[1976]

ANNUAL PROGRESS REPORT

ANADROMOUS FISH PROJECT

PROJECT TITLE: Streamflow Requirements of Salmonids

PROJECT NUMBER: AFS-62

JOB NUMBER: 5

CONTRACT NUMBER: 14-16-0001-4209

PROJECT PERIOD: July 1, 1975 to June 30, 1976

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This project was financed in part with Anadromous Fish Act (PL 89-304) funds through the Bureau of Sport Fisheries and Wildlife.

ABSTRACT

A methodology is being developed that can be used in natural streams to estimate the influence of stream discharge on carrying capacity of salmonids. A habitat rating system has been developed for juvenile coho salmon which explains 72% of the variation recorded in fish biomass in six study sections at three different flow levels in Elk Creek, near Cannon Beach, Oregon. Methods are proposed for evaluating instream flows for salmonid rearing which combine an evaluation of habitat quality and water quality over a range of flow levels.

INTRODUCTION

The maintenance of adequate instream flows to support aquatic life is recognized as a major problem. In Oregon the primary concern is the protection of resident and anadromous salmonids. The Oregon Department of Fish and Wildlife has recommended minimum and optimum flows by month for several hundred streams based on the passage, spawning, incubation and rearing requirements of the salmonid species present (1). Of these requirements, the relationship between rearing and flow is the least understood.

In 1968 the Environmental Management Section of the (then) Oregon Wildlife Commission requested that research be initiated to develop improved methods for recommending rearing flows for salmonids. As a result, a literature survey was initiated in 1971 (2) and preliminary investigations into possible research designs and methods were conducted on Elk Creek, a coastal stream, in the summers of 1973 (3) and 1974 (4). A study designed to measure and evaluate salmonid habitat and carrying capacity over a range of controlled constant flows was implemented in summer 1975.

OBJECTIVE

To determine techniques that can be used in natural streams to estimate the influence of stream discharge on fish production.

PROCEDURES

A. Collect production data from fish and aquatic invertebrate populations in study stream sections subjected to differing streamflow regimes between July 1 and October 31, 1975.

B. Map the physical character of stream channels and document changes in stream hydraulics and fish shelter conditions at different discharge stages between July 1 and September 31, 1975.

C. Analyze contents of fish stomachs and samples of benthos and invertebrate drift organisms collected during the summer field season.

D. Analyze field data from physical and biological investigations through development and utilization of specialized computer programs and statistical techniques and conduct regression analyses of production and physical data.

E. Design and implement similar research under revised flow regimes scheduled for the 1976 field season.

METHODS

A wood piling weir and a 76 cm diameter corrugated metal pipe divert water from the North Fork to the West Fork of Elk Creek (3). A head gate provides control of flows through the study area. The weir is located on the North Fork 1.2 km upstream from its confluence with the West Fork.

Six 30 m study sections were established in the stream below the flow control facility. Each study section was separated from the remainder of the stream by screens and traps. Each section was stocked at a rate of 2 fish/m^2

with age 0+ coho salmon *(Oncorhynchus kisutch)* and age 0+ trout *(Salmo clarki and Salmo gairdneri)* collected elsewhere in the stream.

Summer floods limited the project to four constant discharge levels each of which was studied during individual two-week experiments. The flows were 3.00, 2.25, 1.50 and 0.75 cfs and represent the approximate 5-year recurrence interval, 7-day average low flow[1/] and 25%, 50% and 75% reductions from the same. In each experiment, depths and velocities were measured on 22 cross-sectional transects (at 1-2 m intervals) in each study section. Substrate and cover types were evaluated for each transect in the first experiment. At the end of each experiment fish biomasses were estimated. Water chemistry and temperature were monitored weekly and continuously, respectively.

Rick Hafele, an Oregon State University graduate student in entomology, is studying the effects of reductions in flow on the aquatic insects of Elk Creek. Drift nets, artificial substrates, a benthic sampler and floating traps were used to collect insect samples. Salmonid stomachs were also collected and later examined for food content. Sampling was done systematically following a rigid schedule.

RESULTS

A flood of 165 cfs following Experiment 3 altered the study sections and Experiment 4 could not be compared to the previous three experiments. Study sections 4 and 6 were eliminated from Experiment 4 due to considerable changes in the streambed and a lack of fish with which to restock. Experiment 4 was included in the data summaries presented, however it was not included in further analysis.

[1/] John F. Orsborn, Washington State University, personal communication.

A summary of the mean width, depth and velocity of the study sections during each experiment is presented in Table 1. Sections 2 and 4 had the highest and lowest mean velocity respectively, and also had the lowest coho salmon biomasses (Table 2).

Table 1. Mean width, depth and velocity of six Elk Creek study sections at four different flows.

Sec.		Exp. 1 3.00 cfs	Exp. 2 2.25 cfs	Exp. 3 1.50 cfs	Exp. 4 0.75 cfs
	Width	7.04 m	6.92 m	6.52 m	6.34 m
#1	Depth	16.4 cm	15.0 cm	15.1 cm	13.6 cm
	Velocity	18.1 cm/sec.	14.5 cm/sec.	10.4 cm/sec.	8.4 cm/sec.
	Width	2.68 m	2.59 m	2.37 m	2.08 m
#2	Depth	13.3 cm	11.5 cm	10.6 cm	7.9 cm
	Velocity	34.8 cm/sec.	28.9 cm/sec.	21.7 cm/sec.	17.1 cm/sec.
	Width	5.98 m	5.80 m	5.11 m	4.40 m
#3	Depth	18.0 cm	16.3 cm	17.5 cm	18.0 cm
	Velocity	13.4 cm/sec.	9.6 cm/sec.	7.9 cm/sec.	4.7 cm/sec.
	Width	6.61 m	6.31 m	6.13 m	
#4	Depth	28.6 cm	28.5 cm	27.6 cm	
	Velocity	8.5 cm/sec.	6.5 cm/sec.	5.9 cm/sec.	
	Width	6.02 m	5.84 m	5.63 m	5.27 m
#5	Depth	23.2 cm	22.2 cm	21.2 cm	22.7 cm
	Velocity	19.8 cm/sec.	15.9 cm/sec.	14.7 cm/sec.	8.1 cm/sec.
	Width	8.24 m	7.56 m	6.72 m	
#6	Depth	15.2 cm	15.0 cm	14.4 cm	
	Velocity	14.9 cm/sec.	12.3 cm/sec.	10.3 cm/sec.	

The higher biomass present in the study sections at the end of Experiment 4 compared to that present at the end of Experiment 3 was due in part to a delay of two weeks, caused by the midsummer flood, between the end of Experiment 3 and the beginning of Experiment 4.

Table 3 contains a summary of the water chemistry in the study area during each experiment. Values presented are means of values for each individual study section.

Table 2. Biomass of age 0+ salmon and trout in the six Elk Creek study sections at four constant discharge levels.

Section		Biomass (g/m^2) Exp. 1 3.00 cfs	Exp. 2 2.25 cfs	Exp. 3 1.50 cfs	Exp. 4 0.75 cfs
1	Salmon	3.39	2.65	2.53	4.23
	Trout	0.29	0.23	0.13	0.06
2	Salmon	0.74	0.69	0.64	0.87
	Trout	0.11	0.14	0.12	0.47[a]
3	Salmon	3.31	3.07	2.89	4.41
	Trout	0.14	0.11	0.04	0.03
4	Salmon	2.02	1.82	1.93	
	Trout	0.08	0.06	0.09	
5	Salmon	2.64	2.75	2.51	3.13
	Trout	0.07	0.05	0.06	0.28[a]
6	Salmon	2.15	2.70	2.69	
	Trout	0.62	0.33	0.54	

[a] 10 additional trout were stocked in each of these sections at the beginning of Experiment 4.

Table 3. Mean values for five water chemistry parameters for each experiment.

Parameter	Exp. 1	Exp. 2	Exp. 3	Exp. 4
Water Temp. (°C)	14.00	15.08	14.66	13.94
Dissolved oxygen (mg/l)	9.33	9.25	9.08	7.63
pH	7.08	7.03	7.00	6.80
Total alkalinity (mg/l $CaCO_3$)	25.33	21.50	21.75	20.38
Carbon dioxide (mg/l)	9.67	9.75	10.50	6.70

The results of the analysis of the stomach contents of 59 salmonids, presented in Table 4, indicate that terrestrial and adult aquatic insects landing on the surface were more important as food in September than in August. Unfortunately data on the relative abundance of organisms landing on the surface is available only through the middle of August (Table 5). The floating traps used to collect the insects were either lost or severely damaged by the

the flood which occurred in late August, thus preventing further sampling.

Table 4. A breakdown of the insects found in the stomachs of 59 juvenile salmonids collected from Elk Creek.

Date	No. of fish sampled	Number of food items: Terrestrial and adult aquatic insects	Number of food items: Aquatic nymphs
8/5/75	6	9 (9.5%)	86 (90.5%)
8/21/75	19	147 (7.2%)	1900 (92.8%)
9/3/75	1	10 (20.4%)	39 (79.6%)
9/15/75	33	184 (62.4%)	111 (37.6%)
Total	59	350 (14%)	2136 (86%)

Table 5. The number of terrestrial and adult aquatic insects collected in 4 four floating traps during 7-day periods from July 14 to August 18, 1975.

Week ending	No. of insects: Terrestrial	No. of insects: Adult aquatics	Total
7/21/75	35	446	481
7/28/75	100	1542	1642
8/4/75	49	883	932
8/11/75	62	816	878
8/18/75	99	537	636
Total	345	4224	4569

EVALUATION OF STREAM HABITAT FOR SALMONIDS

As a result of research conducted on Elk Creek in 1975 a system for evaluating coho salmon habitat has been developed. This system is based on a weighting of individual observations taken on cross-sectional transects. The weighting factor consists of a "habitat index" and a species-specific cover preference factor. The "habitat index" is the sum of values developed for a water type, cover, and substrate associated with each observation. These values are derived from a numerical ranking of specific types within each of the three categories (Table 6). The ranking is based on the relative value as coho salmon habitat of one type compared to other types in the same category.

Table 6. Criteria for rating the habitat of two different types of streams for two different salmonid species.

HABITAT INDEX CRITERIA

A. Species: Coho Salmon - Age 0+

Stream: Elk Creek

Habitat Categories:

		Value
Water Type		
Prime	Depth >30 cm Velocity <30 cm/sec	2
Marginal	Depth ≤30 cm Velocity <30 cm/sec	1
Cover Type		
Undercut banks and submerged roots		2
Overhanging cover and submerged logs and limbs		1
No cover		0
Substrate Type		
Cobble		2
Gravel		1
Sand, Silt or Clay		0

B. Species: Brown Trout - ≥15.2 cm (6 in.)

Stream: Little Deschutes River

Habitat Categories:

		Value
Water Type		
Prime	Depth >30 cm Velocity 12-21 cm/sec	2
Marginal	Depth ≤30 cm Velocity ≤21 cm/sec	1
Cover Type		
Undercut banks, overhanging willows and submerged roots		2
Aquatic vegetation and submerged logs and limbs		1
No cover		0
Substrate Type		
Cobble		2
Gravel		1
Sand, Silt, Clay or Bedrock		0

Water Type

This category is used to rank depth and velocity at a given observation point in terms of the requirements for coho salmon habitat. Coho juveniles prefer depths >30 cm and velocities <30 cm/sec. Depth and velocity combinations within these ranges are considered to be prime habitat and are given a value of "2". Depths <30 cm combined with velocities <30 cm/sec are considered marginal habitat and are given a value of "1". Locations with velocity observations of 30 cm/sec or greater are considered unsuitable habitat for coho salmon. Observations from locations unsuitable for coho salmon habitat receive a "habitat index" value of "0".

Cover

On streams without an overhead canopy of trees, streambank cover such as overhanging vegetation and undercut banks is an important source of shade, which salmonids prefer (5, 6). However, since much of Elk Creek has a full canopy of alder, cover is ranked on the basis of its value as a source of protection from avian predators rather than for its value as shade. Undercut banks and submerged root systems are judged to provide the best protection for juvenile coho and are given a value of "2". Overhanging cover within 1.5 meters of the surface and submerged logs and limbs are given a value of "1" and the absence of cover is given a value of "0". The value of substrate as cover will be discussed later. Individual observation points along a transect are given a cover rating based on the best cover within 30 cm.

The preference for a cover of a given salmonid species is taken into consideration in the habitat rating system. Preference for cover is ranked as follows:

high preference for cover = 3;

medium preference for cover = 2; and

low preference for cover = 1.

Examples of species with each of these preferences are brown trout *(Salmo trutta)*, rainbow trout *(S. gairdneri)* and coho salmon, respectively.

Substrate

The substrate at each observation point is ranked on the basis of size. Cobble (>75 mm diameter) is given a value of "2" because it can provide cover (7, 8) and has a greater potential for food production compared to smaller substrate (9, 10). Gravel is given a value of "1" based on its potential for food production. Sand, silt and clay have little value as cover or for food production and therefore receive a value of "0".

Habitat Quality Rating

The habitat of a section of stream is evaluated on the basis of individual observations.

Let: HI be the habitat index value which is equal to the sum of the water type value, the cover value and the substrate value and has a possible range of 1 to 6;

N be a species-specific constant which reflects the degree of preference of a given species for cover (e.g. for coho $N = 1$);

OB_{HI} be the number of observations having a value of HI; and

TOB be the total number of observations taken in the particular section of stream in question.

Then, the habitat quality (HQU) for the section of stream is calculated from the equation:

$$HQU = \sum_{HI=N}^{6} (HI - N) \frac{(OB_{HI})}{TOB} \qquad (1)$$

An example of the calculation of HQU is presented in Table 7.

Table 7. Calculation of the habitat quality *(HQU)* for coho salmon of experimental section 1 at a flow of 3.00 cfs. For coho the value of *N* is 1.

HI	*HI-N*	OB_{HI}	$\frac{OB_{HI}}{TOB}$	$(HI-N)\left(\frac{OB_{HI}}{TOB}\right)$
6	5	0	0.000	0.000
5	4	5	0.016	0.064
4	3	10	0.032	0.096
3	2	40	0.128	0.256
2	1	174	0.558	0.558
1	0	20	0.064	0.000
0		63		
		TOB = 312		*HQU* = 0.974

At present, the habitat rating system described above is specific for coho salmon in Elk Creek. The habitat quality ratings of the six Elk Creek study sections at three flow levels explained 72% of the variation in the coho salmon biomass of the sections (Fig. 1). Additional research is underway to determine its applicability to other streams and species. An example illustrating how the system could be applied to another stream and species is presented in Table 6.

When evaluating the habitat of a different type of stream for coho salmon, alterations must be made in the "cover" and "substrate" categories to include types not found in Elk Creek. For example, on the Little Deschutes River, (Table 6, B) which lacks the alder canopy found on Elk Creek, overhanging willow is an important source of cover. On Elk Creek overhanging cover is not as important. When evaluating the habitat for a different species, the depth and velocity preferences and the value of *N* in equation *(1)* must be adapted to the new species (e.g. for brown trout, *N* = 3).

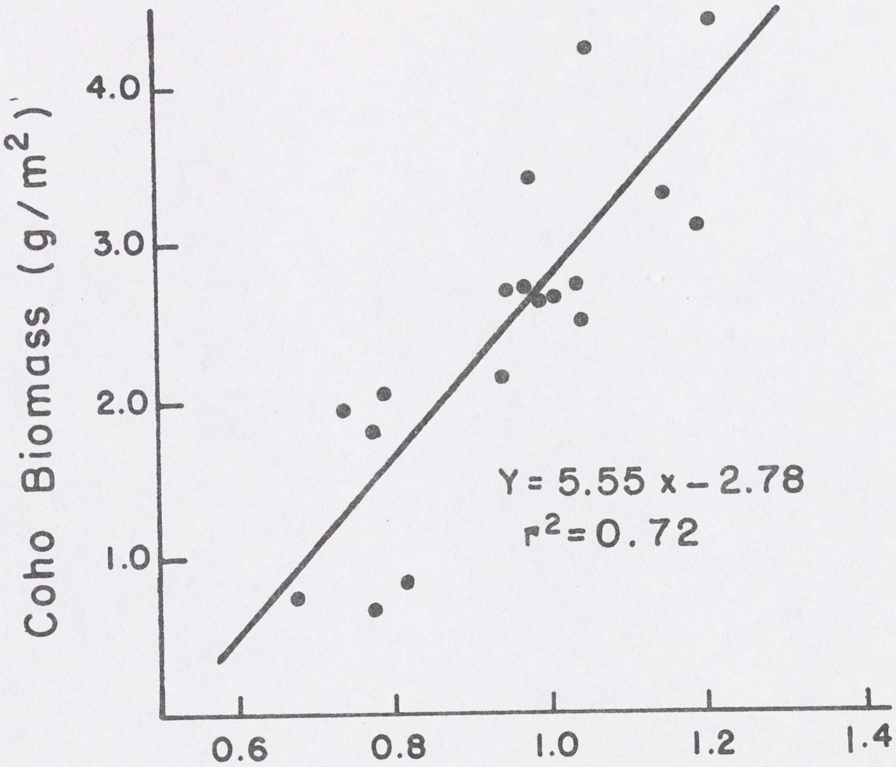

Fig. 1. The relationship between habitat quality *(HQU)* and coho salmon biomass in six Elk Creek study sections at flows of 3.00, 2.25 and 1.50 cfs.

A PROPOSED METHODOLOGY FOR EVALUATING INSTREAM FLOWS FOR SALMONID REARING

The proposed methodology for evaluating instream flows for salmonid rearing is based on the premise that the carrying capacity of a stream for a given species will change as the stream discharge changes. As the instream flow is reduced, changes which affect salmonid carrying capacity will take place not only in the habitat quality (in terms of *HQU*)but in water quality.

The important water quality parameters are water temperature and dissolved oxygen content. When the flow level drops in most streams the temperature increases and dissolved oxygen decreases. Temperatures of 22-25°C have been shown to be lethal to Pacific salmon *(Oncorhynchus spp.)* (11). Sublethal effects such as decreased growth also result from increased temperature (12). Davis (13) reports that if prolonged beyond a few hours, a dissolved oxygen level of 6.0 mg O_2/liter can result in some risk to a portion of an average freshwater salmonid population. A level of 4.16 mg O_2/liter can result in severe deleterious effects to the population. He considers a level of 7.85 mg O_2/liter to be a safe level.

There are some streams in which water quality would not be a factor limiting salmonid carrying capacity when the flow is reduced. In these streams the carrying capacity is controlled primarily by the habitat quality (Fig. 2). However, for many streams there will be a critical flow level above which carrying capacity will be determined primarily by habitat quality and below which carrying capacity will be limited by water quality (Fig. 3). This critical flow level might, for example, be the flow which results in a reduction of the dissolved oxygen content of the stream to 6.0 mg O_2/liter or an increase in temperature to 22°C.

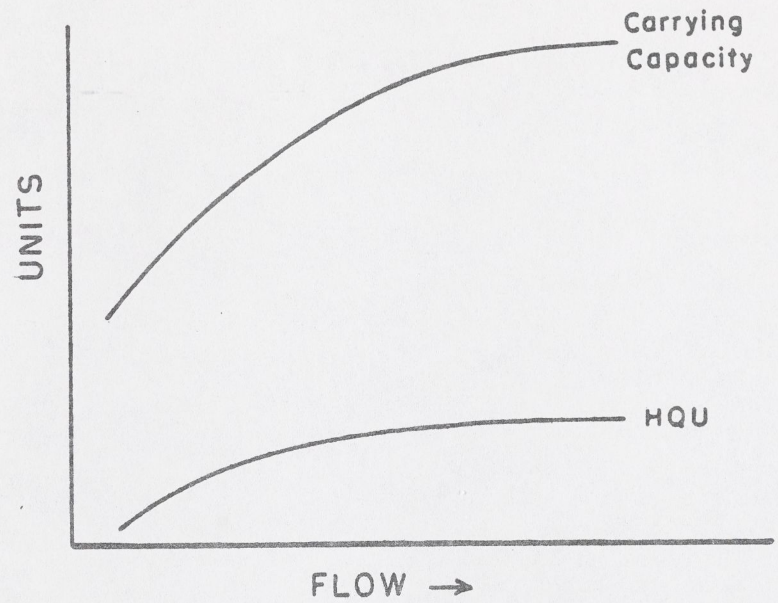

Fig. 2. A hypothetical example of flow reduction decreasing carrying capacity through changes in habitat quality *(HQU)*.

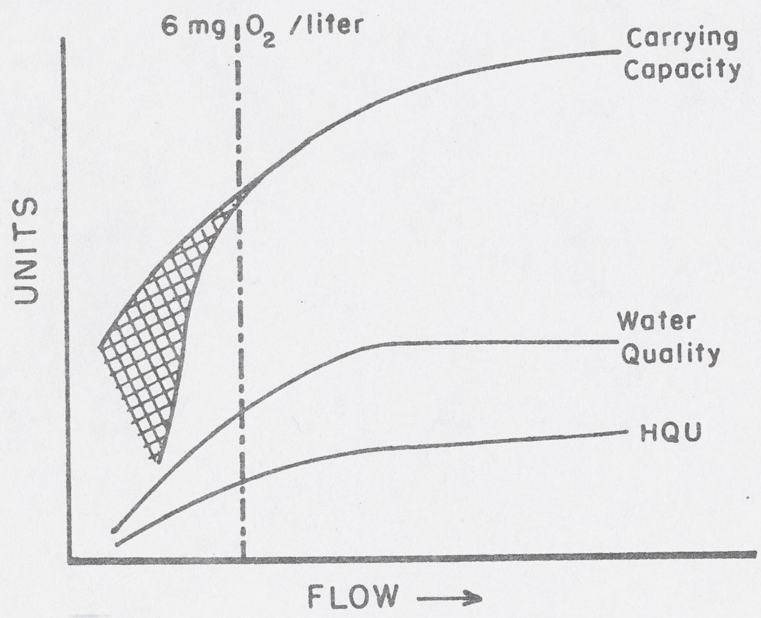

Fig. 3. A hypothetical example of flow reduction decreasing carrying capacity through changes in habitat quality *(HQU)* and then below some critical flow level through changes in water quality. Cross-hatched areas indicate decrease in carrying capacity due to water quality.

The methodology proposed consists of two parts. The first part is the identification of the critical flow level of a stream determined by monitoring water quality over a range of flows. The second part is to evaluate the habitat of a typical section of stream for the species of interest over the same range of flows using the habitat rating system described. The carrying capacity of the stream at flows above the critical level could be estimated from the habitat quality using species-specific relationships as presented in Fig. 1. The minimum flow recommendation would then be the flow which yields the lowest acceptable carrying capacity.

It should be remembered that this is a proposed methodology and has not been tested. We are continuing our work to refine the techniques employed in the methodology and to test its applicability to streams of different sizes and geographic locations.

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JOB FINAL REPORT

FISH RESEARCH PROJECT
OREGON

PROJECT TITLE: Willamette Basin Streamflow Studies

PROJECT NUMBER: 2-4-8-20-02

CONTRACT NUMBER: 14-16-0006-77-020

PROJECT PERIOD: April 1, 1978 to November 30, 1978

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This project is financed by the U. S. Fish and Wildlife Service, Office of Biological Services, Western Water Allocation under the Assessment of Instream Flow Needs, Stream Evaluation Project-Phase II.

INTRODUCTION

The maintenance of adequate instream flows to support aquatic life is recognized as a major problem. In Oregon the primary concern is the protection of resident and anadromous salmonids. The Oregon Department of Fish and Wildlife has recommended minimum and optimum flows by month for several hundred streams based on the passage, spawning, incubation and rearing requirements of the salmonid species present (Thompson 1972). Of these, the flow requirements for rearing are the least understood. Oregon's recommended flows for rearing salmonids were based on a combination of physical measurements, general observations and judgement (Giger 1973).

In 1968 the Environmental Management Section of the (then) Oregon Wildlife Commission requested that research be initiated to develop improved methods for recommending rearing flows for salmonids. As a result, a literature survey was initiated in 1971 (Giger 1973) and preliminary investigations into possible research designs and methods were conducted on Elk Creek, a coastal stream, in the summers of 1973 (Keeley and Nickelson 1974) and 1974 (Nickelson 1975).

It became apparent that a major flaw in the "Oregon Method" as well as in methods proposed by Chrostowski (1972), Tennant (1972) and Collings et al. (1970) was that they could not predict the effects of a given amount of flow reduction on the standing crop of salmonids rearing in a given stream reach, and that development of future methods should be aimed at developing an incremental method which would quantify the changes in salmonid standing crop caused by a given amount of flow reduction.

In 1975 and 1976 we conducted controlled flow experiments at Elk Creek with the objective of determining the relationship between percentage reductions in flow from the 5 year recurring low flow and the standing crop of juvenile coho salmon *(Oncorhynchus kisutch)* and coastal cutthroat trout *(Salmo clarki*

clarki) (Nickelson 1976). A wood piling weir (Fig. 1) and a corrugated metal pipe were used to divert flow from the North Fork to the West Fork of Elk Creek. This facility allowed flows to be controlled at a constant level in the North Fork where our experiments were conducted. Flow levels were maintained for two-week periods during the summer low flow period (Table 1).

Table 1. Summary of flows studied at Elk Creek in 1975 and 1976.

1975		1976	
	Flow (percent)		Flow (percent)
Litres/sec	Min. flow	Litres/sec	Min. flow
84	100	168	200
63	75	112	133
42	50	63	75
21	25	42	50

Summer floods and salmon densities, which were inconsistent between years possibly due to our stocking of the Elk Creek study sections, vitiated the results of these experiments. We decided controlled flows at Elk Creek was not the best approach to pursue, primarily because the results would be applicable only to streams which are similar to Elk Creek. We felt the data would be difficult to apply to other streams because of differences in the relationship between flow and habitat caused by differences in gradient and channel configuration between streams.

We concluded that the most useful methodology for recommending flows which we could develop would be a habitat model which was correlated to salmonid standing crop in any stream. Such a model was developed for coho based on data from Elk Creek (Nickelson 1976) and then improved upon with data from three other northern Oregon coastal streams (Nickelson and Reisenbichler 1977).

In 1977 our field work shifted to the Rogue River Basin in southern Oregon. In April of that year the Oregon Department of Fish and Wildlife entered into a contract with the Office of Biological Services, U. S. Fish and Wildlife Service to develop models that could predict the standing crop of cutthroat and steelhead trout in Willamette Basin streams. Data collected in the Rogue and Willamette basins have been combined in the models discussed in this report.

METHODS

During the summer low flow period of 1977 we sampled 8 streams with predominently cutthroat trout and 11 streams with predominently juvenile steelhead trout (Tables 2 and 3) (Nickelson and Hafele 1978). The streams were located in the Willamette River basin, in the Rogue River basin and on the north coast of Oregon (Figs. 2 - 5). In addition, we sampled six Willamette Basin streams during the summer of 1978 (Tables 4 and 5).

We established 1-10 study sections in each stream. Study sections consisted of one riffle and one pool or in some cases a series of small riffles and pools and ranged in length from 20 to 70 m. Standing crop[1/] of each species of salmonid was calculated from a population estimate made by the removal method (Zippon 1958) and the mean weight of the fish captured.

To describe the stream habitat, depth, velocity, cover and substrate were measured at a minimum of 200 locations per study section on transects placed perpendicular to the thalweg (Fig. 6). For a detailed description of field sampling procedures see Appendix 1.

[1/] *Trout standing crop includes only age 1+ and older fish.*

Figure 1. The flow control facility at Elk Creek.

Figure 2. Section 5 of Rock Creek.

Figure 3. Section 5 of Evans Creek.

