in permanently waterlogged sites, where the lack of oxygen slows decomposition of pollen grains, the valley floor of Waipiʻo provides an ideal study site.

Vegetation Results

A total of 99 vascular plant taxa and four species of macroalgae were noted during the survey. Of these, 85 were introductions, 7 Polynesian-introduced, 7 indigenous (no endemics), and the four species of algae were cryptogenic (Carlton 1996) or species of currently unknown geographic origin (Table 7). Thus, only 7% (7 of 99) of the vascular plant taxa were native, and all sampling stations had very high percentages of introduced riparian and aquatic plant species when separated into the different sampling stations (Figure 5). Also, three green algae and a single species of blue-green alga were identified, however, the native or introduced status of freshwater algae found in the Hawaiian Islands is currently unknown Dr. Alison Sherwood (Department of Botany, University of Hawaiʻi, pers. comm.). Endemic plants are defined here as those that arrived long ago and—cut off from their mother populations—have since evolved to become uniquely Hawaiian; indigenous plants also arrived here by natural means long ago, but are usually readily dispersible by ocean or seabirds (the case with many coastal plants) and are also naturally occurring in other parts of the world; nonindigenous or introduced plants have been introduced in historic times, either intentionally or accidentally, and are now reproducing on their own in the wild; Polynesian introductions include plants believed to have been brought by the original settlers and are now naturalized.

Table 7. Numbers of native, introduced, and cryptogenic riparian plant species found during surveys conducted in March 2001 of lower Wailoa Stream areas, Waipi‘o Valley, Hawai‘i Island.

Station	Number (%) Native spp.	Number (%) Introduced spp.	Number (%) Cryptogenic spp.
1	0 (0%)	1 (100%)	0 (0%)
2	2 (6%)	31 (91%)	1 (3%)
3	2 (5%)	35 (92%)	1 (3%)
4	3 (8%)	32 (87%)	2 (5%)
5	0 (0%)	26 (96%)	1 (4%)
6	0 (0%)	36 (95%)	2 (5%)
All Stations Combined:	7 (7%)	92 (89%)	4 (4%)

No federally listed endangered or threatened species were encountered during this survey. Of note were four new naturalized vascular plant weed records for the island of Hawai‘i—*Alocasia cucullata* (Chinese taro), *Cyperus papyrus* (papyrus), *Solanum seaforthianum,* and *Typha latifolia* (common cattail). The Chinese taro collection is also the first record of its naturalization (collected in Waipi‘o Valley, but outside of the study sites) in the state. Also recorded for the first time in the state was a blue-green alga, *Rhabdoderma gorskii.*

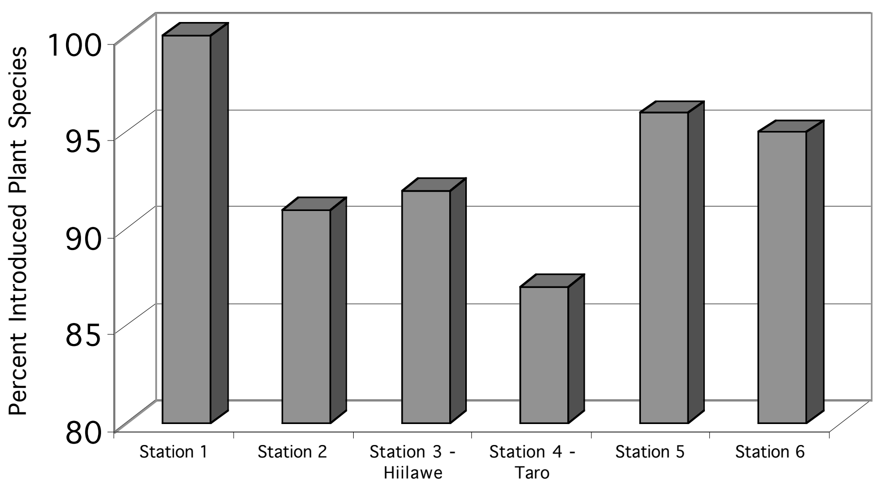


Figure 5. Overall percent riparian and aquatic plants found during this study in the lower Wailoa River, Waipi‘o Valley, Hawai‘i Island study areas.

Vegetation at survey sites

Six different stream or wetland sites in the valley were surveyed for associated flora. The vegetation at each site is briefly characterized below.

Station 1

This site is at the mouth of Wailoa River approaching its entrance into the ocean. The bed is composed of large cobbles; the banks are of sand grading into large cobbles streamward. It was devoid of vascular plants in the river bottom or the immediate riverbank, save for fragments of *Egeria densa* transported from upstream, nor were any algae noted, however, unidentified species of mosses were observed covering the rocks at this station.

Station 2

The waters upstream of the mouth are deep and wide, approximately 28-30 m across about 100 m upstream of the mouth. Only the east streambank was surveyed. Among the floating aquatics along the streambanks, water hyacinth *(Eichhornia crassipes)* and lesser duckweed *(Lemna aequinoctialis)* were common, and water feather *(Myriophyllum aquaticum)* and mosquito fern *(Azolla filiculoides)* only sparingly noted. The long strands of the rooted, submerged aquatic *Egeria densa* were quite common. Another submerged aquatic in the area was marsh purslane *(Ludwigia palustris).* Other common species at water’s edge included umbrella sedge *(Cyperus involucratus)*, a grass (possibly seashore paspalum, *Paspalum vaginatum*), and wedelia *(Sphagneticola trilobata)* groundcover. Scattered trees of false *kamani (Terminalia catappa)* stood back of the streambank. A green alga, *Cloniophora spicata*, formed green felty masses on submerged rocks in the stream.

A portion of the adjoining Lālākea Fishpond to the east was also visited. One section adjacent to the stream had monodominant stands of 3 m tall papyrus *(Cyperus papyrus)*, accompanied by water hyacinth, *honohono (Commelina diffusa)*, and California grass *(Brachiaria mutica).* The water level here was 0.75–1 m high, the substrate a thick muck. There were also extensive stands of the tall, reedlike *kaluhā* or bulrush *(Schoenoplectus californicus)* and smaller stands of umbrella sedge. California grass was a common rank grass on water-saturated soils on the pond banks.

Station 3

The stream here is shallow and about 6 m wide, with a cobbly bed. It lies upstream from a cemented section of the streambed that allows for vehicle crossing. The vegetation was composed of a mixed alien forest with a tall overstory that includes the 18–21 m tall, feathery-foliaged *Albizia chinensis* (white trunk, limp reddish young foliage), jhalna *(Terminalia myriocarpa)*, Australian red-cedar *(Toona ciliata* var. *australis)*, *kukui (Aleurites moluccana)*, and Java plum *(Syzygium cumini).* Common guava *(Psidium guajava)* was a prominent mid-layer species. On the damp banks were a variety of herbs, grasses, and ferns, including palmgrass *(Setaria palmifolia)*, hammock fern *(Blechnum occidentale)*, edible fern *(Diplazium esculentum)*, and *pīkake hohono (Clerodendrum chinense).* The indigenous morning glory *koali ‘awa (Ipomoea indica)* was the only native species noted. A green alga, *Cladophora fracta,* formed loosely floating masses in the stream.

Station 4

Several *kalo* paddies were examined, ranging from flooded fields planted with *kalo* to those laying fallow and overgrown with weeds. The areas of open water in the paddy planted with *kalo* hosted a mixture of parrot's-feather *(Myriophyllum aquaticum),* torpedo grass *(Panicum repens), honohono (Commelina diffusa),* and water hyacinth *(Eichhornia crassipes).* The muddy banks were dominated by torpedo grass, the sedge *kili'o'opu (Kyllinga brevifolia),* and primrose willow *(Ludwigia octovalvis).* Another flooded paddy was solidly covered with a reddish-colored layer of the floating mosquito fern *(Azolla filiculoides).* All of the above species are alien.

Fallow *kalo* paddies with marshy substrates were overgrown with a variety of herbs, sedges, and grasses, and a few scattered woody species. Common cattail *(Typha latifolia)* was a prominent component in one paddy. Other common species included *honohono,* parrot's-feather, and primrose willow; the sedges *Cyperus haspan, kili'o'opu, Schoenoplectus juncoides,* and *S. mucronatus;* and the ferns *neke (Cyclosorus interruptus)* and edible fern *(Diplazium esculentum).* Native elements here were *Cyclosorus, Schoenoplectus juncoides,* and the possibly indigenous ricegrass *(Paspalum scrobiculatum),* seen growing on the paddy banks.

