REPORT NO. 139

EFFECTS OF URBANIZATION ON PHYSICAL HABITAT FOR TROUT IN STREAMS

Montana University Joint
Water Resources Research Center

Date Due - next page

EFFECTS OF URBANIZATION ON PHYSICAL HABITAT FOR TROUT IN STREAMS

by

Ray J. White
Department of Biology
Montana State University
Bozeman, MT 59717

Jerry D. Wells
Montana Department of Fish, Wildlife & Parks
Bozeman, MT 59715

Mary E. Peterson
Graduate Student
Department of Biology
Montana State University
Bozeman, MT 59717

Research Project Technical Completion Report

The work upon which this report is based was supported in part by federal funds provided by the United States Department of the Interior, as authorized under the Water Research and Development Act of 1978, as amended, through annual cooperative program agreement number 14-34-0001-2128. This constitutes the final technical completion report for project A-134-MONT.

Montana Water Resources Research Center
Montana State University
Bozeman, MT 59717

October 1983

ABSTRACT

Non-urban were more favorable than urban stream sections as habitat for trout and held more trout. The major habitat difference was amount of instream solid overhead hiding cover. Urban land modifications had created unnaturally straight, narrow channels with high, unstable banks with little of the undercuts and woody debris that provide shelter for fish. Urban and non-urban sections did not differ significantly with respect to water velocity, dissolved nitrate, or amount of pools or water turbulence. Per unit stream length, non-urban sections averaged 54% more trout larger than 20 cm (8 inches) and 74% greater total trout biomass than urban sections.

In both urban and non-urban areas, trout abundance as kg/ha was generally below the level predicted by the Wyoming Habitat Quality Index (HQI). This could have been due to effects of angling or other unmeasured factors, to measurement errors or to inapplicability of the HQI method to the areas studied. There is evidence that altering the HQI method to consider solid overhead hiding cover and pool-turbulence hiding cover as separate variables rather than as a total cover index will enhance predictiveness.

Implications for urban stream fishery management are discussed.

ACKNOWLEDGEMENTS

This study was suggested in 1980 by Ron Marcoux, then MDFWP Region 3 Fishery Manager, and he participated in early stages of project planning. Chris Clancy, MDFWP District Fishery Biologist at Livingston helped set up study sites on Fleshman Creek. Assisting in construction of electrofishing gear were Daniel Gustafson and Almut White. The following particpated in electrofishing: Daniel Gustafson, Jeff Bagdanov (MDFWP), Wayne Black (MDFWP), Tom Simpson, Sven White, and Jim Hampton, the latter as a volunteer who received neither pay nor university course credit. Helping with habitat measurements were Daniel Gustafson and numerous other fellow graduate students in the Department of Biology, as well as Esther White, Sven White and Sonya White. Daniel Goodman and Andrew Dolloff advised on various aspects of data analysis.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

PROJECT SUMMARY

Trout populations and habitat were analyzed in 16 urban and 14 non-urban areas of four streams in and near Bozeman and Livingston, Montana. The non-urban stream sections had generally undergone less artificial alteration.

Non-urban stream on average held 74% greater weight (biomass) of trout per unit length of channel than did urban stream. Number of over-20-cm (over-8-inch) trout per unit channel length was 54% greater in non-urban than in urban areas.

The urban parts of streams were clearly less favorable habitat for trout in certain key respects. The most striking habitat difference detected between urban and non-urban areas was that urban stream had significantly less hiding cover for trout--hiding cover measured as amount of solid material in the water or within a few centimeters above it that could provide overhead concealment for fish. Also, in urban stream, channel width was less and amount of eroding bank greater. It was apparent that urban landfill along stream banks had created straight, narrow channel with high, unstable banks. Such channels tended to lack undercut banks that could provide shelter for trout. Within such straightened and constricted waterways, the greater forces during high water may have swept away logs and other woody debris that would have formed trout cover. Also, people may have removed debris to tidy the appearance of urban channels or to help them conduct flood water more rapidly, thereby destroying trout habitat.

Urban and non-urban stream did not differ significantly with respect to water velocity, nitrate content, or amount of cover that was in the form of pools or water-surface trubulence.

Trout abundance expressed as kilograms per hectare was generally below the level indicated as potential according to the Wyoming Habitat Quality Index (HQI) in both urban and non-urban areas. This, as well as poor coorelation betwen HQI values and measured trout abundance may have been due to various possible circumstances: (1) suppression of trout abundance by some unmeasured factor or factors, such as angling, pollution or artificial diminution of streamflow discharge, (2) inapplicability of the HQI method to the kinds of stream in the study, (3) error in estimation of habitat and/or trout population variables, or (4) inappropriateness of biomass per unit stream surface area as a measure of trout abundance.

A second type of regression analysis of association between trout abundance and habitat variables indicated that the lumping of all cover types (pool, turbulence and overhead) which is involved in the HQI method may have been a major source of poor predictiveness. Multiple correlation was far higher when overhead cover and pool-and-turbulence cover were treated as separate variables. This analysis indicated that 71% of variation in number of over-20-cm trout/km was attributable to the combined variation in the following habitat factors in this order of importance: (1) mean water velocity in stream reach, (2) ratio of late summer streamflow discharge to mean annual discharge, (3) amount of solid overhead cover, (4) maximum summer water temperature, and (5) amount of aquatic vegetation in the stream.

Trout abundance in some of the relatively unaltered parts of Bozeman Creek compared favorably with that in the more densely populated small trout streams of the same geographic area.

The results suggest that trout abundance can be maintained in streams flowing through areas under urban development if the natural form and vegetation of the stream banks and stream bed are not altered in the ways commonly associated with urbanization. If urban changes in land form are kept well away from the immediate riparian area, the natural channel shape and its natural accumulations of living and dead vegetation will furnish cover for substantial populations of trout. It is especially important not to straighten channels, not to remove certain kinds of bank vegetation (such as high grass and low brush), and not to conduct excessive removal of downed logs and other woody debris from stream channels.

Much could be done to increase trout abundance in physically damaged urban streams by restoring channel form and vegetation to resemble the natural situation. Even in parts of streams that remain unaltered, habitat may often be enhanced and trout populations increased by creating more instream cover for trout than presently exists.

INTRODUCTION

Expanding urbanization and its effects of unfavorably reshaping the channels of urban streams is a serious fisheries problem that has long seemed obvious to biologists but may not be as apparent to others. Urban stream alterations typically regarded as detrimental to fish habitat include channel straightening and other unnatural relocation; excessive stream widening or channel constriction through landfill, bridges and culverts; impoundments; elimination of pools, riffles and biologically productive side channels; removal of instream cover used by fish; and construction of unnatural structures such as bulkheads, walls and certain kinds of deflectors in and along streams. This situation has not been thoroughly studied in quantitative terms, in large part perhaps because it has seemed so blatantly obvious to specialists. Yet, when it comes to making policy decisions on urban development along streams, quantitative data are needed.

Determining components of fish habitat that are adversely affected by practices similar to these, although not necessarily classifiable as urban, has been addressed in several studied. Whitney and Bailey (1959) and Elser (1967) both found that channel alterations involved in highway construction caused significant decrease in the salmonid carrying capacity of two Montana streams. In particular, Elser determined the amount of cover per unit area of stream to be substantially less and the occurrence of areas with more shallow, fast reaches greater in altered stream sections. In a stream-straightening project in Rocky Creek, Gallatin County, Montana, changes in channel morphometry and loss of in-stream and bank cover were responsible for reduced trout abundance (Wells 1977). Still other studies have found trout populations to be limited by quality of physical habitat (Boussu 1954, Kalleberg 1958, Lewis 1969, and Newman 1956).

Our study was intended to evaluate habitat quality by comparing measurements of various habitat attributes between urbanized and non-urbanized sections of stream and analysing them for correlation with abundance of trout. While it is almost impossible to locate pristine, unaltered streams in and near urban areas, one can probably make adequate analyses by comparing altered and "less altered" parts of streams in and near towns within generally urbanized areas.

In urban creeks of the Bozeman area in Montana, stream problems have been studied from water quality/pollutional standpoints (Anderson 1977; Blue Ribbons of the Big Sky Country APO 1979). The emphases of these studies were on sediment pollution and on pollutants hazardous to human health. The urban reaches of streams were not analysed with respect to physical suitability as habitat for fish.

The hypotheses selected for this study were (1) that key habitat characteristics are less favorable to trout in altered than in less-altered parts of urban-area streams and that (2) trout are less abundant in the more altered parts of urban-area streams.

