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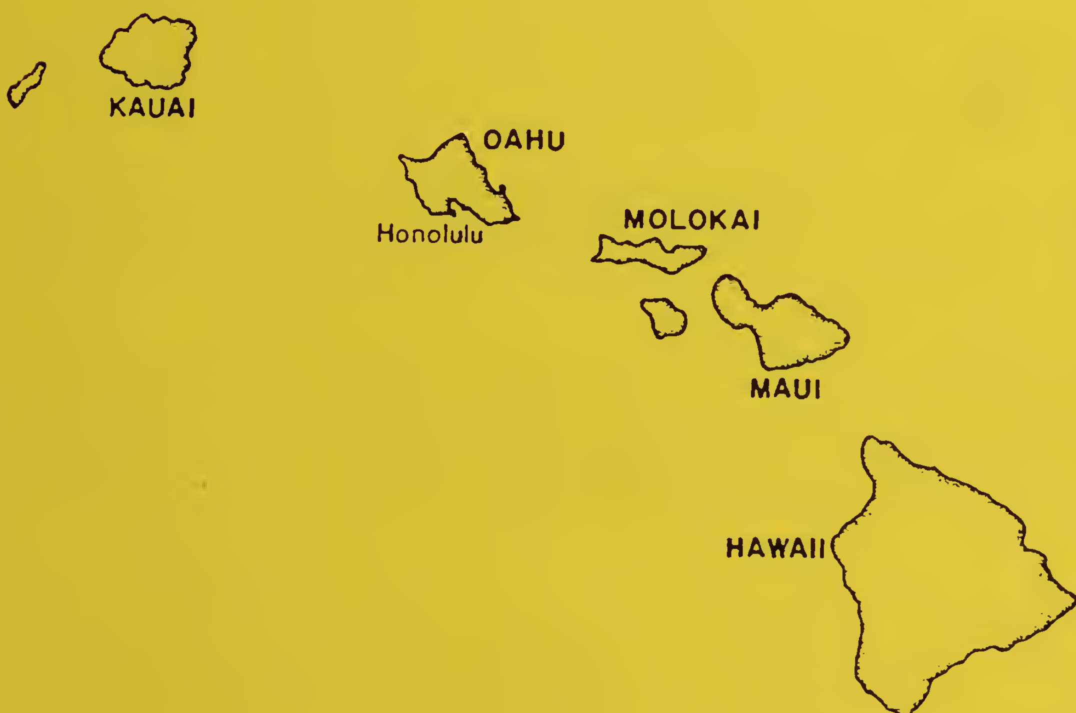
FWS/OBS- 78/17
May 1978

Stream Channel Modification in Hawaii.

Part B: Effect of Channelization on the Distribution and Abundance of Fauna in Selected Streams



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STREAM CHANNEL MODIFICATION IN HAWAII
PART B: EFFECT OF CHANNELIZATION ON THE DISTRIBUTION AND ABUNDANCE OF FAUNA IN SELECTED STREAMS

by

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U.S. Department of the Interior

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PREFACE

This is the second of a four-part report on Stream Channel Modification (Channelization) in Hawaii and Its Environmental Effects on Native Fauna. This part deals with the effects of channelization on the distribution and abundance of fauna in Oahu streams. It is published by the National Stream Alteration Team to provide the much-needed baselines for evaluating future stream alteration proposals as well as ecological information applicable to the protection and preservation of native Hawaiian stream fauna. This report covers measurement of some environmental factors and evaluation of aquatic community structure on selected altered and unaltered streams. The objective is to provide concise information on the nature and magnitude of channel alteration effects on stream species and communities.

An earlier report (Part A: FWS/OBS-78/16 March 1978) is an inventory of Hawaiian perennial streams and stream macrofauna. Forthcoming is Part C (FWS/OBS-78/18) dealing with tolerance of native stream macrofauna to environmental stress. Part D (FWS/OBS-78/19) summarizes the series.

Any suggestions or questions regarding Stream Modification in Hawaii should be directed to:

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EXECUTIVE SUMMARY

In an effort to assess the effects of channelization on the native fauna of Hawaiian streams, macrofaunal communities were analyzed and compared in channelized and unchannelized streams. Kaneohe and Manoa Streams, in which several types of channel alterations are found, were chosen as representative of altered Hawaiian streams. Waiahole Stream, which has no channel alteration, was selected as representative of unaltered Hawaiian streams.

Three physicochemical features were measured to obtain a general idea of habitat factors in altered and unaltered streams. The aquatic community structure was evaluated for each stream, and interstream comparisons were made. Full-scale monitoring was done for 20 months (February 1976 through September 1977).

The altered study streams were found to have higher mean physicochemical values (water temperature, pH, conductivity) coupled with wider ranges than the unaltered study stream. Channel sections with artificial (concrete) bottom exhibited higher values compared with natural bottom channels.

Exotic fishes were predominant in altered streams while both exotic fishes and native crustaceans were predominant in the unaltered stream. Native fishes appeared to be especially reduced in heavily channelized streams. Altered channels with artificial bottom appeared to serve as nurseries for the exotic poeciliids, *Poecilia mexicana* and *P. reticulata*. Species diversity was lower in these artificial bottom channels.

The study results suggest that the delicate ecology of the diadromous native fauna is especially vulnerable to stresses resulting from extreme channelization. There are strong indications that channel alterations, particularly artificially lined channels, are favoring the replacement of native species by valueless exotics. These findings suggest that in Hawaii channelization should be avoided where at all possible. Where it is unavoidable, the use of channels with natural bottom appears to be much less damaging. Any artificial bottom channel should avoid a wide, flat bottom, e.g., by providing a narrower notch in the bottom for a deeper, more natural flow. Detrimental effects of riparian clearing have been demonstrated, and preservation or replanting of stream bank vegetation is an important management tool. Locations of collections of migratory animals lead to a tentative recommendation that where artificially lined channel bottom must be used, not more than 1.5 km be installed as a continuous length. Common features shared with all high islands of the Pacific suggest that these results may be broadly applicable in the region.

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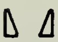
ABBREVIATIONS

cm	centimeters	Ma	Maui Island
cm^2	square centimeters	Mo	Molokai Island
g	grams	m^3/s	cubic meters per second
H	Hawaii Island	No.	number
JTU	Jackson turbidity unit	O	Oahu
		% No.	percentage by number
K	Kaneohe Stream	% Wt.	percentage by weight
Ka	Kauai Island	µmhos	micromhos
km	kilometers	USGS	United States Geological Survey
km^2	square kilometers	USFWS	United States Fish and Wildlife Service
m	meters	W	Waiahole Stream
M	Manoa Stream	wt	weight

SYMBOLS

°C	degrees, Celsius
°N	degrees, North latitude
°W	degrees, West longitude
= = = =	ditch and tunnel
H'	diversity
J'	evenness
Δ	flow gaging station
<	less than
+	plus
⊗	pump
⁚ ⁚	Channel realigned and/or vegetation removed; natural bottom.
	Elevated culvert. Conduit structures that are comparatively short (typically <60 meters), usually found under highways; artificial bottom.
	Lined channel. An artificial channel having both natural banks and stream bed replaced, usually with concrete; artificial bottom.
	Revetment. Stream banks are reinforced but the channel bed is not; natural bottom.

ACKNOWLEDGMENTS

The following made critical reviews and valuable suggestions: James M. Brown and Robert L. Little of the National Stream Alteration Team, Columbia, Missouri; Robert P. Hayden, Regional Activity Leader, Stream Alterations, Sacramento, California; Tim Smith, Department of Zoology, University of Hawaii, Honolulu, Hawaii; and John A. Maciolek, Hawaii Cooperative Fishery Research Unit, Kilauea, Kauai, Hawaii. Carl Couret, Lawrence Cowles, John Ford, Charles Hathaway, Mike Nishimoto, and especially Henri Minette assisted in the field work. Sharon Honda did the typing and Ismael Trono prepared the illustrations.

INTRODUCTION

This study was undertaken to assess the impact of channel alteration on the environmental conditions and macrobiota of Hawaiian streams. Timbol and Maciolek (1978) found that 15% of Hawaii's permanent streams have been channelized. Channel modification is certain to continue as illustrated by the on-going flood control project constructions in Kaneohe Stream on Oahu Island and Iao Stream on Maui Island.

BACKGROUND

The inhabited islands of Hawaii are all high volcanic relicts. Their relative geologic youth is expressed in high, rugged basalt mountains on all the major islands. The islands lie in the prevailing northeast tradewinds. Where their heights intercept the moist air at elevations between a few hundred and about 2,500 meters, the majority of Hawaii's rainfall is generated. The result is very steep rainfall gradients, increasing with elevation, reasonably well watered windward sides of islands, and arid leeward sides. Essentially all streams have high elevation origin, and most flow to windward. Soil profiles are poorly developed over much of the islands and nonexistent at most high elevations. Most soils and basaltic rock are very porous. Streams are often discontinuous, disappearing at some point in their courses, sometimes emerging again at lower elevations. Only four natural basins in the State have the combination of adequate size, basin sealing, and freshwater supply to form natural freshwater lakes. All natural lakes are small and remotely located and of no value for human water supply. Poor natural basin sealing limits the utility of artificial impoundments. Many streams are temporally intermittent, and the flow of perennial streams varies radically with the immediate rainfall history; maximum discharge is often more than a hundred times mean discharge.

Despite these hydrologic characteristics, extensive irrigation-based plantation agriculture and urbanization have developed in varying degrees on all major high islands. Agricultural, municipal, domestic, and sometimes industrial demands led to diversion of large quantities of stream flow through elaborate systems of pipes, ditches, flumes, and tunnels. Export outside the watershed is common, often despite formidable natural barriers. Encroachment of urban development into floodplains has produced the usual rapid proliferation of channel modifications in the name of flood and erosion control. Channelization has been particularly rapid and severe because of the extremely rapid population growth in the last few decades and the highly volatile nature of Hawaiian streams.

Hawaii's 366 perennial streams (Timbol and Maciolek 1978) have an estimated 12,500 km of perennial stream channel. These streams represent the State's principal natural freshwater environment and habitat for both native and introduced animals (Brock 1960, Kanayama 1968, Maciolek In press). Additional information on Hawaiian freshwater ecosystems is available in the Hawaii State Department of Health 208 Technical Committee Report (1977).