The flooded *lo'i* yielded both a green and blue-green alga. The green was common, forming thin mats or strands, but was identifiable only to possible genus *(Rhizoclonium* or *Mougeotia);* the blue-green formed gelatinous floating masses and turned out to be a new species for the state *(Rhabdoderma gorskii).*

Station 5

The stream here is approximately 10-12 m wide, up to 1 m deep, with a cobble and mud bottom. The vegetation is an alien mix. The overstory layer was primarily Java plum *(Syzygium cumini)* and *kukui (Aleurites moluccana)*; the understory was a mix that included edible fern *(Diplazium esculentum),* sourbush *(Pluchea carolinensis),* wedelia *(Sphagneticola trilobata),* Job's tears *(Coix lachryma-jobi),* umbrella sedge *(Cyperus involucratus),* and *maile pilau (Paederia foetida). Egeria densa* was a common submerged aquatic. The green alga *Cladophora fracta* was common at this site.

Station 6

The river here is a rushing torrent about 17 m wide, 1m deep, with a boulder and large cobble bed. The overstory on the heavily vegetated banks was dominated by 3–8 m tall common guava *(Psidium guajava),* along with *kukui* and Java plum. Sourbush *(Pluchea carolinensis)* was a common shrub. The edible fern

(Diplazium esculentum) lined the streambank. This introduced fern has appropriated the Hawaiian common name *hō'i'o* used for the endemic *Diplazium sandwichianum,* whose tender unfurling frond tips are eaten raw and used in salads, just as those of the edible fern are today. Other common elements along the bank were palmgrass *(Setaria palmifolia),* Asian swordfern *(Nephrolepis multiflora),* and Job's tears *(Coix lachryma-jobi).* No native species were noted. Two green algae were collected in the stream at this site: *Cladophora fracta* (common) and *Cloniophora spicata.*

Also at this site on 14 March 2001, two ducks that appeared to be the native endangered *koloa (Anas wyvilliana)* were observed in the rushing stream at this site. Photos were taken and shown to waterbird experts Kim Uyehara (Ducks Unlimited) and Andy Engilis (U. California-Davis). They concluded that the pair appeared to be an adult female and a younger male koloa, although the female had some color markings that were somewhat unusual for the species (Kim Uyehara, Ducks Unlimited, pers. comm.).

Lower Waipi'o Valley Macroalgae

The lower Waipi'o drainage system is depauparate in freshwater macroalgae. Four species of algae were identified to genus and three to species. The cyanobacterium (blue-green alga) *Rhabdoderma gorskii* Woloszynska is a new record to the Hawaiian Islands. Until very recently, limited sampling has been made of Hawai'i's freshwater algae, and virtually no attempt at species identification. Because so little information is available on freshwater algae in Hawai'i, a detailed description of each species found during the current study is provided below.

Hawaiian freshwater algae are currently being researched by Dr. Alison Sherwood (Department of Botany, University of Hawai'i). Her investigations are as yet unpublished. She examined the four species collected during this study and provided the following names. The descriptions below are derived from the material collected in this study and may not represent the range of morphology known within each species.

Green Algae

Cladophora fracta (O.F.Muller ex Vahl) Kutzing

Classification: Algae, Chlorophycota, Chlorophyceae, Cladophorales, Cladophoraceae

Distribution: Worldwide.

Description: Thallus light to dark green, forming loosely floating masses; branching irregular; filaments long-straight to curved; main filaments 50–120 µm diameter with cells 60–300 µm long; branch filaments 20–40 µm diameter; cells 50–250 µm long (L/B ratio 1–6:1).

Note: This worldwide 'form'-species was common in the upper stream Stations 3, 5, and 6 (CP0004, 0006, 0008).

Rhizoclonium or *Mougeotia* sp.

Classification: Algae, Chlorophycota, Chlorophyceae, Cladophorales, Cladophoraceae

Description: Thallus green, forming thin mats or strands of very long wiry entangled filaments; filaments simple, straight, 50–100 µm diameter; cells 50–120 µm long (L/B ratio 1:1).

Note: This species was common in the *kalo lo‘i* (Station 4) (CP0002).

Cloniophora spicata (Schmidle) Islam

Classification: Algae, Chlorophycota, Chlorophyceae, Chaetophorales, Chaetophoraceae

Distribution: Worldwide.

Description: Thallus green, forming felt-like masses on submerged rocks; branching regular on main axes; filaments straight; main filaments 20–40 µm diameter with cells 40–80 µm long; ultimate branch filaments 10–15 µm diameter; cells 12–25 µm long (L/B ratio 1–2:1).

Note: This species was found in the lower and upper stream Stations 2 and 6.

Cyanobacteria (Blue-green algae)

Rhabdoderma gorskii Woloszynska

Classification: Algae, Cyanophyta, Cynaphyceae, Chroococcales, Chrococcaceae

Distribution: Worldwide.

Description: Gelatinous light brown thallus of very thin cylindrical cells within gelatinous matrix forming floating masses; filaments straight, cylindrical 3–5 µm diameter; cells 8–10 µm long.

Notes: This is the first record of this species for Hawai‘i and was found in the *kalo lo‘i* Station 4 (CP0001).

The 7 indigenous and 7 Polynesian-introduced riparian plant taxa are enumerated below, with notes.

Indigenous species

Cyclosorus interruptus, neke, lady fern family (Thelypteridaceae). This fern is widely distributed in the tropics in wet, swampy areas. It has stiff, upright fronds with pinnules margins that appear to have been cut with a pair of serrated scissors, and running rhizomes. *Neke* may be an indicator of previous wetland cultivation in overgrown sites (Stemmermann 1981). It was occasional in the fallow *kalo lo‘i* at Station 4.

Cyperus polystachyos, no common name, sedge family (Cyperaceae). This sedge grows up to 0.3 m tall and is common throughout the Islands, often in open grassy, disturbed areas from coastal sites up to the wet forest zone (Wagner *et al.* 1999). It is native to tropical and subtropical regions worldwide. It was noted on wet streambanks at the Hi‘ilawe Stream site (Station 3).

Hibiscus tiliaceus, hau, hibiscus family (Malvaceae). A sprawling tree with an impenetrable network of branches, round leaves with heart-shaped bases, and typical hibiscus flowers with 5 petals that change from yellow (often with a dark red base) to orange to red during the day. *Hau* is native to tropical and subtropical coastal regions worldwide. In Hawai‘i it frequently grows in dense thickets along coasts, stream courses, and other wet lowland habitats; in Waipi‘o it is commonly seen along watercourses and in disturbed forest, and was noted bordering Lālākea Fishpond in Station 2. It is thought by botanists that *hau* may have arrived in Hawai‘i on its own (and is thus indigenous), but the plant was so useful that the original settlers probably also brought it with them. Uses include fiber for cordage; the light wood for booms and floats of canoe outriggers, fishing net floats, and creation of fire by friction in combination with the harder *olomea (Perrottetia sandwicensis)* wood; and the flowers and bark for medicinal purposes (Wagner et al. 1999).

Ipomoea indica, koali ‘awa, morning-glory family (Convolvulaceae). A pantropical, blue- or purple-flowered morning-glory vine common in Hawai‘i in dry lowland, often disturbed sites. The roots and leaves were used medicinally to treat wounds, sores, and broken bones, and the seeds were used as a cathartic (Wagner et al. 1999). It was noted twining in vegetation along Hi‘ilawe Stream in Station 3.

Ipomoea pes-caprae subsp. *brasiliensis, pōhuehue,* beach morning-glory, morning-glory family (Convolvulaceae). This pantropical vine has thick green stems; shiny green leaves up to 10 cm long, 8 cm wide, usually folded upward at midrib; and funnel-shaped flowers, pink to lavender with a purple throat and up to 8 cm long. In Hawai‘i *pōhuehue* is a common beach plant just above the high-tide line; in Waipi‘o it was noted on the sandy streambank near the mouth of Wailoa Stream at Station 2. Hawaiians ate the roots and stems as a starvation food, but they are cathartic and dangerous if eaten in quantity. The seeds are also cathartic. The vines were used to drive fish into nets, and were slapped on the ocean by surfers to request high surf. The vine was part of a *lei* worn around the necks of new mothers to induce milk flow.

Paspalum scrobiculatum, ricegrass, *mau‘u laiki,* grass family (Poaceae). This grass is thought to be indigenous or a very early introduction and is also native to tropical Asia. In Hawai‘i it grows in wet swampy ground and on poor thin soils. A large patch was noted growing along the bank of a *kalo lo‘i* at Station 4. Neal (1965) related that it was used like *pili (Heteropogon contortus)* as a thatch for houses.

Schoenoplectus juncoides, kaluhā, sedge family (Cyperaceae). This bulrush resembles *makaloa (Cyperus laevigatus),* with erect, bladeless green sheaths 15–75 cm tall, but differs in the arrangement of the bracts on the spikelet: in *kaluhā* they are spiraling around a central axis, while in *makaloa* they are arranged in 2 rows on either side of the axis. It ranges from Japan to Malesia and India, with disjunct populations in Fiji and Hawai‘i; in Hawai‘i it has been recorded in bogs and on pond margins and wet forest trails on Kaua‘i and

Hawai‘i. In Waipi‘o it was occasional in the fallow kalo lo‘i at Station 4. No uses are recorded for this species.