Figure 4. Section 5 of Mill Creek

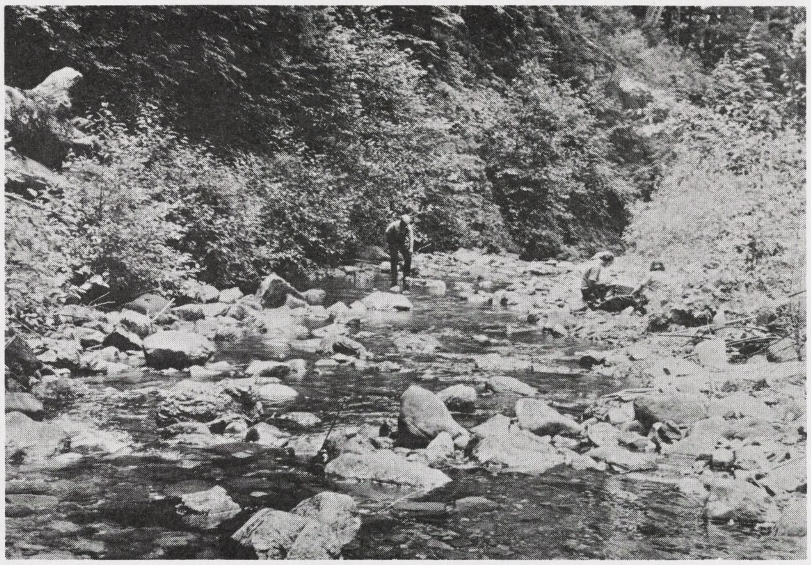
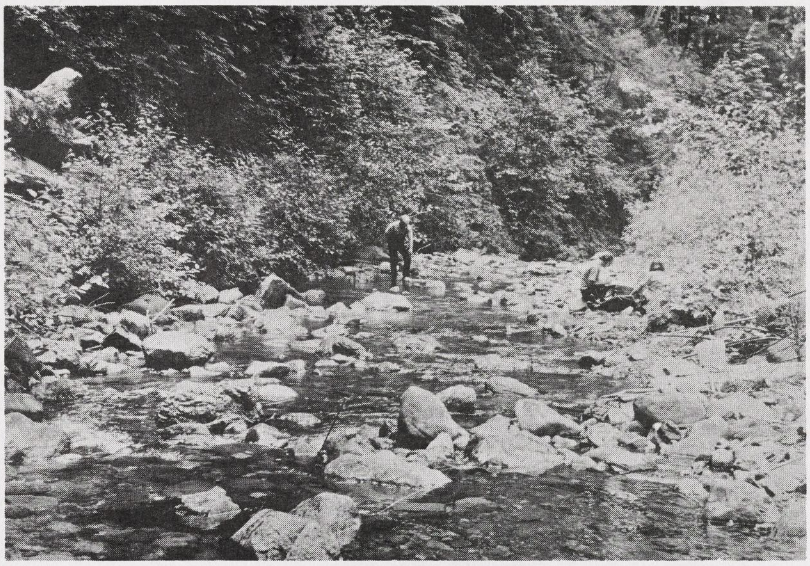


Figure 5. Section 6 of Elk Creek (Willamette Basin).

Figure 6. Measuring stream habitat.

Figure 3. Section 5 of Evans Creek.

Figure 4. Section 5 of Mill Creek



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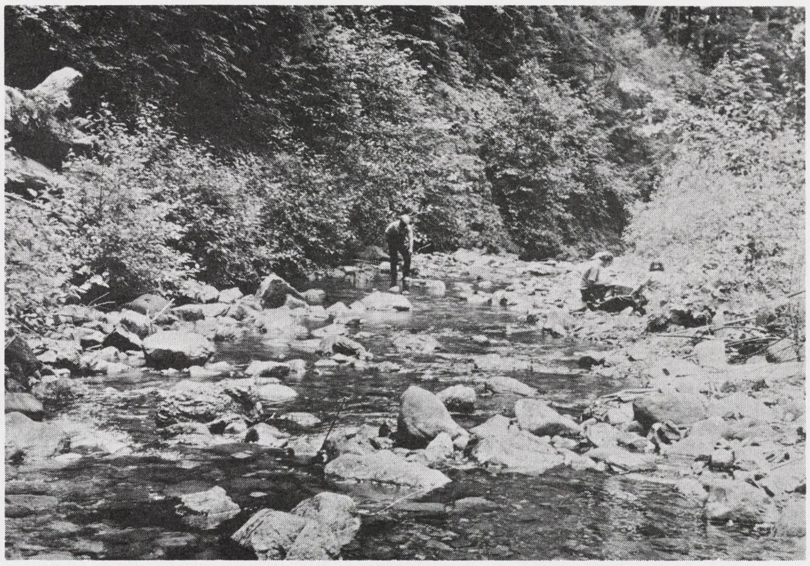

Figure 5. Section 6 of Elk Creek (Willamette Basin).

Figure 6. Measuring stream habitat.

Table 2. A list of the streams sampled in the Rogue River basin during the low flow period of 1977.

Stream	Location	Month	No. of study sections	Predominant species
Taylor Cr.	T35S, R8W	August	6	Steelhead
Evans Cr.	T33S,R2W	August	6	Steelhead
W. Fk. Evans Cr.	T33,34S,R3W	September	7	Steelhead
Briggs Cr.	T36S,R8W	September	7	Steelhead
Althouse Cr.	T40S,R7W	July	5	Steelhead
Greyback Cr.	T39S,R6W	July	6	Steelhead
Grave Cr.	T33S,R4W	July	7	Steelhead
Rancheria Cr.	T34,35S,R3,4E	July	8	Cutthroat
Flat Cr.	T30S,R3W	August	2	Cutthroat

Table 3. A list of the streams sampled in the Willamette River basin during the low flow period of 1977.

Stream	Location	Month	No. of study sections	Predominant species
S. Fk. Rock Cr.	T12S,R7W	August	5	Cutthroat
Oliver Cr.	T14S,R6W	August	7	Cutthroat
Big R.	T23S,R2W	August	7	Cutthroat
Mill Cr.	T16S,R1W	September	6	Cutthroat
Elk Cr.	T11S,R4E	June	1	Cutthroat
Rock Cr.	T10S,R3E	July	5	Steelhead
Cougar Cr.	T6S,R4E	August	5	Steelhead
Lukens Cr.	T6S,R4E	July	5	Steelhead

Table 4. Streams sampled in 1978 to test cutthroat habitat model.

Stream	Location	Month	No. of study sections
Mill Cr.	T16S,R1W	July	6
Oliver Cr.	T14S,R6W	July	8
S. Fk. Gate Cr.	T16S,R3E	August	2
Soda Fk.	T13S,R5E	August	4

Table 5. Streams sampled in 1978 to test the steelhead model.

Stream	Location	Month	No. of study sections
Lukens Cr.	T6S,R4E	August	5
Rock Cr.	T10S,R3E	September	5
Soda Fk.	T13S,R5E	August	2

RESULTS AND DISCUSSION

Model Development

Cutthroat trout

We constructed two habitat models that explain either 91% or 87% of the variation in cutthroat standing crop in 29 study sections of six streams (Figs. 7 and 8, and Table 6). The models compute a habitat quality rating (HQR_{ct}) which is the product of a cover value (C_{ct}), a velocity weighting factor (p) and the wetted area of the study section (A). They differ in the way the cover is calculated:

$$C_{ct1} = 13.859\ (D1) + 12.726\ (D2) + 13.591\ (EC) + 12.966\ (OH) + 93.298\ (T) \quad (1)$$

and

$$C_{ct2} = D1 + D2 + EC + OH + T + VS \quad (2)$$

where:

D1 = frequency of depths 46-60 cm;

D2 = frequency of depths greater than 60 cm;

EC = frequency of escape cover where the depth is greater than 5 cm (undercut banks, rootwads, undercut boulders, etc., within 50 cm upstream of the observation point);

OH = frequency of overhanging cover within 1 m of the surface where the depth is greater than 5 cm;

T = frequency of turbulence where the stream bottom is not visible and the depth is greater than 5 cm; and

VS = frequency of velocity shelter where the depth is greater than 5 cm (logs or boulders within 50 cm upstream of the observation point which slow the velocity).

The coefficients used in the calculation of C_{ct1} have no biological meaning and are not necessarily a unique solution to the equation. For this reason a simpler equation was constructed (C_{ct2}) and is proposed as an alternative.

Using the equations (1) and (2) we obtain the following:

$$HQR_{ct1} = (C_{ct1})\ (A)\ (p) \qquad (3)$$

and

$$HQR_{ct2} = (C_{ct2})\ (A)\ (p) \qquad (4)$$

The velocity weighting factor (p) is determined from a plot of standing crop and mean velocity for sections having similar cover values. Standing crop was adjusted to a scale from 0.0 to 1.0 such that the highest observed standing crop received a value 1.0. The values from this scale were then used as the velocity weighting factor (Fig. 9).

While cover (depths greater than 45 cm are treated as cover), appears to be the most important factor (of those examined) determining cutthroat trout

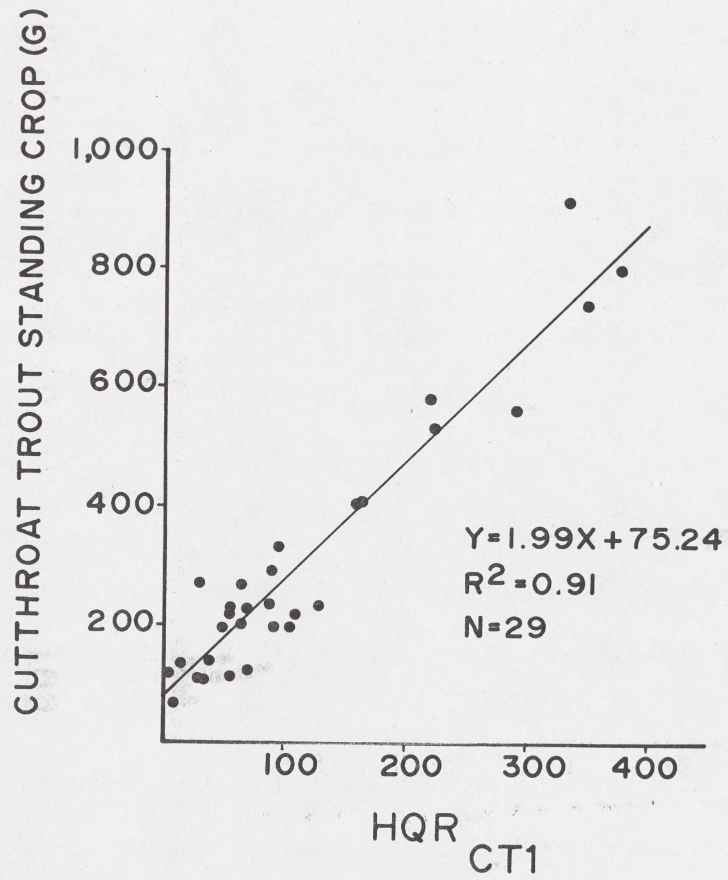

Figure 7. The relationship between HQR_{ctl} and cutthroat trout standing crop.

Table 6. Streams used to develop habitat models.

Cutthroat	Steelhead
Rancheria Cr.	Evans Cr.
Flat Cr.	Briggs Cr.
Elk Cr. (Clatsop Co.)[a]	Lukens Cr.
Oliver Cr.	Cougar Cr.
Mill Cr.	
Elk Cr. (Linn Co.)[a]	

[a] *above impassable falls*

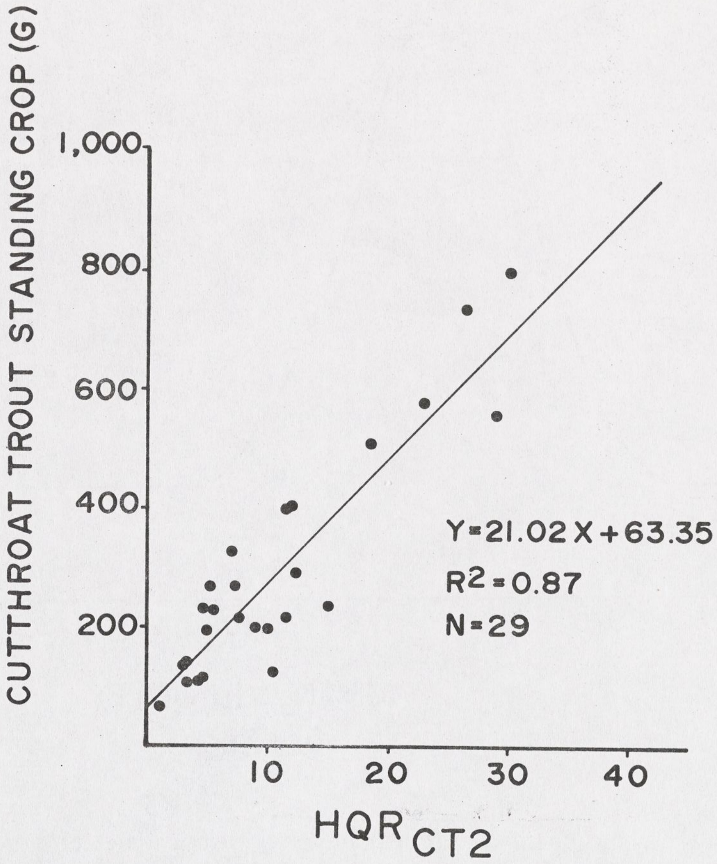

Figure 8. The relationship between HQR_{ct2} and cutthroat trout standing crop.

standing crop (coefficient of determination of 0.41 compared with 0.05 for velocity and 0.08 for area), velocity can decrease the value of the cover in a stream section if it is faster or slower than optimum. This is why we used the velocity weighting factor.

Steelhead trout

We constructed a habitat model which explains 79% of the variation in steelhead standing crop in 23 study sections in four streams (Fig. 10 and Table 6). This model is similar to the cutthroat models in that a habitat quality rating (HQR_{st}) is calculated for each stream section. The elements of HQR_{st} are cover (C_{st}), depth and velocity (DV), and wetted area (A).

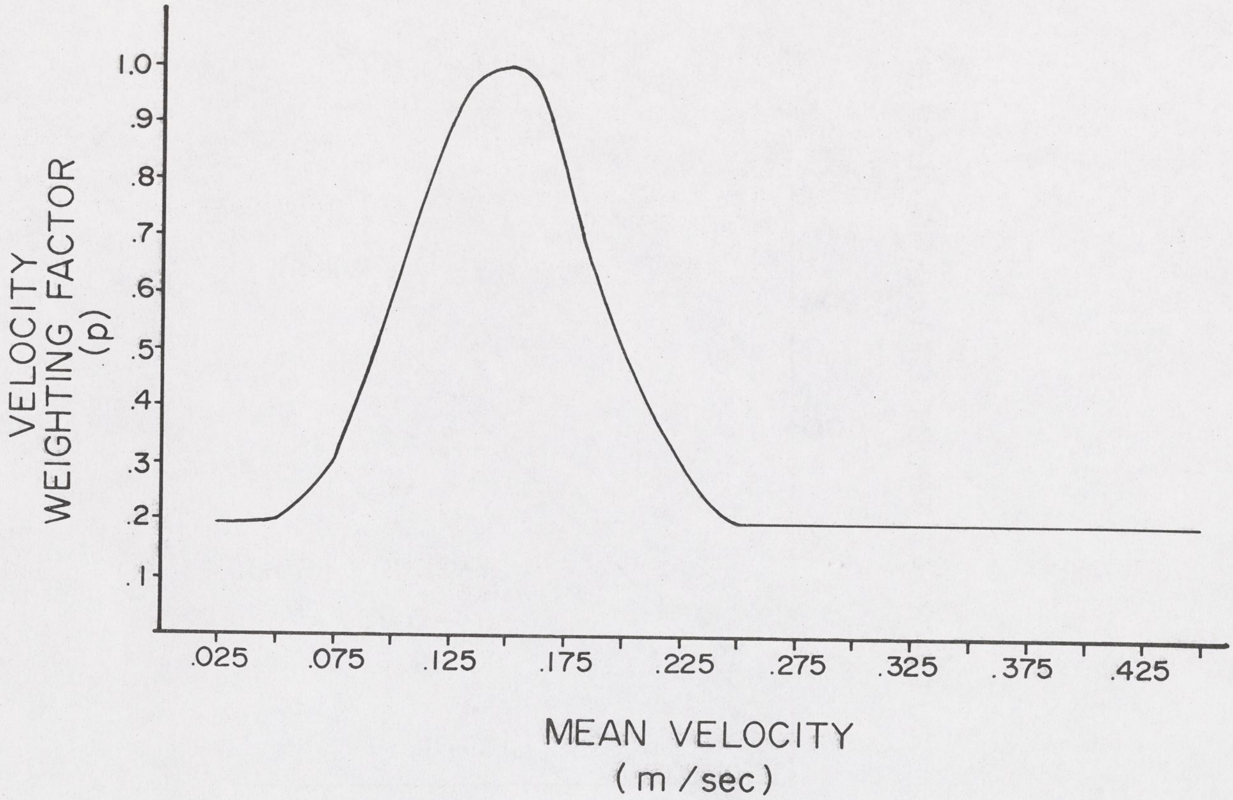

Figure 9. The velocity rating curve used to determine the velocity weighting factor (p).

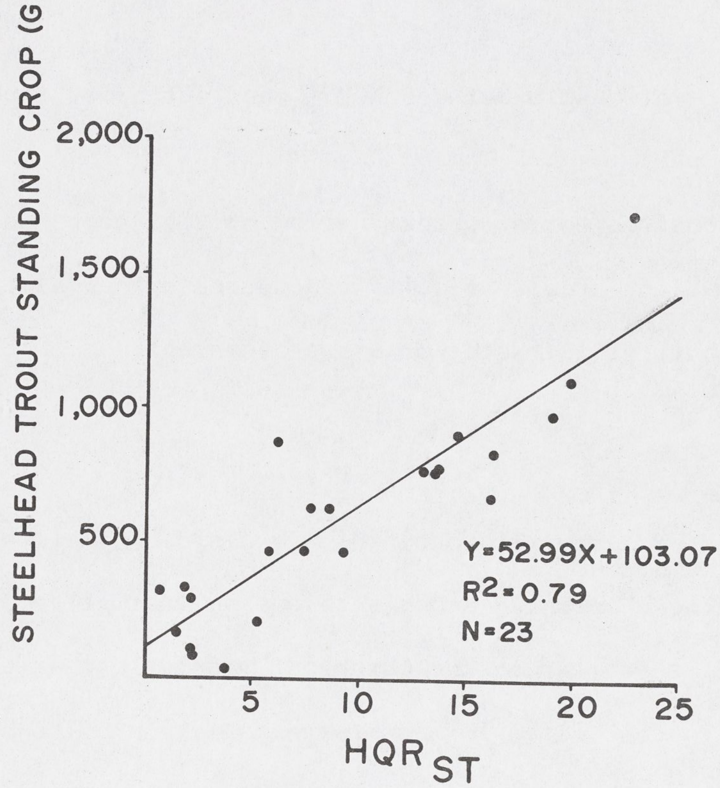

Figure 10. The relationship between HQR_{st} and juvenile steelhead trout standing crop.

Cover appears to be the most important factor determining the standing crop of juvenile steelhead (coefficient of determination of 0.67). Unlike equations 1 and 2, depth is not included as a cover type in the steelhead model.

Thus:

$$C_{st} = EC + OH + T + VS.$$

Depth and velocity have been combined into the single parameter DV using probability of use criteria developed by the Cooperative Instream Flow Service Group (IFG), U. S. Fish and Wildlife Service (Boveee and Cochnauer 1977; Bovee 1978). DV is the mean of the products of the depth (DP) and velocity (VP) probabilities (Fig. 11) for each of the n sampling locations in a study section. Thus we have:

$$DV = \frac{\Sigma(DP)\ (VP)}{n} \qquad (6)$$

Using the wetted area and equations 5 and 6 the habitat quality rating of a stream section is calculated from the equation:

$$HQR_{st} = (C_{st})\ (A)\ (DV) \qquad (7)$$

Assumptions and Hypotheses

Data from streams with populations we believed to be at or near maximum were used in developing the models. Trout standing crops plotted against stream habitat parameters, such as surface area, depth and cover, usually formed a pie-shaped distribution (Fig. 12). The standing crops of streams used in developing the models all fell near the upper left-hand edge of the distribution (shaded area) of Figure 12.

For six of eight cutthroat streams and four out of eleven steelhead streams sampled during the low flow period of 1977, the components of habitat included in the respective models explained more than 75% of the variation in

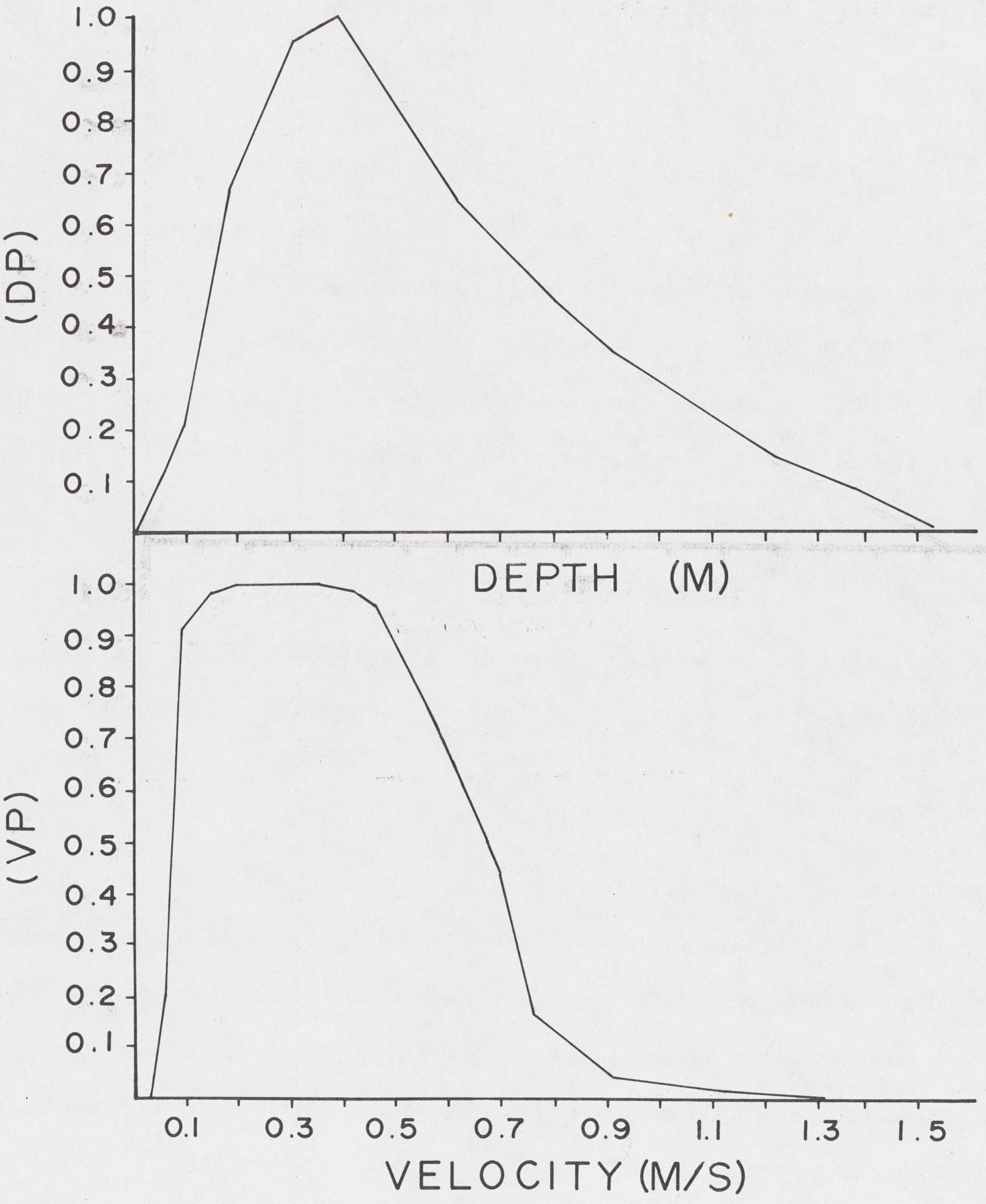

Figure 11. Probability of use criteria for juvenile steelhead trout. Adapted from Bovee (1978).

standing crop of all study sections (Fig. 7, 8 and 10). In three of the remaining seven steelhead streams, all except one study section fell within the 95% confidence limits of the regression line in Figure 10.

The models are one of four hypotheses that explain differences in salmonid standing crop between study sections (Table 7). Since the habitat models are still only hypotheses, they need to be tested. Ideally this testing should be done in streams which have been seeded to capacity. However it would be difficult to seed streams with wild trout and duplicate a natural age structure.

Therefore we sampled additional streams during the 1978 summer low flow

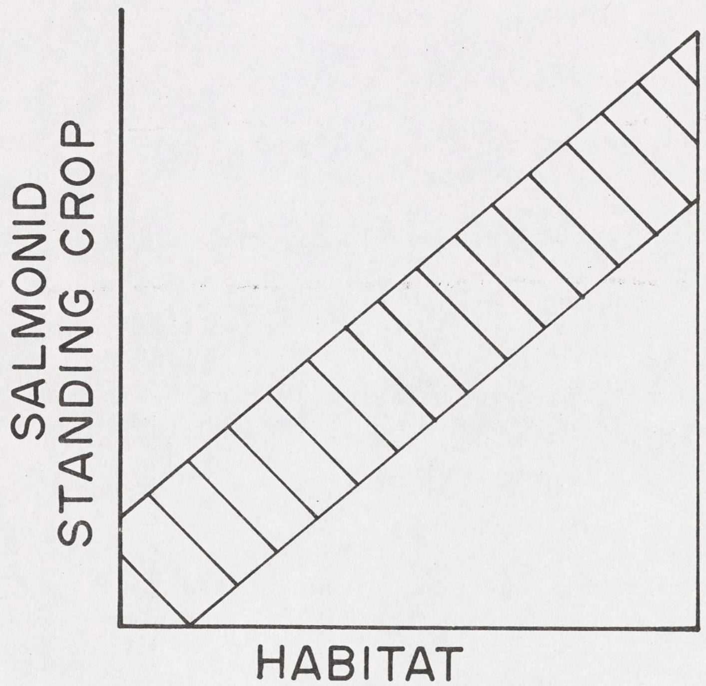

Figure 12. A schematic of the general distribution of salmonid standing crop plotted against stream habitat. Streams whose standing crops fall in the shaded area were used in developing models of the relationship between habitat and standing crop.

Table 7. Hypotheses developed to explain the differences in standing crop of salmonids observed between study sections.

Hypothesis

The potential of a stream to rear salmonids (measured as standing crop) during the low flow period is determined by the habitat parameters as presented in the models we have developed. All data points for as given species should fall within the 95% prediction interval.

Alternate Hypotheses for points which don't fall on the line.

Alternate Hypothesis 1

The stream can actually rear a larger standing crop than was present when the stream was sampled, however factors other than the rearing habitat have limited the standing crop of salmonids.

These factors can be broken into four categories:

1. Features of the habitat such as limited spawning area or poor water quality.

2. Biological factors such as poor escapement of spawners, predation or disease.

3. Random occurences such as floods or mudslides.

4. Harvest by anglers.

Alternate Hypothesis 2

The potential of a stream to rear salmonids during the low flow period is not predicted by the habitat model as presented.

Alternate Hypothesis 3

Our measurements of standing crop and habitat are erroneous.

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period (Tables 4 and 5) and determined the probability of erroneously predicting standing crop using the habitat models. Essentially this means determining the probability of a study section falling outside the 95% prediction intervals of the regression line and therefore having a standing crop different from the standing crop predicted by the habitat model.

1978 Results

Cutthroat trout

Only 48% of the 20 cutthroat sections sampled in 1978 fell within the 95% prediction intervals of the HQR_{ct1} model (Fig. 13) and 57% fell within the 95% prediction intervals of the HQR_{ct2} model (Fig. 14). Part of this difference may be due to the greater width of the prediction intervals of the HQR_{ct2} model due to the larger amount of variation in the original data.