HAWAIIAN STREAM MACROFAUNA

Hawaii has both native and introduced species, with the exotics far outnumbering the natives (see Table 5). The native species are mostly endemic and have a diadromous life cycle, i.e., they reside in streams but their larvae must reach the ocean to develop and re-enter streams as post-larvae. They are therefore more susceptible to channel alteration (channelization) since they need suitable habitat throughout the length of the stream. Some of these native species support ethnic fisheries. The goby, *Awaous stamineus* (o'opu nakea), the mountain shrimp, *Atya bisulcata* (opae kalaole, the native prawn, *Macrobrachium grandimanus* (opae oehaa), and the neritid mollusk, *Neritina granosa* (hihiwai), are harvested for food. Among the introduced species, the Tahitian prawn, *Macrobrachium lar*, also provides food, and the smallmouth bass, *Micropterus dolomieui*, is sought after by sports fishermen. Titcomb (1972) provides additional information on the economic uses of fish in Hawaii's past, and Maciolek (in press) should be consulted for a current description of stream fauna.

CHANNEL ALTERATION

Timbol and Maciolek (1978) found 151 km of altered channels, 134 km (89%) of which were on Oahu Island, the most populous in the State. Six types of alterations were recognized (Table 1 and page viii). Lined channels (type 1), in which the entire wetted channel substrate was artificial construction material, usually concrete, comprised 57+ km. Such an artificial hard stream bottom represents a radical alteration to the natural environment. Type 6 (extended culvert) differed from type 1 only in that the conduit was completely buried below grade. It was much less common and thus less available for meaningful analysis of its effects. Because of their much shorter lengths, the net effect of the artificial channel of elevated culverts (type 3) must be much less than that of open lined channels.

Five of the six types of altered channels can be classified into two groups on the basis of having artificially lined bottom or natural bottom. The former group includes modifications 1, 3, and 6 and comprises 60+ km (or 40%) of the 151 km total altered channels in the State. The second group is composed of modification types 2 and 4 with a total length of 79 km, or 52% statewide. The concrete lined channel is the single most common type of alteration - almost 40% of all the modified length (89% of this occurring on Oahu). All preliminary evidence suggested that major environmental effects on stream communities might be expected from extended lengths of lined channel. Preliminary results obtained by Timbol and Maciolek (1978) showed

Table 1. Statewide Inventory of Stream Channel Alterations by Island[a]

Island	Length of Altered Channel by Type[b] (km)						Total Length of Altered Channel (km)
	1	2	3	4	5	6	
Oahu	57+	36+	1+	31	8	<1	134+
Kauai	0	4	1	3	0	0	8
Maui	<1	2+	<1	2	0	0	5
Hawaii	2	1	<1	<1	0	0	4
Molokai	0	0	<1	0	0	0	<1
Total	60+	43+	4+	36+	8	<1	151
% of Total	40	28	<3	24	5	<1	100%

[a]Adapted from Timbol and Maciolek (1978).

[b]Alteration types:

1 = lined channel
2 = cleared/realigned
3 = elevated culvert
4 = revetment
5 = filled-in
6 = extended culvert

that an average of more than 7° C could be attributed to the warming effect of a lined channel, 4° C for a revetment, and 2° C for a cleared/realigned channel. In terms of extent of modification (both by total channel length and warming effect), concrete lined channels were found to be the most important type of alteration in Hawaii. Therefore, emphasis in this study was placed on communities in such altered channels and comparison with natural channels.

STREAM SELECTION AND RELEVANCE TO OTHER STREAMS

Because of the locations of channel alterations, and time and cost constraints, detailed long-term community comparisons were made only for streams on Oahu Island. The channelized study streams were to be broadly representative of Hawaiian streams on the bases of average size, moderate degradation resulting from channel alteration, and presence of both native and exotic macrofauna. The unchannelized study stream also, was to be broadly representative of unchannelized Hawaiian streams on the bases of size and fauna.

Early results in the inventory of altered streams showed that Manoa and Kaneohe Streams met the three criteria set for study streams. Kahana Stream was pre-selected as representative of unaltered streams based on existing unpublished information. Unfortunately, access to Kahana became so severely restricted that a substitution was necessary. Waiahole Stream drains the next major valley from Kahana. They are similar in elevation of origin, stream gradient, and many physical aspects of their drainage basins. They have similar low levels of human disturbance. Figure 1 is a locator map for the study streams.

Altered Hawaiian streams ranged from serious physical degradation as in Kapalama Stream on Oahu Island (100% altered) to slightly degraded as in Pukihae Stream on Hawaii Island (<1% altered). Based on physical features alone, altered streams may be divided into three groups: slightly degraded, with <1% of their channel length altered; moderately degraded, 1 to 25% altered; and seriously degraded, more than 25% altered. As can be seen in Table 2, Manoa and Kaneohe Stream are moderately degraded, as are 34 other altered streams in the State.

Like Kahana and most streams on Oahu and statewide, Waiahole has irrigation water removed from its upper drainage basin. Its natural stream channel is intact. It is typical of non-channelized streams on Oahu Island.

Based on Timbol and Maciolek (1978) results, these three streams are regarded as representative of Hawaiian streams, and they were found to have most of the animals considered characteristic of Hawaiian streams (see Table 5).

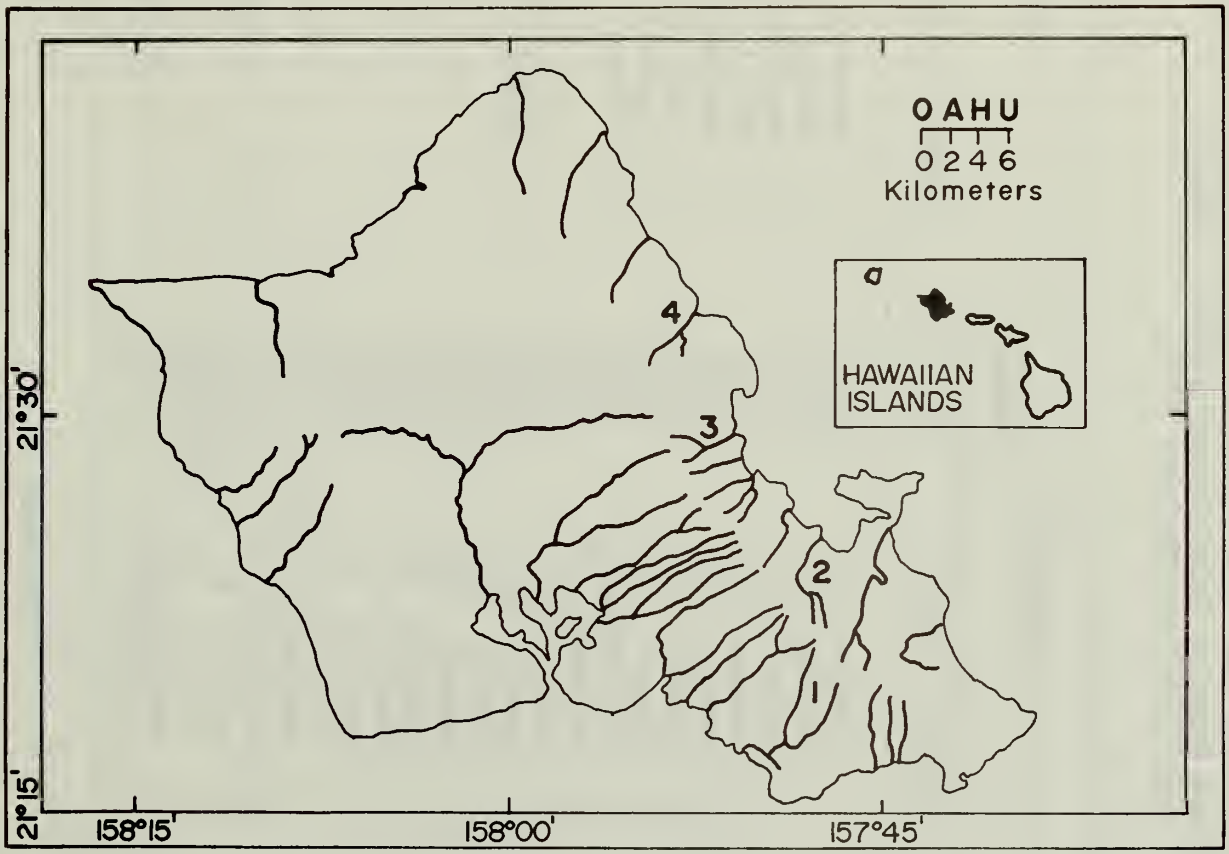


Figure 1. Locations of study streams on Oahu Island - Manoa (1), Kaneohe (2), and Waiahole (3). Kahana stream (4) is also shown.

Table 2. Classification of Altered Hawaiian Streams According to Degree of Degradation Stream-Size Rank Based on Total Channel Length. (Adapted from Timbol and Maciolek 1978.)

Slight[a] Stream: Island[d]	Channel Length (km)/ Rank	Moderate[b] Stream: Island[d]	Channel Length (km)/ Rank	Serious[c] Stream: Island[d]	Channel Length (km)/ Rank
1. Waimea: Ka	373/1	1. Waikele: O	195/2	1. Moanalua: O	44/8
2. Hanapepe: Ka	121/3	2. Waiawa: O	93/5	2. Nuuanu: O	30/14
3. Huleia: Ka	102/4	3. Waimalu: O	46/7	3. Waialaenui: O	14/26
4. Kilauea: Ka	56/6	4. Halawa: O	40/9	4. Makiki: O	10/30
5. Iao: Ma	38/10	5. Kaupuni: O	37/11	5. Kapalama: O	9/31
6. Waipao: Ka	33/13	6. Mailiili: O	34/12	6. Kawa: O	5/34
7. Waikomo: Ka	28/16	7. Manoa[e]: O	34/12	7. Keaahala: O	4/35
8. Waiehu: Ma	23/20	8. Malaekahana: O	30/14	8. Waikoko: Ka	2/37
9. Kamalo: Mo	19/23	9. Maunawili: O	29/15		
10. Pukihae: H	16/25	10. Kaneohe[e]: O	28/16	Total Channel Length	118
11. Anini: Ka	14/26	11. Lawai: Ka	27/17		
		12. Wailoa: H	26/18		
Total Channel Length	823	13. Kahoma: Ma	25/19		
		14. Waikapu: Ma	25/19		
		15. Makaleha: O	23/20		
		16. Kahaluu: O	21/21		
		17. Konohiki: Ka	20/22		
		18. Honokowai: Ma	20/22		
		19. Wahikuli: Ma	19/23		
		20. Kalihi: O	18/24		
		21. Kalauao: O	13/27		
		22. Wailupe: O	13/27		
		23. Waimanalo: O	12/28		

Continued

Table 2. (Concluded)

Slight[a]		Moderate[b]		Serious[c]	
Stream: Island[d]	Channel Length (km)/ Rank	Stream: Island[d]	Channel Length (km)/ Rank	Stream: Island[d]	Channel Length (km)/ Rank
		24. Heeia: 0	11/29		
		25. Aiea: 0	11/29		
		26. Kaipapau: 0	11/29		
		27. Pia: 0	11/29		
		28. Kauaula: Ma	10/30		
		29. Oio: 0	10/30		
		30. Ulehawa: 0	8/32		
		31. Puukumu: Ka	7/33		
		32. Lamimaumau: H	5/34		
		33. Papuaa: H	5/34		
		34. Kuliouou: 0	4/35		
		35. Kaalaea: 0	4/35		
		36. Kumukumu: Ka	3/36		
		Total Channel Length	928		

[a]Slightly degraded: <1% of total channel length altered.

