Biological Services Program

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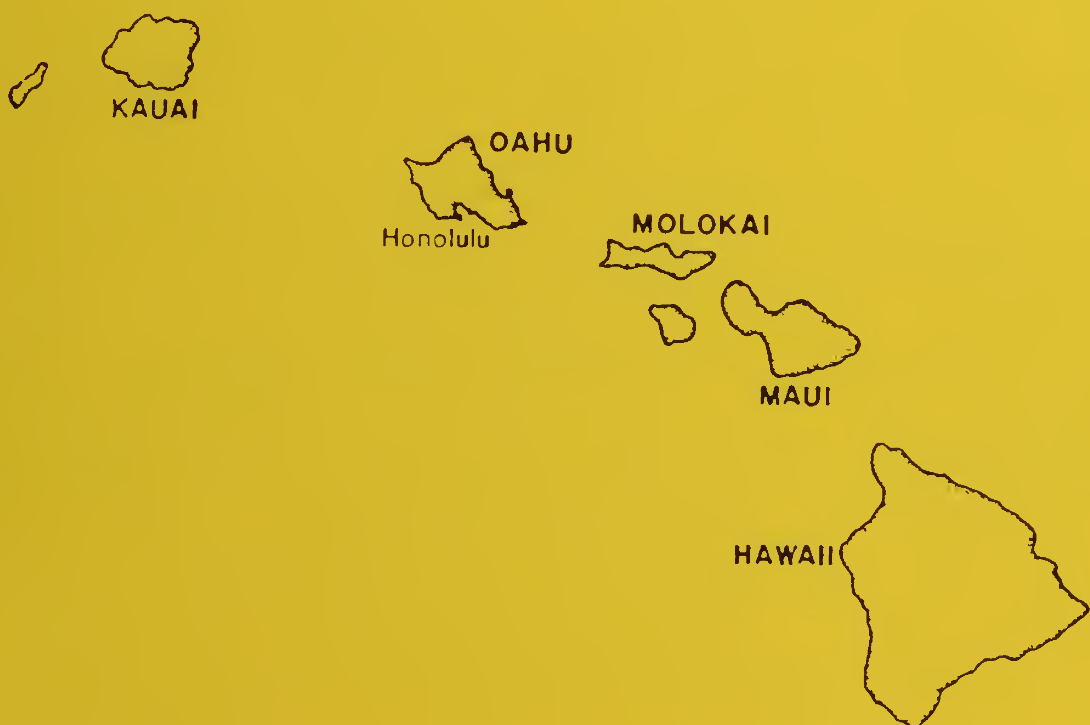
Stream Channel Modification in Hawaii. Part D: Summary Report



Fish and Wildlife Service
U.S. Department of the Interior

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> To strengthen the Fish and Wildlife Service in its role as a primary source of information on national fish and wildlife resources, particularly in respect to environmental impact assessment.
>
> To gather, analyze, and present information that will aid decision-makers in the identification and resolution of problems associated with major changes in land and water use.
>
> To provide better ecological information and evaluation for Department of Interior development programs, such as those relating to energy development.

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October 1978

STREAM CHANNEL MODIFICATION IN HAWAII
PART D: SUMMARY REPORT

by

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PREFACE

This is the last of a four-part series on Stream Channel Modification (Channelization) in Hawaii and Its Effects on Native Fauna. The four parts (FWS/OBS-78/16, 17, 18, and 19) were prepared for 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 contains a general summary of project results and a guide to the location of more detailed information reported in Parts A, B and C. A general discussion of conclusions and management recommendations is included. This report is based on data and analysis covering the entire contract period: July 1975 through October 1978.

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

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EXECUTIVE SUMMARY

A 3-year, statewide study was made of the occurrence and consequences of channelization in Hawaiian streams. The 366 perennial streams of the State were inventoried for the first time, and some basic information was catalogued on their physical characteristics, complete status of channel alteration, and macrofaunal communities. Fifteen percent of the State's streams have channels altered in at least 1 of 6 forms. There are 151 km of altered channel, 89% of which is on Oahu. Forty percent of the modified channel length is concrete lined - the form of alteration found to be most ecologically damaging.

Field measurements showed that channel alterations commonly caused large changes in environmental parameters. Whereas the average pH value in natural streams was 7.2, the yearly mean mid-afternoon pH in lined channels was as high as 9.9. Conductivity and dissolved oxygen were significantly increased. The range of daily temperatures in lined channels was 17.8 - 36.2°C as compared to 19.5 - 26.8°C in natural channels. The diel insolation cycle of exposed, artificial channels caused extreme diel change in all these environmental parameters. The native species tested in the laboratory had less tolerance of high temperatures than exotics, and some natives had upper lethal temperature limits within the temperature range measured in channelized streams.