Approximately 50% of the data points collected in 1978 fell above the prediction intervals of the models. The location of these points leads us to accept Alternative Hypothesis 2 (Table 7) i.e. the model is not a good predictor of trout standing crop. We believe the poor performance of the models is due to the way that velocity is incorporated into them.

In an effort to simplify the models and reduce the field measurements required to use them, we used mean velocity of the section to calculate the velocity weighting factor (Fig. 9). In 1977 only two of the ten sections having mean velocities $\geq$ 24 cm/s had trout densities greater than 2 g/m^2.

In 1978 summer flows were higher than in 1977 and 75% of the cutthroat sections sampled had mean velocities $\geq$ 24 cm/s. Of those 15 sections, eleven had trout densities greater than 2 g/m^2. These differences in trout density could not be accounted for by cover. Thus we now question the validity of some of the data which was used to develop the velocity weighting curve and use of mean velocity in the models. It may be that the mean velocity of the section is not a good predictor of the effects of velocity on a trout population.

Additional study is needed to determine how velocity should be incorpor-

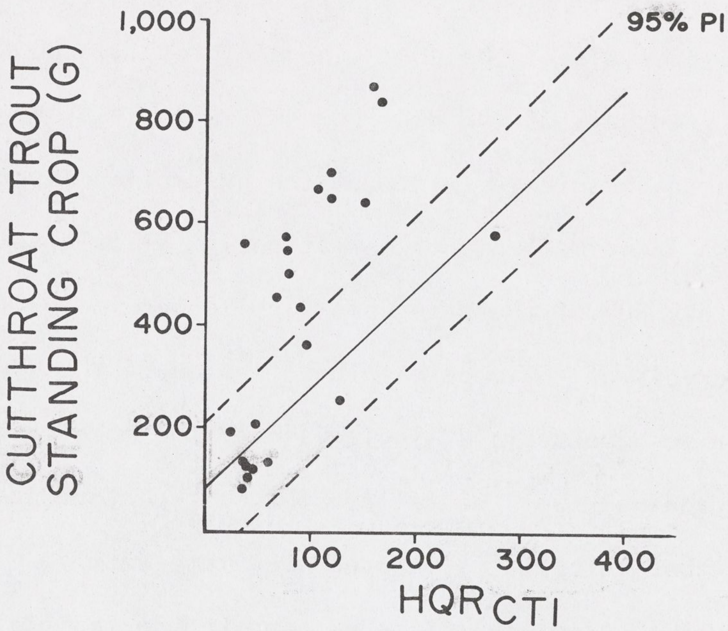

Figure 13. Distribution of data collected in 1978 in relation to the cutthroat trout habitat model.

ated into the habitat models for cutthroat trout. Ideally, additional data collection of the type which we have conducted should be done in streams which have been stocked such that the habitat is being used to its full potential by the trout population.

Steelhead trout

The steelhead model fared better than the cutthroat models. Seventy-five percent of the sections sampled in 1978 fell within the 95% prediction intervals of the HQR_{st} model (Fig. 15). More information is needed to determine which alternate hypopthesis (Table 7) is appropriate for the remaining 25% of the study sections. Since only twelve sections were used to test this model, more streams over a larger geographical area should be sampled before this model is widely used.

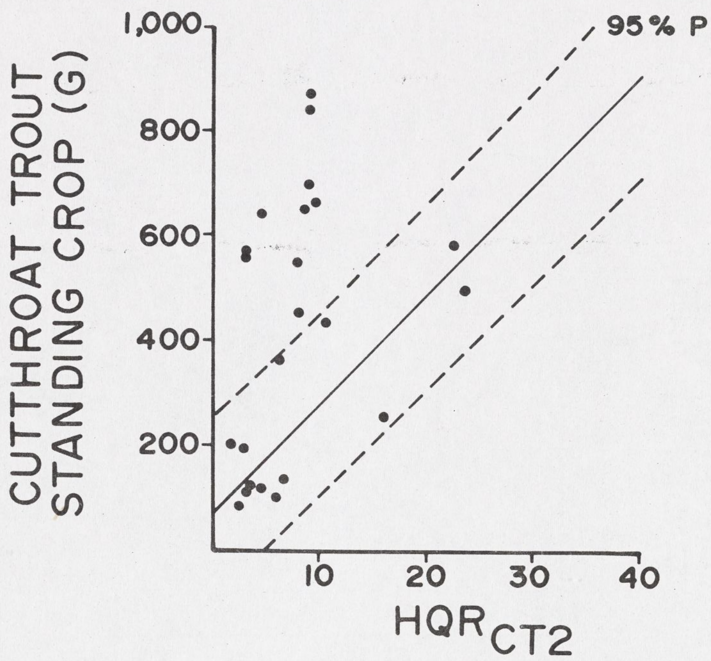

Figure 14. Distribution of data collected in 1978 in relation to the alternative cutthroat trout habitat model.

SUMMARY

At this time we feel additional study is needed to correct the problems in the cutthroat models and further test the steelhead model. We would advise those who use the models to keep in mind the proportion of the results which may be erroneous.

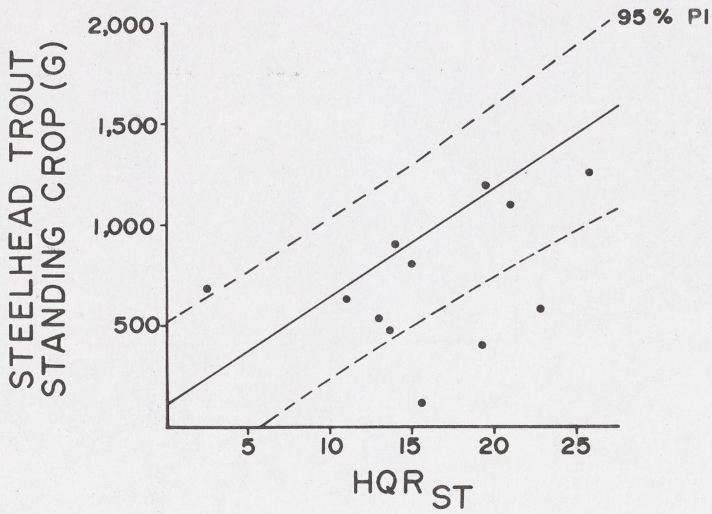

Figure 15. Distribution of data collected in 1978 in relation to the steelhead trout habitat model.

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Appendix I. Sampling Procedures

A. Standing crop of salmonids was estimated for each study section.

1. Population estimates were made by the two-pass or three-pass removal method. Each unit of effort consisted of a pass upstream and then downstream through the section with electrofishers. A blocking seine was placed at the bottom of the section and fish were collected from it at the end of each pass. When possible pools were seined as part of each unit of effort.
2. Length and weight were measured for all salmonids captured.
3. Standing crop was calculated from the population estimate and the mean weight of the fish captured.

B. Evenly spaced cross-sectional transects were established in each study section at 0.75-5.0 metre intervals perpendicular to the flow. Depth and velocity were measured and cover and substrate evaluated on each transect at 50 cm intervals for a total of at least 200 observations per study section. Stream width was measured on each transect.

1. Depth was measured to the nearest centimeter with a meter stick or stadia rod.
2. Velocity was measured with a Gurley meter at four tenths off the bottom for depths of $\geq$ 30 cm. At depths of <30 cm a red biodegradable dye was used to measure the time of travel from 25 cm above the observation point to 25 cm below the point.
3. Cover was recorded as follows:
   a. Undercut banks
   b. Overhanging cover (within 1 m)
   c. Velocity shelter - instream cover (logs, boulders, etc.) within 50 cm upstream of the observation point which

slows the velocity.

d. Escape cover - instream cover within 50 cm upstream of the observation point which, in addition to slowing the velocity, offers a hiding place (undercut boulders, root wads, etc.).

e. Turbulence cover - surface turbulence such that the stream bottom is not visible.

4. Substrate was evaluated as follows:

   a. Wood

   b. Bedrock

   c. Sand, silt or clay less than 2.5 mm diameter

   d. Small gravel 0.25 to 2.5 cm diameter

   e. Gravel 2.6 to 7.5 cm diameter

   f. Cobble 7.6 to 15.0 cm diameter

   g. Rubble-boulders 15.1 to 30.0 cm diameter

   h. Boulders greater than 30.0 cm diameter

5. Width was measured by recording the left and right waterlines of each stream channel which the transect encompasses.

Appendix II. Summary of data from streams sampled at low flow in 1977 for use in the habitat models.

Stream	Sec. no.	Mo.	Section Length	Average width (m)	Average depth (m)	Average velocity (m/sec)	Population estimate	Predominant species	Mean weight	Biomass
Oliver Cr.	1	8	34.6	3.66	.127	.156	8	Cutt.	29.45	235.59
"	2		17.8	3.50	.102	.230	3	"	45.55	136.66
"	3		26.0	3.48	.138	.114	6	"	33.04	198.22
"	4		41.6	3.58	.128	.153	13	"	61.46	798.94
"	5		23.6	4.85	.081	.191	5	"	25.29	126.46
"	6		23.1	5.05	.112	.212	12	"	16.43	197.14
"	7		32.5	3.71	.096	.236	9	"	15.86	142.70
Mill Cr.	1	9	67.5	5.31	.169	.214	25	Cutt.	22.49	562.15
"	2		49.9	5.46	.169	.228	19	"	30.71	583.45
"	3		65.5	7.72	.099	.242	10	"	23.62	236.16
"	4		34.3	5.28	.184	.320	13	"	31.02	403.31
"	5		24.5	4.31	.181	.583	10	"	27.29	272.92
"	6		29.0	10.38	.110	.283	5	"	23.29	116.45
Elk Cr. (Linn Co.)	6[a]	7	33.0	6.52	.122	.183	35	Cutt.	26.09	913.22
Flat Cr.	3[a]		30.5	3.72	.097	.240	3	Cutt.	39.82	119.45
"	4[a]		30.0	3.41	.128	.236	7	"	28.12	196.84
Rancheria Cr.	1	7	40.5	3.74	.144	.343	15	Cutt.	15.26	228.90
"	2		32.5	5.20	.179	.257	12	"	17.88	232.44
"	3		37.3	4.69	.156	.311	12	"	20.74	269.65
"	4		31.9	3.58	.135	.419	8	"	11.19	107.40
"	5		29.9	5.09	.243	.205	19	"	19.34	406.14
"	6		45.4	5.49	.147	.245	16	"	20.82	333.12
"	7		34.6	4.40	.144	.409	19	"	11.55	219.38
"	8		37.8	5.67	.124	.338	10	"	11.07	110.69

[a] *Other sections sampled not used because they contained mixed populations of salmonids.*

Appendix II continued

Stream	Sec. no.	Mo.	Section Length	Average width (m)	Average depth (m)	Average velocity (m/sec)	Population estimate	Predominant species	Mean weight	Biomass
Big River	1	8	35.5	10.89	.114	.222	3	Cutt.	66.07	198.21
"	2		36.9	9.92	.188	.182	3	"	51.62	154.85
"	3		38.0	8.33	.265	.129	40	"	39.75	1589.96
"	4		32.5	8.10	.142	.262	1	"	59.04	59.04
"	5		49.0	6.01	.212	.245	5	"	77.13	385.63
"	6		33.4	4.87	.221	.288	5	"	60.00	300.00
S. Fk. Rock Cr	1	8	37.5	4.21	.070	.133	16	Cutt.	12.46	211.86
(Marys)	2		27.1	3.32	.087	.138	9	"	17.12	171.20
"	3		37.4	2.40	.068	.099	13	"	14.40	288.00
"	4		22.0	2.97	.085	.174	15	"	15.81	316.27
"	5		36.0	3.83	.060	.129	10	"	11.88	332.64
Rock Cr.	1	7	41.5	7.52	.164	.325	24	Stlhd.	21.98	527.56
(Santiam)	2		26.4	5.80	.192	.353	34	"	28.70	1062.03
"	3		37.0	5.51	.216	.302	50	"	29.10	1483.99
"	4		32.5	5.29	.136	.459	30	"	30.07	902.10
"	5		39.0	6.82	.139	.271	40	"	30.40	1216.18
Lukens Cr.	1	7	35.5	6.66	.133	.256	86	Stlhd.	20.04	1723.25
"	2		21.5	4.93	.277	.231	49	"	20.13	986.26
"	3		30.5	5.77	.173	.269	63	"	17.65	1112.20
"	4		27.3	4.35	.202	.340	37	"	18.26	675.62
"	5		21.6	5.44	.250	.226	47	"	16.47	774.10
Cougar Cr.	1	8	31.3	3.69	.105	.343	21	"	22.47	471.92
"	2		36.5	3.71	.153	.269	43	"	19.47	837.21
"	3		33.6	5.10	.127	.274	31	"	24.49	759.31
"	4		31.0	5.38	.130	.282	43	"	20.99	902.46
"	5		25.0	4.61	.120	.249	32	"	19.76	632.16
Greyback Cr.	1	8	46.9	6.43	.177	.425	35	Stlhd.	18.68	653.78
"	2		46.3	6.18	.135	.405	55	"	14.47	795.64

Appendix II continued

Stream	Sec. no.	Mo.	Section Length	Average width (m)	Average depth (m)	Average velocity (m/sec)	Population estimate	Predominant species	Mean weight	Biomass
Greyback Cr.	3		41.2	5.33	.172	.279	45	Stlhd.	19.34	870.22
"	4		42.3	6.28	.173	.412	15	"	18.26	273.87
"	5		33.8	6.08	.175	.437	20	"	19.25	385.04
"	6		61.0	7.24	.173	.432	47	"	20.13	946.11
Althouse Cr.	1	7	39.0	8.20	.106	.364	21	Stlhd.	20.65	433.58
"	2		37.0	4.02	.234	.429	12	"	34.13 b/	527.43
"	3		32.6	7.01	.162	.320	8	"	57.22	457.74
"	4		22.6	5.68	.199	.317	13	"	21.92 b/	413.53
"	5		22.4	7.16	.121	.385	3	"	16.84	50.53
Jumpoff Joe Cr	1	6	38.0	3.83	.127	.356	15	Stlhd.	21.22	318.31
"	2		39.5	3.87	.278	.280	24	"	26.81	643.39
"	3		32.5	4.19	.125	.293	15	"	29.60	443.99
"	4		25.5	3.30	.150	.301	16	"	33.53	536.44
"	5		24.5	3.98	.143	.271	23	"	24.47	562.89
"	6		27.0	3.98	.187	.339	17	"	24.53	417.03
"	7		25.5	2.98	.136	.251	10	"	35.65	356.50
Briggs Cr.	1	9	55.4	5.64	.224	.109	8	Stlhd.	31.58	252.64
"	2		29.2	3.17	.085	.157	5	"	24.23	121.15
"	3		23.2	3.67	.228	.047	3	"	26.27	78.81
"	4		23.3	3.11	.078	.120	5	"	23.21	116.05
"	5		25.2	2.86	.167	.097	7	"	22.47	157.29
"	6		26.0	3.72	.135	.118	6	"	52.58	315.48
"	7		23.0	2.47	.100	.162	4	"	23.34	93.36
Taylor Cr.	1	8	32.0	2.90	.116	.067	1	Stlhd.	5.64	5.64
"	2		37.0	2.50	.106	.067	1	"	6.07	6.07
"	3		35.5	3.31	.172	.026	1	"	14.60	14.60

b/ *One large fish was excluded from calculation of mean but was included in biomass estimate.*

Appendix II continued

Stream	Sec. no.	Mo.	Section Length	Average width (m)	Average depth (m)	Average velocity (m/sec)	Population estmate	Predominant species	Mean weight	Biomass
Taylor Cr.	4		21.0	2.14	.118	.101	6	Stlhd.	17.83	106.98
"	5		27.0	2.64	.095	.093	14	"	16.01	224.14
"	6		33.0	2.32	.095	.102	15	"	20.59	308.85
Evans Cr.	1	8	41.0	4.02	.157	.172	42	Stlhd.	13.27	557.34
"	2		35.0	4.92	.122	.155	49	"	10.82	530.18
"	3		20.6	3.84	.097	.243	23	"	12.01	276.23
"	4		33.5	3.93	.108	.242	60	"	14.10	846.00
"	5		39.5	4.93	.136	.152	48	"	12.03	577.44
W. Fk. Evans	1	9	22.5	6.21	.072	.227	23	Stlhd.	6.48	149.04
Cr.	2		33.0	3.56	.196	.123	26	"	9.31	242.05
"	3		31.0	4.06	.167	.193	10	"	17.18	171.80
"	4.		32.0	4.23	.177	.346	17	"	9.78	166.26
"	5		35.0	6.74	.116	.179	20	"	7.19	143.80
Grave Cr.	1	7	40.8	7.83	.170	.277	44	"	12.85	565.52
"	2		36.3	8.02	.250	.157	25	"	16.04	400.98
"	3		32.3	5.73	.217	.151	21	"	12.56	263.78
"	4		40.7	11.50	.228	.074	22	"	16.35	359.73
"	5		47.4	4.42	.133	.231	29	"	16.81	487.43
"	6		37.6	4.95	.149	.183	35	"	12.56	439.61
"	7		39.7	5.61	.206	.110	15	"	12.87	193.05

[1979]

FINAL REPORT

FISH RESEARCH PROJECT
OREGON

PROJECT TITLE: Streamflow requirements of salmonids

PROJECT NUMBER: AFS-62

SEGMENT NUMBER: 8

JOB NUMBER: 1-4

CONTRACT NUMBER: 14-16-0001-78-525

PROJECT PERIOD: July 1, 1971 to June 30, 1979

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This project was financed in part with Anadromous Fish Act (PL 89-304) funds through the U. S. Fish and Wildlife Service.

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INTRODUCTION

The maintenance of adequate instream flows to support aquatic life is recognized as a major problem. In Oregon the primary concern is the protection of resident and anadromous salmonids. The Oregon Department of Fish and Wildlife has recommended minimum and optimum flows by month for several hundred streams based on passage, spawning, incubation and rearing requirements of salmonid species present (Thompson 1972). Of these, the flow requirements for rearing are the least understood. Oregon's recommended flows for rearing salmonids were based on a combination of physical measurements, general observations and judgement (Giger 1973). As a result, when conflicts for water arise the Department finds it difficult to justify the minimum rearing flows which it recommended.

In 1968 the Environmental Management Section of the (then) Oregon Wildlife Commission requested that the Research Section develop improved methods for determining rearing flows for salmonids. The purpose of this report is to summarize the research which was undertaken and our recommendations for implementation of our findings.

BACKGROUND

A literature survey was initiated in 1971 (Giger 1973) and preliminary investigations of research designs and methods were conducted on Elk Creek (Fig. 1), a coastal stream, in the summers of 1973 (Keeley and Nickelson 1974) and 1974 (Nickelson 1975). It became apparent that a major flaw in the "Oregon Method" as well as in methods proposed by Chrostowski (1972), Tennant (1972) and Collings et al. (1970) was that they could not predict the effects of a given amount of flow reduction on the standing crop of salmonids rearing in a given stream reach, and that development of future methods should be aimed at developing an incremental method which would quantify the changes in salmonid standing crop caused by a given amount of flow reduction.

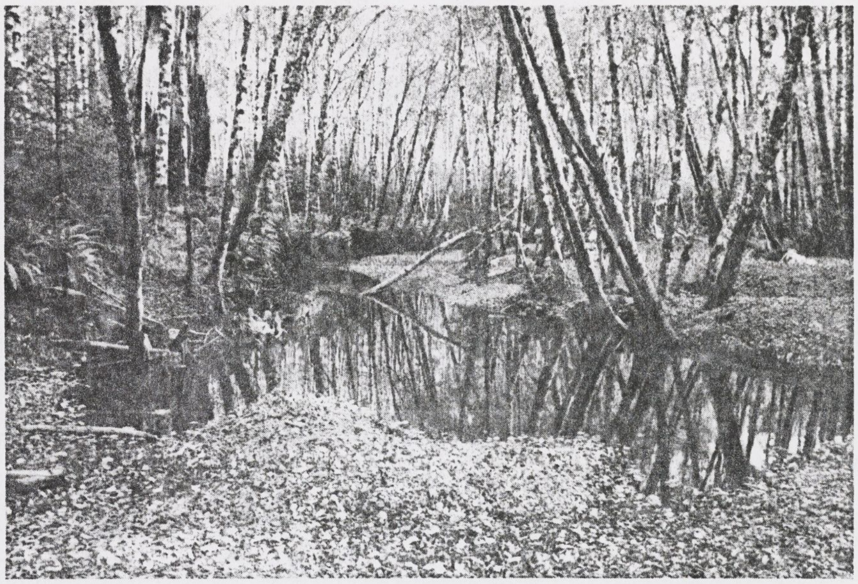

Fig. 1. A typical reach of Elk Creek, Caltsop County, Oregon.

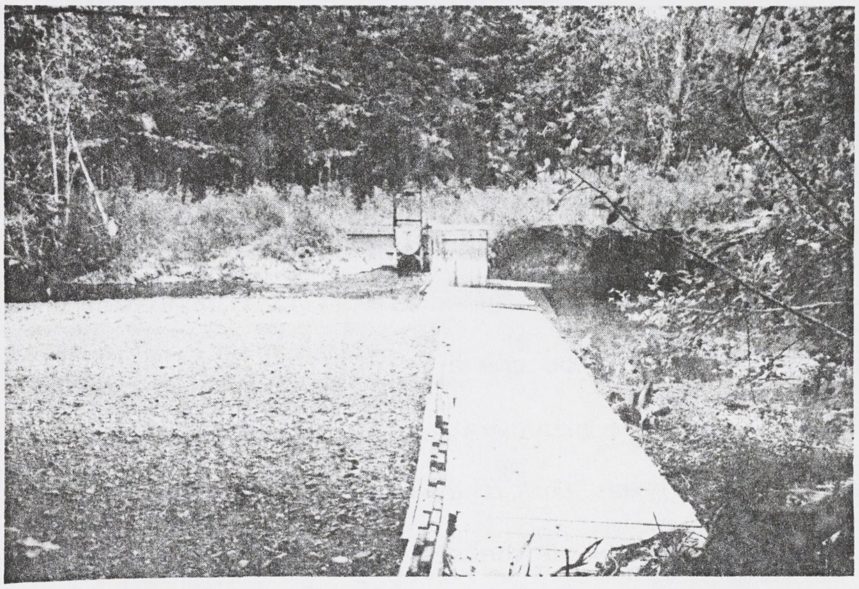

Fig. 2. The flow control facility at Elk Creek.

In 1975 and 1976 we conducted controlled flow experiments at Elk Creek with the objective of determining the relationship between percentage reductions in flow from the 5 year recurring low flow and the standing crop of juvenile coho salmon (*Oncorhynchus kisutch*) and coastal cutthroat trout (*Salmo clarki clarki*) (Nickelson 1976). A wood piling weir (Fig. 2) and a corrugated metal pipe were used to divert flow from the North Fork to the West Fork of Elk Creek. This facility allowed flows to be controlled at a constant level in the North Fork where our experiments were conducted. Each flow level was maintained for a two-week period during the summer low flow period (Table 1).

Table 1. Summary of flows studied at Elk Creek in 1975 and 1976.

1975		1976	
Litres/sec.	Percent of Min. flow	Litres/sec.	Percent of Min. flow
84	100	168	200
63	75	112	133
42	50	63	75
21	25	42	50

Salmon densities, which were inconsistent between years possibly due to summer floods and our stocking of the Elk Creek study sections, vitiated the results of these experiments. We decided to abandon the controlled flow approach at Elk Creek because of our inability to control flows throughout the summer.

We concluded that the most useful methodology for determining minimum flows would be a habitat model which correlated stream habitat to salmonid standing crop in any stream combined with a hydraulic simulation model which would predict the habitat value of a stream reach at any given flow. A habitat model was developed for coho based on data from Elk Creek (Nickelson 1976) and then improved upon with data from three northern Oregon coastal streams (Nickelson and Reisenbichler 1977).

In 1977 our field work shifted to the Rogue River Basin in southern Oregon. In April of that year the Oregon Department of Fish and Wildlife entered into a contract with the Office of Biological Services, U.S. Fish and Wildlife Service to develop models that could predict the standing crop of cutthroat and steelhead trout (*Salmo gairdneri gairdneri*) in Willamette Basin streams.

Data collected in 1976 and 1977 were used to develop habitat models for juvenile coho salmon, cutthroat trout and steelhead trout. Data collected in 1978 were used to test the models.

SUMMARY OF HABITAT MODELS

Model Development

Cutthroat trout

We developed two habitat models that explain 91% and 87% of the variation in standing crop of age I+ and older cutthroat trout in 29 study sections of six streams depending on how cover is calculated (Figs. 3 and 4 and Table 2). The models compute a habitat quality rating (HQR_{ct}) which is the product of a cover value (C_{ct}), a velocity weighting factor (p) and the wetted area of the study section (A).

$$C_{ct1} = 13.859\ (D1) + 12.726\ (D@) + 13.591\ (EC) + 12.966\ (OH) + 93.298\ (T) \quad (1)$$

and

$$C_{ct2} = D1 + D2 + EC + OH + T + VS \quad (2)$$

Table 2. Streams used to develop habitat models.

Cutthroat	Coho	Steelhead
Rancheria Cr. (Rogue)	Elk Cr. (Pacific Ocean)	Evans Cr. (Rogue)
Flat Cr. (Rogue)	Bergsvik Cr. (Necanicum)	Briggs Cr. (Rogue)
Elk Cr. (Pacific Ocean)[a]	Beneke Cr. (Nehalem)	Lukens Cr. (Willamette)
Oliver Cr. (Willamette)	Cronin Cr. (Nehalem)	Cougar Cr. (Willamette)
Mill Cr. (Willamette)		
Elk Cr. (Willamette)[a]		

[a]*Above impassable falls.*

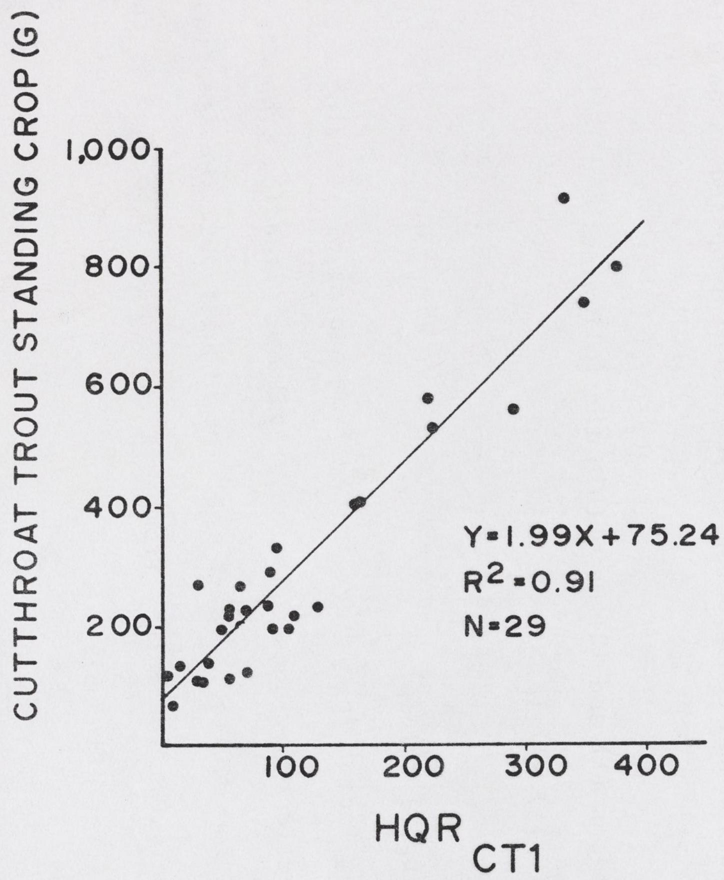

Fig. 3. The relationship between cutthroat habitat quality (HQR_{ct1}) and cutthroat trout standing crop.

