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# TECHNICAL REPORT #17
# A LIMNOLOGICAL SURVEY OF LOWER PALIKEA AND PĪPĪWAI STREAMS, KĪPAHULU, MAUI

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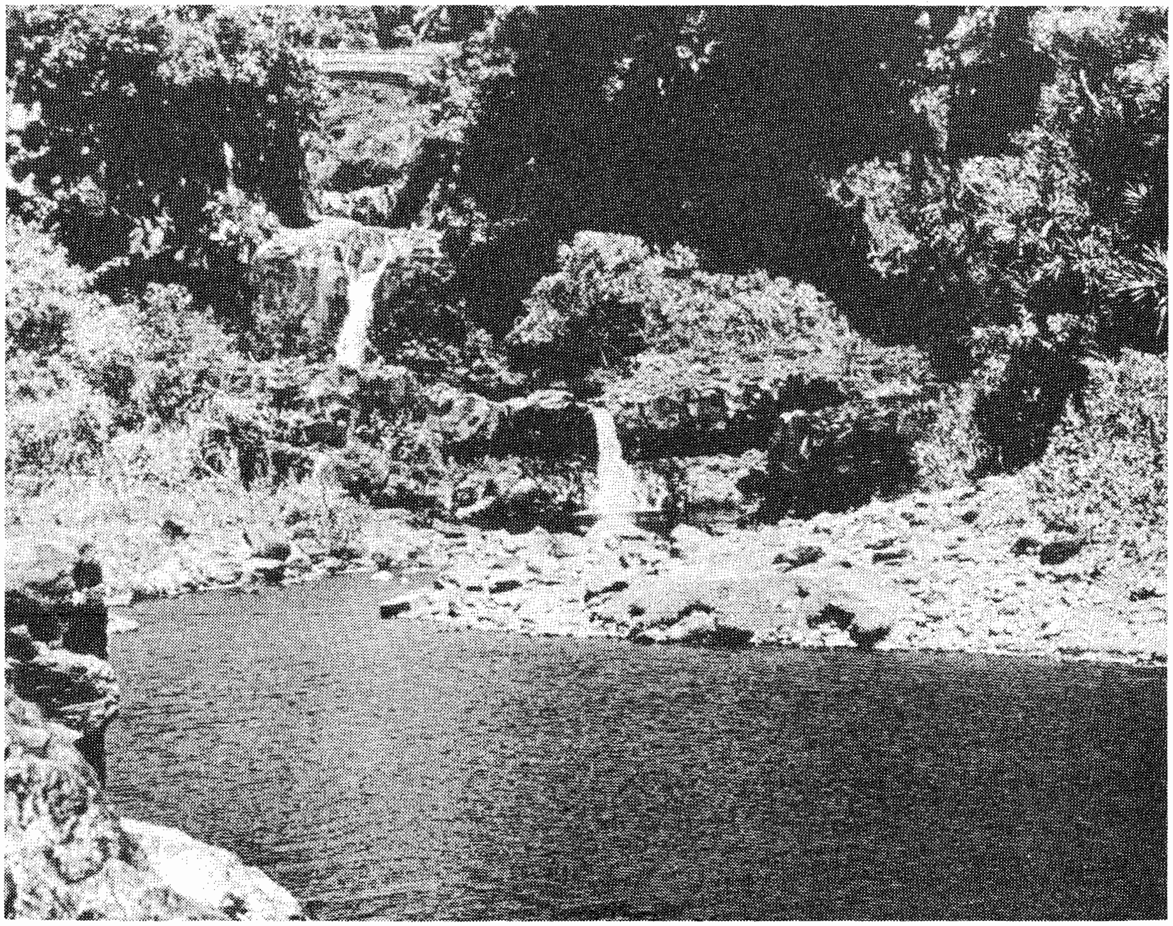
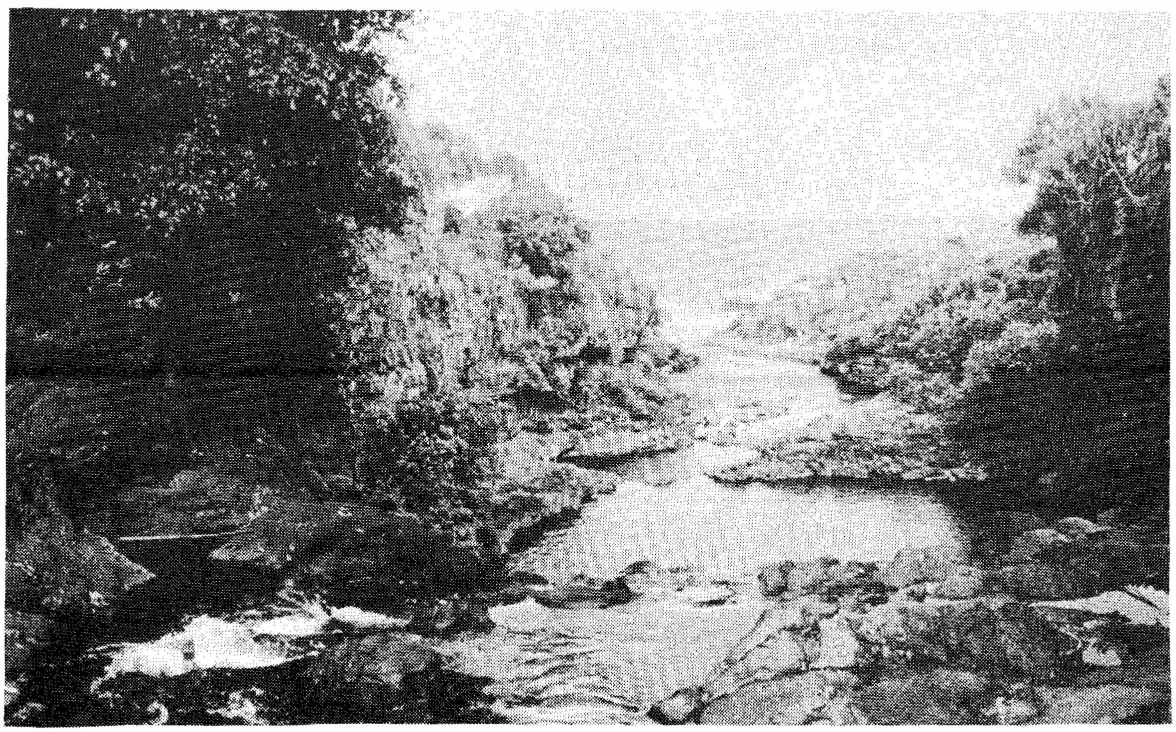
The National Park Service and the University of Hawaii signed the memorandum of agreement establishing this Cooperative National Park Resources Studies Unit (CPSU UH) on March 16, 1973. The CPSU UH provides a multidisciplinary approach to studies on the biological resources in the National Parks in Hawaii, that is, Hawaii Volcanoes National Park, Haleakala National Park, City of Refuge National Historical Park, and Puukohola Heiau National Historic Site. Through the Unit Director, projects are undertaken in areas identified by park management. These studies provide information for resource management programs. The involvement of University faculty and students in the resource management of the National Parks in Hawaii leads to a greater awareness of the problems and needs of the National Park Service. At the same time, research not directly or immediately applicable to management is also encouraged through the CPSU UH.

Contribution numbers are assigned as follows. CPSU UH identifies the Cooperative National Park Resources Studies Unit of the University of Hawaii. This is followed by a three-digit number assigned in sequence to each new project of this CPSU. The fourth digit indicates the report number for that particular project.





'Ohe'o Gulch (Seven Pools) area, Kīpahulu Valley, Maui.

# A LIMNOLOGICAL SURVEY OF LOWER PALIKEA AND PĪPĪWAI STREAMS, KĪPAHULU, MAUI

May 1977

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We would especially like to acknowledge the help of Kimo Mitchell, and dedicate this study to his memory with hopes that it may lead to the perpetuation of a part of the Hawai'i he loved so much.

# INTRODUCTION

Since 1969, all of Kīpahulu Valley above Palikea Peak, as well as Palikea Stream, have been part of Haleakala National Park. The "seven pools" area within 'Ohe'o Gulch has become a prime visitor destination, and continues to attract increasing numbers of tourists as well as island residents. The National Park Service is considering improvements in the 'Ohe'o-Pīpīwai area which will accomodate existing visitor use levels, while maintaining the cultural and aesthetic integrity of the Kīpahulu coastal area. These plans are discussed in the 55-page Draft Development Concept Plan for Haleakala National Park, Kipahulu District (NPS 1045) published in June 1976.

Another important concern which has been given careful attention is the need to protect the Palikea Stream ecosystem in its natural state. Palikea's waters flow from the undisturbed, forested slopes of Kīpahulu Valley, over Makahiku Falls, and through some of the most interesting geologic formations and scenic areas in East Maui. Palikea is one of the largest streams on Maui (by length and discharge) which is not diverted, and therefore it may provide a suitable reservoir for significant communities of endemic aquatic organisms. Because most freshwater ecosystems in Hawai'i are degraded, and many of the remainder are threatened by water exploitation and development, it is important to realize that Palikea-Pīpīwai is the only major perennial stream system of high natural quality that is currently under the jurisdiction of the National Park Service. Thus, the stream is an important asset to the Park Service in its efforts to preserve representative parts of the Hawaiian environment for aesthetic recreation, resource interpretation, and scientific uses. Furthermore, Palikea provides an important educational function: it is a showcase of the native freshwater biota, unique to Hawai'i. National Park status, however, does not in itself guarantee adequate environmental protection. The State of

Hawaii, in deeding its Kīpahulu lands to the National Park, has retained water development rights below the gauging station--a situation which could have serious impacts upon stream quality and endemic stream life if such development occurs. It is therefore imperative that special attention and effort be placed upon the preservation and enhancement of the Palikea-Pīpīwai-'Ohe'o stream ecosystem.

To this end, and as part of a continuing inventory of biological resources within Haleakalā, the National Park Service and the Cooperative National Park Resources Studies Unit of the University of Hawaii retained us to initiate an aquatic survey of the lower reaches of these streams. Research was initiated in November 1975 and involved two extended field expeditions into lower Kīpahulu Valley. The specific purposes of the study were to: (1) present a general description of the major aquatic features and riparian floral communities; (2) conduct a survey of stream biota with special emphasis on obtaining information about native and endemic macrofauna and their relative abundance; (3) determine as far as possible the physical and biological quality of the stream with regard to questions of stream ecology and stream utilization as a park resource; and (4) make recommendations for planners concerned with the protection of the natural character and educational potential of Palikea.

In Palikea Stream, research efforts were restricted to the 3.9 km (2.4 miles) reach below the USGS gauging station at an altitude of 471 m (1546 ft) (Figure 1). To clarify further discussion, that 2.1-km (1.3-mile) portion of the stream between the gauging station and the confluence of Palikea and Pīpīwai streams (145 m [476 ft] altitude) will be called "lower Palikea." The 1.8-km (1.1-mile) portion which flows from the confluence through the "seven pools" to the sea will be called "'Ohe'o," and the 1.2 km (0.75 mile) of Pīpīwai Stream between the confluence and Waimoku Falls (342 m [1122 ft] altitude) will be referred to as "Pīpīwai."