Twenty-five species of fish and decapod crustaceans were collected statewide, of which only 8 were native. Native species were not abundant in most areas intensively surveyed; they appeared to thrive only in areas remote from development. Certain introduced species, notably poeciliid fishes, were abundant in the most heavily channelized sections, whereas native species were almost entirely absent.

Channelization in its various forms (1) increases turbidity, (2) destroys natural substrate habitat, (3) creates wide, shallow, unnatural flows, (4) causes excessive illumination, water temperatures, and pH levels, and (5) creates topographical difficulties for upstream migration. Effects (2) and (4) are believed to create especially serious problems for the native macrofauna that is benthic/demersal, cryptic, and obligately diadromous. As a result, present channelization practices appear to be damaging the quality of extensive stream habitat for native species and contributing to their replacement by hardy, useless exotics.

Mitigation should include (1) minimizing channelization projects, (2) maintaining the natural length of channels, (3) maintaining (replanting)

the vegetative canopy, (4) maintaining natural bottom material wherever possible, (5) using intermittent sections of natural bottom between minimum sections where lined channel is unavoidable, (6) building a narrow, low-flow notch into the bottom of flat lined channels, (7) installing minimum length culverts in ways that will avoid downstream elevations above stream level (waterfalls).

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LIST OF ABBREVIATIONS AND SYMBOLS IN TEXT

ABBREVIATIONS

g	grams
km	kilometers
LD_{50}	lethal temperature at time of 50% sample mortality during a gradual heating test
m	meters
m^3/s	cubic meters per second
mg/ℓ	milligrams per liter
NTU	nephelometric turbidity units
µmhos	micromhos

SYMBOLS

°C	degrees, Celsius

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INTRODUCTION

The Hawaiian stream environment is like nothing in mainland America. The inhabited islands are all of recent volcanic origin, with small land area, dominated by steep slopes of porous, igneous rock, and lacking extensive coastal plains. Climate is dominated by prevailing oceanic trade winds that shed rainfall mostly between elevations of a few hundred and about 2500 meters on the windward sides of the high islands. This results in great local variability in climate and stream locations, with a strong concentration of streams on windward slopes. Streams tend to have steep gradients, rocky channels, heavy vegetative canopy cover, and great temporal variability in discharge. A natural result is frequent and considerable flooding of the narrow plains in the lower reaches. These plains are the locations of extremely rapid recent residential and commercial development brought about by the State's explosive growth in population and tourism. Extensive stream channelization has resulted over a very short period of time (Most has been performed within the last 2 decades).

Before this study, the extent and nature of these modifications were poorly known, and their environmental effects on the unique Hawaiian stream ecosystems had not been studied. The hydrological uniqueness of the streams made it hard to predict environmental changes. The uniqueness of the poorly studied native fauna made it hard to predict biological results. Many of the State's streams were poorly characterized on a geographical/hydrological basis.

The present study was conceived to provide a start at addressing all these major information needs. It consists of (1) a physical inventory of all perennial streams in the State (None existed previously!) and an inventory of channel modification types and locations and associated fauna, (2) a set of measurements designed to show the effects of channel modification on environmental parameters, and (3) an assessment of biological results both by controlled manipulation of individual parameters in the laboratory and by comparison of natural communities in the field. The results as reported herein and in the companion reports (FWS/OBS-78/16, -78/17 and -78/18) provide a valuable basis for intelligent planning concerning channel modification in Hawaii. They should also be directly applicable to the high tropical islands of Puerto Rico, the U.S. Virgin Islands, and the U.S. Trust Territory, and tropical oceanic high islands generally.

BACKGROUND: ECOLOGY OF NATIVE SPECIES

The native Hawaiian freshwater fauna is very limited and highly specialized, the result of evolutionary processes on small, geographically young, strongly isolated land masses. Of the 5 truly freshwater native fish species (all gobies), 4 are endemic; both native decapods are endemic (see Table 2, p. 8). Thus, aside from any other importance, native species have intrinsic biological value, and any threat to their limited insular habitat must be weighed against the requirements for survival of a species on earth. The endemic goby, *Lentipes concolor*, has been proposed for endangered status, and other native species have been mentioned for consideration of special protective concern (Miller 1972). Some of the native species had important positions in traditional diet and culture (Titcomb 1972). At least 4 native species - *Awaous stamineus*, *Macrobrachium grandimanus*, *Atya bisulcata*, and *Neritina granosa* - are still taken as food and/or bait.