Polynesian introductions

Aleurites moluccana, kukui, candlenut tree, spurge family (Euphorbiaceae). This tree is conspicuous from a distance because of its light grayish green, maple-like foliage. The fruits are rounded, about 5 cm across, green to brown, and contain 1 or 2 black, hard-shelled seeds. It is native to Malesia and widespread in the tropics; in Hawai‘i it is a common tree in semi-wet valleys and on slopes. In Waipi‘o it is one of the most common forest trees and a common element along stream courses as well. *Kukui* was declared the state tree by the 1959 Hawai‘i State Legislature for its many uses and beauty. The wood was used for canoes and fishnet floats; the oily seeds strung on coconut midveins as candles or eaten after roasting in a condiment called *‘inamona;* oil from the seed burned in stone lamps, mixed with soot and used as paint, and used medicinally; the white latex used medicinally, as glue, and used to waterproof *kapa;* the nuts used to make *lei;* and the green fruit husk and root bark used to produce a black dye, the latter used to stain canoes. The raw seeds are highly purgative.

Alocasia macrorrhizos, ‘ape, elephant’s-ear, aroid family (Araceae). A large *kalo* relative up to 2 m tall with basally attached, glossy green, heart-shaped leaf blades up to 1.2 m long and 0.75 m wide. Its origin is unknown, but it is widely cultivated and naturalized from India and Sri Lanka through southeastern Asia and Polynesia; in Hawai‘i it occurs in valleys along streams and in other wet sites. In Waipi‘o *‘ape* is a common roadside plant, but during this survey it was seen only alongside the stream at Station 5. The underground stems are a source of starch but require much preparation to remove calcium oxalate crystals that can cause intense burning and swelling of mucous membranes; thus in Hawai‘i it was used only as a famine food. The leaves were sometimes used to wrap a patient for sweating to reduce a fever.

Cocos nucifera, niu, coconut, palm family (Arecaceae). One of the most recognizable palms in tropical areas, the coconut was one of the most valuable plant resources of the Hawaiians, with most parts used ethnobotanically. The origin of the coconut is unknown, but it is mostly likely of Indo-Pacific origin. Young coconut plants were noted only along the streambank of Station 3, although it is common in the valley.

Colocasia esculenta, kalo, taro, aroid family (Araceae). The mainstay crop of the Hawaiians, *kalo* may have its origins in India. The underground corm was baked or steamed, then mashed to form *poi,* the primary Hawaiian food staple. Waipi‘o Valley was historically a famous *kalo*-growing area, and it remains the primary crop produced there. *Kalo* was noted growing in uncultivated settings at the margins of a couple of streams.

Ludwigia octovalvis, kāmole, primrose willow, evening primrose family (Onagraceae). This upright herb with narrow leaves and yellow flowers is usually present in fallow *kalo lo‘i* and wet seeps. No uses for this plant are recorded, and it is thought that seeds may accidentally have been brought by the Polynesian settlers, but it could also have been brought naturally by migratory birds (Wagner et al. 1999). This herb was occasionally seen on wet soils.

Musa x*paradisiaca, mai‘a,* banana, banana family (Musaceae). A complex hybrid developed through thousands of years of cultivation, the banana was a staple crop of the Hawaiians, who developed around 70 cultivars, including 20 or so that still exist today (Wagner et al. 1999). A single clump of unknown strain was noted on this survey in a fallow *kalo* patch.

Syzygium malaccense, ‘ōhi‘a ‘ai, mountain apple, myrtle family (Myrtaceae). Tree up to 18 m tall with leathery, glossy leaves 18–31 cm long, 8–13 cm wide; flowers in purplish red to pink powderpuff clusters borne directly on the upper trunk and main branches; and pear-shaped fruit maturing dark red, up to 8 cm long, with a crisp white, watery flesh. It is not related to the true apple, which is in the rose family. Mountain apple is probably native to Indo-Malaysia; in Hawai‘i it is long cultivated and naturalized in low-elevation semi-wet to wet sites, especially moist valleys; on this survey it was noted only at Station 3, although it is common in parts of the valley. The fruit is eaten raw, cooked, or pickled. Hawaiians used the trunks as house posts and rafters and to build temple enclosures, the wood to carve religious images, and an infusion of the astringent bark as a sore throat remedy.

Wetland Ratings

Forty-four of the 99 vascular plant taxa encountered during this survey were rated at least equally as likely to occur in wetlands as in non-wetlands (Reed 1988), and they are listed below, with comments. Wetlands are generally defined as “those areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions” (Corps of Engineers, 33 CFR Part 328.3).

The following wetland indicator categories do not refer to the degree of wetness, but to the prevalence of finding that species in a wetland. For example, obligate wetland species can occur in permanently flooded areas, or they may occur in areas that are only seasonally flooded a few weeks a year.

- Obligate Wetland (OBL): Occur almost always in wetlands (est. probability >99%)
- Facultative Wetland (FACW): Usually occur in wetlands (est. probability 67-99%)
- Facultative (FAC): Equally likely to occur in wetlands or nonwetlands (est. probability 34-66%)

- Facultative Upland (FACU): usually occurring in non-wetlands (est. probability 67–99%)
- Upland (UPL): usually occurring in non-wetlands (est. probability >99%).

Taxa not appearing in the following lists are FACUs and UPLs. During this survey there were no plants found that have been rated as UPL in Reed (1988). Also not included are those species for which insufficient information was available to assign an indicator rating and not included in Reed (1988). One of the latter, *Diplazium esculentum,* edible fern, appears in the field to be at least a facultative wetland (FACW) species, and it was added to the list on that basis; another, *Schoenoplectus mucronatus,* appears to be an obligate wetland species.

Obligate wetland species (OBL) : species that occur almost always (est. probability >99%) under natural conditions in wetlands. These are very good wetland indicator species:
Azolla filiculoides—Native to the Americas, water fern was brought to Hawai‘i for mosquito control in rice fields in the early 1900s. It is now widespread in flooded croplands, ditches, and ponds, where it forms thick, floating mats that cover the water surface. *Azolla* fixes nitrogen, aiding in better crop yields (Wilson 1996). A collection (C. Imada & C. Puttock 2001-8) was made from a *kalo lo‘i* with a red-tinged carpet of water fern.

Colocasia esculenta; profiled above, under Polynesian Introductions.

Cyclosorus interruptus; profiled above, under Indigenous Species.

Cyperus papyrus—The well-known papyrus of the Egyptians, this sedge is native to tropical Africa and Madagascar and is cultivated in water gardens. Previously known to be naturalized in Hawai‘i only on Kaua‘i, a dense naturalized stand was noted with stems 2.5 m tall in Lālākea Fishpond, and a voucher (R.Englund sub C.Imada 2001-16) taken. It represents the first naturalized collection of this species on the Big Island.

Egeria densa—This escaped aquarium plant, native to South America, has densely whorled leaves that give it a pipe-cleaner aspect. It was first collected in Hawaiian Islands on the Big Island in 1937 (Wagner et al. 1999). It can sometimes form dense submerged patches rooted in ponds and slow-moving waters. In Waipi‘o, it was noted at Stations 2 and 5, where it was fairly common.

Eichhornia crassipes—A floating herb with shiny green leaves and pretty violet flowers, water hyacinth is often cultivated as an aquatic ornamental. When it escapes into waterways, however, this fast-growing plant can form masses that impede navigation, cut off sunlight, and deplete oxygen. This native of the Neotropics is said to have been introduced into the Islands in the late 1800s (Wagner *et al.* 1999). In Waipiʻo, patches of water hyacinth were seen in Lālākea Fishpond and along the stream margin at Station 2.

Lemna aequinoctialis—Duckweed is a tiny floating water plant with a single root per leaf. This cosmopolitan weed can be found in *kalo loʻi,* ditches, and ponds in slow-moving water, and was first collected in Hawaiʻi in 1895 (Wagner et al. 1999). It was noted along the stream margin at Station 2.

Ludwigia octovalvis; profiled above, under Polynesian Introductions.

Ludwigia palustris—Marsh purslane is a small, creeping, rooted herb with opposite leaves and red stems found on wet soils and sometimes submerged underwater. First collected in Hawaiʻi in 1934, it is native from the Americas through Africa (Wagner et al. 1999). It is a common element of wetlands in Waipiʻo.

Myriophyllum aquaticum—Native to South America, parrot's-feather has whorled, finely divided, feathery foliage on weak stems rooted in the substrate. It occurs in standing or running water. First collected in Hawaiʻi in 1919 (Wagner et al. 1999), in Waipiʻo it was the dominant weed in an operating *kalo loʻi,* surrounding the *kalo* plantings, and was also found in other settings in Wailoa Stream.