[b]Moderately degraded: between 1 and 25% of total channel length altered.

[c]Seriously degraded: between 25 and 100% altered.

[d]Symbols used to represent islands are:
H for Hawaii, Ka for Kauai, Ma for Maui, Mo for Molokai, and 0 for Oahu.

[e]Study streams.

DESCRIPTION OF STUDY AREAS

Fed primarily by orographic rainfall, the study streams originate from the Koolau Range, Manoa draining the leeward, and Kaneohe and Waiahole draining the windward side. The locations are shown in Fig. 1.

Manoa Stream (Fig. 2) is situated in the Honolulu district and is associated with the watershed area known as Manoa Valley. Land use in Manoa Valley reflects a high level of development, with approximately half the total drainage area devoted to urban uses, primarily residential (Chun et al. 1972). Six tributaries contribute to the Manoa Stream discharge, five of which originate from the Koolau Range between Pauoa Flats and Waahila Ridge. The confluence of the mainstream and the sixth tributary (Palolo) occurs at an elevation of about 6 m, 1.7 km above the stream mouth. The stream discharges into the estuarine Ala Wai Canal which empties into Mamala Bay 1.2 km downstream. Approximately 24% of the total 34 km channel length has been altered. Types of modification include the concrete lined channel, realigned channel with vegetation removed, elevated culvert, and revetment (Timbol and Maciolek 1978).

Kaneohe and Waiahole Streams both drain northeasterly to Kaneohe Bay (Fig. 1). However, these two streams are set apart ecologically as a result of land use differences in their respective watershed areas. The Kaneohe Stream drainage basin is located near the southern section of the Kaneohe Bay watershed where considerable urban development has taken place (U.S. Army Corps of Engineers 1975). Kaneohe Stream, as shown in Fig. 3, encompasses four major tributaries. Urbanization in this area has resulted in encroachment of the stream's flood plain (Hawaii Environmental Simulation Laboratory 1974). Current construction of an embankment and concrete spillway structure for a dam will close Kamooalii and Kuou Tributaries to create a 10.5-hectare (26-acre) artificial lake. The completion date for this project is June 1979. Other forms of channel modification in Kaneohe Stream include the concrete lined channel, realigned channel with vegetation removed, and elevated culvert. Nearly 25% of the total 28 km channel length has been modified (Timbol and Maciolek 1978).

In contrast to the Manoa and Kaneohe watershed areas, the Waiahole drainage basin is relatively undeveloped. The basin ranges in elevation from approximately 750 m to sea level, with the limited agricultural and grazing, as well as residential land uses, limited to areas of less than 25 m elevation. There are no commercial or industrial developments in the drainage basin. Waiahole mainstream converges with Uwau tributary at 20 m elevation (Fig. 4). Some water is removed from the drainage basin above both Uwau tributary and Waiahole mainstream.

The gradients of Manoa and Kaneohe Streams are similar and steeper than that of Waiahole Stream. Some other physical features of these drainages are given in Table 3.

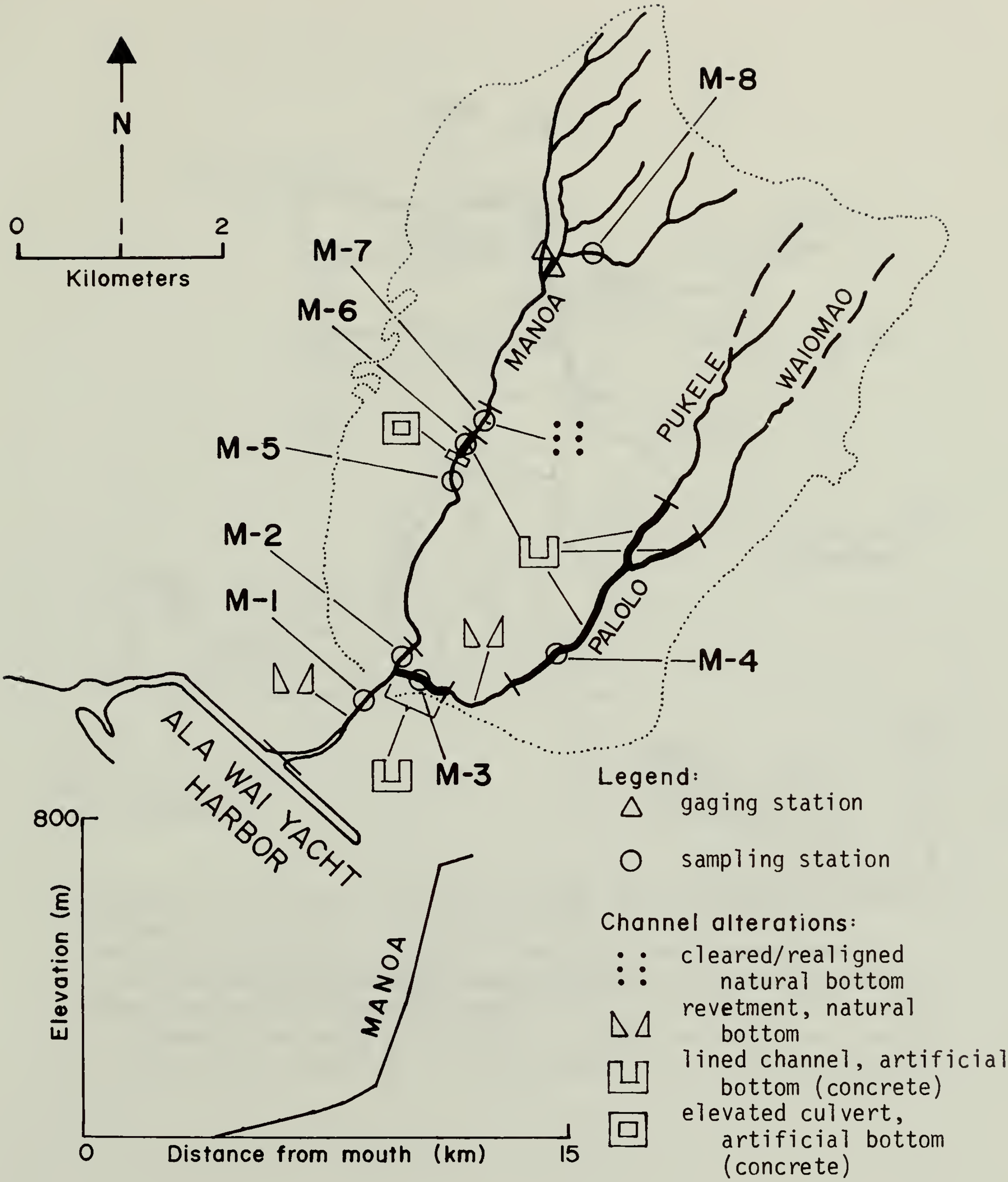


Figure 2. Drainage of Manoa Stream, Oahu, showing locations of sampling stations, flow gaging stations, channelized sections of stream, and watershed limits. Longitudinal gradient of Manoa mainstream (m/km) = 64.

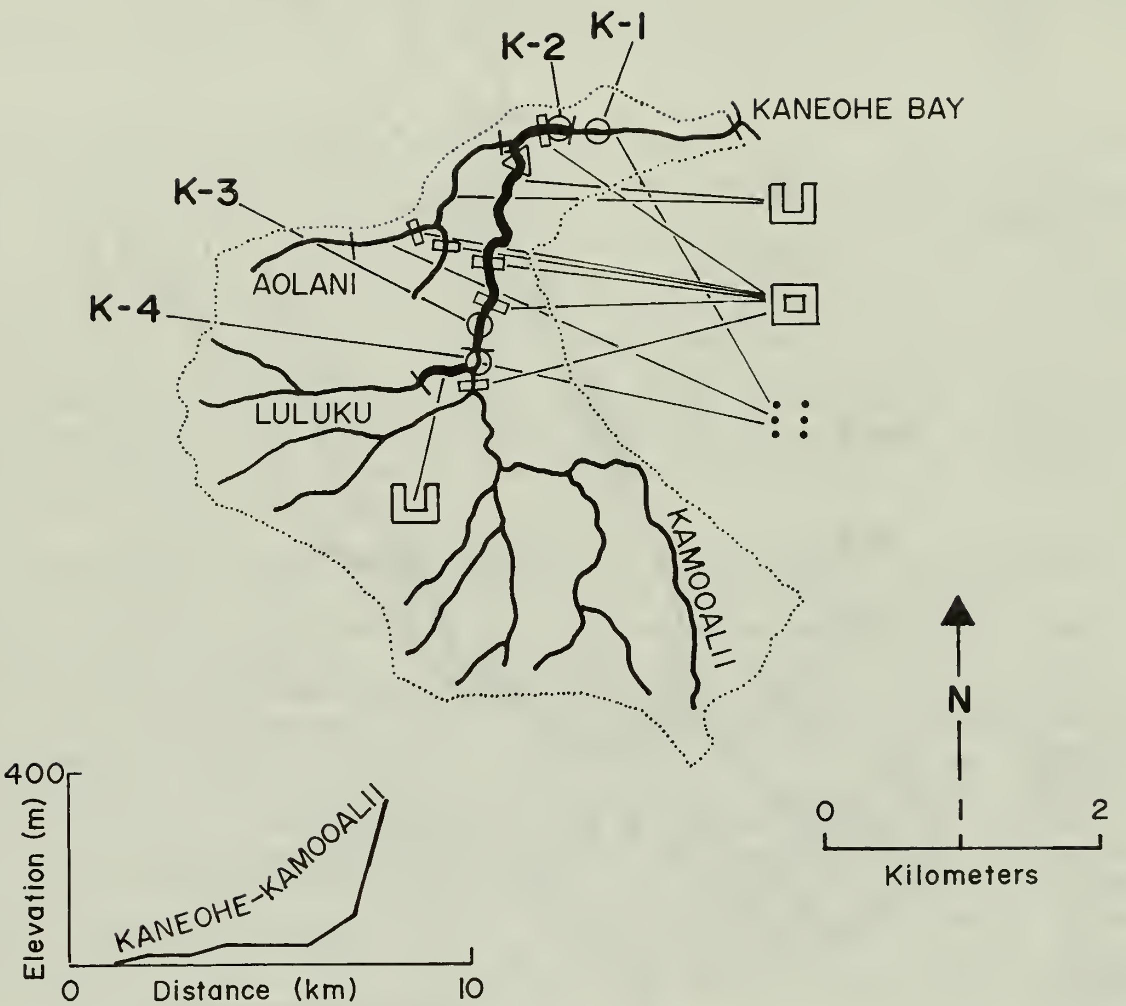


Figure 3. Drainage of Kaneohe Stream, Oahu, showing locations of sampling stations, flow gaging station, channelized sections of stream, and watershed limits. Longitudinal gradient of Kaneohe mainstream (m/km) = 67. Refer to Fig. 2 for symbol definitions.

