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WRRI-91

November 1983

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FINAL TECHNICAL COMPLETION REPORT
for Project No. B-077-ORE
Matching Grant Agreement No. 14-34-0001-1259

to
United States Department of the Interior
Bureau of Reclamation
Washington, D.C. 20240

Project Sponsored by:
Water Resources Research Institute
Oregon State University
Corvallis, Oregon 97331

The research on which this report is based was financed in part by the United States Department of the Interior as authorized by the Water Research and Development Act of 1978 (P.L. 95-467).

WRRI-91 November 1983

ABSTRACT

Research to examine the potential effects of small-scale hydroelectric dams on fish communities in the Willamette River was divided into two aspects. The first was to determine whether or not models of habitat assessment based solely upon physiological tolerances would be suitably accurate for prediction of impact. The second was to gather physical and ichthyofaunal characteristics for unimpounded streams and for streams impounded by various types of small-scale dams. By this approach, empirical information concerning the impact of small-scale dams would be gathered, and the predictive capacity of the habitat suitability models would be evaluated concurrently.

We found that ecological processes such as interspecific competition greatly limited the accuracy of habitat models based solely on physical variables. A second factor emerged: distributional patterns of fishes in different streams differed. We presumed that this may be caused by different limiting factors of different systems which shift behavior in a nonadditive way. We developed a multivariate approach to define habitat selection, by denoting habitat availability and habitat occupation based on microhabitat characteristics.

The second aspect of the study was to survey a small sample of sites impounded by small-scale dams and to

determine the types of impacts that could occur. In general, we found that the larger dams caused more negative impact due to diminution of flow, a greater amount of siltation, and a larger impounded area. Small dams in areas subjected to low summer flows may be beneficial, offering pool refuge for cutthroat trout. Predators of juvenile anadromous salmonid fishes are attracted to tailraces below dams and may cause a bottleneck to seaward migration for important sport and commercial fishes.

FOREWORD

The Water Resources Research Institute, located on the Oregon State University campus, serves the State of Oregon. The Institute fosters, encourages and facilitates water resources research and education involving all aspects of the quality and quantity of water available for beneficial use. The Institute administers and coordinates statewide and regional programs of multidisciplinary research in water and related land resources. The Institute provides a necessary communications and coordination link between the agencies of local, state and federal government, as well as the private sector, and the broad research community at universities in the state on matters of water-related research. The Institute also coordinates the inter-disciplinary program of graduate education in water resources at Oregon State University.

ACKNOWLEDGEMENTS

We thank the following graduate students for assistance in the field: Gordon Reeves, Gordon Kruse, Gregory Short, Dennis Lassuy. We thank our high school interns of American Indian descent: James McKay, Archie Nelson, Virginia Martin, and Lorraine Gonzales for their aid during the summers. Mark Wade and Charles Dewberry helped us find suitable sampling sites. We appreciate the statistical advice of Norbert Hartman. We discussed problems and approaches of habitat modeling with Bob House, Phil Larson, Bob Hughes, Jim Sedell, Mits Parsons, Bob Raleigh, and Jim Terrell. We thank the Oregon Department of Fish and Wildlife for the use of a pickup truck during the study.

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INTRODUCTION

The Concern

One hundred and twenty-eight dams have been proposed for low-head hydroelectric energy generation (Oregon's Environment, 1980). If all these sites came on line, it has been estimated that they could generate more energy than a typical nuclear power plant. River impoundments have had profound impacts on the fauna both upstream and downstream of the project (Holden, 1979; Vanicek et al., 1970; Spence and Hynes, 1971; Erman, 1973; Baxter, 1977). Presently, the habitat requirements of the fishes native to the Willamette River system are imperfectly known and the impacts of small-scale dams on aquatic fauna have not been examined. There is serious concern that changes could greatly influence the establishment and reestablishment of anadromous salmonid stocks within the basin.

Habitat Assessment Models

Models of habitat assessment have been constructed for two purposes, both of which are useful for estimating impacts of small-scale hydropower impoundments. The first purpose is to quantitatively evaluate in a quick, efficent, and inexpensive manner, the capacity of a given geographical locale to support fish species of interest. The second is to predict the kinds of impacts on areas where perturbations from various proposed developments may result.

There are two major types of models which have been proposed for use: (1) the Incremental Methodology of the Instream Flow Group, U.S. Fish and Wildlife Service (U.S.F.W.S.), and (2) aggregate models such as the Habitat Suitability Index Model (HSI model) or the Fish Habitat Index of the U.S. Forest Service (U.S.F.S.). The differences between the two types of models are that (a) the Incremental Methodology depends on relatively few variables (flow, depth, and substrate) whereas the aggregate approaches use many more variables, and (b) the means by which they derive habitat rankings are slightly different.

The models are similar in that habitat preferences are described by curves that depict the relationship of species performance to different independent variables. These are called habitat-suitability curves by the Incremental Methodology (Bovee and Cochnauer, 1977), and the Suitability Index curves by the HSI Model. Examples are shown in Figures 1 and 2.

The habitat-suitability curves are combined with the Manning equation, which describes hydraulic processes, in a computer program for Physical Habitat Simulation (PHABSIM). This simulates changes of fish habitat as altered by changes in flow (Milhous, 1979). The habitat is divided into an array of rectangular cells in this model. Each cell, C, is described as follows:

