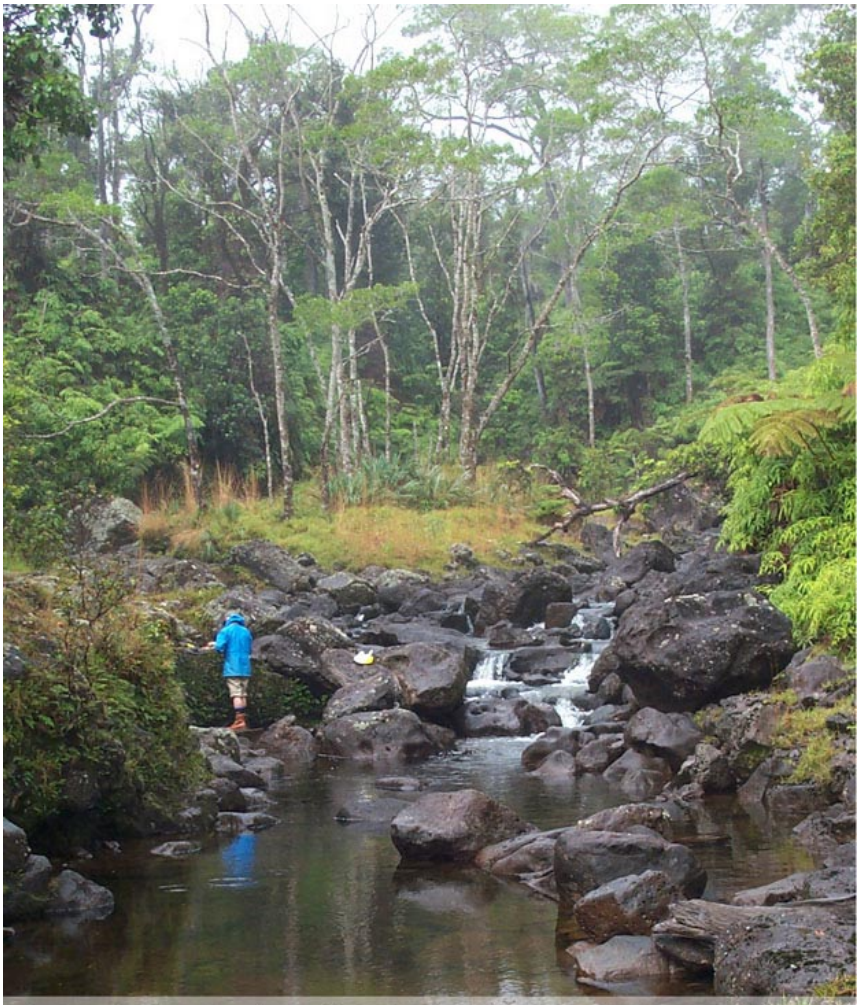

Aquatic Organism Study for the Koa Timber Commercial Harvest Operation, South Hilo District, County of Hawai'i

Hawaii Biological Survey

Final Report **April 2002**

Aquatic Organism Study for the *Koa* Timber
Commercial Forestry Operation
South Hilo District, County of Hawai'i

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EXECUTIVE SUMMARY

The Hawaii Biological Survey (HBS) of the Bishop Museum conducted aquatic biological surveys as part of an environmental impact statement for the proposed *Koa* Timber Commercial Forestry Operations project. Selective commercial helicopter logging of *koa* (*Acacia koa*) is proposed for 13,129 acres of Conservation District land in the South Hilo District of the Big Island. These surveys specifically were conducted to assess native and introduced aquatic organisms, and particularly to determine if sensitive, rare, or Candidate Threatened or Endangered Species would be impacted by the proposed selective commercial harvest of *koa*. The objectives of this assessment was to 1) describe baseline distribution of native and introduced fish, crustaceans, mollusk, aquatic insect species, in the proposed project area, and 2) assess potential environmental impacts on native aquatic species from the commercial harvest of *koa* in Conservation District land.

Six major streams flowing within the project area surveyed from south to north included Honoli'i, Pāhoehoe, Kapue, Hanawī, Kawainui, and Wai'a'ama Streams. The lowest and highest elevations accessible by helicopter in the project area for each major stream were surveyed. Streams within the study area were sampled along an altitudinal gradient. Elevations ranged from a low of 1760 ft on lower Honoli'i, to mid-elevations of 2300 ft at Hanawī Stream, to the upper reaches of Kapue (2900 ft) and Honoli'i Streams (3300 ft). The wide range of elevations evaluated during this survey allowed a thorough sample of the entire range of aquatic habitats available found within the proposed project area.

Overall, native aquatic animal species predominated in aquatic habitats sampled within the proposed project area, indicating one of the most pristine aquatic ecosystems remaining in the Hawaiian Islands. A total of 61 species of aquatic macrofauna were collected in the six streams examined during this study, with forty-nine native aquatic species (mostly insects) and 11 introduced species were found. For all stations combined, 82% of the aquatic taxa found during this study were native (either endemic or indigenous) species and 18% were introduced. Fish species composition in the six streams examined in the study area consisted of one species, the native *'o'opu 'alamo'o* or *'o'opu hi'ukole* (*Lentipes concolor*) being found in Honoli'i, Pāhoehoe, Kapue, and Hanawī Streams. A major finding of this study was the rediscovery of one population of native aquatic insect that was presumed extinct, the long-legged fly *Sigmatineurum omega*. Despite numerous attempts to find this species in streams around Hilo, it had not been collected since 1971.

Every effort needs to be made to reduce invasive species from gaining increased access to areas where *koa* is selectively helicopter logged. All used logging equipment (e.g., chainsaws, ropes, etc.) brought in from the mainland should be steam-cleaned or disinfected and sterilized prior to use to eliminate any hitchhiking invasive species, especially ants, which can destroy the invertebrate ecosystem in only a few years. Any

helicopters brought in from the mainland should have their skids sterilized or disinfected prior to use in a Hawai'i *koa* forest. If invasive species start to become established in these small open areas, then weed control of some kind will be required, and these areas need to be immediately replanted with *koa* and/or *'ōhi'a* seedlings. Net beneficial effects to the native ecosystem would accrue if strawberry guava is cleared and replanted with *koa* seedlings in the lower elevations of the project area.

The major concern from an aquatic ecosystem perspective would be that weed control needs to be strong in the patches were *koa* is logged. This would ensure strawberry guava does not replace the mature *koa* that has just been logged. Aquatic biota would be adversely impacted if invasive weed species become established because they are not adapted to heavily sedimented water conditions. To ensure buffer zones are maintained and that invasive species do not gain a foothold in areas where *koa* is selectively logged, it is recommended that forest regeneration is monitored for the life of the project by a botanist or forester with experience in native Hawaiian rainforest ecosystems. It is also recommended that aquatic habitats and aquatic biota be monitored for the life of the project to ensure logging does not increase rates of sedimentation that would adversely impact native aquatic biota.

'O'opu hi'ukole (Lentipes concolor)

Pinao'ula (Megalagrion blackburni)

INTRODUCTION

The Hawaii Biological Survey (HBS) of the Bishop Museum conducted aquatic biological surveys as part of an environmental impact statement for the proposed *Koa* Timber Commercial Forestry Operations project. Selective commercial helicopter logging of *koa* (*Acacia koa*) is proposed for 13,129 acres of Conservation District land in the South Hilo District of the Big Island, and HBS surveyed aquatic biota in the six major streams and adjacent wetlands in the proposed project area. These surveys were conducted specifically to assess native and introduced aquatic organisms, and particularly to determine if sensitive, rare, or Candidate, Threatened or Endangered Species would be impacted by the proposed selective commercial harvest of *koa*. The objectives of this assessment were to 1) describe baseline distribution of native and introduced fish, crustaceans, mollusks, and aquatic insect species, in the proposed project area; and 2) assess potential environmental impacts on native aquatic species from the commercial harvest of *koa* in Conservation District land.