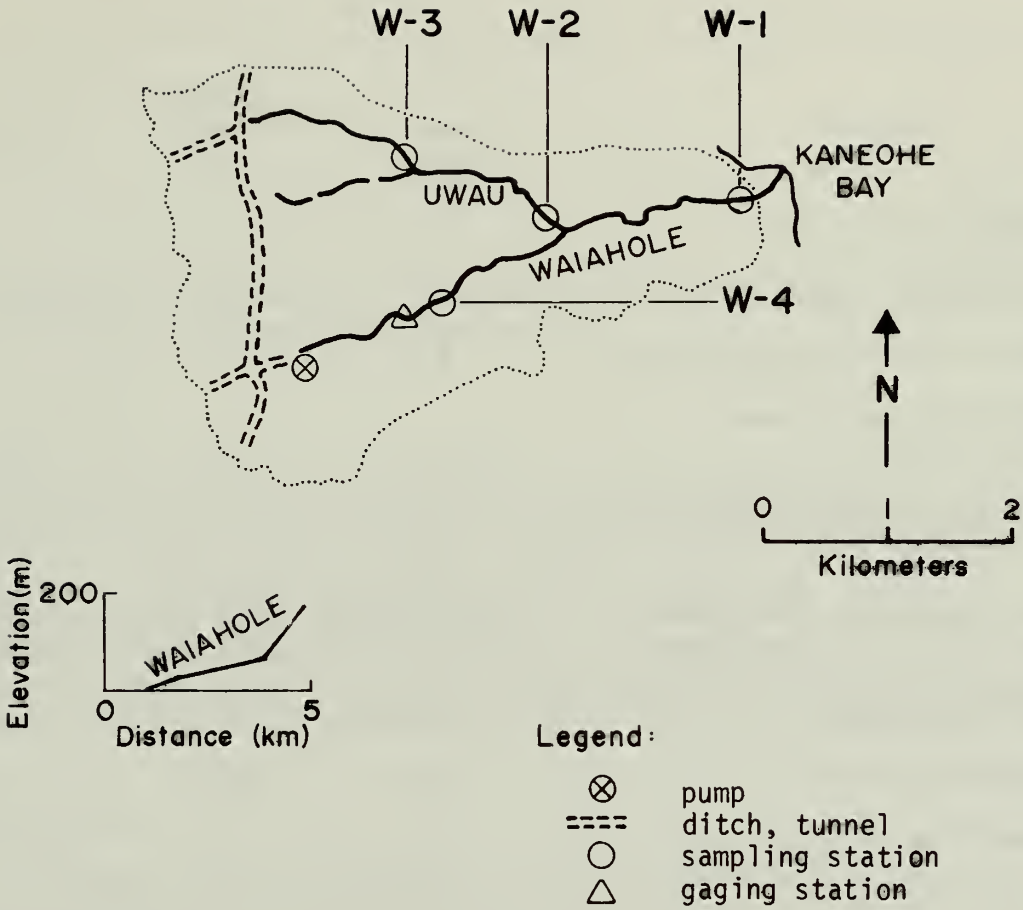


Figure 4. Drainage of Waiahole Stream, Oahu, showing locations of sampling stations, flow gaging station, and watershed limits. Longitudinal gradient of Waiahole mainstream (m/km) = 31. Ditch/tunnel/pump system collects water from watershed above the heads of stream channels.

Table 3. Locations, Physical Dimensions, and Discharge Features[a] of Three Oahu Study Streams

Feature	Streams		
	Manoa	Kaneohe	Waiahole
Drainage Basin (km^2)	27.0	13.0	10.2
Total channel length (km)	34	28	10
Longest tributary length (km)	9.6	9.1	5.5
Longitudinal mainstream gradient (m/km)	64	67	31
Drainage area above gaging stations[a] (km^2)	5.7	11.3	2.6
Mouth coordinates (latitude) (longitude)	21°17'24"N; 157°49'51"W	21°24'56"N; 156°47'09"W	21°29'14"N; 156°51'45"W
Mean flow (m^3/s)	0.25[b]	0.42[c]	0.60[d]
Maximum flow (m^3/s)	179.5	340.0	3.7
Minimum flow (m^3/s)	0.1	0.1	0.1

[a]Discharge data do not represent stream total discharge. See footnotes and figures for specifics of measurements.

[b]58-yr mean, combined flow at two gaging stations (USGS 1977). No diversion. Refer to Fig. 2 for locations of gaging stations.

[c]14-yr mean (USGS 1977). No diversion above gaging station. Refer to Fig. 3 for location of gaging station.

[d]Water year 1968 (USGS 1970). Diversions above gaging station. Location of gaging station and dewatering complex shown in Fig. 4.

METHODS

Full quantitative collections in this study were made at approximately monthly intervals from February 1976 through May 1977. Less complete and quantitative sampling covered a longer period.

SAMPLING STATIONS

Sampling stations were established in the lower and middle reaches of study streams and located with regard to concrete lined channels and accessibility. Manoa Stream had eight stations (Fig. 2): Kaneohe and Waiahole Streams each had four stations (Figs. 3, 4). The stations in Manoa Stream covered the widest elevational range (3 to 110 m) while Kaneohe Stream stations were from 21 to 37 m elevation and Waiahole Stream were from 5 to 67 m elevation. A more detailed description of location and environmental conditions at sampling stations is given in Appendix A.

PHYSICOCHEMICAL

In an attempt to begin assessment of the environmental factors that affect the distribution of macrofauna in streams, water temperature, conductivity, and pH were measured. Water temperature was determined with a mercury thermometer; conductivity was measured with a YSI Model 33 S-C-T meter; and pH was measured with an AM model 107 analytical pocket pH meter. A subsequent report (FWS/OBS-78/18) will treat a range of physicochemical parameters and their effects in much greater detail.

FAUNAL COLLECTION

Fauna was sampled by electrofishing using a small gasoline-powered backpack unit which generated pulsating direct current (Coffelt Electronics model BP-1). Electrofishing appears to be the most practical, effective means of semi-quantitative sampling for fish and large crustaceans (many of which are cryptic) in shallow, rocky Hawaiian streams. Limitations of the method were discussed in Timbol and Maciolek (1978).

Macrofauna were collected from stations approximately 20 m X 1 m in dimensions. Some preliminary work done to test this collection method indicated that as many as 250 animals could be obtained in a single collection and that continued sampling over a longer reach of stream did not yield any new species. The method permits direct comparison of results with more widespread and less intensive sampling of many other altered and unaltered Hawaiian streams (Timbol and Maciolek 1978).

DATA ANALYSIS

Specimens were preserved in 10% formalin and identified in the laboratory. Certain poeciliids were identified by Dr. William Fink of the Smithsonian Institution.

Biomass data were obtained by weighing specimens individually on an analytical balance (Mettler M-15) to the nearest milligram, after excess moisture had been removed. Animals were measured for total length to the nearest millimeter.

Collection data were used to compile faunal inventories, by numbers and biomasses. Species diversity, H', at each sampling station, was computed by the Shannon-Wiener index (Pielou 1975) as

$$H' = -\Sigma\, p_i \ln_e p_i$$

where p_i was the proportion of the ith species in the population. The evenness measure, J', (Pielou 1975) for the s species in each sample was computed as

$$J' = H'/\ln_e s.$$

RESULTS AND DISCUSSION

ENVIRONMENTAL FEATURES OF SAMPLING STATIONS

The mean values and ranges of the physicochemical parameters measured at monthly intervals, usually during the early afternoon, appear by station in Table 4.

In Manoa Stream, the sample variances for these parameters at stations in lined channels were significantly greater than those at stations on natural bottom (F test, $p = 0.01$). Extreme high values for these parameters were recorded near the downstream end of long lined channels.

STREAM MACROFAUNA

Within the scope of this study, the term "macrofauna" refers to the larger stream animals, including fishes and crustaceans. Mollusks, annelids, and other lower invertebrates are not included in the samples. The 17 species of fishes and crustaceans recovered from study streams are detailed in Table 5. Based on extensive sampling experience elsewhere in the State, this is 81% (17 of 21) of the total species expected to be present in streams of these sizes.

Description of Species

Collections yielded five native fishes and two native decapod crustaceans (Fig. 5). Three of the five native species of diadromous gobioid fishes were represented, including *Awaous genivittatus* (o'opu naniha), *A. stamineus* (o'opu nakea), and *Eleotris sandwicensis* (o'opu okuhe). Ō'opu nakea and naniha, as members of the family Gobiidae, possess morphological adaptations facilitating upstream migration. The pelvic fins of these fishes are fused to form a sucking disc in the throat region which enables them to attach to rocks in swift currents. O'opu okuhe, a member of the family Eleotridae, lacks this sucking disc.

