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Technical Report 27

AN ECOLOGICAL SURVEY OF PUA'ALU'U STREAM

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by R. A. Kinzie, 111, and J. I. Ford

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by D. E. Hardy

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PREFACE

In 1969 the National Park Service acquired a substantial addition to Haleakala National Park on the island of Maui, Hawai'i. This new corridor encompasses all of Kīpahulu Valley from the rim of Haleakalā to the ocean. Portions of Koukouai and Kalena streams lie within the western sector of the lower park area in Kīpahulu. The Palikea/'Ohe'o and Pua'alu'u watersheds lie within the eastern sector of the lower park (Fig. 1). As part of the continuing study of the unique biological characteristics of the new Kīpahulu District of Haleakala National Park, an inventory and limnological survey of the lower Palikea-Pīpīwai-'Ohe'o stream complex was conducted in November 1975 and May 1976 (Kinzie and Ford 1977). Brief reconnaissance surveys of the remaining watersheds within the Park were conducted by the junior author in May 1977 to determine the nature of the aquatic biota in each stream. At the time of these surveys, Kalena Stream channel carried no water and access to Koukouai was prohibited by steep channel walls and torrential discharge (testimony to the tremendous variation in geology and groundwater hydrology between adjacent streams). In contrast, Pua'alu'u Stream contained a healthy complement of native stream life.

Surprisingly dense populations of the colorful goby fish Lentipes concolor were discovered at all sampling locations at Pua'alu'u. First described from the island of O'ahu in 1860, Lentipes now appears to be extinct on that island. Maciolek (1977) has observed this endemic and monotypic species in only 22 streams on the five major Hawaiian Islands (6% of the total streams in the archipelago). He has further stated that effective breeding populations may be maintained in only a few of these. Lentipes was observed by Kinzie and Ford (1977) in Pīpīwai Stream but the species was uncommon. Although Lentipes was not observed in 'Ohe'o, larvae and post-larvae must pass through this lower reach, both to and from the sea, to gain access to Pīpīwai.

The continuing degradation of Hawaiian streams due to habitat alteration and dewaterment, and the accidental and intentional introduction of foreign aquatic species is threatening the existence of this unique species. In fact, Maciolek (1977) has recommended that Lentipes be afforded the protection of endangered species status so-that steps may be taken to protect and perpetuate it.

The fortuitous inclusion of Pua'alu'u, which apparently possessed a rich population of Lentipes ('o'opu 'alamo'o, also called hi'u-'ula or hi'u-kole), into Haleakala National Park provided the initial impetus for the limnological survey of Pua'alu'u Stream, the results of which are presented in this report. The study had three basic goals: (a) to verify the abundance of Lentipes in Pua'alu'u; (b) to conduct an inventory of stream biota and provide a general description of its ecology; and (c) if Lentipes proved to be abundant, to develop an hypothesis which could account for the phenomenon in light of the results of the survey and our present knowledge of the species.

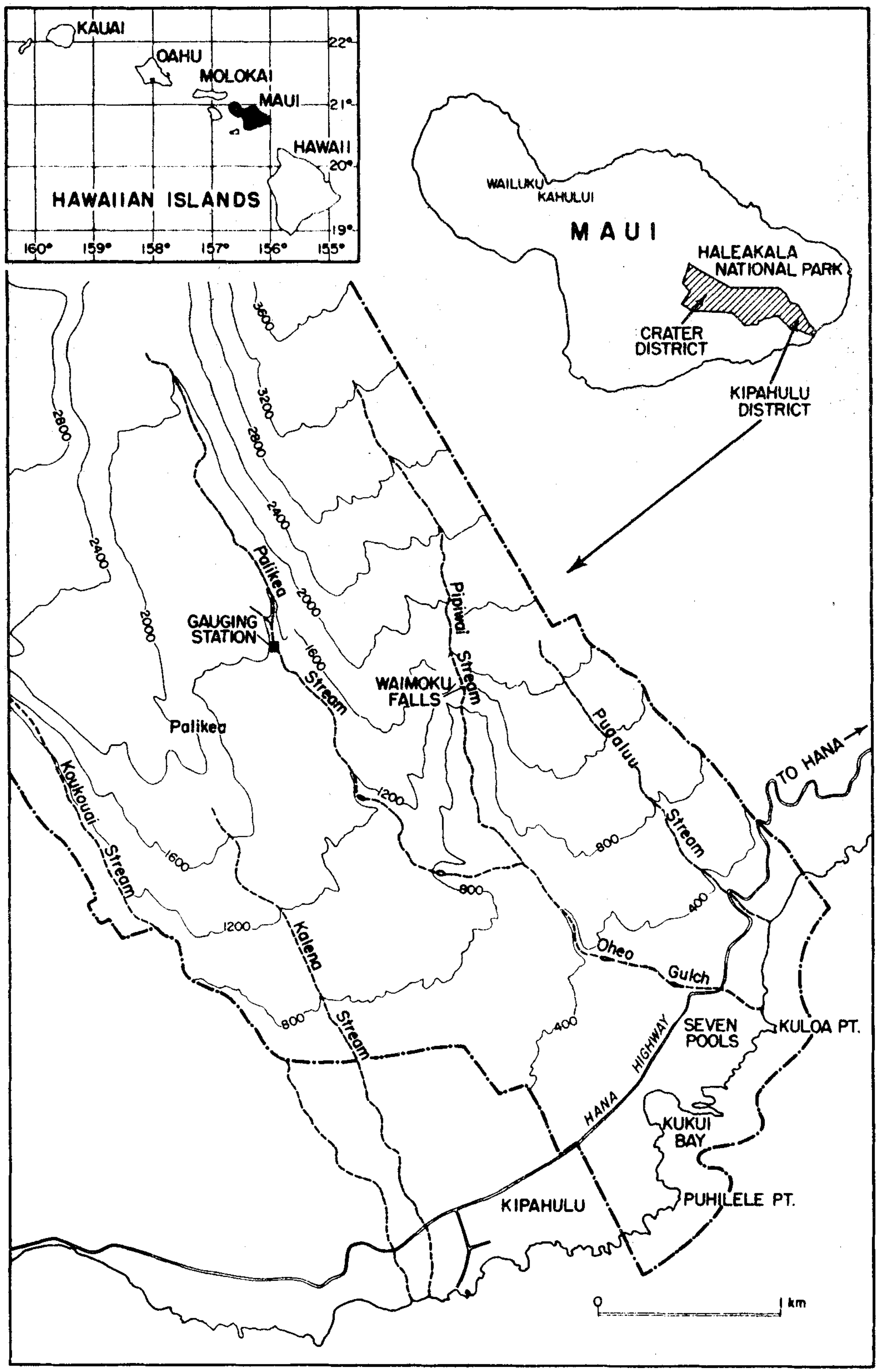

FIGURE 1. Lower Kīpahulu Valley and Haleakala National Park, Maui.

ABSTRACT

1) A limnological survey of Pua'alu'u Stream, Haleakala National Park, was conducted addressing the following points:

a) Verification of the Lentipes concolor abundance in the stream;

b) Assessment of the stream's fauna;

c) Study of the unique nature of the stream.

2) Lentipes concolor indeed proved to be very common in Pua'alu'u.

3) The stream appeared to be particularly suited to this species by virtue of its geomorphology and its consequent species composition and distribution.

4) Pua'alu'u proved to be unique in terms of its insect fauna, its flora, and its stream fauna.

5) An hypothesis is developed which may prove to be applicable not only to the potentially rare and endangered Lentipes but which could be the basis of a paradigm for the determination of critical habitats for other Hawaiian freshwater species.

6) The flora of the stream bank is predominantly exotic with dense thickets of bamboo in many areas.

7) The bamboo has had a negative impact on the insect fauna as well as being probably responsible for significant erosion of the stream course banks.

8) The insect fauna below 150 m has been seriously depleted by the activity of the long-legged ant (Anoplolepis longipes).

9) Recommendations for the protection of the stream and its banks are suggested.

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PART I

BIOLOGICAL SURVEY OF PUA'ALU'U STREAM, MAUI

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INTRODUCTION

Pua'alu'u Stream is a small, exorheic (flowing to the ocean), second-order stream (see Glossary) which drains gently sloping pasture lands in east Maui near Kīpahulu. The approximate coordinates of the mouth of the stream are 20°40'11" N, 156°02'37" W. The total drainage area is only 156 acres (63 ha), which is slightly less than 3% of the Palikea/'Ohe'o drainage basin. The headwaters originate at about 1800 feet (549 m) and flow a distance of 1.5 miles (2.4 km) to the sea. Average annual precipitation at 250 feet (76 m) elevation at Kīpahulu is 104 inches (264 cm) (Department of Commerce 1965). Mid-elevation rainfall near 1100 feet (335 m) has been gauged at 120 inches (305 cm) (Tagliaferro 1959). Although the period of highest rainfall appears to be November through April, mean monthly rainfall values do not fluctuate greatly.

Pua'alu'u flows across the western portion of a large planeze of Kula series lava which extends from Pīpīwai Stream to Waiho'i Valley (Stearns and MacDonald 1942). A similar structure extends from Koukouai Stream west to Manawainui Stream at Kaupō. The Pleistocene Kula lavas between Waiho'i, Pīpīwai, and Koukouai were not covered by the later Hāna series lavas as Kīpahulu, Kaupō, and Waiho'i valleys were. Where late Kula lavas have filled gullies and have had flows shortened by subsequent erosion, groundwater is collected and seeps emerge. In general, Kula lavas are far less permeable than either the underlying Honomanū basalts or the recent Hana series rocks, and tend to channel surface runoff and spring flow into perennial streams.

Pua'alu'u Stream is perennial and discharges approximately 175,000 gallons per day (gpd) or 0.27 cubic feet per second (cfs), based upon the records of Stearns and MacDonald (1942). Due in part to its small watershed and to stream channel geomorphology, it does not appear to be subject to the frequently torrential flows characteristic of neighboring Palikea/'Ohe'o. The source of perennial flow in Pua'alu'u is primarily leakage from perched aquifers (a body of water generally in some porous material restrained from downward percolation by impervious material) similar in geologic structure to those which supply Big Spring in Hanawī Valley, near Nāhiku, Maui.

At Big Spring, water is confined under pressure in a permeable pāhoehoe basalt lava between two or more dense layers of 'a'ā (Stearns and MacDonald 1942). At Pua'alu'u, mid-level groundwater is held above the basal water table in interstratified clinker beds that have been decomposed by circulation water. This mid-level water percolates down through more permeable structures until it contacts less-permeable lavas which slow percolation and direct the flow laterally. From that point, it is released into the stream channel near 1000 feet (305 m) elevation, where seeps are exposed in the channel wall.

Pua'alu'u Stream gathers surface waters from springs and seeps, and flows across small riffles above 1000 feet (305 m). Many of these seeps consist of brittle rocky substrata covered with mosses and algae which are often so thick that they temporarily retain much detritus. Below an altitude of approximately 1000 feet (305 m), riffles are noticeably absent.