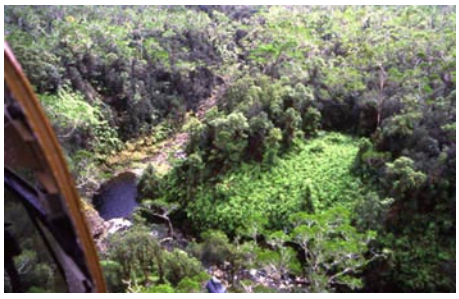
STUDY AREA

The project site is located ten miles northwest of Hilo on the southeastern flanks of Mauna Kea, and ranges in elevation from approximately 1400 to 3400 ft (Figure 1). The 13,129-acre project area lies within the eastern slopes of Mauna Kea, near Hilo, in the wettest region of the Big Island, with yearly annual rainfalls ranging from 200–240 inches (Juvik and Juvik 1998). The study area has few major landscape features other than the various stream canyons that are incised to as deep as several hundred feet in the lower sections. Otherwise, it consists of an almost featureless, gradually upsloping, and heavily forested area in the upper bounds of the study area. The one exception is the prominent Ka'uku pu'u or cinder cone (1964 ft) found at the extreme northeastern property boundary, adjacent to the lowest reaches of Wai'a'ama Stream. Streams draining this region of Mauna Kea generally flow in a west to east direction with permanent flow often appearing below the 4500 ft level. The higher sections of streams draining Mauna Kea (> 4500 ft), such as those found in Hakalau National Wildlife Refuge, often have permanent pools but flow only during periods of heavy rain.

The general topography of the project area is one of heavily forested, gradually sloping hills with no exposed rock faces or cliffs, except along the stream corridors. The upper portions of the study area are dominated by a mixed *koa* (*Acacia koa*) and *'ōhi'a lehua* (*Metrosideros polymorpha*) forest, with a thick understory of *uluhe* fern (*Dicranopteris linearis*) and a wide variety of other native plants. Starting around

the 2800 ft level, the forest becomes stunted with smaller trees in places, accompanied by a zone of more open *uluhe* fern bogs. Although introduced plants such as strawberry guava (*Psidium cattleianum*) were found in the highest reaches of our survey (3400 ft), they were relatively uncommon in the upper boundaries. Strawberry guava appeared to be the worst invasive plant in the area, forming an almost dominant monoculture in some lower portions of the study site below 2000 ft elevation. The forested areas composed of invasive species such as *Eucalyptus* or strawberry guava appeared to have little capacity to retain topsoil, and also were heavily disturbed by pigs. A general observation of siltier, warmer side tributaries flowing through either strawberry guava or *Eucalyptus* and entering the larger streams was observed in all of the lower reaches of the study area.

Within the proposed project area, all the major named streams on the U.S. Geological Survey (USGS) topographic quad maps were sampled. Some streams found in our current study area in the South Hilo District have names identical to streams found in Waipi'o Valley or elsewhere on Hawai'i Island, but obviously have no hydrological connection. The six major streams flowing within the project area surveyed from south to north included Honoli'i, Pāhoehoe, Kapue, Hanawī, Kawainui, and Wai'a'ama Streams. The lowest and highest elevations accessible by helicopter in the project area for each major stream were surveyed, with the exceptions of Kawainui and Hanawī Streams. Streams within the study area were sampled along an altitudinal gradient. Elevations ranged from a low of 1760 ft on lower Honoli'i, to mid-elevations of 2300 ft at Hanawī Stream, to the upper reaches of Kapue (2900 ft) and Honoli'i Streams (3300 ft). The wide range of elevations evaluated during our survey allowed us to thoroughly sample the entire range of available aquatic habitats found within the proposed project area.



Because of their small size, feasible helicopter landing zones (LZ) for both Kawainui and Hanawī Streams could only be located in their mid-to-upper reaches, and only one safe LZ for each of these streams was found within the project area. Sampling within a specific stream study site occurred within the confines of upstream and downstream waterfalls that were usually large enough to preclude further progress along the streambed.

A description and GPS coordinates (using Old Hawaiian datum) for the sampling stations are given below. GPS coordinates correspond to helicopter landing zones in the streambed at each site.

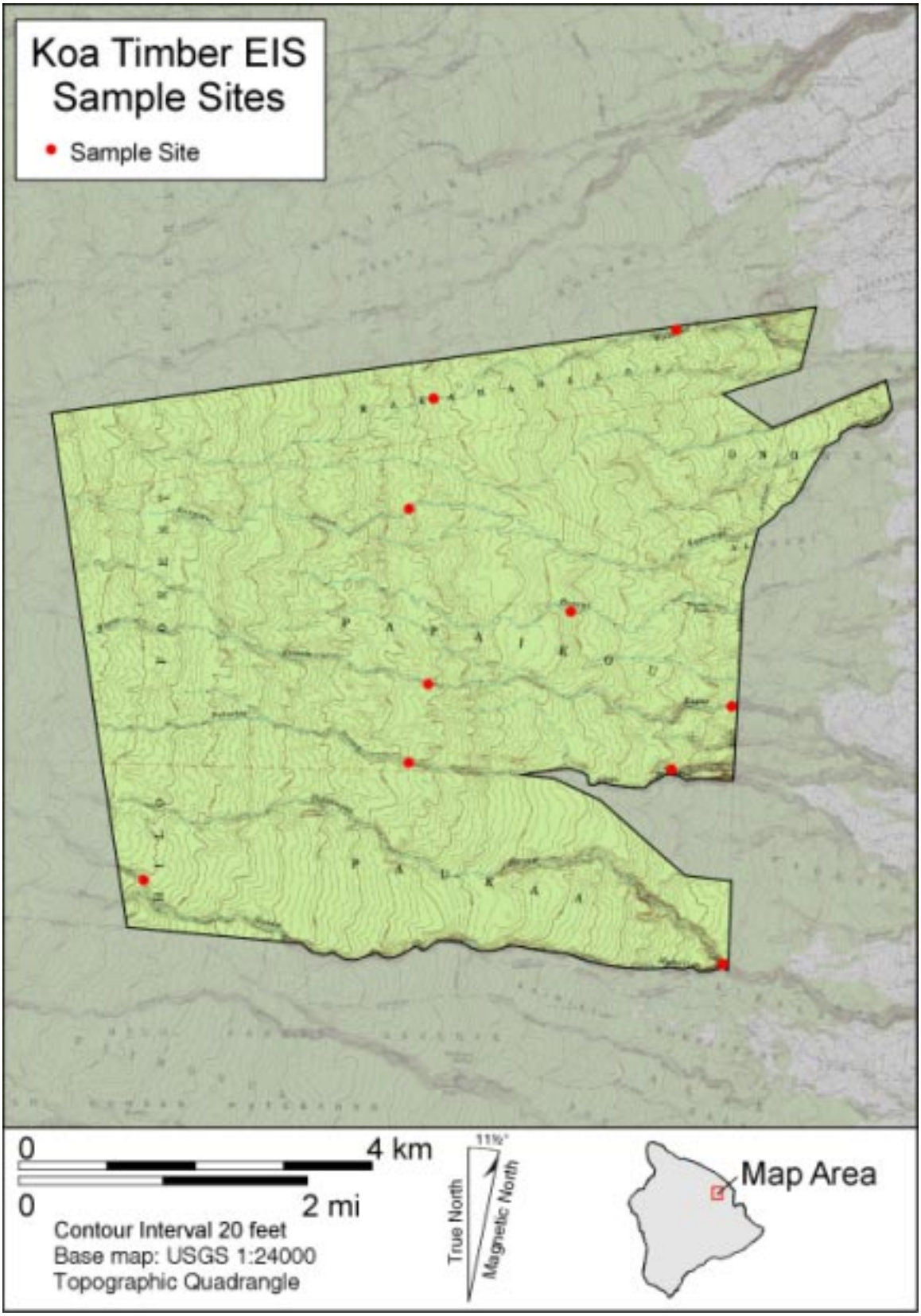


Figure 1. Study area and sampling stations for the *Koa* Timber surveys.

Station Descriptions and GPS Coordinates

Lower Honoli'i Stream – 1760 ft (19°46.388'N, 155°09.927'W)

Honoli'i Stream in this area is downstream of the confluence with Pōhakupa'a Stream, and this area was the largest stream examined during this study. Approximately 0.25 mi upstream a large waterfall at least 50 ft high impeded upstream progress, while the moderately sloping, incised canyon at this station ranged from 100-150 ft deep. A small tributary draining the strawberry guava monoculture and emptying into Honoli'i Stream was noticeably dirtier and siltier than the main stream channel. The raised banks of the stream here were often 10-15 ft above the low baseflow channel, and often contained standing water habitats because of the many seeps and springs flowing from the sides of the canyon in the area. The stream substrate seemed somewhat scoured from the recent high flows, but not as much as in upper Honoli'i, where little or no algae were observed on the rocks.

Large, deep (> 20 ft) pools were intermixed between riffles and cascades. During snorkeling observations only a slight layer of silt was observed on algae covering the rocks. The streambanks were lined with strawberry guava, *uluhe*, and *māmaki* (*Pipturus albidus*), with some remnant *koa* found higher above the stream canyon. Water temperature at this station was 61 °F, pH was 8.0.