DESCRIPTION OF STUDY AREAS

Thirty channel reaches (stations) totalling 3,772 meters of stream were analysed for trout habitat attributes and trout abundance in four creeks that have undergone varying degrees of artificial alteration in the course of urbanization (Table 1). Three of the streams flow through the city of Bozeman (Fig. 1)

Table 1. Number of study stations, total length of stream studied, and trout species present in the study streams.

Stream	Number of study station	Total length (m)	Trout: Species	Trout: Prevalence
Bozeman Cr.	18	2,064	rainbow	numerous
			brook	numerous
			brown	few
Mathew Bird Cr.	7	739	rainbow	numerous
			brook	numerous
Figgins Cr.	2	379	brook	numerous
Fleshman Cr.	3	590	brown	numerous
			brook	few
			rainbow	few
Total	30	3,772	-	-

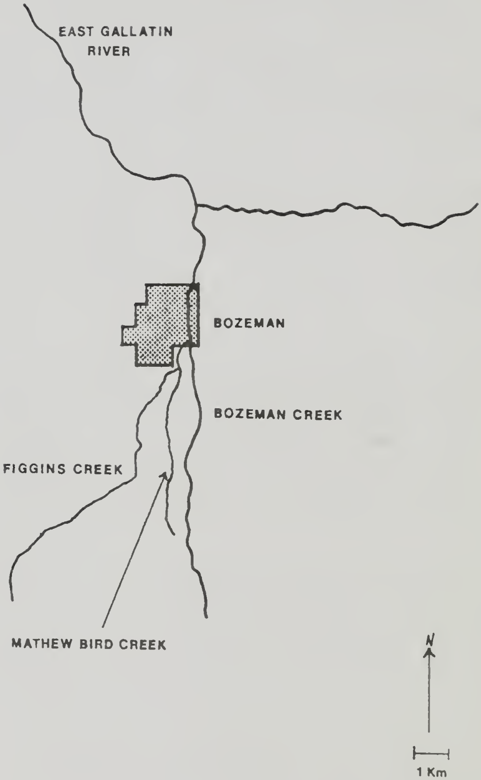

Figure 1. Streams in the vicinity of Bozeman, Montana.

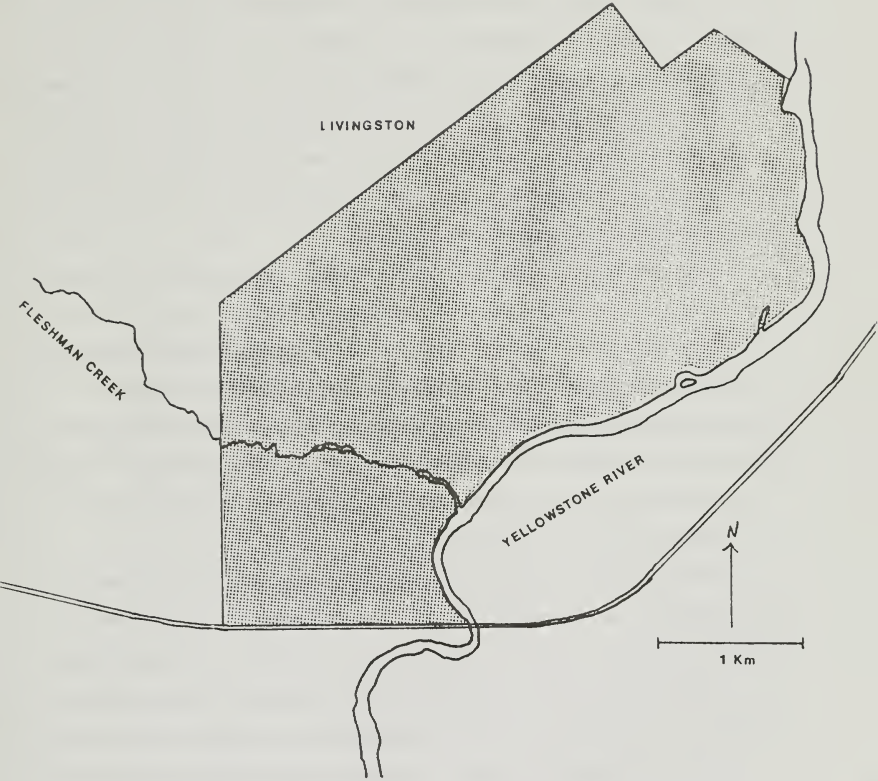

Figure 2. Fleshman Creek and Livingston, Montana.

in Gallatin County: Bozeman Creek (18 stations of ca. 100-200 m each, distributed over 6.4 km of stream), Mathew Bird Creek (7 stations) and Figgins Creek (2 stations). One stream, Fleshman Creek (3 stations) flows through the city of Livingston (Fig. 2) in Park County. Details of station locations are in Appendix I

Urban stations did not include the most drastically altered parts of some streams--those parts that had been completely enclosed in culvert for one or more city blocks. It would have been too dangerous to electrofish and perhaps also to do other sampling in these sections.

Study station lengths ranged from 89 to 201 m, except for one that was 300 m long. Seventy-two per cent of stations were between 90 and 100 m long.

Bozeman (Sourdough) Creek originates at the outlet of Mystic Reservoir (elevation 1950 m) in the north end of the Gallatin Range in southwestern Montana and flows northwest for 26.6 km, dropping 510 m (19.2 m/km) to its mouth (elevation 1440 m) at the East Gallatin River below Bozeman. The Bozeman Creek drainage basin covers about 168 km^2. Average annual precipitation for the basin is 61 cm (24 inches).

Mathew Bird Creek (Spring Creek on the Bozeman topographic quadrangle of 1953) is tributary to Bozeman Creek at about stream km 3.5 at elevation 1475 m. Elevation of the source is 1585 m. Stream length is about 3.3 km.

Figgins Creek (Middle Creek Ditch), enters Mathew Bird Creek at stream kilometer 1.6. It originates from Hyalite Creek in T3S,R8E,Sec. 3.

Fleshman Creek heads in eastern foothills of the Bridger Range in Park County and flows southeast for 14.8 km before discharging into the Yellowstone River in the city of Livingston. Its elevations at origin and mouth are 1707 m and 1372 m, respectively. The average annual precipitation for the Fleshman Creek drainage basin is 40.6 cm (16 inches).

Large parts of these four streams are bordered by agricultural, industrial and municipal lands. Land uses include ranching, small grain production, small industry, and urban development--and in the headwaters of Bozeman and Fleshman Creeks, forest uses. A shift from agricultural to urban-municipal use is rapidly occurring in many parts of the bordering lands, with increase in artificial alterations of stream channels and banks.

The range of approximate annual mean discharges over all study sites was 0.04 m^3/sec to 1.46 m^3/sec. Average critical period discharge (late summer flow from August 1 to September 15) ranged from 0.034 m^3/sec to 0.80 m^3/sec.

METHODS

Selection of Study Stations

Potential study streams were suggested by fishery biologists of the Montana Department of Fish, Wildlife and Parks. Identification of deliberate stream course relocations done in recent decades was accomplished by inspection of aerial photos (scale: 12 inches/mile) taken in 1937, 1954 and 1977.

Each stream was divided into reference-station reaches by measuring and marking of 100-m reaches contiguously from the mouth upstream for several kilometers including both urban and non-urban areas, but with some gaps in the system of stations, owing to access problems. Within each stream, the stations were classified as being either urban (definitely within an urban-impacted area) or control (non-urban--although perhaps "suburban" in some cases--and relatively less impacted by artificial alteration). Within each category, a sample of stations was selected for study.

On Bozeman Creek, many of these stations were contiguous in groups of two or three. For some analyses, contiguous stations were treated as combined areas, called "sections," with the data lumped within sections.

Estimates of Trout Population and Biomass

Between August 1 and September 8, 1982, electrofishing for mark-recapture estimates of trout populations was done in each of the 30 stations selected for study. The electrofishing unit consisted of a 240-volt, 3500-watt alternator and Coffelt control box (150 to 600 volts DC) mounted in a canoe and towed upstream by a crew using two positive electrodes ahead of the unit, a negative electrode trailing in the water behind the canoe--except in very shallow stations, where long-line gear was used instead of the canoe-mounted unit. Collected fish were anesthetized in MS-222 (Tricane Methanesulfonate), weighed to the nearest 2 grams, and measured to the nearest 1 mm in length. The lower caudal fin was clipped; when two 300-meter sections were contingous, the upper caudal fin of the upstream section trout was clipped. Fish were carried in large frame nets downstream to the bottom of the station from which they had been caught and released. Two weeks were allowed between the marking and recapture runs.