All the truly freshwater fish and decapod species are of marine derivation, and all have diadromous life histories, i.e. they reside in streams as adults, but their larvae must reach the sea to develop and later migrate upstream as post-larvae. The extent of adult up- and downstream movement is poorly known and certainly varies among species. However, at some stage of their lives, some species such as *A. stamineus* migrate many kilometers up to elevations of over 500 m. Thus, almost all actual and potential locations for channel modifications lie within the obligatory migration path of several native species. If impacts are severe enough due to disturbance at any channel section in the stream, the life cycle of the species in the stream cannot be completed, even though acceptable adult habitat remains above the alteration.

The native macroinvertebrates are, of course, benthic animals, and the native fishes are demersal to the point of being almost of the benthos as well. The 4 gobiid fishes have fused pelvic fins with which they cling to the substrate; the eleotrid is also strongly demersal. All are more or less cryptic, and make considerable use of rocks and other stream bottom cover for protection. Most species appear to browse benthic algae as an important part of the diet. As is often the case with endemics that have evolved isolated from vigorous competition, the native species appear to be poorly equipped to compete successfully with some of the many hardy species recently introduced to the State's streams.

PHYSICAL INVENTORY

The physical inventory revealed 366 perennial streams in the 5 major islands of the State (Table 1). Fifty-nine percent of these streams are continuous (i.e. containing water in their channels continuously from the highest point to the mouth). Fifteen percent of all streams have been channelized (Table 1); 56% of all altered streams are on Oahu, the most populous island in the State.

Six types of channel modifications have been indentified: (1) channel realigned and/or vegetation removed, (2) channel walls revetted, (3) channel directed through an elevated culvert, (4) channel bottom and sides lined, usually with concrete, (5) extended culvert (a longer version of (3) above), and (6) channel blocked or filled in. A total length of 151 km of these modifications was found statewide, 89% on Oahu. Twenty-eight percent of the total was realigned/cleared, 24% revetment, 3% elevated culvert (mostly road crossings), 40% lined channel, <1% extended culvert, and 5% blocked channel. Timbol & Maciolek (1978) provide a fuller description of channel alteration types, detailed island-based breakdown of channelization statistics, a complete tabular list of all State streams with some basic physical data and ecological quality ratings on them, maps of all channelized streams showing watershed limits, stream channels, longitudinal gradient of main stream, and approximate locations of the various types of channel alterations. For most channelized streams, results of field collections of macrofauna are shown, giving some indication of the nature of living stream communities.

Table 1. Inventory Data Summary on Hawaiian Streams and Stream Channel Modifications (Data from Timbol and Maciolek 1978)

Island	Oahu	Maui	Molokai	Hawaii	Kauai	Total
Perennial streams						
Total number	54	96	37	123	56	366
Continuous	53%	58%	43%	57%	77%	59%
Water diverted	58%	59%	12%	60%	45%	53%
Physically pristine[a]	0	1%	49%	11%	32%	14%
Pristine-Preservation ecological quality[b]	0	34%	81%	21%	20%	27%
Channelized	31 (57%)	7 (7%)	1 (3%)	4 (3%)	12 (21%)	55 (15%)
Modified channel						
Total modified length (km)	134	5	0.1	4	8	151
Types (% of total modified length)						
Cleared/realigned	27	54	0	31	51	28
Revetment	23	34	0	23	35	24
Elevated culvert	< 1	4	3	2	14	3
Lined channel	43	8	0	44	0	40
Extended culvert	< 1	0	0	0	0	<1
Blocked/filled	6	0	0	0	0	5

[a]Channel not altered, water not diverted, no road crossings (except foot trails).

[b]Highest ecological quality status in the system devised by the State Department of Health (Timbol and Maciolek 1978).

ENVIRONMENTAL CHANGES AND ENVIRONMENTAL TOLERANCES

Hawaiian streams have a unique combination of physical/chemical properties. The largest mean discharge is only 9.7 m^3/sec (maximum instantaneous discharge, 271 m^3/sec). Huge temporal flow variations occur; even among a group of the 3 largest streams of each island, the ratio of mean to minimum discharge is over 1000 in 2 cases. Discharge of many streams (53% statewide) is greatly reduced by the diversion of water for irrigation and domestic uses (Table 1). In a good many cases, dry reaches of channel result during most of the year, and diadromous migration is impeded. The range of temperatures measured in this complete study in unaltered streams, over the full range of elevation, season and time of day, was 19.5 to 26.8°C. Island average pH values ranged from 6.2 on Hawaii to 7.5 on Maui (7.2 on Oahu). Conductivity ranged from 43 μmhos on Hawaii to 180 μmhos on Oahu. Corresponding dissolved solids values were 31.0 mg/ℓ to 112.2 mg/ℓ.