$C_i = fv(V_i) \times fd(D_i) \times fs(S_i)$,

where $fv(V_i)$ = suitability weighting factor for the velocity of cell i,

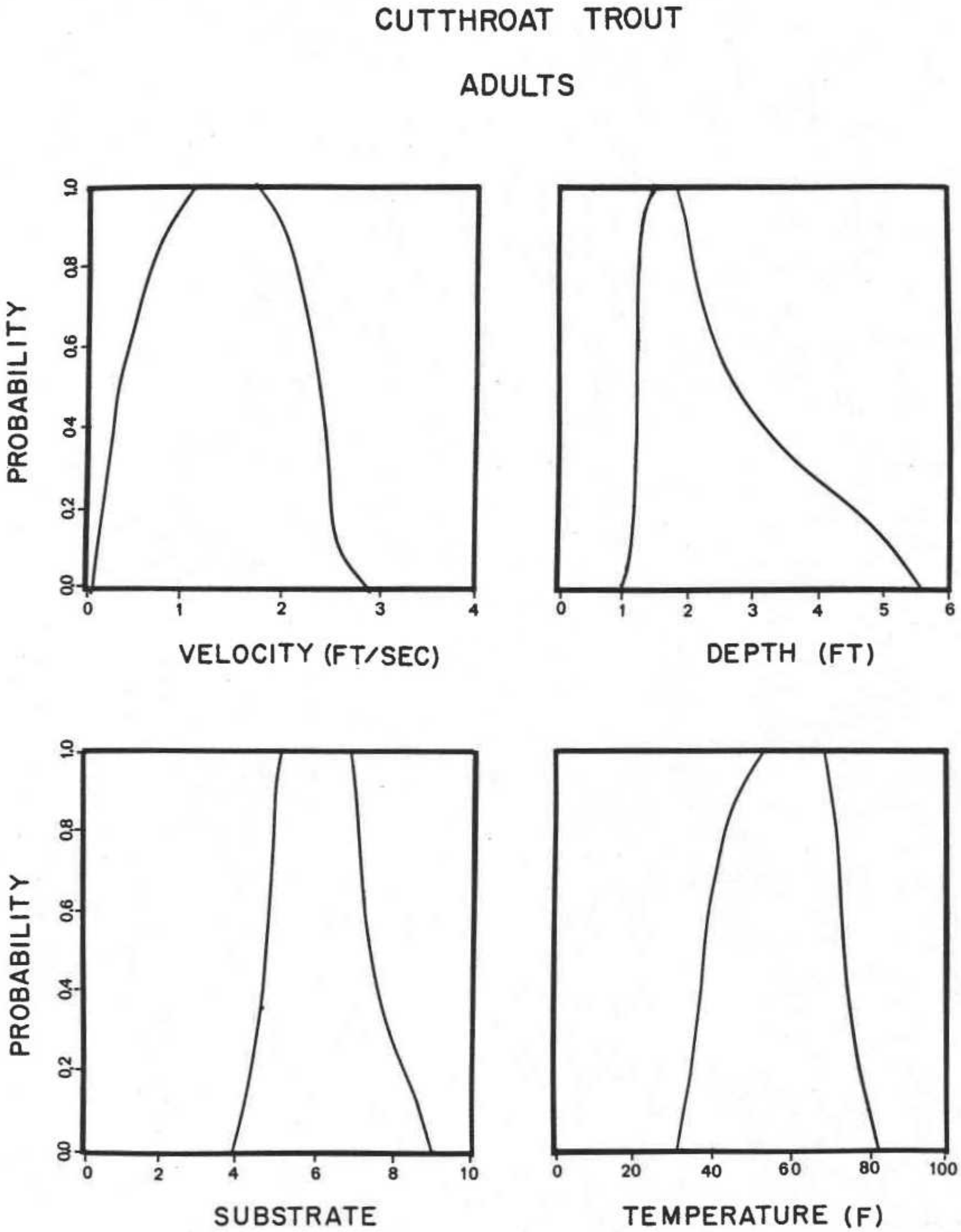


Figure 1. Examples of Habitat-Suitability Curves

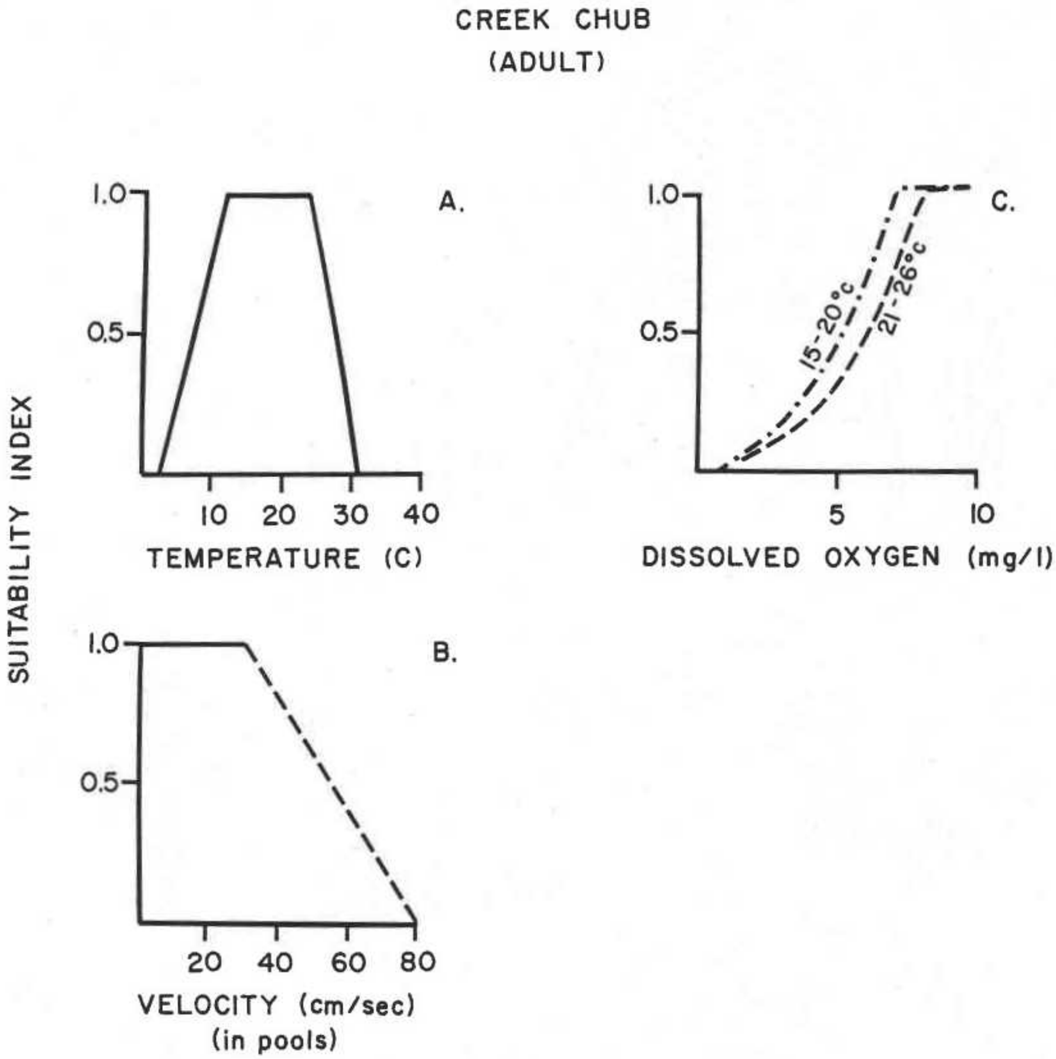


Figure 2. Examples of Suitability Index Curves

$fd(D_i)$ = suitability weighting factor for depth of cell i,

$fs(S_i)$ = suitability weighting factor for substrate type of cell i.

The habitat rating of a reach is calculated by adding the product of the suitability ranking of each cell by the area of that cell. The equation of this weighted usable area (WUA) is given below:

$$WUA = \Sigma C_i A_i,$$

where A_i = the area of cell i,

and n = the number of cells in the reach in question.

The assumptions which are specific to the Incremental model are (1) fish distribution is primarily governed by flow, depth, and substrate, (2) changes in the flow regime do not effect changes in channel morphology, (3) there is a positive, linear relationship between WUA and fish standing stock or habitat use (Orth and Maughan, 1982).

The ranking of habitat quality is different in the HSI methodology from that in the incremental method. Site-specific data comprising measurements of various physical variables are used to generate a Habitat Suitability Index from a number of models, including structural, pattern recognition (multivariate statistical approaches), linear regression models, and written descriptions (U.S.F.W.S., 1981). Habitat units (HU's) are generated from the following equation:

Habitat area x HSI = HU.