Upper Honoli'i Stream – 3300 ft (19°46.593'N, 155°13.477'W)

Located at a major branching area for upper Honoli'i Stream, this station allowed for sampling of both the south and north branches of Honoli'i. The helicopter LZ was located in small clearing approximately 250 yds upstream from the confluence of these two major branches. Our campsite was located near the north branch, where light trapping at night as well as daytime sampling took place. The water clarity at this station was very high, with > 25 ft visibility in the deepest pools. Much of the stream channel here was a scoured, bedrock channel, but the stream here was also lined with large (2-6 ft) boulders and had a moderate gradient punctuated by high waterfalls both up and downstream of the confluence. The north tributary had a bare bedrock channel with little sign of algae on the rocks, apparently the high flows of the previous week had scoured this tributary. In contrast, the south branch above the confluence had a slightly smaller (ca. 1/3 less) estimated flow than the north branch.

The highly invasive gorse (*Ulex europaeus*) was found around and below the confluence of the two major forks of Upper Honoli'i Stream, but only in the open areas along the stream channel. Apparently gorse seeds have washed down from higher elevation areas where this noxious plant is firmly established, but was only found along the stream corridor and had not yet penetrated the native forest.

Upper Honoli'i Stream contrasted from the other streams examined in this study because of the heavy scouring that occurred during heavy flows in the week prior to these surveys. The near complete lack of algae on the rocks on the north tributary and fresh rock piles that had been re-arranged by the high flows were evidence of these recent high flows. Because it drains a much larger land area, Honoli'i Stream has greater peak flows when compared to the smaller watersheds examined such as Kawainui Stream. Nighttime MV light trapping also occurred on the banks of the upper Honoli'i Stream, near the helicopter LZ area. Water temperature at this station was 60 °F, pH was 6.5. This was the lowest pH recorded during these surveys.

Lower Pāhoehoe Stream – 2000 ft (19°47.213'N, 155°10.561'W)

Lower Pāhoehoe Stream at this elevation was large and contained significant flow and deep pools in the reaches we surveyed. A strawberry guava zone was evident at this elevation, with dense growths found along the riparian zone and up the canyon walls. Downstream of the LZ and starting at the top of the canyon rim a landslide of strawberry guava approximately 30 ft in diameter had fallen to near the stream channel. Seeps were found in abundance at this station, with many found elevated above the streambed on the canyon walls. The seeps also fed the elevated side-pools along the raised rock shelf or ledge common that was located above the stream channel. Other than strawberry guava, riparian vegetation consisted of tree ferns, *koa*, and *'ōhi'a*.

The water was very clear at this station, and the bottom of an estimated 30 ft pool at the base of large waterfalls near the helicopter LZ was easily observed while snorkeling. The stream at this site contained a good mixture of aquatic habitats, with ample riffle and run habitat. A thick algal growth on rocks in both fast-water velocity runs and riffles indicated this section of stream had not had a devastating scouring flow in some time, in contrast with the upper Honoli'i Stream. Water temperature at this station was 60 °F, pH was 7.5-7.6.

Upper Pāhoehoe Stream – 2700 ft (19°47.375'N, 155°10.561'W)

Pāhoehoe Stream in this area flows through a mostly pristine *koa* and *'ōhi'a* forest, with many deep (> 20 ft) pools interspersed between a mostly lava bedrock channel. In contrast to most of the other sites, upper Pāhoehoe Stream had several smaller tributaries and streamlets where it was possible to hike upstream. These small streamlets offered habitats different than those found in the much larger main channel of the stream, and we sampled these areas for aquatic invertebrates as well. Near the helicopter LZ area, the stream branched for about 50 yds forming a small, raised island of *koa*. Only a few strawberry guava were found in the forest around the stream zone, and the native forest here was almost entirely intact.

Numerous slick, flat-rock lava ledges were found in the streambed, and stairstep ledges formed by pāhoehoe lava were formed as the stream changed in elevation. Large pools stream pools were found at the base of some of these cascades and waterfalls, and were estimated to be 20 ft deep and as large as 50 x 60 ft in dimension. The streambed was mostly bedrock, with areas occasional large and small boulders in riffles. Water temperature at this station was 58 ºF, pH was 7.3-7.4.

Lower Kapue Stream – 1900 ft (19°47.703'N, 155°09.712'W)

The helicopter LZ was located on a fairly level rock area, just above one of the tallest (> 100 ft) waterfalls observed in the study area, near the boundary with Conservation District land. Lower Kapue Stream also had the only diversion that we observed in the study area. This large diversion appeared to currently be working and was diverting a substantial amount of stream flow but it was unknown where the diversion terminated. Around the diversion was also the only location where the introduced aquatic plant watercress (*Nasturtium microphyllum*) was found.

Several large, pond-like habitats were found upstream of the diversion and they appeared to be overflow ponds that directed water into the diversion. Large pond habitats were not observed elsewhere in the study area, and these side-channel ponds were potential habitat for the very rare endemic *Megalagrion pacificum* damselfly. Upstream, and on the same side of the stream as the diversion, a small tributary flows through a dense stand of strawberry guava that was heavily disturbed by feral pigs. There was a noticeable increase in silt on the rocks in this tributary, and water clarity was lower. The surrounding forest still had large amounts of *koa*, *'ōhi'a* and *uluhe*, although strawberry guava had completely encroached in the small tributary immediately upstream of the diversion.

Stream substrate consisted of small amounts of large and small boulders, but was mainly lava bedrock. In places the lava bedrock formed chutes, and large piles of rocks were found in the bottom of the pools formed below the chutes. Cloud cover and light rain during our time at this site may have precluded capture of some native damselfly species here, particularly *M. pacificum*. Water temperature was noticeably warmer at this station and was 64 ºF, pH was 7.9.

Upper Kapue Stream – 2700 ft (19°47.993'N, 155°12.691'W)

The area surrounding the stream consists of a diverse old growth *'ōhi'a* and *koa* forest, with the *koa* standing taller than the *'ōhi'a*. Interspersed and found within the forest canopy were other native plants such as *Clermontia parviflorum and Trematolobelia grandiflorum,* although feral pigs have eaten most of the ground-dwelling *T. grandiflorum* in this area, and it was only observed growing out of *'ōhi'a* trunks. *Koa* trees were also actually growing within the streambed itself. Nighttime light trapping was conducted on the stream banks adjacent to Kapue Stream, near the campsite and helicopter LZ.

The stream flowed over slick red lava bedrock with almost no substrate, and only a limited amount of loose substrate. Many of the rock ledges adjacent to the stream channel contained standing water, and were also ideal aquatic habitats for insects. Upper Kapue Stream appeared to have a more stable flow than upper Honoli'i Stream because the stream substrate was not as scoured, but the smaller fist-sized rocks were clean, indicating some scouring had occurred during the recent high storm flows. However, growths of algae and mosses were found in areas around the mainstream channel indicating scouring was not severe. Around the camp area there were many deep (> 9 ft) pools formed by cascades and riffles.

Downstream of the camp and LZ the stream channel spread out into a low gradient wide, nearly flat area causing the stream to spread out into a wide, thin laminar flow, with few deep pools. The channel was estimated to be over 150 ft wide in places, with little riffle habitat and no substrate, only bedrock. This continued for nearly 0.5 miles until a large 80 ft impassable waterfalls is encountered. Water temperature at this station and was 60 ℉, pH was 6.9.

Hanawī Stream – 2300 ft (19°48.268'N, 155°10.817'W)

Hanawī Stream in this area is small, and composed of lava chutes with relatively little substrate except where rocks are flushed into the bottom of pools during high flows. The forest surrounding the stream was almost entirely native *koa*, 'ōhi'a, and *uluhe* fern. Because this is such a short watershed, helicopter access was very limited both up and downstream of this area, and there were few landing zones once past the planted rows of *Eucalyptus* sp. marking the Conservation District boundary line. Also, because of the small size of the Hanawī watershed, there were no observable scouring effects from the recent storm, and luxuriant growths of algae covered the stream bottom. The section of Hanawī Stream sampled contained a sloping but traversable long bedrock cascade, perhaps 40-50 ft high. Approximately 0.25 mi downstream of the sloping cascade near the helicopter LZ impassable falls were encountered. Water temperature at this station and was 61 ℉, pH was 7.7.