Throughout the remainder of its course Pua'alu'u flows over numerous cascades, each with a small, often deep plunge pool at its base. Although deep, these plunge pools generally lack stagnant backwaters; the cascades are characterized by strong, fast currents and a stable substratum consisting of solid rock masses (Fig. 2). Immediately adjacent to these areas are splash zones consisting of a thin veneer of water formed by the fine spray from the cascades. Ultimately, after tumbling over a sinuous terminal cascade, Pua'alu'u discharges directly onto a narrow strip of black sand at the shore where freshwater is immediately washed by the waves (Fig. 3).

A substantial quantity of water, relative to the estimated average discharge of 175,000 gpd (0.27 cfs) at Pua'alu'u springs, is diverted for domestic and agricultural uses in the Kīpahulu area. 'Ulupalakua Ranch first installed a wier and 1-inch pipeline in Pua'alu'u in 1922. This system was upgraded to the existing 1.5-inch pipeline in 1957. The flow currently exported by this pipeline is estimated to be between 5,000—and 10,000 gpd (0.01-0.0s. cfs). A second water system, the 'Aina 'O Kīpahulu system, was installed in 1972-1973 by Hāna Ranch. This 2.5-inch pipe exports an estimated 30,000 to 35,000 gpd (0.05 cfs) at the present time; however, the total capacity of the system may be much greater. Both water system intakes are located at an altitude of 950 feet (290 m) and draw surface flow from the stream. Together, a total flow approaching an estimated 50,000 gpd (0.08 cfs) may be removed from the stream. This allows a discharge of approximately 70% of the estimated average discharge to flow downstream to the sea. Two additional pipes were observed during this study immediately above the highway bridge. Location of their intake structures or existing uses of this water are presently unknown to us. Since no biological data is available from Pua'alu'u Stream prior to 1972, the effects of initial stream diversion cannot be evaluated. Historically, Pua'alu'u has generally been considered as the "only" available source of potable water in the Kīpahulu-Kaupō area and is in jeopardy of further exploitation.

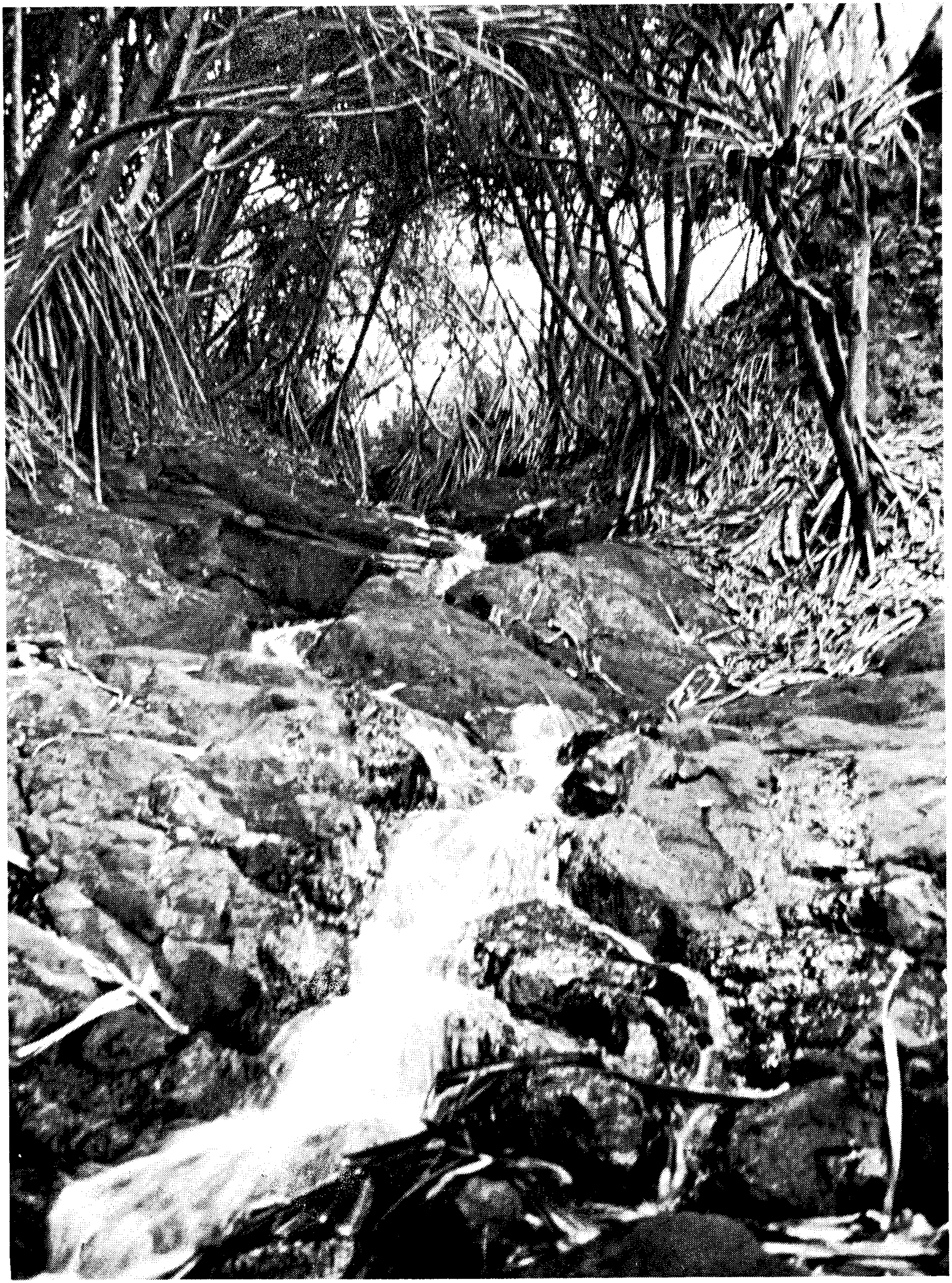


FIGURE 2. Cascade between sampling stations 1 and 2, showing well-scoured stream bed. Note the predominance of *Pandanus* lining the channel.

FIGURE 3 Mouth of P[illegible]a'alu'u Stream showing the debouchment of the stream across the narrow black sand beach.

Cattle graze the western portion of the drainage periodically and cow trails criss-cross the stream banks and channel slopes at several locations above the highway. Cattle frequent the stream to drink near sampling station 5 (420 ft./128 m) where we discovered a large and malodorous cattle wallow.

Soil types in Pua'alu'u gulch are limited to rocklands above 350 feet (107 m), and to rough mountainous lands from this point to the sea (USDA Soil Conservation Service 1372). These soils are relatively acid. The pasturelands bordering the stream channel to the east and west consist largely of Maka'ale Silty Clay. These are well-drained soils which have developed in volcanic ash. Runoff is slow to medium and the hazard of erosion is reported to be slight. The surface horizons of this soil series are very acid.

The riparian vegetation (living on the bank of the stream) at Pua'alu'u is described by Higashino and Croft (Part 11). They emphasized that the vegetation above the highway was virtually completely exotic in origin. Both Hardy (Part III) and Higashino and Croft noted the dense, apparently monospecific bamboo stands along the stream channel above 400 feet (120 m). Below this, the vegetation is typical of low coastal areas and consists largely of Pandanus, Scaevola, Aleurites, and introduced shrubs and herbs.

METHODS OF INVESTIGATION

Ten sampling stations were established along the stream course (Fig. 4). At each of these stations, qualitative assessments of stream biota along a 5-meter reach were made by direct visual examination using face masks, and by removing rocks and leaf packs from the stream to examine their associated macrofauna. Semiquantitative collections for population estimates were made with a gasoline-powered electrofishing unit, with the aid of dip nets. The catching efficiency of this method varies according to the conductivity, temperature, and velocity of the water; the cross-sectional area and substratum of the stream channel; the skill of the unit operator; and how well illumination, water turbidity, and depth allow the operator to see and capture the specimens (White and Brynildson 1967). These factors vary from one reach to the next and from day to day even within the same watercourse. Therefore, a "one-time" sample taken at each station can be misleading in making comparisons between streams or between different portions of the same stream. Because electrofishing biases the sample toward larger, motile macrofauna (fishes and crustaceans), and is less effective in streams of low specific conductance (generally less than 50 µmhos), samples were also collected on subsequent field trips with locally manufactured "'ōpae nets." 'Opae nets may be easily operated by an individual and may effectively sample motile organisms (greater than 0.25 in. [0.8 cm] in greatest dimension) within a wide cross-section of a stream.

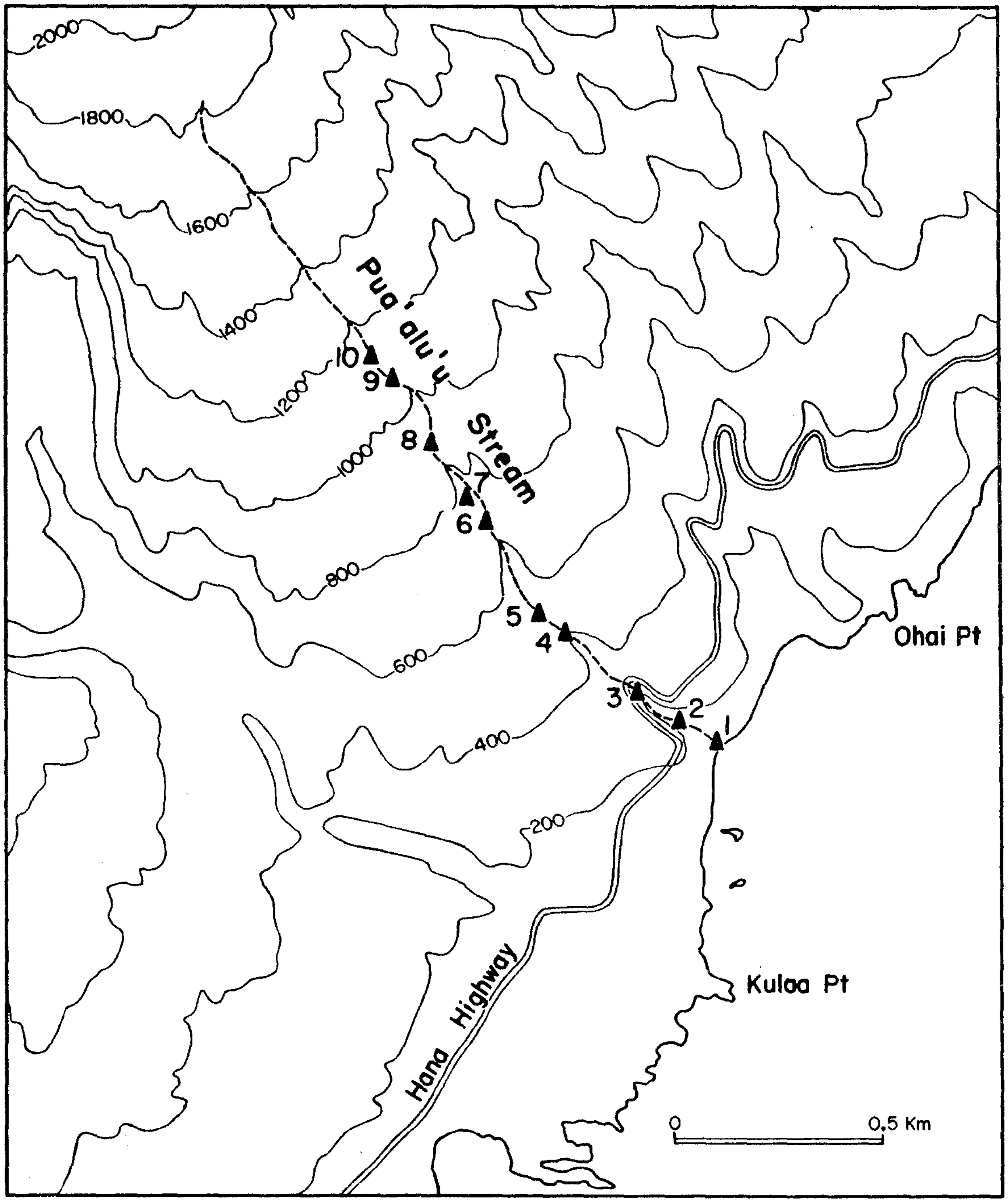


FIGURE 4. Location of sampling stations at Pua'alu'u Stream.