Persicaria punctata—Water smartweed is a thin-stemmed herb with narrow white flower spikes. Native to the Americas and the West Indies, it is widely naturalized along streams and in running or standing water (Wagner et al. 1999). Water smartweed was first collected in Hawaiʻi in 1909; in Waipiʻo it was occasionally seen in kalo loʻi and in stream settings. It is listed at *Polygonum punctatum* Elliot in Wagner et al. (1999).

Schoenoplectus californicus—*Kaluhā* is a large bulrush that forms monodominant stands up to 3.5 m tall in lowland salt or freshwater marshes. Native to the Americas, in Hawaiʻi it was first collected in 1912 (Wagner et al. 1999). It can be confused with *S. lacustris* (L.) Palla ssp. *validus* (Vahl) T. Koyama, an indigenous bulrush that grows sympatrically with *kaluhā.* In the field, *S. californicus* usually has triangular stems and a shiny green cast; *S. lacustris* has round stems and a dull grayish green cast. In Waipiʻo, *kaluhā* was plentiful in Lālākea Fishpond.

Schoenoplectus juncoides; profiled above, under Indigenous Species.

Schoenoplectus mucronatus—This recently introduced sedge was first identified in 1997 (Strong and Wagner 1997). It has previously been collected at Waimea Reservoir (1986) and Kehena Reservoir (1992) in the

North Kohala District of the Big Island. This clumping sedge has sharply 3-angled stems with sides that are usually concave. It was occasional as thick, clumping patches 0.75–1 m tall in flooded and fallow *kalo lo‘i.*

Typha latifolia—Common cattail has stout stems 1.5–2.75 m tall with long, swordlike leaves. Native to Eurasia, northern Africa, and North America, in Hawai‘i it was first collected on O‘ahu in 1979 (Wagner et al. 1999). It occurs in marshy lowland sites; in Waipi‘o it was collected *(C.Imada & R.Englund 2001-13)* in a fallow *kalo lo‘i,* and represents the first confirmed naturalized collection of the species from the Big Island.

Facultative wetland species (FACW) : species usually occurring in wetlands (est. probability 67–99%), but occasionally found in nonwetlands

Coix lachryma-jobi—Job’s-tears is a robust, cornlike grass. The white to black, beadlike “seeds” that are collected and strung into necklaces are specialized structures that produce the male and female inflorescences. Native to Asia, the first collection in Hawai‘i was in 1903. Job’s-tears can be found naturalized along streams and wet ditches; in Waipi‘o it was occasionally seen in such situations.

Commelina diffusa—*Honohono* is a ubiquitous herbaceous, grasslike groundcover in the spiderwort family (Commelinaceae), sometimes forming thick mats on wet soils. Native to the Old World tropics, *honohono* is widely naturalized. In Hawai‘i it can be found in a variety of habitats ranging from mesic to wet sites and was first collected in 1837 (Wagner et al. 1999); in Waipi‘o it occurred in every site except Station 1.

Cyperus haspan—This slender, pantropical sedge grows up to 1.5 ft. tall and is commonly found in open muddy areas and wet fields. It was first collected in Hawai‘i on Kaua‘i in 1957 (Wagner et al. 1999); in Waipi‘o it was mainly noted in the fallow *kalo lo‘i* at Station 4.

Cyperus involucratus—Umbrella sedge is so-called for the many radiating rays of the inflorescences, creating an umbrella-like effect; the basal leaves are reduced to bladeless sheaths. It is often cultivated and can be found naturalized in streams and marshes, where it can grow 1–2 m tall. Native to tropical Africa, umbrella sedge may have been introduced to Hawai‘i around 1900 (Wagner et al. 1999). It was an occasional streamside weed in Waipi‘o.

Diplazium esculentum—Edible fern was introduced to Kaua‘i in 1910 and still had limited distribution in 1950 (Wilson 1996), but is now naturalized on all of the larger islands except Moloka‘i. In Waipi‘o it is ubiquitous along streams and in wet sites, often forming dense, monodominant stands. The tender, unfurling young shoots are eaten as vegetables.

Echinochloa colona—An annual grass up to 0.75 m tall, jungle-rice is paleotropical and now widely naturalized in wet or seasonally wet, disturbed areas. It was first collected in Hawai‘i in 1835 (Wagner et al. 1999); in Waipi‘o it was noted in fallow *kalo lo‘i.*

Echinochloa crus-galli—Barnyard grass is an annual that usually grows taller than *E. colona* and is often distinguished from it by having long black or purplish awns on the spikelets. Found in warm temperate and tropical regions worldwide, it was first collected in Hawai‘i in 1846 (Wagner et al. 1999). Barnyard grass is found in the same habitats as *E. colona;* in Waipi‘o it was noted in fallow *kalo lo‘i.*

Eclipta prostrata—A small, branching, erect to prostrate, annual herb with white flowers, false daisy is native to the Americas and the Old World tropics. In Hawai‘i it has been naturalized in disturbed sites since at least 1871 (Wagner et al. 1999), often on wet soils. In Waipi‘o it was noted on the streambank at Station 2.

Hibiscus tiliaceus; profiled above, under Indigenous Species.

Paspalum vaginatum—Seashore paspalum often forms a dense, deep, monodominant groundcover in brackish marshes and along seashores around stream mouths. Of unknown native range, it was first collected in Hawai‘i in 1936 and has been documented from Kaua‘i, O‘ahu, Maui, and Hawai‘i. In Waipi‘o it was noted on the streambank at Station 2.

Facultative species (FAC) : species equally likely to occur in wetlands or nonwetlands (est. probability 34–66%). These taxa are listed alphabetically but are not profiled.

Ageratum conyzoides
Alocasia macrorrhizos
Clerodendrum chinense
Cuphea carthagenensis
Cyperus polystachyos
Digitaria ciliaris
Drymaria cordata var. *pacifica*
Hedychium sp.
Ipomoea pes-caprae subsp. *brasiliensis*
Kyllinga brevifolia
Momordica charantia
Nephrolepis multiflora
Panicum repens

Paspalum conjugatum

Paspalum scrobiculatum

Plantago major

Pluchea carolinensis

Sacciolepis indica

Syzygium jambos

Endangered Species

A query of the Hawaii Biological Survey's botany database revealed no endangered plant vouchers from the lower part of Waipi‘o Valley, and no taxa on the U.S. Fish & Wildlife Service endangered and threatened plant list were seen during the survey. A separate query was done to determine all of the native vascular at-risk taxa that might conceivably be found in the riparian and wetland habitats surveyed. A recent publication (Wagner, Bruegmann, Herbst and Lau 1999) assigns at-risk ratings to a total of 638 Hawaiian vascular taxa ranging from Extinct to Endangered, Rare, or Vulnerable. Extraction of all taxa that were also given wetland ratings of OBL, FACW, or FAC in Reed (1988) resulted in a list of 89 at-risk wetland species. The vast majority were from upland bog or wet forest situations (e.g., many lobeliads in the genera *Clermontia, Cyanea,* and *Lobelia*). Three species, however, emerged as possibilities for the types of lowland habitats surveyed in Waipi‘o Valley: two sedges, *Cyperus odoratus* L. and *C. trachysanthos* Hook. & Arn. (both facultative wetland species), and a fern, *Marsilea villosa* Kaulf (obligate wetland). The latter two species are federally listed endangered species that have never been collected on the Big Island, though, and the only collection of *Cyperus odoratus* (listed by USFWS as a species of concern, and formerly known as *Torulinium odoratum* (L.) S. S. Hooper ssp. *auriculatum* (Nees & Meyen) T. Koyama) at BISH was made by Joseph Rock (Rock 12756) from "forests of Hilo." Nevertheless, a more complete survey of the wetland areas in Waipi‘o Valley might consider the presence of these taxa.

CONCLUSIONS

Brief History of Waipi‘o Valley Occupation and Cultivation

One of the first foreign visitors to Waipi‘o Valley was missionary William Ellis in 1823, at which time he was accompanied by fellow missionary Asa Thurston and a native guide, Makoa. Both Ellis and Thurston stayed in the valley for several days and Thurston trekked back into the valley on both the east and west sides for several miles. Thurston's observations documented that the main lower valley, as well as the upper valleys of Waimā, Ko‘iawe, Alakahi and Kawainui were in cultivation at the time of his visit. Ellis and Thurston noted four villages or house clusters in the lower valley, the largest of which was Napo‘opo‘o with 43 residences. Houses were also dispersed among the fields. They also noted how well cultivated the valley was and described the crops as including *kalo*, *mai‘a* (bananas), *kō* (sugar-cane), and other cultivated plants. Ellis further estimated that there were a total of 265 houses in the valley. This estimate would probably have been sufficient to house about 1,325 people, assuming about 5 people per household (Lebo *et al.* 1999). A census by the missionaries in 1831-1832 using the Waimea Station estimated the population of Waipi‘o Valley at about 1200 people (Cordy 1994). Cordy (2000) estimated that Waipi‘o Valley had a pre-western contact population of over 2,500 people, and had some of the highest known population densities in the Hawaiian archipelago at the time. The missionary records also documented four population or housing clusters within the valley--Napo‘opo‘o, Keone, Nā‘ālapa, and Kouka (Koauka), which probably also correspond to the villages observed by Ellis in 1823.