Kawainui Stream – 2700 ft (19°48.832'N, 155°10.992'W)

Kawainui Stream was also one of the smaller watersheds, with limited helicopter landing zones. An overnight camp and nighttime light trapping of aquatic insects occurred along the stream banks here, with the camp located on a rocky shelf 75 ft downstream from the boggy helicopter LZ that was located near the stream channel. Upstream was a series of riffles and stairstep cascades approximately 8-10 ft high, with a small channel only 2-3 ft wide in the shallow run and riffle areas. The steam at this location was generally

too small for snorkeling, with the exception of one very large pool upstream. Flowing through a bedrock channel, this area also had some cobble substrate in contrast to many of the other stream areas examined in the study area that were mostly lacking substrate.

Feral pig activity (e.g., rototilled soil) was also greater here than at the other high elevation stations, with pigs observed crossing the stream during the middle of the day. Water temperature at this station and was 58 ºF, pH was 7.3.

Lower Wai'a'ama Stream – 1950 ft (19°49.936'N, 155°10.385'W)

In the otherwise relatively featureless 13,129-acre project area, this study site occurred near one of the few landmarks, the Ka'uku pu'u (cinder cone), which can be seen from downtown Hilo, approximately 10 miles away. The lowest reaches of Wai'a'ama Stream are located at the extreme northeastern boundary of Conservation District land, and the lower reaches of Wai'a'ama Stream flow around the base of Ka'uku pu'u. In contrast to the higher elevation study site of Wai'a'ama Stream, the stream in this area flowed through a large *Eucalyptus* plantation, and dense strawberry guava was observable around the observable riparian zone. Upstream of the LZ the riparian vegetation turns into guava and *uluhe*, with some older remnant *koa* and *'ōhi'a*, however, no young *koa* recruits were observed. Feral pig activity and resultant damage to the surviving native forest was extremely high at this station.

The stream channel here is large and incised into an approximate 50 ft deep canyon, and comparable only to the lower Honoli'i, with deep pools (> 30 ft) connected by long riffles and runs. The *Eucalyptus* appear to have negative effects on water quality, because a > 1 inch thick layer of silt was observed on the stream substrate. Additionally, a small tributary flowing through the *Eucalyptus* (at the LZ) and over the rock wall of the canyon to the mainstream was noticeably more silty. The wetted area of the falls on this small rock wall tributary also had a noticeably thick silt layer. This silt layer provided further evidence of the negative impacts of introduced plants, including strawberry guava, on water quality. Elevated sidewater pocket water habitats were observed above the stream channel, mostly downstream of the LZ, and these elevated habitats appeared to be fed by the emergent seeps and springs issuing from the canyon walls. Water temperature at this station and was 61 ºF, pH was 7.3.

Upper Wai'a'ama Stream – 2640 ft (19°49.510'N, 155°11.750'W)

The main stream channel was hardly incised, and at this station was only 10-15 ft below a nearly impenetrable *koa*, *'ōhi'a*, and *uluhe* fern forest. As the elevation increased, Wai'a'ama Stream became smaller and consisted of stairstep, narrow cascades and a series of narrow lava chutes with excellent water clarity. Stream gradient was moderate, with a series of 10-30 ft high cascades that were mostly passable

because of their gradual nature. Although the stream was small in this area, pools as deep as 8-10 ft were common at the base of each cascade.

Stream flow appeared to be quite stable at this station, as the recent rains appear to have caused no scouring of algae or mosses from the mainly bedrock lava chutes. Many of the rock potholes above the main stream channel here were full of water from either the recent rains or high stream flow, and were also full of aquatic insect life. At 56 °F, the coldest water temperatures during this study were found here, while pH was measured at 7.0.

METHODS

Field work for this study was conducted by staff from the Hawaii Biological Survey from 6-15 February 2002. Sampling took place during a period of low baseflow, clear stream conditions, and mostly dry and sunny weather. Occasional light misty rain occurred only near the end of fieldwork (14 February); however, this rain was not enough to cause the streams to noticeably increase in flow or effect water clarity. Habitat conditions for native aquatic organisms were evaluated at each sampling station. Altitude was determined by using a combination of USGS topographic quadrangle maps, helicopter altimeter, and a hand-held altimeter. Stream names were taken from USGS topographic quadrangles.

Aquatic Insect Sampling

Aquatic insect sampling methodology followed Englund *et al.* (2000) and Englund and Preston (1999). Collections of both immature and adult specimens were conducted with MV (mercury vapor) light traps at three streams: Honoli'i, Kapue, and Kawainui. Malaise traps, yellow pan traps, aerial nets, dip nets, selective fogging of aquatic habitats with pyrethrins, and benthic kick and Surber samples were all used to collect larval and mature stages of aquatic insects. Immature aquatic insects were also collected from rocks found in riffles by using a toothbrush and fine-point tweezers to extricate larvae from algae covering the rocks and into a yellow pan. Visual observations for aquatic insects, especially of larger taxa such as Odonata (dragonflies and damselflies) were also conducted as we hiked along the streambed. Although sampling effort was focused on habitat suitable for native insects: splash zones around riffles and cascades and wet rock faces associated with springs and seeps, waterfalls, and wetland areas near and along the stream corridor, all aquatic habitats were sampled.

General collecting was conducted in prime native aquatic insect habitats with numerous aerial net sweeps taken around riffle splash-zones, cascades, seeps, and waterfall areas. 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 gently sweep immature aquatic insects and other aquatic invertebrates off from the stream rocks. Nighttime surveys using light traps powered by a portable generator were located on the riverbank and employed to comprehensively collect aquatic insects that are only active nocturnally. These areas were sampled using an MV (mercury vapor) light shining on a white sheet, and night sampling started before dark at 1730 hrs and continued to at least 2230 hours, during a moonless night. Arthropods attracted to the sheet 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.

Fish, Crustacean, and Amphibian Sampling

Fish and crustacean underwater sampling conformed to Hawaii Division of Aquatic Resources (HDAR) native fish sampling guidelines (Baker and Foster 1992). However, because this study was focused more on examining biodiversity rather than being a long-term monitoring study, point counts were not used to determine native fish densities. Fish densities were generally low and limited the usefulness of point counts, thus snorkel transects (as recommended by Baker and Foster 1992) were more appropriate for this study.

Snorkeling at least 300-400 yds of stream channel and more when possible at each sampling station allowed a thorough inventory to be conducted for all aquatic macrofauna found at each study site. Snorkeling also allowed us to find cryptic species that would not have been observed if above-water observation was the only method used to assess streams, e.g., the native gobiid *Lentipes concolor* and aquatic species such as native diving beetles and dragonfly larvae were found during snorkeling, and would not have been found if only above-water observations were conducted. Because of low fish densities, transect snorkeling was used to assess fish and crustacean species composition throughout the study area. This involved snorkeling through an entire habitat or large section of stream and visually assessing species composition and estimating relative densities of fish and crustaceans. Amphibian sampling consisted of both above water and underwater visual observations, and was presence or absence with areas of particularly high densities noted.

Mollusk Survey Methods

The purpose of the mollusk survey was to develop an inventory of aquatic mollusk species present in the study area and to assess the status of the aquatic mollusk fauna found within study area streams. At each survey site searches were made in the water by visual inspection from the bank, by wading, and by snorkeling. Hīhīwai sampling also conformed with HDAR sampling guidelines (Baker and Foster 1992), although none were observed in the study site. All mollusk species that were observed were collected, and 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).

RESULTS AND DISCUSSION

Overall, native aquatic animal species predominated in aquatic habitats sampled within the proposed project area, indicating one of the most pristine aquatic ecosystems remaining in the Hawaiian Islands. A total of 61 species of aquatic macrofauna were collected in the six streams examined during this study (Table 1), and a complete list of species including their geographic origin can be found in Tables 2 and 3. In the study area forty-nine native aquatic species (mostly insects) and 11 introduced species were found (Table 1). For all stations combined, 82% of the aquatic taxa found during this study were native (either endemic or indigenous) species and 18% were introduced (Table 1).

Table 1. Summary of the native or nonindigenous status and total number (percent) of aquatic species found in all reaches combined in six streams assessed for the *Koa* Timber commercial logging EIS, South Hilo District, Hawai'i Island.

Geographic Status	All Aquatic Species	Amphibians	Fish	Mollusks	Aquatic Insects	Crustaceans	Oligochaete
Introduced	11 (18%)	1 (100%)	0 (0%)	1 (100%)	8 (14%)	0 (0%)	1 (100%)
Native	50 (82%)	-	1 (100%)	0 (0%)	48 (86%)	1 (100%)	0 (0%)
Total	61	1	1	1	56	1	1

Aquatic insects were by far the most species-rich group found in the study area, with 56 species collected (Table 1), and numerically were also the most abundant group. Figure 2 represents the total number of species found for each major aquatic taxa observed in study area streams. The native or nonindigenous status of arthropods was ascertained from Nishida (2002). Nonindigenous aquatic species have been brought into Hawai'i both accidentally and intentionally, and now comprise a major portion of aquatic biota found in many Hawaiian streams.