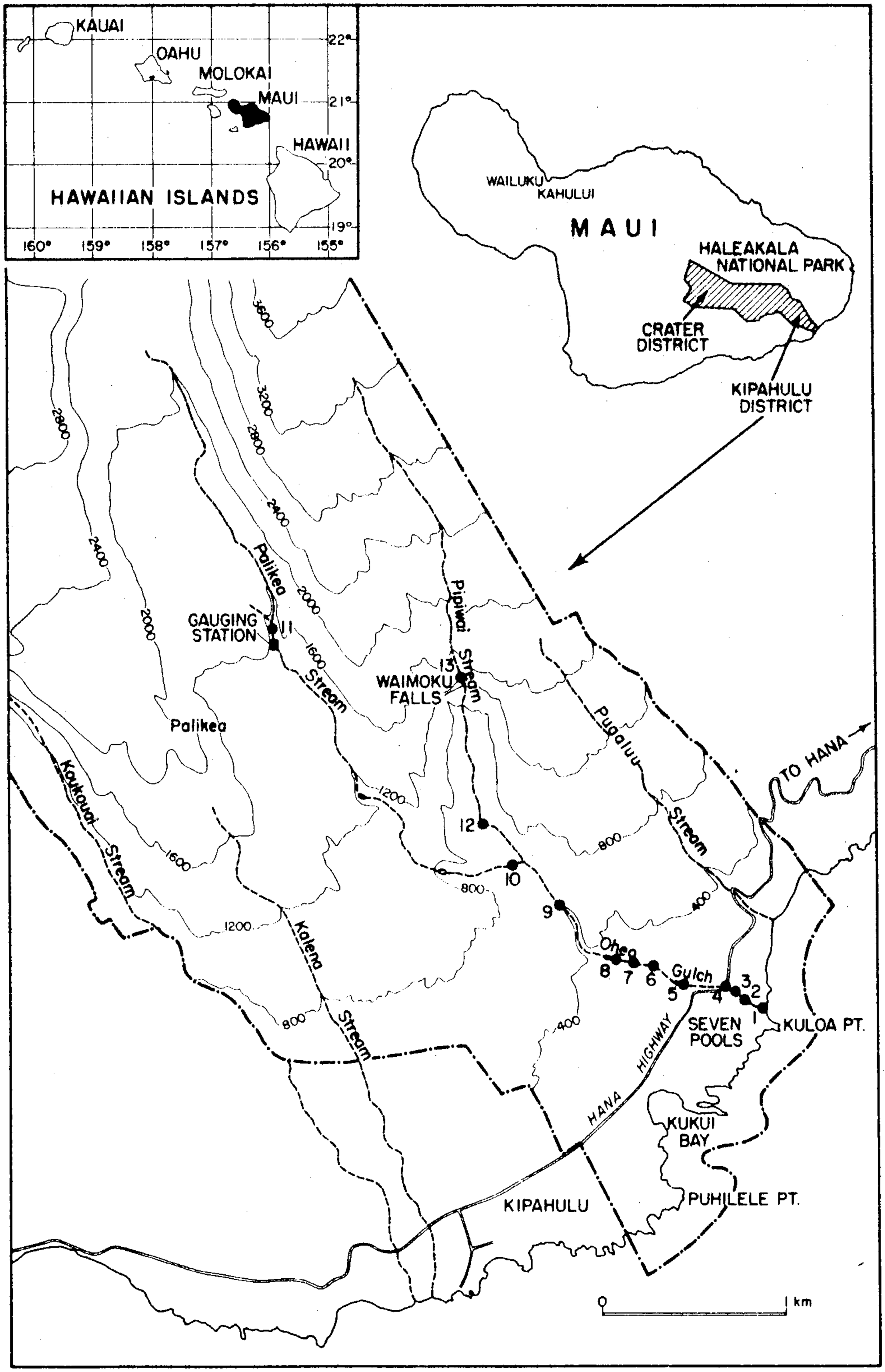


FIGURE 1. Lower Kīpahulu Valley and the Palikea-Pīpīwai-'Ohe'o stream system, Haleakala National Park, Maui.

# PHYSICAL ENVIRONMENT

Palikea Stream is the major drainage of Kīpahulu Valley on the eastern flank of Haleakalā, Maui. The stream, which follows the eastern edge of the valley, joins with Pīpīwai to reach the ocean via 'Ohe'o Gulch, which is located approximately 7.5 miles (12 km) southeast of Hāna, Maui. Palikea is an interrupted, second-order stream which, along with its major perennial tributary, Pīpīwai, drains a total area of 2,250 ha (5,560 acres) and flows a distance of 12 km (7.5 miles) from its headwaters at an altitude of 1,800 m (5,906 ft) (Figure 2). The mean annual discharge (as recorded by the United States Geological Survey) is 58 cfs (1.6 $m^3/s$); however, the flow regime is highly erratic. Hydrological evidence suggests that the stream responds rapidly to rainfall (Takasaki and Yamanaga 1970), and monthly discharge rates appear to be closely related to the mean monthly rainfall (Figure 3). The periods of greatest flow are April, November, December, and January. In January 1965, a record instantaneous flow of 16,100 cfs (456 $m^3/s$) was recorded. Park rangers have observed the water level in 'Ohe'o Gulch rising several feet per hour. During periods of little rain, lower Palikea may not flow at all; however, an abundance of ecologically significant year-round pools exist along the stream course which can harbor aquatic animals during these periods. Maintenance of flow through 'Ohe'o Gulch even during dry periods appears to be sustained by Pīpīwai Stream and subsurface flow of Palikea.

Stearns and MacDonald (1942) provide a clear geological description of the area. The bedrock within the lower Kīpahulu watershed is largely lava of the Hāna volcanic series (primarily thin, permeable pāhoehoe and 'a'ā flows) which overlie older Kula lavas. The stream flows over characteristic columnar rock formations through lower Palikea and 'Ohe'o. The high cliffs surrounding Pīpīwai are composed of thin beds of highly weathered tuff interbedded with lavas. Both rock types may carry perched water. Below Waimoku Falls, the

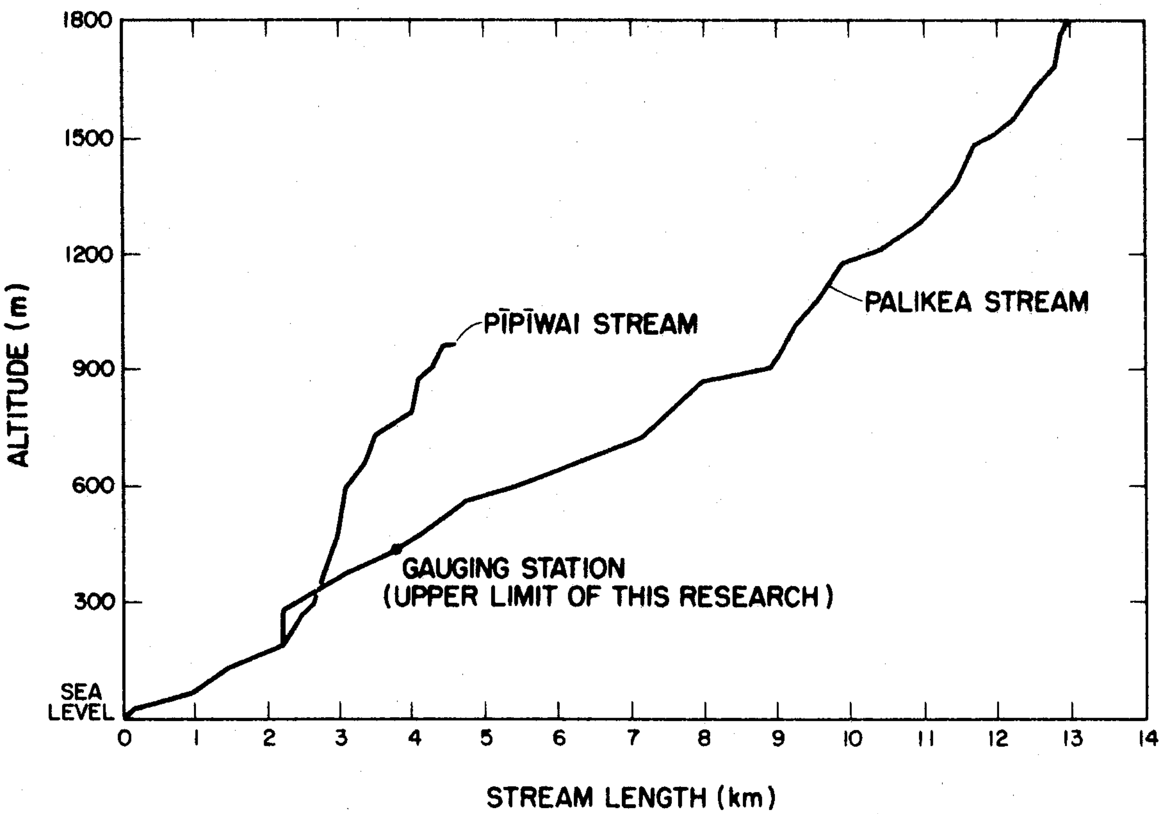


FIGURE 2. Profiles of Pīpīwai and Palikea Streams, Kīpahulu Valley, Maui.

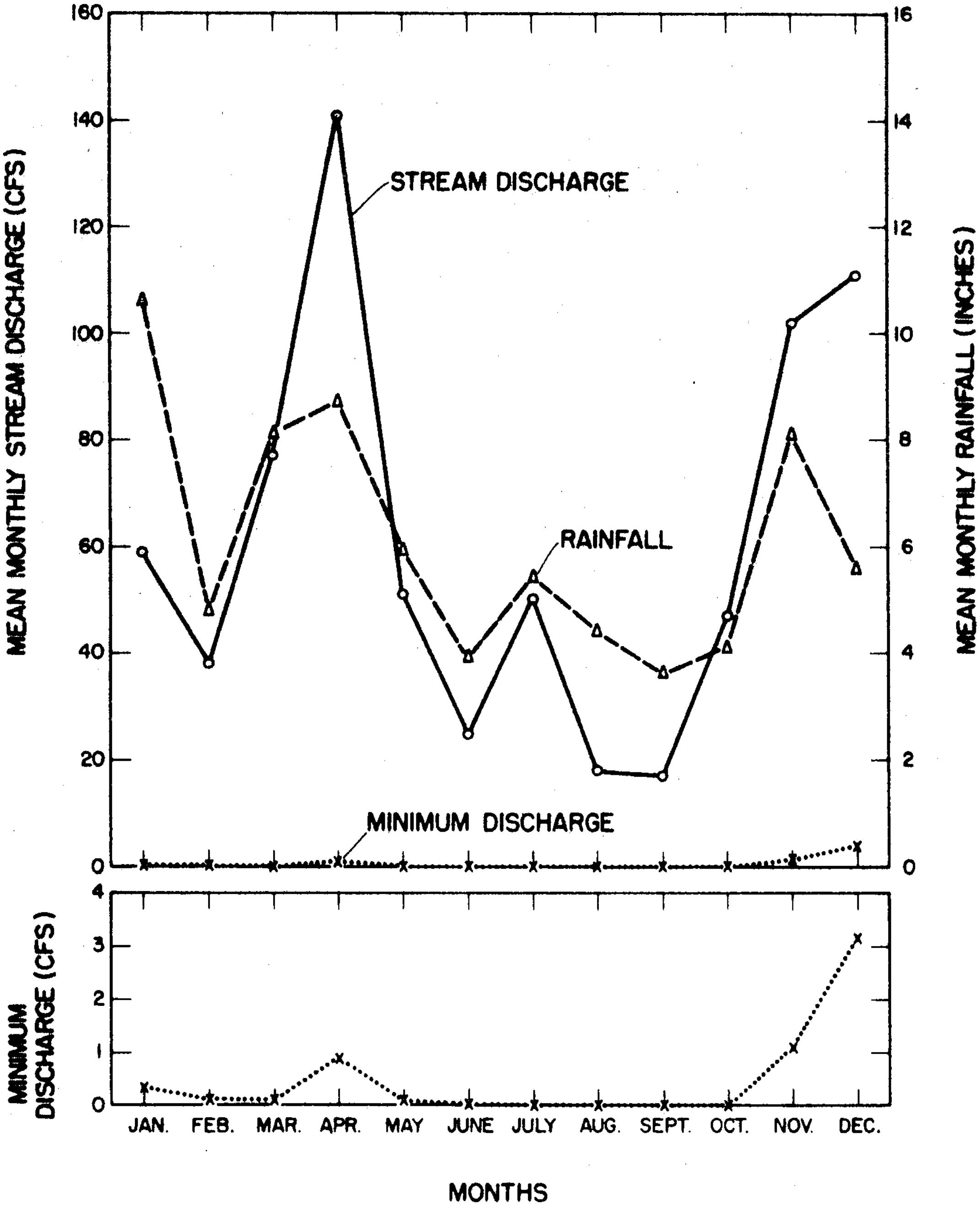


FIGURE 3. Monthly patterns of rainfall and discharge at Palikea Stream, Kīpahulu Valley, Maui. (Discharge data from US Geological Survey 1976.)

stream channel is largely older alluvium, deeply weathered, impermeable conglomerates forming terraces along the stream. These grade into coarse angular talus and landslide deposits at the base of the falls.