Rice Production

Further agricultural changes are seen with the introduction of rice farming and water buffaloes. Water buffaloes were introduced to work the rice patches. Several rice mills appear on an 1881 map of Waipio Valley completed by J.S. Emerson, a surveyor of the Hawaiian Kingdom (Emerson 1881). Rice agriculture continued in the valley until the early 20th century. It was dominated by Chinese rice farmers and mill owners, and to a lesser extent by Hawaiian, Japanese, and other groups living in the valley. Many of the Chinese and Japanese immigrants came to Hawai‘i as indentured laborers and later moved into Waipio Valley to begin intensive rice agriculture. Prior to 1914, rice agriculture in Waipio was a common economic pursuit and generally there were two crops a year (Char and Char 1983).

Rice planters are identified in Waipio Valley in the business directories available between 1880-1881 and 1942. Rice cultivation covered much of the agricultural floor of the valley in the 1890s and all of the lower valley in 1906 (UH Ethnic Studies 1978). Oral interviews with Nelson Ah Hoy Chun reveal that he produced the last crop of rice in the valley about 1928. Afterward, Chun, like many rice farmers in Waipio Valley, converted to *kalo* farming.

A wide variety of crops were grown in Waipio Valley other than rice and *kalo*. In an 1884 business directory one individual was listed as having a peach orchard (Lebo *et al.* 1999). A Land Study Bureau publication (Land Bureau1960) documents about 580 acres in Waipio Valley as being under rice and *kalo* cultivation in 1902. As of January 1960, agricultural production, based on farmer estimates, had shrunk to about 100 acres of *kalo*, less than five acres of lotus root, a single two-acre orchard of coffee trees, about eleven acres of macadamia trees and scattered orange trees. One individual recalled that by the time he was born in 1895, virtually all plant foods used by the Chinese had been introduced into the valley. Lotus lily, water chestnuts, buffalo nuts, and the si ku (or Indian potato), and watercress were among those that he remembered. Lai chee, lon gan, ung nim (star apple), lo quat palm, and Chinese banana are among others that were in use by this time (Kane 1994)

Environmental consequences of continued Hawaiian cultural practices

Overall Findings:

The primary objectives of this study were to assess whether native stream biota or rare and endangered aquatic species were: 1) present in aquatic habitats within the lower Wailoa River, including wetland areas, and, 2) would be adversely impacted by continued cultural practices associated with *kalo wai*, or the growing of wetland taro, including the operation and maintenance of 'auwai. The current *kalo wai* practices in Waipi'o Valley are not appreciably different than from what has occurred there since approximately A.D. 1200 (Kirch 2000), thus no new environmental impacts to native aquatic species would be expected to occur when farmers maintain and restore irrigation ditches. The estimated Waipi'o Valley pre-contact population of 2,500 (Cordy 2000) is far less than the current 50-75 estimated (J. Dockall, Bishop Museum, unpub. data) permanent residents currently living in the valley. Because both the total area of *kalo* presently grown (Olszewski et al. 2000) and the total human impacts today are just a small fraction compared to pre-contact times or even recent times, current cultural practices have few impacts compared to historical times.

Although not within the scope of this report, it should also be mentioned that *kalo lo'i* provide important habitat for endangered Hawaiian waterbirds (Pratt et al. 1987) such as the *'alae'ula* (*Gallinula chloropus sandvicensis*) and *'alae kea* (*Fulica americana alai*). Any additional *kalo lo'i* would clear unsuitable aquatic habitats that are choked with weeds and provide more habitat for these endangered waterbirds.

No Federally Threatened, Endangered, rare, or imminently threatened species of aquatic animals or terrestrial or aquatic plants were found in or around the areas of the lower Wailoa River that were assessed during the present study. Because any impacts from restoring *kalo lo'i* or *'auwai* would only be short-term sedimentation inputs, no greater than those caused by the many heavy rainstorms regularly occurring in this very wet valley, and because no endangered species would be impacted, it is recommend that current and past cultural practices such as the repair and maintenance of *'auwai* and the future restoration of *kalo lo'i* be allowed to proceed.

Stream Management Options for Lower Wailoa River

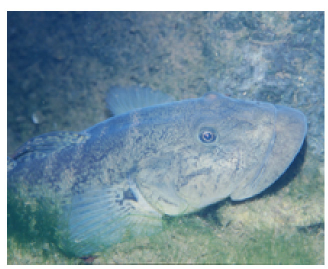
The findings of this study indicate that the lower Wailoa River in Waipi'o Valley, Hawai'i Island contains a relatively unimpacted population of aquatic stream animals and aquatic habitats, especially when compared to streams flowing through heavily urbanized areas such as those on O'ahu. However, it appears that introduced aquatic species have caused some impacts in the lower sections of the Wailoa River, with these impacts extending into the headwater tributaries of Waipi'o Valley. For example, it is possible to snorkel long distances in the headwater tributaries of Waipi'o Valley, both above and below the Lower Hāmākua Ditch, and see few or no native *'o'opu*. Generally, these impacts appear to result from introduced aquatic species, primarily fish, but the impacts on some of the native biota, such as aquatic insects, decrease as stream elevation increases. Above Station 6 at 37 m elevation, and above the highest *kalo lo'i*, there appear to be few visible impacts from the most aggressive alien aquatic species such as tilapia and mosquitofish, because only low densities of introduced fish were observed here. However, the impacts of introduced fish predation and disease on returning post-larval *'o'opu* are one of the most likely reasons for extremely low densities of native *'o'opu* in the five upper Waipi'o Valley headwater tributaries (Englund and Filbert 1997).

While a more comprehensive study would be required to provide specific cause and effect data, it is clear from studies conducted since 1997 that low native fish densities are found above the most upstream *kalo 'auwai*. Large numbers of native stream *'o'opu* are seasonally found in the kalo 'auwai, which are also teeming with alien fish species. The fact that significant numbers of native post-larval *'o'opu* can make it at least as far as the *kalo 'auwai*, but are not found upstream of them strongly indicates traversing this area is difficult for native stream fish. Stream flow, while important, is likely not the overriding factor that is causing the near complete lack of recruitment of native post-larval *'o'opu*.

The major impacts alien species have on native species are likely one of predation on post-larval *'o'opu* in the *kalo lo'i* and the spreading of disease. Few native fish were observed above the *kalo lo'i*, although at times high densities of *hinana* can be found within these areas. In contrast to pre-contact times (prior to the introduction of alien species), native *'o'opu* are unlikely to survive for long in *kalo lo'i* because of the high densities of introduced tilapia, poeciliids (e.g., mosquitofish), introduced crayfish (*Procambarus clarkii*), and the introduced diseases brought in by these aliens, to which the native fish have no developed resistance. Any management options reducing the attractiveness of the *kalo lo'i* to native *'o'opu* would enhance their populations by allowing *'o'opu* to bypass the *kalo lo'i*. One possible strategy would be to encourage taro farmers to use pvc pipes where possible to drain water from individual *lo'i* (Dr. R. Nishimoto, HDAR, pers. comm.). There would need to be at least 8-13 cm of free space between the pvc pipe and the pond to where the pipe was draining to ensure the *hinana* could not gain access to the *lo'i*.

Another management strategy to reduce stream disturbance and erosion would be to encourage taro farmers to line the *'auwai* with concrete in selected areas, and decrease the use of the black plastic linings that are commonly used. Currently, there is a constant shifting of the *'auwai* channel whenever there is a large rainstorm, and often there will be a loss of the gravel lining the black plastic during rainstorms. By lining the *'auwai* with concrete in certain critical areas such as at the diversion point, there could be a potential reduction in long-term maintenance and sediment inputs.

A community effort to reduce alien fish numbers in the lower reaches of the Wailoa River would have very beneficial impacts on all native aquatic biota throughout the entire Waipi'o Valley watershed. This could involve a wide variety of possibilities such as using gill nets, fine-mesh seines, fish traps, and other techniques. The emphasis would be on the local community working together to reduce alien fish numbers in the area of the Wailoa Stream mouth at the ocean, in the *kalo lo'i*, and in all backwater areas of the lower Wailoa River. It is possible that even a small reduction in alien fish numbers would enhance recruitment of native *'o'opu* throughout the entire watershed. Reductions in alien fish numbers would also enhance native invertebrate populations as well. Additionally, the Hawaii Division of Aquatic Resources (HDAR) has indicated that they would be a willing partner to work with the community to help reduce alien fish numbers (Dr. R. Nishimoto, pers. comm.). Special collecting permits could be issued to the community by HDAR to allow for alien fish removal activities. These activities would necessarily involve the use of restricted fishing gear such as fine-mesh gill nets, seines, and perhaps other practical fish collection devices. Community benefits would be potentially be substantial; for example, tilapia could be sold in local markets with profits going back to the community. Alien fish removal would certainly be as beneficial to the health of the entire Waipi'o Valley aquatic ecosystem as would clearing the stream mouth to decrease the amount of stagnant water and flooding danger to residents and farmers.