Alteration of the natural channel condition produced significant (sometimes dramatic) changes in physical/chemical parameter values. These changes in field values and the results of laboratory experiments on the effects upon stream animals of parameter values in and near this range are reported by Hathaway (1978). His measurement of field parameters was concentrated in 3 streams on Oahu, containing conditions ranging from natural channels through several major types of channelization. Stream sampling statewide confirmed the general trend of response of the environmental parameters to the channel alterations.

For the intensively studied streams over a year's sampling, the full range of temperatures in channelized sections was 17.8-36.2°C. Fig. 1 is representative of the strong diurnal heating and large diel variation in temperature that occur in a concrete lined channel (the most common alteration in urban areas) compared to a natural channel. Similar trends were consistently recorded in pH, conductivity and dissolved oxygen. The temporal cycle of the latter 3 parameters (like that of temperature) seems largely dependent on insolation; pH, oxygen, and probably conductivity respond positively to the resulting photosynthesis of the lush algal growth commonly attached to concrete channel surfaces. Levels of pH measured in several lined channel stations frequently exceeded levels generally considered suitable for most aquatic animal species and far exceeded the maximum limit of 8.0 in Hawaii Department of Health water quality standards. Mean mid-afternoon values over a year's time ranged for 5 lined channel stations from 7.5 to 9.9. Peak values were as high as 10.4.

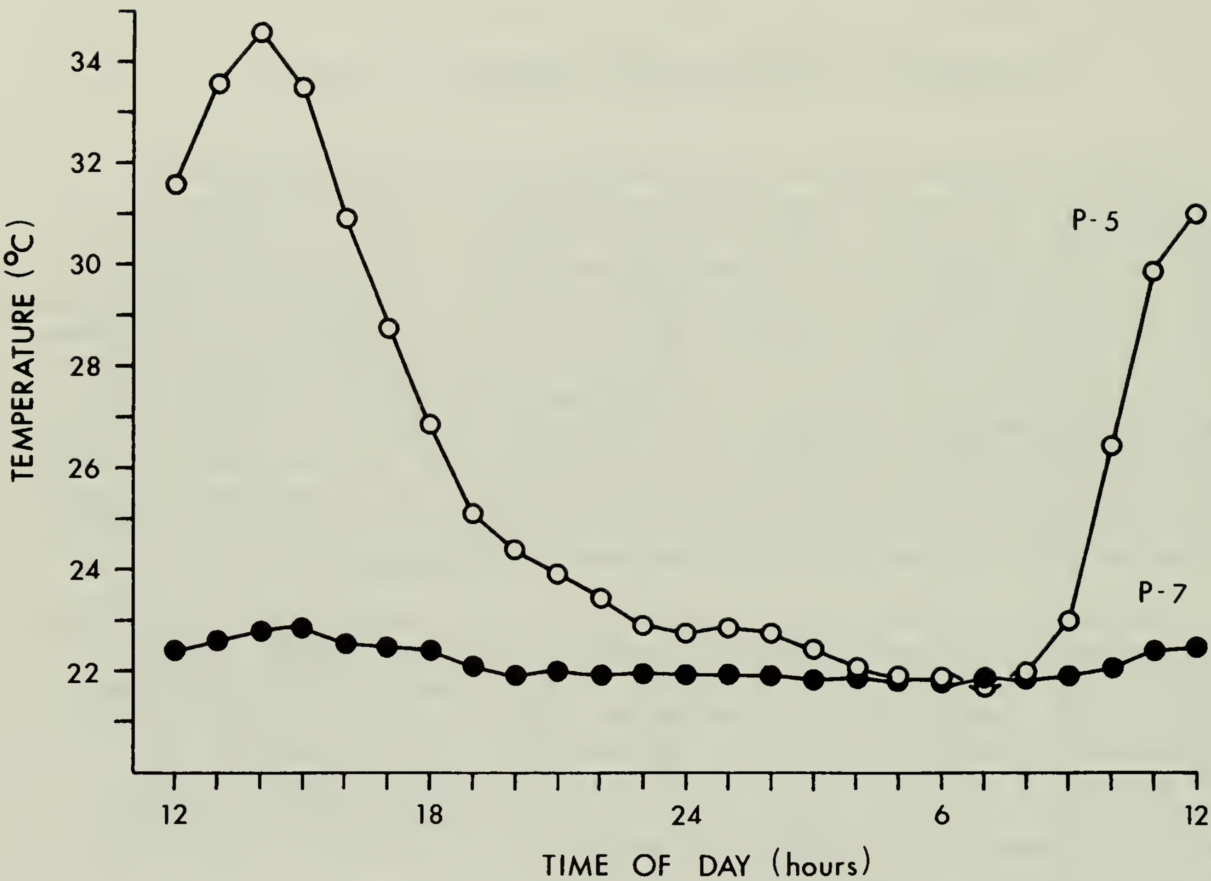

Figure 1. Diel cycle of water temperature (1) in a natural section of stream channel (●), and (2) after flowing through 2400 m of concrete lined channel (o). (From Hathaway 1978).