Soil types are of the Hydrandepts-Tropaquods association, Maka'ale series, and rough mountainous land (USDA Soil Conservation Service 1972). These have a sticky, plastic nature, are high in organic content (40-60%) and strongly acid. The Tropaquods soils are generally wet and are interspersed with small, peaty bogs of very high acidity.

The lower forests and surrounding valley floor were once cultivated for taro and other Hawaiian crops. In the late 1920's, this land was converted to cattle pasture and sugar cane. Currently, cattle graze the lower valley slopes above the sea up to the lip of 'Ohe'o Gulch in some locations. Kīpahulu Valley today has a large population of feral pigs which disrupt vegetation along the entire stream course. Several small jeep and foot trails provide visitor access to areas of lower Palikea and Pīpīwai for hiking, swimming, bathing, camping, and fishing.

## A Note on Hawaiian Stream Life

The fauna of Hawaiian streams is receiving increasing international attention because of its unique nature, and its distinctive adaptive strategies for life in precipitous island streams. These natural communities are characterized by a low diversity of species but a high degree of endemism (Maciolek 1975).

Among the endemic fauna only the larger animals, visible by eye to the observer, have been described in detail. These include many aquatic insects and other invertebrates as well as fishes. The endemic damselfly genus *Megalagrion* has 28 species--all of which have apparently evolved from a single ancestral form. The adults of this genus, most of which metamorphose from aquatic naiads, possess striking coloration and may be found at virtually all elevations (Zimmerman 1948).

Many of the more characteristic species--goby fishes ('o'opu), shrimps ('ōpae), and mollusks (hīhīwai and hapawai) --demonstrate their ancestral ties to a marine origin in their diadromous life cycle. After the eggs of these animals hatch in fresh water, stream currents carry the larvae to the ocean where they undergo early development as marine plankton for a period ranging from a week to several months. During this time, the larvae may be transported great distances by littoral currents. Upon receiving an appropriate stimulus, they settle at stream mouths as prejuveniles and migrate upstream to find suitable habitats and continue their growth to maturity.

All endemic stream animals are rheophilic (current-loving) and have adapted for movement and feeding in torrential streams. Only members of the teleost family Gobiidae ('o'opu) possess sucker-like, fused pelvic fins which enable them to cling to stones in riffles and waterfalls. It is by this mechanism that the juvenile 'o'opu are able to traverse long distances upstream. Similarly, it is not uncommon to find individual *Neritina granosa* (hīhīwai)--a species with a large, muscular foot--above 'Akaka Falls (396 m altitude [1,300 ft]) on the island of Hawai'i. Large numbers of the rare *Lentipes concolor* ('o'opu 'alamo'o) (Figure 4), *Sicydium stimpsoni* ('o'opu nōpili), and the mountain shrimp *Atya bisulcata* ('ōpae-kala-'ole) migrate above seemingly impossible barriers to inhabit the upper reaches of pristine streams (the latter by traveling through dense strands of filamentous algae and mosses which cling to the face of waterfalls).

An excellent characterization of the native Hawaiian fauna is presented by Maciolek (forthcoming). Titcomb (1972) provides a lively discussion on the importance of the endemic fishes to the culture and economy of prehistoric Hawai'i.

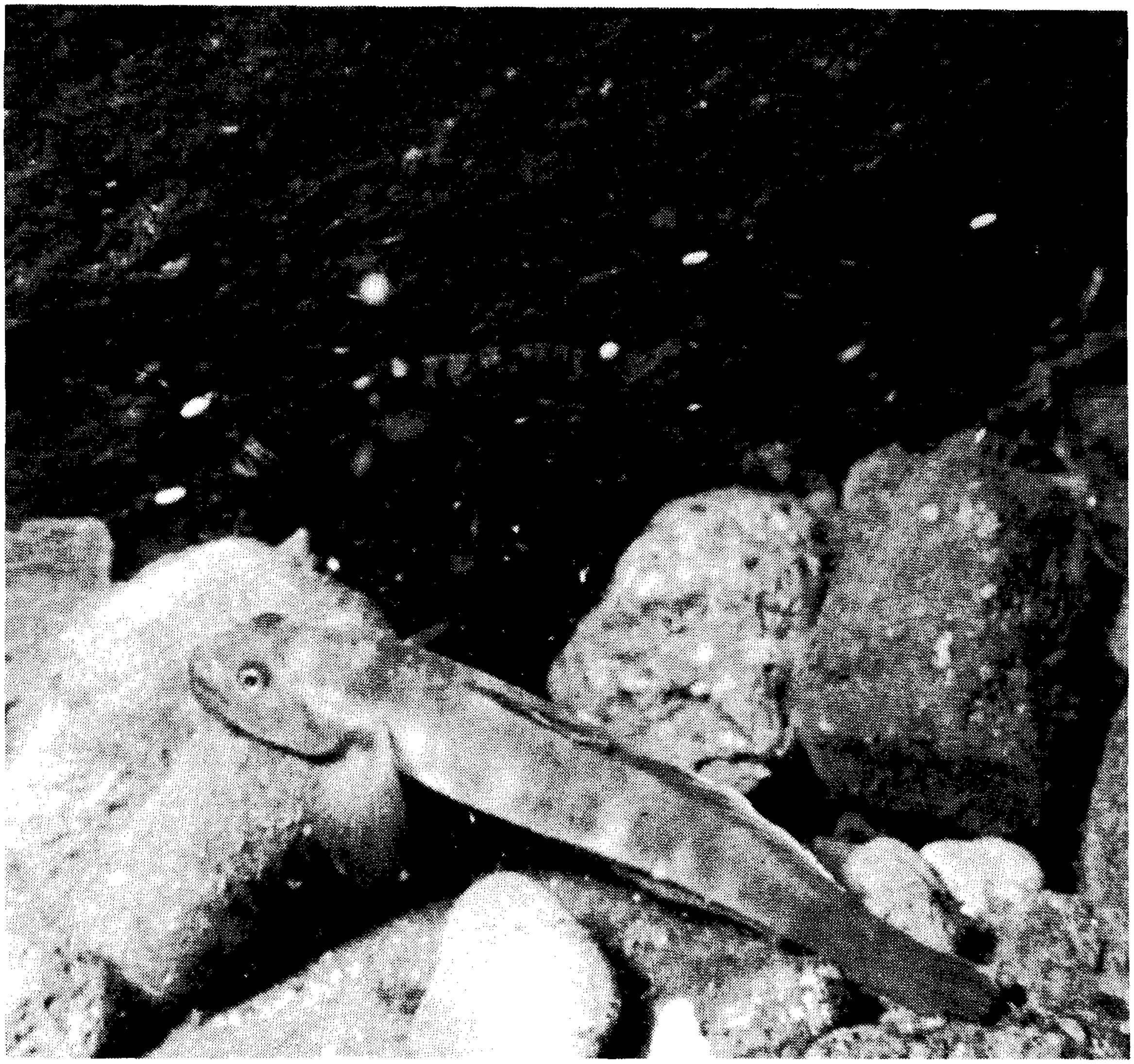

FIGURE 4. Small populations of the goby *Lentipes concolor* ('o'opu 'alamo'o), which is endemic to the Hawaiian Archipelago at the generic level (Maciolek 1977), were observed in Pīpīwai Stream. The Endangered Species Committee of the American Fisheries Society lists *L. concolor* as rare and endangered (Miller 1972). This photo of a small female *L. concolor* was taken by J. Ford in Wailau Stream, Moloka'i. A single hīhīwai, *Neritina granosa*, can be seen in the background.

# METHODS OF INVESTIGATION

Because the intent of this survey was descriptive, qualitative methods were chosen. This allowed more sites to be sampled while providing the required information. Our first expedition to Kīpahulu was made from November 27 to November 30, 1975. During that time, heavy rains in the mountains created torrential stream flows. The second survey was conducted under more favorable conditions from May 15 through May 24, 1976. Methods used during both surveys were substantially the same.

The original plan was to collect fishes and crustaceans with a portable electrofishing device. Unfortunately, the unit did not operate during either survey. Because of this, biological collections were made with a Surber net (Welch 1948), complemented by visual inspections using a facemask.

The Surber net was used in two ways. To collect drift samples, the net was anchored in a riffle and left for 20 minutes, at which time trapped material was sorted and preserved. Demersal biota was sampled by anchoring the net as before and overturning rocks two to three meters upstream, gradually working downstream to the mouth of the net. Some fishes, crustaceans, and insects were dislodged and swept into the net. Many of the larger animals could not be caught in this manner because of their motility. Their abundances and distributions were therefore assessed by making visual surveys using facemasks. This method proved effective in both pools and shallow riffles.

Samples of aquatic insects were collected both by Surber and hand nets, and periphyton samples were collected by hand. Collections of emergent aquatic plants and riparian vegetation were also made.

It should be reiterated that this survey was intended to be qualitative in nature. In many cases, the presence or absence of species was all that was recorded. At most, rough estimates of abundance were made.

Physicochemical data were collected using standard limnological methods, and compared with existing water quality records for Palikea Stream collected by the US Geological Survey (Table 1). We attempted to duplicate the sampling efforts during the second survey. Sampling sites are shown in Figure 5 with designations which will be used throughout the report.

## RESULTS AND DISCUSSION

### 'Ohe'o

Species distributions along the stream course appear to be discontinuous. This may be due, in part, to the irregular and often severe fluctuations in water quality (Figures 6, 7, 8). In particular, the hydrogen ion concentration in the stream appears to rise radically during freshets. Instantaneous pH measurements taken in Palikea near Sample Stations 5 and 6 during spates were as low as 1.3. Initially, such values may seem erroneous: most texts (Reid 1962; Ruttner 1963; Wetzel 1975) note that pH changes derived from organic acids are rarely depressed below 3.5. However, Lau* (pers.comm.) confirms that such values are not uncommon in Hawai'i, where streams drain watershed areas containing acid bogs. These bogs, high in organic (humic) acids which impart a brownish color to the water, usually possess a significant amount of $H_2S$ gas in bottom sediments (Malmer 1975). Such waters will increase the acidity of a stream in the immediate area of their introduction. Very low pH values may be accounted for by the production of trace amounts of $H_2SO_4$ from the oxidation of $H_2S$ by sulphur bacteria. As this natural effluent moves downstream and becomes diluted, the water regains its buffering capacity ($CO_2$ is lost, and the pH rises).