Falls at Honoli'i Stream, 1760 ft. elevation

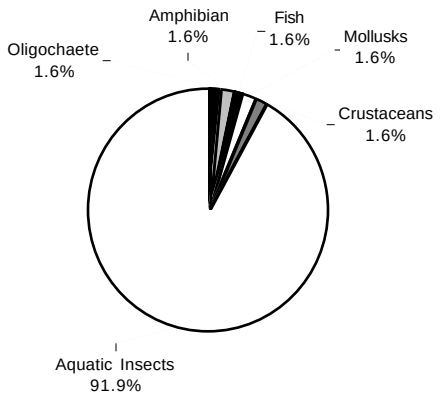


Figure 2. Percent composition of number of species of introduced and native aquatic macrofauna taxa found in six streams in the proposed *koa* timber logging area, South Hilo District, Hawai'i Island, February 2002.

Amphibians

The alien bullfrog (*Rana catesbeiana*) was the only species of amphibian observed within the project area, and was found in five of the six streams examined (Tables 2 and 3). High tadpole densities were found in certain areas such as lower Kapue Stream, with many observed in stream pools found near the irrigation diversion. The stomach contents of one bullfrog were examined in upper Kapue Stream, and an adult Hawaiian damselfly (*Megalagrion blackburni*) was found, along with the elytra of several terrestrial beetles. The impacts of bullfrogs on native aquatic biota, however, have not been quantified. Both and adults and tadpoles were found in the uppermost elevations of the project area, to 2900 ft in upper Kapue Stream. It was surprising to find tadpoles at such a high elevation, but it is also possible that bullfrogs have been coming down into the forest from the cattle ponds located above the Conservation District boundaries. While not observed in the upper stations at Honoli'i and Pāhoehoe Streams, it is likely that bullfrogs will eventually inhabit all the upper elevation stream areas because the adults appear to be going around the many waterfalls by dispersing through the surrounding rainforest and coming back to the stream to breed.

Fish

Fish species composition in the six streams examined in the study area consisted of one species, the native *'o'opu 'alamo'o* or *'o'opu hi'ukole* (*Lentipes concolor*) (Tables 2 and 3) being found in Honoli'i, Pāhoehoe, Kapue, and Hanawī Streams. As is the case with all native Hawaiian stream animals, the habitat requirements of *L. concolor* consist of clear, excellent water quality, and an unbroken stream connection to the ocean (Yamamoto and Tagawa 2000), all of which were found in the study area. Finding only one species of fish might initially seem to indicate the study area is poor for native fish species; however, the opposite is actually true. The presence of this fish species indicates that the entire watershed within the project area continues to function as a healthy ecosystem. *Lentipes concolor* is sensitive to ecological

disturbance (Yamamoto and Tagawa 2000) such as stream dewatering and siltation, and its presence indicates a healthy and functioning Hawaiian rainforest. The complete absence of alien fish species in the study area also indicates the aquatic habitats found here are some of the highest quality remaining in the State of Hawaii.

Lentipes concolor was commonly found in four of the six study streams, ranging from a low elevation of 1760 ft in Honoli'i to 2300 ft in Hanawī Stream. Although *L. concolor* has been found in streams above the town of Waimea, Hawai'i Island to elevations of nearly 3000 ft (D. Kuamo'o, HDAR, pers. comm.), the finding of this species as high as 2300 ft in the study area was significant. This is because streams draining the Waimea region are much lower gradient and lack the numerous large waterfalls that are present in all the streams we examined during the current study. Thus, it is a much greater physical challenge for the fish to ascend the numerous waterfalls within the study area.

Lentipes concolor populations were observed to have subtle but observable differences between streams. For example, of the estimated 20 individuals observed both in deep pools and shallow runs in Hanawī Stream, all were large adults, with lengths ranging from 3.5 – 5.5 inches, and with females generally smaller and males being very large. Small or recently recruited fish were not observed in Hanawī Stream, which contrasts with the much lower elevation station of lower Honoli'i Stream (1760 ft), where *L. concolor* as small as 1.25 inches were observed. It is possible that recruitment into the higher areas of Hanawī Stream is difficult because of the many falls that need to be ascended, and this may account for the current lack of recent recruits. *Lentipes concolor* were also common in lower Kapue Stream, with the base of each plunge pool having 1 to 5 fish (3-5 inches long), and some individuals also observed in shallow runs. One smaller, relatively recent recruit (2 inches long) individual was also observed in lower Kapue Stream. Lower Pāhoehoe Stream (2000 ft elevation) contained a significant *L. concolor* population, with as many as one fish observed every 10 ft during snorkeling transects in runs.

Lentipes concolor

Table 2. Results of Hawaii Biological Survey, Bishop Museum surveys of aquatic species in Honoli'i, Pāhoehoe, and Kapue Streams, South Hilo District, Hawai'i Island.

Taxon	Honoli'i Stream 1760 ft	Honoli'i Stream 3200 ft	Pāhoehoe 2000 ft	Pāhoehoe 2700 ft	Kapue 1900 ft	Kapue 2900 ft	Geographic Status
Amphibians							
Rana catesbeiana	X		X		X	X	Introduced
Fish							
Lentipes concolor	X		X		X		Endemic
Mollusks							
Physidae sp.					X		Introduced
Crustaceans							
Atyoida bisulcata	X				X		Endemic
Oligochaeta (semi-aquatic worms)							
Megascolecidae							
Amynthas diffringens		X					Introduced
Aquatic Insects							
Anisoptera (Dragonflies)							
Aeschnidae							
Anax strenuus	X	X	X	X	X	X	Endemic
Libellulidae							
Pantala flavescens	X		X		X		Indigenous
Zygoptera (Damselflies)							
Coenagrionidae							
Enallagma civile					X		Introduced
Ischnura posita					X		Introduced
Megalagrion blackburni	X	X	X	X	X	X	Endemic
Megalagrion calliphya	X	X	X	X	X	X	Endemic
Megalagrion hawaiiense	X	X	X			X	Endemic
Heteroptera (True Bugs)							
Mesoveliidae							
Mesovelia amoena							Introduced
Saldidae							
Saldula exulans	X	X	X	X	X	X	Endemic
Saldula procellaris	X	X		X	X		Endemic
Saldula oahuensis	X						Endemic
Veliidae							
Microvelia vagans	X	X	X	X	X	X	Endemic
Coleoptera (Beetles)							
Carabidae							
Bembidion cf. *ignicola*		X				X	Endemic
Dytisicidae							
Rhantus pacificus		X		X			Endemic
Diptera (Flies, gnats)							
Canacidae							
Procanace acuminata					X	X	Endemic
Procanace bifurcata					X		Endemic

Table 2 (cont.). Results of Hawaii Biological Survey, Bishop Museum surveys of aquatic species in Honoli'i, Pāhoehoe, and Kapue Streams, South Hilo District, Hawai'i Island.

Taxon	Honoli'i Stream 1760 ft	Honoli'i Stream 3200 ft	Pāhoehoe 2000 ft	Pāhoehoe 2700 ft	Kapue 1900 ft	Kapue 2900 ft	Geographic Status
Procanace confusa	X				X	X	Endemic
Procanace constricta					X		Endemic
Procanace new sp.	X	X		X	X		Endemic
Ceratopogonidae							
Dasyhelea hawaiiensis		X		X		X	Endemic
Dasyhelea sp. not *hawaiiensis*						X	Endemic
Forcipomyia hardyi		X	X			X	Endemic
Forcipomyia sp.	X						Endemic
Chironomidae							
Chironomus prob. *hawaiiensis*		X					Endemic
Cricotopus bicinctus	X	X	X	X	X	X	Introduced
Orthocladius sp.					X		Endemic
Orthocladius prob. *grimshawi*		X			X	X	
Pseudosmittia paraconjuncta	X		X		X	X	Endemic
Telmatogeton torrenticola	X				X		Endemic
Dolichopodidae							
Campsicnemus modicus							Endemic
Campsicnemus tibialis	X	X		X		X	Endemic
Eurynogaster new sp.		X		X		X	Endemic
Paraliancalus metallicus							Endemic
Sigmatineurum omega							Endemic
Ephydridae							
Hydrellia tritici						X	Introduced
Scatella amnica							Endemic
Scatella cillipes	X				X	X	Endemic
Scatella clavipes	X	X			X	X	Endemic
Scatella hawaiiensis							Endemic
Scatella oahuense	X		X		X		Endemic
Scatella warreni		X			X	X	Endemic
Scatella williamsi	X				X	X	Endemic
Psychodidae							
Psychoda sp.	X						Endemic
Trichomyia hawaiiensis							Endemic
Tipulidae							
Limonia hawaiiensis	X	X	X	X		X	Endemic
Limonia jacoba	X	X	X		X	X	Endemic
Limonia kauaiensis	X	X				X	
Limonia nigropolita	X						Endemic
Limonia stygipennis		X					Endemic
Limonia swezeyi	X	X		X			Endemic
Limonia sp.	X				X		Endemic

Table 2 (cont.). Results of Hawaii Biological Survey, Bishop Museum surveys of aquatic species in Honoli'i, Pāhoehoe, and Kapue Streams, South Hilo District, Hawai'i Island.