The population estimate for each station (and 3-station section) was calculated by the modified Petersen mark-recapture formula of Ricker (1975). Fish were grouped into 20-mm size classes, 100 to 119 mm being the smallest. Where numbers were too low to calculate a reliable pouplation estimate for each species within a station, data were lumped either by species or by combining several stations, and the estimates calculated then reapportioned according to total of fish marked on first run plus the unmarked (new) fish caught on the second run.

Biomass was calculated by multiplying length-group estimates of trout numbers by mean weight for the group. Mean weight of length group was determined from length-weight regression equations for each species in each station. Standing crop in kilograms and numerical density of over-20-cm trout were calculated on per-hectare and per-stream-kilometer bases.

The 95% confidence intervals (Ricker, 1975: 81) for the estimates of numbers of trout over 20 cm were also calculated for each station and section and converted to density.

Habitat Measurements

Stream habitat attributes were measured during the low flow period of September 1982 to March 1983, following the prcedures described by Binns (1979, 1982) for the Wyoming Habitat Quality Index. Habitat variables measured or evaluated were maximum summer water temperature, stream discharge, channel width, percent of eroding banks, length of thalweg, mid-channel length, amount of submerged aquatic vegetation (substrate), nitrate nitrogen level, mean water velocity through station, and percent cover. The cover designation included any of the following features that occurred in water at least 15 cm deep: undercut banks, instream and closely overhanging terrestrial vegetation, instream debris (brush, logs and "snags"), pockets of surface turbulence, and pools. Pools were identified as abrupt increases in water depth. The length and width of these cover features were measured, summed and converted to per cent of total stream surface area in the station. Subsequently, the categories of pool and surface turbulence pockets were, for more detailed analyses, separated from the other cover types--which could be categorized as "solid overhead cover."

Mean water velocity through station was measured by timing an injection of rhodamine dye (Binns 1982).

Nitrate nitrogen levels were measured by the ultraviolet spectrophotometric method as described in Standard Methods for Examination of Water and Wastewater

(1976).

Annual stream flow variation was determined by the use of past discharge records and estimates from governmental agencies. Late summer streamflow discharge for each stream was measured with a gurley "pigmy" flow meter. Stream discharge gauging records were available only for Bozeman Creek. The USDA Soil Conservation Service operated a gauge at stream kilometer 5.6 in 1977 and 1978.

Data Analysis

The mean values of urban- and control-section data on habitat and trout population variables were compared. The data were examined for significant differences via the non-parametric Mann-Whitney U test.

Data on habitat variables were entered into the Wyoming Habitat Quality Index Model II (Binns 1979). The resultant predictions of trout abundance in kilograms per hectare were compared with the actual measurements of trout abundance.

The relationship of trout abundance to habitat variables was further analysed by multiple-regression modelling. The logarithms (base 10) of habitat data were entered as independent variables. The logarithms of four expressions of trout abundance (number of over-20-cm trout per stream kilometer and per hectare and kilograms of all trout per stream kilometer and per hectare) were entered separately as dependent variables. In the step-wise procedure, the F-value set for exclusion of independent variables from the model was 1.0.

RESULTS AND DISCUSSION

Comparisons between Urban and Control Areas

The most striking difference detected between urban and control areas of the streams was in terms of amount of solid overhead concealment cover for trout--cover submerged in the stream or within a few centimeters above the water surface. Averaged over all 30 study stations, control areas had 60% more such cover than did urban areas--8.33% vs 5.22%, a difference significant at the 97.5% confidence level (Table 2). For Bozeman Creek alone, the difference was even more pronounced. Urban areas contained especially low amounts of cover, slightly less than 1%, and the control areas did not have particularly high amounts, 5.3%, but this was a several-fold difference or 485% more in control areas, a difference significant at the 99.8% level.

It can be inferred that reduction of instream concealment cover is a major impact of urbanization along trout streams of the types included in our study. Wells (1977) also found that cover reduction was strongly associated with channel straightening in another stream near Bozeman, although that was not a consequence of urbanization.

The only other measured habitat variables having significant urban-vs-control differences at the 90% confidence level or higher were channel width, which was narrower in urban areas (96.3% confidence level), and amount of eroding bank--34% in urban areas vs 23% in control areas, a difference of 48% relative to the control figure and significant at the 90% confidence level (Table 2).

Part of the difference in channel width could be an artifact of the longitudinal distribution of study stations within the stream systems. This possible effect has not yet been analysed. However, we suspect that encroachment on the channel by land fill involved in urban development may have been a major influence in narrowing the urban stream sections.

The higher degree of bank erosion in urban areas may represent decreased

Table 2. Unweighted mean values for habitat and trout population variables in urban (U) and control (C) stations of study streams. Values of p are from Mann-Whitney U tests.

Variable	Station type	Bozeman Creek (n=9U,9C)	Mathew Bird Creek (n=4U,3C)	Figgins Creek (n=1U,1C)	Fleshman Creek (n=2U,1C)	All stations (n=16U,14C)
		Habitat Variables				
Channel width (m)	U	4.84	2.31	1.40	2.15	3.65
	C	7.01	2.34	1.58	1.73	5.24
		(p<.001)	(ns)			(p=.047)
Solid over-head cover (%)	U	0.91	9.24	30.42	3.94	5.22
		5.32	17.53	13.33	2.84	8.33
		(p<.002)	(ns)			(p=.025)
Pool, turbu-lence cover(%)	U	7.13	8.52	0.50	7.38	7.09
	C	4.78	7.21	5.47	6.38	5.46
		(ns)	(ns)			(p=.377)
Eroding banks (%)	U	32.85	24.01	12.65	70.3	33.8
	C	19.07	1.95	9.00	126.0	22.6
		(ns)	(ns)			(p=.101)
Water velocity (cm/sec)	U	79.5	43.5	12.2	32.6	60.4
	C	77.2	22.9	12.2	26.0	57.3
		(ns)	(p<.02)			(p=.790)
NO_3-N (mg/l)	U	0.420	0.612	0.325	0.414	0.393
	C	0.371	0.338	0.338	0.429	0.431
		(ns)				(p=.822)
		Trout Variables				
Number of Trout 20 cm and Larger						
Per stream km	U	323	188	64	87	244
	C	523	79	241	83	376
		(p<.02)	(ns)			(p=.154)
Per stream ha	U	673	827	456	421	666
	C	754	346	1524	483	702
		(ns)	(ns)			(p=.984)
Kilograms of All Trout						
Per stream km	U	56.9	35.4	15.3	20.1	44.3
	C	104.1	24.7	51.0	18.6	77.2
		(p<.01)	(ns)			(p=.052)
Per stream ha	U	118.5	155.1	109.5	93.1	123.9
	C	152.4	107.5	322.9	107.5	151.8
		(ns)	(ns)			(p=.355)

channel stability, a hydraulic response of the streams to construction of unnaturally straight and narrow channels with high, steep and constricting banks. There had apparently also been some past artificial channel straightenings in some of the control stations. Had that not been the case, perhaps the difference in amounts of bank erosion between urban and control areas would have been even greater.

Most of the erosion was at high elevation on banks, apparently coinciding with spring flood stage. Urban station 4 on Mathew Bird Creek, while having only 9.76% erosion of banks, showed obvious potential for erosion due to urban development. With construction of condominiums occurring within 30 meters or less of the stream, all of the riparian willows and high grasses had been removed. Where natural deeply undercut bank cover had been formed by the stream action, major portions of it were beginning to slump into the stream, leaving bare soil exposed. Fleshman Creek's stations (including the control station which had apparently been ditched some years ago) had the highest average percent of eroding banks (88.89%). We do not believe eroding stream margins to be of direct detriment to trout in the immediate vicinity of the erosion but suspect they may be indicative of unfavorable action of currents at high flow in unnatural channel configurations, and there may often be damage to downstream areas via siltation of spawning and food-producing stream bed.

The urban areas had somewhat greater measured amounts of stream area in pools or having the water surface broken by turbulence that might provide concealment cover for fish. However the urban-vs-control differences in this variable were not statistically significant at the 95% level of confidence. There was even less difference in the water velocity and nitrate-nitrogen variables.