Tarzwell (1966) suggests that under normal conditions freshwater animals may be able to withstand a wide range of pH. Generally, no harmful effects to fishes have been demonstrated in the range of pH 5 to 9. However,

*S. Lau, Director, Water Resources Research Center, University of Hawaii. Personal communication, 1976.

TABLE 1. USGS WATER QUALITY RECORDS (ARRANGED IN ORDER OF INCREASING DISCHARGE) FOR PALIKEA STREAM, MEASURED AT THE GAUGING STATION (ALTITUDE 470 M).

| Water Quality Parameters | Date of Measurement | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | July 1975 | Oct. 1974 | Jan. 1973 | Nov. 1972 | Oct. 1973 | Mar. 1975 | Jan. 1972 | Apr. 1972 | Nov. 1973 | Mar. 1974 |
| Discharge (cfs) | 0.03 | 0.05 | 1.0 | 1.1 | 1.4 | 1.5 | 2.9 | 275 | 425 | 1020 |
| Temperature (°C) | 23.5 | 22.5 | ..... | ..... | 21.5 | 18.0 | 16.0 | 16.0 | 18.0 | 15.5 |
| pH | 6.5 | 7.3 | 6.7 | 6.3 | 6.9 | 6.8 | 6.6 | 6.7 | 6.2 | 5.6 |
| $HCO_3^-$ (mg/l) | 21 | 9 | 7 | 8 | 8 | 11 | 12 | 4 | 4 | 2 |
| $CO_3^{2-}$ (mg/l) | 0 | ..... | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Specific conductance (μmhos) | 46 | 34 | 30 | 33 | 36 | 48 | 38 | 23 | 18 | 15 |
| Dissolved solids (mg/l) | 37 | 23 | 16 | 19 | 27 | 30 | 27 | 14 | 13 | 11 |
| Total hardness (mg/l) | 22 | 8 | 6 | 6 | 10 | 16 | 9 | 4 | 2 | 3 |
| Dissolved nitrite/ nitrate (mg/l) | 0.03 | 0.18 | 0.00 | 0.10 | 0.01 | 0.02 | 0.10 | 0.00 | 0.01 | 0.03 |
| Dissolved ortho-phosphorus (mg/l) | 0.00 | 0.00 | ..... | 0.00 | 0.00 | 0.00 | ..... | ..... | 0.01 | 0.01 |

SOURCE: Water Resources Data for Hawaii and Other Pacific Areas, USGS publication.

NOTE: Table designed to easily show changes in physicochemical parameters with increase in discharge, rather than chronological changes.

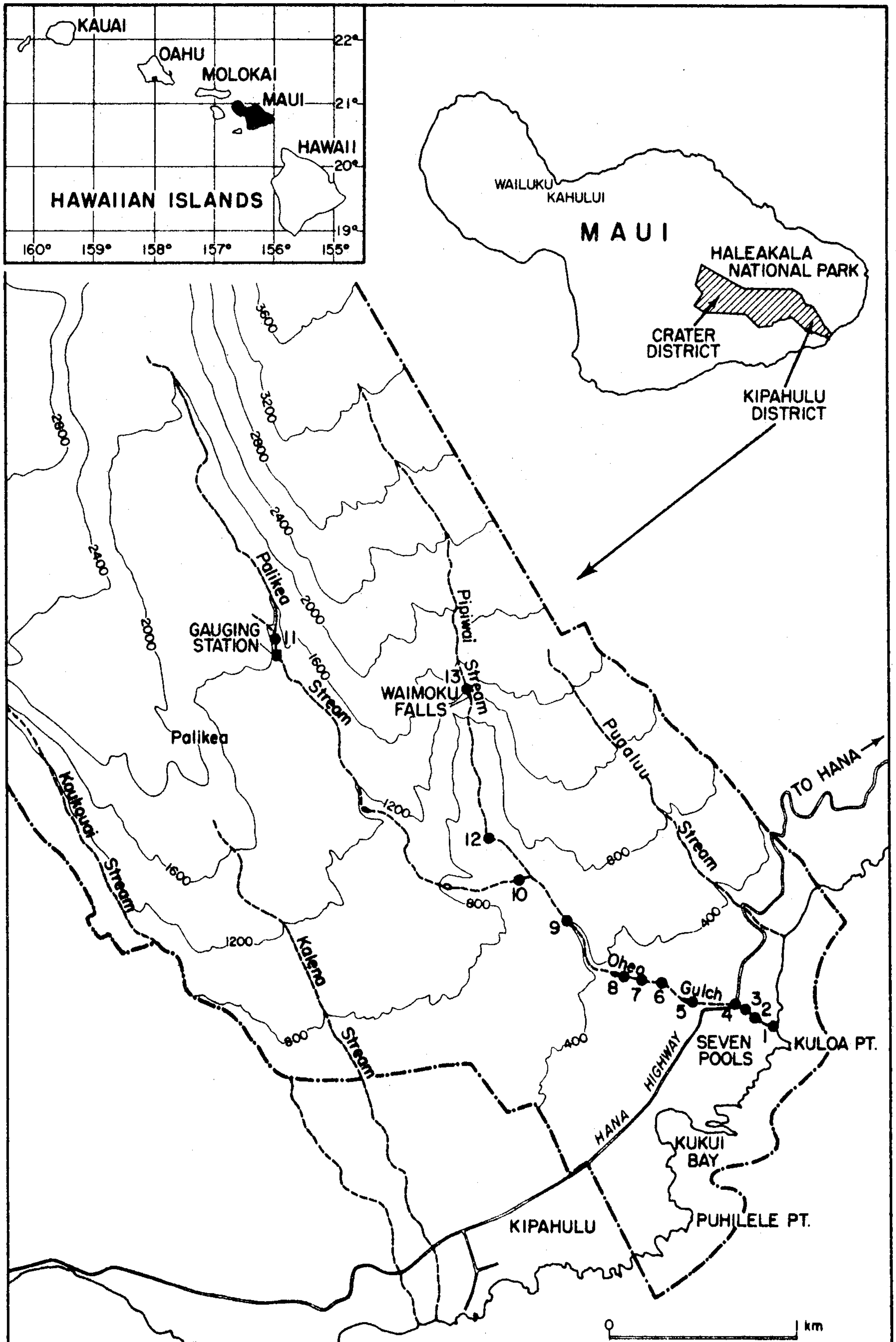


FIGURE 5. Sampling sites along Palikea, Pīpīwai, and 'Ohe'o Streams used during this survey.

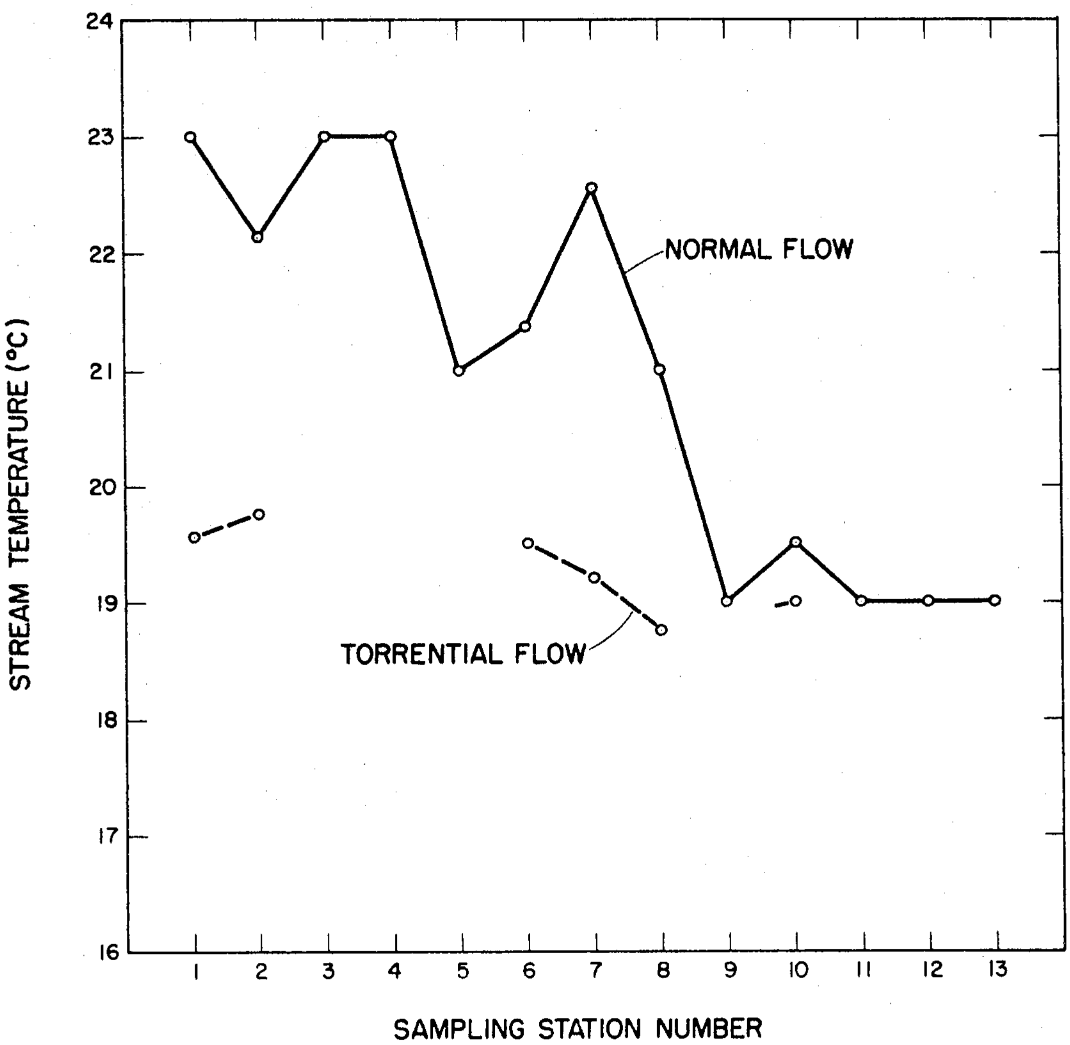


FIGURE 6. Observed changes in stream temperature during normal (May 1976) and torrential (November 1975) flows in Palikea and Pīpīwai Streams. Gaps in data due either to equipment failure or to inaccessibility of stations during torrential flow.