In the structural model, the field data are used to generate Suitability Indices (SI's), which range from 0 (unsuitable) to 1.0 (optimal). An SI is derived for each variable by comparing the field measurement to an SI curve that is a graphical presentation of performance by the species over a range of values of that factor. A number of these SI relationships have been established. A value of HSI can be generated using different assumptions, the simplest of which is to assume that the lowest SI value among those gathered represents the most limiting factor and cannot be compensated by high values of other factors. The other assumption is that high values of some factors can compensate for low values of other factors and that a value of HSI can be obtained by taking the geometric mean of the environmental factors:

$$HSI = (SI1 \times SI2 \times \ldots \times SIn)^{1/n}$$

where n = number of measured variables.

Assumptions common to both the Incremental method and the HSI method are as follows:

(1) the models assume that physiological responses to environmental gradients are the only factors governing habitat selection;

(2) habitat selection by each species is relatively fixed and not flexible;

(3) the factors are independent and do not interact;

(4) biological interactions are relatively unimportant determinants of habitat quality; and

(5) hierarchical spatial and temporal relationships of the site are unrelated to habitat use by the organism.

These are assumptions that need to be tested. Certain species inhabit a variety of habitats. Cutthroat trout (Salmo clarki) and redside shiners (Richardsonius balteatus) inhabit both lakes and streams (Lindsey and Northcote, 1963; Scott and Crossman, 1973; Moyle, 1976), suggesting that fishes are flexible in habitats occupied. There is evidence to show that competitive interactions can affect distributions of species within a community (Andruszak and Northcote, 1971; Werner and Hall, 1976; Werner, 1977) and evidence which indicates that predation is a potent force affecting the distribution of species (Moyle, 1976; Stein, 1979; Zaret, 1979). However, the models may be robust if the biological interactions act on a smaller spatial scale than the physical forces that physiologically limit the species of interest. The stream continuum concept suggests that functional groups of stream organismns, as exemplified by the stream insects, occupy different types of streams, roughly equivalent to stream order (Vannote et al., 1980). Only Small (1975), and Schlosser (1982) have examined the distribution of stream fishes from a perspective similar to that of the concept of the stream continuum, but it is known that fish species are added to the species pool downstream (Horwitz, 1978; Sheldon, 1978). This may be due to differences in physiological tolerance or to saturation of niches in increasingly more complex complex habitats along a stream gradient. This has not been resolved.

Study Objectives

The objectives of our research were as follows:

(1) Build a data base from which the performance of various species to different physical factors can be ascertained;

(2) Determine how each of the two models performs with respect to predictive accuracy;

(3) Examine biological mechanisms associated with the assumption of additive and independent properties so we can determine how this assumption influences the accuracy of each model;

(4) Improve habitat assessment approaches; and

(5) Estimate the impact of small-scale dams upon the fish fauna of the Willamette River drainage basin.

Organization of the Report

The report consists of three main chapters. The first two chapters address the adequacy of the current models to assess habitat quality and cover the first four objectives. The first chapter examines the influence that interspecific competition for space can have on the accuracy of predicting habitat quality for cutthroat trout. It demonstrates that habitat use by a fish is not a fixed relationship to physical gradients. The second chapter also addresses the assumption that habitat selection is an invarying response to physical gradients. It demonstrates that important physical variables related to habitat selection by redside shiners can change seasonally, depending upon the availability of microhabitats, and reinforces the idea that fishes are flexible in habitats they select. The third chapter is an assessment of the distribution of Willamette River fishes inhabiting three impounded streams in two different drainages and discusses the degree to which the dams influence the patterns of physical habitat and the species compositions involved. The summary and conclusion integrates the findings of each chapter and suggests means of improving habitat assessment models so that they will be of more value to resource managers.

TEST OF COMPETITION AND DRAINAGE-SPECIFIC FACTORS ON HABITAT MODELING

Introduction

If we are to assess the impacts of small-scale hydropower dams using the present models, we must examine carefully the assumptions of the models. All the previously discussed models assume that only physiological responses to environmental gradients are necessary to predict the use of a particular habitat by a given species of interest. We tested the accuracy of this assumption by examining the impact of competition for space, a biological factor, by steelhead trout (*Salmo gairdneri*) and coho salmon juveniles (*Oncorhynchus kisutch*) on the habitat use of cutthroat trout (*Salmo clarki clarki*), a year-around native salmonid of the Willamette drainage.

Study Areas

Two tributaries of the Nestucca drainage provided a natural experiment to examine competition for space by the three salmonid fishes. These are Bear Creek and Elk Creek, shown in Figure 3. They are particularly suitable because of natural barriers blocking the upper portion of each reach to one of the species. Below the barriers, all three species were sympatric (living together). Above the waterfall on Elk Creek, cutthroat trout were allopatric (isolated) from