Trout abundance was higher overall in control stations than in urban stations with respect to all four expressions of abundance that were calculated (Table 2). Trout abundances expressed per unit of stream length showed much greater statistical significance of urban-vs-control differences than did per-unit-area expressions. In terms of kilograms per stream kilometer, control areas had 74% more trout than urban areas did, a difference significant at the 97.5% confidence level. In Bozeman Creek, the control sections averaged 83% more kg of trout per km, a difference significant at the 99% level. The urban-vs-control differences in terms of number of over-20-cm (over-8-inch) trout per kilometer were significant at the 85% level overall and at the 98% level for Bozeman Creek, which had the majority of stations.

It can be concluded that the results are consistent with the hypotheses of this study: (1) that key habitat variables are less favorable for trout in altered (urban) than in less altered stream sections, and (2) that trout are less abundant in the more altered sections. The following sections of this report further support these conclusions and provide some information toward identifying possible causative processes.

Application of the Wyoming HQI

Application of the Wyoming Habitat Quality Index Model II (Binns 1979) to the data from all 30 study stations yielded poor correlation (r = 0.228) between predicted and actual standing crops of trout expressed as kg/ha (Table 3, Figure 3), however it appears that if data from study sections (combinations of contiguous stations) were plotted instead of stations, variability would be reduced and the fit would be somewhat tighter. (This analysis remains to be done.) It would still be the case, however, that in the great majority of cases, predicted values fall below the actual values of standing crop.

Table 3. Comparison of trout standing crop predictions by the Wyoming HQI method (Model II) against measured values.

Station	Type*	Standing Crop of Trout (kg/ha) Predicted	Measured
		Bozmean Creek	
7	C	284	141
8	C	150	91.4
9	C	253	175
13	C	229	306
14	C	237	117
15	C	229	119
19	U	26.2	83.2
20	U	253	181
21	U	179	81
22	U	148	123
23	U	148	216
24	U	226	125
26	U	116	97.1
27	U	148	93.9
28	U	148	73.0
36	C	148	227
60	C	214	96.7
61	C	296	100
		Mathew Bird Creek	
1	U	307	160
2	U	181	179
3	U	285	148
4	U	148	133
5	C	265	34.2
6	C	265	161
7	C	297	127
		Figgins Creek	
1	U	259	109
2	C	223	323
		Fleshman Creek	
1	U	61.2	96.2
2	U	61.2	90.0
3	C	61.2	108

* U = urban, C = control

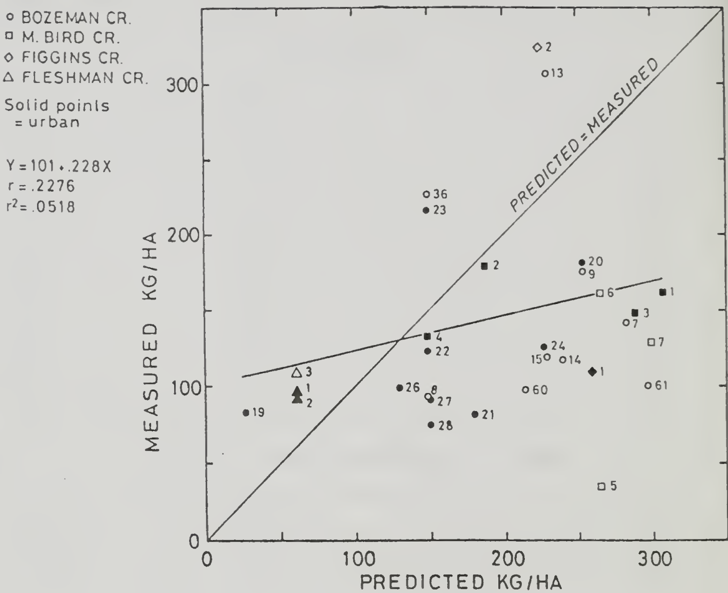

Figure 3. Relationship of standing crops of trout as measured in the study stations and as predicted by the Wyoming Habitat Quality Index Model II.

This could be interpreted in several ways. The HQI model may not be applicable to the trout/habitat relationships in the kinds of streams included in our study. The poor fit of the data might also be due to deficient accuracy or precision in our measurement of some habitat variables or of standing crop of trout. Some of the habitat measurements called for in the HQI method seem more subjective than would be desirable (e.g., vegetative substrate) or anotherwise difficult to accurately determine (e.g. annual streamflow variation), but this may be compensated for at least partially by the transformation of measurements to class ratings involved in the procedure (Binus 1979).

Comparison of the results of the HQI method against results of the multiple-regression analysis in the following section of the report would seem to indicate that much of the unpredictiveness of the HQI in our streams lay in the procedure of combining all forms of cover, i.e., failure to distinguish between pool-and-turbulence cover and solid overhead cover. Comparison of the predictiveness of the HQI method in our streams against the better predictiveness of the multiple-regression analyses desribed below may also point to an inappropriateness of using biomass per unit of stream surface area as an expression of trout abundance.

It is far more important to consider the possible inference from the lower-than-predicted distribution of actual trout abundances that some <u>unmeasured</u> influence is preventing trout in these streams form being as abundant as the HQI predicts they should be, i.e., as the physical habitat would allow. Actual abundance is lower than HQI-predicted abundance particularly in the stations with highest predicted values, i.e., highest habitat rating (Fig. 3). Candidate variables for such abundance-depressing effect would be water pollution and intense angling harvest. Neither were measured in this study, however, urban water pollution problems were revealed in a previous study on Bozeman Creek (Blue

Ribbons of the Big Sky Country APO 1979).

It could also be that streamflow variability was not adequately estimated. The summer low flow may often be less due to irrigation withdrawal than it was when measured in 1982, a fairly wet summer. Also, there may be withdrawals for municipal water supply, making winter low flow severe in the Bozeman Creek system. This was not analysed in our study.

Insufficient reproduction of trout could be another factor preventing standing crop from reaching the potential indicated by the HQI. Although age-structure analyses of the trout populations have not yet been done, the size structures of the Bozeman Creek rainbow trout population, the main fish in that stream, appear to indicate fewer fish of age I and II than of age III or IV. This is the reverse of the situation that must exist in a population being replenished by local reproduction. It is likely that the rainbow trout population of our study area on Bozeman Creek consists largely of immigrants from upstream or from the East Gallatin River, downstream. The combination of immigration, body growth and whatever reproduction exists within the study may not be creating enough biomass to saturate the habitat. If low reproductive rate is also an influence for brook trout in Bozeman Creek and in the other study streams (it is the predominant fish in the other streams), it is not as strongly the case. Size distributions of brook trout in most study stations indicate that a more normal age structure probably exists.

Multiple-regression Modelling of Trout and Habitat Relationships

When logarithms of the habitat variables involved in the HQI (but not transformed to class ratings) were entered as independent variables into stepwise multiple regression against logarithms of each of the four trout abundance expressions used separately as dependent variables, stronger correlations resulted than in the

HQI model. Further, when the HQI cover variable was separated into a solid-overhead-cover component and a pool-and-turbulence-cover component and these new components entered as independent variables along with the rest, much stronger correlation yet was obtained.

In a set of stepwise multiple regressions involving (1) all 30 study stations, (2) control stations only, and (3) urban stations only, mean channel width was the first variable entered, based on its high initial influence relative to that of other independent variables. However, as other variables were entered, mean width rapidly lost significance, its F-value falling below the predetermined rejection level of 1.0. It is inferred that channel width was meaningless in describing the effect of habitat on trout abundance. Another stepwise multiple regression was run with the channel-width variable omitted, and the correlation improved (Table 4).

Number of over-20-cm trout/km was consistently the dependent variable having tighest correlation (Table 4). We infer that the habitat variables are related to trout abundance in a linear, rather than areal fashion. Trout abundance per unit stream surface area is likely to be poorly correlated with habitat quality because trout orient strongly to instream cover (Hunt 1971, Wesche 1976, Devore and White 1978, Enk 1977) which tends to be concentrated along channel margins, hence is a rather linear variable.

With the channel-width variable omitted from multiple regression, the dependent trout abundance variable most highly correlated with habitat variables was still the number of over-20-cm trout/km (Table 4). For the model involving all 30 stations, the adjusted r^2 values* indicated that variation in habitat

---

*Adjusted $r^2 = r^2 - [(K-1)/(N-k)][1-r^2]$, where K = number of independent variables and N = number of cases.

Table 4. Adjusted r squares from stepwise multiple regression of four estimates of logs of trout abundance against logs of habitat variables, before and after mean width was removed as an independent variable.