Taxon	Honoli'i Stream 1760 ft	Honoli'i Stream 3200 ft	Pāhoehoe 2000 ft	Pāhoehoe 2700 ft	Kapue 1900 ft	Kapue 2900 ft	Geographic Status
Trichoptera (Caddisflies)							
Hydropsychidae							
Cheumatopsyche analis	X				X		Introduced
Hydroptilidae							
Hydroptila potosina	X						Introduced
Lepidoptera (Aquatic Moths)							
Hyposmocoma sp. 1	X	X	X	X	X	X	Endemic

Elevated aquatic habitats found above streambed in Honoli'i Stream, 1760 ft elevation.

Pristine aquatic habitats, Honoli'i Stream, 3300 ft elevation

Table 3. Results of Hawaii Biological Survey, Bishop Museum surveys of aquatic species in Hanawī, Kawainui, and Wai'a'ama Streams, South Hilo District, Hawai'i Island.

Taxon	Hanawī Stream 2300 ft	Kawainui Stream 2700 ft	Wai'a'ama Stream 1950 ft	Wai'a'ama Stream 2640 ft	Geographic Status
Amphibians					
Rana catesbeiana	X		X		Introduced
Fish					
Lentipes concolor	X				Endemic
Mollusks					
Physidae sp.				X	Introduced
Crustaceans					
Atyoida bisulcata			X		Endemic
Oligochaeta (semi-aquatic worms)					
Megascolecidae					
Amynthas diffringens		X	X		Introduced
Aquatic Insects					
Anisoptera (Dragonflies)					
Aeschnidae					
Anax strenuus	X	X	X	X	Endemic
Libellulidae					
Pantala flavescens	X		X		Indigenous
Zygoptera (Damselflies)					
Coenagrionidae					
Enallagma civile					Introduced
Ischnura posita					Introduced
Megalagrion blackburni	X	X	X	X	Endemic
Megalagrion calliphya	X	X	X	X	Endemic
Megalagrion hawaiiense					Endemic
Heteroptera (True Bugs)					
Mesoveliidae					
Mesovelia amoena		X			Introduced
Saldidae					
Saldula exulans	X	X	X	X	Endemic
Saldula oahuense					Endemic
Saldula procellaris	X	X		X	Endemic
Veliidae					
Microvelia vagans	X	X	X	X	Endemic
Coleoptera (Beetles)					
Carabidae					
Bembidion cf. *ignicola*					Endemic
Dytisicidae					
Rhantus pacificus				X	Endemic
Diptera (Flies, gnats)					
Canacidae					
Procanace acuminata	X				Endemic
Procanace bifurcata					Endemic

Table 3 (cont.). Results of Hawaii Biological Survey, Bishop Museum surveys of aquatic species in Hanawī, Kawainui, and Wai'a'ama Streams, South Hilo District, Hawai'i Island.

Taxon	Hanawī Stream 2300 ft	Kawainui Stream 2700 ft	Wai'a'ama Stream 1950 ft	Wai'a'ama Stream 2640 ft	Geographic Status
Procanace confusa					Endemic
Procanace constricta					Endemic
Procanace new sp.			X	X	Endemic
Ceratopogonidae					
Dasyhelea hawaiiensis		X			Endemic
Dasyhelea sp. not *hawaiiensis*					Endemic
Forcipomyia hardyi		X	X	X	Endemic
Chironomidae					
Chironomus sp.			X		Endemic
Cricotopus bicinctus	X	X	X	X	Introduced
Orthocladius sp.	X	X			Endemic
Orthocladius prob. *grimshawi*	X	X	X		Endemic
Pseudosmittia paraconjuncta	X	X	X		Endemic
Telmatogeton torrenticola			X		Endemic
Culicidae					
Aedes albopictus			X		Introduced
Dolichopodidae					
Campsicnemus modicus	X				Endemic
Campsicnemus tibialis	X	X	X	X	Endemic
Eurynogaster new sp.	X				Endemic
Paraliancalus metallicus		X		X	Endemic
Sigmatineurum omega		X			Endemic
Ephydridae					
Hydrellia tritici			X		Introduced
Scatella cillipes	X	X	X		Endemic
Scatella clavipes	X	X	X		Endemic
Scatella hawaiiensis		X	X		Endemic
Scatella oahuense		X			Endemic
Scatella warreni	X				Endemic
Scatella williamsi	X	X	X		Endemic
Psychodidae					
Psychoda sp.		X			Endemic
Trichomyia hawaiiensis		X			Endemic
Tipulidae					
Gonomyia sp.					Endemic
Limonia hawaiiensis				X	Endemic
Limonia jacoba	X	X		X	Endemic
Limonia kauaiensis		X			Endemic
Limonia nigropolita					Endemic
Limonia stygipennis					Endemic
Limonia swezeyi		X			Endemic
Limonia sp.		X			Endemic

Table 3 (cont.). Results of Hawaii Biological Survey, Bishop Museum surveys of aquatic species in Hanawī, Kawainui, and Wai'a'ama Streams, South Hilo District, Hawai'i Island.

Taxon	Hanawī Stream 2300 ft	Kawainui Stream 2700 ft	Wai'a'ama Stream 1950 ft	Wai'a'ama Stream 2640 ft	Geographic Status
Trichoptera (Caddisflies)					
Hydropsychidae					
Cheumatopsyche analis	X			X	Introduced
Hydroptilidae					
Hydroptila potosina					Introduced
Lepidoptera (Aquatic Moths)					
Hyposmocoma sp. 1	X	X	X	X	Endemic

Crustaceans

One native species, the mountain dwelling freshwater shrimp or *'ōpae kuahiwi* (*Atyoida bisulcata*), was found within the study area and was abundant in Honoli'i, Kapue, and Wai'a'ama Streams (Tables 2 and 3). Because of their amphidromous nature, the mountainous *'ōpae kuahiwi* must pass through the stream mouth area at least two times to complete their life cycle. Their presence indicates an unbroken connection between the streams and the ocean. The shrimp were abundant in the three streams where they were present.

'Ōpae kuahiwi were in two of the four streams where the native fish *L. concolor* was present (Hanawī and Pāhoehoe were the two streams where these species were not found together). The absence of *'ōpae* from the streams containing *'o'opu* was especially puzzling, although the altitude of Hanawī Stream (2300 ft) where *L. concolor* was found was exceptionally high, especially considering the numerous waterfalls that must be ascended. Generally, the maximum elevational range of native *'ōpae kuahiwi* is far higher than that of native fish (see Englund and Polhemus 2001). Thus it would be expected that the two streams containing native fish would also contain *'ōpae kuahiwi*. For whatever reason, this was not the case, and the native fish exhibited a higher elevation distribution than *'ōpae kuahiwi* in these streams. Seasonality or some other unknown factors may be responsible for the observed distributions of native fish and shrimp. Native shrimp are often extremely abundant when present in the windward Hawai'i Island streams (e.g., upper Waipi'o Valley streams), and both numerous benthic samples and underwater surveys indicated that the shrimp were indeed not found in the two streams (Hanawī and Pāhoehoe) where *L. concolor* was common. However, it was not surprising to find *'ōpae kuahiwi* in a station of lower Wai'a'ama Stream lacking native stream fish, as finding native shrimp higher than the native stream fish is a more usual pattern.