Invertebrate drift was sampled with a standard Surber net. Sessile macroinvertebrates were collected with kick samples using both the Surber and 'ōpae nets. All specimens that could be easily identified were returned to the stream; other material which could not be adequately keyed was preserved in 10% neutral Formalin and returned to the laboratory.

At each sampling station, species represented by greater than 10 individuals were considered to be abundant. Common species were represented by 4-9 individuals, and uncommon forms by 3 or fewer specimens.

Because no systematic effort was made during these initial surveys to quantitatively collect at each station, the information in this report must be viewed as a preliminary qualitative species inventory. Owing to size- and species-selectivity of the electrofishing equipment, this "one-time" sample cannot provide a definitive indication of total species populations and their size- and age-structures. Furthermore, the observations discussed in this report represent only the resident stream community during the time of the survey (October-November 1977). Therefore, the inventory may not represent a complete species list or pattern of species distribution in either space or time.

Physicochemieal parameters including temperature, conductivity, pH, and dissolved oxygen were measured over a four-day period at least twice at each sampling station. Temperature was measured with a hand-held thermometer. Conductivity values were determined with a YSI S-C-T Model 33 meter. An Analytical Measurements Model 107 pH meter was used to measure pH in the field. Dissolved oxygen was measured with a YSI Model 54 oxygen meter. Stream discharge values were taken from Stearns and MacDonald (1942).

RESULTS

Physicochemical Parameters

Mean values and ranges of stream temperatures, conductivity, pH, and dissolved oxygen concentration measured during this study are presented in Table 1. Water temperature exhibits a slight decrease toward the upper stream reaches. The low temperatures characteristic of the headwaters of longer perennial streams in Hawai'i (ranging from 14-19°C) were not encountered. This suggests that the artesian source of surface waters at Pua'alu'u does not originate at high elevations as it does in Hanawī Valley. Although Big Spring in Hanawī Valley discharges at an altitude of 540 feet (165 m) compared to 1400 feet (427 m) for Pua'alu'u springs, the average water temperature is 15°C, and the source has been traced to approximately 4000 feet (1220 m) (Stearns and MacDonald 1942).

TABLE 1. Physicochemical parameters observed in Pua'alu'u Stream, October 8-11, 1977.

Sampling Station Number	Stream Temperature (°C)		Dissolved Oxygen (mg/l)		Oxygen Saturation (% volume)		Specific Conductance (µmhos)		pH	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
1	22.8	22.0-24.0	5.6	4.25-6.5	63	47-75	115	110-121	7.93	7.90-7.95
2	22.8	22.0-23.5	5.6	5.50-7.7	63	62-90	107	85-129	7.25	7.00-7.50
3	23.5	22.0-25.0	5.8	5.40-6.2	66	60-74	130	128-132	...	.....
4	22.0	21.5-22.5	6.6	6.40-6.8	75	71-77	186	185-186	...	.....
5	21.8	21.5-22.0	5.2	4.30-6.1	58	48-68	361	350-378	8.00	.....
6	21.5	21.0-22.0	5.4	.....	60	60-61	110	.....	8.10	.....
8	22.0	21.5-22.5	5.6	5.50-5.6	62	61-63	329	328-330	8.00	.....
9	20.5	20.0-21.0	4.7	4.10-5.3	52	45-57	104	100-108	7.35	.....
10	20.8	20.5-21.0	5.2	.....	57	57-58	103	.....	7.50	.....

NOTE: Physicochemical parameters not measured at Station 7.

Observed conductivity values did not reflect the expected pattern of increasing dissolved ion concentrations toward the mouth of the stream. Instead, the highest recorded values (350-378 µmhos) were found at the cattle wallow (station 5 at 420 ft./128 m). It is possible that the presence of the cattle and associated disturbance and waste products accounted for the high conductivity here. The existence of ocherous seeps at station 8 (1020 ft./310 m) could have created a similar effect there. The relatively low conductivity of stream water below 400 feet (120 m) may be correlated with the observed reduction in pH.

The pH showed slightly higher than expected values at stations 5 to 8 (420-840 ft./130-255 m) (Table 1). Again, the anoxic muds at the cattle wallow may influence the alkalinity of the water. It is interesting to note that pH values €or Pua'alu'u are higher than those of Palikea/'Ohe'o over the same elevation range (Kinzie and Ford 1977).

Dissolved oxygen values show no correlation with altitude or with other parameters (Table 1). Recorded levels ranged from 4.7 to 6.6 mg/l which is equivalent to 52-75% saturation at ambient temperatures, These values are unusually low and must be viewed with some skepticism.

Aquatic Community

Species distributions and relative abundances are presented in Tables 2 and 3. As this information demonstrates, our preliminary observations on the abundance of Lentipes were confirmed in this survey (Table 3). Lentipes was found in abundance at all stations in Pua'alu'u with the sole exception of the small spring pool (station 7 at 840 ft. [255 m]). Maciolek (1977) states that Lentipes is usually found at higher elevations in certain perennial streams and occurs sympatrically (living together) with the endemic atyid shrimp Atya bisulcata ('ōpae kala'ole). Lentipes clearly dominated the fish fauna at Pua'alu'u (Fig. 5). The fact that there had been no significant rainfall or notable increase in stream flow prior to our observations, and that similar population densities have been observed on subsequent field trips indicated that this phenomenon does in fact accurately represent the actual state of the species within the stream. Two other endemic gobiids were observed in Pua'alu'u below the highway during subsequent field trips. Only two sightings of Awaous stamineus ('o'opu nākea) were made: one large specimen (about 12 inches in length) was seen at station 3; an individual of equal size was seen at station 1. The second species, Sicydium stimpsoni ('o'opu nōpili), was represented in larger numbers. Although no specimens of Sicydium were found among the samples above the highway, their presence in the mid- and upper-reaches would normally be expected (Tomihama 1972). However, their apparent absence above 400 feet (120 m) elevation may be correlated with environmental and ecological factors which will be discussed later.

TABLE 2. Distribution of aquatic insects in Pua'alu'u Stream, Maui. Data from Hardy, discussion in Part III (x = observation).

Stream Fauna (Insects)	Sampling Stations									
	Lower Reach			Mid-Reach					Headwaters	
	1	2	3	4	5	6	7	8	9	10
CHIRONOMIDAE										
<u>Orthocladius grimshawi</u>	x	x	x	.	.	.	.		.	
<u>Telmatogeton abnormis</u>	x	.		.	.	.	.		.	
<u>T. torrenticola</u>	x	.		.	.	.	.			.
EPHYDRIDAE										
<u>Donaceus nigrotarsus</u>	x	x		.	.	.				.
<u>Neoscatella clavipes</u>	x	.	.	.	.	.	.			
<u>N. warreni</u>	x		.	.	.	.				
CANACEIDAE										
<u>Procanace acuminata</u>	x	x		.	.	.				
<u>P. constricta</u>	x	x	.	.	.	.	.			
TIPULIDAE										
<u>Limonia advena</u>	x	x	.	.	.	.				
<u>L. jacobus</u>		.		.	.	.		.	x	x
<u>L. variabilis</u>		.		.	.	.	.		x	x
DOLICHOPODIDAE										
<u>Sigmatineurum chalybeum</u>	x	x	.	.	.	.				
<u>Syntormon distortitarsus</u>	x	x		.	.	.				
CERATOPOGONIDAE										
<u>Dasyhelia glatychaeta</u>		.		.	.	.	.		x	x
SCIARIDAE										
<u>Bradysia bishopi</u>	.	.	.	.	.	.	.		x	x
AESHNIDAE										
<u>Anax junius</u>				.	.	.			x	x
<u>Nesogonia blackburni</u>	.	.		.	.	.			x	x
COENAGRIIDAE										
<u>Megalagrion blackburni</u>	.	.	.	.	.	.	.		x	x
<u>M. hawaiiensis</u>	.	.		.	.	.			x	x
*<u>M.</u> sp. (naiad)	.	.	.	.	.	.	x			
HYDROPSYCHIDAE										
*<u>Cheumatopsyche analis</u>		.	.	x	x	.	.	.		.
Total Number of Insect Species/Station	11	7	1	1	1	0	1	0	8	8