		Mean Width Included				Mean Width Removed			
		Number of trout ≥ 200 mm		Kg of all trout		Number of trout ≥ 200 mm		Kg of all trout	
Stations included	N	per/ha	per/km	per/ha	per/km	per/ha	per/km	per/ha	per/km
ALL	30	.26419	.70280	.08297	.63579	.26419	.71321	.08370	.63981
CONTROL	14	.59689	.83535	.51918	.76876	.57821	.85665	.46961	.78018
URBAN	16	.59832	.84021	.48567	.81690	.70769	.89810	.45491	.80846

variables accounted for 71% of variation in number of trout/km. The habitat variables in that model were water velocity, late summer flow/mean flow, solid overhead cover, max summer water temperature, and vegetative substrate ratings (Appendix III).

For the multiple regression models involving urban or control stations only, the r^2 values were even higher and the solid-overhead-cover variable dropped out (Appendix III), as it had been the most significantly differing variable between the urban and control categories of stream (Table 2). Percent pool-and-turbulence cover and percent eroding banks entered only into the urban model. Water velocity was the first variable to enter into all three models (Appendix III) after channel width was omitted.

Other Observations on Fish Populations

The species of fish collected in the study sites were rainbow trout (*Salmo gairdneri*), brook trout (*Salvelinus fontinalis*), brown trout (*Salmo trutta*), longnose sucker (*Catostomus catostomus*), white sucker (*Catostomus commersoni*), mountain sucker (*Catostomus platyrhynchus*), and mottled sculpin (*Cottus bairdi*).

Standing crop per unit stream area ranged from 34 kg/ha in station 5 of Mathew Bird Creek to a high of 305 kg/ha in station 13 of Bozeman Creek. In terms of numbers of over-20-cm trout per kilometer, abundance ranged from 30 to 611 in the same stations (Table 5). Grouping of the stations into longer stream sections reduced the confidence intervals of trout population estimates (Table 6), enabling clearer indication of relationships between different parts of the stream in Bozeman Creek (Figures 4 and 5).

In Bozeman Creek, number/km for station 36, a control station of greater-than-average length and lying just below a mink farm where mink feed and manure are reportedly introduced into the stream, was significantly higher than in

Table 5. Estimated number of over-20-cm trout/km for individual stations.

Stream	Stations	Urban or Control	Number trout over 200 mm per km	95% Confidence Interval
Bozeman Creek	7	C	644	469 - 1030
	8	C	457	283 - 914
	9	C	533	371 - 857
	13	C	611	506 - 802
	14	C	412	266 - 714
	15	C	542	374 - 869
	19	U	209	146 - 428
	20	U	499	297 - 940
	21	U	386	193 - 914
	22	U	272	212 - 363
	23	U	549	435 - 795
	24	U	240	200 - 400
	26	U	319	150 - 798
	27	U	296	245 - 459
	28	U	135	127 - 195
	36	C	882	729 - 1128
	60	C	326	289 - 400
	61	C	299	269 - 359
Mathew Bird Creek	1	U	253	*
	2	U	167	130 - 315
	3	U	179	*
	4	U	155	141 - 247
	5	C	30	*
	6	C	121	111 - 192
	7	C	87	*
Figgins Creek	1	U	64	43 - 133
	2	C	241	204 - 320
Fleshman Creek	1	U	70	*
	2	U	105	98 - 173
	3	C	83	63 - 136

* Not available

Table 6. Numbers of over-20-cm trout/km for grouped stations (sections).

Stream	Stations	Urban or Control	Number trout over 200 mm per km	95% Confidence Interval
Bozeman Creek	7 - 9	C	579	452 - 757
	13 - 15	C	511	433 - 726
	19 - 21	U	355	251 - 570
	22 - 24	U	351	305 - 442
	26 - 28	U	218	190 - 294
	36	C	883	729 - 1128
	60 - 61	C	311	284 - 352
Mathew Bird Creek	1 - 3	U	183	143 - 287
	4	U	155	141 - 247
	5 - 7	C	79	76 - 96
Figgins Creek	1	U	64	43 - 133
	2	C	241	204 - 320
Fleshman Creek	1	U	70	Numbers to low to compute CI
	2	U	105	98 - 173
	3	C	83	63 - 136

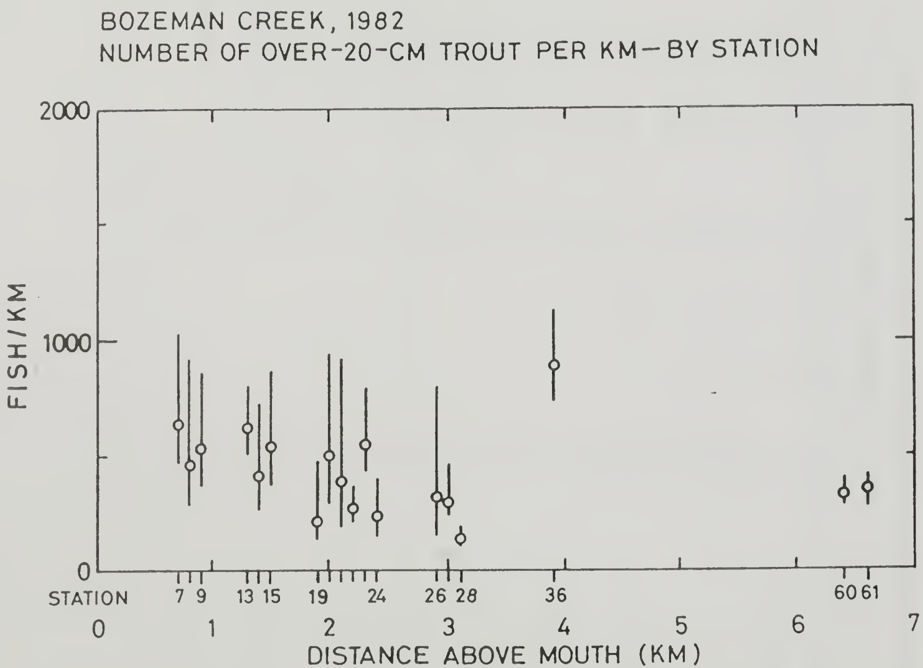

Figure 4. Numerical density of over-20-cm trout in study stations of Bozeman Creek, August 1982. Error bars shown are at 95% level.

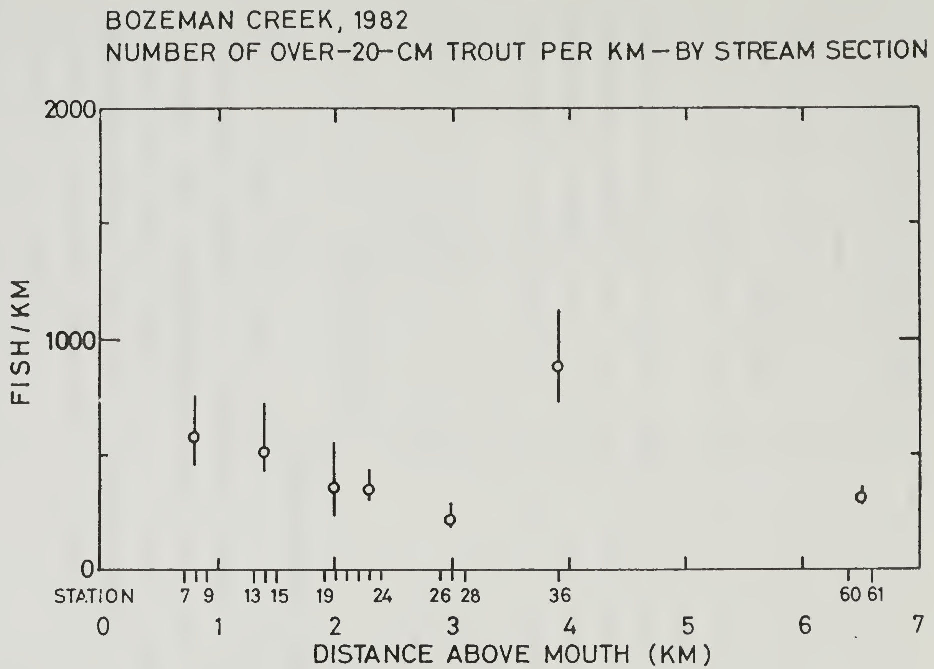

Figure 5. Numerical density of over-20-cm trout in study sections (stations grouped) in Bozeman Creek, August 1982. Error bars shown are at 95% level.

any of the grouped-station sections except section 7-9, which itself had significantly greater trout abundance than several of the other sections (Figure 5).

The relative abundance of rainbow trout by number decreased in the upstream direction, from about 80% of the trout population in the lowermost section to about 49% in the uppermost section (Table 7). Brook trout rose in relative abundance further upstream, their highest proportion being 51.4% of the trout population in section 60-61.