O'opu nakea is the only native fish obtained in these collections which is restricted to fresh water during postlarval life (Gosline and Brock 1960). This endemic goby is an omnivore, feeding on filamentous algae and benthic animals. It is the largest of the o'opu, and on Kauai it supports a seasonal fishery (Ego 1956). O'opu naniha and okuhe are euryhaline, inhabiting brackish waters as well as lower reaches of streams. O'opu

Table 4. Physicochemical Features of Water at Sixteen Stations in Manoa (M), Kaneohe (K), and Waiahole (W) Streams, Oahu, Measured between 1300 and 1600 hr at Monthly Intervals from February 1976 to May 1977

Station	Elevation (m)	Temperature (°C)		Conductivity (μmhos)		pH	
		Mean	Range	Mean	Range	Mean	Range
M-1	3	22.5	21.0-24.1	170	133-248	7.7	7.2-8.6
M-2	6	23.3	22.0-25.8	158	112-200	7.8	7.0-8.5
M-3[a]	6	28.6	26.2-36.0	248	203-335	8.8	7.7-10.0
M-4[a]	61	23.8	21.5-26.7	236	118-290	8.4	7.2-9.6
M-5	43	23.3	22.3-25.0	151	102-208	7.7	7.1-8.4
M-6[a]	49	23.0	21.2-25.6	140	83-188	7.8	6.8-8.1
M-7	49	22.8	21.7-25.6	146	95-188	7.6	7.0-8.0
M-8[b]	110	20.8	19.8-22.8	109	53-126	7.3	6.5-8.0
K-1	21	26.0	22.2-27.4	180	150-190	8.2	7.0-9.1
K-2[a,c]	21	26.2	22.2-27.7	178	160-191	8.2	6.9-9.1
K-3[a]	37	24.8	21.0-28.3	163	132-214	7.6	7.1-8.6
K-4	37	24.6	21.0-25.8	164	151-184	7.6	7.0-8.4

Continued

Table 4 (Concluded)

Station	Elevation (m)	Temperature (°C)		Conductivity (µmhos)		pH	
		Mean	Range	Mean	Range	Mean	Range
W-1	5	22.4	21.1-23.8	143	128-160	7.2	6.8-7.8
W-2	24	22.3	21.1-24.7	132	124-152	7.2	6.3-7.8
W-3	61	21.4	20.0-23.0	135	120-183	7.1	6.9-7.5
W-4	67	21.0	20.2-22.1	124	109-138	7.2	6.9-7.6

[a]Stations on concrete lined channels.

[b]Turbidity was 3 JTU on December 19, 1977, and 4 JTU on May 4, 1978, at this station (USGS 1977).

[c]Turbidity was 10 JTU on May 13, 1978, at this station (USGS 1977).

Table 5. Nomenclature and Origins of Aquatic Macrofauna in Three Oahu Streams (Manoa, Kaneohe, and Waiahole)

Scientific Name	Common Name	Status[a]
Fishes		
Awaous genivittatus	goby, o'opu naniha	indigenous
Awaous stamineus	goby, o'opu nakea	endemic
Clarias fuscus	Chinese catfish	introduced
Eleotris sandwicensis	sleeper, o'opu okuhe	endemic
Gambusia affinis	mosquitofish	introduced
Kuhlia sandvicensis	aholehole	endemic
Misgurnus anguillicaudatus	Oriental weatherfish, dojo loach	introduced
Mugil cephalus	striped mullet, amaama	indigenous
Poecilia mexicana	shortfin molly	introduced
Poecilia reticulata	guppy	introduced
Tilapia [=*Sarotherodon*] *mossambica*	tilapia, Mossambique mouthbrooder	introduced
Xiphophorus helleri	green swordtail	introduced
Xiphophorus maculatus	southern platyfish	introduced
Crustaceans		
Atya bisulcata	opae kalaole	endemic
Macrobrachium grandimanus	opae oehaa	endemic

Continued

Table 5 (Concluded)

Scientific Name	Common Name	Status[a]
Macrobrachium lar	Tahitian prawn	introduced
Procambarus clarkii	crayfish	introduced

[a]Terms used: Endemic - occurring naturally in Hawaii only. Indigenous - occurring naturally in Hawaii and elsewhere. Introduced - brought to Hawaii either intentionally or accidentally; exotic.

a

b

c

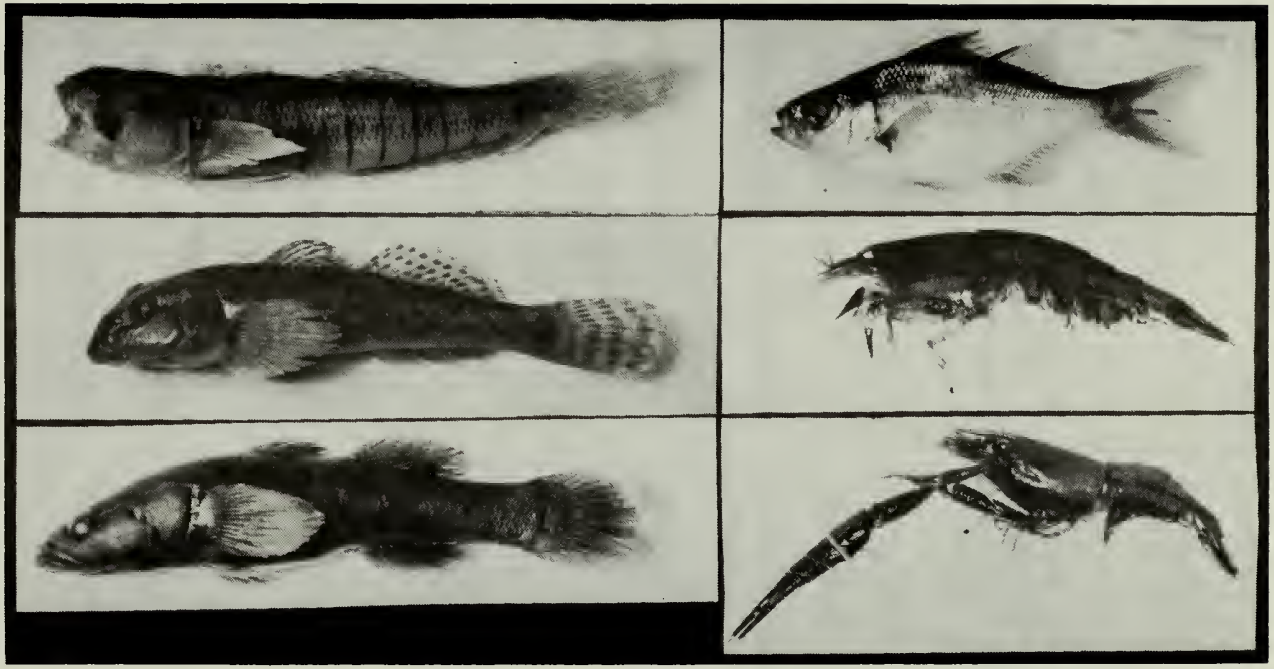


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Figure 5. Four native fishes and two native crustaceans collected from three Oahu study streams.

a. *Awaous genivittatus*
b. *Awaous stamineus*
c. *Eleotris sandwicensis*
d. *Kuhlia sandvicensis*
e. *Atya bisulcata*
f. *Macrobrachium grandimanus*

naniha is an omnivore that also occurs on other Pacific islands, and o'opu okuhe is a predacious endemic species. Two other euryhaline fishes were collected in this study. The endemic Kuhlia sandvicensis (aholehole) and the indigenous Mugil cephalus (amaama) are characteristically marine and estuarine. However, as juveniles they frequent the lower reaches of streams.

Five of the eight species of exotic fishes represented in the collection are members of the family Poeciliidae, including Gambusia affinis (mosquitofish), Poecilia mexicana (shortfin molly), P. reticulata (guppy), Xiphophorus helleri (green swordtail), and X. maculatus (southern platyfish) (Fig. 6). This group of livebearing topminnows originates from the American tropics and subtropics. Males have an intromittent organ, the gonopodium, and fertilization is internal. Intervals between broods are approximately 30 days, with the young emerging live from females (Breder and Rosen 1966). These fishes feed on minute insects and other small animals (Eddy 1969).

Other exotic fishes collected in this study include Clarias fuscus (Chinese catfish), Tilapia mossambica (tilapia), and Misgurnus anguillicaudatus (dojo). The Chinese catfish and dojo have the capacity to acquire oxygen from the air. The Chinese catfish can live in stagnant waters, often with soft bottoms, and may survive out of water for relatively long periods (Sterba 1962). This fish is omnivorous. Dojo inhabiting muddy areas are known for their burrowing activities (Sterba 1962). Tilapia exhibit high growth rates and rapid reproduction (Bridges 1970). Common in fresh and brackish waters, these fish are voracious feeders with omnivorous tendencies (Sterba 1962).

Both the diadromous, endemic shrimps inhabiting Hawaiian streams were present in these collections. Atya bisulcata (opae kalaole) is primarily a detrital filter feeder and typically occurs in great numbers at higher elevations (Couret 1976). Macrobrachium grandimanus (opae oehaa) is a larger, euryhaline decapod. This animal prefers downstream habitats and estuaries. Opae, especially opae kalaole, are used as food items and also serve as fishbait.

Exotic crustaceans in the collections included Macrobrachium lar (Tahitian prawn) and Procambarus clarkii (crayfish). The Tahitian prawn is morphologically very similar to M. grandimanus but considerably larger. It prefers shady, sheltered habitats and has been characterized as a nocturnal omnivore. This diadromous animal is euryhaline, occurring in estuaries and extending far upstream (Kubota 1972). In contrast, the crayfish is limited to freshwater. It is also nocturnal and feeds opportunistically on both plant and animal material. In streams, crayfish avoid currents by hiding beneath sheltering rocks (Usinger 1967).