Peak daily temperatures averaged over a year's time were raised as much as 7.8°C in the process of flowing a distance of 2400m through a lined channel. Elevations as great as 9.1°C above the temperature in the natural channel, and absolute values of 36.2°C, were recorded at times. The persistence of water temperatures well above normal was demonstrated for hundreds of meters downstream of the end of a channelized section. Highest temperatures cross-stream were measured near the edge of the channel (as much as 4.5°C higher than mid-stream values, such as all those reported above). At the channel edge, water speed was lowest, and presumably moving upstream would be hydrodynamically easiest for stream animals. These effects would make it especially difficult for post-larvae to complete a normal migration upstream from the sea.

Upper lethal temperature limits for adults of 9 native and 2 exotic stream species were tested in the laboratory (Table 2). In the actual field situation, mortality would normally occur at somewhat lower temperatures, and successful spawning would be restricted to lower temperatures yet. For some of the now scarce native fish species (e.g. *Sicydium stimpsoni* and *L. concolor*) and both the native crustaceans, the laboratory lethal temperatures fall within the measured range of peak daily water temperatures in lined channels. The 2 exotic fishes have by far the highest lethal temperatures, and these are well above the highest water temperatures encountered in lined channels. Interestingly, the statewide field studies showed that these 2 species are very abundant in lined channel sections; *Poecilia mexicana* is often the dominant animal. Tests on post-larval fish of several of the species indicated acute stress at lower temperatures than for the adults, but higher upper lethal temperatures. Individuals collected from more degraded stream sections showed no different thermal tolerance from individuals collected from natural stream sections.

Laboratory growth tests indicated increased growth rate and increased variance in growth rate with increasing temperature above natural stream values up to about 30-32°C. Growth rate was reduced at still higher temperatures (still several degrees below lethal limits in 3 goby species). The physiological consequences of unnaturally rapid growth are unknown. In animals evolutionarily adapted to warm tropical temperatures, this may constitute a chronic physiological stress.

Table 2. Upper Lethal Temperature Limits of Native and Selected Exotic Species (Data from Hathaway 1978)

Group Species	Lethal Range (°C)	LD_{50} (°C)
Fish		
Awaous genivittatus (indigenous)	39.2-39.7	39.7
Awaous stamineus (endemic)	37.2-38.8	38.2
Eleotris sandwicensis (endemic)	39.2-39.6	39.3
Sicydium stimpsoni (endemic)	35.4-35.8	35.6
Lentipes concolor (endemic)	35.9-36.3	36.1
Poecilia mexicana (exotic)	41.2-41.4	41.3
Sarotherodon (=*Tilapia*) sp. (exotic)	42.7-43.1	42.9
Mollusks		
Neritina granosa (endemic)	38.4-40.1	38.8
Melania sp. (indigenous)	36.7-38.6	37.5
Crustaceans		
Atya bisulcata (endemic)	34.0-34.5	34.2
Macrobrachium grandimanus (endemic)	36.4-37.3	36.8

BIOLOGICAL RESULTS

Twenty-five species of fish and decapod crustaceans were collected in the statewide stream inventory (Table 3). Seventeen of these species are exotic. As a general trend, exotic species tend to be more dominant on more heavily developed islands, and this trend appears clearly in comparing areas within an island. Table 4 indicates the dominance of exotic species in channelized compared to unaltered streams in Oahu. A number of native species, particularly the gobies, S. stimpsoni and L. concolor, were dramatically more abundant in less developed areas. L. concolor, originally described from Oahu, where the bulk of channelization has occurred, was not found there in the entire survey and apparently is extinct there. The data on occurrence and abundance of S. stimpsoni, together with what is known of its habitat requirements, suggest using any decline or disappearance of its population as an indication of serious stream degradation. Several introduced species (primarily poeciliids) were prominent in most channelized streams; the introduced guppy, Poecilia reticulata, was the most widely distributed and abundant of all fish species. Further details on a statewide basis appear in Timbol & Maciolek (1978).