Few brown trout were captured in Bozeman Creek. Station 60 yielded the most--four with total weight of 0.673 kg. Station 9 had the largest-sized brown trout--three for a total weight of 1.374 kg. Mountain, longnose, and white suckers were collected as a large proportion of the fish populations in stations 7 through 14 and 21 through 24.

Brown trout was the principal species collected in the urban sections of Fleshman Creek. Other species captured in urban stations were rainbow and brook trout. Brook trout (population data from Clancey and Gould 1982) was the only species collected in the Fleshman Creek control station.

Comparisons with Other Streams

Trout abundance varies greatly throughout small streams of the Gallatin, Madison, and Jefferson River drainages. There are 34 population estimates available on 31 rather scattered stream sections with lengths of about 130 to 380 m on 17 creeks (Table 8). Trout biomass per unit length of stream averaged 66 kg/km and ranged from 8.9 to 222 kg/km, with 50% of cases lying between 27 and 87 kg/km. With those sections omitted which are known to have been physically altered by artificial means (straightening or bank landfill, urban and otherwise), the mean of the 20 more natural remaining cases was 77.5 kg/km, and 50% of the cases lay between 42 and 112 kg/km.

Table 7. Species composition of the trout pouplations in streams of the Bozeman Creek system, August 1982.

Section	Rainbow trout	Brook trout	Total
	Bozeman Creek		
7 - 9	200 78.7%	54 21.3%	254
13 - 15	170 78.7%	46 21.3%	216
19 - 21	121 86 %	20 14 %	141
22 - 24	137 79.7%	35 20.3%	172
26 - 28	62 61.4%	39 38.6%	101
36	88 64.7%	48 35.3%	136
60	35 32 %	47 68 %	82
61	68 52.3%	62 47.7%	130
60 - 61	103 48.6%	109 51.4%	212
	Mathew Bird Creek		
1 - 3	30 39 %	47 61 %	77
4	0 0 %	43 100 %	43
5 - 7	4 13.8%	25 86.2%	29
	Figgins Creek		
1	0	26	26
2	0	70	70

Table 8. Trout abundance and stream characteristics in various small streams of the Gallatin, Madison, and Jefferson River drainages, southwestern Montana.

Stream	Alteration*	Mean discharge at mouth (m^3/sec)	Drainage area (km^2)	Yield (liters per sec per km^2)	Mean bed slope (m/km)	Station lth (m)	Distance above mouth (km)	Trout standing crop (kg/km)	Data Sourc
Bozeman Cr.		1.02	168	6.1	19				
MDFWP sta					24	305	13.7	41.7	1
Sta 60-61					10	363	6.5	60.4	2
Sta 36					10	130	3.9	155.0	2
Sta 26-28	U				10	316	3.0	42.6	2
Sta 22-24	U				10	305	2.3	75.0	2
Sta 19-21	U				10	298	2.0	53.8	2
Sta 13-15	S				10	321	1.4	113.2	2
Sta 7-9					10	330	0.8	108.9	2
Mathew Bird Cr.		0.09**	?	?	33				
Sta 1-3	U					300	0.6	35.4	2
Sta 4	U					142	1.5	35.7	2
Sta 5-7	?					302	3.0	24.7	2
Figgins Cr.		0.001**	?	?	13.5				
Sta 1	U					188	0.2	15.3	2
Sta 2						191	0.5	51.0	2
Fleshman Cr.		0.07**	?	?	23				
Sta 1	U					157	ca 1	23.0	2
Sta 2	U					133	ca 2	17.3	2
Sta 3	S?					300	ca 3	18.6	3
Hell Roaring Cr.		1.27	78	16.3	65	305	ca 1	26.8	1
Hyalite Cr.		1.97	306	6.4	29	305	ca 50	111.6	1
Porcupine Cr.		0.69-0.86	78	9-11	51	305	ca 1	8.9	1
S. Cottonwood Cr.		1.01	109	9.3	41	305	ca 14	163.7	1
S. Fk. Spanish Cr.		?	105	?	60	305	ca 12	26.8	1
Squaw Cr.		1.37	142	9.6	53	305	ca 4	66.9	1
Taylor Fork		2.77-3.01	277	10-11	27	305	ca 0.5	61.0	1
W. Fk. Gallatin R.		1.95	202	9.6	23	305	ca 1	26.8	1
Rocky Cr.		1.01	225	4.5	9.5				
Sect A						282	4.8	193-222	4
Sect B	S					381	1.6	25-87	4
Sect C	S					305	0.8	72-82	4
South Boulder R.		1.45	246	5.9	28	305	?	59.5	1
Whitetail Cr.		0.62	482	1.3	22	305	?	159.1	1
Jack Cr.		1.00	166	6.0	36	305	?	47.6	1
N. Meadow Cr.		1.02	137	7.4	39	305	?	35.7	1

*U = urban, S = straightened
**Summer low discharge

Data sources: 1 = MDFWP 1981; 2 = This study; 3 = Clancy & Gould 1982; 4 = Wells 1977

Within a single stream, Rocky Creek near Bozeman, there was variation from 25 kg/km in a straightened section in springtime to 222 kg/km in an unaltered section in autumn. In Bozeman Creek, where we have data from 8 sections (encompassing 18 shortered stations), trout abundance ranged from 42 kg/km in one urban section and in one natural section far upstream to 155 kg/km in a relatively unaltered section (station 36) which, however, may have been influenced by nutrients from a mink farm.

Trout biomass abundance of natural stream sections was inversely related to channel steepness (Table 8, Figure 6). From the plot of trout abundance against channel gradient in Figure 6, it is evident that urban or straightened sections held less trout than natural stream sections of equivalent gradient. The estimates of stream gradient must be regarded as rather rough. Within the apparent gradient-trout relationship, sections of Bozeman Creek having highest abundance of trout compared favorably with abundances in other streams that had natural channels.

Further Analysis Planned

Further refinement and augmentation of various aspects of the data analysis in this study are warranted. Confidence limits on estimates of biomass remain to be calculated, as well as improvements in computations involving grouped data for contiguous stations (stream sections). HQI analysis and multiple-correlation analysis of data from the 30 stations should be repeated using stream section data instead. Comparisons of means should be further analysed with weighting of data according to stream station or section length.

Most aspects of trout population size structure and age-growth analyses remain to be performed. Scale samples were taken from most fish captured

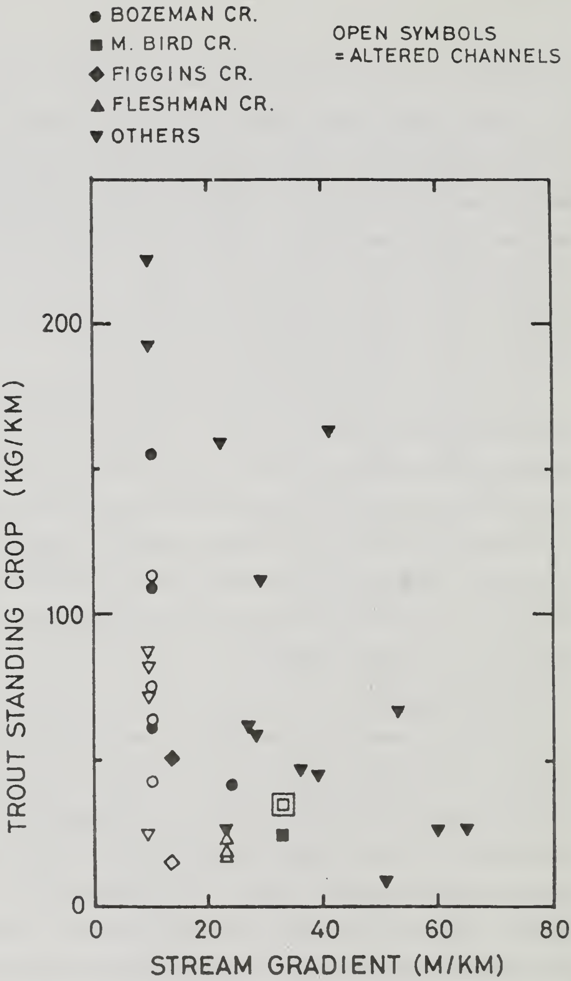

Figure 6. Relationship of standing crops of trout to stream gradient in creeks of the Gallatin, Madison and Jefferson River drainages in southwestern Montana (data from Table 8).

during electrofishing, but these have not yet been mounted and read.

It is expected that the further analyses will result primarily in augmentation of present information, not in revision of the primary conclusions.