Faunal Collections

Sampling of fauna at 16 stations in the three study streams over the course of this study yielded 11,644 specimens of these 17 species of fishes a c

b d

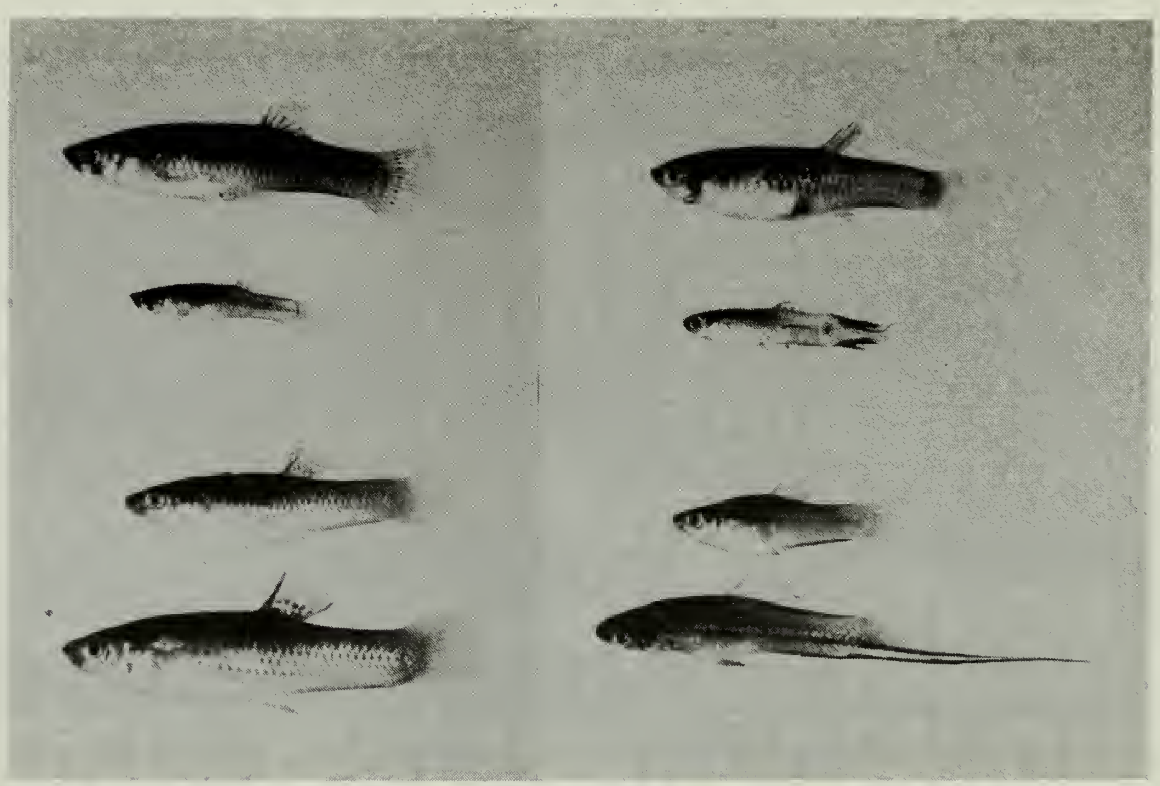

Figure 6. Four exotic poeciliid fishes, both sexes, collected from three Oahu study streams. Top: female. Bottom: male.

a. <u>Gambusia affinis</u>
b. <u>Poecilia mexicana</u>
c. <u>Poecilia reticulata</u>
d. <u>Xiphophorus helleri</u>

and crustaceans (Table 5). The number of complete collections procured from each station ranged from 10 to 13; mean collection yields are given in Table 6. The nature of the macrofaunal communities in the individual study streams will be described before comparing streams.

Manoa Stream. A total of 16 species was collected from Manoa Stream. The mean number and weight of each species per collection from each sampling station, along with the species diversity and evenness values, are presented in Tables 7 and 8, respectively. These data indicate that exotic fishes were dominant members of the macrofaunal communities in Manoa Stream. Exotic fishes of the family Poeciliidae were the most numerous animals at the seven downstream stations, while the exotic crustacean, *Procambarus clarkii*, was more numerous at the upstream station, M-8.

Collections from stations in concrete lined channels generally yielded fewer species of animals than those from stations on natural bottoms. No native species were recovered from concrete lined channels in Manoa Stream. Regular inhabitants of these areas included two species of topminnows, *Poecilia mexicana* and *P. reticulata*. Crayfish, dojo, and Chinese catfish were incidental members of these communities, and the specimens recovered were usually relatively small.

Biomass yields from concrete lined channel stations in Manoa Stream were significantly lower than those from natural bottom stations (Wilcoxon test for nonparametric data, p = 0.05; Sokal and Rohlf 1969). However, the mean numbers of animals obtained from two concrete lined channel stations, M-3 and M-6, were significantly higher than those from natural bottom stations (Wilcoxon test for nonparametric data, p = 0.05). This observation reflects the maintenance of high density populations of *Poecilia mexicana* within these concrete lined stream segments.

Kaneohe Stream. Collections from four stations in Kaneohe Stream located in and adjacent to both ends of a concrete lined channel yielded nine species. The mean abundance of each species per collection at each station and the diversity and evenness values are recorded in Table 9.

Exotic fishes were prominent in collections from all stations and *Poecilia mexicana* was the most abundant fish. No native fishes were recovered from concrete lined channel stations, in contrast to natural bottom stations which harbored *Awaous stamineus*.

Both native prawns were recovered from Kaneohe Stream stations. While one *Macrobrachium grandimanus* individual was found in one collection from each of the concrete lined channel stations, it occurred much more frequently at the downstream natural bottom station. *Atya bisulcata* was present at the natural bottom station upstream of the concrete lined channel modification. It is significant that diadromous, native animals (*A. stamineus* and *A. bisulcata*) occurred upstream from the concrete lined channel, indicating their ability to traverse 1.8 km of continuous concrete lined channel. The exotic crustacean, *Procambarus clarkii*, was abundant

Table 6. Mean Collection Yields of Aquatic Macrofauna from Sixteen Stations on Manoa (M), Kaneohe (K), and Waiahole (W) Streams between February 1976 and May 1977

Station	Elevation (m)	No. of Samples	No. of Species	Mean No. of Animals	Mean Wt. of Animals (g)
M-1	3	12	12	27	87
M-2	6	11	10	28	100
M-3[a]	6	11	6	135	30
M-4[a]	61	12	7	26	25
M-5	43	12	6	19	51
M-6[a]	49	12	5	69	41
M-7	49	12	7	37	123
M-8	110	12	4	34	67
K-1	21	13	8	96	195
K-2[a]	21	13	5	91	118
K-3[a]	37	12	7	128	73
K-4	37	12	7	68	91
W-1	5	11	7	44	34
W-2	24	11	6	24	12
W-3	61	10	7	25	61
W-4	67	11	6	139	56

[a]Artificial (concrete) bottom channel.

Table 7. Mean Numbers of Animals Per Sample from Manoa Stream Stations between February 1976 and May 1977. See Tables 6 and 11 for Numbers of Collections from Stations and Total Numbers of Animals in Manoa Stream Collections, Respectively

Species	Stations							
	M-1	M-2	M-3[a]	M-4[a]	M-5	M-6[a]	M-7	M-8
Pisces								
Native								
Awaous genivittatus	0.8	1.0						
Awaous stamineus		0.3					0.6	
Eleotris sandwicensis	2.4							
Kuhlia sandvicensis	0.1							
Mugil cephalus	0.3							
Exotic								
Clarias fuscus		0.1		0.1				
Gambusia affinis	9.9	5.8	0.3	0.2	2.5	0.1	0.2	
Misgurnus anguillicaudatus				0.1	0.1	0.2	0.3	
Poecilia mexicana	3.8	13.4	118.1	12.1	5.1	64.3	26.4	
Poecilia reticulata	0.8	4.5	16.0	12.6	5.8	4.1	6.3	13.3
Tilapia mossambica	0.3	0.5						
Xiphophorus helleri	0.3				1.5		2.3	
Xiphophorus maculatus	7.1		0.3					

Continued

Table 7. (Concluded)

Species	Stations							
	M-1	M-2	M-3[a]	M-4[a]	M-5	M-6[a]	M-7	M-8
<u>Crustacea</u>								
Native								
<u>Atya bisulcata</u>								1.7
<u>Macrobrachium grandimanus</u>	0.2							
Exotic								
<u>Procambarus clarkii</u>	1.2	1.4	0.1	0.8	3.9	0.4	2.9	16.3
Total	27.2	28.3	134.8	25.9	18.9	69.1	37.3	33.6
Diversity (H')	1.73	1.49	0.40	0.87	1.52	0.28	0.93	1.04
Evenness (J')	0.70	0.68	0.25	0.49	0.85	0.18	0.48	0.76

[a]Concrete lined channel station.

Table 8. Mean Weights (g) of Animals Per Sample from Manoa Stream Stations between February 1976 and May 1977. See Tables 6 and 11 for Numbers of Collections from Stations and Total Numbers of Animals in Manoa Stream Collections, Respectively

Species	Stations							
	M-1	M-2	M-3[a]	M-4[a]	M-5	M-6[a]	M-7	M-8
Pisces								
Native								
Awaous genivittatus	2.71	4.14						
Awaous stamineus		5.24					8.53	
Eleotris sandwicensis	15.42	10.23						
Kuhlia sandvicensis	0.05							
Mugil cephalus	0.76							
Exotic								
Clarias fuscus		3.64		3.33				
Gambusia affinis	3.19	1.10	0.02	0.01	0.26	0.01		
Misgurnus anguillicaudatus				0.42	0.42	0.13	1.27	
Poecilia mexicana	4.32	34.40	28.82	16.61	4.48	40.06	59.00	
Poecilia reticulata	0.17	0.50	1.09	3.08	0.97	0.74	1.13	2.85
Tilapia mossambica	35.48	15.45					34.08	
Xiphophorus helleri	0.44				0.85			2.45
Xiphophorus maculatus	0.07		0.08					

Continued

Table 8. (Concluded)

Species	Stations							
	M-1	M-2	M-3[a]	M-4[a]	M-5	M-6[a]	M-7	M-8
Crustacea								
Native								
Atya bisulcata								1.70
Macrobrachium grandimanus	0.22							
Exotic								
Procambarus clarkii	24.56	25.30	0.01	2.02	44.00	0.49	18.47	60.47
Total	87.39	100.00	30.02	25.47	50.98	41.43	122.51	67.47
Diversity (H')	1.51	1.72	0.17	1.06	0.55	0.17	1.27	0.43
Evenness (J')	0.61	0.78	0.11	0.59	0.31	0.11	0.65	0.32

[a]Concrete lined channel station.

Table 9. Mean Numbers and Weights (g) of Animals Per Sample from Kaneohe Stream Stations between February 1976 and May 1977. See Tables 6 and 11 for Numbers of Collections from Stations and Total Numbers of Animals in Kaneohe Stream Collections, Respectively

Species	Stations							
	K-1		K-2[a]		K-3[a]		K-4	
	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.
Pisces								
Native								
Awaous stamineus	0.3	3.69					0.3	3.00
Exotic								
Gambusia affinis	3.1	0.76	0.2	0.01	3.4	0.44	7.4	1.09
Poecilia mexicana	85.7	188.59	89.2	118.24	109.8	48.97	46.8	44.62
Poecilia reticulata	5.7	0.78	1.2	0.17	13.3	1.63	4.4	0.66
Xiphophorus helleri	0.1	0.16			0.5	0.55	1.3	0.48
Crustacea								
Native								
Atya bisulcata							0.1	0.88
Macrobrachium grandimanus	0.9	0.75	0.1	0.02	0.1	0.03		

Continued

Table 9. (Continued)

Species	Stations							
	K-1		K-2[a]		K-3[a]		K-4	
	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.
Exotic								
Macrobrachium lar	0.2	0.10			0.2	2.43		
Procambarus clarkii	0.2	0.33	0.1	0.01	0.3	18.98	23.8	41.12
Total	96.2	195.16	90.8	118.45	127.6	73.03	84.1	91.05
Diversity (H')	0.48	0.19	0.09	0.01	0.51	0.88	1.14	0.94
Evenness (J')	0.23	0.09	0.06	0.01	0.28	0.45	0.59	0.48

[a]Concrete lined channel section.

upstream from the concrete lined channel (K-4). Most crayfish within concrete lined channels were small (40% less than 20 mm total length within a range extending to 110 mm).