Table 3. Occurrence of Macrofaunal Species in Statewide Stream Inventory (Data from Timbol and Maciolek 1978)

Island	Oahu	Maui	Molokai	Hawaii	Kauai	Total
No. native fish species	5	6	6	6	6	6
No. exotic fish species	14	3	0	3	7	15
Total no. fish and decapod crustaceans	23	13	9	12	17	25
% of native species in the macrofauna	30	62	89	67	47	32

Table 4. Comparisons of Numbers and Weights Per 20 m X 1 m Station of Different Groups of Macrofauna in 17 Altered and 6 Unaltered Streams on Oahu. Native Species are Associated Mostly with Unaltered Streams, While Exotic Species Predominate in Altered Streams (From Timbol and Maciolek 1978)

Stream Fauna-Grouped	Unaltered		Altered	
	% No. (No.)	% Wt. (Wt., g)	% No. (No.)	% Wt. (Wt., g)
Native Crustaceans	53 (177)	13 (186.0)	7 (293)	2 (242.4)
Native Fishes	19 (64)	47 (646.8)	7 (262)	11 (1759.9)
Exotic Crustaceans	10 (32)	31 (424.5)	11 (434)	21 (3110.2)
Exotic Fishes	18 (62)	9 (126.2)	75 (2923)	66 (10094.1)

A more intensive study of entire communities in natural versus altered channels was conducted in 3 Oahu streams over a period of about 2 years. Several of the stations were also used for the above mentioned intensive environmental measurements (Hathaway 1978). The results are reported in detail in Norton et al. (1978). Exotic fishes were dominant in both artificial and natural bottom channel sections in altered streams (Table 5). The two poeciliids, P. mexicana and P. reticulata, were most abundant. These species were regularly present in abundance in lined sections of the channels, whereas no native species was ever found in lined channel sections, and native decapods appeared to avoid this substrate also. Thus, diversity was lower in lined channel sections. Biomass was also significantly lower, but numbers were greater due to the abundance of small poeciliids. As in many Hawaiian streams, the introduced crayfish, Procambarus clarkii, and the introduced prawn, Macrobrachium lar, were prominent. The latter is probably present in every stream in the State, and based on the statewide survey, appears to be displacing the endemic M. grandimanus. The intensive study results are consistent with those of the statewide inventory in which Timbol and Maciolek (1978) found that exotics comprised 97% by number and 92% by weight of all fishes and decapods in artificial bottom channel sections.

Table 5. Relative Abundances of Native and Exotic Faunal Groups in Different Channel Types, Collected from Three Study Streams (From Norton et al. 1978)

Faunal Group	Altered Streams				Unaltered Stream	
	Concrete Lined		Natural Bottom		Natural Bottom	
	% 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

In the unaltered stream, both exotic fishes and native crustaceans were prominent (Table 5). Native fishes were present throughout the stream, but they were nowhere abundant in any stream in this intensive study. Because of the predominance of exotics in the altered streams, one of them (Manoa) had more total macrofaunal species than the unaltered stream. All evidence in this study accords with casual observations over the last several years indicating that the hardier exotics are progressively displacing native stream species, especially in areas of greater human activity. This study strongly suggests that channelization practices, particularly long lined channel sections, are aiding this takeover by exotics.

EFFECTS OF CHANNELIZATION AND MITIGATION

Virtually every channel modification project begins with destroying some or all of the streamside vegetation and digging into channel surfaces. This activity alone causes short-term destruction of habitat and creates very high short-term levels of turbidity. A "worst case" example may be that of Kamooalii tributary of Kaneohe Stream, Oahu, where extensive earth moving work has resulted in repeated turbidity measurements of 220 NTU or greater and readings as high as 530 NTU (personal communication, Environmental Consultants, Inc.). These levels are orders of magnitude above the usual 2 to 6 NTU for natural Hawaiian streams at moderate discharges. But records indicate that occasional storm freshets can increase the turbidity in a natural stream by a factor of 100 or more. Although native species must have developed some tolerance for very short-term high levels of turbidity, prolonged high levels during and for some period after channel modification probably displace them from portions of the stream and discourage migration in the channel downstream of the work site. Where the stream surroundings are simply cleared and the channel widened and/or realigned, long-term turbidity levels can be mitigated by allowing or encouraging revegetation of stream banks.

In channel projects where the cleared and dug channel is left with "natural" soil/rock surfaces (not revetted or lined), the most harmful effects are probably excessive illumination and warming due to removal of streamside vegetation. Laboratory and field studies indicated that native species avoid both excessive illumination and heat and seek sheltered habitat. In the long term, the quality of the natural community in these channels seems to depend largely on the degree of shading. Much of the damage done by realignment could be mitigated by intelligently replanting streamside canopy vegetation.