REFERENCES CITED

Anderson, W. C. 1977. Inventory of sediment pollution on private lands in the Blue Ribbons of the Big Sky Country APO. US Soil Conservation Service, Bozeman, Montana. 28 p.

APHA. 1976. Standard methods for examination of water and waste-water. 14th ed. Method 419A, Ultraviolet Spectropholometric Method, p. 42.

Binns, N. A. 1979. A habitat quality index for Wyoming, trout streams. Wyoming Game and Fish Department. Monograph Series 2. 75 p.

Binns, N. A. 1982. Habitat quality index procedures manual. Wyoming Game and Fish Department. 209 pp.

Blue Ribbons of the Big Sky Country Areawide Planning Organization. 1979a. Final report and water quality management plan. Bozeman, MT. 166 pp. + appendix.

Boussu, M. F. 1954. Relationships between trout populations and cover on a small stream. J. Wildl. Mgmt. 18:229-239.

Clancey, P. and W. R. Gould. 1982. Effects of renovation on the Sacajawea Lagoon System in Livingston, Montana. Report to Community Development Office, Livingston, MT by the Montana Cooperative Fishery Rsearch Unit, Bozeman. 7 pp.

DeVore, P. W. and R. J. White. 1978. Daytime responses of brown trout (Salmo trutta) to cover stimuli in stream channels. Trans. Am. Fish. Soc. 107 (6): 763-771.

Elser, A. A. 1968. Fish populations of a trout stream in relation to major habitat zones and channel alterations. Trans. Am. Fish. Soc. 97(4):389-397.

Enk, M. D. 1977. Instream overhead bank cover and trout abundance in two Michigan streams. M. S. Thesis, Mich. State Univ., East Lansing. 127 pp.

Hunt, R. L. 1971. Responses of a brook trout pouplation to habitat development in Lawrence Creek. Wis. Dept. Natural Resour. Tech. Bull. 48. 35 pp.

Kalleberg, H. 1958. Observations in a stream tank of territoriality and competition in juvenile salmon and trout (Salmo salar and Salmo trutta). Inst. Fresw. Res. Drottningholm. 39:55-59.

Lewis, S. L. 1969. Physical factors influencing fish populations in pools of a trout stream. Trans. Am. Fish. Soc. 98(1):14-19.

Newman, M. A. 1956. Social behavior and interspecific competition in two trout species. Physio. Zool. 29:64-81.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Canada Fisheries and Marine Service Bull. 191. 382 p.

Wells, J. D. 1977. The effect of land use practices on trout populations in Rocky Creek, Montana. In 208 Fisheries Study, Blue Ribbons of the Big Sky Country Areawide Planning Organization, Bozeman, MT.

Wesche, T. A. 1976. Development and application of a trout cover rating system for IFN determinations. Pages 224-234 in J. F. Orsborn and C. H. Allman, eds. Instream flow needs, Volume 2. American Fisheries Society, Bethesda, Maryland.

Whitney, A. N. and J. E. Bailey. 1959. Detrimental effects of highway construction on a Montana stream. Trans. Am. Fish. Soc. 88(1):72-73.

Appendix I. Study station marker locations (upstream boundaries of stations).

Station	Landmark, Street or Property Designation	Location
	Bozeman Creek	
7	Bond St.	NE$\frac{1}{4}$, SW$\frac{1}{4}$, NE$\frac{1}{4}$, T2S, R6E, S6
8	Midway	SE$\frac{1}{4}$, SW$\frac{1}{4}$, NE$\frac{1}{4}$, T2S, R6E, S6
9	Gold St.	NE$\frac{1}{4}$, NW$\frac{1}{4}$, SE$\frac{1}{4}$, T2S, R6E, S6
13		NW$\frac{1}{4}$, NW$\frac{1}{4}$, SE$\frac{1}{4}$, T2S, R6E, S6
14	Kenyon-Noble	SW$\frac{1}{4}$, NW$\frac{1}{4}$, SE$\frac{1}{4}$, T2S, R6E, S6
15	Tamarack	SW$\frac{1}{4}$, NW$\frac{1}{4}$, SE$\frac{1}{4}$, T2S, R6E, S6
19	Kwik-Way	SW$\frac{1}{4}$, SW$\frac{1}{4}$, SE$\frac{1}{4}$, T2S, R6E, S6
20		NW$\frac{1}{4}$, NW$\frac{1}{4}$, NE$\frac{1}{4}$, T2S, R6E, S7
21	Rouse	NW$\frac{1}{4}$, NW$\frac{1}{4}$, NE$\frac{1}{4}$, T2S, R6E, S7
22	Skiway	SE$\frac{1}{4}$, NE$\frac{1}{4}$, NW$\frac{1}{4}$, T2S, R6E, S7
23		NE$\frac{1}{4}$, SE$\frac{1}{4}$, NW$\frac{1}{4}$, T2S, R6E, S7
24	Library	NE$\frac{1}{4}$, SE$\frac{1}{4}$, NW$\frac{1}{4}$, T2S, R6E, S7
26	Pavillion	NE$\frac{1}{4}$, NE$\frac{1}{4}$, SW$\frac{1}{4}$, T2S, R6E, S7
27	Bogert	SE$\frac{1}{4}$, NE$\frac{1}{4}$, SW$\frac{1}{4}$, T2S, R6E, S7
28	Story	SE$\frac{1}{4}$, NE$\frac{1}{4}$, SW$\frac{1}{4}$, T2S, R6E, S7
36	Ice Pond	SW$\frac{1}{4}$, NW$\frac{1}{4}$, NE$\frac{1}{4}$, T2S, R6E, S18
60	Picton	NW$\frac{1}{4}$, SE$\frac{1}{4}$, NE$\frac{1}{4}$, T2S, R6E, S18
61	Meadowlark	SW$\frac{1}{4}$, SE$\frac{1}{4}$, NE$\frac{1}{4}$, T2S, R6E, S19
	Mathew Bird Creek	
1	Teepee	NW$\frac{1}{4}$, NE$\frac{1}{4}$, NW$\frac{1}{4}$, T2S, R6E, S18
2		NW$\frac{1}{4}$, NE$\frac{1}{4}$, NW$\frac{1}{4}$, T2S, R6E, S18
3		SW$\frac{1}{4}$, NE$\frac{1}{4}$, NW$\frac{1}{4}$, T2S, R6E, S18
4	Wood Brook	NE$\frac{1}{2}$, NW$\frac{1}{4}$, SW$\frac{1}{4}$, T2S, R6E, S18
5	Graf 1	NE$\frac{1}{4}$, SW$\frac{1}{4}$, NW$\frac{1}{4}$, T2S, R6E, S19
6	Graf 2	E$\frac{1}{2}$, SW$\frac{1}{4}$, NW$\frac{1}{4}$, T2S, R6E, S19
7	Graf 3	SE$\frac{1}{4}$, SW$\frac{1}{4}$, NW$\frac{1}{4}$, T2S, R6E, S19
	Figgins Creek	
1	Hoffman	SE$\frac{1}{4}$, NW$\frac{1}{4}$, SW$\frac{1}{4}$, T2S, R6E, S18
2	Control	NW$\frac{1}{4}$, SW$\frac{1}{4}$, SW$\frac{1}{4}$, T2S, R6E, S18
	Fleshman Creek	
1	Sacajawea	NW$\frac{1}{4}$, SW$\frac{1}{4}$, NW$\frac{1}{4}$, T2S, R9E, S24
2	Crawford	SE$\frac{1}{4}$, NW$\frac{1}{4}$, NW$\frac{1}{4}$, T2S, R9E, S24
3	Clancy	SE$\frac{1}{4}$, SE$\frac{1}{4}$, SW$\frac{1}{4}$, T2S, R9E, S14

Appendix II. Habitat and trout variables for the study stations. Explanation of variables in Binns (1979).