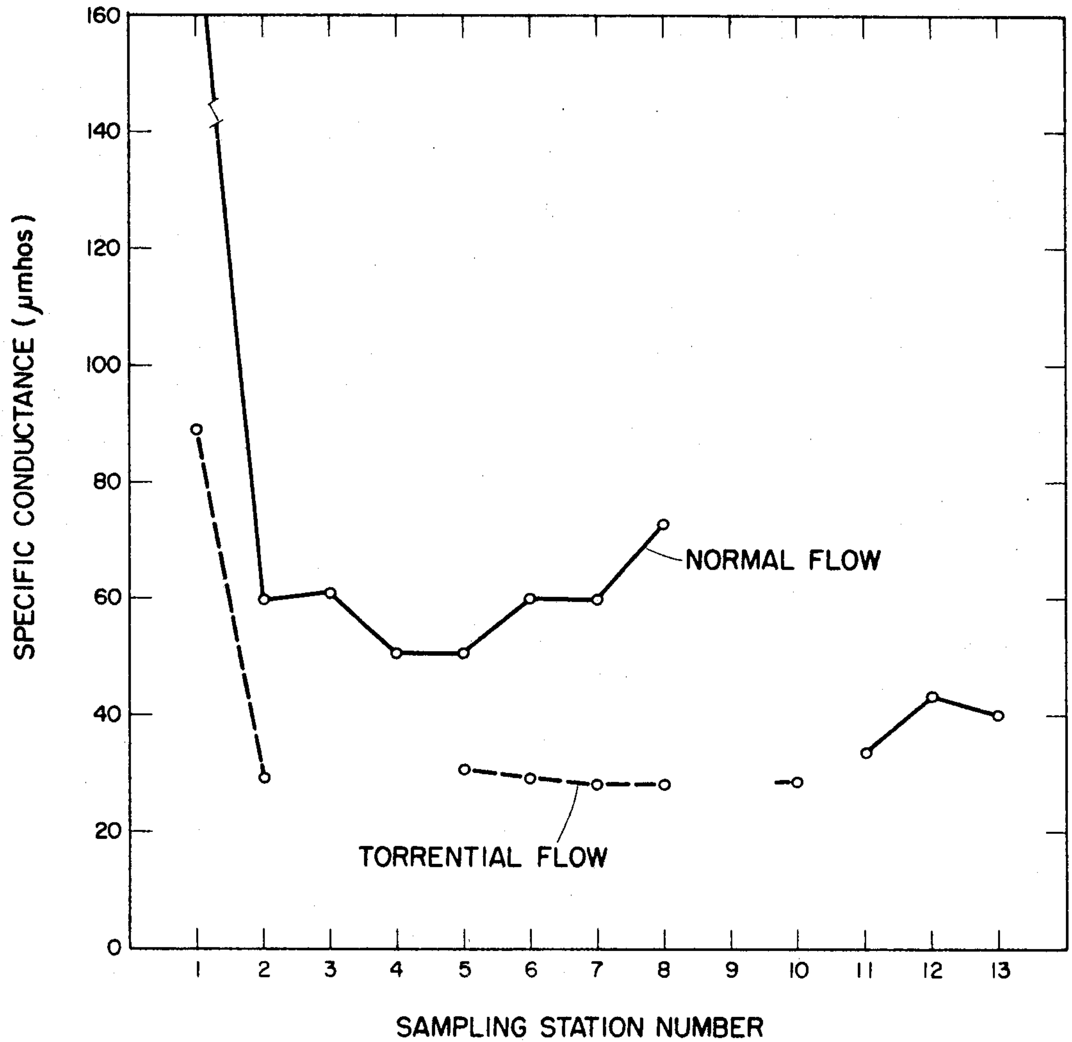


FIGURE 7. Observed variation in specific conductance during normal (May 1976) and torrential (November 1975) flows in Palikea and Pīpīwai Streams.

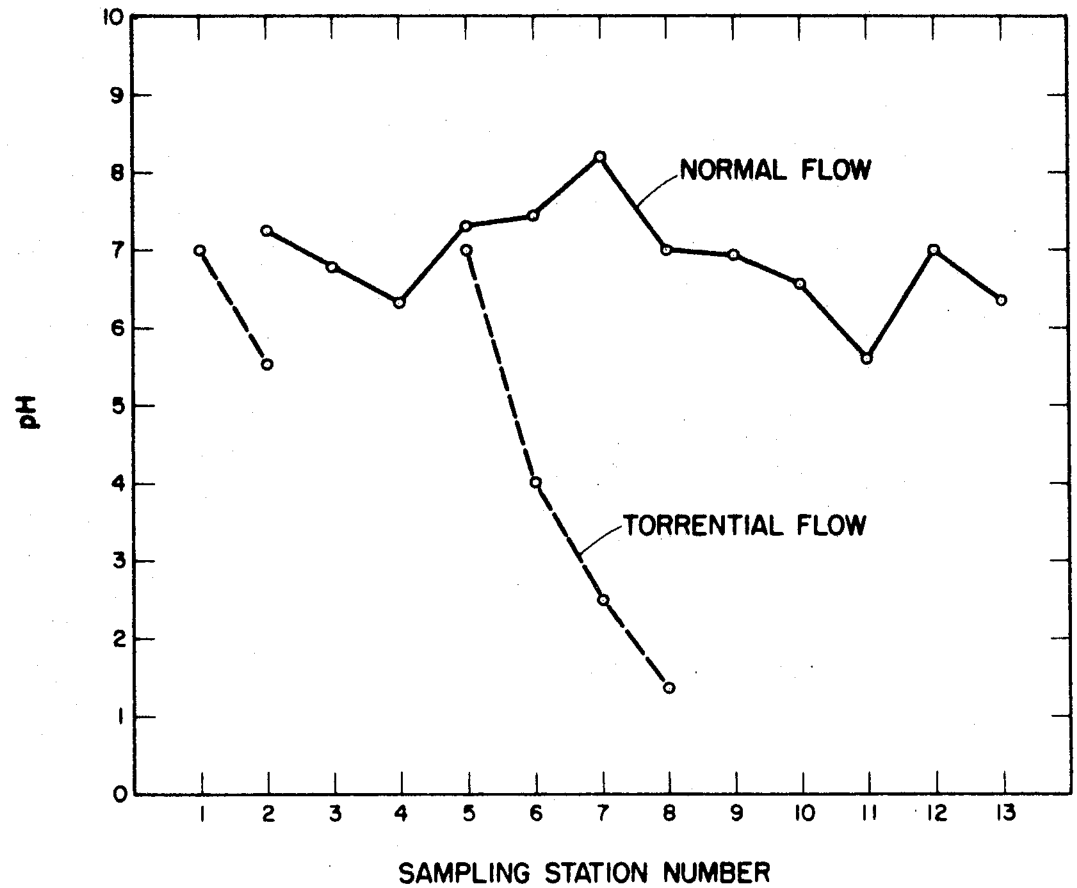


FIGURE 8. Observed fluctuations in pH during normal (May 1976) and torrential (November 1975) flows in Palikea and Pīpīwai Streams.

Hendrey et al. (1976) concluded that the abundance of invertebrate fauna in Norwegian lakes and rivers is greatly reduced by low pH. They attribute this reduction in part to the direct effects of acidification on the animals (for example, low pH may interfere with the normal sodium flow in crustaceans). Macan (1974) further shows that acidification can increase the respiration rates of some fishes. Hendrey (1976) also suggests that some of the low diversity in waters with a high hydrogen ion concentration is due to acid-induced food shortages resulting from the depletion of microbial communities and a subsequent reduction in the breakdown of detritus.

In addition to acid runoff, we noted that boulders in the stream below 450 m (1,476 ft) (and particularly below the confluence with Pīpīwai and Palikea) were coated with red clay sediments. These sediments form thick mats on the rocks demonstrating recent high water levels (Figure 9). Such sedimentation was not observed at or above the gauging station. (We also note that the US Geological Survey records at this altitude do not indicate significant pH variations associated with high stream flows.) It is possible, therefore, that some factors within the lower park boundaries (below the gauging station) may be contributing to this situation.

That excessive organic and inorganic sediment loads are detrimental to virtually every developmental stage of most aquatic organisms cannot be disputed. Sediments in suspension can inhibit photosynthesis, and abrade the sensitive gill tissues of fishes and invertebrates. Silt which settles into rock interstices reduces the exchange of surface waters with oxygen-poor water within the streambed, thereby reducing the oxygen available for developing eggs of many demersal species. In sluggish waters, such an accumulation of silt can physically block the escape of fry and cause their death by starvation or poisoning with $H_2S$.

FIGURE 9. Boulders in the stream below the gauging station were coated with thick mats of red clay sediments demonstrating recent high water levels.

We know of no research that has established tolerance levels of the endemic fauna to extremes of current velocity, temperature, acidity, or sediment load. The Hawaii Cooperative Fishery Research Unit at the University of Hawaii is currently making field and laboratory studies to determine these parameters as part of an ongoing research program on the effects of channel alteration upon aquatic organisms.

Cordone and Kelly (1961) have also shown that silt which blankets the substratum can also destroy algae by the inhibition of photosynthesis, thereby severely limiting primary productivity. An increase in turbidity also has a negative effect upon recreation activities and aesthetic values (Andrews et al. 1976; Masteller et al. 1976).

The first pool located at the mouth of 'Ohe'o is unique in that it is mixohaline: the pool is frequently washed by waves and is probably completely inundated during spring tides and high seas. The influence of the saline intrusion is reflected in the presence of the intertidal mollusks *Nerita picea* (pipipi), *Theodoxus vespertinus* (hapawai), and *Isognomon californicum*. Large numbers of a still-unidentified isopod were observed along the walls and bottom of the pool. This was the only location where the endemic, euryhaline teleost *Kuhlia sandvicensis* (āholehole) was seen. Juvenile āholehole and mullet (pua 'ama'ama) may commonly be found far upstream in watersheds with a slight initial altitude gradient, such as Hanawī Stream on Maui, and Wailau Stream on Moloka'i; however, the precipitous morphological profile of the mouth of 'Ohe'o (Figure 10) may limit āholehole, pua 'ama'ama, and 'o'opu 'ōkuhe (*Eleotris sandwicensis*) to this first pool.

Representatives of the algal genera *Enteromorpha* and *Hildenbrandtia* were observed in dense mats at the water's edge. The stream margins here are bare rock with a sparse cover of *Scaevola taccada* (naupaka). Several isolated pools

FIGURE 10. The steep morphological profile of the mouth of Palikea Stream may prohibit access of several euryhaline species to the lower pools.

perched above the level of the stream contained populations of zygopteran naiads, notonectids, the indigenous pulmonate gastropod *Melania*, and gobiid fry.

Between the first pool and the confluence, the stream possesses a complement of aquatic insect species and harbors small populations of the characteristic Hawaiian diadromous fauna (Appendix A). A surprising feature of the lower stream course is that the endemic fishes are not abundant. In fact, two species common statewide, *Awaous genivittatus* ('o'opu naniha) and *Eleotris sandwicensis* ('o'opu 'ōkuhe) were not found in 'Ohe'o during this study.

Palikea

Access to Palikea Stream above the confluence is more difficult than the lower 'Ohe'o Gulch area. We sampled above the confluence only along Pīpīwai, and at the gauging station. Conditions at the confluence were not unlike the lower reaches of the stream. In the November survey our pH sample values were nearly neutral although streamflow was high. The only species observed here were *Atya bisulcata* and *Megalagrion* (damselfly) naiads and adults. Riparian vegetation was also similar to that of the lower stream, being characterized by dense *Psidium guajava* thickets, mango, ti, ginger, and *Eupatorium* (Appendix B).

The trail to the gauging station passes through a dense rose apple forest and several small, peaty bogs. Wallows, tracks, and droppings provided indications of abundant feral pig populations in these damp areas. The aquatic faunal communities at the gauging station consisted solely of atyid shrimp and numerous insects, particularly tipulids and odonates. The plant associations, however, were quite different from those encountered downstream. This was the only station where endemic plants comprised a large proportion of our sample. The higher ground was dominated by *Acacia koa* and *Metrosideros collina*, while in the streamside associations *Cyrtandra* and *Clermontia* were notable.

Streams are generally dependent upon imported organic matter from the surrounding terrestrial ecosystem for the majority of their trophic energy. Initially, this can take the form of bark, leaves, or twigs which fall directly into the stream from overhanging vegetation, or of particulate organic matter which is carried into the stream in surface runoff. Leachates from decomposing leaf litter on the forest floor can also enter the stream via runoff as dissolved organic matter. Aggregates of allochthonous (imported) organic materials, such as leaf packs which become lodged in stream substrata, immediately begin to undergo colonization by fungi which grow in complex successional patterns (Cummins 1974). As the plant material is degraded, the solubilized products are used by bacteria which serve (along with this plant matter) as a major nutritive source for numerous aquatic invertebrates, especially insect larvae (Cummins 1973).