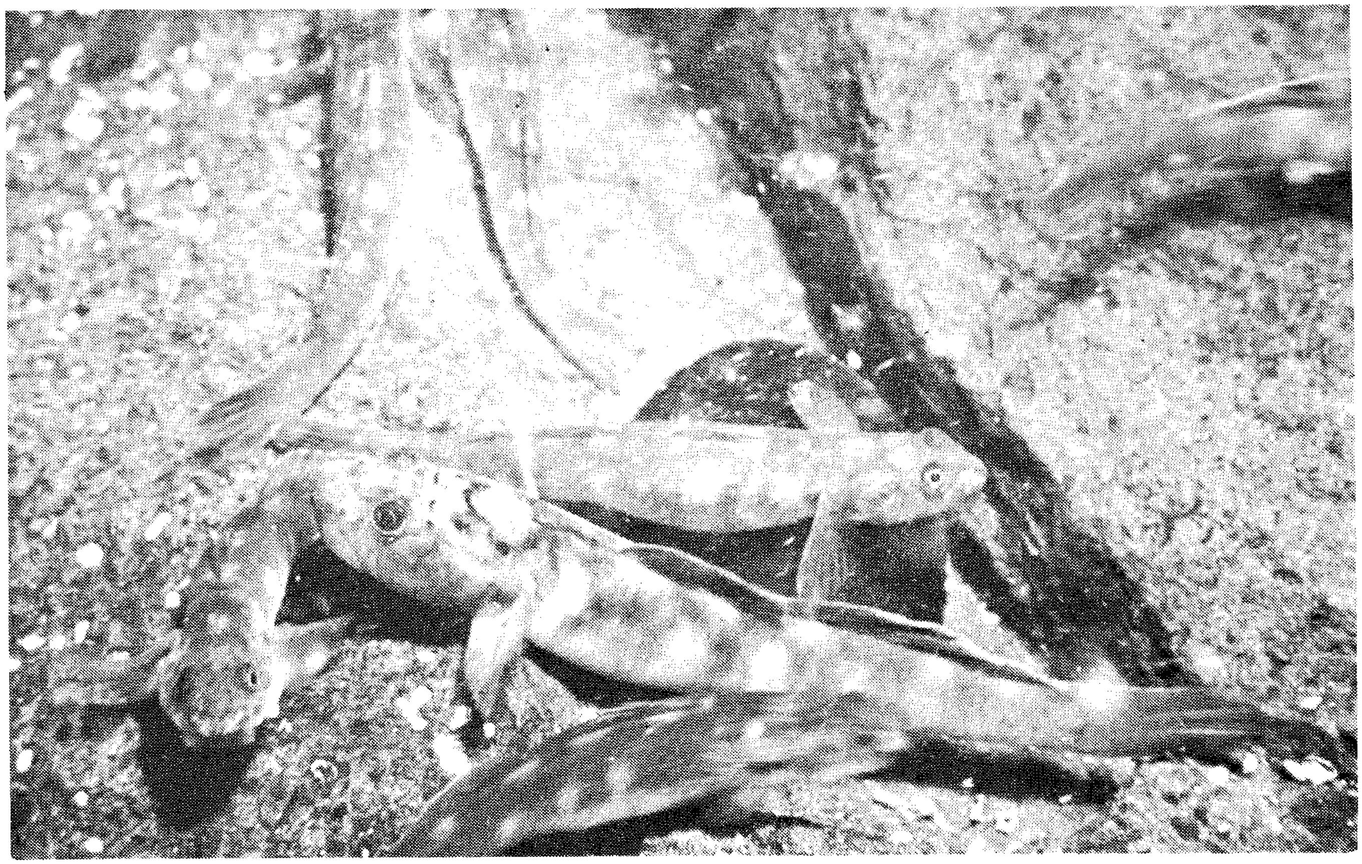
*Observed by Kinzie and Ford.

TABLE 3. Distribution and relative abundance of macrofauna in Pua'alu'u Stream, Maui, October to November 1977 (U = uncommon; C = common; A = abundant).

Stream Fauna	Sampling Stations									
	Lawer Reach			Mid-Reach					Headwaters	
	1	2	3	4	5	6	7	8	9	10
ANNELIDA										
Hirudinea										
Unidentified leech	.		.	.	U	.	.	.		
MOLLUSCA										
Lymnaeidae										
Pseudisidora producta	.	.	.	C	C	C	A	C	C	C
Erinna aulocospira			.	.	.	C	A	C	C	C
Ancylidae										
Ferrissia sharpi			.	C	A	A	.	A	A	A
Thiaridae										
(genus & sp. unknown)	C	C	C	A	A	A	.	.		
Neritidae										
Neritina granosa	A	A	A	C	U	U	.	.		
CRUSTACEA										
ISOPODA										
Philoscia (3) sp.	.	U	.	.	.	.	.	.	.	
AMPHIPODA										
Orchestia pickeringi	.	U	.	.	.	.	.	.	.	
DECAPODA										
Atyidae										
Atya bisulcata	A	A	A	A	A	A	.	A	A	A
Palaemonidae										
Macrobrachium grandimanus	.	U	U	.	.	.	.	.		
M. lar	.	.	U	.	.	.	.	.		.

TABLE 3--Continued.

Stream Fauna	Sampling Stations: Lower Reach 1	2	3	Mid-Reach 4	5	6	7	8	Headwaters 9	10
CHORDATA										
PISCES										
Gobiidae										
Awaous stamineus	U	U	.	.	.	.	.	.	.	
Sicydium stimpsoni	A	A	C	.	.	.	.	.	.	
Lentipes concolor	A	A	A	A	A	A	.	A	A	A
Number of Macrofaunal Species/Station (excl. insects)	6	9	7	6	7	7	2	5	5	5
Total Number of Species/Station (incl. insects)	17	16	8	7	8	7	3	5	13	13



FIGUXE 5. An aggregation of *Lentipes concolor* photographed at station 1. A single *Neritina granosa* is visible in the background. Small (2-3 mm in length) white spots on rocks are egg capsules of *N. granosa*.

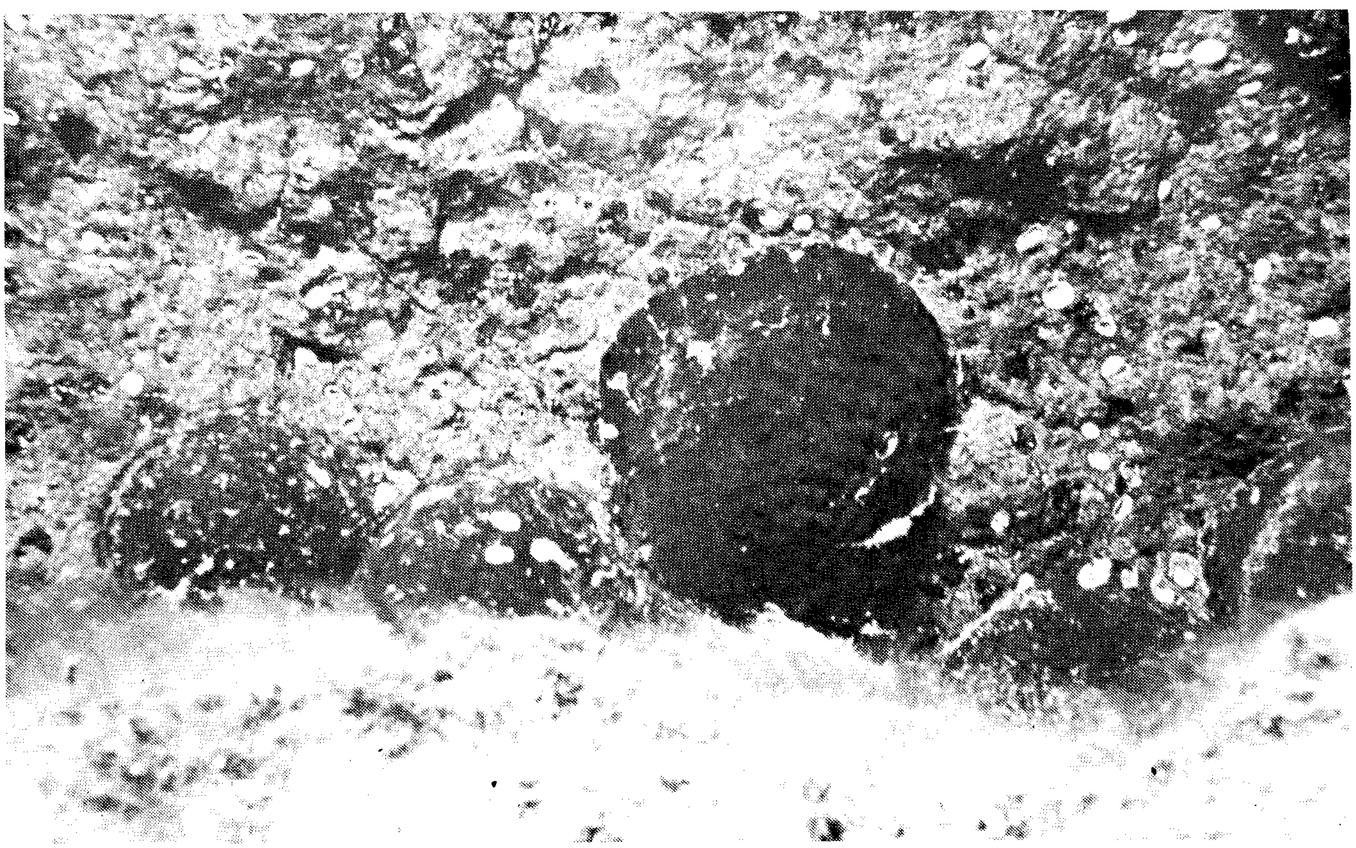


FIGURE 6. *Neritina granosa* and egg capsules observed near station 3.

These three species were the only fishes observed in the stream. Itinerant marine and euryhaline fishes such as Mugil cephalus ('ama'ama), Kuhlia sandvicensis (āholehole), and the predatory eleotrid Eleotris sandwicensis ('o'opu 'ōkuhe) which frequent the terminal reaches of most perennial streams in Hawai'i were notably absent here. As will be discussed, the presence or absence of these species may be controlled by a mechanism as simple as stream morphology, and yet their exclusion from the stream may lead to a radically different community structure, species diversity, and abundance.

The endemic atyid shrimp or "mountain 'ōpae," Atya bisulcata ('ōpae kala'ole), was abundant at all sampling stations. According to Couret (1976), Atya is normally more abundant in the middle and upper elevations of perennial and some interrupted streams. Based upon his collections from the Wailuku River on the island of Hawai'i, the upper limit for the species appears to be in excess of 1000 m. In Pua'alu'u, however, adults were well represented at station 1 just above the stream mouth as well as throughout the remainder of the stream course sampled. Hawai'i's only endemic prawn, Macrobrachiurn grandimanus ('ōpae 'oeha'a), was represented in Pua'alu'u by only three individuals which were observed below the highway. Numerous Macrobrachium lar were observed in Palikea/'Ohe'o by Kinzie and Ford (1977); however, only a single specimen was found in Pua'alu'u Stream, at station 3.

The molluscan fauna of Pua'alu'u is both abundant and diverse. Five endemic species and an indigenous species, together representing four families and five genera of molluscs, were found. The two most conspicuous forms at lower elevations are a thiarid (family of molluscs with lungs) which has in the past been called Melania and which is apparently indigenous to Oceania, and the endemic neritid, Neritina granosa (hihiwai or wī). The systematics of the Thiaridae in Hawai'i are in complete disarray. The thiarid snail is apparently represented by numerous shell forms affected by various degrees of susceptibility to whorl erosion in fresh and brackish water habitats throughout the state. Neritina granosa, perhaps the largest rheophilic (current-loving) neritid in the world (Ford, in prep.), is characteristically found in remote perennial streams on Kaua'i, Moloka'i, Maui, and Hawai'i. Locally high densities may be found in shallow riffles with rocky substrata and pristine water quality, generally below 1000 feet (305 m) elevation. Both Ford (in prep.) and Maciolek (in press) have observed two major shell forms which are related to altitude: rough-surfaced shells with broad wing-like apical margins are characteristic of the terminal and lower reaches, and smooth rounded shells are normally found in the middle and upper limits of the species distribution within a given stream. Both shell morphs were observed in Pua'alu'u during this study. Although hīhīwai were also found in Palikea/'Ohe'o by Kinzie and Ford (1977), the higher relative abundance and presence of neritid egg capsules on rocks suggest that Pua'alu'u may harbor a larger population (Fig. 6).