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. Only one species of aquatic snail, an introduced species in the Physidae family, was collected during the survey, in lower Kapue Stream, near the area where watercress had been planted by the irrigation diversion. This physid species was very abundant on the rocks, watercress, and other aquatic vegetation at this station. As the only species of aquatic snail observed throughout the entire study area, it was no coincidence that this species was found near planted watercress and a major irrigation diversion. These findings are of interest because this indicates that the pristine streams sampled during this study are naturally devoid of both native and introduced aquatic snails. The limited range of the introduced physid species indicates that with the exception of the large neritid snail *hīhīwai* (*Neritina granosa*), only found in the lower reaches of streams, aquatic snails are not native or found in streams draining Mauna Kea.

Aquatic Insects

No federally listed candidate aquatic insect species were observed in the study area. A total of 56 aquatic insect species representing 92% of the aquatic macrofauna were collected in the six streams within the study area. When all stations were combined, 86% were native and 14% were introduced aquatic insect species (Table 4). Generally, upper elevation stations contained a slightly greater proportion of native species than the lower elevations, with upper Honoli'i Stream (3200 ft) having the highest percentage of native species, while upper Kawainui Stream (2700 ft) had the greatest number of native species.

Table 4. Numbers of native and introduced aquatic insect species found in six streams assessed for the *Koa* Timber commercial logging EIS, South Hilo District, Hawai'i Island.

Station	Elevation	Number (%) Native spp.	Number (%) Introduced spp.	Total Aquatic Insect spp.
Honoli'i	1760 ft	27 (90%)	3 (10%)	30
Honoli'i	3200 ft	24 (96%)	1 (4%)	25
Pāhoehoe	2000 ft	13 (93%)	1 (7%)	14
Pāhoehoe	2700 ft	15 (93%)	1 (7%)	15
Kapue	1900 ft	24 (86%)	4 (14%)	28
Kapue	2900 ft	24 (92%)	2 (8%)	26
Hanawī	2300 ft	20 (91%)	2 (9%)	22
Kawainui	2700 ft	26 (93%)	2 (7%)	28
Wai'a'ama	1950 ft	18 (86%)	3 (14%)	21
Wai'a'ama	2640 ft	14 (88%)	2 (12%)	16
All Streams Combined:		48 (86%)	8 (14%)	56

A major finding of this study was the rediscovery of one population of native aquatic insect that was presumed extinct, the long-legged fly *Sigmatineurum omega*. Despite numerous attempts to find this species in streams around Hilo, it had not been collected since 1971 (Evenhuis and Polhemus 1994). Historically, this species had been collected from as low as 850 ft elevation (the "Boiling Pots" area) to 4220 ft elevation in the Wailuku River, with only five individuals collected prior to this study (Evenhuis and Polhemus 1994). *Sigmatineurum omega* is a large, metallic green fly in the family Dolichopodidae, and five individuals were found during the present study in Kawainui Stream. Adults were collected with sweep nets in the splash zones of cascades having a thick layer of green algae growing on the rock faces. Kawainui Stream was relatively small at the station sampled, and in places was only 2-3 ft wide, with a relatively stable flow through a bedrock channel. Despite apparently suitable habitat in nearby streams, *S. omega* was only collected at one station in one stream in the entire study area. The very low numbers and limited distribution of this species reflect its rarity, although very little is known about its biology other than adults (and presumably immatures) prefer splash-zone areas of cascades.

Two species of undescribed (new to science) aquatic flies were discovered during this study; new species in the genera *Eurynogaster* and *Procanace*. Species in the endemic genus *Eurynogaster* are only in found in undisturbed, high elevation habitats. Adults of the new *Eurynogaster* species were collected from 2300 ft elevation on Hanawī to 3200 ft in Honoli'i Stream, during aerial handnet sampling of large cascade and waterfall faces. The new *Procanace* sp. was found from a low of 1900 ft in Kapue Stream to upper Honoli'i Stream at 3200 ft elevation. Because these species have just been found during the present study, virtually nothing is known about their biology or life history, other than adults are found in splash-zones of cascades and waterfalls in relatively high elevation areas of pristine Hawai'i Island streams. Because the two new species have not been found during recent intensive surveys conducted by Hawaii Biological Survey staff in streams draining the Kohala volcano, it is likely they are restricted to upper elevation streams draining Mauna Kea.

Unlike aquatic vertebrates, most aquatic insects have narrow habitat tolerances meaning they can only live in certain sections of flowing water habitats, for example seeps, riffles, or cascade splash-zones. These narrow habitat preferences also have the effect aquatic insects being much more vulnerable to stream disturbances such as stream channelization, dewatering, and invasive species. Because aquatic insects are much less flexible in their habitat requirements than aquatic vertebrates, it then follows that insects provide an excellent tool for assessing the health of an aquatic ecosystem. The overwhelmingly high percentages of native species found during this present study indicate that aquatic habitats within the study area are some of the most untouched and pristine found within the Hawaiian archipelago. The study area compares as well as or better than other pristine aquatic habitats in Hawai'i that have been assessed by staff from the Hawaii

Biological Survey since 1990 (Englund 2001, Englund and Polhemus 2001, Englund *et al.* 2000, Englund and Preston 1999, Englund and Filbert 1997, Polhemus 1995). For example, Koai'e Stream (3700 ft elevation) in Kōke'e State Park, Kaua'i has the greatest number of native aquatic insects recorded from any stream in the Hawaiian archipelago, with 31 native and 8 introduced species of aquatic insects, for a total native percentage of 78% (Englund and Polhemus 2001, Englund *et al.* 2000). Streams sampled during the present study had lower numbers of total species than the exceptional Koai'e Stream, Kaua'i. A greater number of native species would be expected on a geologically older island such as Kaua'i, but all streams examined in the current study had higher percentages (as calculated by species numbers) of native aquatic insects (see Table 4) than the nearly pristine streams recently studied on Kaua'i (Englund and Polhemus 2001)

Five endemic aquatic insect species considered sensitive to environmental disturbance were found during this study: three species of damselfly (*Megalagrion blackburni*, *M. calliphya*, *M. hawaiiense*), the giant Hawaiian chironomid midge (*Telmatogeton torrenticola*), and the long-legged fly *Sigmatineurum omega*. All of these natives are highly sensitive to invasive species and environmental change, and none are found in disturbed environments. Although the three damselfly species remain common in undisturbed Hawai'i Island streams, *T. torrenticola* is becoming increasingly rare, and *S. omega* remains one of the rarest and most elusive of all aquatic insect species in the Hawaiian Islands. The presence of these species in both lower and upper elevation regions of the study area indicated aquatic habitats remain almost completely unimpacted (with a few notable exceptions) when compared to freshwater habitats found in closer proximity to the ocean. Although a limited number of small, silted tributaries flowed into larger streams in the lower study area (see Study Area), the overall waterflow contribution from these areas was insignificant and the impacts were not large enough to effect aquatic insects sensitive to siltation. For example, *Telmatogeton torrenticola* is one of the best indicators of water quality and water quantity of any aquatic species, and can only be found in clear flowing, unsilted stream habitats. Accordingly, this species was only found in the lower reaches of the largest streams in the study area: Honoli'i, Wai'a'ama, and Kapue Streams. *Telmatogeton torrenticola* was not found in the upper reaches of these streams, or the smaller side streams sampled because its larvae require crashing cascade and waterfall habitats (Benbow *et al.* 1997). It appeared that water volume in the uppermost reaches of the study area was not sufficient to support this species because streams draining Mauna Kea gain waterflow as elevation decreases. However, other species sensitive to disturbance such as the long-legged fly (previously believed extinct) *Sigmatineurum omega* were only found at high elevations within the study area, indicating the upper and lower portions of the study area supports invertebrate species sensitive to disturbance.

CONCLUSIONS

Overall Findings

The six major streams examined in this study included Honoli'i, Pāhoehoe, Kapue, Hanawī, Kawainui, and Wai'a'ama Streams, all located within the South Hilo District, Hawai'i Island. No Federally Threatened, Endangered, Candidate, or eminently threatened species of aquatic animals were found in or around the major stream ecosystems examined during the present study. Aquatic habitats within the proposed project area were found to be some of the most pristine remaining within the State of Hawai'i, and the lack of any major alien aquatic fauna within these habitats was unusual. The high percentages of native aquatic fauna found within the proposed project area, great densities of native aquatic species, and the high diversity of native taxa all indicate the aquatic habitats within the proposed area contain some of the best remaining examples of endemic native Hawaiian aquatic biodiversity within the archipelago.

Despite the high native aquatic biodiversity, some native invertebrates including important Hawaiian cultural food items such as the freshwater crustacean *'ōpae kuahiwi* are seriously threatened in this area by introduced ungulates such as feral pigs, and by introduced plants such as strawberry guava. Both feral pigs and strawberry guava threaten native aquatic habitats because they negatively impact water quality by increasing sediment inputs into streams, and can change a clear, cold mountain stream into turbid, warm habitats much less suitable for native fish, crustaceans, and aquatic insects and other native aquatic invertebrates.