Aside from their role as energy sources, riparian floral communities serve to regulate stream temperatures (depending upon the extent of the canopy). Their network of roots stabilizes stream banks, preventing rapid erosion, and provides cover for reclusive aquatic animals. Many researchers and resource managers stress the importance of keeping natural riparian plant associations intact, both as a valuable buffer zone and to maintain an acceptable environmental regime within the stream.

## Pīpīwai

Although no water records are available for Pīpīwai, its average discharge appears to be much less than that of Palikea. The morphology of the streambed and channel walls suggests that Pīpīwai is not subject to the type of scouring torrential floods common to Palikea. The bottom sediments are heterogeneous with a large proportion of fine materials, and the riparian vegetation extends to the margins of the stream, creating much shade. No radical fluctuations in water quality were observed at any time during our research.

Relative to the rest of the lower stream system, Pīpīwai possesses a high species diversity. As expected, mountain shrimp (*Atya bisulcata*) populations, and immature stages of numerous endemic insects representing the Chironomidae, Ephydridae, and Coenagriidae are the most abundant residents throughout the reaches of Pīpīwai covered by this study. Larvae of the exotic caddisfly *Cheumatopsyche analis* are ubiquitous on rock surfaces all along this section.

We discovered a small population of the rare endemic goby *Lentipes concolor* (Figure 4) above the confluence. *Lentipes* actively migrates upstream during its early development, and normally occurs with *Atya* at higher stream elevations. 'O'opu 'alamo'o (lizard-like goby) was regarded with disgust by early Hawaiians who believed that the fish was a relative of the feared mo'o god, and it was not captured for food. Some interesting legends regarding this fish and other native gobies are provided in Titcomb (1972). It seems surprising that this species, originally described from O'ahu, is now extinct on that island; large populations may only be found today in remote, pristine streams such as Hanawī on Maui, Wailau on Moloka'i, and the more remote streams of northwest Kaua'i. Its decline may be attributed to subtle and often not-so-subtle changes in the environment brought about by human activities. Maciolek (1977) reported the extinction of *Lentipes* sp. from Pi'ina'au Stream at Ke'anae, Maui, after completion of a streamside arboretum. Because it is not abundant in Pīpīwai, special care should be taken to insure that future park developments are not detrimental to Pīpīwai and 'Ohe'o Streams.

Another interesting endemic animal was found only on moss-covered rocks under perennial seeps around the perimeter of Waimoku Falls. *Erinna aulacospira* (Morrison 1968) is a tiny, fragile pulmonate gastropod in the family Lymnaeidae. Hubendick (1952) studied collections of this species from streams and falls on Kaua'i, Moloka'i, Maui, and Hawai'i.

Another closely related species, *Erinna newcombi*, has been reported only from Kaua'i. Maciolek (forthcoming) confirms that all recent observations of these animals have been in such protected seeps along the sides of falls and not in the streams as earlier reported. Gon (1976) reports finding *Erinna* from only one such location within the Manawainui Stream watershed, near Kīpahulu.

## CONCLUSIONS

Lower Palikea Stream represents a unique freshwater ecosystem both from the standpoint of its impressive geological formations and from its erratic discharge and discontinuous species distributions. Furthermore, the inclusion of Palikea in Haleakala National Park is fortunate, as it is the only stream which in its entirety is under the protective jurisdiction of the National Park Service in Hawai'i. Because of its relatively easy access, Palikea may provide an excellent opportunity for intensive research on such problems as the effects of a highly variable environment upon the abundance and distribution of stream fauna, and the effects of increasing public access and activities on the quality of the stream.

The accessibility and native character of Palikea make it especially valuable as a resource, since many typical Hawaiian streams are fairly remote or situated in large part on private land. Because the "seven pools" area is a well-known destination area for both tourists and residents, the National Park Service has a unique opportunity to educate visitors on the significance, uniqueness, and fragility of streams in Hawai'i. This would be particularly valuable to residents, who through this education could develop a greater sense of awareness and appreciation for Hawaiian freshwater ecosystems, and in turn may learn to be more sympathetic to conservation and preservation efforts in other parts of the state.

Palikea is an interrupted stream, subject to rapid changes in current velocity and discharge, and radical fluctuations in water chemistry. These oscillations are accentuated by an influx of allochthonous organic material and terrestrial sediments. Palikea illustrates an important ecological concept which few resource managers in Hawai'i have yet understood: mean or average environmental parameter values are meaningless, particularly when evaluated intermittently; it is the extremes which are of paramount importance to living things. For example, to argue that dewaterment of a stream would (or would not) be detrimental to a particular aquatic community based upon average flow data is senseless because average stream flows may often be far in excess of critical minimum flows. Existing water quality records for Palikea do not reflect the range of variation encountered during our studies. Although specific experimental evidence is lacking, it is our impression that the unusual abundance and distribution patterns of the endemic stream fauna are largely influenced by these fluctuations in the physicochemical environment.

At present we have found no clear evidence of serious detrimental effects caused by normal park activities. However, these activities may be causing subtle changes in the stream ecosystem which may not be detectable for several years. There exists a particular danger from soil erosion. In extreme situations, ecological conditions in the lower course may deteriorate to the point where passage of the diadromous fauna to and from the sea is impossible, and populations upstream would subsequently disappear. This situation has occurred in instances of extreme sedimentation, channel alteration, and pollution (O'ahu), and dewaterment (West Maui). Therefore, any development or plan for an increased utilization of lower Palikea must be kept within limits so as not to interfere with the important role 'Ohe'o plays in the ecology of the entire stream ecosystem. We suggest that efforts be made to determine the major source(s) of erosional sediments and that steps be taken to reduce the loss of soils and subsequent damage to the stream. The benefits derived from these efforts to water quality, and recreational and aesthetic values, would well repay the cost involved. Wilson (1957), in a study of northwestern streams, observed that after the cessation of erosion, the complete removal of silt by freshets from pools and riffles and the attendant recovery of stream life occurred within two years.

We present the following recommendations as guidelines for maintaining the integrity of the stream within the park boundaries, and to aid in the general education of park visitors.

1. Efforts should be initiated to fence the southwestern ridgeline above the stream to prohibit all vehicular traffic and cattle grazing within an approximately 100-foot margin from the stream channel. This buffer area must be widened where the slope becomes greater. Motorbikes and four-wheel-drive vehicles are a negative factor in terms of noise and destruction to ground cover. Cattle grazing along the ridgetops contributes significantly to the potential for excessive erosion. Only foot trails should be provided to scenic lookouts in this area.
2. Pig fencing should be installed in the vicinity of the gauging station and within the rose apple forests below to prevent the destruction of vegetation and ground cover along the ridgetops bordering the stream. The National Park Service may wish to consider allowing a controlled increase in public access specifically for pig hunting.
3. Due to the nature of the soils on the valley floor, foot trails retain much water. This fact frequently induces hikers to stray away from muddy trails. This activity must be discouraged because of the disruption to native plant species such as *Clermontia* and *Cyrtandra* which are rare in the lower valley, and because of the greater potential for soil erosion.

4. Although swimming in deeper pools has little or no effect upon the stream or its biota, excessive disruption of the stream bed, particularly the shallow riffles below the highway, should be discouraged. This area is critical to the successful migration and survival of juvenile animals.
5. Large signs should be installed where hiking trails meet the stream explaining the character of Hawaiian streams and their unique fauna, and itemizing rules of hiker etiquette with regard to stream quality.
6. More detailed information (photographs, aquaria) on stream life and the historic and current significance of streams to Hawai'i may be presented at a central park location. Such an exhibit is popular at the Marine Life Conservation District at Hanauma Bay, O'ahu.

Summary

Two surveys of the lower Palikea-Pīpīwai-'Ohe'o stream system were conducted: the first in November 1975 encountered high stream flow following a freshet; the second in May 1976 was made during a period of lower stream flow. These surveys concentrated on physical parameters of the stream system and on the stream fauna. In addition, observations were made on riparian vegetation, and factors that are potentially dangerous to the maintenance of stream quality.

The three "streams" in this system--'Ohe'o, Palikea, and Pīpīwai--were shown to be quite distinct lotic systems as reflected in differences in their physicochemical characteristics, biota, and riparian vegetation. These differences result from the morphology of the stream channels, and in part are due to the fluvial dynamics of the streams.

Due to the diadromous nature of much of the Hawaiian stream fauna, the perpetuation of the animal populations is dependent on the maintenance of the stream flow to the

sea in an uninterrupted and unaltered fashion. For this reason, protection of the lowest reaches of 'Ohe'o Stream is critical for the continued existence of the rich native fauna of Pīpīwai.

Continued sedimentation in lower Kīpahulu Valley will likely have deleterious effects on the lower parts of the stream. A substantially higher visitor load could have negative effects unless precautions are implemented. It appears that the utilization of lower Kīpahulu for park recreation and education purposes can be accommodated as long as these findings are kept in mind. With some care, the park will be able to continue these functions as well as perpetuate its heritage.

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APPENDIX A. INVENTORY OF THE AQUATIC MACROFAUNA OF PALIKEA AND PĪPĪWAI STREAMS, KĪPAHULU. Research expeditions conducted in November 1975 and May 1976.

| Species | Status | Sampling Stations | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 'Ohe'o | | | | | | | | | Palikea | | Pīpīwai | |
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| INSECTS | | | | | | | | | | | | | | |
| <u>Diptera</u> | | | | | | | | | | | | | | |
| Chironomidae (Midges) | | | | | | | | | | | | | | |
| *Chironomus hawaiiensis* | E | . | . | . | + | . | . | . | . | . | . | . | . | . |
| *Calopsectra* spp. | E | . | + | + | . | + | + | . | + | + | + | + | + | . |
| *Telmatogeton* spp. | E | . | . | . | . | . | . | . | . | + | + | . | . | . |
| Chironomid | . | . | . | . | . | + | . | . | . | . | . | . | + | + |
| Tipulidae (Craneflies) | | | | | | | | | | | | | | |
| *Limonia* spp. | E | . | . | + | . | + | . | . | + | . | + | + | + | . |
| Ephydridae (Brineflies) | | | | | | | | | | | | | | |
| *Scattela* sp. | . | . | . | . | . | + | . | . | . | . | . | . | + | . |
| Culicidae (Mosquitos) | | | | | | | | | | | | | | |
| *Culex pipiens* | X | . | . | + | + | + | + | . | . | . | . | . | . | . |
| <u>Trichoptera</u> | | | | | | | | | | | | | | |
| Hydropsychidae (Caddisflies) | | | | | | | | | | | | | | |
| *Cheumatopsyche analis* | X | . | + | + | . | + | + | . | + | . | + | + | . | + |
| <u>Hemiptera</u> | | | | | | | | | | | | | | |
| Notonectidae | | | | | | | | | | | | | | |
| *Buenoa* sp. | E | + | . | . | . | . | . | . | . | . | . | . | . | . |

NOTE: Status: E = Endemic, I = Indigenous, X = Exotic.
Presence is indicated by "+".