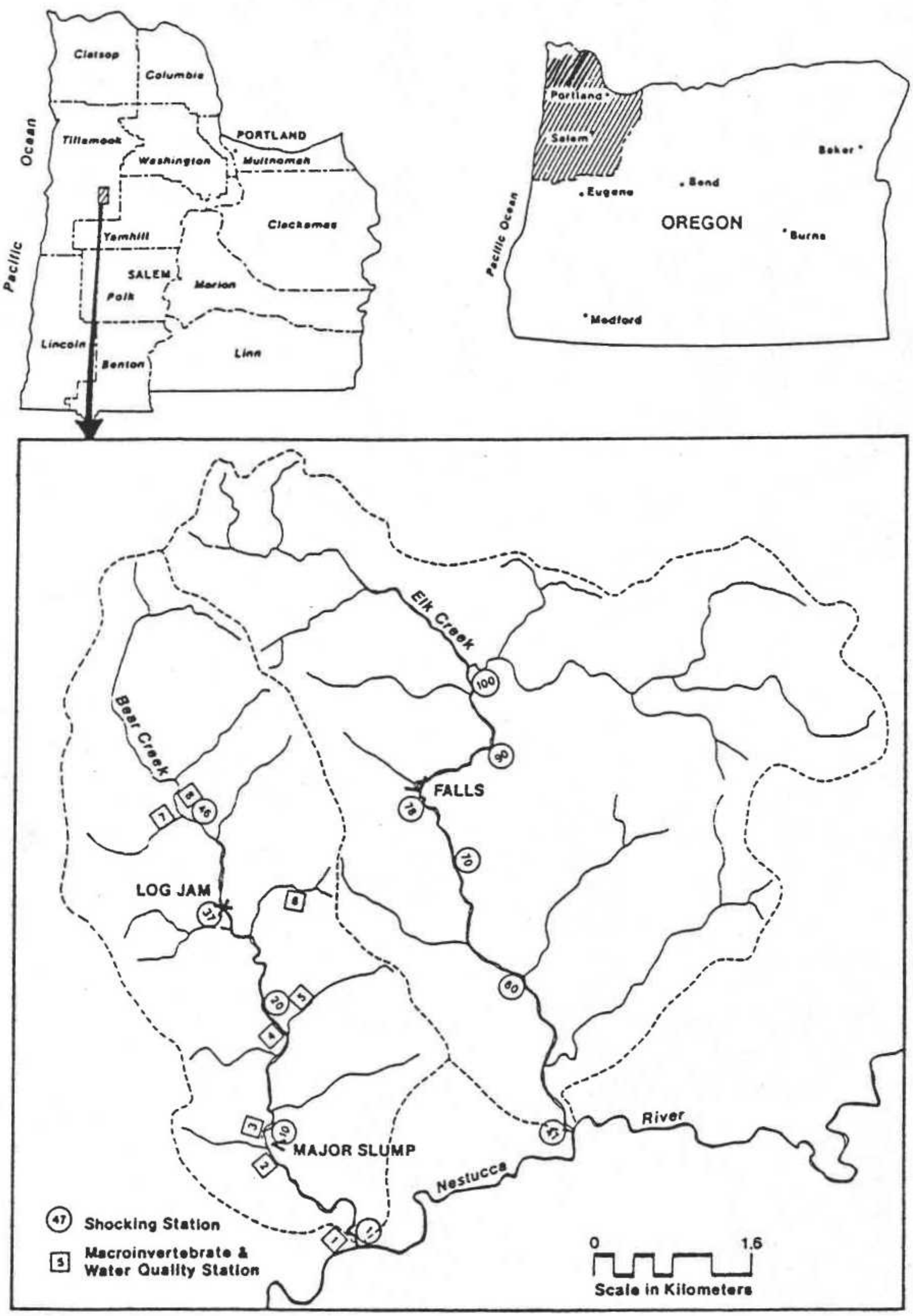


Figure 3. Location Map of Bear and Elk Creek Drainages, Oregon

steelhead trout, but found in sympatry with coho salmon planted above the barrier by the Oregon Department of Fish and Wildlife. Cutthroat trout above the log debris pile in Bear Creek were allopatric from coho salmon, but sympatric with steelhead trout. Thus above the barrier in each stream system, the cutthroat trout was under less competitive stress than below the barrier and the impact of competition could be observed.

Methods

Data gathered in cooperation with Bob House and Paul Bahne, Bureau of Land Management, were standardized in the HSI model format. The largest standing crop of cutthroat trout was found in the upper section of Elk Creek (0.055 fish/m^2). The Suitability Index (SI) was derived by dividing all other standing crops from other reaches by this value. Suitability profiles, or bivariate Cartesian plots relating variation in SI to different physical gradients were then constructed. One method of detecting competition was to compare the suitability profiles of cutthroat trout above and below the barriers. If competition did not cause a change in habitat use, then the two profiles should be similar, given that differences in physical habitat were not a factor. If competition is important, we should see that the profile above the barrier should be larger than that below the barrier for every given factor.

A multivariate statistical means of discriminating clusters for classification purposes was used to test whether or not the sections of each creek differed in habitat quality. This tool was also used to determine the habitat factors associated with different SI values for cutthroat trout. Four habitat classes were defined, each by an SI interval, which is defined as the ratio of standing crop to the maximum standing crop obtainable. The classes are defined as follows from least suitable to most suitable: 0 to 0.24, 0.25 to 0.49, 0.5 to 0.74, and 0.75 to 1.0.

Two habitat classifications were developed: one based on relationships between cutthroat SI values and physical habitat variables, and the other on combined physical and biological characteristics (i.e. densities of competitors). A classification results when a reach is assigned to a particular class (e.g. 0 to 0.25) because a certain set of rules is developed to relate habitat variables to habitat class. Better classifications have a higher percent of correct assignments than poorer ones. Important variables are those that are given more weight in the classification scheme. The many variables are reduced to two dummy variables called canonical discriminant functions. Important habitat variables contribute more to the dummy variable.

Results

Figure 4 illustrates that the four sections of Bear Creek and Elk Creek are physically different from each other.

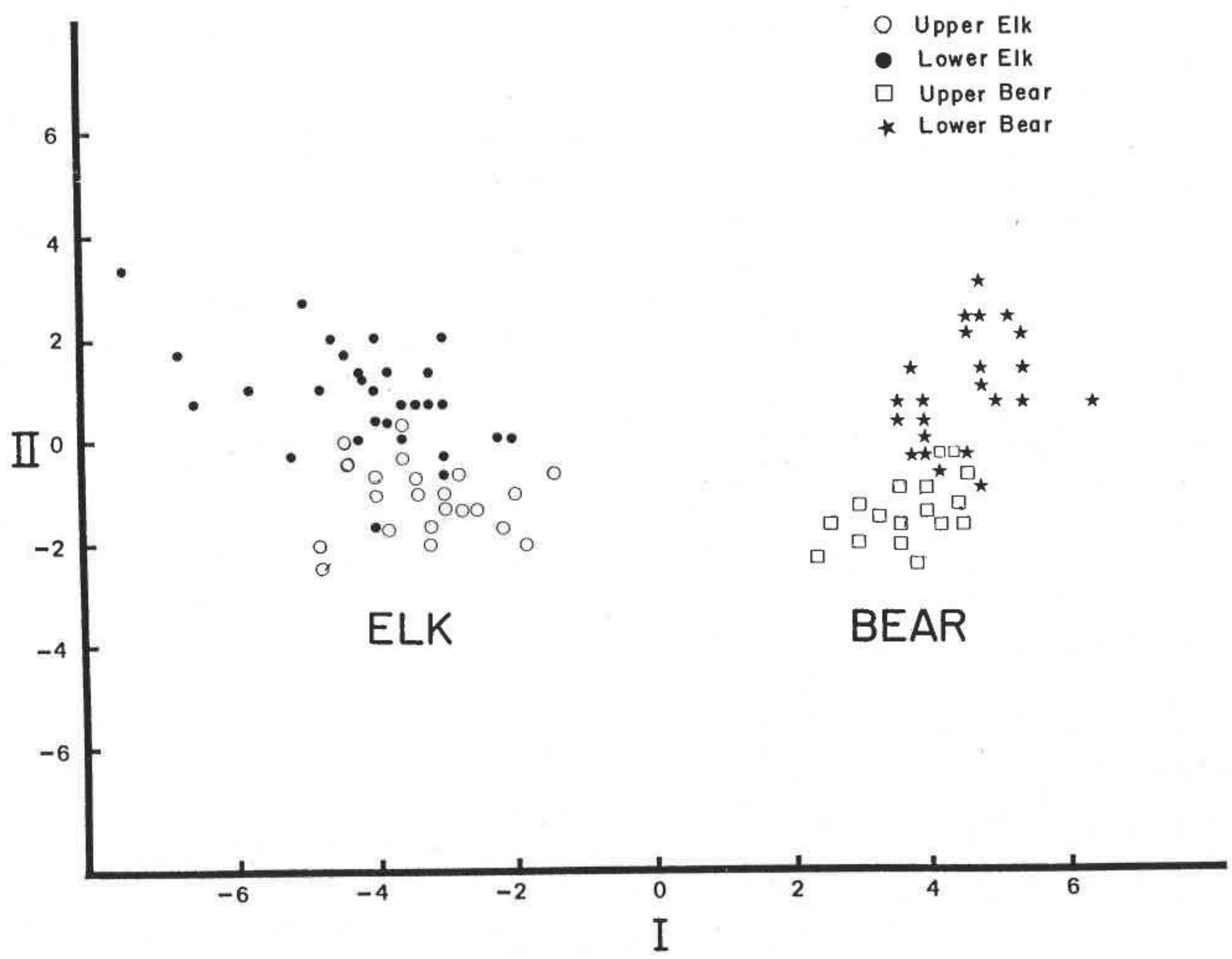


Figure 4. Reaches of Elk Creek and Bear Creek Clustered Along Canonical Discriminant Functions I and II

The percent of the correct assignments of cases to their correct classes was 92%. The first canonical function contributed 91% of the variance. This separated out the differences between creeks, but was not sufficient to differentiate between the sections within each creek. This canonical discriminant function is related to differences in discharge. Bear Creek was distinguished by a positive loading for greater width of the wetted perimeter (0.80), stream grade (0.26), percent stream shaded (0.22) and a substrate characterized by coarse gravel (0.22). Elk Creek was characterized by a strong negative loading of the variable of channel width (-1.37) and percent of large boulders in the substrate (-0.47). Discrimination of the four sections became clearer with the addition of the second discriminant function which contributed 6% of the variation. The most important variable associated with this function is stream gradient (-0.41). The results of this test suggest that one must account for between-stream differences as well as competition effects. Within-stream differences are relatively minor. Therefore, it will be possible to compare differences in habitat quality as due to the presence of competitors within a creek, but between creeks such comparison may not be fair.