Station	Stream length (m)	Thalweg length (m)	Mean width (m)	Solid overhead cover (%)	Pool & turbulence cover (%)	Eroding banks (%)	Water velocity (cm/sec)	Annual flow variation (%)	CPDF/ADF* (%)	Max summer temp (C)	NO_3-N (mg/l)	Vegetational substrate rating	Numerical density of trout ≥ 20 cm (n/km)	(n/ha)	Standing crop of all trout (kg/km)	(kg/ha)
							BOZEMAN CREEK									
CONTROL STATIONS																
7	108.7	113.2	7.75	6.04	8.39	4.97	75.5	950	65.6	15.5	.400	little	644	831	109.4	141.2
8	92.0	105.3	9.19	3.08	3.45	39.67	87.8	950	65.6	15.5	.362	little	457	497	84.0	91.4
9	129.4	139.15	7.22	7.44	3.48	30.15	73.2	950	65.6	15.5	.388	little	533	739	126.2	174.8
13	104.8	105.3	5.75	10.09	7.39	3.82	82.3	950	65.6	15.5	.388	little	611	1062	175.7	305.5
14	109.2	107.0	6.68	9.86	2.79	4.58	85.6	950	65.6	15.5	.388	little	412	617	78.0	116.8
15	107.1	106.0	7.41	1.49	0.63	10.36	78.5	950	65.6	15.5	.388	occas.	542	731	87.9	118.7
36	130.3	136.2	6.83	3.89	5.00	23.40	80.0	950	65.6	15.5	.440	little	882	1292	155.0	226.9
60	162.3	183.2	6.25	2.18	2.32	14.80	76.0	950	65.6	15.5	.254	little	326	522	60.4	96.7
61	201.0	201.9	6.04	3.85	9.59	39.90	56.1	950	65.6	15.5	.335	little	299	494	60.3	99.9
Mean			7.01	5.32	4.78	19.07	68.3	950	65.6	15.5	.371	little	522.9	753.9	104.1	152.4
URBAN STATIONS																
19	95.8	95.8	4.43	1.98	8.69	17.75	67.9	950	65.6	15.5	.436	none	209	471	36.8	83.1
20	104.1	104.0	4.34	1.93	12.38	27.86	65.5	950	65.6	15.5	.436	little	499	1151	78.4	180.7
21	98.4	98.4	5.46	0.80	3.58	0.01	73.0	950	65.6	15.5	.436	little	386	707	44.2	81.1
22	99.4	95.8	5.52	0.86	7.58	30.20	76.6	950	65.6	15.5	.414	little	272	492	67.7	123.2
23	105.7	108.9	4.96	0.41	3.70	57.30	80.7	950	65.6	15.5	.414	little	549	1074	107.1	209.6
24	100.0	100.7	3.84	0.22	14.28	18.00	90.2	950	65.6	15.5	.414	little	240	621	48.2	124.7
26	100.3	100.0	4.54	0.85	6.02	63.00	4.54	950	65.6	15.5	.411	little	319	705	44.1	97.4
27	98.0	101.3	5.25	0.43	5.27	59.00	84.4	950	65.6	15.5	.411	little	296	545	50.9	93.9
28	118.0	106.7	5.21	0.74	2.68	22.50	82.1	950	65.6	15.5	.411	none	135	288	34.4	73.0
Mean			4.84	0.91	7.15	32.96	79.5	950	65.6	15.5	.420	little	322.8	672.7	56.9	118.5

* Critical period daily flow as a percentage of average daily flow.

Appendix II (cont'd.)

Station	Stream length (m)	Thalweg length (m)	Mean width (m)	Solid over-head cover (%)	Pool & turbulence cover (%)	Eroding banks (%)	Water velocity (cm/sec)	Annual flow variation (%)	CPDF/ADF* (%)	Max summer temp (C)	NO_3-N (mg/l)	Vegetational substrate rating	Numerical density of trout ≥ 20 cm (n/km)	Numerical density of trout ≥ 20 cm (n/ha)	Standing crop of all trout (kg/km)	Standing crop of all trout (kg/ha)
MATHEW BIRD CREEK																
CONTROL STATIONS																
5	100.0	108.1	2.44	9.09	6.67	0.04	21.2	300	47.0	16.7	.612	abund.	30	123	8.3	34.2
6	99.2	105.2	2.24	21.13	2.25	0.01	23.4	300	47.0	16.7	.612	abund.	121	540	36.1	161.4
7	103.0	119.6	2.33	22.36	12.70	5.44	24.2	300	47.0	16.7	.612	abund.	87	375	29.6	127.0
Mean			2.34	17.53	7.21	2.28	22.9	300	47.0	16.7	.612	abund.	79.3	346	24.7	107.5
URBAN STATIONS																
1	102.9	100.5	2.37	14.37	7.37	42.13	50.0	300	47.0	16.7	.347	occas.	253	1066	38.0	160.4
2	107.7	107.5	1.97	10.43	13.84	44.13	44.8	300	47.0	16.7	.347	occas.	167	849	35.3	179.4
3	89.4	100.7	2.19	9.62	10.85	0.01	41.3	300	47.0	16.7	.347	occas.	179	817	32.4	147.9
4	142.0	147.4	2.69	2.54	2.01	9.76	37.8	300	47.0	16.7	.310	occas.	155	576	35.7	132.7
Mean			2.31	9.24	8.52	24.01	43.5	300	47.0	16.7	.338	occas.	188.5	827	35.4	155.1
FIGGINS CREEK																
2(CTRL)	191.0	191.0	1.58	13.33	5.47	12.65	12.2	300	75.0	12.8	.388	abund.	241	1524	51.0	322.9
1(URBN)	188.0	192.0	1.40	30.42	0.50	9.00	12.2	300	75.0	12.8	.325	abund.	64	456	15.3	109.5
FLESHMAN CREEK																
3(CTRL)	300.0	300.0	1.73	2.84	6.38	126.0	26.0	6180	29.0	14.4	.429	none	83	483	18.6	107.5
URBAN STATIONS																
1	157.0	152.3	2.39	5.22	2.76	52.87	26.0	6180	29.0	14.4	.377	little	70	293	23.0	96.2
2	132.8	141.0	1.92	2.66	12.00	87.80	39.2	6180	29.0	14.4	.451	little	105	549	17.3	90.1

Appendix III. Multiple-regression models describing numerical density of over-20-cm trout (trout/km) as a function of stream habitat variables.

1. All 30 stations included (urban and controls)

log trout/km = 15.289 + 1.77 log water velocity
+ 0.153 log critical period flow/mean flow
+ 0.317 log of solid overhead cover
- 0.348 log max summer water temp
+ 0.243 log vegetational substrate rating

r = 0.8733, simple r^2 - 0.763, adjusted r^{2*} = 0.713

Order or entry	Variable	Adj. r^2 at step	F-values at step: log wtrvel	log CPF/MF	log cover	log maxT	log substr
1	log wtrvel	.542	35.297				
2	log CPF/MF	.641	23.606	8.768			
3	log cover	.670	25.994	8.647	3.352		
4	log maxT	.703	30.856	4.902	6.124	3.845	
5	log substr.	.713	25.552	1.154	5.103	5.902	1.922

2. Urban Stations Only

log trout/km = - 64.235 - 0.762 log water velocity
+ 0.903 log vegetational substrate rating
+ 1.360 log NO_3-N
+ 0.724 log annual streamflow variation
+ 1.827 log max T
+ 1.044 log critical period flow/mean flow
- 0.422 log % pool & turbulence cover
+ 0.215 log % eroding bank

r = 0.976, simple r^2 = 0.952, adjusted r^2 = 0.899

Order or entry	Variable	Adj. r^2 at step	F-value at step: log wtrvel	log substr	log NO_3	log ASFV	log maxT	log CPF/MF	log pool	loger. bu
1	log wtrvel	.594	22.966							
2	log substr	.710	35.277	6.567						
3	log NO_3	.715	28.540	7.687	1.232					
4	log ASFV	.746	12.404	5.598	3.747	2.466				
5	log maxT	.741	3.051	5.828	4.309	2.460	0.796			
6	log CPF/MF	.843	0.872	15.550	5.463	3.519	8.783	7.474		
7	log pool	.858	0.829	19.139	7.554	1.961	10.736	4.567	1.967	
8	log er.buk.	.898	3.343	30.580	14.650	2.778	19.088	7.740	5.225	4.145

* Adjusted $R^2 = r^2 - [(K-1)/N-K)][1-r^2]$, where K = number of independent variables, N = number of cases.

Appendix III. Continued.

3. Control Stations Only

$$\log \text{trout/km} = 44.211 + 1.300 \log \text{water velocity} - 0.768 \log \text{maxT} - 0.344 \log \text{annual streamflow variation} + 0.298 \log NO_3\text{-N}$$

$r = 0.949$, simple $r^2 = 0.901$, adjusted $r^2 = 0.857$

Order of entry	Variable	Adj. r^2 at step	F-value at step: log wtrvel	log maxT	log ASFV	log NO_3
1	log wtrvel	.578	18.841			
2	log maxT	.761	40.700	10.162		
3	log ASFV	.837	61.105	20.625	6.114	
4	log NO_3	.857	45.614	20.266	7.032	2.383