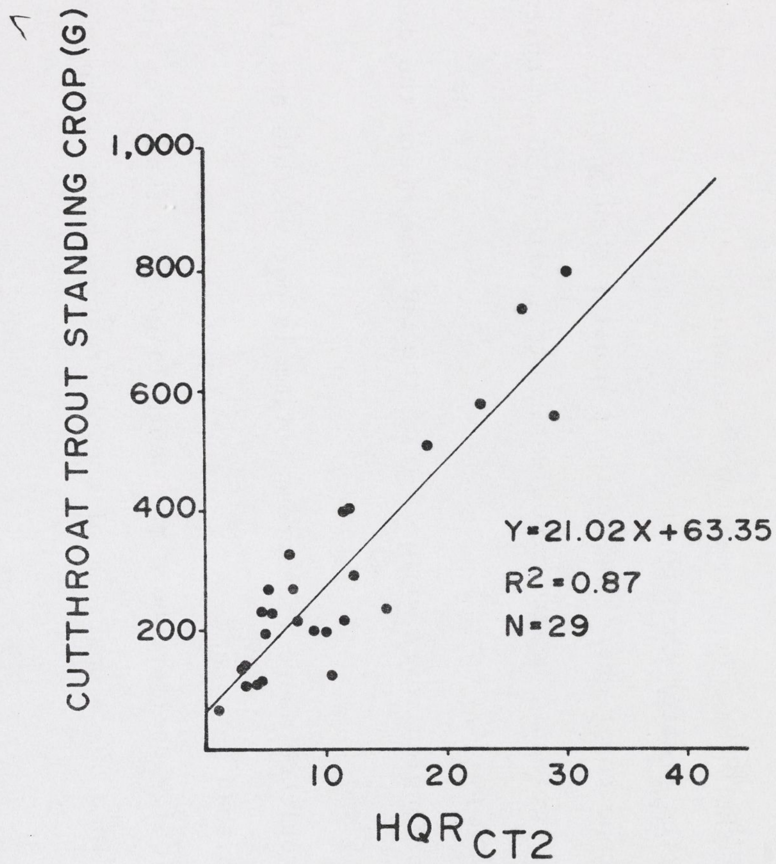

Fig. 4. The relationship between cutthroat habitat quality (HQR_{ct2}) and cutthroat trout standing crop.

where:

D1 = frequency of depths 46-60 cm;

D2 = frequency of depths greater than 60 cm;

EC = frequency of escape cover where the depth is greater than 5 cm (undercut banks, rootwads, undercut boulders, etc., within 50 cm upstream of the observation point);

OH = frequency of overhanging cover within 1 m of the surface where the depth is greater than 5 cm;

T = frequency of turbulence where the stream bottom is not visible and the depth is greater than 5 cm; and

VS = frequency of velocity shelter where the depth is greater than 5 cm (logs or boulders within a 50 cm upstream of the observation point which slow the velocity).

The coefficients used in the calculation of C_{ct1} have no biological meaning and are not necessarily a unique solution to the equation. For this reason a simpler equation was constructed (C_{ct2}) and is proposed as an alternative.

Using the equations (1) and (2) we obtain the following:

$$HQR_{ct1} = (C_{ct1})\ (A)\ (p) \tag{3}$$

and

$$HQR_{ct2} = (C_{ct2})\ (A)\ (p) \tag{4}$$

The velocity weighing factor (p) is determined from a plot of standing crop and mean velocity for sections having similar cover values. Standing crop was adjusted to a scale from 0.0 to 1.0 such that the highest observed standing crop received a value 1.0. The values from this scale were then used as the velocity weighting factor (Fig. 5).

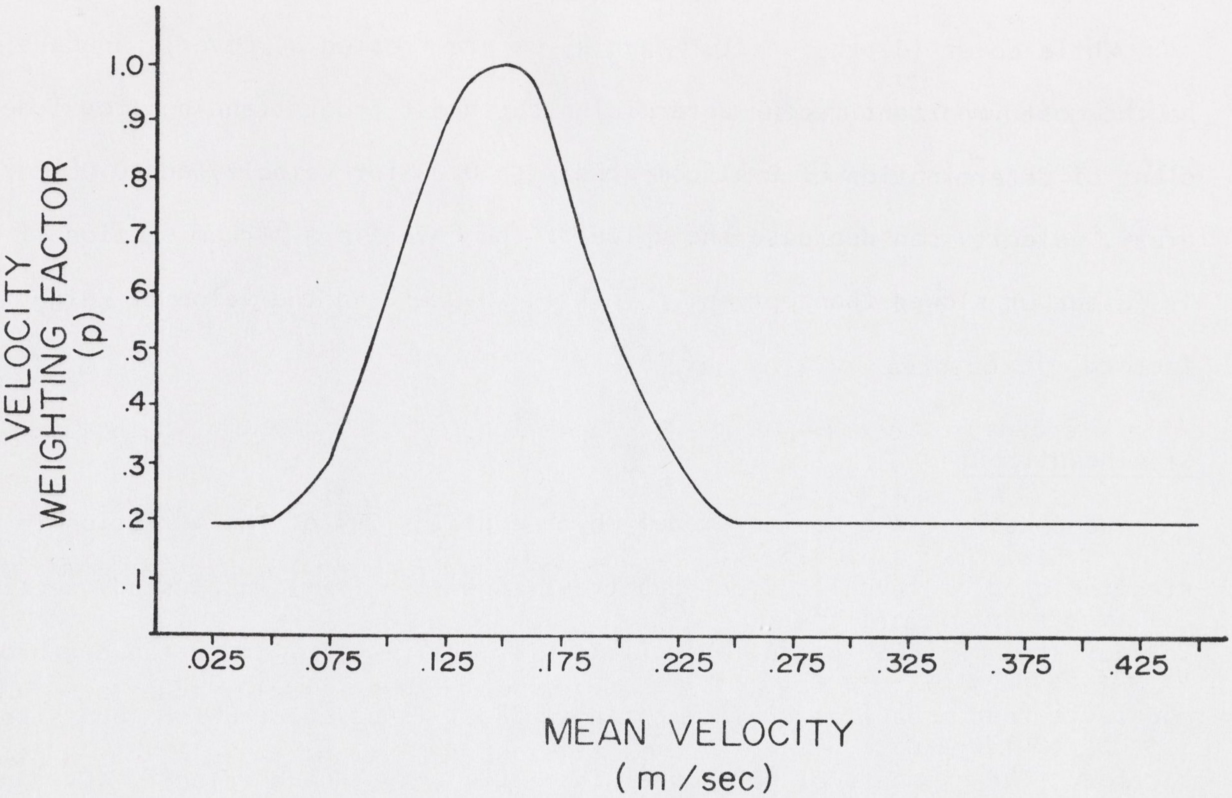

Fig. 5. The velocity rating curve used to determine the velocity weighting factor (p).

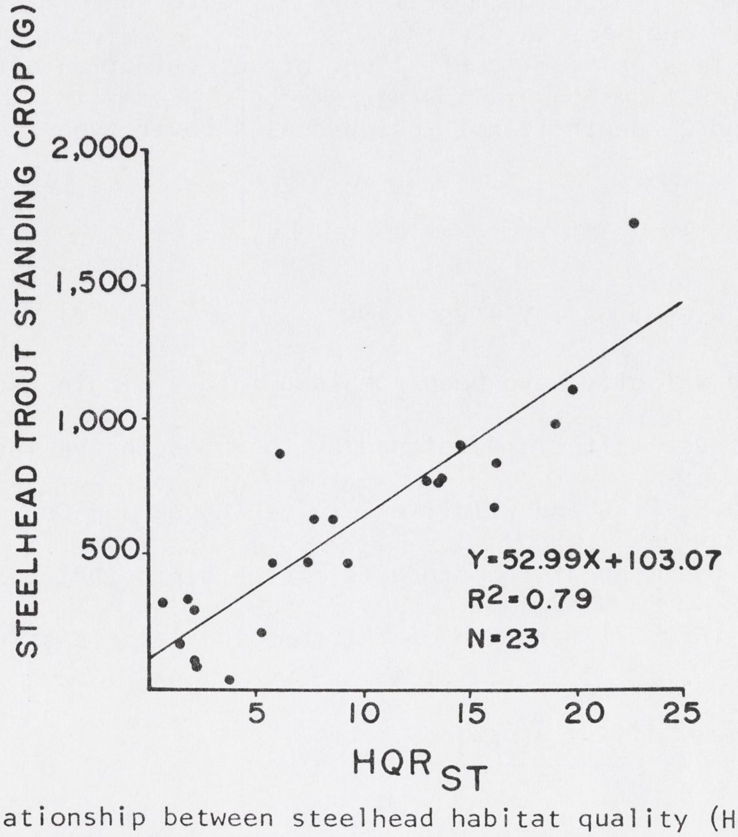

Fig. 6. The relationship between steelhead habitat quality (HQR_{st}) and juvenile steelhead trout standing crop.

While cover (depths greater than 45 cm are treated as cover), appears to be the most important factor determining cutthroat trout standing crop (coefficient of determination of 0.41 compared with 0.05 for velocity and 0.08 for area), velocity can decrease the value of the cover in a stream section if it is faster or slower than optimum. This is why we used the velocity weighting factor.

Steelhead trout

We constructed a habitat model which explains 79% of the variation in standing crop of juvenile steelhead trout (age I+ - III+) in 23 study sections in four streams (Fig. 6 and Table 2). This model is similar to the cutthroat models in that a habitat quality rating (HQR_{st}) is calculated for each stream section. The elements of HQR_{st} are cover (C_{st}), depth and velocity (DV) and wetted area (A).

Cover appears to be the most important factor determining the standing crop of juvenile steelhead (coefficient of determination of 0.67). Unlike equations 1 and 2, depth is not included as a cover type in the steelhead model.

Thus:

$$C_{st} = EC + OH + T + VS. \quad (5)$$

Depth and velocity have been combined into a single parameter DV using probability-of-use criteria developed by the Cooperative Instream Flow Service Group (IFG), U.S. Fish and Wildlife Service (Bovee and Cochnauer 1977; Bovee 1978). DV is the mean of the products of the depth (DP) and velocity (VP) probabilities (Fig. 7) for each of the sampling locations (n) in a study section. Thus we have:

$$DV = \frac{\Sigma[(DP)(VP)]}{n} \quad (6)$$

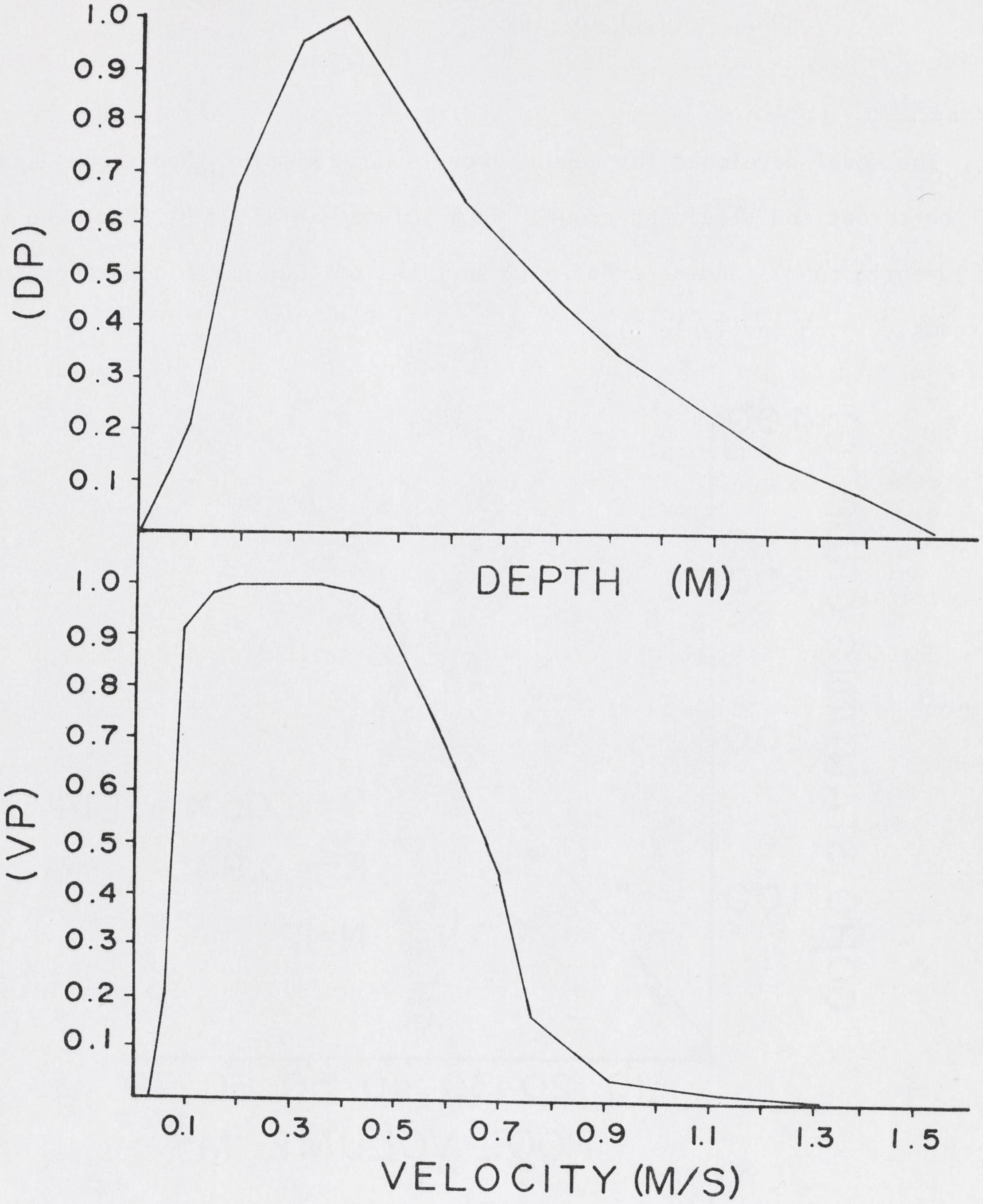

Fig. 7. Probability of use criteria for juvenile steelhead trout. Adapted from Bovee (1978).

Using the wetted area and equations 5 and 6 the habitat quality rating of a stream section is calculated from the equation:

$$HQR_{st} = (C_{st})\ (A)\ (DV). \qquad (7)$$

<u>Coho salmon</u>

The model developed for coho salmon is much simpler than those developed for cutthroat and steelhead trout. Pool volume explained 93.5% of the variation in juvenile coho standing crop in 12 sections of four north coast Oregon streams (Fig. 8 and Table 2).

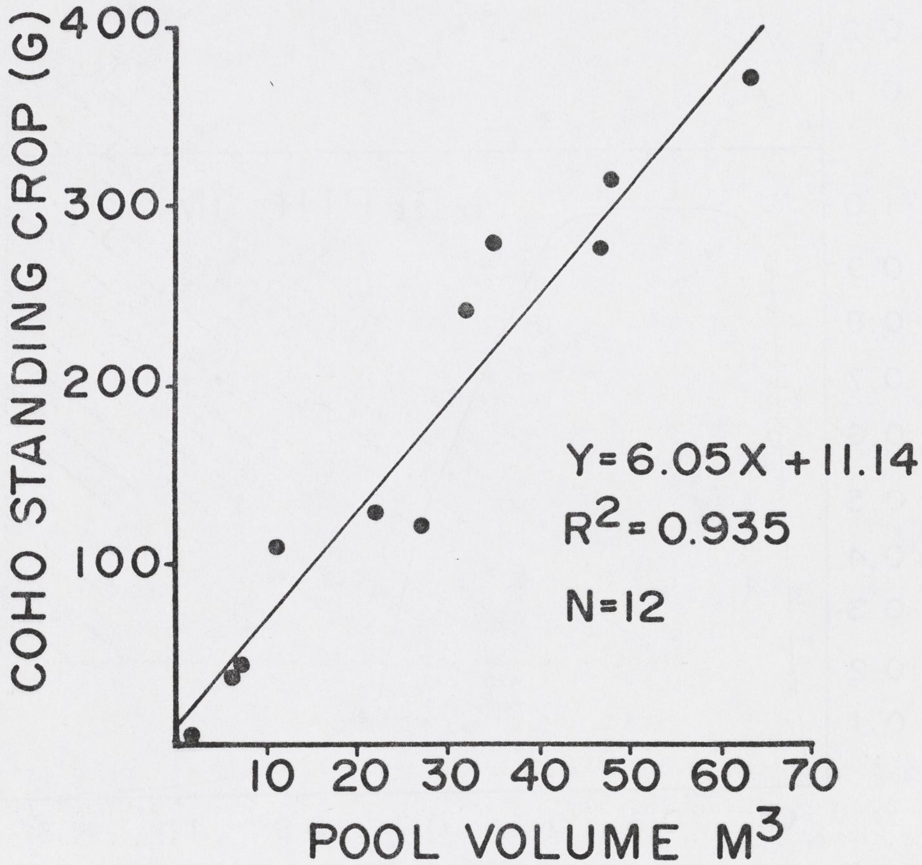

Fig. 8. The relationship between pool volume and juvenile coho salmon standing crop.

Assumptions and Hypotheses

Data from streams with populations we believed to be at or near the capacity of the available habitat were used in developing the models. This was to assure that existing habitat was influencing standing crop. Trout standing crops plotted against stream habitat parameters, such as surface area, depth and cover, usually fall in a triangular-shaped area (Fig. 9). The standing crops of streams used in developing the models all fell near the upper left-hand edge of the distribution (cross-hatched area) of Figure 9.

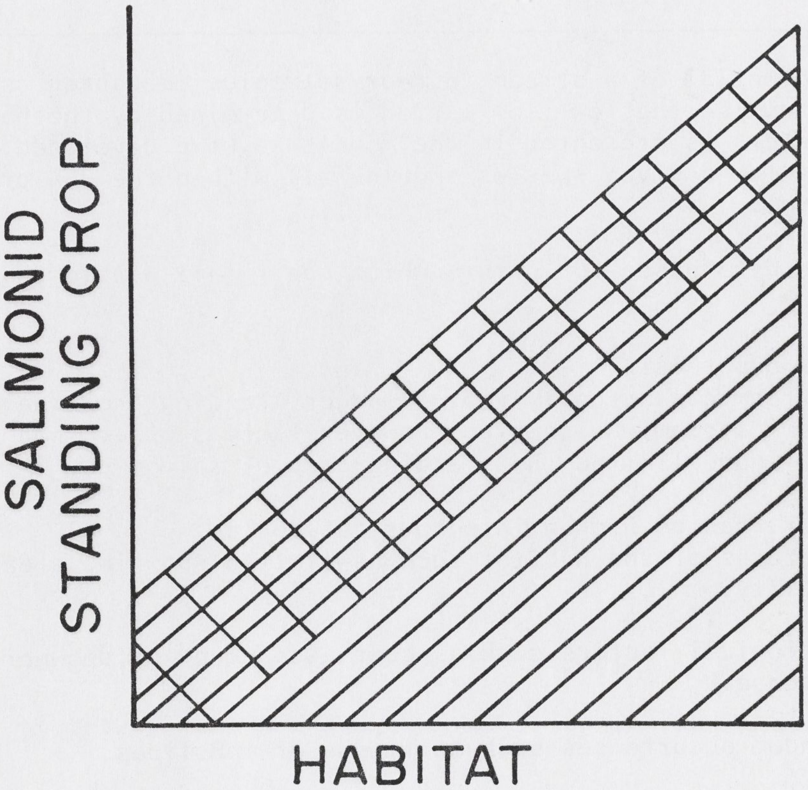

Fig. 9. A schematic of the general distribution of salmonid standing crop plotted against stream habitat. Streams whose standing crops fall in the cross-hatched area were used in developing models of the relationship between habitat and standing crop.

The models were one of four hypotheses that explain differences in salmonid standing crop between study sections (Table 3). Since the habitat models were still only hypotheses, they needed to be tested. Ideally this testing should have been done in streams which were seeded to capacity. However it would be be difficult to seed streams with wild trout and duplicate a natural age structure. Therefore we sampled additional streams during the 1978 summer low flow period and determined the probability of erroneously predicting standing crops using the habitat models. Essentially we determined the probability of a study section falling outside the 95% prediction intervals of the regression line and therefore having a standing crop different from the standing crop predicted by the habitat model.

Table 3. Hypotheses developed to explain the observed differences in standing crop of salmonids among study sections.

The potential of a stream to rear salmonids (measured as standing crop) during the low flow period is determined by the habitat parameters as presented in the models we have developed. All data points for a given species should fall within the 95% prediction interval.

Alternative Hypotheses for points which don't fall within the prediction interval.

Alternative Hypothesis 1

The stream can actually rear a larger standing crop than was present when the stream was sampled, however factors other than the rearing habitat have limited the standing crop of salmonids.

These factors can be broken into four categories:

1. Features of the habitat such as limited spawning area or poor water quality.

2. Biological factors such as poor escapement of spawners, predation or disease.

3. Random occurrences such as floods or mudslides.

4. Harvest by anglers.

Alternative Hypothesis 2

The potential of a stream to rear salmonids during the low flow period is not predicted by the habitat model as presented.

Alternative Hypothesis 3

Our measurements of standing crop and habitat are erroneous.

TESTING THE MODELS

Methods

We established 1-10 study sections in each stream sampled in 1978 (Tables 4 and 5). Study sections ranged from 20 to 70 cm and consisted of one riffle and one pool or in some cases a series of small riffles and pools.

In the coho streams (Table 6) study sections consisted of individual pools. In seven of these streams, every tenth pool was sampled throughout the length of stream accessable to coho. The Devils Lake Fork was not sampled as intensively as most of our coho study streams due to its larger size. Twenty-five pools were sampled in the mainstem and 17 pools were sampled in five tributaries.

Table 4. Streams sampled in 1978 to test the cutthroat habitat model.

Stream	Month	No. of study sections	Flow (cfs)
Mill Cr.	July	6	7.7
Oliver Cr.	July	8	6.4
S. Fk. Gate Cr.	August	2	9.8
Soda Fk.	August	4	21.3

Table 5. Streams sampled in 1978 to test the steelhead habitat model.

Stream	Month	No. of study sections	Flow (cfs)
Lukens Cr.	August	5	15.2
Rock Cr.	September	5	20.5
Soda Fk.	August	2	21.3

Table 6. Streams sampled in 1978 to test the coho habitat model.

Stream	Month	No. of study sections	Flow (cfs)
Cronin Cr.	August	70	4.6
Farmer Cr.	August	28	5.0[a]
Horse Cr.	July	48	1.7
Green Cr.	August	33	0.8
Marlow Cr.	August	53	2.0
Alder Cr.	August	19	1.7
Moon Cr.	September	31	0.9
Devils Lake Fk.	August	24	31.0
5 tributaries	August	17	0.4-6.1

[a]*Estimated low flow from past records.*

Standing crop[1] of each species of salmonid was calculated from a population estimate made by the removal method (Zippin 1958) and the mean weight of the fish captured.

To describe trout habitat, depth, velocity, cover and substrate were measured at a minimum of 200 locations per study section on transects placed on perpendicular to the thalweg (Fig. 10; Appendix 1). On the coho streams, pool volume was measured using a grid system which is described in Appendix 1.

Fig. 10. Measuring stream habitat.

[1]*Trout standing crop does not include age 0+ fish.*

Results

Cutthroat trout

Only 48% of the 20 cutthroat sections sampled in 1978 fell within the 95% prediction intervals of the HQR_{ct1} model (Fig. 11) and 57% fell within the 95% prediction intervals of the HQR_{ct2} model (Fig. 12). Part of this difference may be due to the greater width of the prediction intervals of the HQR_{ct2} model due to the larger amount of variation in the original data.

Approximately 50% of the data points collected in 1978 fell above the prediction intervals of the models. The location of these points leads us to conclude that the model is not a good predictor of trout standing crop. We believe the poor performance of the models is due to the way that velocity was incorporated into them.

In an effort to simplify the models and reduce the field measurements required to use them, we used mean velocity of the section to calculate the velocity weighting factor (Fig. 5). In 1977 only two of the ten sections having mean velocities ≥ 24 cm/s had trout densities greater than 2 g/m^2. In 1978 summer flows were higher than in 1977 and 75% of the sections sampled had mean velocities ≥ 24 cm/s. Of these 15 sections, eleven had trout densities greater than 2 g/m^2. These differences in trout density could not be accounted for by cover. Thus we now question the validity of some of the data which was used to develop the velocity weighting curve and use of mean velocity in the models. It may be that the mean velocity of the section is not a good predictor of the effects of velocity on a trout population.

Additional study is needed to determine how velocity should be incorporated into the habitat models for cutthroat trout. Ideally, additional data should be from streams which have been stocked such that the habitat is being used to its full potential by the trout population.

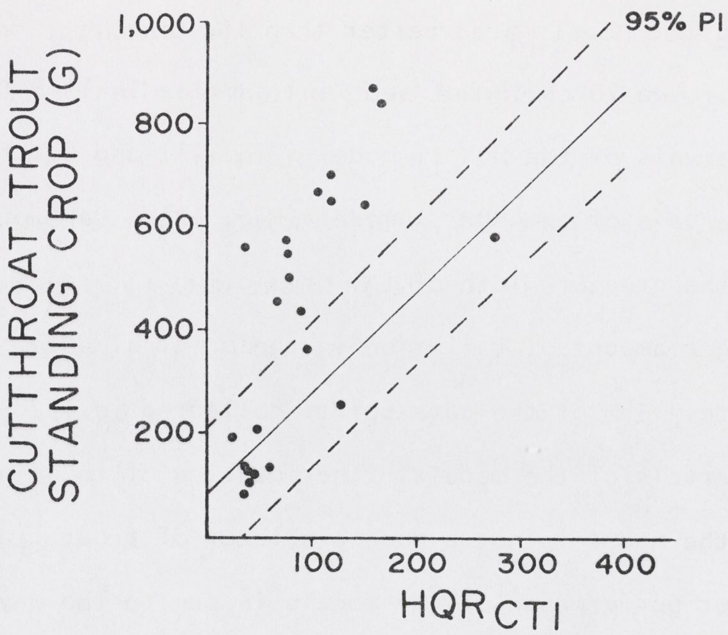

Fig. 11. Distribution of data collected in 1978 in relation to the cutthroat trout habitat model.

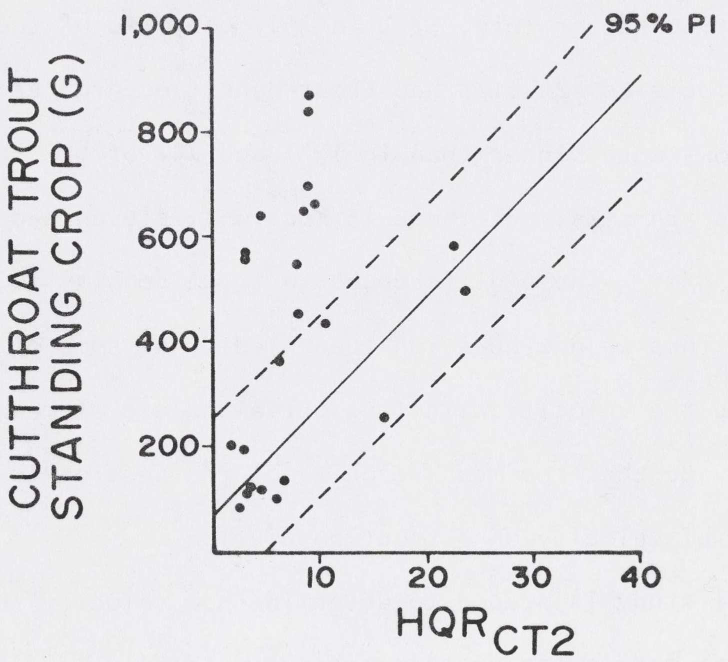

Fig. 12. Distribution of data collected in 1978 in relation to the alternative cutthroat trout habitat model.

Steelhead trout

The steelhead model fared better than the cutthroat models. Seventy-five percent of the sections sampled in 1978 fell within the 95% prediction intervals of the HQR_{st} model (Fig. 13). More information is needed to determine which alternate hypothesis (Table 3) is appropriate for the remaining 25% of the study sections. Since only twelve sections were used to test this model, more streams over a larger geographical area should be sampled before this model is widely used.