Table 1 shows that there is an increase in percent correct classification when each creek is evaluated separately than when both creeks are combined into a single model of habitat quality. It also reveals that the percent

Table 1. Percent correct assignment of various classes of habitat using different models of habitat classification.

Variables evaluated	Combined	Bear	Elk	Steel. sec.	Coho sec.
	Stream Sections*				
physical only	70	78	69	-	-
both competitors	72	78	74	-	-
steelhead competitors	-	83	72	90	80
coho competitor	-	78	69	81	72

*Steel. sec. and Coho sec. columns refer to sections of both creeks where steelhead and/or coho salmon are sympatric with cutthroat trout, respectively, but allopatric with each other.

correct classification generally increases when the density of competitors are included into the model of habitat quality. Entering steelhead trout as a variable of the classification always increases the precision of the classification. In fact, the classification with the highest degree of accuracy is obtained in those sections where cutthroat trout are sympatric with steelhead trout. On the other hand, densities of juvenile coho salmon, when considered as a variable of classification, do not always increase its accuracy. Note that the values for assigning classes of cutthroat trout habitat correctly in Elk Creek when coho juveniles are entered as a biological variable is the same as that derived using only physical variables. Juvenile coho salmon was an important variable in describing cutthroat habitats where two sections of stream within which all three species were present (lower Elk Creek and lower Bear Creek) were contrasted with one section of stream where coho salmon were not present (upper Bear Creek). The reason that this contrast was done was to examine the increase ranges of the physical parameters in sympatric zones on the value of the classification. One will notice that in any classification wherein the Elk Creek system is considered, the increases in percentage of reaches properly classified are not as great as those in Bear Creek.

Table 2 shows that the addition of steelhead trout as a variable was important. Age 0+ steelhead was the second variable entered into the classification in the description

Table 2. Variables entered sequentially into the stepwise discriminant classification of habitat.*

Variables evaluated	Combined	Bear	Elk	Steel. sec.	Coho sec.
		Stream Sections			
physical only	wtwd	chwd	-	-	-
	%lb	%slt	%lb	-	-
	%slt	%cvr	%shd	-	-
	%poo	%snd	%cob	-	-
	%snd	%lb	%slt	-	-
	%cob	%rif	-	-	-
	chwd	-	-	-	-
	%shd	-	-	-	-
	%rub	-	-	-	-
both competitors	wtwd	chwd	chwd	-	-
	st0	st0	st1	-	-
	%lb	%slt	%lb	-	-
	chwd	%rif	%slt	-	-
	%slt	%cvr	%cob	-	-
	%cob	%snd	%shd	-	-
	%poo	%lb	coho	-	-
	%rub	%rub	-	-	-
	%snd	-	-	-	-
steelhead competitors	-	chwd	chwd	wtwd	wtwd
	-	st0	st1	st0	plb
	-	%slt	%lb	chwd	%slt
	-	%rif	%slt	%slt	%cob
	-	%cvr	%cob	%rif	st1
	-	%snd	%shd	%poo	-
	-	%lb	-	flo	-
	-	%rub	-	%cgv	-
coho competitors	-	chwd	chwd	coho	wtwd
	-	%slt	%lb	wtwd	%lb
	-	coho	%shd	%slt	%slt
	-	%cvr	%cob	%poo	%cob
	-	%snd	%slt	%cvr	-
	-	%lb	-	flo	-
	-	%rub	-	-	-

*chwd = width of channel cross section, wtwd = width of the wetted perimeter, %lb = percent large boulders (> 91 cm diam.), %cob = percent cobble (15 to 30 cm diam.), %rub = percent rubble (7.6 to 15 diam.), %cgv = percent coarse gravel (2.6 to 7.5 cm diam.), %snd = percent sand (< 0.25 cm diam.), %slt = percent silt, %shd = percent stream shaded, %rif = percent riffle, %poo = percent pool, %cvr = percent cover, st0 = age 0 steelhead trout, st1 = age 1 steelhead trout, coho = juvenile coho salmon, steel. sec. and coho sec. = sections of both creeks where steelhead and coho salmon are sympatric with cutthroat trout, respectively, but allopatric with each other.

of cutthroat habitat quality for Bear Creek, and for the sections of both creeks where cutthroat and steelhead trout were sympatric. Densities of age 1+ steelhead were important in determining habitat quality for cutthroat trout when habitats in Elk Creek were evaluated, but not when the habitats in sections of Elk Creek and lower Bear Creek were examined as a unit. Note that the physical variables important to the classification of habitat classes differs depending upon the degree to which the reaches of the Nestucca drainage are lumped together.

Table 3 shows the variables influential in the canonical discriminant functions. Only two functions were needed to separate habitat classes. Only those variables that contributed more than 50% of the most influential variable were listed to simplify the presentation. Note the relative contribution of competing species in the first canonical discriminant function. This indicates that competitors were highly influential in the various classifications previously discussed. By recalling the sign of this variable and relating it to the value of the canonical discriminant function at the group centroid (or group) mean for each of the habitat classes, one will appreciate how the habitat classes shift in pattern qualitatively. Table 4 shows that the worst habitat class is associated with the presence of the competitor. No sign was presented if the value of the canonical discriminant function was less than 0.1.