Above the highway the diversity of molluscs increases. The most abundant although least conspicuous species found at Pua'alu'u is the tiny ancylid Ferrissia sharpi. This poorly known species was incorrectly identified as F. rivularis by Kinzie and Ford (1977), who found it in both Palikea and Pipiwai streams. The species is described from Kaua'i, O'ahu, Moloka'i, and Hawai'i by Hubendick (1966). As far as we can ascertain, our report represents the first observation of F. sharpi from Maui. Apparently endemic to Hawai'i, this opaque little limpet grows to a length of only 2-3 mm and can be found in abundance on submerged leaf litter and occasionally on gravel. Its habits and ecology are as yet unknown. Also found sympatrically with F. sharpi is the endemic lymnaeid snail Pseudisidora producta. P. producta, referred to as Lymnaea reticulata in Hubendick (1952), is the only sinistral species of the Lymnaeidae of which we are aware (Morrison 1968). P. producta is- reported to be rheophilic. Numerous specimens collected from rocks and gravel exposed to the current at Pua'alu'u supported this observation. To our knowledge, our report represents the first record of this species on Maui. Another endemic lymnaeid, Erinna aulocospira, was found at Pua'alu'u in springs and seeps along the upper portion of the stream, and in the aquatic mosses growing on channel walls exposed to the fine spray of cascades. Much needs to be done before we can understand the contribution of this diverse mollusc fauna to Hawaiian stream communities.

Other less common organisms at Pua'alu'u Stream include the amphipod Orchestia pickeringi; the isopod Philoscia (?) sp.; a single, unidentified leech found at station 5; and the pupae of the exotic caddisfly Cheumatopsyche analis. C. analis was introduced to Hawaiian inland waters by the State Division of Fish and Game in the mid-1950's as a food source for exotic game fishes. It is now perhaps one of the most ubiquitous exotic species occurring in Hawaiian streams. In many streams C. analis is very abundant, constructing tiny stone cases on the underside of rocks in shallow riffles.

A comparison of the total number of species of macrofauna observed does not reveal significant differences between stations (Table 3). However, if the aquatic insects found by Hardy (Part 111) are included, it can be seen that the two lowest stations and the two uppermost stations have the greatest diversity. Surprisingly few insects were observed in the middle reaches of the stream. In the sections heavily shaded by dense stands of bamboo, molluscs clearly dominate the benthos. Only two other species are found in abundance at all stations on the main stream: Atya bisulcata and Lentipes concolor.

Incidental observations on the general nature of the stream bed and riparian vegetation suggest that this stream may possess other unique properties and perhaps problems. At numerous locations along the stream course there was evidence of recent and occasionally extensive cliff slumping and rock falls. In a few areas portions of the entire stream bank had slipped into the stream. Much of this talus appeared to be of very recent origin. Near station 9, a large boulder (about 1 m^3) had separated from the stream channel wall, fallen, and crushed several bamboo plants on the stream bank. The stems and leaves of these plants were still green suggesting recent occurrence. At station 3 a massive block greater than 3 m^3 had separated from the channel wall apparently only hours before our arrival at the station and fallen into the plunge pool at the base of a small fall virtually filling it. Fox (1976) observed similar phenomena in Manawainui Valley near Kaupō, Maui. There, numerous talus fans, rockfalls, and occasionally individual boulders lay strewn along the stream, suggesting recent and severe erosion and cliff collapse. Gon (1976) stated that Manawainui Stream was continually pelted with small rocks and falling gravel (which made collection and movements within the valley floor rather dangerous and exciting). Fox has attributed this condition to the erosion of the large, blocky 'a'ā lava cores of the Kula Series which comprise the channel walls at Manawainui. This may explain in part the nature of the observed erosion in Pua'alu'u since both streams flow across similar Kula lava structures.

At several other stations, particularly in areas of dense bamboo growth, the extensive root networks of these plants often formed large escarpments overhanging the stream where the subsoil had been eroded away. As these mats failed and fell into the stream, soils, rocks, and numerous large plants would follow often leaving a dense "raft" of bamboo lying across the stream at right angles to the streambed (Fig. 7). Our observations suggested that the density of the bamboo itself could in fact be responsible for the extensive erosion in the bamboo thickets. During rains the smooth leaves and stems of the bamboo are unlikely to significantly impede or retain much water, delivering most of it immediately to the forest floor. The dense canopy retards evaporation while the compact root mats and abundant leaf fall will all contribute to saturation of the upper soil. This, combined with the tightly interlocked but shallow root systems of the bamboo, appears to promote both the undercutting of bamboo sods and the extensive knockdowns and rafts of bamboo. Because the bamboo is such an aggressive species in the Park as well as adjacent areas of East Maui this possibility should be studied in the near future.

At station 7, we made an attempt to survey a portion of the dense bamboo forest lining the stream banks. Near the crest of the channel rim there was a sharp interface between the monospecific bamboo and a similarly dense thicket of Dicranopterus linearis (false staghorn fern or uluhe). The uluhe extended over the rim and part way into the adjacent pasture lands.

At an elevation of about 675 feet (206 m) the stream forks. The west fork was followed for about 100 meters until a waterfall made further progress impossible. The rich madicolous (the habitat affected by spray, mist, etc., from a waterfall) fauna of these spring-fed falls was in striking contrast to the east fork which appeared to carry little surface water. A few backwater pools perched above the level of the stream harbored populations of atyid shrimp and dragonfly naiads. The stream bed of the east fork, while essentially dry, showed evidence of extensive erosion

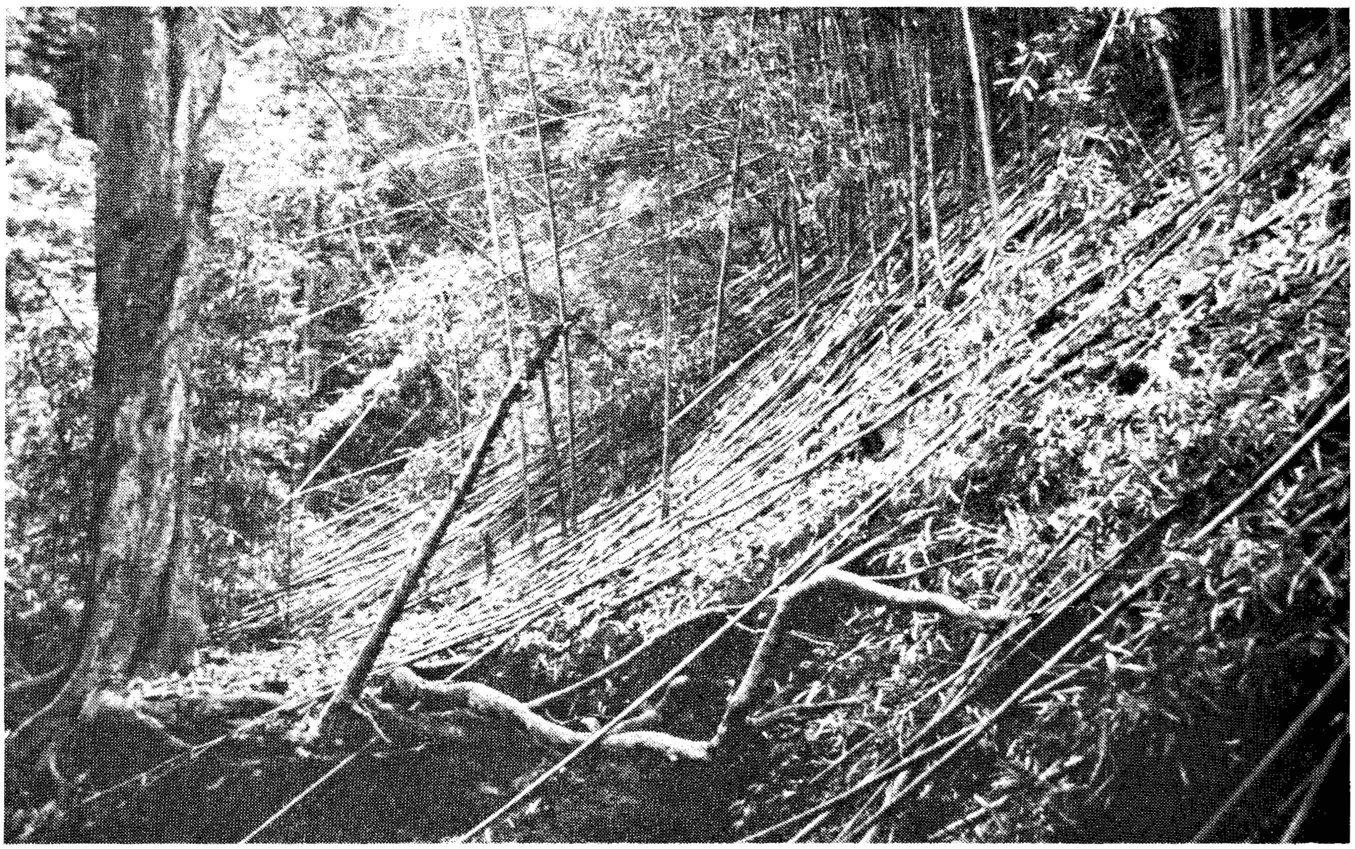


FIGURE 7. View of the bamboo thickets lining the upper stream course. Note density of fallen bamboo. This is characteristic throughout the riparian bamboo forest, particularly where stream bank erosion is common.

FIGURE 8. Small plunge pool (station 1) harboring a large population of Lentipes concolor. Note precipitous channel walls and abundance of Pandanus litter.

both recent and of apparently long duration. The riparian vegetation of this fork was entirely bamboo.

DISCUSSION

Pua'alu'u presents a striking illustration of how the geology of the watershed, the morphology of the stream course, and the nature of the riparian vegetation can affect the abundance and distribution of macrofauna within the stream, and in fact the structure of an entire lotic (pertaining to still water) ecosystem. The less-permeable Kula Series lavas which form the channel walls and bottom allow the stream to carry perennial water from perched aquifers year round, thereby providing the basic requirement for the majority of the Hawaiian endemic freshwater macrofaunna. The striking absence of itinerant marine forms and estuarine predators may be accounted for by the precipitous nature of the terminal cascade at the mouth of Pua'alu'u. These species are excluded from the upper stream by their inability to surmount this physical barrier. The absence of an entomous (of insects) fauna above an altitude of 250 feet (75 m) within the bamboo forests remains a puzzle. Hardy (Part 111) has speculated that the invasion of the lower portion of the stream channel by the predaceous ant Anoplolepis longipes and the dense growth of bamboo along the channel have resulted in the reduction of much of the stream's insect diversity. Undoubtedly, the dense canopy of bamboo over the stream has an enormous impact on the structure of the benthic periphyton (the plant micro community growing attached to other plants), but these communities were not studied in sufficient detail to allow any definite conclusions to be drawn at this time. The possibility of a causative relationship between the absence of aquatic insects and the abundance and diversity of molluscs in the mid-reaches of the stream is a further area for study.