Revetment of stream banks is the next step away from the natural situation. It can reduce turbidity caused by bank erosion, although the long-term effect is probably minor. It may complicate the problem of replanting streamside vegetation. In theory, some increase in water temperature might be expected beyond the natural bank situation. Where other factors are equal, revetted streams with natural bottoms appear to have communities much like realigned streams with channels of natural materials.

The lined channel appears to offer considerably more serious environmental problems. In addition to short-term construction problems, habitat destroyed during construction is never recovered. Channel surfaces are usually relatively smooth concrete. Even where constructed of mortared stone, they provide essentially no shelter for native animals. The often long and totally bare expanses of concrete offer substrate that is in no way natural or suitable for demersal native stream species, all of which orient strongly to the natural substrate. Since lined channels are sized for freshet flows (and thus have large cross-section), the common flat-bottom geometry results in very shallow water depths across the entire flowing stream during most of the year, when flows are hundreds or thousands of times less than peak flow. The result is a very unnatural and inhospitable habitat to stream species accustomed to frequenting pools as well as riffles. An additional problem is the common practice of clearing the channels of sediment periodically by running a bulldozer through the channels, greatly increasing turbidity and disturbing habitat.

Illumination levels in exposed lined channels are extremely high, typically 70 times as high as in a natural stream channel beneath its normal tree canopy. Where occasional lined channels were found that had partial canopy shading from "volunteer" secondary growth, illumination levels were 3 to 10 times higher than those under a natural stream channel canopy. Lined channels cause the most rapid water heating of any type of modification. Water passing through a lined channel is heated more than water in a natural channel even when shading by vegetative canopy is comparable (either heavy or absent). This appears to be due to the shallow depth maintained by flat channel bottoms, high solar heat transfer by the concrete/masonry material, and probably by a focusing effect of solar energy caused by the usual rectangular lined channel cross-section.

Temperature and other physicochemical water parameters (e.g. pH, conductivity) do not change linearly with length of modified channel. Thus, water quality can be seriously affected by rather short lengths of artificial channel. However, prolonged channelized lengths increase the risk of exceeding the animals' temporal tolerance to elevated levels, with immediate or delayed lethal effects or interruption of the migration behavior necessary to maintain the populations. The harmful effects may operate within the channel or hundreds of meters downstream.

Mitigation may be provided by interrupting channelized sections with alternating sections of natural channel with vegetative canopy. This will give water quality periodic opportunity to recover and provide shaded areas of acceptable habitat for native species. These "rest stops" along the way are likely to permit migration in otherwise impassable altered reaches of streams. A simple form of mitigation that will reduce heating and improve habitat quality is addition of a narrow notch in the channel bottom to provide a narrower, deeper watercourse during low flows. The U.S. Army Corps of Engineers is currently constructing an imitation "natural" bottom in a lined channel in Iao Stream, Maui.

The effects of culverts are least well studied. All culverts replace natural substrate with artificial, while producing greatly reduced illumination and solar heating. Most are short, so that little habitat is lost, and there is no evidence from the study that short lengths of culvert at stream grade cause serious restriction to movements of native species. If the downstream end is sufficiently elevated above downstream channel level, they may represent a barrier to upmigration of post-larvae, especially the poorer "climbers" such as Eleotris sandwicensis. The survey data spot checks on communities suggest in a few cases that such negative pressure on migration may be operating, but results are not definitive. Since all Hawaiian stream species have some facility for ascending stream gradients, mitigation is feasible through modified culvert design, e.g. a sloped culvert installation rather than a high, horizontal culvert that creates an artificial waterfall at the downstream end.

Extended culverts (≥60m long and usually of concrete box form) are much less common, and their distribution has made their effects difficult to isolate from other activities in the same streams. The total lack of illumination, in situ primary productivity (most native species browse algae) and natural substrate suggest that they are unsuitable habitat. The data do not clearly indicate whether great lengths of culvert are serious barriers to migration, but the habits of the native animal species suggest that they may be.

Blocking or filling in a channel results in destruction of the stream as habitat for native aquatic animals. Whatever disposition is made of the water flow, the downstream fluvial habitat and the migratory path are destroyed, which eliminates the native fauna.

SUMMARY AND CONCLUSIONS

The 5 major islands of Hawaii contain about 366 perennial streams. A considerable amount of physical and ecological field survey information on them has been collected and catalogued in Timbol and Maciolek (1978). Six types of channel alterations have been identified, affecting 151 km of channel in 15% of the State's streams. Oahu is most heavily channelized (57% of its streams, 134 km of alterations); 43% of the altered length is concrete lined channel - the most ecologically damaging type of alteration. Fifty-three percent of State streams have some form of water diversion; only 14% are physically pristine. Only about 27% could be placed in the highest ecological quality category; none of these is on Oahu.