The native Hawaiian *'o'opu nākea* (*Awaous guamensis*), an important food fish.

Appendix: Waipi‘o Valley Plant Species List

The following is a list of plant taxa noted during walk-through surveys of six wetland and stream sites in the lower part of Waipi‘o Valley on 13–14 March 2001. A total of 99 vascular plants and 4 algae are included.

Plants are divided into 5 main groups: blue-green algae, green algae, ferns and fern allies, dicots, and monocots. Within these groups, plants are arranged alphabetically by family, genus, and species. Each entry includes scientific name with author citation, biogeographic status, common name (if available), and presence or absence at each of 6 stations. Taxonomy, status, and common names of the vascular plants are in accordance with Wagner et al. (1999) or Staples and Herbst (in press). A number of specimens were collected and deposited in the Bishop Museum's Herbarium Pacificum; some unknown species were collected and compared with herbarium collections to secure correct identifications. Drs. Derral R. Herbst (vascular plants) and Alison Sherwood (algae) are thanked for assistance with identifications. An explanation of abbreviations used in the list follows.

Biogeographic Status

end Endemic: native, occurring only in the Hawaiian Archipelago; species that have evolved into something uniquely Hawaiian after arriving naturally from elsewhere.

ind Indigenous: native, occurring naturally in the archipelago but also outside of Hawai‘i; many of these species inhabit the coastal zone, where they can be readily dispersed by water or seabirds.

nat Naturalized: introduced to the archipelago directly or indirectly by humans since Western contact and reproducing and spreading vegetatively or from seed.

pol Polynesian introduction: introduced by original Polynesian settlers, either intentionally or unintentionally, and now naturalized.

ind? Questionably indigenous: probably indigenous, possibly naturalized.

nat? Questionably naturalized: probably naturalized, possibly indigenous.

pol? Questionably a Polynesian introduction; possibly introduced in historic times.

Plant Wetland Rating

OBL Obligate Wetland : occur almost always in wetlands (est. probability >99%)

FACW Facultative Wetland : usually occur in wetlands (est. probability 67-99%)

FAC Facultative: equally likely to occur in wetlands or nonwetlands (est. probability 34-66%)

FACU Facultative Upland: usually occurring in non-wetlands (est. probability 67–99%)

+/- Positive or negative sign specifies if on wetter or drier end of category

* Asterisk means not enough information to give definitive rating

Plant survey Stations

1 Wailoa River mouth at last riffle nearest open ocean

2 Wailoa River just upstream of Station 1

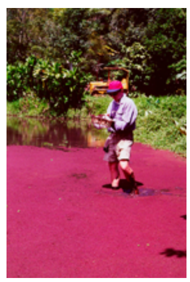
3 Hi'ilawe Stream tributary, just above confluence with Wailoa River

4 Kawashima *kalo* field (both fallow and in cultivation)

5 Wailoa River upstream of Kawashima kalo field

6 Wailoa River at beginning of highest 'auwai in Waipi'o Valley

New Hawai'i Island record: *Cyperus papyrus*



Lesser duckweed at Kawashima *kalo lo'i*

C. Imada collecting riparian vegetation at Station 6

Blue-green Algae

Family/Scientific name	Status	**Common name**	WetlandRating	1	2	3	4	5	6
Chrococcaceae									
Rhabdoderma gorskii Woloszynska	?						x		

Green Algae

Family/Scientific name	Status	**Common name**	Wetland Rating	1	2	3	4	5	6
Chaetophoraceae									
Cloniophora spicata (Schmidle) Islam	?				x				x
Cladophoraceae									
Cladophora fracta (O. F. Muller ex Vahl) Kutzing	?					x		x	x
Rhizoclonium or *Mougeotia* sp.	?						x		

Ferns & Fern Allies

Family/Scientific name	Status	**Common name**	Wetland Rating	1	2	3	4	5	6
Athyriaceae									
Deparia petersenii (Kunze) M. Kato	nat								x
Diplazium esculentum (Retz.) Sw.	nat	edible fern, vegetable fern				x	x	x	x
Azollaceae									
Azolla filiculoides Lam.	nat	mosquito fern	OBL				x		
Blechnaceae									
Blechnum occidentale L.	nat	hammock fern				x			x
Nephrolepidaceae									
Nephrolepis multiflora (Roxb.) F. M. Jarrett ex C. V. Morton	nat	Asian swordfern	FAC*						x
Polypodiaceae									
Phlebodium aureum (L.) J. Sm.	nat	*laua'e haole,* golden polypody							x
Phymatosorus grossus (Langsd. & Fisch.) Brownlie	nat	*laua'e, maile*-scented fern	FACU		x				x
Thelypteridaceae									
Christella dentata (Forssk.) Brownsey & Jermy	nat	*pai'i'ihā,* downy maiden fern	FACU			x			x
Christella parasitica (L.) Leveille	nat					x			x
Cyclosorus interruptus (Willd.) H. Ito	ind	*neke*	OBL				x		

Dicots

Family/Scientific name	Status	**Common name**	Wetland Rating	1	2	3	4	5	6
Acanthaceae									
Dicliptera chinensis (L.) Juss.	nat				x				x
Anacardiaceae									
Schinus terebinthifolius Raddi	nat	*wilelaiki,* Christmas berry	FACU-		x				

Dicots (cont.)

Family/Scientific name	Status	**Common name**	Wetland Rating	1	2	3	4	5	6
Apiaceae									
Cryptotaenia canadensis (L.) DC.	nat	honewort							x
Asteraceae									
Ageratina riparia (Regel) R. M. King & H. Rob.	nat	Hāmākua *pāmakani*	FACU			x			x
Ageratum conyzoides L.	nat	*maile hohono*	FAC*		x			x	x
Conyza canadensis (L.) Cronquist var. *pusilla* (Nutt.) Cronquist	nat	*lani wela*, horseweed				x			
Eclipta prostrata (L.) L.	nat	false daisy	FACW		x				
Emilia sonchifolia (L.) DC. var. *javanica* (Burm. f.) Mattf.	nat	Flora’s paintbrush			x				
Pluchea carolinensis (Jacq.) G. Don	nat	sourbush, marsh fleabane	FAC*		x	x	x	x	x
Pseudelephantopus spicatus (Juss. ex Aubl.) Vahl	nat	elephant's-foot							x
Senecio madagascariensis Poir.	nat	German ivy, Italian ivy			x				
Sphagneticola trilobata (L.) Pruski	nat	wedelia	FACU		x			x	
Balsaminaceae									
Impatiens wallerana Hook. f.	nat	busy Lizzy, patient Lucy				x			
Buddleiaceae									
Buddleia asiatica Lour.	nat	*huelo ‘īlio*, dog tail				x			x
Caprifoliaceae									
Sambucus mexicana C. Presl ex A. DC.	nat	Mexican elder	FACU					x	
Caryophyllaceae									
Drymaria cordata (L.) Willd. ex Roem. & Schult. var. *pacifica* M. Mizush.	nat	*pipili, pilipili*	FAC		x	x		x	x
Casuarinaceae									
Casuarina equisetifolia L.	nat	common ironwood, she oak	FACU		x				
Combretaceae									
Terminalia catappa L.	nat	tropical almond, false *kamani*			x	x			
Terminalia myriocarpa Van Heurck & Müll. Arg.	nat	jhalna				x			
Convolvulaceae									
Ipomoea alba L.	nat	*koali pehu*, moon flower	FACU			x	x		
Ipomoea indica (Burm.) Merr.	ind	*koali ‘awa*	FACU			x			
Ipomoea pes-caprae (L.) R. Br. subsp. *brasiliensis* (L.) Ooststr.	ind	*pōhuehue*, beach morning glory	FAC		x				
Cucurbitaceae									
Momordica charantia L.	nat	bitter melon	FAC*			x	x		
Euphorbiaceae									
Aleurites moluccana (L.) Willd.	pol	*kukui*, candlenut tree				x		x	x
Fabaceae									
Albizia chinensis (Osbeck) Merr.	nat					x			
Canavalia cathartica Thouars	nat	*maunaloa*	FACU		x		x		

Dicots (cont.)