Biomass yields at concrete lined channel stations were less than those at natural bottom stations at similar elevations, but greater numbers of animals occurred at the upstream (37 m elevation) concrete lined channel station compared to the upstream natural bottom station. These differences were not statistically significant (Wilcoxon test for nonparametric data, $p = 0.05$).

Waiahole Stream. Among the 11 species collected in Waiahole Stream, two fishes and two crustaceans were common to all four sampling stations. The mean abundance of each species per collection at each station and the species diversity and evenness values are reported in Table 10.

Native crustaceans were dominant at stations with the highest and lowest elevations. At Station W-4 (67 m), large numbers of one endemic shrimp, *Atya bisulcata*, were recovered. The other endemic prawn, *Macrobrachium grandimanus*, was common at downstream Station W-1 (5 m elevation). Exotic crustaceans occurred less frequently than natives in Waiahole Stream.

Native fishes occurred at three of the four stations, but their abundances were relatively low compared to exotic fishes. Assemblages of exotic fishes in Waiahole Stream were comprised, for the most part, of topminnows. *Poecilia reticulata* and *Xiphophorus helleri* were more abundant than *P. mexicana*.

Inter-Stream Comparisons

Species inventories were compiled in order to compare the composition of macrofauna in the three streams (Table 11).

The composition of macrofauna in the various channel types was also compared. This process was facilitated by grouping animals into four classes: native fishes, exotic fishes, native crustaceans, and exotic crustaceans (Table 12). Exotic fishes were prominent in both concrete lined and natural bottom channel sections in altered streams. They comprised a greater proportion of the numbers and biomasses of animals in the concrete lined channel stations than in the natural bottom stations. These results generally agree with results of an earlier study under the same project (Timbol and Maciolek 1978). In the unaltered stream, both exotic fishes and native crustaceans were prominent.

Table 10. Mean Numbers and Weights (g) of Animals Per Sample from Waiahole Stream Stations between February 1976 and May 1977. See Tables 6 and 11 for Numbers of Collections from Stations and Total Numbers of Animals in Waiahole Stream Collections, Respectively

Species	Stations							
	W-1		W-2		W-3		W-4	
	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.
Pisces								
Native								
Awaous genivittatus	0.4	1.38						
Awaous stamineus					0.3	5.90	0.2	0.39
Eleotris sandwicensis	0.4	3.42						
Exotic								
Clarias fuscus					0.1	4.09		
Poecilia mexicana			1.1	2.77				
Poecilia reticulata	3.3	1.09	20.7	4.71	14.4	3.76	7.4	2.21
Xiphophorus helleri	2.6	8.95	1.6	2.80	2.6	4.99	2.6	4.38
Crustacea								
Native								
Atya bisulcata	21.6	0.26	0.1	0.01	4.2	1.67	127.2	37.60
Macrobrachium grandimanus	14.8	17.84	0.7	0.69	2.4	3.73		

Continued

Table 10. (Concluded)

Species	Stations							
	W-1		W-2		W-3		W-4	
	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.
Exotic								
Macrobrachium lar	1.5	4.23	0.2	0.82	1.4	36.95	0.8	8.78
Procambarus clarkii							0.5	2.75
Total	44.6	34.17	24.4	11.80	25.4	61.09	138.7	56.11
Diversity (H')	1.29	1.41	0.61	1.38	1.30	1.35	0.36	1.06
Evenness (J')	0.66	0.73	0.34	0.77	0.67	0.69	0.20	0.59

Table 11. Mean Number of Animals per Sample from Three Study Streams between February 1976 and May 1977

Species	Streams		
	Manoa	Kaneohe	Waiahole
Pisces			
Native			
Awaous genivittatus	0.2		0.1
Awaous stamineus	0.1	0.1	0.1
Eleotris sandwicensis	0.5		0.1
Kuhlia sandvicensis	0.01		
Mugil cephalus	0.03		
Exotic			
Clarias fuscus	0.02		0.02
Gambusia affinis	2.4	3.4	
Misgurnus anguillicaudatus	0.1		
Poecilia mexicana	29.6	83.2	0.3
Poecilia reticulata	7.9	6.0	11.4
Tilapia mossambica	0.2		
Xiphophorus helleri	0.5	0.5	2.3
Xiphophorus maculatus	0.9		
Crustacea			
Native			
Atya bisulcata	0.2	0.02	39.1
Macrobrachium grandimanus	0.02	0.3	4.5
Exotic			
Macrobrachium lar		0.1	1.0
Procambarus clarkii	3.5	1.9	0.1
Total	46.2	95.5	59.0

Table 12. Relative Abundances of Native and Exotic Faunal Groups in Different Channel Types, Collected from Three Study Streams between February 1976 and May 1977

	Altered Streams				Unaltered Stream	
	Concrete Lined		Natural Bottom		Natural Bottom	
Faunal Group	% No.	% Wt.	% No.	% Wt.	% No.	% Wt.
Native Fishes	0	0	4	8	1	6
Exotic Fishes	99	92	79	50	46	37
Native Crustaceans	0	0	1	1	50	32
Exotic Crustaceans	1	8	16	41	3	25

The mean values of diversity and evenness for the channel types were:

Station Channel Type	Diversity; Evenness by Number	Diversity; Evenness by Biomass
Concrete lined	0.43; 0.25	0.46; 0.25
Natural bottom (altered stream)	1.19; 0.61	0.94; 0.46
Natural bottom (unaltered stream)	0.89; 0.47	1.30; 0.70

Both diversity and evenness values were significantly lower in concrete lined channel sections of streams compared to natural bottom sections (Wilcoxon test for nonparametric data; $p = 0.05$).

SUMMARY AND CONCLUSIONS

PHYSICOCHEMICAL FACTORS

Water Temperature

The two altered streams studied showed different temperature regimes. Kaneohe, on the windward side, exhibited slightly higher temperatures than Manoa, on the leeward side. The differences are consistent with differences in ambient air temperature and precipitation. Water temperatures were, however, considerably higher and more variable in the altered streams than in the unaltered one.

Conductivity

Conductivity was higher and more variable in altered streams than in unaltered ones. Conductivity was not correlated with the type of channel bottom.

pH

Altered streams had very high and variable pH, often exceeding the 8.0 units proposed maximum for Hawaiian fresh waters. The parameter was not correlated with bottom type. The unaltered stream had stable, near neutral values and did not exceed the recommended maximum for pH.

BIOLOGICAL FEATURES

The distribution and relative abundances of fishes and crustaceans in altered and unaltered streams on Oahu were studied.

Manoa Stream

Exotic fishes were dominant members of the macrofaunal communities in Manoa Stream. The exotic poeciliids were dominant in the lower elevations while the exotic crustacean, *Procambarus clarkii*, was more numerous at the higher elevations.

Fewer species were found in concrete lined channel stations than in natural bottom stations. No native species were found in concrete lined channel stations. Regular inhabitants of concrete lined channel stations were two species of topminnows, Poecilia mexicana and P. reticulata. Biomass yields from concrete lined channel stations were significantly lower than those from natural bottom stations, but the mean numbers were significantly higher due to high densities of small Poecilia mexicana.

Kaneohe Stream

Exotic fishes were dominant in collections from all stations, and Poecilia mexicana was the most abundant. No native fish was recovered from concrete lined channel stations, and the native crustacean, Macrobrachium grandimanus, also appeared to avoid the concrete substrate.

Biomass yields at concrete lined stations were less than those at natural bottom stations at similar elevations, but greater numbers of animals were collected.

Waiahole Stream

Native animals were dominant in the highest and lowest elevation stations in this unaltered stream. Native fishes were less abundant than exotics at all stations. Exotic fishes consisted mainly of poeciliids; Poecilia reticulata was more abundant than Poecilia mexicana.

Inter-Stream Comparison

Manoa Stream had the highest number of species, followed by Waiahole and Kaneohe in decreasing order.

Exotic fishes were dominant in both artificial and natural bottom channels in altered streams. In unaltered streams, both exotic fishes and native crustaceans were prominent. Species diversity was lower in concrete lined channel stations compared to natural bottom stations.

STREAM MANAGEMENT IMPLICATIONS

Hawaii's native stream fauna is unique in several ways. It is also very fragile. Hawaiian stream animals are particularly adapted to the rocky, precipitous, freshet-flow nature of Hawaiian streams. The numbers of species within a given taxon are few but most of them are endemic. Excluding insects, all larger native stream species are diadromous (having marine larval development) as a consequence of oceanic insular evolution. The impact of stream channel alteration on fauna of oceanic islands such as Hawaii can be especially severe inasmuch as the most extensive modifications are developed mainly in the lower reaches of streams which, in addition to being habitats of some species, are the essential migratory pathways for both seaward-moving larvae and returning juveniles of all the larger native species inhabiting the upper reaches. Perhaps it is no coincidence that *Lentipes concolor*, originally described in part from Oahu, where today stream channel alteration is most extensive, is now unknown on that island.

Commentaries relevant to management of Hawaiian streams are made for two purposes. First, there is a recognition both of the demands for agricultural and domestic water supplies for the economic and population growth in the State, and the need to protect unique biota and conserve fishery resources and recreational opportunities. Further, all "high island" streams in the Pacific have enough common features to make results transferable. Thus, results of this Hawaii channelization study can, with proper caution, be applied to high islands of Guam, Commonwealth of the Northern Marianas, Micronesia, American Samoa, and some other Pacific high islands. Some details regarding transferability of information are forthcoming (USFWS, in preparation).

IMPACT OF CHANNEL ALTERATION

Stream management must address the possible effects which channel alterations may have on the diadromous native animals, the possible reasons for adverse effects, and possible mitigative actions that might be taken. A related preliminary study addressing the potential impacts of hydroelectric and support facilities on the Hawaiian stream macrofauna has been done by Timbol (1977).

Environmental Factors

An immediate effect of almost any type of channel alteration is a reduction in the heterogeneity of the habitat, particularly the substrate.

Shade and bottom shelter are usually reduced. This normally results in more extreme values of environmental variables (e.g., water temperatures). The magnitude of the impact depends on the nature of the alteration, with highest impacts occurring within artificially lined channel bottoms. In addition, alteration of a portion of a channel may have degrading effects on total stream quality; in the present study, natural bottom sections of altered streams exhibited more variable physicochemical features than natural bottoms of unaltered streams.