The distribution and abundance of Lentipes in Pua'alu'u is possibly the most interesting feature of this stream. Lentipes adults are found in the shallow pool immediately above the terminal cascade (Fig. 8), and occur throughout the entire stream course sampled. This observation agrees with Maciolek (1977) that adults can be found near the stream mouth in small precipitous streams. With our earlier observations on the abundance of Lentipes confirmed, the primary question remaining is why does L. concolor dominate the fish fauna of Pua'alu'u? At this point, we will attempt to use the information gained during the Pua'alu'u survey and existing knowledge of the evolution, ecology, and habits of this species to develop an hypothesis.

Lentipes is the only stream-dwelling fish endemic to Hawai'i at the generic level (Maciolek 1975a, 1977). This is particularly interesting in light of the fact that no other freshwater and perhaps no marine fish genus is endemic to the Hawaiian archipelago, although endemism at the species level is notably high for both freshwater (80%) and marine fishes *(30%)* according to Maciolek (1975b) and Briggs (1974), respectively. Gosline and Brock (1960) suggest that three genera of shallow water marine fishes--Gregoryina, Microbrotula, and Pogonemus--are known exclusively from the Hawaiian Islands. However, the entire family Gregoryinidae is based on only a single specimen a little over two inches long "obtained at Laysan Island, where it was brought to a nest by a white tern." Similarly, the genus Microbrotula is based upon only two specimens. It may well be that these fishes exist elsewhere but remain as yet undescribed.

In comparison with other freshwater forms from Hawai'i and Oceania, Lentipes may be considered to be highly evolved. It is the only representative of the "scaleless" gobies in Hawai'i; only one other scaleless goby has been found elsewhere in the Pacific by Couret (1978) but has yet to be identified (Couret, pers. comm.). Lentipes is also the only freshwater fish exhibiting bright coloration. The posterior half of territorial males becomes bright red.

The prehistoric Hawaiians recognized the bright red coloration of the males and gave the species the name 'o'opu hi'u-kole or hi'u-'ula (red-tailed). Mature males of this species are strongly territorial (Maciolek 1977), and spawning apparently occurs in home territories. Females and juveniles of both sexes, on the other hand, are relatively drab in appearance and not territorial, and non-territorial males are similarly less bright and aggressive. This is a familiar pattern that is frequently encountered in vertebrates, particularly birds and fishes (Poulton 1890; Beddard 1892; Parker 1948). One of the possible explanations for this pattern is that the bright coloration of the territorial males increases their susceptibility to predation. It would therefore be to the advantage of the fish to limit these costly factors (territorial defense, courtship behavior, and bright color) to the minimum time when they contribute to the species fitness, and to exhibit the drab coloration and less conspicuous behaviors at all other times. McPhail (1969) has suggested that differential predation upon red male sticklebacks, Gasterosteous, by a carnivorous mudminnow, Novumbra, has provided the selective pressure necessary to favor a dull black nuptial coloration in sticklebacks of the Chehalis river system on the Olympic Peninsula, Washington. These facts suggest that predation should be considered in speculation about the evolution of Lentipes. These specialized traits imply that Lentipes has either evolved more rapidly than the other freshwater gobiids or that its history in the Hawaiian Islands may extend farther back in time.

Because of countless extinctions it is impossible to estimate the number of Hawaiian birds which may have preyed upon stream macrofauna in the past. Today, the Black-crowned Night Heron (Nycticorax nycticorax hoactli) and possibly migratory shorebirds, most notably the 'ūlili (Heteroscelus incanus), are known to feed along stream banks: however, the composition of their diets is largely unknown.

The most voracious predatory fish native to Hawaiian streams is the large eleotrid Eleotris sandwicensis ('o'opu 'okuhe) which is common in the lower reaches of most perennial streams, and in estuaries. It is likely that E. sandwicensis preys upon juvenile gobiids, shrimps, and prawns throughout its range in lower streams. Two other potential predators on Lentipes may be found sympatrically with the eleotrid. These are the itinerant marine aholehole, Kuhlia sandvicensis, and the prawn Macrobrachium grandimanus.

Another possible predator which may have evolved with Lentipes is the large aquatic naiad of the endemic dragonfly Anax strenuus. Attaining a length of up to 7 cm prior to final metamorphosis, these odonate larvae are capable of devouring shrimps and fishes of nearly their own length. However, naiads are generally found in pools and backwaters rather than in the swift waters normally inhabited by Lentipes. Only at higher elevations where the stream flow is markedly reduced does the habitat of the two species overlap. The fact that by the time migrating Lentipes individuals reach the upper stream they have reached adult size may reduce predation by odonate naiads.

Hence it appears that predation on Lentipes may act as a selective factor only in the lowest reaches of perennial streams, with potential predation intensity decreasing with distance upstream.

Maciolek (1977) has characterized the habitat of Lentipes as the middle and upper reaches of streams. In light of the facts presented above, this distribution might be the result of the fact that the presence of high levels of fish predation make it impossible for Lentipes to carry out its unique breeding behavior in the lower reaches of most streams. Kami et al. (1974) suggest a similar process controlling fish distribution in the Geus River. The rheophilic gobiids that do breed in the lower reaches are all drab in coloration year round. The other note concerning habitat that Maciolek makes is that "Lentipes streams" are characteristically precipitous. Clearly, the steep morphological profile of the terminal cascade at Pua'alu'u and the absence of a predominantly freshwater pool at its base certainly must be considered to meet these criteria. Our survey has shown Eleotris and Kuhlia to be totally absent and M. grandimanus sparse. With this lack of predators, Lentipes adults occur down to the lowest part of the stream. A further suggestion arises from these observations: the relatively greater abundance of Lentipes compared to other gobiids could be related to the absence of predation pressure. Lentipes, arguably the most evolved Hawaiian (or Pacific) freshwater gobiid, may be the best competitor such that in the absence of predation, the diversity of the stream community would be reduced by competitive exclusion. It must be emphasized at this point that this suggestion is only an hypothesis since the existing data are circumstantial and do not constitute a test. One weakness this hypothesis shares with McPhail's (1969) study is that we do not have conclusive evidence that any of the potential predator species actually prey upon

Lentipes. Additionally, recent finds (Ziegler, pers. comm.) suggest that extinct components of the Hawaiian avifauna could contain as yet undiscovered stream predators.

Ultimately, we look forward to the generation of a predictive, heuristic (helping to discover) hypothesis which might explain the character of "Lentipes streams" in which the species might be expected to flourish. However, at this time, based upon our studies at Pua'alu'u, we can state that the basic requirements of such an ecosystem will include a perennial pristine stream environment and a mechanism to exclude predatory species from the stream system. At Pua'alu'u the precipitous stream mouth serves this purpose. Although Lentipes has also been observed to be the dominant gobiid near 250 feet (75 m) elevation in the neighboring watersheds of Hāhālawe and Kakiweka streams, the profiles of the terminal reaches of the streams have not yet been characterized. Recently, Gon (1976) has observed Lentipes above 800 feet (245 m) in Manawainui Stream. Here Lentipes was observed to outnumber the only other fish found there, Awaous stamineus, by a factor of almost 2:1. Surprisingly, the lower reaches of Manawainui flow across very permeable Hāna Series rocks and often disappear into subsurface flows. In this way, therefore, the interrupted stream (sensu Maciolek [1975b]) acts to exclude predators from the lower reaches while apparently allowing some diadromous species to enter during freshets. Because of the startling difference in the composition and abundance of Hawaiian stream fauna between Palikea/'Ohe'o and Pua'alu'u streams, and the potential similarities between Pua'alu'u and nearby small streams, we recommend that these drainages also be studied in order to provide additional and more conclusive data on which to base this hypothesis. Such studies may allow for the first time the development of an objective and quantitative definition of critical habitat for a rare and possibly endangered Hawaiian species.

It may be that a few streams are dominated by this species due to geomorphological, hydrological, and subsequently ecological factors which we believe may be predicted "a priori." We are not suggesting that Lentipes is more abundant or found in more streams than previously reported. Thus, "Lentipes streams" may be considered as critical habitats in that the crucial, effective breeding populations are maintained there.

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PART II

CATALOGUE OF THE VASCULAR PLANTS AT PUA'ALU'U, MAUI

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A list of the plants found at the various study sites along Pua'alu'u stream are listed in Table 1. The names of the ferns and fern allies follow that of Wagner (unpublished) and St. John (1973) for the angiosperms. Where it is known, the vernacular name is given for each species as well as the status of the plant in the Hawaiian Islands (Endemic: plants found only in the Hawaiian Islands; Indigenous: plants naturally present in the Hawaiian Islands; P. Introd.: plants introduced by the early Polynesians, prior to 1778; and H. Introd.: plants introduced after 1778).

A brief description of the vegetation at each study site is shown in Table 2. The descriptions refer to the daninant species and their stature only.

The vegetation of Pua'alu'u is predominantly exotic (Table 3). The higher percentage of endemic and indigenous ferns is probably due to their lesser significance to man. The high percentage of Polynesian introductions in the monocotyledons reflects the high usage of this group in the pre-Historic Hawaiian economy.

The bamboo infestation along the stream course is the most significant plant resource management problem. The herbicide Roundup is said to be quite effective. However, there are two problems associated with such an approach.

1. We do not know the impact of the herbicide on aquatic fauna and flora in Hawai'i. Thus caution should be used if the herbicide is applied close to the stream. Recently developed fine spray applicators would diminish the amount of herbicide introduced into the ecosystem because they facilitate absorption of the herbicide by the plants. Lower quantities of herbicide are needed to bring about the same effects of conventional techniques reducing the herbicide load of the sprayed area.

2. The size of the bamboo thickets as well as the size of individual spikes make their control a major operation. One technique that should be tried would be to saw down the spikes (all cuts must be at right angles to the long axis of the spike so as not to produce pointed stumps). When new sprouts emerge they should be sprayed.

The eradication of the bamboo should be coordinated with a program to reintroduce native species such as hala, hau, lama, and 'ōhi'a. The reestablishment of a native flora should be one of the long-range goals for the stream.

TABLE 1. Catalogue of the vascular plants at the study sites along Pua'alu'u, Maui.