Family/Scientific name	Status	**Common name**	Wetland Rating	1	2	3	4	5	6
Desmodium sandwicense E. Mey.	nat	Spanish clover, chili clover	FACU*		x				
Mimosa pudica L. var. *unijuga* (Duchass. & Walp.) Griseb.	nat	*pua hilahila*, sensitive plant	FACU				x	x	
Samanea saman (Jacq.) Merr.	nat	*‘ohai*, monkeypod			x	x			x
Senna pendula (Humb. & Bonpl. ex Willd.) H. S. Irwin & Barneby var. *advena* (Vogel) H. S. Irwin & Barneby	nat						x		
Haloragaceae									
Myriophyllum aquaticum (Vell.) Verdc.	nat	parrot's feather, water feather	OBL		x		x	x	
Lamiaceae									
Hyptis pectinata (L.) Poit.	nat	comb hyptis			x				
Lythraceae									
Cuphea carthagenensis (Jacq.) J. F. Macbr.	nat	tarweed, Colombian cuphea	FAC		x			x	x
Malvaceae									
Hibiscus tiliaceus L.	ind?	*hau*			x				
Sida acuta Burm. f. subsp. *carpinifolia* (L. f.) Borss. Waalk.	nat								x
Malvaceae (cont.)									
Sida rhombifolia L.	nat		FACU					x	
Meliaceae									
Toona ciliata M. Roem. var. *australis* (F. Muell.) C. DC.	nat	Australian red cedar				x			
Myrtaceae									
Psidium guajava L.	nat	*kuawa*, common guava	FACU			x	x		x
Syzygium cumini (L.) Skeels	nat	Java plum, jambolan plum	FACU			x	x	x	x
Syzygium jambos (L.) Alston	nat	*‘ōhi‘a loke*, rose apple	FAC						x
Syzygium malaccense (L.) Merr. & L. M. Perry	pol	*‘ōhi‘a ‘ai*, mountain apple				x			
Oleaceae									
Fraxinus uhdei (Wenz.) Lingelsh.	nat	tropical ash				x			
Onagraceae									
Ludwigia octovalvis (Jacq.) P. H. Raven	pol?	*kāmole*, primrose willow	OBL				x	x	
Ludwigia palustris (L.) Elliott	nat	marsh purslane	OBL		x		x	x	
Oxalidaceae									
Oxalis corymbosa DC.	nat	*‘ihi pehu*, pink wood sorrel				x		x	
Passifloraceae									
Passiflora edulis Sims	nat	passion fruit, *liliko‘i*				x			
Plantaginaceae									
Plantago major L.	nat	broad-leaved plantain, *laukahi*	FAC*						x
Polygonaceae									
Persicaria punctata (Elliott) Small	nat	water smartweed	OBL				x	x	x

Proteaceae									
Macadamia integrifolia Maiden & Betche	nat	macadamia							x
Rubiaceae									
Paederia foetida L.	nat	*maile pilau*					x	x	
Urticaceae									
Pilea microphylla (L.) Liebmann	nat	artillery plant, gunpowder plant				x			x
Verbenaceae									
Clerodendrum chinense (Osbeck) Mabb.	nat	*pīkake hohono*	FAC			x	x		
Verbena litoralis Kunth	nat	vervain, *ōwī, oī*					x		

Monocots

Family/Scientific name	Status	**Common name**	Wetland Rating	1	2	3	4	5	6
Araceae									
Alocasia cucullata (Lour.) G. Don	nat	Chinese taro						x	
Alocasia macrorrhizos (L.) Schott	pol	*‘ape*, elephant’s-ear	FAC-						x
Colocasia esculenta (L.) Schott	pol	*kalo*, taro	OBL			x	x	x	
Epipremnum pinnatum (L.) Engl.	nat	taro vine, pothos				x			
Xanthosoma roseum Schott	nat	*‘ape*						x	x
Arecaceae									
Cocos nucifera L.	pol	*niu*, coconut	FACU			x			
Cannaceae									
Canna indica L.	nat	*ali‘ipoe*, Indian-shot	FACU				x	x	
Commelinaceae									
Commelina diffusa Burm. f.	nat	*honohono*	FACW		x	x	x	x	x
Cyperaceae									
Cyperus haspan L.	nat		FACW+			x	x		
Cyperus involucratus Roxb.	nat	*‘ahu‘awa haole*, umbrella plant	FACW		x			x	
Cyperus papyrus L.	nat	*kaluhā*, papyrus	OBL		x				
Cyperus polystachyos Rottb.	ind		FAC*			x			
Cyperus rotundus L.	nat	nut grass, *kili‘o‘opu*	FACU		x				
Kyllinga brevifolia Rottb.	nat	*kili‘o‘opu*	FAC		x		x	x	
Schoenoplectus californicus (C. A. Mey.) Palla	nat?	*kaluhā*	OBL		x				
Schoenoplectus juncoides (Roxb.) Palla	ind	*kaluhā*	OBL				x		
Schoenoplectus mucronatus (L.) Palla	nat						x		
Hydrocharitaceae									
Egeria densa Planch.	nat		OBL	x	x			x	
Lemnaceae									
Lemna aequinoctialis Welw.	nat?	lesser duckweed	OBL		x				
Musaceae									
Musa x *paradisiaca* L.	pol	*mai‘a*, banana	FACU				x		
Poaceae									
Andropogon virginicus L.	nat	broomsedge, yellow	FACU				x		

		bluestem							

Monocots (cont.)

Family/Scientific name	Status	**Common name**	Wetland Rating	1	2	3	4	5	6
Coix lachryma-jobi L.	nat	*pū'ohe'ohe*, Job's-tears	FACW+			x		x	x
Digitaria ciliaris (Retz.) Koeler	nat	*kūkaepua'a*, Henry's crabgrass	FAC						x
Echinochloa colona (L.) Link	nat	jungle-rice	FACW				x		
Echinochloa crus-galli (L.) P. Beauv.	nat	barnyard grass	FACW				x		
Eleusine indica (L.) Gaertn.	nat	*mānienie ali'i*, wiregrass	FACU-		x				x
Panicum maximum Jacq.	nat	Guinea grass	FACU			x			
Panicum repens L.	nat	torpedo grass, quack grass	FAC+				x		
Paspalum conjugatum Bergius	nat	Hilo grass, sour paspalum	FAC+				x		x
Paspalum scrobiculatum L.	ind?	ricegrass, *mau'u laiki*	FAC*				x		
Paspalum vaginatum Sw.	nat	seashore paspalum	FACW+		x				
Sacciolepis indica (L.) Chase	nat	Glenwood grass	FAC+		x		x		
Setaria palmifolia (J. Kōnig) Stapf	nat	palmgrass				x			x
Pontederiaceae									
Eichhornia crassipes (Mart.) Solms	nat	water hyacinth	OBL		x		x		
Typhaceae									
Typha latifolia L.	nat	common cattail	OBL				x		
Zingiberaceae									
Hedychium sp.	nat	ginger	FAC			x			x

REFERENCES CITED

Alicata, J. E. 1969. *Parasites of man and animals in Hawaii.* S. Karger, Basel and New York. [v] + 190 p.

Athens, J. S., and J. V. Ward. 1993. Environmental change and prehistoric Polynesian settlement in Hawai'i. *Asian Perspectives* 32(2): 205–223.

Baker, J. A., and S. A. Foster. 1992. Estimating density and abundance of endemic fishes in Hawaiian streams. Division of Aquatic Resources, Hawai'i Department of Land and Natural Resources, 50 pp.

Bird, I. 1964 [reprint]. Six months in the Sandwich Islands. Univ. Hawai'i Press, Honolulu.

Burch, T. A. 1995. *Corbicula fluminea* Mūller (Mollusca: Bivalvia) established on Oahu. *Bishop Museum Occasional Papers* 42: 58.

Carlton, J. T. 1996. Biological invasions and cryptogenic species. *Ecology* 77:1653-1655.

Char, T. Y. and W. J. Char. 1983. Chinese Historic Sites and Pioneer Families of the Island of Hawaii. University of Hawaii Press, Honolulu.

Cordy, R. 1994. A regional synthesis of Hāmākua district, island of Hawai'i. Historic Preservation Division, Dept. Land & Natural Resources, State of Hawai'i.

Cordy, R. 2000. Exalted sits the chief: the ancient history of Hawai'i Island. Mutual Publishing, Honolulu, Hawai'i. 464 pp.

Cowie, R. H. 1995. Identity, distribution and impacts of introduced Ampullariidae and Viviparidae in the Hawaiian Islands. *Journal of Medical and Applied Malacology* 5[1993]: 61-67.

Cowie, R. H. 1997. Catalog and bibliography of the nonindigenous nonmarine snails and slugs of the Hawaiian Islands. *Bishop Museum Occasional Papers* 50: 1-66.

Cowie, R. H. 1998. Patterns of introduction of non-indigenous non-marine snails and slugs in the Hawaiian Islands. *Biodiversity and Conservation* 7(3): 349-368.

Cowie, R. H. 2000. Non-indigenous land and freshwater molluscs in the islands of the Pacific: conservation impacts and threats. In: *Invasive species in the Pacific: a technical review and regional strategy* (ed. Sherley, G.), p. 143-172. South Pacific Regional Environment Programme, Apia.

Cowie, R. H. 2001. Mollusks. In: *Hawai'i's Invasive species. A guide to invasive plants and animals in the Hawaiian Islands* (eds. Staples, G.W. and Cowie, R.H.). Mutual Publishing and Bishop Museum Press, Honolulu.