The greatest threat from selective *koa* logging to native aquatic biota would be an increase in sediment input into streams flowing within the project area. Increased sedimentation resulting from this project could occur from two primary pathways: either through direct disturbance during the actual logging process, or from an increase in invasive species after the *koa* has been logged. Siltation or sediment input has been found to be the greatest single water pollutant in terms of ecological and economic impacts affecting streams in the United States (Waters 1995). Not only can silt impair fish reproductive and physiological processes, siltation also directly impacts fish food organisms such as aquatic insects and other invertebrates (Waters 1995). Small increases in sediment load can result in drastic changes in aquatic invertebrate species density and composition. Waters (1995) in his monograph on stream sediment stated that "…additions of anthropogenic sediment would result in loss of the best benthos habitat..." and consequently would lead to reductions in invertebrate populations and the fish that rely on these invertebrates for food.

Potential Impacts of Commercial *Koa* Harvest


Muddy guava tributary-Honoli'i Stream, 1760 ft

We observed that streamlets flowing through strawberry guava in the lower project areas were extremely silted. This silting is a result of a domino-effect of the alien invasive, strawberry guava (Staples 2001). Guava secretes an allelopathic chemical that kills off other plant species, and leaves a monoculture with no shrub or brush understory (Stone and Pratt 1994). Lacking this understory, there is nothing to hold the soil in place during heavy rains. The resultant soil erosion in these water drainages renders formerly clear streams cloudy (see picture above). Feral pigs increase the problem by spreading guava very efficiently through the feeding on fruits and spreading seeds through their fecal material (Kishinami 2001). They also increase soil disturbance in areas both with strawberry guava and in pristine areas by way of rooting up soil for food (usually tubers or roots).

A major concern from an aquatic ecosystem perspective would be that weed control needs to be effective in the patches were *koa* is logged. This would ensure strawberry guava does not replace the mature *koa* that has just been logged. Aquatic biota would be adversely impacted if invasive weed species become established because they are not adapted to heavily sedimented water conditions. To ensure buffer zones are maintained and that invasive species do not gain a foothold in areas where *koa* is selectively logged it is recommended that forest regeneration be monitored for the life of the project by a botanist or forester with experience in native Hawaiian rainforest ecosystems. It is also recommended that aquatic habitats and aquatic biota be monitored for the life of the project to ensure logging does not increase rates of sedimentation that would adversely impact native aquatic biota.

Logging areas lacking riparian buffer zones have higher suspended sediment levels and decreased fish and invertebrate densities (Waters 1995). A buffer zone is an area where *koa* logging does not occur, and this minimizes sediment impacts into the streambed that could harm native Hawaiian aquatic species. If a buffer zone were maintained, the physical act of selectively harvesting *koa* using helicopters at the rate of one tree per acre would have likely little or no impact on aquatic species. However, once logging is completed there is a strong potential that alien plant species will gain inroads into the native forest, especially in the upper project areas (> 2300 ft elevation). This is because by necessity the *uluhe* fern will be cleared for the loggers to gain access to the base of the *koa* trees, opening up this area to invasion by strawberry guava. It

should be noted that *uluhe* fern grows as high as 30 ft up a *koa* trunk, so the amount of *uluhe* clearing around the *koa* trees to be harvested will not be trivial.

Buffer strips are an old and reliable technique used to control excessive sediment input into a stream from forestry operations, and they operate by retaining and filtering sediment that would otherwise directly go into a stream (Waters 1995). Buffer strips leave an uncut zone of natural vegetation along the sides of streams where logging occurs (Waters 1995). Buffer zone measurements are the total width along a stream corridor starting from the edge of each side of a stream; e.g., a 70-foot buffer zone would be 35 feet of uncut forest on each side of the streambank, measured horizontally from the high-water mark or bank-full flow area (Platts et al. 1983) of each streambank.

It is recommended that a riparian buffer zone (an area where no timber harvest occurs) be maintained at least 75 feet away from the streambed (Waters 1995). However, Waters (1995) also mentioned other studies that showed the width of effective buffer strips was dependent on local conditions. Riparian buffer zone (or Streamside Management Zones-SMZs) recommendations by Hawaii DOFAW (1996) state that "SMZs should be designed on a case by case basis", and will be dependent on terrain, soil type, stream sensitivity, precipitation, and other factors.

DOFAW [see page 21] (1996) recommends a minimum width of 35 feet on each side of the stream, for a total buffer strip of 70 feet of protected stream width. The minimum riparian buffer zone recommended by DOFAW approximately equals the 75-foot total length recommended by Waters (1995), although partial harvesting, as allowed by the DOFAW (1996) guidelines, was not recommended by Waters (1995). However, it should be emphasized that the project area has a wide variety of soil types, wetlands, and deeply incised gorge areas. Thus, determining one overall buffer zone width for the entire project area is not possible, but will have to be done within each watershed and at each particular elevation and logging area. Determination of specific buffer zones will be dependent upon local conditions found along each stream, and will vary along a specific stream going from lower to higher elevations within the project area. Buffer zones will be need to be determined by a registered professional forester taking into account soil type, slope, wetlands, and other factors, but should be at minimum approximately 75 feet in total width.

Fortunately there is a program in Hawaii administered by the USDA Natural Resources Conservation Service that will actually pay private landowners to set aside buffer zones in and around streams in places such as the proposed *koa* logging area. A yearly rental rate will be paid to the private landowner by the USDA to maintain a buffer zone, this is called the Conservation Reserve Program (CRP). Details on this program are available at http://www.hi.nrcs.usda.gov/whip/whip.htm. This economic incentive provides further reasons for maintaining a no-cut buffer zone along the stream corridors within the project area.

Although DOFAW (1996) guidelines state that buffer zones (SMZs) are not "timber harvest 'keep out' zones" (page 20), they also state several sentences later that the "sensitivity of stream" should be a factor in establishing the width of SMZs. Because of the many sensitive and rare species of native aquatic animals found within the study area, we recommend against any timber harvesting within the riparian buffer zone. Additionally, the DOFAW (1996) guidelines that allow selective harvest within the buffer zone contrast with the findings of the scientific literature (see Belt et al. 1992; Waters 1995), and management plans for high quality streams in place for many states and provinces (Belt et al. 1992). According to Belt et al. (1992) timber harvest within the riparian buffer zone has the potential to affect water quality and fish habitat by removing forest canopy that reduces shading and raises water temperature. This adversely impacts fish food supply (i.e., invertebrates), and also alters the amount of large organic debris (LOD) that is important for fish habitat.

Mitigation of Impacts

Every effort needs to be made to reduce invasive species from gaining increased access to areas where *koa* is selectively helicopter logged. All used logging equipment (e.g., cages, chainsaws, ropes, etc.) brought in from the mainland should be steam-cleaned or disinfected and sterilized prior to use to eliminate any hitchhiking invasive species, especially ants, which can destroy the invertebrate ecosystem in only a few years. Any helicopters brought in from the mainland should have their skids sterilized or disinfected prior to use in a Hawai'i *koa* forest. If invasive species start to become established in the small open areas where *koa* is harvested, then weed control of some kind will be required, and these areas need to be immediately replanted with *koa* and/or *'ōhi'a* seedlings. Net beneficial effects to the native ecosystem would accrue if strawberry guava is cleared and replanted with *koa* seedlings in the lower elevations of the project area. Monitoring by foresters and biologists trained in Hawaiian ecosystems should be conducted to ensure control of alien species in areas where *koa* is selectively logged, and ensure no further degradation of the watershed.

Other potential mitigation measures could include an increase of feral pig hunting in the project area by providing access to local hunters. A successful model for increased local hunter participation that has reduced the impacts of feral pigs has been effectively used in Pelekunu Valley, Moloka'i by The Nature Conservancy of Hawai'i. Additionally, because of the extremely remote nature of the property, hunting may not always be possible or effective in all areas, and fencing may be required to exclude pigs from returning to areas where *koa* is being reforested. Fences are effective and would not need to be constantly monitored. Any needed monitoring could be conducted incidentally during the many helicopter flights required to transport *koa* logs throughout the project area. Federal agencies such as the USDA Natural Resources Conservation Service assist private landowners in habitat improvement projects such as feral ungulate fencing. Further information about this is available at http://www.hi.nrcs.usda.gov/whip/whip.htm.

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