Species	Status	1	2	3	4	5	6	7	8	9	10
		Station Numbers									
FERNS AND FERN ALLIES											
ADIANTACEAE											
Adiantum capillus-veneris L. 'Iwa'iwa	Indigenous	x	.	.	.	.	.	.	.	.	.
Adiantum cuneatum Lang. & Fisch. 'Iwa'iwa	H. Introd.	.	x	x	x	x	.	x	x	x	.
ASPIDIACEAE											
Athyrium japonicum (Thunb.) Copel.	H. Introd.	.	.	.	x	x	.	x	.	.	.
Athyrium sandwichianum Presl Hō'i'o	Endemic	.	x	.	.	.	.	.	.	.	.
Cyclosorus parasiticus (L.) Farwell	H. Introd.	.	x	x	x	x	.	.	x	x	x
BLECHNACEAE											
Blechnum occidentale L.	H. Introd.	.	x	.	.	x	.	.	.	.	.
Sadleria cyatheoides Kaulf. 'Ama'u, 'ama'uma'u	Endemic	.	.	.	.	.	.	.	x	.	.
DAVALLIACEAE											
Nephrolepis exaltata (L.) Schott 'Okupukupu, pāmoho	H. Introd.	.	x	x	x	x	.	.	x	x	x
DICKSONIACEAE											
Cibotium glaucum (J. Sm.) H. & A. Hapu'u	Endemic	.	.	.	.	.	.	.	.	x	.
GLEICHENIACEAE											
Dicranopteris linearis (Burm.) Underw. Uluhe	Indigenous	.	.	.	.	.	.	.	x	x	.
HYMENOPHYLLACEAE											
Gonocormus minutus (Bl.) v.d. Bosch	Indigenous	.	.	.	.	x	.	.	x	.	.
Vandenboschia davallioides (Gaud.) Copel. Palai-hihi	Endemic	.	.	.	.	x	.	.	.	.	.
POLYPODIACEAE											
Microsorium scolopendrium (Burm.) Copel. Laua'e	H. Introd.	x	x	x	x	.	.	.	x	x	x
Pleopeltis thunbergiana Kaulf. Pākahakaha, 'ēkaha-'ākōlea	Indigenous	.	.	x	.	x	.	.	x	.	x

TABLE 1--Continued.

Species	Status	1	2	3	4	5	6	7	8	9	10
FERNS AND FERN ALLIES (con't.)											
PSILOTACEAE											
Psilotum nudum (L.) Griseb. Moa	Indigenous	.	.	.	.	.	.	.	X	X	.
SELAGINELLACEAE											
Selaginella arbuscula (Kaulf.) Spring Lepelepe-a-moa	Endemic	.	.	.	.	X	.	X	X	X	.
FLOWERING PLANTS											
MONOCOTYLEDONS											
ARACEAE											
Colocasia esculenta (L.) Schott Taro	P. Introd.	.	X	X	.	.	.	.	.	.	.
Philodendron sp.	H. Introd.	.	.	X	.	.	.	.	.	.	.
CANNACEAE											
Canna indica L. Indian shot	H. Introd.	.	.	.	.	.	.	.	.	.	X
COMMELINACEAE											
Commelina diffusa Burm. f. Honohono	H. Introd.	.	X	X	.	X	.	.	.	.	X
CYPERACEAE											
Carex wahuensis C. A. Mey.	Endemic	X	.	X	.	.	.	.	.	.	.
Cyperus sp.	H. Introd.	.	.	X	.	X	.	.	.	.	X
GRAMINEAE											
Bamboo		.	X	X	.	X	X	X	X	X	X
Digitaria sanguinalis (L.) Heist. in Scop. Large crabgrass	H. Introd.	X	.	.	.	.	.	.	.	.	.
Oplismenus hirtellus (L.) Beauv. Basketgrass	H. Introd.	.	X	X	X	X	.	.	X	X	X
Paspalum conjugatum Berg. Hilo grass	H. Introd.	.	.	X	.	.	.	.	.	.	X
Paspalum sp.	H. Introd.	.	.	.	X	.	.	.	.	.	.
Pennisetum purpureum Schumach. Elephantgrass	H. Introd.	.	X	.	.	.	.	.	.	.	.

TABLE 1--Continued.

Species	Status	1	2	3	4	5	6	7	8	9	10
		Station Numbers									
FLOWERING PLANTS (con't.)											
MONOCOTYLEDONS (con't.)											
GRAMINEAE (con't.)											
Setaria geniculata (Poir.) Beauv. Perennial foxtail	H. Introd.	.	.	x	.	x	.	.	.	.	.
Setaria palmaefolia (Koen.) Stapf Palmgrass	H. Introd.	.	.	.	.	x	.	.	x	.	.
Sporobolus sp.	H. Introd.	.	.	x	.	.	.	.	.	.	.
LILIACEAE											
Cordyline terminalis (L.9 Kunth Ti	P. Introd.	.	x	x	x	x	.	.	x	.	.
MUSACEAE											
Musa sp. Banana	P. Introd.	.	.	.	.	.	.	.	.	x	.
PALMAE											
Cocos nucifera L. Niu		.	.	x	.	x	.	.	.	.	.
PANDANACEAE											
Pandanus odoratissimus L. f. Pūhala, hala	Indigenous	x	x	x	x	.	.	.	.	.	.
ZINGIBERACEAE											
Phaeomeria speciosa (Bl.) Koord. Torch ginger	H. Introd.	.	.	x	.	.	.	.	.	.	.
Zingiber zerumbet (L.) Roscoe in Sm. 'Awapuhi kua hiwi	P. Introd.	.	x	.	x	x	x	x	x	x	x
DICOTYLEDONS											
ANACARDIACEAE											
Mangifera indica L. Mango	H. Introd.	.	.	x	x	x	x	.	.	.	x
BALSAMINACEAE											
Impatiens sultani Hook. f. Impatiens	H. Introd.	.	.	x	.	.	.	.	.	.	.
COMPOSITAE											
Bidens pilosa L. Spanish needle	H. Introd.	.	.	x	.	.	.	.	.	.	.
Emilia sonchifolia (L.) DC. Lilac pualele	H. Introd.	.	.	x	.	.	.	.	.	.	.

TABLE 1--Continued.

Species	Status	1	2	3	4	5	6	7	8	9	10
		Station Numbers									
FLOWERING PLANTS (con't.)											
DICOTYLEDONS (con't.)											
COMPOSITAE (con't.)											
Erechtites valerianaefolia (Wolf) DC.	H. Introd.	.	x	.	.	.	.	.	.	.	.
Erigeron bonariensis L. Hairy horseweed	H. Introd.	.	x	.	.	.	.	.	.	.	.
Eupatorium riparium Regel Spreading mist flower	H. Introd.	.	.	x	.	.	.	.	.	.	.
Pluchea odorata (L.) Cass. Shrubby fleabane	H. Introd.	.	x	x	.	.	.	.	.	.	.
Senecio sylvaticus L. Wood groundsel	H. Introd.	x	.	.	.	.	.	.	.	.	.
Sonchus oleraceus L. sow thistle	H. Introd.	.	.	x	.	.	.	.	.	.	.
Synedrella nodiflora (L.) Gaertn. Synedrella	H. Introd.	.	x	.	.	.	.	.	.	.	.
Compositae		.	.	.	.	.	.	.	x	.	x
CONVOLVULACEAE											
Ipomoea sp. Morning glory	Indigenous	.	.	x	.	.	.	.	.	.	.
CRUCIFERAE											
Nasturtium microphyllum Boenn. ex Reichenb. Watercress	H. Introd.	.	.	x	.	.	.	.	.	.	.
EUPHORBIACEAE											
Aleurites moluccana (L.) Willd. Kukui	P. Introd.	.	x	x	x	.	x	.	x	.	x
GOODENIACEAE											
Scaevola taccada (Gaertn.) Roxb. Naupaka-kahakai	Indigenous	x	.	.	.	.	.	.	.	.	.
LAURACEAE											
Persea americana Mill Avocado	H. Introd.	.	.	x	.	.	.	.	.	.	.
LEGUMINOSAE											
Desmodium uncinatum (Jacq.) DC. Spanish clover	H. Introd.	.	.	.	.	.	.	.	.	.	x
Vine ?		.	.	.	.	.	.	.	.	.	x

TABLE 1--Continued.

Species	Status	1	2	3	4	5	6	7	8	9	10
		Station Numbers									
FLOWERING PLANTS (con't.)											
DICOTYLEDONS (con't.)											
LOBELIACEAE											
Clermontia sp. 'Ohā-wai	Endemic	.	.	.	.	.	.	.	x	.	.
LYTHRACEAE											
Cuphea carthagensis (Jacq.) Macbride Tarweed	H. Introd.	.	.	x	.	.	.	.	.	.	.
MORACEAE											
Artocarpus altilis (Parkins. ex Z) Fosb. 'Ulu	E. Introd.	.	.	.	.	x	.	.	.	.	.
MYRSINACEAE											
? *Ardisia crispa* (Thunb.) A. DC. Hen's eyes	H. Introd.	.	x	.	.	.	.	.	.	x	.
MYRTACEAE											
Eugenia cumini (L.) Druce Java plum	H. Introd.	.	.	.	.	x	.	.	.	.	.
Psidium cattleianum Sabine Strawberry guava	H. Introd.	.	.	.	.	x	.	x	x	x	.
Psidium guajava L. Guava	H. Introd.	.	.	.	x	x	.	.	x	x	x
OXALIDACEAE											
Oxalis corniculata L. Yellow wood sorrel, lady's sorrel	H. Introd.	.	.	x	.	.	.	.	x	.	.
Oxalis martiana Zucc. Pink wood sorrel	H. Introd.	.	x	.	.	.	.	.	.	.	.
PASSIFLORACEAE											
Passiflora	H. Introd.	.	x	.	.	.	.	.	.	.	.
PIPERACEAE											
Peperomia sp. 'Ala'ala-wai-nui	Endemic	.	x	.	.	.	.	.	.	.	.
PLANTAGINACEAE											
? *Plantago lanceolata* L. Narrow-leaved plantain	H. Introd.	.	.	x	.	.	.	.	.	.	.

TABLE 1--Continued.

Species	Status	1	2	3	4	5	6	7	8	9	10
		Station Numbers									
FLOWERING PLANTS (con't.)											
DICOTYLEDONS (con't.)											
ROSACEAE											
Rubus rosaefolius Sm. Thimbleberry	H. Introd.	.	.	.	x	x	.	.	x	.	x
RUBIACEAE											
Coffee arabica L. Arabian coffee	H. Introd.	.	.	.	x	.	.	.	.	.	.
Morinda citrifolia L. Noni	P. Introd.	.	x	.	.	.	.	.	.	.	.
UMBELLIFERAE											
Centella asiatica (L.) Urban Asiatic penneywort	H. Introd.	.	x	x	x	.	.	x	x	x	.
URTICACEAE											
Pilea peploides (Gaud.) H. & A.	Indigenous	.	x	.	.	.	.	.	.	.	.
Pipturus sp. Māmaki	Endemic	.	.	.	.	x	.	x	.	.	.
VERBENACEAE											
Stachytarpheta jamaicensis (L.) Vahl Jamaica vervain	H. Introd.	.	x	.	x	x	.	.	.	.	x

TABLE 2. Vegetation structure at the study sites along Pua'alu'u, Maui.