APPENDIX A--Continued

| Species | Status | Sampling Stations | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 'Ohe'o | | | | | | | | | Palikea | | Pīpīwai | |
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| INSECTS | | | | | | | | | | | | | | |
| <u>Anisoptera</u> | | | | | | | | | | | | | | |
| Aeshnidae | | | | | | | | | | | | | | |
| *Anax strenuus* | E | . | . | . | . | . | . | . | . | + | . | + | + | . |
| *A. junius* | X | . | + | . | . | . | . | . | . | . | . | . | . | . |
| Libellulidae | | | | | | | | | | | | | | |
| *Pantala flavescens* | I | . | . | . | + | + | . | . | . | . | . | . | . | . |
| <u>Zygoptera</u> | | | | | | | | | | | | | | |
| Coenagriidae | | | | | | | | | | | | | | |
| *Megalagrion blackburni* | E | . | . | . | . | + | . | . | . | . | . | . | . | . |
| *Megalagrion* spp. | E | . | . | . | . | . | . | . | + | + | + | + | + | + |
| MOLLUSKS | | | | | | | | | | | | | | |
| <u>Gastropoda</u> | | | | | | | | | | | | | | |
| Neritidae | | | | | | | | | | | | | | |
| *Nerita picea* | . | + | . | . | . | . | . | . | . | . | . | . | . | . |
| *Theodoxus vespertinus* | I | + | . | . | . | . | . | . | . | . | . | . | . | . |
| *Neritina granosa** | E | . | + | + | . | . | + | . | + | . | . | . | . | . |
| Ancylidae | | | | | | | | | | | | | | |
| *Ferrissia rivularis* | X | . | . | . | . | . | . | . | . | + | . | . | + | . |

*Diadromous life cycle.

APPENDIX A--Continued

| Species | Status | Sampling Stations | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 'Ohe'o | | | | | | | | | Palikea | | Pipiwai | |
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| MOLLUSKS | | | | | | | | | | | | | | |
| <u>Basommatophora</u> | | | | | | | | | | | | | | |
| Lymnaeidae | | | | | | | | | | | | | | |
| *Pseudisidora rubella* | E | . | . | . | . | . | . | . | + | . | . | . | . | . |
| *Erinna aulacospira* | E | . | . | . | . | . | . | . | + | . | . | . | . | + |
| <u>Pelecypoda</u> | | | | | | | | | | | | | | |
| Dysodonta | | | | | | | | | | | | | | |
| *Isognomon californicum* | . | + | . | . | . | . | . | . | . | . | . | . | . | . |
| CRUSTACEANS | | | | | | | | | | | | | | |
| <u>Peracarida</u> | | | | | | | | | | | | | | |
| Isopoda | | | | | | | | | | | | | | |
| *Gnoriosphaeroma* sp. | I | + | . | . | . | . | . | . | . | . | . | . | . | . |
| Amphipoda | . | . | . | . | . | . | . | . | . | . | . | . | + | . |
| <u>Natantia</u> | | | | | | | | | | | | | | |
| Palaemonidae | | | | | | | | | | | | | | |
| *Macrobrachium lar** | X | . | + | + | . | + | . | + | + | + | . | . | . | . |
| *M. grandimanus** | E | . | + | . | . | . | . | . | . | . | . | . | . | . |
| Atyidae | | | | | | | | | | | | | | |
| *Atya bisulcata** | E | . | + | + | + | + | + | . | . | + | + | + | + | + |
| SPONGES | | | | | | | | | | | | | | |
| *Heteromyenia baileyi* | E | . | . | . | . | . | . | . | . | . | + | . | . | . |

*Diadromous life cycle.

APPENDIX A--Continued

| Species | Status | Sampling Stations | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 'Ohe'o | | | | | | | | | Palikea | | Pīpīwai | |
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| LEECHES | | | | | | | | | | | | | | |
| Hirudinea | . | . | . | . | . | . | . | . | . | . | . | + | . | . |
| FISHES | | | | | | | | | | | | | | |
| Percoidei | | | | | | | | | | | | | | |
| Kuhliidae | | | | | | | | | | | | | | |
| *Kuhlia sandvicensis* | E | + | . | . | . | . | . | . | . | . | . | . | . | . |
| Gobioidei | | | | | | | | | | | | | | |
| Gobiidae | | | | | | | | | | | | | | |
| *Awaous stamineus** | I | . | + | + | . | + | . | . | + | . | . | . | . | . |
| *Sicydium stimpsoni** | E | . | + | + | . | . | . | . | . | . | . | . | . | . |
| *Lentipes concolor** | E | . | + | + | . | . | . | . | . | . | . | . | + | . |
| TOTAL NUMBER OF SPECIES: | | 6 | 10 | 9 | 3 | 10 | 4 | 1 | 9 | 7 | 7 | 7 | 10 | 5 |

*Diadromous life cycle.

APPENDIX B. INVENTORY OF THE RIPARIAN FLORA OF PALIKEA AND PĪPĪWAI STREAMS, KĪPAHULU. Research expeditions conducted in November 1975, May 1976, and May 1977.

| Species | Sampling Stations | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 'Ohe'o | | | | | | | | | Palikea | | Pipiwai | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| MOSSES | | | | | | | | | | | | | |
| *Bryum apiculatum* Schwaegr. | . | . | . | . | . | . | . | . | + | . | . | . | . |
| *Campylopus praemorsus* (C. Müll.) Jaeg. | . | . | . | . | . | . | . | . | . | . | + | . | . |
| *C. umbellatus* (Arn.) Par. | . | . | . | . | . | . | . | . | . | . | + | . | . |
| *Glossadelphus limnobioides* Broth. | . | . | . | . | . | . | . | . | . | . | . | . | + |
| *Hyophila involuta* (Hook.) Jaeg. | . | . | . | . | . | . | . | . | + | . | . | . | . |
| *Platyhypnidium muelleri* (Jaeg.) Fleisch. | . | . | . | . | . | . | . | . | + | . | . | . | . |
| *Racopilum cuspidigerum* (Schwaegr.) Aongstr. | . | . | . | . | . | . | . | . | + | . | . | . | . |
| LIVERWORTS | | | | | | | | | | | | | |
| *Marchantia crenata* | . | . | . | . | . | . | . | . | + | . | . | . | . |
| FERNS AND FERN ALLIES | | | | | | | | | | | | | |
| Adiantaceae | | | | | | | | | | | | | |
| *Adiantum cuneatum* Langs & Fisch. | . | + | + | . | + | . | + | + | + | + | . | + | + |
| Aspidiaceae | | | | | | | | | | | | | |
| *Athyrium* sp. | . | . | . | . | . | . | . | . | . | . | . | + | + |
| *Cyclosorus dentatus* (Forsk.) Ching | . | . | . | + | + | + | + | + | + | + | + | + | + |
| *Elaphoglossum* sp. | . | . | . | . | . | . | . | . | . | + | . | . | . |
| *Tectaria gaudichaudii* (Mett.) Maxon | . | . | . | . | . | . | . | . | . | . | . | . | + |
| Aspleniaceae | | | | | | | | | | | | | |
| *Asplenium nidus* L. | . | . | . | . | . | . | . | . | . | + | . | + | . |
| Blechnaceae | | | | | | | | | | | | | |
| *Blechnum occidentale* L. | . | + | . | . | + | + | + | . | + | + | . | + | . |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |

APPENDIX B--Continued

| Species | Sampling Stations | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 'Ohe'o | | | | | | | | | Palikea | | Pipiwai | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| FERNS AND FERN ALLIES | | | | | | | | | | | | | |
| <u>Davalliaceae</u> | | | | | | | | | | | | | |
| *Nephrolepis cordifolia* (L.) Presl | . | . | . | . | . | . | . | . | + | + | . | . | . |
| *N. exaltata* (L.) Schott | . | + | + | . | + | + | + | + | + | + | . | + | + |
| <u>Hymenophyllaceae</u> | | | | | | | | | | | | | |
| *Gonocormus minutus* (Blume) V.D. Bosch. | . | . | . | . | . | . | . | . | . | + | . | + | . |
| Hymenophyllaceae sp. | . | . | . | . | . | . | + | . | . | . | . | . | . |
| <u>Lindsaeaceae</u> | | | | | | | | | | | | | |
| *Sphenomeris chusana* (L.) Copel. | . | + | + | . | + | + | . | . | + | + | + | . | . |
| <u>Polypodiaceae</u> | | | | | | | | | | | | | |
| *Microsorium scolopendrium* (Burm.) Copel. | + | + | + | + | + | + | + | . | + | + | . | . | . |
| *Pleopeltis thunbergiana* Kaulf. | . | . | . | . | . | . | . | . | + | + | . | + | . |
| *Polypodium pellucidum* Kaulf. | . | . | . | . | . | + | + | . | . | . | . | . | . |
| <u>Psilotaceae</u> | | | | | | | | | | | | | |
| *Psilotum nudum* (L.) Beauv. | . | . | . | . | . | . | . | . | . | + | . | . | . |
| <u>Selaginellaceae</u> | | | | | | | | | | | | | |
| *Selaginella arbuscula* (Kaulf.) Spriz | . | + | . | . | . | . | + | + | . | + | . | + | + |
| FLOWERING PLANTS | | | | | | | | | | | | | |
| MONOCOTYLEDONS | | | | | | | | | | | | | |
| <u>Amarylidaceae</u> | | | | | | | | | | | | | |
| *Agave sisalana* Perrine ex Engelm. | . | . | + | . | + | + | . | . | . | . | . | . | . |
| <u>Araceae</u> | | | | | | | | | | | | | |
| *Alocasia* sp. | . | . | . | . | . | . | + | . | . | . | . | . | . |
| *Colocasia esculenta* (L.) Schott | . | . | . | . | . | . | . | . | . | . | . | + | + |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |

APPENDIX B--Continued

| Species | Sampling Stations | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 'Ohe'o | | | | | | | | | Palikea | | Pipiwai | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| MONOCOTYLEDONS | | | | | | | | | | | | | |
| Cannaceae | | | | | | | | | | | | | |
| *Canna indica* L. | . | . | . | + | . | . | . | . | . | . | . | . | . |
| Commelinaceae | | | | | | | | | | | | | |
| *Commelina diffusa* Burm. | . | + | . | + | + | + | + | + | + | + | . | + | + |
| Cyperaceae | | | | | | | | | | | | | |
| *Carex wahuensis* C.A. Mey. | + | + | . | . | . | . | . | . | . | . | . | + | . |
| *Cyperus brevifolius* (Rottb.) Hassk. | . | + | + | . | . | . | . | . | . | . | . | . | . |
| *C. javanicus* Houtt. | + | + | . | . | . | . | . | . | . | + | . | + | . |
| *C. polystachyus* Rottb. | + | . | . | . | + | + | + | + | + | + | . | . | . |
| *Fimbristylis pycnocephala* Hbd. | + | . | . | . | . | . | . | . | . | . | . | . | . |
| *Rhynchospora lavarum* Gaud. | . | . | . | . | . | . | . | . | . | + | . | . | . |
| *Scirpus* sp. | . | . | . | . | . | . | . | . | . | . | . | + | + |
| Dioscoreaceae | | | | | | | | | | | | | |
| *Dioscorea* sp. | . | . | . | . | + | + | + | . | . | . | . | . | . |
| Gramineae | | | | | | | | | | | | | |
| *Axonopus affinis* Chase | . | . | . | . | . | . | . | . | . | + | . | . | . |
| Bamboo sp. | . | . | . | . | . | . | + | + | . | . | . | . | . |
| *Cynodon dactylon* (L.) Pers. | . | . | . | . | . | + | + | . | . | . | . | . | . |
| *Deschampsia australis* Nees ex Steud. | . | . | . | . | . | . | + | + | + | + | . | . | + |
| *Digitaria sanguinalis* (L.) Heist. in Scop. | + | + | . | . | . | . | . | . | + | + | . | . | + |
| *Melinis minutiflora* Beauv. | . | . | . | + | . | . | . | . | . | . | . | . | . |
| *Oplismenus hirtellus* (L.) Beauv. | . | . | . | + | + | . | + | . | + | + | . | + | . |
| *Paspalum conjugatum* Berg. | . | + | + | . | + | + | + | + | + | + | + | + | + |
| *P. orbiculare* Forst. f. | . | + | + | . | + | + | . | . | . | + | . | . | . |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |

APPENDIX B--Continued

| Species | Sampling Stations | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 'Ohe'o | | | | | | | | | Palikea | | Pipiwai | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| MONOCOTYLEDONS | | | | | | | | | | | | | |
| Gramineae | | | | | | | | | | | | | |
| *Pennisetum purpureum* Schumach. | . | . | . | + | + | . | . | . | . | . | . | . | . |
| *Sacciolepis indica* (L.) Chase | . | . | . | . | + | + | . | . | + | + | . | . | + |
| *Sorghastrum nutans* (L.) Nash in Small | . | . | . | . | . | . | . | + | . | . | . | . | . |
| *Sporobolus africanus* (Poir.) Robyns & Tournay | . | + | + | . | + | + | . | . | . | + | . | + | . |
| *S. diander* (Retz.) Beauv. | . | + | . | . | + | . | . | . | . | . | . | . | . |
| Liliaceae | | | | | | | | | | | | | |
| *Cordyline terminalis* (L.) Kunth. | . | . | . | + | . | . | . | . | + | + | + | + | + |
| Musaceae | | | | | | | | | | | | | |
| *Musa* sp. | . | . | . | . | . | . | + | . | . | . | . | + | . |
| Orchidaceae | | | | | | | | | | | | | |
| *Spathoglottis plicata* Bl. | + | + | . | + | + | + | . | + | + | . | . | . | + |
| Palmae | | | | | | | | | | | | | |
| *Cocos nucifera* L. | . | + | . | + | . | . | . | . | . | . | . | . | . |
| Pandanaceae | | | | | | | | | | | | | |
| *Pandanus odoratissimus* L.f. | + | + | + | + | + | . | . | . | . | . | . | . | . |
| Zingiberaceae | | | | | | | | | | | | | |
| *Alpinia purpurata* (Vieill.) K.Schum. | . | . | . | . | + | + | + | . | + | . | . | + | . |
| *Zingiber zerumbet* (L.) Roscoe in Sm. | . | . | . | . | . | . | . | . | . | + | . | . | . |
| DICOTYLEDONS | | | | | | | | | | | | | |
| Aizoaceae | | | | | | | | | | | | | |
| *Sesuvium portulacastrum* (L.) L. | + | . | . | . | . | . | . | . | . | . | . | . | . |
| Anacardiaceae | | | | | | | | | | | | | |
| *Mangifera indica* L. | . | . | . | . | + | + | + | + | + | + | . | . | . |
| *Schinus terebinthifolius* Raddi | . | . | + | . | . | + | . | + | + | + | . | . | . |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |

APPENDIX B--Continued

| Species | Sampling Stations | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 'Ohe'o | | | | | | | | | Palikea | | Pipiwai | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| DICOTYLEDONS | | | | | | | | | | | | | |
| <u>Caricaceae</u> | | | | | | | | | | | | | |
| *Carica papaya* L. | . | . | . | + | . | . | + | + | . | . | . | . | . |
| <u>Caryophyllaceae</u> | | | | | | | | | | | | | |
| *Drymaria cordata* (L.) Willd. ex R. & S. | . | . | . | . | . | . | + | . | + | + | . | . | + |
| <u>Casuarinaceae</u> | | | | | | | | | | | | | |
| *Casuarina equisetifolia* Stickm. | + | . | . | . | . | . | . | . | . | . | . | . | . |
| <u>Combretaceae</u> | | | | | | | | | | | | | |
| *Terminalia catappa* L. | + | + | + | + | + | . | . | . | . | . | . | . | . |
| <u>Compositae</u> | | | | | | | | | | | | | |
| *Ageratum conyzoides* L. | . | . | . | . | + | + | + | . | + | + | . | . | + |
| *Bidens hillebrandiana* (Drake) Deg. | + | . | . | . | . | . | . | . | . | . | . | . | . |
| *B. pilosa* L. | . | . | . | . | . | . | . | . | + | . | . | . | . |
| *Emilia sonchifolia* (L.) DC. | + | . | . | . | + | . | . | . | . | . | . | . | . |
| *Erechtites hieracifolia* (L.) Raf. | . | . | . | . | . | . | . | . | + | . | . | + | . |
| *Erigeron bonariensis* L. | . | + | . | . | . | + | + | . | + | + | . | . | . |
| *Eupatorium adenophorum* Spreng. | . | . | . | . | . | . | . | . | . | . | . | . | + |
| *E. riparium* Regel | . | + | + | . | + | + | + | + | + | + | + | + | + |
| *Pluchea odorata* (L.) Cass. | . | . | . | . | . | + | . | + | + | . | . | . | + |
| *Sonchus oleraceus* L. | + | + | + | + | . | . | . | . | . | . | . | . | . |
| *Tridax procumbens* L. | . | + | . | . | . | . | . | . | . | . | . | . | . |
| *Vernonia cinerea* (L.) Less | . | . | . | . | + | + | . | . | . | + | . | . | . |
| *Youngia japonica* (L.) DC. | . | . | . | . | . | . | . | . | + | . | . | + | . |
| <u>Convolvulaceae</u> | | | | | | | | | | | | | |
| *Ipomoea* sp. | + | . | . | . | . | . | . | . | . | . | . | + | . |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |

APPENDIX B--Continued

| Species | Sampling Stations | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 'Ohe'o | | | | | | | | | Palikea | | Pipiwai | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| DICOTYLEDONS | | | | | | | | | | | | | |
| Crassulaceae | | | | | | | | | | | | | |
| *Kalanchoe pinnata* (Lam.) Pers. | . | . | . | + | . | + | + | + | . | . | . | . | . |
| Euphorbiaceae | | | | | | | | | | | | | |
| *Aleurites moluccana* (L.) Willd. | . | . | . | . | . | . | + | + | + | + | . | + | . |
| *Euphorbia hirta* L. | . | + | . | . | + | . | . | . | . | . | . | . | . |
| *Ricinus communis* L. | . | . | . | + | . | . | . | . | . | . | . | . | . |
| Gesneriaceae | | | | | | | | | | | | | |
| *Scaevola* sp. | . | . | . | . | . | + | . | . | . | . | + | . | . |
| *S. taccada* (Gaertn.) Roxb. | + | . | + | . | . | . | . | . | . | . | . | . | . |
| Leguminosae | | | | | | | | | | | | | |
| *Acacia koa* Gray | . | . | . | . | . | . | . | . | + | + | + | . | . |
| *Cassia leschenaultiana* DC. | . | + | + | + | + | + | . | . | + | + | . | + | . |
| *Desmodium canum* (Gmel.) Schinz & Thell. | . | + | . | . | . | . | . | . | . | . | . | . | . |
| *D. triflorum* (L.) DC. | . | + | . | . | + | . | . | . | . | . | . | . | . |
| *D. uncinatum* (Jacq.) DC. | . | + | + | . | + | . | . | . | + | + | . | . | . |
| *Mucuna gigantea* (Willd.) DC. | . | . | . | . | . | . | + | + | + | + | . | . | + |
| Lobeliaceae | | | | | | | | | | | | | |
| *Clermontia* sp. | . | . | . | . | . | . | . | . | . | . | + | + | . |
| *Cyanea* sp. | . | . | . | . | . | . | . | . | . | . | . | + | . |
| Lythraceae | | | | | | | | | | | | | |
| *Cuphea carthagenensis* (Jacq.) Macbride | . | . | . | . | . | . | . | . | + | + | . | . | + |
| Malvaceae | | | | | | | | | | | | | |
| *Hibiscus tiliaceus* L. | . | . | . | + | + | . | + | . | . | . | . | . | . |
| Menispermaceae | | | | | | | | | | | | | |
| *Cocculus ferrandianus* Gaud. | + | . | . | . | . | . | . | . | . | . | . | . | . |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |

APPENDIX B--Continued

| Species | Sampling Stations | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 'Ohe'o | | | | | | | | | Palikea | | Pipiwai | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| DICOTYLEDONS | | | | | | | | | | | | | |
| Moraceae | | | | | | | | | | | | | |
| *Artocarpus altilis* (Parkins. ex Z.) Fosb. | . | . | . | + | + | . | + | . | . | . | . | . | . |
| *Ficus* sp. | . | + | . | + | + | . | + | + | + | . | . | . | . |
| Myrtaceae | | | | | | | | | | | | | |
| *Eugenia cumini* (L.) Druce | + | + | + | + | + | + | + | + | + | + | . | . | . |
| *Metrosideros collina* (J.R. & G.Forst.) Gray | . | . | . | . | . | . | . | . | . | . | + | + | . |
| *Psidium guajava* L. | . | + | . | . | + | + | + | + | + | + | + | + | + |
| Nyctaginaceae | | | | | | | | | | | | | |
| *Pisonia umbellifera* (J.R. & G. Forst.) Seem. | . | . | . | . | . | . | . | . | . | . | . | . | + |
| Onagraceae | | | | | | | | | | | | | |
| *Ludwigia octivalis* (Jacq.) Raven | . | . | . | . | . | . | . | . | + | . | . | + | + |
| Oxalidaceae | | | | | | | | | | | | | |
| *Oxalis corniculata* L. | . | . | . | . | . | . | . | . | . | + | . | . | + |
| Passifloraceae | | | | | | | | | | | | | |
| *Passiflora* sp. | . | . | . | . | . | . | . | . | . | + | . | . | . |
| Plantaginaceae | | | | | | | | | | | | | |
| *Plantago major* L. | + | . | . | . | . | . | . | . | . | . | . | . | . |
| Portulacaceae | | | | | | | | | | | | | |
| *Portulaca oleracea* L. | + | . | . | . | . | . | . | . | . | . | . | . | . |
| Rosaceae | | | | | | | | | | | | | |
| *Rubus rosaefolius* Sm. | . | + | . | . | . | + | + | . | + | + | + | + | + |
| Rubiaceae | | | | | | | | | | | | | |
| *Coffea arabica* L. | . | . | . | . | . | . | . | . | . | + | + | . | . |
| Scrophulariaceae | | | | | | | | | | | | | |
| *Bacopa monnieria* (L.) Wettst. | + | . | . | . | . | . | . | . | . | . | . | . | . |
| Ulmaceae | | | | | | | | | | | | | |
| *Trema* sp. | + | . | . | . | . | . | . | . | . | . | . | . | . |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |

APPENDIX B--Continued

| Species | Sampling Stations | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 'Ohe'o | | | | | | | | | Palikea | | Pipiwai | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| DICOTYLEDONS | | | | | | | | | | | | | |
| Umbelliferae | | | | | | | | | | | | | |
| *Centella asiatica* (L.) Urban | + | + | . | . | + | + | . | . | + | . | + | . | + |
| *Hydrocotyle verticillata* Thunb. | . | . | . | . | . | . | + | . | . | . | . | . | . |
| Urticaceae | | | | | | | | | | | | | |
| *Pilea peploides* (Gaud.) H. & A. | . | + | + | + | . | . | . | + | + | . | . | . | + |
| *Pipturus* sp. | . | . | . | . | . | . | . | . | . | . | . | + | . |