When administrators are faced with no alternative but to allow some form of channel alteration in a stream, an alteration leaving the stream bottom in a natural state is much the best choice ecologically. The worst choice is a concrete lined channel which replaces the diverse character of the natural stream channel with a smooth, featureless channel of uniform cross-section, current and substrate. Flow in such a lined channel is typically in a uniform, very thin sheet. These characteristics lead to poor water quality, e.g. extreme temperatures, pH as high as 10 (two units higher than the maximum specified in Hawaii's water quality standards).

Concomitant with channel alteration is riparian clearing. It should be kept to a minimum, and where devegetation is unavoidable, replanting of riparian trees should be part of stream management. Devegetation eliminates overhead cover, resulting in excessive radiant heat transfer, which leads to wider ranges in temperature (e.g., very high in the afternoons and very low in the early mornings). Intense daytime light and heat promote excessive algal growth. The photosynthetic activity causes strong diel fluctuations in pH and dissolved oxygen content and creates an unnatural benthic floral community.

Biological Implications

If the stream course is straightened, as is usually done in channel alterations, hydraulic resistance is lessened, resulting in increased water velocity. Gebhards (1973) stated that increased water velocity and loss of shelter are prime factors that affect stream macrofauna. He estimated that channel alteration in two trout streams in Idaho reduced game fish production by 87%. Reductions in game fish in other altered streams were: North Carolina, 76%; Missouri, 79%; and Montana, 90%. In game fish exceeding six inches in length, a 90% reduction in both weight and number occurred in North Carolina streams following channelization (Bayless and Smith 1964). Loss of shelter can be highly detrimental to the survival of fishes in streams, particularly to demersal, cryptic forms such as all the native Hawaiian stream species. Although these fishes are fair swimmers in short bursts, lactic acid accumulates rapidly, and shelters for frequent resting are required. Thus, the maintenance of long sections of natural channel bottom is particularly important to these substrate dependent species.

Habitat features resulting from stream channel alteration in Hawaii favor exotic fishes, particularly poeciliids, over native species. Except in a few cases of recreational fishery importance, exotic species are considered pests in Hawaiian streams. They appear to compete with native species for food and shelter, and at least some predation occurs (e.g., Tomihama (1972) observed the exotic Tahitian prawn capturing the native goby, Sicydium stimpsoni). Often exotic species have broader environmental tolerances than native species and flourish in degraded streams as in the case of topminnows (P. mexicana) in Manoa and Kaneohe Streams. Preliminary results of the final portion of this study support this impression; definitive results are forthcoming in Part C (FWS/OBS-78/18).

In the present study, fewer macrofaunal species thrived in artificial bottom channels than in natural bottom channels. Biomass yield was likewise lower but numbers were higher due to high densities of the topminnows. Artificial bottom stations, especially those lined with concrete, appear to serve as nurseries for these ubiquitous topminnows, undesirable species compared with any of the native species of gobies that they appear to be displacing. In an earlier study, Timbol and Maciolek (1978) found that exotic fishes and crustaceans strongly dominated all artificial bottom channels both by number (97%) and weight (92%).

MITIGATIVE ACTIONS

Most of the native Hawaiian stream fish and crustaceans are diadromous. They need suitable passageway throughout the stream length for their larvae to reach the ocean and the postlarvae to return upstream to their adult habitat. In particular, the endemic goby, Awaous stamineus, which supports a seasonal fishery on Kauai Island, migrates downstream to spawn. Their larvae spend from four to seven months in the sea as plankton before they migrate upstream as postlarvae (Ego 1956). To provide a suitable habitat for this valuable fish as well as other native diadromous fishes and crustaceans, the following actions may be taken.

Alteration of the stream bed should be minimized or avoided whenever possible. When an artificially lined channel is unavoidable, it is desirable to concentrate the stream flow into a deeper water column by either a v-notch on the new channel bottom or a slanting channel bottom. The present common method of channel alteration whereby a sinuous channel is replaced with a straight, and consequently shorter channel, should be modified. The new stream channel should have the same total channel length as the one it replaced. Straight channels reduce sheltering slack water adjacent to banks at times of rising flow which results in populations of native animals being swept to the ocean where most adults cannot survive for any length of time.

The most obvious effect of channel alteration is scenic degradation. The straight and angular channels in the lower reaches of Manoa Stream compared with its almost pristine and scenic channels at higher elevations is but one example. This type of degradation is detrimental both to the native stream animals and to the tourist industry.

To provide a suitable habitat for diadromous native animals, reduce scenic degradation, and at the same time provide for cultural needs for a growing human population, it seems prudent to recommend tentatively that a continuous length of concrete lined channel should be no more than 1.5 km before a natural bottom section is provided. Results of this study indicated that at least one native prawn and one native goby negotiated a 1.8 km length of lined channel. A figure of 1.5 km is recommended as a conservative value considering species population requirements.

This study showed that the removal of stream cover resulted in adverse physicochemical conditions. Permanent removal of tree cover can result in the disappearance of the native *Macrobrachium*, as was the case with two *Macrobrachium* spp. in Malaya (Johnson 1966). It can also be expected to lead to the continued decrease of the endemic *M. grandimanus* and the displacement of this endemic prawn in freshwater habitat by the exotic *M. lar*. *M. lar* has been observed to kill *M. grandimanus* in the absence of cover (Kubota 1972).

To provide mitigative conditions, riparian vegetation should be planted along the new channel to replace young trees and shrubs removed. The recommended formula is one-for-one of particular species (U.S. Fish and Wildlife Service 1974) with the additional proviso that woodlands should be replaced by planting 1 1/2 acres of young plants for each acre cleared. There are no Hawaiian data comparable to the U.S. Fish and Wildlife Service recommendations. There is some evidence that Hawaiian riparian trees and shrubs will thrive under conditions other than their natural environment as can be seen in the use of strawberry guava trees, *Psidium cattleianum*, in Honolulu's Ala Moana Shopping Center and the wetland hau, *Hibiscus tiliaceus*, for shade trees in Waikiki. This revegetation also replaces some of the lost sources of organic input in the stream waters, which according to Fisher and Likens (1973), is 99% of the annual energy input to the stream system.

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Appendix A. Physical Features of Sampling Stations

The following is a brief description of the sampling stations including the location, elevation, mean stream width, depth range, bottom type, and flow characteristics (riffle/pool). It should be noted that the information provided below does not reflect conditions which may prevail during periods of peak flow. Compare with text Figs. 2, 3, and 4.

MANOA STREAM

M-1 Adjacent to Kaimuki High School, 3 m elevation; 3.5 m wide; 15-31 cm deep; pebble and cobble bottom; riffle.

M-2 15 m upstream of the Manoa-Palolo confluence; 6 m elevation; 7.5 m wide; 6-15 cm deep; boulder and pebble bottom; riffle.

M-3 Palolo Tributary concrete lined channel 20 m upstream of the Manoa-Palolo confluence; 6 m elevation; 3.5 m wide; 3-6 cm deep; concrete bottom; riffle.

M-4 Palolo Tributary concrete lined channel adjacent to Palolo School; 61 m elevation; 4 m wide; 5-9 cm deep; concrete bottom; riffle.

M-5 30 m downstream from Woodlawn Drive crossing; 43 m elevation; 10 m wide; 40-60 cm deep; mud and silt over pebble bottom; pool.

M-6 Concrete lined channel adjacent to Manoa Park; 49 m elevation; 5.5 m wide; 5-8 cm deep; concrete bottom; riffle.

M-7 Adjacent to Manoa Park; 49 m elevation; 7.5 m wide; 34-38 cm deep; pebble and cobble bottom; riffle.

M-8 Upstream of the 4th bridge on Waaloa Way; 110 m elevation; 2.0 m wide; 10-16 cm deep; boulder and cobble bottom with some silt; riffle.

KANEOHE STREAM

K-1 Adjacent to Kaneohe Public Library; 21 m elevation; 10.5 m wide; 16-21 cm deep; mud and silt over pebble and cobble bottom; riffle.

K-2 Concrete lined channel adjacent to Kaneohe Public Library; 21 m elevation; 17.7 m wide; 5-10 cm deep; concrete bottom; riffle.

K-3 Uppermost section of Kamooalii tributary concrete lined channel; 37 m elevation; 6.7 m wide; 5-8 cm deep; concrete bottom; riffle.

K-4 Kamooalii tributary 50 m upstream of concrete lined channel; 37 m elevation; 9.5 m wide; 14-17 cm deep; silt and mud over pebble bottom; riffle.

WAIAHOLE STREAM

W-1 Approximately 0.2 km from highway, adjacent to Waiahole Valley Road; 5 m elevation; 4.9 m wide; 22-23 cm deep; pebble bottom with mud and silt; riffle.

W-2 Uwau tributary 20 m downstream of bridge crossing of south fork of Waiahole Valley Road; 24 m elevation; 2.1 m wide; 12-29 cm deep; mud over pebble bottom; riffle.

W-3 Uwau tributary at end of north fork of Waiahole Valley Road; 61 m elevation; 3.6 m wide; 12-21 cm deep; boulder and pebble bottom; riffle.

W-4 Approximately 0.4 km along Hawaiian Electric Company trail at end of south fork of Waiahole Valley Road; 67 m elevation; 4.1 m wide; 18-33 cm deep; boulder and pebble bottom; riffle.

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16. Abstract (Limit: 200 words)
Effects of channelization on native Hawaiian stream fauna were assessed by making physio-chemical measurements and analyzing and comparing macrofaunal communities in channelized and unchannelized streams. The altered study streams had higher mean water temperature, pH, and conductivity and wider ranges of these variables than the unaltered stream. Channel sections with concrete bottom had higher values than sections with natural bottom. Exotic fishes predominated in altered streams; exotic fishes and native crustaceans predominated in unaltered streams. Native fishes appeared to be especially reduced in heavily channelized streams. Channels with artifical bottom seemed to provide nurseries for the exotic poeciliids, Poecilia mexicana and P. reticulata; species diversity was lower in these channels.

Extreme channelization seems to stress the diadromous native fauna. Channel alterations, particularly artificially lined channels, appear to favor worthless exotics in replacing native species. Channelization in Hawaii should be minimized to protect native fauna. Where it is unavoidable, natural bottom channels seem least damaging. Artificial bottom channels, if used, should provide for reasonable water depth at low flow, and the length of continuous sections should be minimized. Riparian bank vegetation should be maintained. Results of this study are relevant to many tropical oceanic high islands.

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