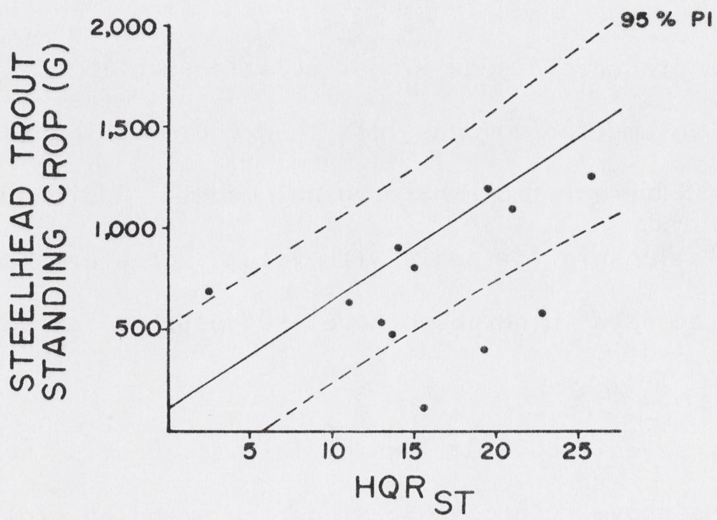

Fig. 13. Distribution of data collected in 1978 in relation to the steelhead trout habitat model.

Coho salmon

A total of 318 pools were sampled for coho salmon in eight study streams during the 1978 low flow period. Eighty-eight percent of the study sections fell within the 95% prediction intervals of the pool volume-coho standing crop model (Table 7). However, the original model consisted of data from only 12 pools, whereas more than 12 pools were sampled from each stream in 1978. We therefore developed a new relationship between pool volume and coho standing crop based on the new set of data.

Table 7. A summary of the pool volume-coho standing crop relationship in relation to the 95% prediction intervals of the coho habitat model.

Stream	Number of sections	Number within 95% PI	Number below 95% PI	Number above 95% PI
Alder Cr.	19	19	0	0
Marlow Cr.	53	44	0	9
Green Cr.	33	31	2	0
Horse Cr.	48	44	0	4
Farmer Cr.	28	26	1	1
Devils Lake Fk.	24	14	7	3
tributaries	17	14	0	3
Cronin Cr.	65	60	0	5
Moon Cr.	31	29	0	2
Totals	318	281 (88%)	10 (3%)	27 (8%)

This data produced a good linear relationship (R^2=0.72) between standing crop and pool volume for volumes less than 100 m^3 (Fig. 14) which is not significantly different from the original model. Additional data is needed to define the relationship for pools with volumes greater than 100 m^3, however, the very limited data which we do have, suggests a flattening off of the relationship.

The first seven study sections of mainstem Devils Lake Fork were not included in the above relationship since the standing crop for a given pool volume in these sections fell much below that of the other streams and this reach of stream is many times larger than the other streams (Table 6). A second line (R^2=0.71) with a flatter slope (2.70 compared to 7.49) described the relationship between pool volume and coho standing crop for the lower Devils Lake Fork (Fig. 14). Thus, we have a relationship for small streams and the beginning on one for large streams.

DISCUSSION

The purpose of this project was to develop a method which could be used to recommend minimum streamflows for rearing salmonids in Oregon streams. We felt

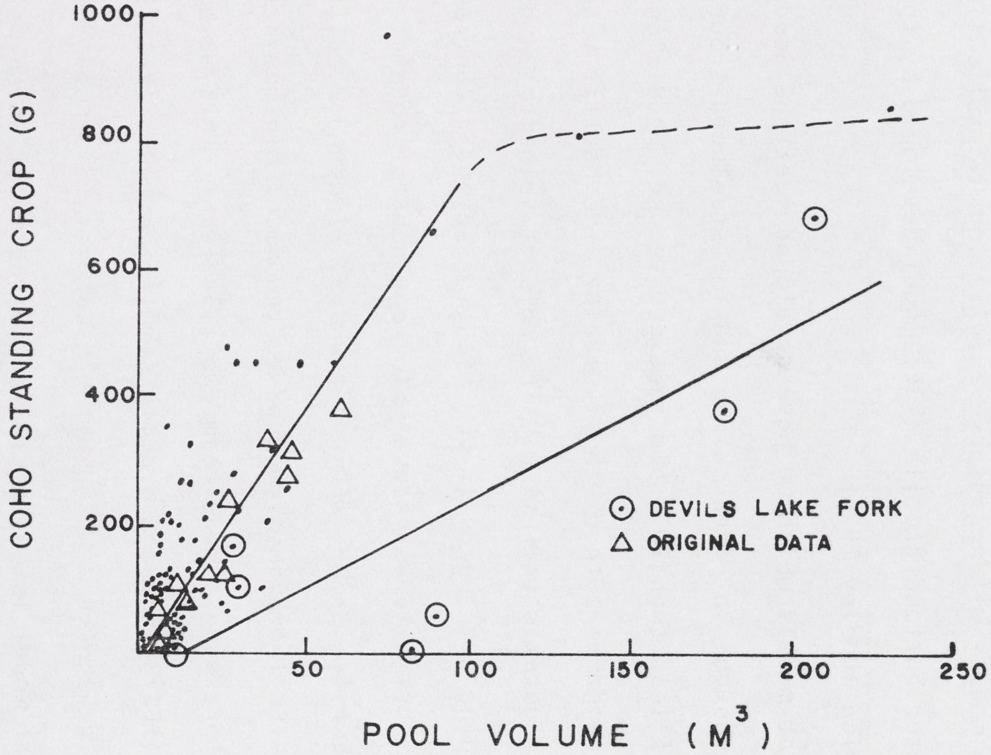

Fig. 14. The relationships between pool volume and juvenile coho standing crop. The upper curve is developed from several streams, the lower is from only Devils Lake Fork.

that to be of value, the technique must be incremental in nature, such that for a given increment of flow reduction, the increment of impact on the salmonid population could be predicted. The method would consist of two parts: 1) a model which defines the relationship between habitat and the standing crop of a given species which that habitat could support; and 2) a hydraulic simulation model which will predict the habitat value of a given reach of stream at any given flow. We concentrated our effort on the development of habitat models and planned to modify, if necessary, an existing hydraulic simulation model such as the Water Surface Profile (WSP) model developed by the Water and Power Resources Service (Dooley 1976).

The habitat models which we have developed meet the needs of the first part of the technique for coho salmon and for steelhead trout in streams having summer flows of less than 10 cubic feet per second. Additional data would be valuable to strengthen both of these models. The habitat models for cutthroat trout are inadequate at this time. The role of velocity in determining cutthroat standing crop needs to be investigated under controlled conditions.

At the same time we were developing our habitat models, the Cooperative Instream Flow Service Group (IFG) of the U.S. Fish and Wildlife Service was developing the IFG Incremental Method to recommend minimum streamflows for each major life history stage for stream dwelling fish. This method contains both a habitat model (IFG-3) and a hydraulic simulation model (IFG-4) (Bovee and Milhous 1978).

The habitat model is quite similar to the model which we originally developed for coho salmon in 1975 (Nickelson 1976), and in fact, the model which we developed for steelhead uses probability-of-use criteria developed by IFG. However, there is a major difference between the approach which we took to develop the habitat models and that which IFG took.

We collected data in the field and determined the importance of habitat parameters based on how well they correlated with salmonid standing crop. IFG relied on an analysis of published and unpublished data (mostly observations of fish at various depths and velocities) to determine the relative importance of various amounts and types of habitat. They then assumed a one to one correlation existed between their calculated habitat value and fish standing crop (Bovee and Cochnauer 1977).

Data which we collected in 1976 and 1977 were used to test the assumption that the weighted useable area (WUA) of a stream reach, as calculated by the IFG Incremental Method, is correlated with the standing crop of juvenile coho salmon, cutthroat trout and steelhead trout. We found that WUA was significantly correlated with juvenile cutthroat and juvenile steelhead standing crop (Table 8) but explained only 27% of the variation in cutthroat standing crop and 52% of the variation in steelhead standing crop. WUA was not significantly correlated with juvenile coho salmon standing crop.

Cover as calculated by equations 2 (page 4) and 5 (page 8) explained a greater percentage of the observed variation in standing crop of cutthroat and steelhead, respectively, than did WUA (Table 8). When cover was combined with WUA a considerable increase in correlation with steelhead standing crop was observed. This is the relationship presented in Figure 6. This was was not the case, however, with cutthroat (Table 8).

Pool area and pool volume explained 74% and 92% of the variation in coho standing crop, respectively. The use of substrate in addition to depth and velocity in the calculation of WUA for coho did not increase the correlation (Table 8). One reason these two correlations were not significant may have been the small sample size.

Table 8. Correlations between habitat parameters and standing crop of salmonids.

Species	Independent variable	R^2
Cutthroat	WUA[a]	0.27*
	WUA * Cover[b]	0.30*
	Cover * Area[c]	0.41*
	Area	0.08
Steelhead trout	WUA[a]	0.52*
	WUA Cover[d]	0.79*
	Cover * Area	0.67*
	Area	0.12
Coho salmon	WUA[a]	0.53
	WUA[e]	0.51
	Pool Volume	0.92*
	Pool Area	0.74*

[a]*WUA includes depth and velocity*
[b]*See equation 2*
[c]*Wetted area*
[d]*See equation 5*
[e]*WUA includes depth, velocity and substrate*
**Significant correlations* ($p<0.05$).

The field of water resource management needs a uniform, widely accepted method for recommending minimum streamflows for the maintenance of aquatic life, and in particular, valuable fisheries resources. The IFG Incremental Method has the potential of becoming that method. It has been widely publicized, and, although much improvement is still needed, it is rapidly becoming the accepted state of the art.

A major advantage of the IFG Incremental Method is that it includes all life history phases of a species in a single methodology. Thus, once the surveys of a stream reach have been completed, spawning flows, incubation flows and rearing flows for a number of species can be recommended without further field work. The primary weakness we see in this technique, as discussed above, is in the habitat model. We believe the habitat models which we have developed for coho salmon and steelhead trout could help strengthen this weakness in the IFG Incremental Method.

We have demonstrated the importance of cover to both cutthroat and steelhead trout. Wesche (1976), Gibson and Keenleyside (1966) and McCrimmon and Kwain (1966) have demonstrated the importance of cover to other trout species. A quantification of cover must be included in the IFG Incremental Method. IFG personnel are working on this problem and have very recently devised a method to accomplish this. According to IFG, the method is still quite cumbersome and is recommended only for users very familiar with the Incremental Method (IFG 1980). Since cover is such an important factor controlling trout standing crop, it is important that the method be refined to allow for more general use.

We have also demonstrated that pool volume is the critical habitat parameter for juvenile coho salmon in Oregon coastal streams. The relationship between pool volume and coho standing crop which we developed should be included in the IFG Incremental Method. A summary of the advantages and disadvantages of the IFG Incremental Method and our habitat models is presented in Table 9.

We believe that the modifications which we suggest will make the IFG Incremental Method a viable technique for recommending minimum flows for Oregon streams. It would be counter-productive for the Oregon Department Fish and Wildlife to propose a totally new method for recommending minimum streamflows in light of the recent development of the IFG Incremental Method. This method contains both elements which we identified as being needed to recommend minimum streamflows:a habitat model and a hydraulic simulation model. The Department should adopt the IFG Incremental Method to reevaluate present flow recommendations and to develop future recommendations.

Table 9. A comparison of the advantages and disadvantages of the IFG Incremental Method and the habitat models which we've developed.

IFG Incremental Method	Our Habitat Models
Advantages:	**Advantages:**
1. All life history phases included in one methodology.	1. Good correlations have been demonstrated between habitat and standing crop for coho salmon and steelhead trout.
2. The method is becoming widely used and accepted.	2. Cover is easily evaluated.
3. The method is incremental in nature and has predictive capabilities.	3. The models are incremental in nature.
4. The method is flexible and easily allows incorporation of new biological data.	
Disadvantages:	**Disadvantages:**
1. The method needs work to develop the relationships between habitat and standing crop - we have found this relationship for coho salmon and cutthroat and steelhead trout to be poor[1].	1. The models are specific for the rearing phase of life history - other methods are available for other phases.
2. Cover is not easily evaluated[1].	2. More work is needed to develop predictive capabilities.
3. Presently the computer access needed to use the method is available only in limited locations.	3. The models have not been applied to an actual flow recommendation.

[1] *Modifications to the Incremental Method based on our models could help minimize this disadvantage.*

RECOMMENDATIONS

1. In light of the need for a uniform, widely accepted method for recommending minimum streamflows, the Oregon Department of Fish and Wildlife should adopt the IFG Incremental Method. This method is being widely used, has been used in Oregon by the U.S. Fish and Wildlife Service, National Marine Fisheries Service and at least two ODFW District Biologists, and is rapidly becoming the accepted state of the art. Given the modifications which we have suggested, the IFG Incremental Method will be superior to any other method for recommending flows for Oregon streams. Adopting the IFG Incremental Method will require that appropriate personnel be trained in its use (a course will be conducted by IFG in Portland in August 1981). The Department should also acquire the computer programs needed to use the method.
2. The Oregon Department of Fish and Wildlife should reassess existing flow recommendations with the newly developed method. Existing flow recommendations on some streams are higher than the naturally occurring flows (Elk Creek, Clatsop Co. is an example), thus damaging the Departments credibility and ability to defend recommended flows during litigation.
3. Since the pool volume is a good predictor of juvenile coho salmon standing crop, we recommend that the Instream Flow Service Group incorporate pool volume into the IFG Incremental Method. Since cover is an important factor regulating juvenile salmonid density, an easy-to-use cover evalation technique must also be incorporated into the IFG Incremental Method.
4. In streams containing sympatric populations of coho salmon and steelhead trout, minimum rearing flows should be based on the trout since their habitat is more severely impacted by flow reductions than is the salmon habitat.

5. Research should be conducted under relatively controlled conditions, (such as in an artificial stream), on the effects of velocity on cutthroat trout standing crop. This relationship is unclear at this time and is needed to predict the impact of flow reductions on cutthroat standing crop.

ACKNOWLEDGMENT

We would like to express our appreciation to the many seasonal aides who worked on the Streamflow Project over the years, without whom the project would not have been possible.

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Appendix 1. Sampling Procedures

All Streams

Standing crop was estimated for each study section.

1. Population estimates were made by the two-pass or three-pass removal method. Each unit of effort consisted of a pass upstream and then downstream through the section with electrofishers. A blocking seine was placed at the bottom of the section and fish were collected from it at the end of each pass. When possible, pools were seined as part of each unit of effort.
2. Length and weight were measured for all salmonids captured.
3. Standing crop was calculated from the population estimate and the mean weight of the fish captured.

Trout Streams

Evenly spaced cross-sectional transects were established in each study section at 0.75-5.0 meter intervals perpendicular to the flow. Depth and velocity were measured and cover and substrate evaluated on each transect at 50 cm intervals for a total of at least 200 observations per study section. Stream width was measured on each transect.

1. Depth was measured to the nearest centimeter with a meter stick or stadia rod.
2. Velocity was measured with a Gurley meter at four tenths off the bottom for depths of $\geq$30 cm. At depths of $\leq$30 cm a red biodegradalbe dye was used to measure the time of travel from 25 cm above the observation point to 25 cm below the point.
3. Cover was recorded as follows: a. Undercut banks b. Overhanging cover (within 1 m)

c. Velocity shelter -instream cover (logs, boulders, etc.) within 50 cm upstream of the observation point which slows the velocity.

d. Escape cover - instream cover within 50 cm upstream of the observation point which, in addition to slowing the velocity, offers a hiding place (undercut boulders, root wads, etc.).

e. Turbulence cover - surface turbulence such that the stream bottom is not visible.

4. Substrate was evaluated as follows:

a. Wood b. Bedrock c. Sand, silt or clay less than 2.5 mm diameter d. Small gravel 0.25 to 2.5 cm diameter e. Gravel 2.6 to 7.5 cm diameter f. Cobble 7.6 to 15.0 cm diameter g. Rubble-boulders 15.1 to 30.0 cm diameter h. Boulders greater than 30.0 cm diameter.

5. Width was measured recording the left and right waterlines of each stream channel which the transect encompasses.

Coho Streams

Pool volume was measured by using a 1m x 0.5 m sampling grid over each pool. On larger pools the grid spacing was increased. A tape was placed to measure length and then transect tapes were placed perpendicular to it at 1 m intervals. The width was measured on each transect. Depth, cover and substrate were measured in the same way as for trout streams at 50 cm intervals on each transect.

[ca. 1983]
Draft

A REVIEW OF MODELS THAT PREDICT STANDING CROP OF STREAM FISH FROM HABITAT VARIABLES

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Running Head: Stream Fish-Habitat Models

ABSTRACT

Mathematical models that predict standing crop of stream fish (number or biomass per area or length of stream) from measurable habitat variables are reviewed. Models can be classified on three types of variables used (geomorphic and watershed variables, channel morphometry and flow variables, and microhabitat variables) as well as on mathematical structure. Most models are linear or multiple linear regressions, while fewer are curvilinear functions (exponential or power), use multivariate techniques (principal components or factor analysis), or combine independent variables into an index. We grouped models according to the types of independent variables found to be significant during model development: (1) only geomorphic and watershed variables, (2) only microhabitat variables, and (3) a combination of all three variable types. Of the 26 models we reviewed, 19 were in the last category. Of the 43 variables found significant in models, instream cover, substrate, and depth were used in the most models. Because development of models that predict standing crop from habitat is a relatively new and dynamic field, model assumptions, statistical confidence intervals, and model testing have received minimal attention. These areas, as well as the variability in measuring independent habitat variables and the generality of models, need more attention by future investigators. Development of models for regions with homogeneous geomorphic and climatic characteristics would improve prediction accuracy.

A major goal of research in fisheries biology is the prediction of fish abundance or production from measurable characteristics of the environment. Mathematical models to predict fish abundance must be based on the mechanisms underlying fish production, but once developed would save fisheries managers the time-consuming and difficult or impossible task of censusing populations directly. These prospects have spurred investigators to search for variables linked closely to fish production in streams for at least 30 years (Allen 1951).

Models that predict standing crop of stream fish (numbers or biomass per area or length of stream) from measurable physical, chemical, and biological variables that make up fish habitat have become more common since the mid-1970's. These models range in complexity from linear regressions that predict standing crop from one independent habitat variable, such as overhead cover, to complex functions involving many independent variables.

Our purpose is to critically review models that predict standing crop of stream fish as a function of measurable independent habitat variables. Our review includes all models we were able to find in the primary literature, reports of state and federal fisheries or fish habitat managment agencies, and theses, as well as those from personal sources. We feel this review will be useful to managers of stream fisheries and fish habitat, and to researchers constructing similar models because relatively few are published in primary fisheries or aquatic bology journals, so that review and comparison of models by individuals is difficult.

In our review we sought to evaluate:

1. The independent habitat variables most frequently measured in streams, and those most often judged significant in models.

2. Model assumptions.

3. Whether models had been tested after initial development.

4. Potential for error in measuring independent and dependent variables, and in predicting standing crops.

5. Whether models made "biological sense". That is, are variables known to affect stream fish populations, and are they combined in reasonable ways in the model?

Types of Independent Variables and Models

Physical, chemical, and biological variables related to habitat that were used by investigators as independent variables in models may be divided into three categories that relate to the method and scale of measurement. Geomorphic and watershed variables were usually derived from measurements of topographic maps, and were therefore generally of coarse scale in relation to size of stream channels. This variable type includes characteristics such as drainage basin area, mean basin elevation, total channel length, drainage density, stream order, and stream gradient (when derived from a map). Most are standard geomorphic variables used by fluvial hydrologists to model stream flow and sediment yield, and can be found in standard hydrology references such as Chow (1964).

A second class of independent variables are those that relate to channel morphometry and flow, which are usually derived from field measurements taken along transects perpendicular to stream flow. These variables include the various measures of stream discharge (also available from U.S.G.S. gage records), width, depth, mean velocity, wetted area, pool volume, gradient (if measured in field over a stream reach), and percents of habitat types (pool, riffle, run, etc.) by area. These characteristics are measured on a finer scale than geomorphic and watershed variables.

Our third class of variables includes those that assess physical microhabitat, water chemistry, and biological characteristics in streams, all of which are measured in the field. Because a majority of these variables relate to the fish's immediate environment, we term them microhabitat variables. Physical microhabitat variables include the various forms of cover for fish, stream bank stability, substrate composition, temperature, and depth and velocity preferenda. Some of these are difficult to measure and are often subjectively evaluated. Water chemistry (hardness, nitrate nitrogen), and biological variables (invertebrate abundance, standing crops of other fish) are used in a few models.

Models can be classified according to mathematical structure, and according to which of the three types of independent variables are used to construct the model. A majority of models are simple or multiple linear regressions fit by least squares procedures, and are of the form:

$$SC = a + bX_1 + cX_2 + ... + nX_n \qquad (1)$$

Where: SC = standing crop of stream fish in numbers or biomass

$X_1, X_2, ...X_n$ = independent habitat variables

a, b, ...n = regression coefficients

An advantage of these models is that significance of regression coefficients, confidence intervals around the regression line, and the amount of variation in standing crop accounted for by the independent variables in the model (r^2) are easily calculated using standard statistical procedures.

Other models are more complex exponential (equation 2) or power functions (3) of the form:

$$SC = a \quad e^{bX} \qquad (2)$$

$$(\log_e SC = \log_e a + bX)$$

$$SC = a \quad X^{b} \qquad (3)$$

$$(\log_e SC = \log_e a + b \log_e X)$$

These equations are most often transformed to straight lines using logarithms, as shown in parentheses below each equation, and the coefficients determined using simple linear regression. A number of the models presented below are more complex combinations of these types of functions.

Some investigators combined independent variables into an index, and then developed a relationship between standing crop and the index using linear regression. Finally, some investigators use the multivariate techniques of factor analysis and principal component analysis to select linear combinations of independent variables, thereby reducing the dimensions of the data. It is hoped that these techniques reveal the important habitat variables, but Johnson (1981) gives several cautions about the use of multivariate statistics in these situations.

The models we reviewed may also be classified according to the types of independent variables shown to be significant during model development. A first category included those models that used only geomorphic and watershed variables to predict standing crop of stream fish. A second category groups those models that employ primarily microhabitat variables, and a third group primarily uses combinations of several of the variable types to predict standing crop. In this third group, most models used a combination of channel morphometry and flow variables, and microhabitat variables to predict standing crop of fish. A short description of models in each of these three categories is provided below.

Judging the statistical validity of models requires that certain information be reported when results are published. Most investigators reported the coefficient of determination (r^2 or R^2) for their models but few tested whether regression coefficients were significantly different from zero, calculated standard errors for regression coefficients, or calculated confidence intervals around the regression line. In order for models to be judged useful in further prediction of standing crop, they should be tested by collecting additional data from other similar streams and comparing observed standing crops with those predicted by the model. Only then can a prospective user determine how widely applicable or robust the model is under other conditions, but few investigators undertook this additional work to test their models.

Models based on Geomorphic and Watershed Variables

Ziemer (1973) developed a model to predict the escapement of pink salmon (*Oncorhynchus gorbuscha*) spawning in Alaskan streams from quantitative geomorphology of the drainage basins. His main tenet was that, within a geologically and climatically stable region, flow regime and channel morphology control fish production, and are related to measurable characteristics of the drainage basin. He measured eight geomorphic variables from topographic maps for 25 streams, and assumed that historical measurements of pink salmon escapement were adequate measures of standing crop. Ziemer (1973) developed two indices of potential fish production from geomorphic variables that affect runoff, one of which he found to be correlated with pink salmon escapement (Table 1), although no statistical analyses are reported. Although the data are variable, we found that the power function Ziemer (1973) reported that relates standing crop to the index explained 34% of the variation in pink salmon numbers (after linear transformation, see equation 3) when three outliers he identified were excluded.

Burton and Wesche (1974) measured 18 geomorphic and watershed variables for 11 fourth and fifth order streams in two regions of Wyoming and related these to standing crops of brook (Salvelinus fontinalis), brown (Salmo trutta), and rainbow trout (Salmo gairdneri) determined by a removal method using electrofishing. Multiple regression was ineffective due to intercorrelation among independent variables, but four variables highly correlated to trout standing crops were combined in a "productivity index". A power function of standing crop as a function of this index accounted for 33 percent of the variation after transformation to a line. Burton and Wesche (1974) also found a significant difference between summer flow-duration curves, which indicate the stability of base flow, for streams with high (> 200 trout/acre) and low (< 200 trout/acre) standing crop.

Wesche et al. (1977) chose geomorphic and watershed variables from the indices of Ziemer (1973) and Buron and Wesche (1974) that were significantly correlated with standing crops of Colorado River cutthroat trout (Salmo clarki pleuriticus) in 12 Wyoming streams, and combined these in an index (Table 1). The index is composed of two variables from Ziemer's (1973) index and three variables from Burton and Wesche's (1974) index, and explained 66 percent of the variation in standing crops of Colorado River cutthroat trout larger than 6 in, determined by a removal method using electrofishing.

Models Based on Microhabitat Variables

Six of the models we reviewed predict standing crop of stream fish from microhabitat variables that describe physical microhabitat, water chemistry and biological characteristics. However, channel morphometry and flow variables were measured by several investigators during development of these models.

Klamt (1976) measured standing crops of salmonids (primarily age-0 chinook salmon, *O. tshawytscha*) by underwater observation in 23 pool-riffle complexes in two tributaries of the Salmon River in Idaho, and related them to percent fine sediment in riffles, invertebrate drift, and cover using multiple regression (Table 2). Several models using percent fine sediment in riffles or percent total pool area as cover, in combination with insect drift per pool area, explained more variation (r^2 = 0.39-0.61) than the model we chose, but Klamt (1976) suggested that using drift per pool area, a ratio of variables, in the multiple regression rendered these models less valid. The model we chose predicted standing crop in one stream as a function of percent pool area as boulder-and-log cover, and invertebrate drift.

Enk (1977) developed linear regressions to predict brook and brown trout standing crops measured by mark-recapture electrofishing in two Michigan streams from length of overhead bank cover that met Wesche's (1974) criteria of being at least 9 cm wide and having at least 15 cm of water beneath it. A maximum of 72 and 89 percent of variation in trout biomass was explained by the single cover variable in 22 sections of the two streams.

Harshbarger and Bhattacharyya (1980) measured 18 characteristics related to cover for trout in 100 sections of 20 streams in western North Carolina, and estimated standing crops of wild trout (species not reported, but most likely brook and/or rainbow trout) by electrofishing using a removal method. They used both factor analysis and multiple linear regression to predict standing crop from the cover variables, and found that the six most significant independent variables in multiple regressions explained more variation in standing crops of each age class of trout (maximum of 66 percent for age-II trout) than did six derived factors, which are linear combinations of all 18 cover variables. The number of rocks affording cover, percent brush cover, and percent cover as bank vegetation trailing in the water were significant variables common to models for all four age classes of trout.

Barber et al. (1981), Barber et al. (1982), and Oswood and Barber (1982) predicted standing crops of five stream fish for 76 stations in 12 southeast Alaska streams from independent physical microhabitat variables measured using a standing transect method and using a technique they developed to map area of different microhabitat within sections. They found their "area" method to be superior, and developed a multiple regression model that explained 76 percent of variation in age-0 coho salmon (*O. kisutch*) standing crop from three independent variables: $\log_{10}$ available spawning area, area of overhanging vegetation, and the day of season. When they calculated principal components using all 17 variables, and used these as independent variables in multiple regressions, 81 percent of the variation was explained for age-0 coho salmon. They also developed models for age-I coho salmon, Dolly Varden trout (*Salvelinus malma*), cutthroat trout (*Salmo clarki*), and coast range sculpin (*Cottus aleuticus*).