Station	Vegetation Description
1	Scattered 3-5 m Pandanus odoratissimus and Scaevola taccada
2	Open 3–5 m Pandanus introduced shrubs and herbs (Cordyline, Microsorum, Oplismenus, Centella, Zingiber, Nephrolepis)
3	Open 10–25 m Aleurites moluccana, scattered 5–1Q m Pandanus. introduced shrubs and herbs
4	Closed 10–25 m Bamboo, scattered 10-25 m Mangifera, introduced herbs
5	Open 10–25 m Mangifera, closed 10–25 m Bamboo, herbs
6	Closed 10–25 m Bamboo, scattered 10–25 m Mangifera, herbs
7	Closed 10–25 m Bamboo, scattered 10–25 m Manqifera, herbs
8	Closed 10–25 m Bamboo, Dicranopteris, herbs
9	Open 5–10 m Aleurites, open 3–5 m Psidium guajava and herbs
10	Closed 10–25 m Bamboo, herbs

TABLE 3. The percentage of species in each distribution status for the vascular plants at Pua'alu'u, Maui.

Distributional Status	Ferns	Taxonomic Group Monocots	Dicots
Endemic	31	6	9
Indigenous	31	6	6
P. Introd.	0	25	6
H. Introd.	38	63	80
Total Percentage	100	100	101
No. of Species	16	16	35

PART III

REPORT OF PRELIMINARY ENTOMOLOGICAL SURVEY OF PUA'ALU'U STREAM, MAUI

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INTRODUCTION

This survey was conducted by D. E. Hardy and assistant Bert Tanoue, January 4-6, 1978.

Entomologically, this is a strange, most frustrating stream. The complete takeover of the stream course by bamboo appears to have had a drastic effect upon the fauna. Coupled with this, the invasion of the lower portion of the area up to about 150 m by a predacious ant (Anoplolepis longipes [Jerdon]) has resulted in a depauperation of the insect fauna.

The bottom part of the stream is normal up to about 50 m distance from entering the ocean (10-12 m elev.), with a fairly rich fauna of Chironomidae, Ephydridae, Canaceidae, Tipulidae, and Dolichopodidae. Above this point (the two lower stations of Kinzie and Ford), the stream is completely abnormal as far as the insect fauna is concerned. We found no evidence of aquatic insects until we reached the upper portion of the stream (310-320 m, the two highest stations of Kinzie and Ford). In this area, four species of Odonata were foraging up and down the stream (probably feeding on the Drosophila sulphurigaster Duda breeding in the rotting guavas and the mosquitoes, Aedes albopictus [Skuse], breeding in bamboo shoots); two species Tipulidae, one Sciaridae, and one Ceratopogonidae were collected along the stream: also, one species of Chironomidae was collected above one of the pools.

LISTING OF SPECIES COLLECTED WITH BIOLOGICAL NOTES

Mouth of stream, 1-10 m elevation

CHIRONOMIDAE

Orthocladius grimshawi Hardy. Taken hovering near the two pools (lower collecting stations of Kinzie and Ford). This is a bottom breeder and no doubt occurs in all the pool areas of this stream.

Telmatogeton abnormis (Terry)? or a new species. The larvae of this species live in silken tunnels on the rocks, in the last rapids on the stream before it enters the ocean: in the zone 1 to 6 or 8 m from the mouth (1-2 m elev.).

Telmatogeton torrenticola Terry overlaps slightly with T. abnormis in the 6-8 m zone and occurs in the rapids (torrents) approximately 50-60 m up the stream (to 10-12 m elev.).

This was an exciting discovery, and this habitat will be most important in our studies of the evolution of these midges. Dr. Lester Newman, Portland State University, is studying the genetics of this group and according to his phylogeny based upon the polytene chromosomes, "abnormis" is apparently the ancestral species of the freshwater Telmatogeton which arose from the marine species, T. japonicus Tokunaga. T. torrenticola then arose from abnormis and the populations of what has been called "torrenticola," based upon adult morphology from streams of East Maui, West Maui, Moloka'i, and two different stream systems on Hawai'i, consist of five distinct species based upon the genetics. The two presently recognized freshwater species from O'ahu and the two from Kaua'i (including the true abnormis) then arose from the West Maui "torrenticola." Pua'alu'u Stream will play an important part in working out the evolution of this group.

The genus Telmatogeton Schiner belongs to the subfamily Clunionae (the Marine Midges). The immature stages of these midges live in algae in the intertidal zone on rocky coastlines over much of the world. Hawai'i is the only place in the world where freshwater species have evolved. In the streams, the larvae live in silken tunnels on the rocks in the torrents, and the adults live on the wet rocks in the splash zone. The larvae are algae feeders.

EPHYDRIDAE

Neoscatella clavipes Wirth and N. warreni Cresson, living sympatrically. The larvae live on the bare rock in the swift flowing water; they are fitted with specialized morphological structures for clinging onto the rocks. The adults live in the wet splash zone with Telmatogeton and occur in moderate numbers (ca. 100+ individuals collected in a series of 4-5 sweeps with a small--6-inch diameter--net) along the rapids in the lower 50-60 m of the stream (up to 10-12 m elevation).

Members of this genus (13 endemic species known in Hawai'i) are associated with an assortment of aquatic habitats ranging from intertidal zone, still water pools to rapidly flowing streams. They constitute a major component of most Hawaiian streams.

Donaceus nigrotarsus Cresson, an introduced species, breeds in the mud on the sides of pools (first two lower collecting stations 1 and 2). This species was scarce; only one specimen was collected--by sweeping the wet banks of the pools.

CANACEIDAE

This is a small family of approximately 40 known species for the world (11 species now known for Hawai'i) which breed along coastlines on algae covered rocks between the tide levels. In Hawai'i, the Procanace have evolved into freshwater habitats and are important components of our streams. The larvae live in tiny "pukas" in the smooth rocks in the torrential waters of the stream. They are algae feeders. The adults live in the splash zone in close association with the Telmatogeton and Neoscatella.

Procanace acuminata Hardy and Delfinado and P. constricta Hardy and Delfinado, n. spp. in press, are living sympatrically in the Power 50 m of the stream (to ca. 10 m elevation).

TIPULIDAE

Limonia (Geranomyia) advena Alexander. Breeding in large numbers in the moss and algae along the stream banks.

DOLICHOPODIDAE

Sigmatineurum chalybeum (Parent). A predaceous endemic species; the adults forage on the wet rocks, the larvae forage in the moss and algae along-the banks.

Syntormon distortitarsis van Duzee. An introduced species, same habits as above except that the adults forage along the banks (first record of this species from Maui).

Stations 9 and 10--head of stream, 310-320 m

We found only sparse evidence of a few groups of insects breeding in the upper portion of the stream.

TIPULIDAE

Limonia (Dicranomyia) jacobus (Alexander) and L. (D.) variabilis Grimshaw breeding in algae in the stream.

CHIRONOMIDAE

Orthocladius grimshawi Hardy breeding in mud on bottom of pools.

CERATOPOGONIDAE

Dasyhelia platychaeta Hardy? (female) probably breeds along banks.

SCIARIDAE

Bradysia bishopi Steffan? (female) supposedly phytophagous, breeding site unknown.

ODONATA

A dozen or more specimens were foraging up and down the stream course (this is the only area of the stream where we saw any activity of these insects). The following were collected:

AESHNIDAE

Anax junius (Drury). The nymph live in the pools and would be predators on fish, crustacea, and other arthropods.

Nesogomia blackburni (McLachlan) breeds in pools, preys on small invertebrates.

COENAGRIIDAE

Mégalagrion blackburni McLachlan lives in mosses and algae in streams and on wet banks. Preys on small invertebrates.

Mégalagrion hawaiiensis (McLachlan) lives in the stream and along the wet banks. Preys on small invertebrates.

DISCUSSION AND SUMMARY

The lower portion of this stream, 50–60 m from where it enters the ocean, is a normal Hawaiian stream with a rather rich fauna of the aquatic insects typically found in similar streams over the Islands. Specimens of Anaplolepis longipes were present, but the predation pressure obviously was not great enough to have a serious effect upon the fauna.

Above this section to about 150 m, the ants completely took over and have apparently wiped out most of the insect fauna, Comparison was made on 'Ohe'o Stream where I have done surveys many times before the invasion of Amaplolepis. Previous to its getting in, the stream contained large populations of Telmatogeton, Neoscatella, Procanace, etc,, but now nothing!! or practically nothing (I did dig out two specimens of Neoscatella living under one of the waterfalls where they could escape the ants) lives in the stream. It is a shocking contrast.

The ant (*Anoplolepis longipes* [Jerdon]) is a relatively new immigrant to the Hawaiian Islands. The earliest record is December 1950, collected at Barber's Point, O'ahu. It was recorded at Kona, Hawai'i, November 1954 and is now a serious pest in the Kona section. It was first reported on Maui, January 1973 but probably has been there since the mid-sixties.

The paucity of the insect fauna above 150 m cannot be blamed on the ants but must be related to the sterilizing effect of the bamboo on the environment.

The headwater area of the stream (310-320 m) contained some of the elements of a normal stream fauna but in very small numbers of individuals. In an area like this, at this elevation, we normally find large numbers of individuals of an assortment of aquatic insects.

RECOMMENDATIONS

1. The stream should be protected from human activity as much as possible. No fishing should be permitted.

2. Cattle should be prevented from using the stream. Apart from the disturbance to the banks which results in erosion, the pollution from urine, feces, and muddy water are detrimental impacts on the stream.

3. The bamboo should be eradicated. The eradicated bamboo should be replaced with native species. The native species hala, hau, lama, and 'ōhi'a should be planted in the area at the same time that the bamboo is controlled.

4. The predacious ant, *Anoplolepis longipes* (Jerdon), should be eradicated. No effective attractants are known at present. An investigation of the problem is recommended.

5. No new water intakes should be constru'cted.

6. The streamflow should be carefully monitored to ensure that the amount of water, removed from the stream does not significantly reduce the flow (significant must be defined in terms of the particular characteristics of Pua'alu'u, not an arbitrary percentage of annual flow).

7. The stream is within the expanded boundaries of Kīpahulu District yet this important resource is not mentioned in the proposed General Management Plan. The area should be maintained for restricted access only.

GLOSSARY

entomous	of insects.
exorheic	flowinq to the sea.
heuristic	helpinq to discover or learn.
lotic	pertaininq to still water: the lake or pond habitat.
madicolous	of or pertaining to falling water: the habitat affected by spray, mist, etc., from a waterfall.
perched aquifer	a body of water generally in some porous material restrained from downward percolation by impervious material.
peripkyton	the plant micro community growing attached to other plants.
rheocrene	running spring.
rheophilic	"current-loving"; a behavior that tends to bring an organism into areas of moving water.
riparian	relating to or living on the bank of a river or stream.
second-order	refers to stream-order designation of stream hierarchy in which finger-tip tributaries are called first-order streams; two or more first-order streams join to form a second-order stream, etc.
sympatrically	living together; used to indicate that two species occur in the same area.
thiarid	a family of pulmonate gastropods.