Table 3. Variable loadings on canonical discriminant functions I and II.*

Variables evaluated	Stream Sections: Combined	Bear	Elk	Steel. sec.	Coho sec.
physical only	**canonical discriminant function I.**				
	%slt(+.63)	chwd(-.84)	chwd(-.97)	-	-
	%snd(+.50)	%rif(+.50)	%cob(+.55)	-	-
	-	-	%shd(+.55)	-	-
	canonical discriminant function II.				
	%lb (+.75)	%slt(+1.25)	%lb(+1.01)	-	-
	%poo(-.88)	%cvr(+.54)	-	-	-
	-	%snd(-.84)	-	-	-
both competitors	**canonical discriminant function I.**				
	%slt(+.58)	%rif(+.48)	chwd(+.74)	-	-
	%cob(+.42)	%rub(+.40)	st1(+.65)	-	-
	%rub(+.40)	sto(-.66)	%slt(-.64)	-	-
	st0(-.64)	chwd(-.61)	%cob(-.44)	-	-
	wtwd(-.59)	-	-	-	-
	canonical discriminant function II.				
	%slt(+.64)	%snd(+.88)	%lb(+1.03)	-	-
	%poo(-.95)	%slt(-1.22)	-	-	-
steelhead competitors	**canonical discriminant function I.**				
	-	%rif(+.48)	chwd(+.81)	st0(+.73)	%slt(+.62)
	-	%rub(+.40)	st1(+.62)	chwd(+.55)	%cob(+.49)
	-	st0(-.66)	%cob(-.52)	flo(+.47)	%lb(+.45)
	-	chwd(-.61)	%cob(-.52)	%rif(-.58)	wtwd(-.72)
	-	-	%slt(-.52)	-	st1(-.67)
	canonical discriminant function II.				
	-	%snd(+.88)	%lb(+1.07)	%slt(+1.14)	%lb(+.94)
	-	%slt(-1.22)	-	%poo(-.98)	%cob(-.53)
coho competitors	**canonical discriminant function I.**				
	-	%rub(+.40)	%shd(+.55)	coho(+.74)	%slt(+.67)
	-	chwd(-.66)	%cob(+.55)	wtwd(+.57)	%cob(+.49)
	-	coho(-.52)	chwd(-.97)	-	wtwd(-.84)
	canonical discriminant function II.				
	-	%slt(-1.31)	%lb(+1.01)	%slt(+1.09)	%lb(+.95)
	-	-	-	%poo(-.89)	%cob(-.52)

*The key to the variables is the same as in Table 3.

Table 4. Signs of canonical discriminant functions evaluated at group centroids.*

Variables evaluated	Combined	Stream sections Bear	Elk	Steel. Sec.	Coho Sec.
Habitat class	1234	123	1234	123	1234
physical only					
I.	(68)-+++	(58)-++	(71)-+++		
II.	(21) -++	(42) -+	(26) -+		
both competitors					
I.	(75)-+++	(69)-++	(73)+---		
II.	(16) -++	(31) +-	(23) --+		
steelhead competitors					
I.		(69)-++	(77)+---	(82)+--	(82)-+++
II.		(31) +-	(21) --+	(18) -	(18) --+
coho competitors					
I.		(62)-++	(71)-+++	(30)+--	(73)-+++
II.		(38) +-	(26) -+	(30) -+	(27) --+

*Parentheses enclose the variation to group classification attributable to that function, which is denoted in Roman numerals.

Figures 5 and 6 are samples of Suitability Index curves. Here, there is no attempt to fit an average line to the data set. Instead, the extrema are connected because the capacity is considered biologically more important. The two curves depict the capacities in terms of standing crops of cutthroat trout in different reaches of stream. One set of reaches is in the area of sympatry, where the three species coexist, and the other is upstream. We suggest that the greater capacities of the sections of streams above the barriers reflect less interspecific competitive pressure on cutthroat trout. Figures 7 and 8 show the relationship of current to SI profiles in the two sections. The same relationship holds. Note also that the capacities in the two creeks are different for each variable in each of the figures.

Discussion

We conclude that the applicability of a general model will be greatly influenced by two factors: each system may be limited by different physical characteristics, and that in turn may affect interspecific competition for space and resources within the system. This will considerably affect the distribution of the species of interest, in this case, cutthroat trout. The influence of competition is more obvious in Bear Creek. Elk Creek is less disturbed by logging practices than Bear Creek, and perhaps resources are distributed in such a way that competition is less intense. For instance, Elk Creek has larger pools than Bear Creek and that factor may play a role in competition for space.