Paragamian (1981) predicted abundance of juvenile and adult smallmouth bass (Micropterus dolomieui) measured by electrofishing using a Schnabel estimate, in 11 sections of an Iowa river from percent area with exposed 16-256-mm substrate. Width, depth, velocity, and section gradient were also tested as independent variables but were not found significant. An exponential function best fitted the relationship between percent area of exposed coarse gravel-cobble substrate (16-256mm) and standing crop of smallmouth bass (biomass or numbers) for each of two years (r^2 = 0.41-0.90). Paragamian (1981) is one of the few investigators that report standard errors and confidence intervals for regression coefficients.

During a study of cumulative impacts of micro-hydropower projects on a northern Idaho river, Leathe and Graham (1983) developed relationships between standing crop of both juvenile bull trout (Salvelinus confluentus) and brook trout in 14 tributary reaches as a function of percent fine (< 6.4 mm) material in the stream bed. Density of bull trout declined as percent fines increased, but brook trout density increased although this trend may also be explained by the greater use of lower gradient reaches by brook trout and higher gradient reaches by bull trout. The percent fines in the stream bed can be predicted from the percent sediment yield above natural levels using a sediment yield model developed by Cline et al. (1981) for these forested watersheds.

Models Based on Combinations of all Variable Types

Most models predict standing crops from a combination of types of independent variables, although channel morphometry, flow, and physical microhabitat variables are most frequently used. The earliest report we found of such a model is Lewis (1969), who developed a model to predict standing crop of brown and rainbow trout in 19 pools of a Montana stream as a function of pool area, width, depth, current velocity, cover area, and percent cover (Table 3). All six variables accounted for 70-77 percent of variation in trout numbers, which were measured by one-pass electrofishing. Mean current velocity and cover area accounted for 66 percent of variation in both total trout and brown trout numbers in pools, and current velocity alone explained 51 percent of variation in rainbow trout numbers. Because cover was a more significant variable than current velocity in the brown trout relationship, Lewis (1969) inferred that cover was the most important factor to brown trout, and current velocity to rainbow trout, a conclusion that coincides with what is known about the ecology of these species.

Havey and Davis (1970) related standing crop of two age classes of landlocked Atlantic salmon (Salmo salar) determined by mark-recapture electrofishing in one reach of a Maine stream to rainfall (an index of flow) and standing crops of salmon and other fish for five consecutive years. The best two-variable multiple regressions show that more than 90 percent of variation in standing crops of age-0+ and age-I+ salmon can be accounted for by these independent variables, but most of the variation is attributed to other standing crop variables. Unfortunately, these latter standing crops are as difficult to measure as the salmon standing crops being estimated, which along with the small sample size renders the models of little practical use in estimated standing crop from characteristics of their environment. Havey and Davis (1970) did find that 88 percent of variation in age-0+ salmon survival could be accounted for by rainfall alone.

Stewart (1970) related the mean standing crop of brook and rainbow trout measured each month during June through September in 41 short sections of a Colorado stream to 15 channel morphometry, flow, and physical microhabitat variables using multiple regression. All fish 18 cm and larger were assumed to be captured by one-pass electrofishing using block nets.

Stewart (1970) found that 43 percent of variation in rainbow trout biomass was explained by mean depth and two variables describing the area under rocks accessible to fish for cover. Similarly 36 percent of variation in brook trout biomass was accounted for by mean depth and a variable made up of areas of rock cover, undercut bank, and deep turbulent water.

Hunt (1971) correlated standing crop (numbers and biomass measured by mark-recapture electrofishing) of brook trout in 17 sections of a Wisconsin stream to five channel morphometry variables and overhead bank cover for three-year periods before and after habitat improvement was done. In eight multiple correlations these six variables accounted for 59-85 percent of variation in numbers or biomass of trout. Pool area and bank cover were the most important variables, explaining 68 percent of variation in number of trout over six inches after habitat development.

In a series of three reports Hendrickson and Doonan (1972) and Hendrickson et al. (1973a, 1973b) related standing crops of trout in Michigan and Wisconsin (data from state fisheries agencies) to numerous variables in all three variable categories. Although species are not reported, most fish were probably brook, brown, and rainbow or steelhead trout. Hendrickson and Doonan (1972) found significant correlations between trout biomass (lb/acre) in 16 streams of Michigan's lower peninsula and both mean annual maximum temperature ($r = 0.63$, $p < .01$) and the ratio of 90 percent-to-10 percent duration discharge ($r = 0.49$, $p < .05$), the latter being an indicator of stability of stream flow.

Hendrickson et al. (1973a) developed multiple regressions to predict trout standing crop (lb/mile and lb/acre) for 29 streams in Michigan's upper peninsula and northern Wisconsin from measures of discharge, stability of flow, mean velocity, instream vegetation, and temperature. These models indicated streams that discharge relatively large amounts of ground water, and thus have stable flows and water temperatures, are most favorable for trout. The models are complex power functions (Table 3) that account for 41 percent of variation in lb/mile of trout and 47 percent of variation in lb/acre of trout. Hendrickson et al. (1973a) also report standard errors for estimates of trout biomass, which were 64 percent of the estimate for lb/mile and 79 percent for lb/acre.

In a similar analysis Hendrickson et al. (1973b) developed complex power function models using multiple regression that predict standing crops of trout in 88 segments selected from 57 Michigan and Wisconsin streams, from independent variables of channel morphometry, flow, and physical microhabitat (Table 3). In the best model for all stream segments these variables accounted for 38 percent of variability in trout biomass (lb/mile), and had the lowest standard error of 84 percent of the estimate. These models also indicate that trout populations are highest in streams with relatively high groundwater discharge, which in turn produces stable baseflows, stable water temperatures, and higher water hardness (a general index of productivity).

Platts (1974, 1976) made complete censuses of Dolly Varden trout, cutthroat trout, rainbow trout, and juvenile chinook salmon populations in 291 sections of 38 Idaho streams using explosives, and measured 2 geomorphic and watershed variables, 5 channel morphometry variables, and 13 physical habitat variables along transects. Multiple linear regressions of the 20 independent variables explained 10 to 35 percent of variation in numbers of four salmonids, but elevation, stream width, and a pool rating were the most significant variables explaining variation in total fish numbers (Platts 1974). Moreover, Platts (1974) found that when land is classified according to geology and geomorphic process, certain relationships among variables, such as among elevation, gradient, and channel width, cause predictable changes in the species and numbers of fish present.

White (1975) found a significant correlation between spring standing crop of brook and brown trout, determined by mark-recapture electrofishing in a Wisconsin stream, and mean discharge during the previous January and February ($r = 0.87$, $p < .01$) using eight years of data. White (1975) concluded that annual variation in low flows, which occur during winter in this Wisconsin stream, may govern trout abundance there.

White et al. (1976) related brook and brown trout populations, estimated by mark-recapture electrofishing in six Wisconsin and Michigan streams, to seven streamflow variables and two measures of previous standing crops. Latta (1965) had earlier shown that groundwater level, assumed to be related to baseflow discharge, accounted for 71-74 percent of variation in fall numbers of age-0 brook trout over nine years in two sections of a Michigan stream, but accounted for relatively little of the variation in age-0 brown trout abundance. In contrast, White et al. (1976) found no significant relationships between age-0 brook trout and flow variables using 17 years of data then available for the same stream, although a multiple regression of age-0 brown trout numbers on flow variables explained 37 percent of variation. Significant regressions of fall age-0 trout numbers on flow and previous standing crop variables for four of the other streams explained 66-95 percent of variation in standing crop. Similarly, all but one multiple regression of total trout standing crop (kg/km) on similar variables explained 50-94 percent of variability. White et al. (1976) concluded that high, stable stream discharge and lack of severe floods, especially in winter, are favorable conditions for trout in midwestern streams.

One of the most widely known models that predicts trout standing crop from habitat variables is the habitat Quality Index (HQI) of Binns (1979) and Binns and Eiserman (1979). During the initial development of HQI Model I, Binns (1979) measured standing crops of brook, brown, rainbow, and cutthroat trout in 20 Wyoming streams by mark-recapture or removal methods using electrofishing, and regressed these against relative ratings of four channel morphometry and flow variables and six microhabitat variables. The structure of the model is complicated because each independent variable is converted to a rating from 0 (worst) to 4 (best) based on quantitative criteria. Furthermore, some ratings are multiplied together to form an index, and the model is in the general form of a power function (Table 3) that was fitted using a multiple linear regression by taking the logarithm of both sides of the equation. All of these complicating factors make interpretation of the model difficult. However, Model I explains 95 percent of variation in standing crop (kg/hectare) of trout at the initial 20 sites.

Binns (1979) collected data from 16 more streams to test Model I, and also developed another equation using these new data. Model I explained 59 percent of variation in standing crop at the 16 new sites, but the relative percent error in prediction may be more significant in judging model accuracy. The standing crop predicted by Model I differed from actual biomass by 38 percent on average. Binns (1979) revised Model I by replacing fish food abundance and diversity variables, which were time consuming to measure, with a measure of substrate available for benthic macroinvertebrate use, and by making several other modifications in the way variables were combined into indexes. Model II, also a complex power function of ratings and indexes, explained 97 percent of variation in trout biomass for the combined 36 stations described above. Binns (1979) collected data from eight more sites to test Model II, which explained 93 percent of variation and averaged only 12.5 percent error between predicted and measured biomass for the new sites.

The Instream Flow and Aquatic Systems Group (IFASG) of the U.S. Fish and Wildlife Service's Western Energy and Land Use Team has developed a set of models of physical habitat for stream fish referred to as the Instream Flow Incremental Methodology (IFIM), originally conceived to show changes in fish habitat caused by changes in stream discharge. These models predict changes in velocity, depth, and substrate (microhabitat), and in temperature and water quality (macrohabitat) as functions of flow. The microhabitat suitable for each life stage of a species is determined by measuring depth, velocity, and substrate at frequent intervals along closely-spaced transects. The area of each "cell" in which measurements are taken is multiplied by the relative preference of the fish species for the combination of depth, velocity, and substrate found there, and values for all cells are summed to determine the Weighted Usable Area (WUA). Bovee (1982) describes several ways that joint preference functions may be derived for fish species, and indicates that more recent IFIM procedures incorporate cover preference as well. The reaches of stream with suitable water quality and temperature for each species at each discharge are also predicted by the models.

An obvious test of WUA is to use it as an independent variable to predict fish standing crop. Stalnaker (1979) used data from Wesche (1976) in one of the first of such tests, and found that WUA explained 81 percent of variation in brown trout biomass (kg/km) for 19 reaches of Wyoming streams. Nehring (1979) found that WUA accounted for 76 percent of variation in brown trout biomass (lb/acre) in 7 Colorado streams, but found no such relationship for either brook (11 streams) or cutthroat trout (5 streams). Nehring (1979) explained this by noting that the microhabitat preference curves for the latter two species are considered only fair, while those for brown trout are considered good or excellent. In a similar test, Wesche (1980) found that WUA explained 82 percent of variation of brown trout biomass in four reaches of larger Wyoming streams. In contrast, Annear and Conder (1983) found that WUA explained little variation in brown trout and rainbow trout ($r^2 = 0.06$ for both and neither were significant) biomass for ten Wyoming streams. But in five streams the habitat measurements were made one to three years later than the population estimates, which casts serious doubts on the results for these streams.

Orth and Maughan (1982) developed depth, velocity, and substrate preferenda for freckled madtom (Noturus nocturnus), central stoneroller (Campostoma anomalum), and orangebelly darter (Etheostoma radiosum) by sampling individual fish in an Oklahoma stream using electrofishing. Then they measured WUA during each season for two years in two riffles and two pools for these three species and for juvenile and adult smallmouth bass using preference functions of Orth et al. (1982) for the smallmouth bass. They found no significant correlations between WUA and standing crop (kg/hectare) of either adult or juvenile smallmouth bass during any season. Similar correlations for freckled madtom, central stoneroller, and orangebelly darter were highest during summer, when habitat is assumed to be most limited for stream fish due to low flow; WUA explained 86, 70, and 70 percent of the variation in the respective standing crops of each species.

Ken Bovee of the IFASG (personal communication) is currently compiling case histories of attempts to test how well fish biomass correlates with WUA as calculated by IFIM. He finds that investigators are likely to find a positive correlation when (1) the assumptions of the models are met, (2) the best preference curves of fish for microhabitat are used, (3) habitat and fish populations are carefully measured, and (4) sample sizes are reasonably large.

Nickelson et al. (1979) developed models to predict standing crops of cuttroat trout, juvenile steelhead trout, and juvenile coho salmon in Oregon streams. Standing crops of biomass were determined by two- or three-pass removal methods using electrofishing, and were used in multiple regressions on four channel morphometry and six physical habitat variables. Nickelson et al. (1979) created a total cover variable for cutthroat trout consisting of the frequency of suitable depth, instream cover, overhead cover, surface turbulence, and velocity refuge. Multiplying this total cover variable by a factor reflecting the suitability of section velocity for cutthroat trout and by section area yielded a Habitat Quality Rating (HQR) which was used as the independent variable to predict standing crop. Nickelson et al. (1979) developed this model using data from 29 sections of six streams (r^2 = 0.87 and 0.91 for two slightly different HQRs) and calculated 95 percent confidence limits around the regressions. Data were then collected from 20 additional streams to test the models; 48 and 57 percent of these 20 new HQRs fell within the 95 percent confidence intervals for the two original HQR equations.

A similar HQR model was developed for juvenile steelhead using the product of total cover (similar to the cutthroat model), a depth-and-velocity preference factor (developed from probability-of-use criteria of Bovee and Cochnauer 1977), and section area. This index accounted for 79 percent of variation in steelhead biomass for 23 sections, and 75 percent of HQRs from 12 additional sections used to test the model fell within the 95 percent confidence limits of the regression.

Biomass of juvenile coho salmon in 12 stream sections was predicted from pool volume alone, which accounted for 93.5 percent of variation, and 88 percent of 318 new sections measured to test the model fell within the 95 percent confidence limits. A more complex habitat quality index for coho proposed by Nickelson (1976) explained 72 percent of variation in standing crop. Nickelson et al. (1979) provide some of the few models that have been tested with additional data, and further are the only investigators that report confidence limits for linear regressions.

Wesche (1974, 1976, 1980) developed a model that predicts brown trout standing crop (lb/acre determined by mark-recapture or removal methods using electrofishing) at 27 study sites on Wyoming streams as a function of a trout cover rating calculated from overhead bank cover, area of rubble-boulder substrate, the preference of trout species for these two habitat features, and in larger streams ($\geq$ 100 cfs mean discharge), the area of water deeper than 1.5 feet. These variables are combined in two indexes (Table 3) which accounted for 60 percent of variation in brown trout biomass in reaches of eight small streams, and 95 percent of variation in biomass of brown trout in reaches of four larger streams. Relationships were poorer when smaller sections were considered, than when several adjacent sections were combined into reaches. No significant relationships were found for brook trout at nine sites, or Colorado River cutthroat trout (*Salmo clarki pleuriticus*) at 12 sites. Wesche (1980) concluded that populations of these species are not controlled by cover as much as those of brown trout. In an earlier test of the trout cover rating, Wesche (1976) found an exponential relationship between standing crop of trout (lb/acre) and the trout cover rating for small streams, but the coefficient of determination was not reported although the regression coefficient was found to be significant.

Eifert and Wesche (1982) tested the trout cover rating for small streams in a different part of Wyoming, and found that it accounted for 19-41 percent of variation in standing crop of brown trout. The area of substrate larger than 3.0 in (rubble-boulder cover) alone explained 71 percent of variation in trout standing crop in these small streams. Eifert and Wesche (1982) also evaluated the use of Binns' (1979) two HQI models, Duff and Cooper's (1978) Stream Habitat Survey, and Pfankuch's (1975) Stream Reach Inventory and Channel Suitability Index as predictors of trout standing crop in the same streams. These indices generally accounted for about 50 percent or less of the variation in trout standing crop.

Murphy et al. (1981) measured biomass of rainbow and cutthroat trout bimonthly during June through October at each of two clearcut, second-growth, and old-growth forest sites in Oregon's Cascade Mountains, and related it to biomass of two functional groups of invertebrates measured in riffles. They found that trout biomass was significantly correlated with total invertebrate biomass ($r = 0.83$, $p < .05$) and with biomass of the collector-gatherer functional group of invertebrates ($r = 0.99$, $p < .01$).

Fraley and Graham (1982) measured standing crops of westslope cutthroat trout (*Salmo clarki lewisi*) and bull trout in Montana streams by snorkeling, and related them to measurements of 30 chemical and physical habitat variables using multiple regression. Overhead-and-instream cover, stream order, and substrate explained 41 percent of variation in trout density (no./m^2) for 134 stream reaches. This regression model was tested using 23 additional reaches in a separate area of Montana. The correlation between observed and predicted trout numbers was 0.63 for these sections, and the relative percent error between observed and predicted numbers averaged 115 percent.

Stowell et al. (1983) provide a compilation of equations based on data from other sources, that predict alevin emergence, summer rearing capacity, and winter rearing capacity for juvenile steelhead trout and chinook salmon as a function of percent embeddedness of the stream bed, for watersheds in the Idaho batholith. The percent embeddedness resulting from fine sediments eroded from these watersheds is predicted from the increase over natural sediment yields due to timber harvest and associated activities, which in turn is calculated using the sediment yield model of Cline et al. (1981). In general, models predicting summer and winter rearing capacity of steelhead and chinook juveniles are negative exponential or polynomial functions of embeddedness, and accounted for 87 to 99 percent of variation in standing crop (no./m^2) of the two salmonids (Table 3).

A model recently being developed in British Columbia (Pat Slaney, British Columbia Ministry of Environment, Fish and Wildlife Branch, personal communication) predicts standing crop (no./m^2) of steelhead smolts in coastal rivers as a function of areas of different microhabitat types, total dissolved solids (TDS), and mean annual stream temperature. The model requires measurement of areas of riffles, runs, flats, flat-runs (runs and flat-runs combined often referred to as glides), pools, and backwater areas, as well as areas of boulders and overhanging vegetation in riffles. The relationship between smolt yield (g/m^2/year) and TDS was developed by linear regression using data from nine Pacific Northwest streams. The model was developed using several years of data from one British Columbia stream, and is structured so that smolt standing crop is increased or decreased proportionally by changes in temperature or TDS from those used to calibrate the model. Data are insufficient at present to determine statistical properties of the model.

Other Models

We found a number of other models, relationships, and procedures that predict attributes of fish populations other than standing crop or production, or that describe characteristics of fish habitat. McKernan et al. (1950) were early investigators that considered commercial catch of chinook salmon in Oregon rivers and the ocean troll fishery, as a function of regulations, hatchery introductions, ocean salinity, logging, streamflows, and fishing intensity. Logging, very high and very low flows, and fishing intensity were correlated with reduced chinook salmon catches. Recently, Scarnecchia (1981) correlated catch of coho salmon by the Oregon commercial troll fishery to measures of stream flow in five coastal rivers, and to upwelling. He found a highly significant relationship between total stream flows during the freshwater residency of juvenile coho for five rivers, and weight of coho caught ($r = 0.68$, $p < .01$) from 1942 to 1962. However, he found a poor correlation between catch and 60 consecutive days of lowest flow two years earlier during juvenile rearing. Scarnecchia (1981) found that catch was significantly correlated with April through June upwelling one year earlier ($r = 0.58$, $p < .05$), corresponding to the period when coho smolts first reach the ocean.

Swanston et al. (1977) used discriminant functions of 21 independent geomorphic variables to distinguish between 22 "very poor" and 56 "very good" pink and chum (*O. keta*) salmon streams (determined from interviews with fisheries managers) in southeast Alaska. They found that a discriminant function using eight of the geomorphic variables minimized the cost of data collection, and maximized the power of separation, correctly classifying 74 percent of the watersheds.

Sonntag et al. (1982) developed a simulation model to examine economic "tradeoffs" in timber, anadromous fish, and wildlife in southeast Alaska. The fisheries submodel begins with escapement of salmon to streams, and calculates spawning success and survival of the subsequent populations of juveniles as functions of water temperature, sediment, stream bed disturbance, and rearing habitat in side channels and pools. Although many components of the overall model are still in the development stage, it is clear that when finished, models such as this will be very useful in integrated planning for optimum use of natural resources.

Heller et al. (1983) also developed a set of models to help Oregon forest managers choose among management options for different natural resources. They first developed a model to predict the natural quality of habitat for the anadromous salmonids based on 34 geomorphic parameters. They related a habitat condition score determined for 38 undisturbed watersheds, stratified into 15 different land types with homogeneous geology and landform, to the independent geomorphic variables and found that four variables adequately described the natural habitat condition. This habitat condition score, ranging from zero to one, was multiplied by acres of habitat to give a Fish Habitat Index (FHI) under natural conditions.

Heller et al. (1983) then assessed FHI under present forest managment by developing models to reflect reductions in habitat quantity due to culverts, logjams, and landslides blocking stream passage of spawners. Similarly, they modeled reductions in habitat quality due to sediment from erosion and landslides, suboptimal water temperatures, reductions in organic debris for cover, and debris torrents that scour or bury streams. These sets of models can then be used to show forest managers the relative improvement or reduction in fish habitat to be expected from future management of logging.

The U.S. Fish and Wildlife Service has developed Habitat Evaluation Procedures (USFWS 1980, 1981) to predict units of habitat from the product of habitat quality and area of habitat for both terrestrial and aquatic organisms. Habitat quality is determined for a fish species using Habitat Suitability Index (HSI) models that take a variety of forms including mathematical and non-mathematical relationships between habitat quality and characteristics of the environment, pattern recognition models, and narrative models (Carl Armour, Western Energy and Land Use Team, U.S. Fish and Wildlife Service, personal communication). HEP are useful in planning and mitigation of projects that affect fish and wildlife habitat.

The U.S. Army Corps of Engineers has developed a similar, but much less extensive set of relationships, called a Habitat Evaluation System (HES) to predict habitat quality and units of suitable habitat for species associations in terrestrial and aquatic habitats. Units of suitable habitat can be calculated for alternatives of water resource development to examine "tradeoffs", similar to other procedures described above.

Discussion

We found that many models that predict standing crops of stream fish from measureable habitat characteristics are closely linked to a state, federal, or provincial government agency responsible for managing fish habitat, such as the U.S. Forest Service, or managing fish populations through manipulation of habitat, which accounted for most of the other agencies. Most of these natural resource management agencies have developed their own research programs to develop predictive relationships between stream fish and their habitat.

A wide variety of the three types of independent variables are used in models that predict standing crop of stream fish. However, of the 44 general types of variables used in models we reviewed (Table 4), several that relate to channel morphometry, flow, and physical microhabitat were found to account for significant portions of variation in standing crop in the most models. Instream cover was the independent variable common to the most models, followed by measures of substrate, depth, temperature, wetted area, water velocity, and width, all of which were significant in four or more models. The other 37 variables were used in one to three models each.

Wesche (1983) characterizes the field of stream fish-habitat model development as a relatively young and extremely dynamic science, with an abundance of different methods, variation in how each method is used by different biologists, and a lack of standardization in measurement techniques. We would add that considerations of statistical inference have often been minimized or overlooked in the reports of models we found. Most investigators reported the significance of regression coefficients, which is equivalent to testing the null hypothesis that there is no relation between Y and X (Neter and Wasserman 1974). Most also reported the coefficient of determination (r^2) and many selected their "best" models based on these values, as we did in this paper for lack of more information on confidence intervals. However, coefficients of correlation (r) and determination are descriptive measures of association between independent and dependent variables, and most statisticians caution that regressions do not imply that Y is caused by X. Rather, this mechanism is for the investigator to decide using biological knowledge. Furthermore, wider spacing of values of the independent variable in the sample tends to inflate the coefficient of determination. Thus the usefulness of regression models depends more on the width of the confidence interval and the needs of the investigator for precision, which varies with each application (Neter and Wasserman 1974). Only a few investigators reported the standard error of regression coefficients (Hendrickson et al 1973a, 1973b, Paragamian 1981) and only Nickelson et al. (1979) calculated confidence intervals around their linear regressions. It is clear that these basic statistical properties of regression models need more attention by future investigators.

Two other procedures that have been neglected are the testing of models and assessing error in measurement of independent habitat variables. Binns and Eiserman (1979), Nehring (1979), Nickelson et al. (1979), Stalnaker (1979), Wesche (1980), Fraley and Graham (1982), Orth and Maughan (1982), and Annear and Conder (1983) went to the effort of testing their own models, or those of other investigators. We found three good examples of models that were tested relatively extensively. Nickelson et al. (1979) calculated 95 percent confidence bands around linear regressions for initial models for three species of salmonids, and then tested the models by determining the percent of new observations that fell within these confidence intervals. One would expect 95 percent of new samples to fall within the confidence interval if the model truly reflects conditions of the new sites. Binns and Eiserman (1979) tested their initial HQI model with new data, then developed a second model and tested that with a third data set. Weighted Usable Area has been tested by a number of investigators for a number of species, which has helped define further data needs for the IFIM procedures, as described above.

Platts (1982), Leathe and Graham (1983), and Platts et al. (1983) are the only investigators we found that present data to evaluate the error in measurement of independent habitat variables. Platts (1982), and Platts et al. (1983) made repeated measurements of independent habitat variables over a 7-year period in 56 streams in Idaho, Nevada, and Utah. They analyzed the precision of these data by calculating 95 percent confidence intervals and expressing these as a percentage of the mean value, and assessed the accuracy of the mean subjectively by observation and photos at specific points to determine whether measurements by different observers over time reflected actual changes in habitat variables. Not surprisingly, variables with excellent precision (< 5% of mean) were generally those, such as stream width and stream depth, that could be precisely defined for an observer and measured with an instrument. Variables showing larger confidence intervals and low precision of measurement were those, such as percent boulder substrate, where classes of substrate sizes were judged by eye. They found that accuracy in measuring habitat variables is hampered by bias caused by different observers and by natural variability over time of habitat features.

Similarly, Leathe and Graham (1983) had two different crews measure habitat in the same sections of two streams in northern Idaho, and calculated the relative percent differences in their measurements. Again, measurements were generally least variable for those parameters measured quantitatively (width, depth, velocity), and most variable for those assessed qualitatively (percent riffle-run, percent pool, channel stability). Variance in independent variables is important when making statistical inferences because an assumption of regression models commonly used is that independent variables are measured without error (Neter and Wasserman 1974, Sokal and Rohlf 1981). Another assumption of regression models is that the dependent variable (i.e., standing crop) is subject to measurement error, but population estimates of fish in streams often have very wide confidence intervals which hampers model development and testing.

Although structure of the models varies widely, a major biological assumption common to each is that the fish population is limited by the set of habitat variables included in the model. This assumption must be satisfied by an investigator in each case where a model is used, according to his knowledge of the dynamics of a particular fish population and the factors that limit it. This leads to questions about the theoretical underpinnings of models -- to what habitat variables should abundance of stream fish be related? Hall and Knight (1981) reviewed the literature on natural variability of salmonid populations in streams, and classified the important factors affecting fish abundance as physical (streamflow and physical habitat) and biological (food abundance, predation, and movement and migration). They report that temporal and spatial variation in salmonid abundance may be as extreme as several orders of magnitude, and that even more moderate annual variation can mask very significant changes in the aquatic environment. Hall and Knight (1981) found, as we did, that physical habitat characteristics, particularly the many forms of cover, were most closely related to salmonid abundance, and suggested that these should be the first variables to include in habitat assessment.

A final consideration in testing and use of models is the "universe" to which they pertain. Johnson (1981) cautions against using models that were developed with data collected from a single study area during a single season or year, to extrapolate results over wider geographic areas or time periods. Unfortunately, the misuse of models in this way is often done not by the investigator, but by other biologists. A good example of a model designed for use over a broad but prescribed geographic area is Binns and

Eiserman's (1979) HQI model developed for use in Wyoming.

One way to develop meaningful models that predict standing crop of stream fish from habitat variables over prescribed geographic regions is to divide watersheds into ecoregions or land types that encompass areas of homogeneous climate, geology, landform and soils. This stratification has long been promoted by Platts (1974), Lotspeich (1981), and Lotspeich and Platts (1982) to simplify management of natural resources. Development of models that apply to specific ecoregions should increase their accuracy of predicting standing crop from measurable habitat variables.