Natural stream temperatures ranged from 19.5 to 26.8°C. Island average pH values were from 6.2 to 7.5, conductivity from 43 to 180 µmhos. Removal of vegetative canopy by channelization produced large diel fluctuations of all these parameters, involving more extreme values. The greatest extremes were produced in lined channels where there was high radiative/conductive substrate heat exchange and shallow, uniform sheet flow. There the temperature range increased to 17.8 - 36.2°C, and elevations as great as 9.1°C above natural channel temperatures occurred. Mid-afternoon annual average pH went as high as 9.9. Deterioration in these water quality parameters was detectable hundreds of meters downstream from lined channel sections.

Upper lethal temperature of native fishes (LD_{50}) ranged from 35.6 to 39.7°C; 2 species, and both species of native decapod crustaceans, had values within the measured range of altered channel temperatures. The 2 exotic fishes tested had much higher lethal temperatures. Laboratory tests of some native fish species showed first an increased growth rate with temperature, followed by decreased growth at higher temperatures.

Of 25 macrofaunal species collected in the statewide inventory, only 8 were native. There was a trend to scarcity of native fish species and strong dominance by exotics in more developed areas of the State, and in particular, in heavily channelized streams. Some exotic species, especially certain poeciliid fishes, were abundant in concrete lined channel sections, whereas native species avoided these areas almost entirely. Two introduced decapods were prominent; the ubiquitous *Macrobrachium lar* seems to be displacing the endemic *M. grandimanus*. In general, channelization practices, particularly lined channels, seem to be contributing to the replacement of a fragile native (large endemic) stream macrofauna by useless exotic species.

Channelization results in initial high turbidity that may ultimately subside to moderate levels. The open channel forms cause undesirable (sometimes dangerous) extremes of illumination, temperature, pH and conductivity. Lined channels produce the most extreme effects of all open channel forms. All forms of channelization disturb important natural substrate habitat during construction. All culverts and lined channels result in permanent loss; with lined channels, the amount (length) of lost habitat may be significant to survival in a stream. The wide, shallow, unnatural water flow created by lined channels is especially inhospitable to native species. Culverts with the downstream end above stream grade (creating a waterfall) may interfere with upmigration of some species. Since all native species are obligately diadromous, their populatious cannot survive confined above modified channel sections. Sufficient deterioration of substrate or water quality at any one point in a channel may curtail the migration necessary for survival of the population.

It appears that channelization has had a considerable negative effect on native stream populations. Further alteration projects should be avoided where possible. Mitigation measures should include maintaining the approximate original channel length to retain natural water speed and avoid destructive erosion below channelized sections. It is especially important to maintain (replant as necessary) streamside vegetation that will provide a canopy to shade the stream. Where at all possible, the bottom should be of natural material. Where an artifically lined bottom is unavoidable, it should be used in minimum length sections alternated with natural bottom sections. A narrow notch should be built into any flat bottom lined channel to provide a narrower, deeper flow cross-section under low flow conditions. Culvert lengths should be kept to a minimum, and the downstream end should be at downstream channel grade (not elevated).

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16. Abstract (Limit: 200 words) A 3-year, statewide study was made of the occurrence and consequences of channelization in Hawaiian streams. The 366 perennial streams of the State were inventoried for the first time, and some basic information was catalogued on their physical characteristics, complete status of channel alteration, and macrofaunal communities. Fifteen percent of the State's streams have channels altered in at least 1 of 6 forms. Forty percent of the modified channel length is concrete lined-the form of alteration found to be most ecologically damaging. Field measurements showed that channel alterations commonly caused large changes in pH valuse, conductivity, dissolved oxygen and daily temperatures. The native species tested in the laboratory had less tolerance of high temperatures than exotics, and some natives had upper lethal temperature limits within the temperature range measured in channelized streams. Twenty-five species of fish and decapod crustaceans were collected statewide, of which only 8 were native. Native species were not abundant in most areas intensively surveyed; they appeared to thrive only in areas remote from development. Certain introduced species, notably poeciliid fishes were abundant in the most heavily channelized sections, whereas native species were almost entirely absent. Recommendations for mitigating the impact of channel modification are included.

17. Document Analysis a. Descriptors Ecology, Aquatic life, Aquatic populations, Biological communities, Biomass, Channel improvement, Channeling, Concrete-lined canals, Crustaceans, Distributions, Fish populations, Environmental Effects, Damages, Freshwater fish, Hawaii, Habitats, Land clearing, Riparian land, Riparian plants, Degradation (Stream), Stream, Watershed (Basins), Water Temperature, Hydrogen ion concentration, Electricl conductance

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