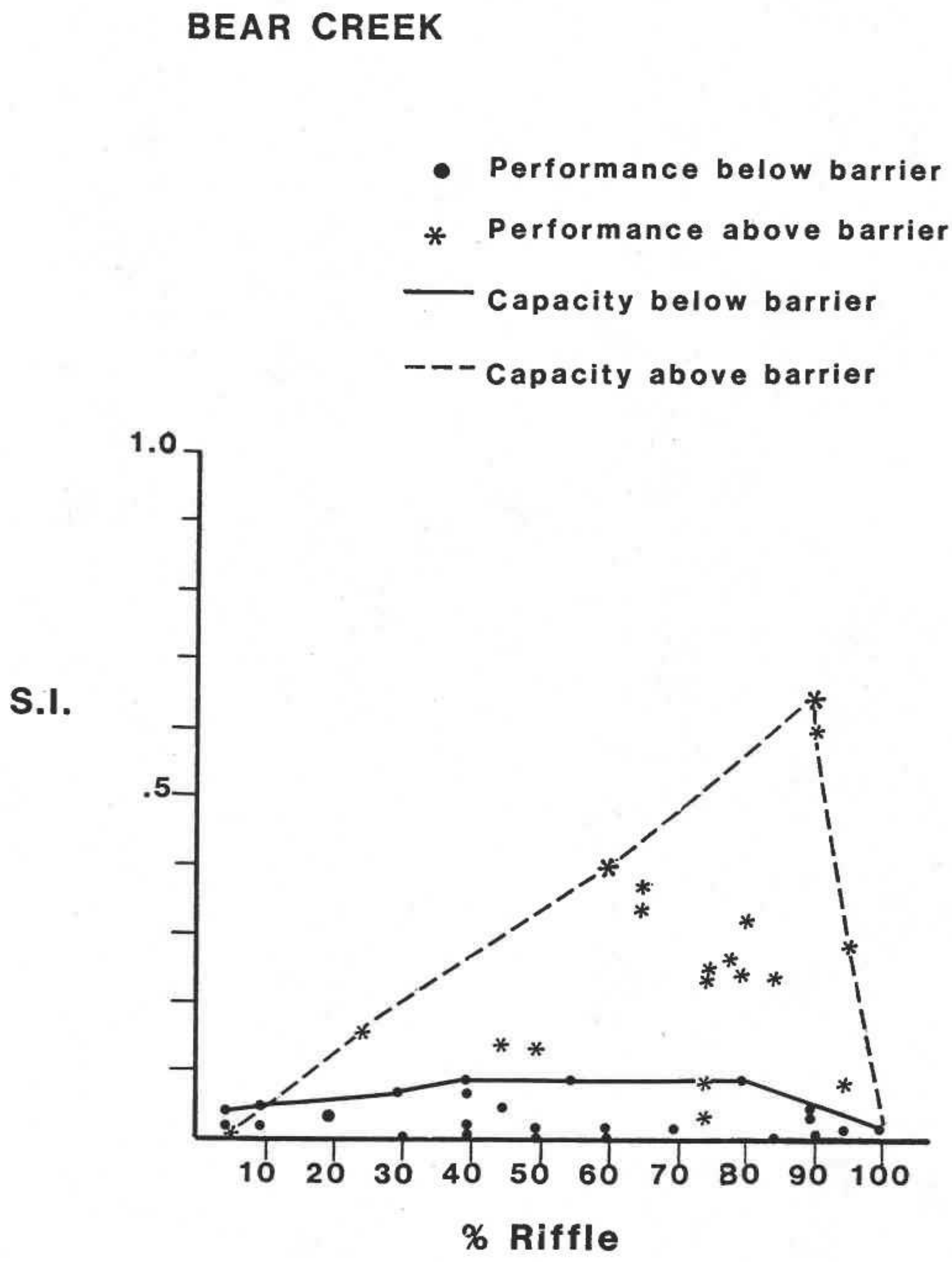


Figure 5. Cutthroat Trout Suitability Index vs. Riffles in Bear Creek

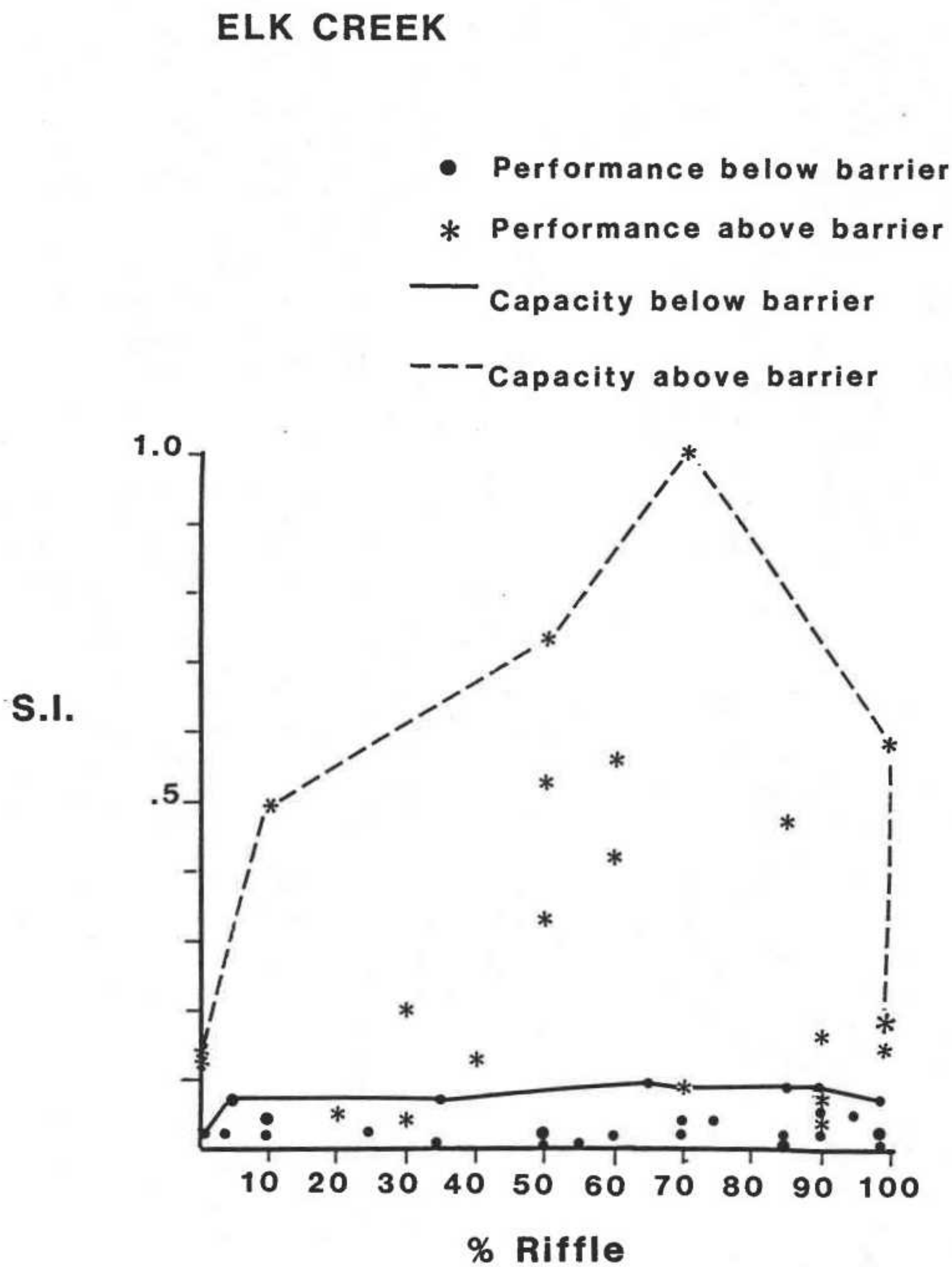


Figure 6. Cutthroat Trout Suitability Index vs. Riffles in Elk Creek

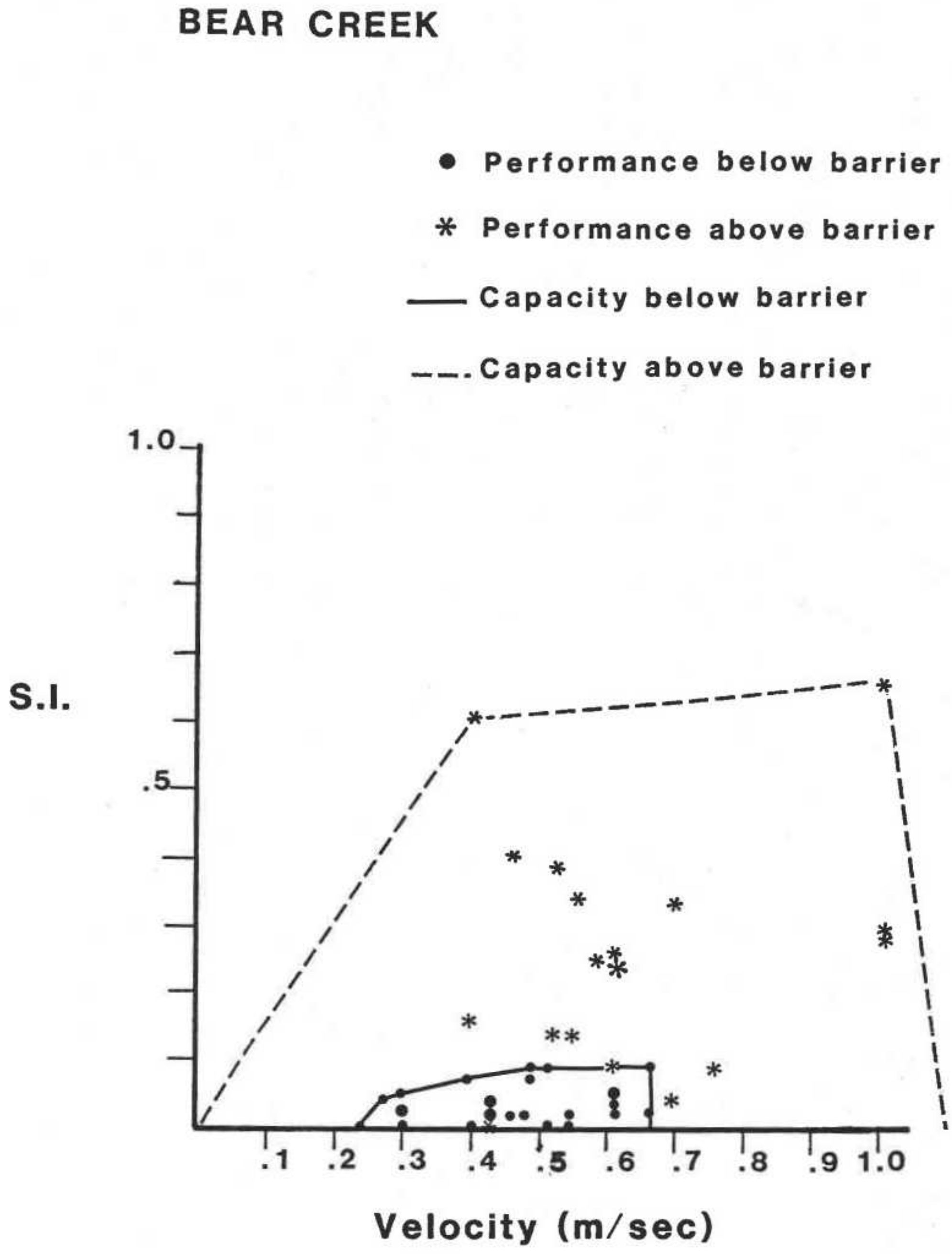


Figure 7. Cutthroat Trout Suitability Index vs. Current (cm/sec) in Bear Creek

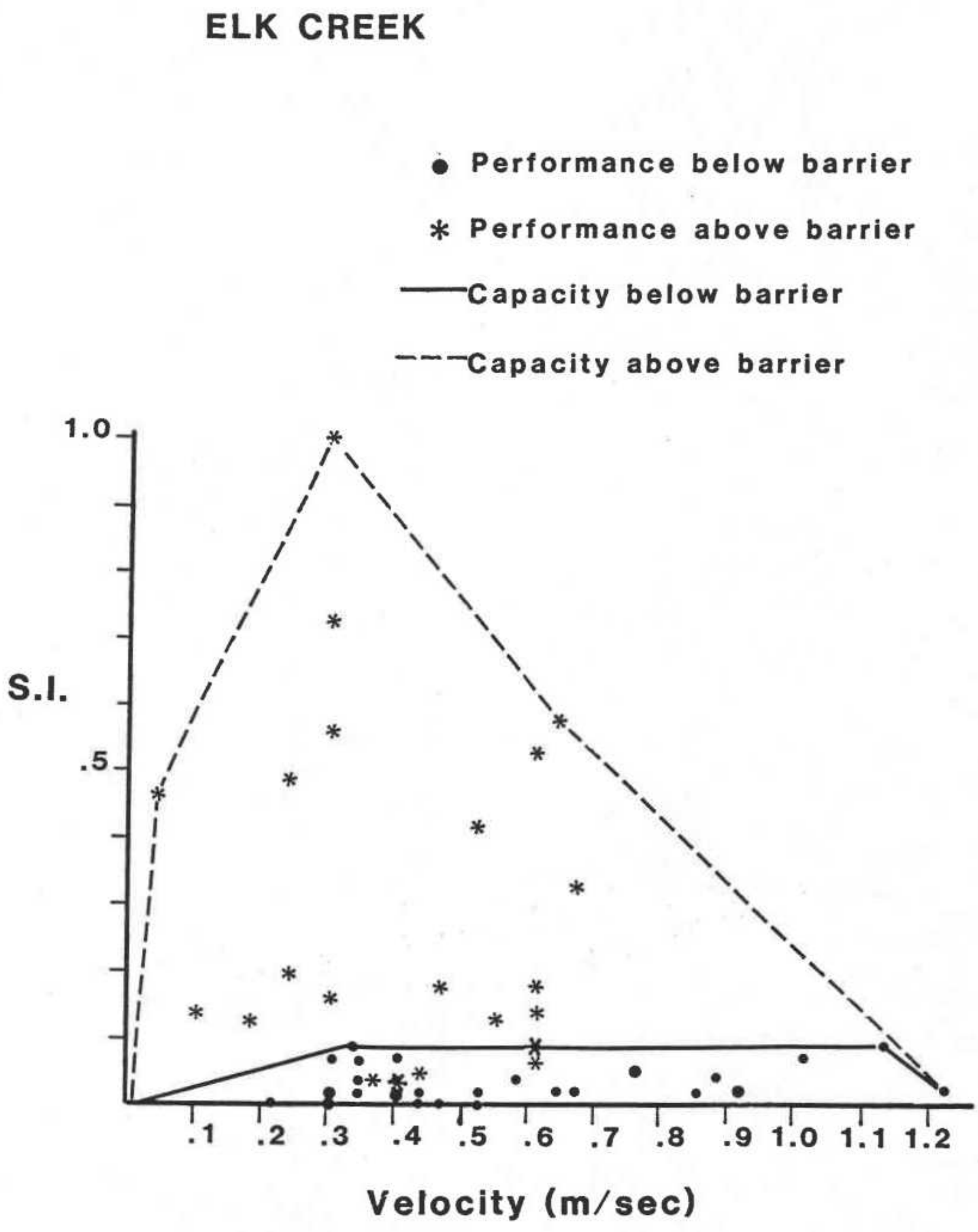


Figure 8. Cutthroat Trout Suitability Index vs. Current (cm/sec) in Elk Creek

Coho salmon juveniles prefer pool habitats (Nickelson, 1976; Nickelson and Beidler, 1978; and Nickelson and Hafele, 1978). Allee (1974) found that coho salmon were competitively dominant over steelhead trout. Juvenile steelhead trout inhabit riffles, but will inhabit pools when coho salmon are absent (Allee, 1974). They are restricted to the heads of pools near the substrate and riffles when coho juveniles are present. Glova (pers. comm.) found that coho juveniles are competitively dominant over juvenile steelhead trout. It appears that the inclusion of steelhead trout as competitors generally has more influence than coho juveniles in the Nestucca system. However, where steelhead trout are sympatric with cutthroat trout, and coho juveniles are restricted from some sections (i.e. Bear Creek and lower Elk Creek), a clearer picture is obtained. We suggest that the following occurs. Coho salmon force steelhead to compete in riffles with cutthroat trout which inhabit riffles preferentially to pools. Bear Creek is poorer habitat and so competition is intense, the response to coho is sharply marked because there is a large gradient of coho density.