Cowie, R. H. in press. Apple snails as agricultural pests: their biology, impacts and management. In: *Molluscs as Crop Pests* (ed. G.M. Barker). CAB International, Wallingford.

Cowie, R. H., Evenhuis, N.L. and Christensen, C.C. 1995. *Catalog of the native land and freshwater molluscs of the Hawaiian Islands.* Backhuys Publishers, Leiden. vi + 248 pp.

Eldredge, L. G. 1994. *Perspectives in aquatic exotic species management in the Pacific islands. Volume 1. Introductions of commercially significant aquatic organisms to the Pacific islands.* South Pacific Commission, Nouméa. v + 127 p.

Ellis, W. 1827 [Reprinted 1963]. Journal of William Ellis: narrative of a tour of Hawaii or Owhyhee; with remarks on the history, traditions, manners, customs, and language of the inhabitants of the Sandwich Islands. Advertiser Publ. Co., Ltd., Honolulu.

Emerson, J. S. 1881. Map of the Valley of Waipio, Hawaii, Showing Estate of C. Kainaina & the Crown Lands. Hawaiian Government Survey. Registered Map No. 912. On file, Surveys Division, Department of Accounting and General Services, State of Hawaii, Honolulu.

Englund, R. A. 1999. The impacts of introduced poeciliid fish and Odonata on endemic *Megalagrion* (Odonata) damselflies on O'ahu Island, Hawai'i. *J. Insect Conserv.* 3: 225-243.

Englund, R. A. 2001. Report on long-term aquatic insect monitoring by Hawaii Biological Survey, Bishop Museum in Pelekunu Valley, Moloka`i, Hawai`i. Report prepared for TNCH Moloka`i Office. Contribution No. 2001-010 to the Hawaii Biological Survey. 7 pp.

Englund, R. A and Y. Cai. 1999. The occurrence and description of *Neocaridina denticulata sinensis* (Kemp, 1918) (Crustacea: Decapoda: Atyidae), a new introduction to the Hawaiian Islands. *Bishop Mus. Occas. Pap.* 58: 58-65.

Englund, R. A. and R. B. Filbert. 1997. Native and exotic stream organisms study in the Kawainui, Alakahi, Koiawe, and Lalakea Streams, Lower Hamakua Ditch watershed project, County of Hawaii. USDA-NRCS Contract No. 53-9251-6-275. 71 pp.

Englund, R. A., D. A. Polhemus and D. J. Preston. 2000. Assessment of the impacts of rainbow trout predation on native aquatic invertebrate species within Kōke'e State Park streams, Kaua'i, Hawai'i. Bishop Museum Technical Report No. 18. Bishop Museum, Honolulu, Hawai'i. 125 pp.

Englund, R. A. and D. J. Preston. 1999. Biological Assessment of the Lower Hamakua Ditch on the Hawaiian Stream Fly (*Sigmatineurum meaohi*) and other aquatic insects. Contribution No. 1999-003 to the Hawaii Biological Survey, Bishop Museum. 31 pp.

Fornander, A. 1916. Hawaiian antiquities and folklore. *Mem. Bernice P. Bishop Museum*, vol. 4.

Glover, N. and C. Campbell. 1994. Apple snails in wetland taro. *Pacific Islands Farm Manual, Taro Pest & Disease Leaflet* 5: 1-4.

Hawaii Stream Assessment. 1990. A preliminary appraisal of Hawaii's stream resources. State of Hawaii/National Park Service.

Imada, C. T. 2000. Vegetation survey of the lower part of Waipi'o Valley, pp. 78–107, 125–132. *In* Olszewski, D. I. (ed.), The mahele and later in Waipi'o Valley, Hawai'i, Research Program, Bishop Museum.

Kane, H. K. 1994. Letters from My Father: Memories of Childhood and Youth in Waipi'o Valley by Herbert Mock "Akioka" Kane, 1895-1970. Manuscript on file, Department of Anthropology, Bishop Museum, Honolulu.

Kay, E. A. 1979. *Hawaiian marine shells.* Bishop Museum Press, Honolulu. xviii + 653 p.

Kirch, P. V. 2000. On the road of the winds: an archaeological history of the Pacific Islands before European contact. University of California Press, Berkeley.

Kobayashi, W., Cowie, R. H. and Glover, N. 1993. Escargot has got to go. *The Taro Tattler* 5(1): 2.

Lach, L., Britton, D. K., Rundell, R. J. and Cowie, R. H. 2001. Food preference and reproductive plasticity in an invasive freshwater snail. *Biological Invasions* 2(4)[2000]: 279-288.

Lach, L. and Cowie, R. H. 1999. The spread of the introduced freshwater apple snail *Pomacea canaliculata* (Lamarck) (Gastropoda: Ampullariidae) on O'ahu, Hawai'i. *Bishop Museum Occasional Papers* 58: 66-71.

Land Bureau Study. 1960. Preliminary Survey of Resource Development and Rehabilitation Opportunities in Waipio Valley, Island of Hawaii. Land Study Bureau, University of Hawaii, Honolulu.

Lebo, S. A., J. E. Dockall, and D. I. Olszewski. 1999. Life in Waipi'o Valley, Hawai'i: 1880-1942. Report for Native Hawaiian Culture and Arts Program, Bishop Museum.

Lennox, C. G. 1954. A report to the Trustees of the Bishop Museum on the resources of Waipio Valley, Island of Hawaii, their past and present uses and an analysis of the problems facing their fuller use in the future. Bishop Museum, Honolulu, unpublished report.

Naylor, R. 1996. Invasions in agriculture: assessing the cost of the golden apple snail in Asia. *Ambio* 25(7): 443-448.

Neal, M. C. 1965. In gardens of Hawaii. 2nd ed. Special Publ. Bernice P. Bishop Mus. 50: 1–924.

Nishida, G. M. 1997. Hawaiian terrestrial arthropod checklist, 3rd Edition (Searchable database on the internet at *http://www.bishopmuseum.org/bishop/ento/entodbhome.html*). Hawaii Biological Survey. Bishop Mus. Tech. Rep. 12. 263 pp.

Nishimoto, R. T. and Kuamo'o D. G. K. 1997. Recruitment of goby postlarvae into Hakalau Stream, Hawai'i Island. Micronesica 30: 41-49.

Olszewski, D. I. (ed.) 2000. The Māhele and later in Waipi`o Valley, Hawai`i. Report for the Native Hawaiian Culture and Arts Program. Bishop Museum, Honolulu, Hawai'i. 132 pp.

Pratt, H. D., P. L. Bruner and D. G. Berrett. 1987. *A field guide to the birds of Hawaii and the tropical Pacific.* Princeton University Press, Princeton.

Reed, P. B., Jr. 1988. National list of plant species that occur in wetlands: Hawaii (Region H). U.S. Fish and Wildlife Service Biological Report 88(26.13), Washington, D.C., 88 pp.

Staples, G. W., and D. R. Herbst. In press. A tropical garden flora. Bishop Museum Press, Honolulu.

Stearns, H. T., and G. A. Macdonald. 1946. USGS Bulletin Number 9: Geology and ground-water resources of the island of Hawaii. Hawaii Division of Hydrography.

Stemmermann, L. 1981. A guide to Pacific wetland plants. U.S. Army Corps of Engineers, Honolulu District, 118 pp.

Strong, M. T., and W. L. Wagner. 1997. New and noteworthy Cyperaceae from the Hawaiian Islands. Bishop Mus. Occ. Pap. 48: 37–50.

Vitousek, P. M., D. Antonio, C. M., Loope, L. L. and Westbrooks, R. 1996. Biological invasions as global environmental change. *American Scientist* 84(September-October): 468-478.

Wagner, W. L., M. M. Bruegmann, D. R. Herbst and J.Q.C. Lau. 1999a. Hawaiian vascular plants at risk: 1999. *Bishop Museum Occasional Papers* 60: 1–58.

Wagner, W. L., D. R. Herbst and S. H. Sohmer. 1999b. Manual of the flowering plants of Hawai‘i. 2 vols. Rev. ed. Univ. Hawai‘i Press & Bishop Museum Press, Honolulu.

Wilson, K. A. 1996. Alien ferns in Hawai‘i. Pac. Sci. 50(2): 127–141.

University of Hawaii at Manoa, Ethnic Studies Program. 1978. Waipi‘o Māno Wai: An Oral History Collection. 2 Volume Ethnic Studies Oral History Project, Ethnic Studies Program, University of Hawaii at Manoa, Honolulu.

USGS 1995. Water budget for the Kohala area, island of Hawaii. U.S. Geological Survey Water-Resources Investigations Report 95-4114.

Yamamoto, M. N. and Tagawa, A. W. 2000. Hawai‘i’s native and exotic freshwater animals. Mutual Publishing, Honolulu.