Acknowledgments

We thank Tom Wesche of the Wyoming Water Research Institute (University of Wyoming, Laramie) who aided us in our search for models while preparing a similar review for a contributed paper at the 1983 Western Division meetings of the American Fisheries Society. We also thank those who helped us locate models that were inaccessible or unknown to us, including Bob Behnke, Ken Bovee, Paul Brouha, Cliff Hawkes and Pat Slaney. Carl Armour and Clair Stalnaker reviewed an earlier draft. Funds for this research were provided by the Wildlife and Fishery Ecology Unit of the USDA Forest Service.

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Table 1. Characteristics of models that use only geomorphic and watershed variables.

Reference	Significant[a] independent variables	No. independent variables assessed[b]	n	Model type[c]	Best[d] model	r^2	p
1. Ziemer (1973)	drainage density (X_1) mean basin length (X_2) mean basin slope (X_3)	4(8)[e]	25	P,I	$SC_{\text{escapement no./stream}} = a \cdot Z^b$ where : $Z = \frac{X_1 \cdot X_2}{X_3}$	0.34[f]	NR[g]
2. Burton and Wesche (1974)	mean basin elevation (X_1) forested area (X_2) drainage area (X_3) total stream length (X_4)	18	11	P,I	$SC_{\text{no./acre}} = a \cdot PI^b$ where : $PI = \frac{X_1 \cdot X_2}{X_3 \cdot X_4}$	0.33	NR
3. Wesche et al. (1977)	mean basin elevation (X_1) drainage area (X_2) mean basin length (X3) total stream length (X_4) mean basin slope (X_5)	7	12	LR,I	$SC_{\text{no. >6 in/mi}} = a + bI$ where : $I = \frac{X_1 \cdot X_2 \cdot X_3}{X_4 \cdot X_5}$	0.66	NR

a. Variables included in final model.
b. Variables measured for development of model.
c. LR = linear regression
P = power function
I = index created by combining independent variables.
d. Model chosen accounted for the most variation in the dependent variable.
e. Ziemer (1973) reported values for eight geomorphic variables but only four were used in models.
f. Our calculation after three outliers justified by Ziemer were removed.
g. NR = not reported by author(s).

Table 2. Characteristics of models that use primarily microhabitat independent variables that measure physical microhabitat, water chemistry, and biological characteristics.

Reference	Significant[a] independent variables	No. independent variables assessed	n	Model type[b]	Best[c] model	r^2	p
1. Klamt (1976)	percent boulder-and-log cover (X_1)	4A[d]	23	MLR	$SC_{no./m^2} = a + bX_1 + cX_2$	0.36[e]	NR[f]
2. Enk (1977)	overhead bank cover (X_1)	1A	--	LR	a. Salmon Trout River (n = 10) $SC_{g\ of\ brook\ trout\ \geq 100\ mm} = a + bX_1$	0.89	< .01
					b. Pigeon River (n = 12) $SC_{g\ of\ all\ trout\ 150\text{-}399\ mm} = a + bX_1$	0.72	< .01
3. Harshbarger and Bhattacharyya (1980)	number of rocks (X_1) percent brush cover (X_2) percent instream bank vegetation (X_3) area overhanging (0-1m) vegetation (X_4) area overhanging (1-2m) vegetation (X_5) total cover area (X_6)	18A	100	MLR, FA	$SC^{g}_{biomass\ age\text{-}II\ trout} = a + bX_1 + cX_2 + dX_3 + eX_4 + fX_5 + gX_6$	0.66	NR
4. Barber et al. (1981)	available spawning area (X_1) overhanging vegetation (X_2) day of season (X_3)	15A,2B	76	MLR, PCA	a. Age-0 coho salmon - MLR $\log SC_{no./section} = a + b \log X_1 + cX_2 - dX_3$	0.76	NR
					b. Age-0 coho salmon - PCA $\log SC_{no./section}$ = linear function of all 17 variables	0.81	NR
5. Paragamian (1981)	16-256 mm substrate (X_1)	1A,4B	11	LR,E	$SC_{kg/ha\ \geq 200\ mm\ in\ 1978} = ae^{bX_1}$	0.90	< .001
6. Leathe and Graham (1983)	percent fine substrate (X_1)	1A	14	E[h], LR	a. Juvenile bull trout $SC_{no./m^2} = ae^{-bX_1}$	0.56	< .01
					b. Brook trout $SC_{no./m^2} = a + bX_1$	0.62	< .01

Table 2. (cont'd)

a. Variables included in final model.

b. LR = linear regression
   MLR = multiple linear regression
   E = exponential function
   FA = factor analysis
   PCA = principal component analysis

c. Model(s) chosen that accounted for most variation in dependent variable.

d. Variables measured for model development. A = microhabitat variables, B = channel morphometry and flow variables.

e. Several models with higher coefficients of determination not reported (see text).

f. NR = not reported by author(s).

g. Units of standing crop in biomass not reported.

h. No equations reported. Model types assumed from terms "linear" and "non-linear" in text and curve shapes in figures.

Table 3. Characteristics of models that use combinations of three types of independent variables.

Reference	Significant[a] independent variables: A. Geomorphic and watershed	B. Channel morphometry and flow	C. Microhabitat	No. independent variables assessed	n	Model type[b]	Best[c] model	r^2	p
1. Lewis (1969)		mean pool current velocity (X_1)	total cover area (X_2)	4B[d],2C	19	MLR	$SC_{no./pool} = a + bX_1 + cX_2$	0.66	<.01
2. Havey and Davis (1970)		rainfall for July - August of last two years (X_1)	standing crop of all salmon (X_2) mean weight of all fish (X_3) standing crop of age-I and older salmon (X_4)	NR[e]	5	MLR	a. Age-0+ Atlantic salmon $SC_{lb/acre} = -a + bX_2 + cX_3$ b. Age-I+ and older salmon $SC_{lb/acre} = -a + bX_4 + cX_1$	0.998 0.94	<.01 <.01
3. Stewart (1970)		mean depth (X_1)	rock cover >0.30 m^2 (X_2) rock cover <0.10 m^2 (X_3) relative rating of all rock cover, undercut bank, and deep turbulent water (X_4)	5B,10C	41	MLR	a. Rainbow trout >18 cm $SC_{g/m} = a + bX_1 + cX_2 + dX_3$ b. Brook trout >18 cm $SC_{g/m} = a + bX_1 + cX_4$	0.43 0.36	<.05 <.05
4. Hunt (1971)		surface area[f] average depth channel volume average pool depth pool area	bank cover	5B,1C	17	MLR[g]	$SC_{lb\ trout/station\ pre\text{-}development}$ = linear function of all six variables	0.85	<.01
5. Hendrickson et al. (1973a)		mean discharge/mi^2 (X_1) median annual 7-day low-flow per mi^2 (X_2) ration 10%/90% duration discharge (X_3) low-flow velocity index (X_4)	percent instream vegetation (X_5) mean annual temperature (°F) (X_6) mean annual temperature (°F)/55 (X_7)	4A,17B,10C	29	MLR,P	a. $SC_{lb/mi} = a \cdot X_2^b \cdot X_3^c \cdot X_5^d \cdot X_6^e$ b. $SC_{lb/acre} = a \cdot X_1^b \cdot X_4^c \cdot X_5^d \cdot X_7^e$	0.64 0.68	<.10 <.10
6. Hendrickson et al. (1973b)		width/depth (X_1)	percent gravel (X_2) percent instream vegetation (X_3) hardness (X_4) mean annual temperature (°F)/55 (X_5)	5A,13B,11C	88	MLR,P	$SC_{lb/mi} = a \cdot X_1^b \cdot X_2^c \cdot X_3^d \cdot X_4^e \cdot X_5^f$	0.62	<.10
7. Platts (1974, 1976)	elevation watershed condition	width section gradient[h] depth percent pool percent riffle	pool rating (2)[i] bank cover (2) substrate (4) bank condition (2) bank type pool feature (2)	2A,5B,13C	291	MLR[g]	a. $SC_{no.\ all\ species/section}$ = linear function of all variables b. $SC_{no.\ rainbow\ trout/section}$ = linear function of all variables	0.32 0.35	NR NR

Reference	Significant[a] independent variables: A. Geomorphic and watershed	B. Channel morphometry and flow	C. Microhabitat	No. independent variables assessed	n	Model type[b]	Best[c] model	r^2	p
8. White (1975)		mean Jan.-Feb. discharge (X_1)		1B	8	LR[g]	$SC_{kg/100\ m} = a + bX_1$	0.75	<.01
9. White et al. (1976)		mean winter flow (X_1) maximum spring flow (X_2) mean summer flow (X_3)	previous spring standing crop (X_4)	7B,2C	--	MLR	a. Age-0 trout in fall, North Branch Au Sable River (n = 9) $SC_{no/km} = a + bX_1 - cX_2 + dX_3$	0.95	<.001
							b. All trout in fall, Big Roche-a-Cri Creek (n = 8) $SC_{kg/km} = a + bX_3 - cX_4$	0.94	<.001
10. Binns and Eiserman (1979), Binns (1979)		late summer flow (X_1) annual flow variation (X_2) section water velocity (X_3) width (X_4)	maximum summer temperature (X_5) nitrate nitrogen (X_6) food abundance (X_7) food diversity (X_8) percent cover (X_9) eroding banks (X_{10}) substrate (X_{11})	6B,16C	--	MLR,P,I	a. Model I (n = 20, 16T[j]) $SC_{kg/ha} = a\ R_{X_1}{}^b \cdot R_{X_2}{}^c \cdot R_{X_5}{}^d \cdot P^e$ where: $P = R_{X_6} \cdot R_{X_2} \cdot R_{X_8} \cdot R_{X_9} \cdot R_{X_{10}} \cdot R_{X_3} \cdot R_{X_4}$ R_{X_1}, R_{X_2}, etc. are ratings of relative quality of flow and microhabitat attributes	0.95	NR
							b. Model II (n = 36, 8T) $SC_{kg/ha} = a \cdot R_{X_1}{}^b \cdot R_{X_2}{}^c \cdot R_{X_5}{}^d \cdot F^e \cdot S^f$ where: $F = R_{X_5} \cdot R_{X_6} \cdot R_{X_{11}} \cdot R_{X_3}$ $S = R_{X_9} \cdot R_{X_{10}} \cdot R_{X_4}$	0.97	NR
11. Nehring (1977) Stalnaker (1979) Wesche (1980) Orth and Maughan (1982) Annear and Conder (1983)		area (X_1) depth (X_2) mean water velocity (X_3)	substrate (X_4) temperature (X_5)	3B,2C	--	LR	a. Brown trout (Nehring 1979, n = 7) $SC_{lb/acre} = a + b \cdot WUA$ where: $WUA = \sum_{i=1}^{n} C_i \cdot X_{1i}$ C_i = joint relative preference function for combinations of depth, velocity, and substrate within cells. Temperature tolerance also accounted for. X_{1i} = surface area of cell i	0.76	NR
							b. Brown trout (Stalnaker 1979, n = 19) $SC_{kg/km} = a + b \cdot WUA$	0.90	NR
							c. Brown trout in larger streams (Wesche 1980, n = 4) $SC_{lb/section} = a + b \cdot WUA$	0.82	<.01
							d. Warmwater stream fish (Orth and Maughan 1982) $SC_{kg/ha} = a + b \cdot WUA$ (n = 8 for each group each season) (1) Adult and juvenile smallmouth bass (no significant regressions during any season)		
							(2) Freckled madtom - summer	0.86	<.001
							(3) Central stoneroller - summer	0.70	<.01
							(4) Orangebelly darter - summer (n = 9)	0.70	<.01
							e. Brown and rainbow trout (Annear and Conder 1983, n = 10) $SC_{lb/acre} = a + b \cdot WUA$ (no significant regression)		

Table 3 (continued).

Reference	Significant[a] independent variables: A. Geomorphic and watershed	B. Channel morphometry and flow	C. Microhabitat	No. independent variables assessed	n	Model type[b]	Best[c] model	r^2	p
12. Nickelson et al. (1979)		depth (X_1, X_2) wetted area (X_3) pool volume (X_4)	instream cover (X_5) overhead cover (X_6) surface turbulence (X_7) velocity refuge (X_9) velocity weighting factor (X_9) depth-and-velocity preference factor (X_{10})	4B,6C	--	LR,I	a. Cutthroat trout (n = 29, 20T) $SC_{g/section} = a + b \cdot HQR_{CT1}$ where: $HQR_{CT1} = (aX_1 + bX_2 + cX_5 + dX_6 + eX_7 + fX_8) \cdot X_3 \cdot X_9$ b. Steelhead trout (n = 23, 12T) $SC_{g/section} = a + b\ HQR_{ST}$ where: $HQR_{ST} = (X_5 + X_6 + X_7 + X_8) \cdot X_3 \cdot X_{10}$ c. Coho salmon (12, 318T) $SC_{g/section} = a + bX_4$	0.91 0.79 0.935	NR NR NR
13. Wesche (1980, 1974)		thalweg[k] length (X_1) section area (X_2)	overhead bank cover (X_3) area with substrate >3.0 in diameter, >0.5 ft deep (X_4) area >1.5 ft deep (X_5) preference factor for X_3 by species (X_6) preference factor for X_4 by species (X_7)	2B,5C	48	I,LR	a. Brown trout in small streams by reach (n = 8) $SC_{lb/acre} = a + b \cdot CR_1$ where: $CR_1 = \frac{X_3}{X_1} \cdot X_6 + \frac{X_4}{X_2} \cdot X_7$ b. Brown trout in larger streams by reach (n = 4) $SC_{lb/acre} = a + b \cdot CR_2$ where: $CR_2 = \frac{X_3}{X_1} \cdot X_6 + \frac{X_4}{X_2} \cdot X_7 + \frac{X_5}{X_2}$	0.60 0.95	<.05 <.05
14. Murphy et al. (1981)			total invertebrate biomass (X_1) collector-gatherer invertebrate biomass (X_2)	2C	6	LR[g]	a. $SC_{g/m^2} = a + bX_1$ b. $SC_{g/m^2} = a + bX_2$	0.69 0.98	<.05 <.01
15. Fraley and Graham (1982)	stream order (X_1)		instream and overhead cover (X_2) substrate (X_3)	30[l]	134, 23T	MLR	$SC_{Age\text{-}I\ and\ older\ trout} = a - bX_1 + cX_2 - dX_3$	0.41	<.05
16. Stowell et al. 1983)			percent embeddedness of stream bed with fine (<6.4 mm) sediment (X_1)	1C	--	E,PL	<u>Summer rearing capacity</u> a. Age-0 steelhead (n = 12) $SC_{no./m^2} = a + bX_1 + cX_1^2$ b. Age-I steelhead (n = 5) $SC_{no./m^2} = a + bX_1^2 + cX_1^3$ c. Age-0 chinook (n = 8) $SC_{no./m^2} = a + bX_1 + cX_1^2$ <u>Winter rearing capacity</u> a. Age-0 chinook (n = 7) $SC_{no./m^2} = a \cdot e^{-bX_1}$ b. Age-0 steelhead (n = 8) $SC_{no./m^2} = a \cdot e^{-bX_1}$	0.87 0.99 0.92 0.99 0.90	.001 <.005 .01 <.005 .01
17. Slaney (personal comm.)		percent riffle area (X_1) percent run area (X_2) percent pool area (X_3) percent flat-run area (X_4) percent flat area (X_5) percent backwater area (X_6)	percent boulder area in riffles (X_7) percent overhanging cover area in riffles (X_8) total dissolved solids (X_9) mean annual stream temperature (X_{10})	6B,4C	--[m]	LR[n],P	$SC_{smolts/m^2} = a \cdot H \cdot N \cdot X_{10}$ where: $H = a\left[(b \cdot X_7 + c \cdot X_9 - d) \cdot X_1 + eX_2 + fX_3 + gX_4 + hX_5 + iX_6\right]$ $N = jX_9 + k$	NR	NR

Table 3 (continued).

a. Variables included in final model.

b. LR = linear regression.
   MLR = multiple linear regression.
   P = power function.
   E = exponential function
   PL = polynomial function.
   I = index created by combining independent variables.

c. Model(s) chosen that explained most variation in dependent variable.

d. Variables measured for model development. Letters A, B, and C refer to categories of independent variables at left.

e. NR = not reported by author(s).

f. Not a significant ($p > .05$) variable in the multiple regression.

g. Regression model not reported by investigator.

h. Measured in the field for each stream section.

i. More than one independent variable of this type in model.

j. T = number of additional observations used to test model.

k. Thalweg is the line of maximum depth.

l. Individual variables not specified by authors.

m. Number of years of data used to develop data not reported.

n. Linear regression used to develop relationship between smolt SC and X_9.

Table 4. Three types of independent variables used in models, and the number of models for which each variable was found to be significant (in parentheses). Some variables were grouped into general categories, and in models where significance of variables was not reported, we judged significance from available information. Tests of models, such as of Weighted Usable Area, were not included, nor was the model of Slaney (pers. comm.).

Geomorphic and watershed	Channel morphometry and flow	Microhabitat
Geomorphic	Channel morphometry	Physical
mean basin length (2)	depth (7)	instream cover (17)
mean basin slope (2)	area (5)	substrate (16)
mean basin elevation (2)	width (4)	temperature (6)
drainage area (2)	volume (2)	depth preferenda (3)
total stream length (2)	thalweg length (2)	instream vegetation (3)
elevation (2)	gradient (2)	overhanging vegetation (2)
drainage density (1)	percent pool (2)	velocity preferenda (2)
stream order (1)	percent riffle (2)	cover preferenda (2)
	width/depth ratio (1)	eroding banks (2)
Watershed		spawning area (1)
	Flow	day of season (1)
forested area (1)		
watershed condition (1)	water velocity (5)	Chemical
	mean summer flow (2)	
	mean winter flow (2)	nitrate nitrogen (2)
	late summer flow (2)	hardness (1)
	annual flow variation (2)	
	maximum spring flow (1)	Biological
	rainfall (1)	
	mean flow (1)	invertebrate food (3)
	median low flow (1)	other standing crops of fish (3)
	10%/90% duration discharge (1)	

4/26/94

DEAR BOB —

THOUGHT YOU MIGHT BE INTERESTED IN THIS RECENT THESIS. IN READJUSTING FISH STOCKING FROM PROGRAMS THAT AREN'T NEEDED BIOLOGICALLY OR ARE INEFFICIENT ECONOMICALLY, WE NEED TO MAKE SURE WE DON'T GIVE CARTE BLANCHE ENDORSEMENT TO HABITAT IMPROVEMENT AS A BETTER WAY TO SPEND OUR MONEY. MANY OF OUR PAST, SITE SPECIFIC HABITAT PROJECTS ARE AS BAD, OR WORSE, ECONOMICALLY AS ANNUAL STOCKING WITH CATCHABLES. HOPEFULLY, THE FUTURE APPROACH TO HABITAT IMPROVEMENT (MANAGEMENT) WILL ADDRESS PROBLEMS AT THE SYSTEMS LEVEL INSTEAD OF SITE SPECIFIC CURES FOR SYMPTOMS.

HABITAT IMPROVEMENT IS POPULAR WITH BIOLOGIST ; ANGLER GROUPS BECAUSE YOU SEE SOMETHING TANGIBLE — SOMETHING "GOOD" IS PRODUCED. I'M SURE THIS IS THE SAME FEELING PEOPLE GET WHEN THEY PLANT FISH OR BUILD DAMS.

I HOPE YOU GET A CHANCE TO FISH WYOMING THIS SUMMER.

REGARDS,

JOHN BAUGHMAN

Executive Summary

"Economic, Biologic and Physical Evaluation of Stream Habitat Improvement Projects in Wyoming"

Submitted to

Wyoming Game and Fish Department
Cheyenne Wyoming

Submitted by

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Laramie, Wyoming

April 1994

Chapter One

GENERAL INTRODUCTION

The goal of this study was to conduct an economic, biologic and physical evaluation of stream habitat improvement projects implemented statewide by the Wyoming Game and Fish Department. The intent of this document is to summarize the findings of two independent, but interrelated, Master of Science theses developed at the University of Wyoming during 1992 and 1993:

Dalton, Robert S. 1993. Economic evaluation of stream habitat improvement projects in Wyoming. M.S. thesis, Agricultural Economics and Water Resources, University of Wyoming, Laramie, WY. 169 pgs.

Hogle, Jeffrey S. 1993. Salmonid habitat and population characteristics related to structural improvement in Wyoming streams. M.S. thesis, Range Management and Water Resources, University of Wyoming, Laramie, WY. 79 pgs.

The reader is directed to these theses for additional detail regarding the study.

Chapter Two

ECONOMIC EVALUATION OF STREAM HABITAT IMPROVEMENT PROJECTS IN WYOMING

The combination of growth in population, higher income levels, and increasing amounts of leisure time have created increased demand for outdoor recreational opportunities. As a result, demand placed on natural resources and the agencies that manage them are constantly increasing. At the same time, budgets necessary to meet these demands are often inadequate. Consequently, difficult choices regarding recreational opportunities and management activities must be made. However, criteria on which these decisions are based are not always clearly defined. Stewardship of our natural resources, popular sentiment of the public, conventionally accepted practices, and economic implications may all be appropriate criteria and should be evaluated in the allocation of scarce management resources. The importance of economic implications as a criteria in helping form these difficult decisions is widely recognized. However, necessary economic information is often unavailable.

As a case example, the Wyoming Game and Fish Department (WGFD) has not had the information available to compare costs of stream habitat improvement work to the economic benefits associated with these projects. Although the cost of a habitat improvement project can be readily estimated, the associated value to Wyoming anglers is largely unknown. Therefore, WGFD has not been able to effectively utilize economic considerations as a criteria for evaluating the relative merit of proposed habitat improvement projects compared to other management programs and activities competing for limited funds.

Objectives

The primary objective of this study was to estimate the value of benefits associated with habitat improvement work on trout streams in Wyoming. Specifically, the study was designed to estimate consumer surplus (net willingness to pay) for trout fishing on Wyoming streams, and for trout fishing on streams with improved habitat. Specific objectives of the study were:

1) Conduct a mail survey of Wyoming anglers to determine their characteristics and preferences.
2) Stratify the market by identifying different types of anglers based on their reasons for fishing.
3) Estimate the economic benefits of habitat improvement projects using a dichotomous choice Contingent Valuation Method (CVM).

Data Collection

The survey sample was drawn from a list provided by Western Aquatics, Inc. of Laramie, Wyoming (Meiers, 1992). Their sample was drawn randomly from fishing license receipts provided by WGFD for license sales in January through November of 1991. Five fishing license types were represented in their sample including resident, nonresident, resident youth, 5-day tourist, and 10-day tourist licenses. The number of receipts sampled was based proportionally on the number of licenses sold during the period. A total of 12,000 observations were drawn randomly from all vendors, representing all counties in Wyoming.

Because of budget constraints, 1800 observations were drawn for this study from the 12,000 random observations provided by Western Aquatics. Addresses which were designated as undeliverable by the U.S. Postal Service during Western Aquatic's survey were eliminated from the sample. Resident youth observations were also discarded, because purchasers of this classification of fishing license are probably not responsible for making financial decisions regarding vacations or expenditures for outdoor recreation. A systematic sample of 1800 observations were drawn from the remaining list based on the proportions of resident, nonresident, 5-day tourist and 10-day tourist licenses to the total number of licenses sold during 1991. This method provided 873 observations from the resident group, 121 observations for the nonresident group and 806 from the two tourist groups totalling 1800 observations in all.

An adaptation of the Dillman Total Design Method was used to conduct a mail survey of the 1800 people in the sample (Dillman, 1978). Of the 1800 surveys mailed, 1165 surveys were returned for a response rate of 65%. The number of usable responses was reduced by the need for information from anglers fishing on streams and not on lakes or reservoirs. Of the 1165 who returned a questionnaire, 325 said they fished lakes or reservoirs 100% of the time, reducing the total number of responses from anglers who said they fished streams at least part of the time to 840.

The questionnaire used in this study was designed for analysis using CVM. The subject good for this study is neither the habitat improvement project itself nor the wildlife it supports. The subject good is the fishing trip and all attendant characteristics and expectations which comprise a wildlife use opportunity (Driver, 1985).

The first section of the survey asked questions regarding experience of the fisherman including the number of years the angler had been fishing, how often they fished for trout and how often they fished for trout in Wyoming.

The second section of the survey was directed specifically to the angler's most recent trip. Questions were asked about the trip such as how long they fished per day, how many days they fished, what equipment they used and how successful they were. Included in this section was the question about the angler's reasons for choosing to fish this site, and whether they had chosen a site where habitat work had been done.

The third section of the survey contained three CVM questions which were utilized to estimate consumer surplus. The angler was first asked how far he travelled (one-way) to fish the site, how many hours were required for travel, and his share of trip expenses. Each angler was then asked if the trip was worth more than what was actually spent. If yes, they were asked if they would still have made the trip if their share of the expenses had been increased a specified amount. Bid amounts from $1 to $600, using 28 different amounts, were systematically placed in the question for all the surveys. The angler could answer yes or no to this question which was designed to elicit consumer surplus (value) for the fishing trip under existing conditions.

Because most anglers are probably unfamiliar with habitat improvement projects per se, willingness to pay (WTP) for habitat work was elicited in terms of the improved conditions resulting from proposed habitat improvement. Anglers were first asked how large a trout would have to be for them to consider it a large trout, and then they were asked how many large trout they caught that trip. This was followed by a question which asked if they would be willing to pay a specified bid amount over current trip expenses given a habitat improvement project which doubled their chances of catching a large trout. Again the bid amounts were varied in the surveys systematically from $1 to $600, and the anglers could answer yes or no. The third WTP question was similar except it asked if they would be willing to pay a specified amount more given a habitat improvement project which increased fish population by a specified percentage. The three proposed percentage increases in population were 25%, 50% and 100%.

The fourth section of the survey focused on angler's preferences regarding management programs for Wyoming trout streams, including protecting and improving trout habitat, stocking streams with hatchery trout, imposing special fishing regulations and improving access. The fifth and final section asked for demographic information from the angler such as age, sex, city and state of residence, highest level of formal education, employment status and annual before tax household income.

Economic Model and Analytical Approach

The multivariate economic model estimated in this study is consistent with the model developed by Duffield et al. (1988) in his evaluation of trout fishing in Montana, which is based on the research of Driver (1985). Driver theorized that the product of public agencies managing wildlife is a recreational opportunity, not the wildlife itself. As such, a recreational fishing trip is defined not just by size and species of fish available, but also by the physical setting, access to the site, distance from home, it's scenic attributes, by the social setting, and number and type of other anglers encountered during the experience (Allen, 1988). An angler's psychological expectations, such as desired consequences of taking a fishing trip and the angler's reasons for fishing, are important aspects of the wildlife use opportunity (Bryan, 1979; Adams, 1979).

The economic model used in this study incorporates these fundamental psychological considerations and expectations. The subject good is a fishing trip and all its attendant characteristics. Economic value, in terms of consumer surplus of the fishing trip under current conditions and under improved conditions contingent on proposed habitat improvement, is estimated based on the functional form of the economic model.

Another objective of this study was to identify different types of anglers and estimate consumer surplus for trout fishing, under current conditions and improved conditions, for each of the angler types identified. Consistent with Allen's work, 17 reasons for fishing were utilized to stratify the market (Allen, 1988). The possible reasons for fishing include general recreational goals such as being outdoors, viewing scenery and getting away from it all, social considerations such as being with family or friends, and factors more specific to the sport such as catching wild trout, catching trout to eat and testing fishing skills. Different angler types were identified using cluster analysis based on each angler's ranking of the relative importance of the reasons for fishing.

Results

Cluster analysis of the responses to this survey identified just two angler groups based on 17 reasons for fishing. There were 197 members in cluster 1 and 501 members in cluster 2. Based on responses to the 17 reasons for fishing , members of cluster 1 might be considered the more traditional anglers by citing scenery, catching trout to eat and nearness to home as the most important reasons for choosing to fish a particular stream on their last trip. Members of cluster 2 might be considered more as the specialists of the two groups. Respondents belonging to cluster 2 cited reasons such as testing fishing skills, catching wild trout and catching a large trout more often than cluster 1 anglers. Solitude, getting away from it all and fishing somewhere new were also often cited as important to cluster 2 anglers.

Anglers in cluster 2 travelled 220 miles farther, spent $238 more on the trip, fished nearly one full day more on the trip, and caught more than twice as many trout. The cluster 2 angler used flies more often and tied their own flies more often than cluster 1 anglers, while cluster 1 anglers relied on lures and bait more often than cluster 2 anglers.

The two cluster groups also differed significantly in their preferences for management programs and regulations or restrictions for increasing the size or number of trout in a stream. Although both groups said they preferred protecting and improving habitat over stocking programs, cluster 2 anglers selected habitat programs as one of their top two choices, 10% more often than cluster 1 anglers. Stocking hatchery trout was the next most popular management program with cluster 1 anglers, while cluster 2 anglers preferred regulations over stocking as a management strategy. Both groups favored increasing access the least, although cluster 1 anglers chose this management option 5.6% more often than cluster 2 anglers. Cluster 2 anglers preferred catching and releasing all trout as a management alternative twice as often as cluster 1 anglers.

Estimates of willingness to pay for the complete sample and both groups are reported in table 1. The sample groups, stratified by reasons for fishing, reveal a substantially different willingness to pay. Consumer surplus is much lower for cluster group 1. The values for cluster group 2 are much larger. All three groups, the complete sample and the cluster groups, have higher WTP estimates for current conditions than for conditions with habitat improvement. Caution must be exercised in interpreting these values. Two factors should be considered before concluding that improved conditions are valued less than current conditions.

Table 1. Consumer Surplus Estimates for Current Conditions, Improvement in Catching Large Trout, and Improving Trout Population.

MODEL	PER TRIP ($)	PER DAY ($)
Complete Sample		
Current Conditions	246.80	183.54
Large Trout Improvement	219.12	131.90
Population Improvement	202.68	101.41
Cluster 1		
Current Conditions	151.87	117.95
Large Trout Improvement	140.73	75.06
Population Improvement	98.83	54.29
Cluster 2		
Current Conditions	277.52	180.98
Large Trout Improvement	254.44	145.02
Population Improvement	241.34	118.84

First, the value for current conditions does not reflect the value for a site perceived as needing habitat work, but rather for a site perceived as having at least adequate trout habitat. Only 21.5% of the respondents felt that management problems existed on their chosen site. Also, 55% of the respondents said their chosen site was either their favorite or one of their favorite places to fish, and 92% of the respondents said they planned to continue fishing that site. Only 9% said they preferred to fish other places. This suggests that anglers are not likely to choose to fish a site perceived as having poor trout habitat, but rather one which offers acceptable trout habitat. This supports the assumption that the current conditions model represents the value for a site with at least adequate to good trout habitat. As perceived by the typical angler, it is of sufficient quality to be considered a favored fishing site.

Second, it is reasonable to conclude that a site perceived as offering poor trout habitat is probably valued at or near zero as a trout fishing site by most anglers, particularly when good sites are readily available.

Considering these two factors, the current conditions model should not be interpreted as estimating the value for a site in need of trout habitat improvement. Rather, survey responses indicate this model estimates consumer surplus or WTP for trout fishing on streams in Wyoming that are viewed as having trout habitat of acceptable quality. Additionally, the higher values for current conditions may suggest a preference for naturally occurring habitat of acceptable quality over artificially improved habitat. If this is the case, one should use the current conditions values only if habitat could be improved in such a manner as to be undistinguishable from naturally occurring habitat. Otherwise, the more conservative values estimated by the population or large trout improvement models would be appropriate for valuing proposed habitat improvement work.

Because the responses to the survey are for favored, chosen sites, WTP values for the improved conditions models should be regarded as conservative values for habitat improvement projects. It is not surprising that the WTP values for these models are somewhat less than the current conditions model considering that the responses are for sites which are not, in general, perceived as needing habitat improvement. The WTP values from the improved conditions models should be considered as conservative estimates of consumer surplus for habitat improvement work on sites that actually do need or could benefit from habitat improvement work. The WTP estimates for current conditions should be considered as a more representative value of consumer surplus for improvements to inferior sites and can be interpreted as an upper limit for valuing habitat improvement work.

Using results from the complete sample, estimated consumer surplus for trout habitat improvement projects ranges from $202.68 to $246.80 per trip.

Valuing Stream Habitat Improvements

Wyoming Game and Fish Department funded this project, in part, to gain information needed to evaluate the economic benefits of stream habitat improvement projects. With the estimates of consumer surplus in Table 1, the potential benefits from a hypothetical stream habitat improvement project can be calculated. The $183.54 per day value for the complete sample and current conditions will be utilized to illustrate how consumer surplus can be used to estimate the economic benefit of a habitat improvement project. Taking $183.54 as the value per fisherman day, the present value of habitat improvement benefits for various combinations of number of fisherman days, project life in years and discount rates can be computed and are shown in table 2.

The lowest consumer surplus estimate of $54.29 was for the cluster 1 group under the population improvement model. Using the $54.29 as the value per fisherman day, the present value of habitat improvement benefits for different combinations of number of fisherman days, project life in years and discount rates was computed and are shown in table 3.

An intermediate estimate of consumer surplus is $118.84, which was for cluster 2 group for the population improvement model. The present value of habitat improvement benefits for different combinations of number of fisherman days, project life in years and discount rates for the $118.84 value per fisherman day are shown in table 4.

In evaluating the desirability of habitat improvement projects, the present value of habitat improvement projects in tables 2, 3 and 4 can be compared directly with the projected cost of a proposed habitat improvement project. For example, the cost of the Beaver Creek project was $32,117. Using the intermediate value of $118.84 per fisherman day and a 4% discount rate, there would have to be at least 20 fisherman days of annual use and the project would have to last 20 years

Table 2. Present Value of Habitat Improvement Benefits with Value Per Fisherman at $183.54

Discount Rate 4%

Number of Fisherman Days — Project Life (years)

	15	20	25	30
10	$20,406.69	$24,943.68	$28,672.77	$31,737.80
20	$40,813.38	$49,887.37	$57,345.53	$63,475.60
30	$61,220.06	$74,831.05	$86,018.30	$95,213.39
40	$81,626.75	$99,774.74	$114,691.06	$126,951.19
50	$102,033.44	$124,718.42	$143,363.83	$158,688.99
60	$122,440.13	$149,662.11	$172,036.59	$190,426.79
70	$142,846.82	$174,605.79	$200,709.36	$222,164.59

Discount Rate 6%

Number of Fisherman Days — Project Life (years)

	15	20	25	30
10	$17,825.86	$21,051.89	$23,462.57	$25,263.97
20	$35,651.72	$42,103.79	$46,925.14	$50,527.94
30	$53,477.59	$63,155.68	$70,387.72	$75,791.91
40	$71,303.45	$84,207.57	$93,850.29	$101,055.88
50	$89,129.31	$105,259.47	$117,312.86	$126,319.86
60	$106,955.17	$126,311.36	$140,775.43	$151,583.83
70	$124,781.03	$147,363.25	$164,238.00	$176,847.80

Discount Rate 8%

Number of Fisherman Days — Project Life (years)

	15	20	25	30
10	$15,710.07	$18,020.23	$19,592.48	$20,662.54
20	$31,420.13	$36,040.46	$39,184.97	$41,325.07
30	$47,130.20	$54,060.68	$58,777.45	$61,987.61
40	$62,840.27	$72,080.91	$78,369.94	$82,650.14
50	$78,550.34	$90,101.14	$97,962.42	$103,312.68
60	$94,260.40	$108,121.37	$117,554.91	$123,975.21
70	$109,970.47	$126,141.59	$137,147.39	$144,637.75

Table 3. Present Value of Habitat Improvement Benefits with the Value Per Fisherman Day at $54.29

Discount Rate 4%
Annual Number Fisherman Days | Project Life (years)

	15	20	25	30
10	$6,036.00	$7,378.00	$8,481.00	$9,388.00
20	$12,072.00	$14,756.00	$16,962.00	$18,776.00
30	$18,109.00	$22,135.00	$25,444.00	$28,164.00
40	$24,145.00	$29,513.00	$33,925.00	$37,551.00
50	$30,181.00	$36,891.00	$42,406.00	$46,939.00
60	$36,217.00	$44,269.00	$50,887.00	$56,327.00
70	$42,253.00	$51,647.00	$59,369.00	$65,715.00

Discount Rate 6%
Annual Number of Fisherman Days | Project Life (years)

	15	20	25	30
10	$5,273.00	$6,227.00	$6,940.00	$7,473.00
20	$10,546.00	$12,454.00	$13,880.00	$14,946.00
30	$15,818.00	$18,681.00	$20,820.00	$22,419.00
40	$21,091.00	$24,908.00	$27,760.00	$29,892.00
50	$26,364.00	$31,135.00	$34,700.00	$37,365.00
60	$31,637.00	$37,362.00	$41,640.00	$44,838.00
70	$36,909.00	$43,589.00	$48,581.00	$52,310.00

Discount Rate 8%
Annual Number of Fisherman Days | Project Life (years)

	15	20	25	30
10	$4,647.00	$5,330.00	$5,795.00	$6,112.00
20	$9,294.00	$10,661.00	$11,591.00	$12,224.00
30	$13,941.00	$15,991.00	$17,386.00	$18,336.00
40	$18,588.00	$21,321.00	$23,181.00	$24,447.00
50	$23,235.00	$26,651.00	$28,977.00	$30,559.00
60	$27,882.00	$31,982.00	$34,772.00	$36,671.00
70	$32,529.00	$37,312.00	$40,567.00	$42,783.00

Table 4. Present Value of Habitat Improvement Benefits with Value Per Fisherman Day at $118.84

Discount Rate 4%
Annual Number of Fisherman Days — Project Life (years)

	15	20	25	30
10	$13,213.09	$16,150.74	$18,565.28	$20,549.85
20	$26,426.18	$32,301.49	$37,130.56	$41,099.70
30	$39,639.27	$48,452.23	$55,695.84	$61,649.56
40	$52,852.37	$64,602.98	$74,261.12	$82,199.41
50	$66,065.46	$80,753.72	$92,826.40	$102,749.26
60	$79,278.55	$96,904.46	$111,391.68	$123,299.11
70	$92,491.64	$113,055.21	$129,956.96	$143,848.97

Discount Rate 6%
Annual Number of Fisherman Days — Project Life (years)

	15	20	25	30
10	$11,542.04	$13,630.85	$15,191.74	$16,358.13
20	$23,084.07	$27,261.71	$30,383.48	$32,716.25
30	$34,626.11	$40,892.56	$45,575.22	$49,074.38
40	$46,168.15	$54,523.42	$60,766.96	$65,432.50
50	$57,710.18	$68,154.27	$75,958.70	$81,790.63
60	$69,252.22	$81,785.13	$91,150.44	$98,148.75
70	$80,794.26	$95,415.98	$106,342.18	$114,506.88

Discount Rate 8%
Annual Number of Fisherman Days — Project Life (years)

	15	20	25	30
10	$10,172.08	$11,667.89	$12,685.90	$13,378.75
20	$20,344.17	$23,335.77	$25,371.81	$26,757.50
30	$30,516.25	$35,003.66	$38,057.71	$40,136.25
40	$40,688.34	$46,671.55	$50,743.62	$53,515.00
50	$50,860.42	$58,339.43	$63,429.52	$66,893.75
60	$61,032.51	$70,007.32	$76,115.42	$80,272.50
70	$71,204.59	$81,675.20	$88,801.33	$93,651.25

for the present value of project benefits to offset the initial cost of the Beaver Creek Project. Following this procedure, the Wyoming Game and Fish Department can select the combination of value per fisherman day, number of fisherman days, project life and discount rate in tables 2, 3, and 4 in computing the present value of habitat improvement benefits for a project. The present value can than be compared with the initial cost plus any annual maintenance costs of the habitat improvement project in assessing the desirability of that project.

Summary and Conclusions

The objective of this study was to estimate economic benefits of trout fishing on Wyoming streams and of habitat improvement work on Wyoming streams. A secondary objective was to address the issue of market stratification. To meet these objectives, a mail survey was conducted to determine characteristics and preferences of anglers fishing Wyoming streams. The market was stratified based on respondents' reasons for fishing. Two angler types were identified using cluster analysis. Anglers in cluster 2 tended to be more experienced and skilled in the sport, travelled farther and incurred larger expenses on their trip than those anglers in cluster 1.

The Contingent Valuation Method (CVM) was employed to estimate economic benefits associated with fishing under both current and improved conditions. Benefits of habitat improvement were in terms of hypothetically improved conditions contingent on improved habitat. Benefits were estimated for hypothetically doubling the chance of catching a large trout, and for hypothetically increased trout populations. Consumer surplus, or willingness to pay, was estimated on a per trip and a per day basis.

Consumer surplus for trout fishing on Wyoming streams for the complete sample was estimated to be $247 per trip, and $184 per day. Benefits for habitat improvement work was estimated to be $203 to $219 per trip, and $101 to $132 per day. Benefits for the smaller, less specialized angler group, cluster 1, ranged from $54 to $118 per day. For the larger, more specialized group, cluster 2, benefits ranged from $119 to $181 per day.

Stratification of the market in this study provides WGFD with the opportunity to manage for specific groups of anglers. For example, a benefit-cost analysis of proposed habitat improvement work on a site which might attract cluster 2 anglers can utilize WTP estimates for that type of angler. In addition, for each angler group a range of benefits can be examined by using the more conservative values estimated by the improvement models and values representing an upper limit of benefits from current condition models.

With cautious estimation of the level of use at individual sites, the results of this study can be utilized by WGFD to evaluate and prioritize potential habitat improvement projects. The Wyoming Game and Fish Department can also utilize these benefit estimates to help with resource allocation decisions between different management activities. In addition, the mail survey provided information on angler's preferences for various management programs and rules and regulations for maintaining or increasing trout populations. The benefit estimates and management preference questions indicate that anglers would most prefer management strategies or improvement projects which allow them to catch more large trout.

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Biological Report 29
March 1995

The Instream Flow Incremental Methodology

A Primer for IFIM

by

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Holland & Peters 94
HSIs modified fn. Peters et al (89)

5 8 hr
+ $30

Figures

- Compare Time periods and/or sites - different "preferences" depth, velocity, substrate - "Suitability" "Preferences" denotes genetic, hereditary based stereotypical behavoir - evolutionary programming.
- Most revised HSI. Best (1.0) velocities 0/0-10/
- Speckled dace fig. 26
- Note dif. velocity utiliz - 1987-90 vs. 1992-93

* - Chadwick - 1992 - high flows - lower abundance but some sites would have higher velocities ("preferences" utiliz)?

Niche - NB corn Gause/Hutchinson

Otter Crk. RB/BN sucker/dace, Au Sable (Trying ...)

Red R. US Justice, SRP, LAWP - Mono L, NPS (Glacier)

IFIM - as basis - ?

reality / assumptions / patterns / testing

hydrology (hydraulics) unstable ...
biology - flow - habitat - fish (niche) bio / abiotic -
- assumptions
- how used
- IFIM.

BSP - unresolved - repro. early life history overwinter connectedness flows -

Reality - MMM how did 800 ...

flushing flows - ... - what good
- re. peak flows Ecosystem health - biodiv
- cut down
guilds - quality controls.
- oversight -
- peer review

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Uncertainty and Instream Flow Standards: Perspectives Based on Hydropower Research and Assessment

By Webster Van Winkle, Charles C. Coutant, Henriette I. Jager, Jack S. Mattice, Donald J. Orth, Robert G. Otto, Steven F. Railsback, and Michael J. Sale

In a thought-provoking essay, "Uncertainty and Instream Flow Standards," Castleberry et al. (1996) argue that currently no scientifically defensible method exists [including the Physical Habitat Simulation System component (PHABSIM) of the Instream Flow Incremental Methodology (IFIM)] for defining instream flows needed to protect fish or aquatic ecosystems. They suggest (1) that an adaptive management approach is preferable, involving protective interim standards, a monitoring program, and an effective [institutional] procedure for revising interim standards in light of new information; and (2) that scientists and managers need to understand and consider the uncertainties in instream flow methods, develop and implement monitoring methods that will realize the potential of adaptive management, and develop the basic (mechanistic) biological knowledge about how flows affect the survival and reproduction of individuals.

We want to add to these constructive ideas to promote further discussion on the important issue of instream flow management. The scientific defensibility of any predictive assessment methodology needs to be judged based on its scientific foundations and its proven track record of use in specific environmental assessments. The adaptive management approach, while having a sound scientific foundation, is still developing a proven track record. Many perceive this approach as trial-and-error manipulations that provide an excuse for maintaining the status quo. Stated more strongly, adaptive management can be primarily a political process of adapting to changing political pressures, rather than a scientific process of adapting to increased scientific understanding. In reality, adaptive management requires dramatic experiments, including predictive models. We identify three additional needs to obtain the benefits of more flexible approaches such as adaptive management.

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Decision-making Framework

Adaptive management requires a high level of institutional, legal, and political flexibility—more than now typically occurs (Castleberry et al. 1996). Many fisheries agencies have insufficient resources for the current backlog of hydropower instream flow studies (Railsback et al. 1990), much less for long-term monitoring and adaptive management at each site. In addition, deregulation of electricity generation in the United States is creating a competitive climate such that hydropower operators will be less able to afford adaptive management experiments.

However, the benefits of flexible requirements are being recognized and gradually implemented. In addition to the "Hodge Decision" (Castleberry et al. 1996), examples include the settlement agreements for the Skagit River Project in Washington and the New Don Pedro Project in California, both of which allow flows to be varied according to agreed rules as more information and better models are obtained from monitoring studies. Additional opportunities for adaptive management lie with federal water projects [e.g., the Glen Canyon Project (U.S. Bureau of Reclamation 1995)]. Federal projects are not bound by the procedures of the Federal Energy Regulatory Commission, and study and mitigation costs (including funding of resource agency participation) are heavily subsidized.

> adaptive management can be primarily a political process of adapting to changing political pressures, rather than a scientific process of adapting to increased scientific understanding

Management Objectives

A challenge to any approach based on population- or community-level effects is achieving agreement on management objectives that are acceptable to the public, simple to understand, ecologically meaningful, and measurable before designing a monitoring program or a model. The objective could range from target values for adult population density or production of a key fish species to maintainance of a balanced and indigenous fish community. Many of these objectives are difficult to measure. For example, providing a specified long-term average number of outmigrating salmon smolts per spawner may seem like a simple, well-defined management objective. However,

Uncertainty and Instream Flow Standards

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Several years ago, *Science* published an important essay (Ludwig et al. 1993) on the need to confront the scientific uncertainty associated with managing natural resources. The essay did not discuss instream flow standards explicitly, but its arguments apply. At an April 1995 workshop in Davis, California, all 12 participants agreed that currently no scientifically defensible method exists for defining the instream flows needed to protect particular species of fish or aquatic ecosystems (Williams, in press). We also agreed that acknowledging this fact is an essential step in dealing rationally and effectively with the problem.

Practical necessity and the protection of fishery resources require that new instream flow standards be established and that existing standards be revised. However, if standards cannot be defined scientifically, how can this be done? We join others in recommending the approach of *adaptive management*. Applied to instream flow standards, this approach involves at least three elements.

First, conservative (i.e., protective) interim standards should be set based on whatever information is available but with explicit recognition of its deficiencies. The standards should prescribe a reasonable annual hydrograph as well as minimum flows. Such standards should try to satisfy the objective of conserving the fishery resource, the first principle of adaptive management (Lee and Lawrence 1986).

Second, a monitoring program should be established and should be of adequate quality to permit the interim standards to serve as experiments. Active manipulation of flows, including temporary imposition of flows expected to be harmful, may be necessary for the same purpose. This element embodies the adaptive management principles that management programs should be experiments and that information should both motivate and result from management action. Often, it also will be necessary to fund ancillary scientific work to allow more robust interpretation of the monitoring results.

Third, an effective procedure must be established whereby the interim standards can be revised in light of new information. Interim commitments of water that are in practice irrevocable must be avoided.

The details of the monitoring program should vary from case to case. Where protection of particular populations is emphasized, the monitoring program should produce estimates of population size. However, population estimates by themselves often will not provide useful guides to action. This is particularly likely with anadromous fishes such as salmon, where populations of adults depend on harvest, ocean conditions, and other factors not related to instream flows, and populations of juveniles are hard to estimate accurately. Managers will learn more if the monitoring program also includes a suite of indices of the growth, condition, and development of the target species. These indices need to be interpreted with awareness of the complications arising from variations in life history patterns within and among populations. However, the indices and population estimates together will offer the best evidence of the mechanisms by which flows affect the survival and reproduction of individuals and thus the persistence of populations.

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The 1990 "Hodge Decision" in the case of *Environmental Defense Fund v East Bay Municipal Utility District* [Superior Court of Alameda County (California) No. 425955], with which several of us have been involved, exemplifies this approach. Judge Richard Hodge set flow standards for the American River, a major tributary to the Sacramento, that are intended to protect chinook salmon and other public trust resources from diversions by the East Bay Municipal Utility District. However, Hodge recognized the "fundamental inadequacy" of existing information regarding flow needs, so he retained jurisdiction and ordered parties to the litigation to cooperate in studies intended to clarify what the flow standards should be. Experience with these studies motivated the April 1995 workshop.

Our claim that there is now no scientifically defensible method for defining flow standards implies that the Physical Habitat Simulation Model (PHABSIM), the heart of the Instream Flow Incremental Methodology (IFIM), is not such a method. We have divergent views on PHABSIM. Some of us think that, with modification and careful use, it might produce useful information. Others think it should simply be abandoned. However, we agree that those who would use PHABSIM, or some modification of it, must take into account the following problems: (1) sampling and measurement problems associated with representing a river reach with selected transects and with the hydraulic and substrate data collected at the transects; (2) sampling and measurement problems associated with developing the suitability curves; and (3) problems with assigning biological meaning to weighted usable area (WUA), the statistic estimated by PHABSIM. Estimates of WUA should not be presented without confidence intervals, which can be developed by bootstrap methods (Efron and Tibshirani 1991; Williams 1996). Nor should any analytic method become a substitute for common sense, critical thinking about stream ecology, or careful evaluation of the consequences of flow modification, as has sometimes happened with the implementation of the IFIM.

Establishing instream flows involves both policy and science, and scientists and resource managers have challenging roles in the process. Managers need to accept the existing uncertainty regarding instream flow needs and make decisions that will both protect instream resources and allow development of knowledge that will reduce the uncertainty. Scientists need to develop and implement monitoring methods that will realize the potential of adaptive management, and develop the basic biological knowledge that will provide a more secure foundation for decisions that must balance instream and consumptive uses of water.

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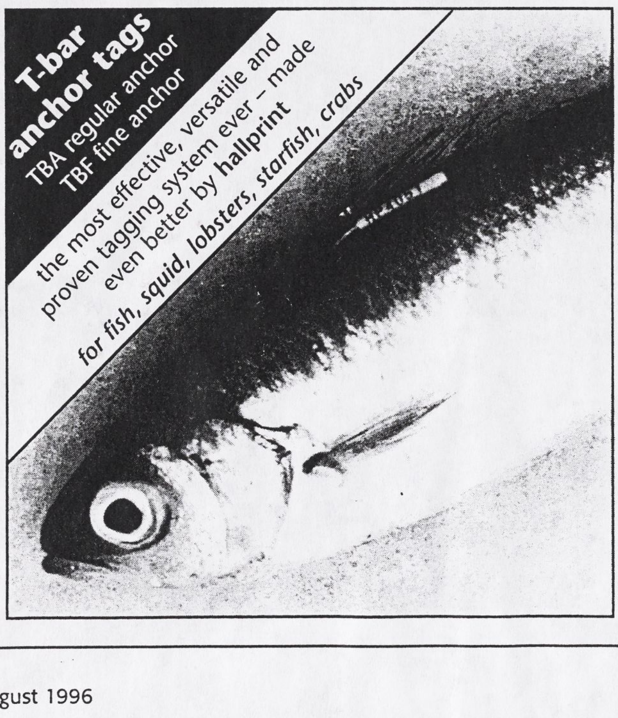

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determining whether this objective is being met based on variable and uncertain data gathered throughout the years is not simple. Nonetheless, the need to define such management objectives can be viewed as a strength of population- and community-level approaches (Orth 1995); while difficult, it does force decision makers to focus on real project effects, management options, and uncertainty.

Flow Manipulations, Monitoring Programs, and Models

The adaptive management approach requires several key components. The flow manipulation must involve a major change in the base flow regime for regulators and scientists to expect a measurable change. Minor flow changes may not provide the contrast needed to test the knowledge base and models used to develop management regulations and, thus, would fail to serve the decision-making purpose. While necessary for the adaptive management approach, flow manipulations and monitoring programs alone are not sufficient. For the adaptive management approach to be successful, it must include a methodology that provides two critical functions. First, it must provide the qualitative framework for identification and consensus-building concerning management objectives, flow manipulations, and monitoring. Second, it must provide a quantitative predictive tool [always combined with common sense, critical thinking about stream ecology, and careful evaluation of the actual consequences of flow modification (Castleberry et al. 1996)] that synthesizes the results from the monitoring program and makes quantitative predictions (absolute or relative) of fish population responses to alternative instream flow regimes and mitigation measures. Adaptive management can treat these predictions as hypotheses and design experiments to test their validity and improve predictions.

Although it has its weaknesses because of its limited focus on physical habitat, PHABSIM is such a tool. The individual-based modeling approach is another such tool that does not have this limitation. It replaces PHABSIM's reliance on habitat suitability curves with a mechanistic representation of the processes underlying fish growth, survival, and reproduction (e.g., Van Winkle et al. 1993). This representation varies with the life history of the species of interest, and density dependence (i.e., compensation) is an emergent population property of what happens to the individual model fish.

One such individual-based instream flow model (Van Winkle et al. 1996) is being developed in conjunction with a field evaluation of PHABSIM (Studley et al. 1996). By monitoring fish populations and habitat at 9 hydropower sites throughout 11 years and experimentally changing minimum flows (Studley et al. 1996), this study indicates that population responses to flow can be complex yet predictable. For example, at sites within one 5-km reach of the Tule River, California, factors that limited trout populations included base flows, scouring of redds by floods, winter temperatures too high for incubation, high summer temperatures, scarce spawning habitat, and interspecies competition. Physical habitat assessments alone cannot be expected to do well in such situations, yet many of these population-limiting factors have been successfully captured in the individual-based model and could be represented in a more comprehensive suite of models in IFIM. Preliminary results also indicate that relatively simple improvements to typical PHABSIM methods can produce instream flow assessments that are reasonably accurate and far less expensive than an adaptive management approach. At the very least, they can provide the initial predictions on which adaptive management can build.

Castleberry et al. (1996) correctly point out the uncertainties in simplistic instream flow assessments. We agree that the adaptive management approach has potential benefits and, in fact, we see a gradual trend toward more flexible assessment and management of water projects. However, before the adaptive management approach can be fully successful, it is clear that (1) decision-making frameworks; (2) management objectives; and (3) flow manipulations, monitoring programs, and models all need improvement. We emphasize that mechanistic models that depict the factors affecting the target aquatic resources (and not just physical habitat) must be key components of the adaptive management process. Without such models, the uncertainties may be greater than those currently encountered with habitat models, and as a consequence, eventual costs may be much higher than necessary.

Acknowledgments

The authors appreciate the constructive comments and perspectives of C. B. Stalnaker and two other reviewers. Preparation of this essay was supported by the Electric Power Research Institute under contract RP2932-2 (DOE ERD-87-672) with the U. S. Department of Energy, under contract DE-AC05-96OR22464 with Lockheed Martin Energy Research Corporation. This is Publication No. 4649 of the Environmental Sciences Division, Oak Ridge National Laboratory.

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