Ordinarily, it is dangerous to presume the presence of competition just through the interpretation of statistical patterns (Li, 1975). In this case there are supportive observations and studies which reinforce the interpretation and we stand on reasonably firm ground. Results of this study suggest that the physical and the biological environment interact in such a way that the two general approaches of habitat modeling previously discussed are inadequate. Note that competitors are strongly associated with the worst class of habitat. Habitat may be unsuitable because of dominant competitors. This same conclusion was reached by Skud (1982) for marine fishes; competition can mask responses to environmental gradients by a species. Additionally, changes in the environment can alter the competitive relationship. A scheme of habitat analysis that allows the expression of regional characteristics of the physical and biological environment in its formulation of habitat quality should be developed.

<u>Implications for Small-scale Hydropower Development</u>

The first three objectives were addressed in this part of the study. We gained a larger understanding of the habitat requirements of steelhead trout, cutthroat trout and coho salmon. We tested the assumptions of the HSI and Incremental approaches to habitat assessment and have concluded that they will not be able to predict the impact of small-scale hydropower projects because they do not consider two important factors. First, biological interactions were observed to have profound influences upon habitat suitability (the third objective of the study). An analogy for humans is that the presence of grizzly bears in the outback of Glacier National Park influences the habitability of campsites. The second factor is that between-drainage differences probably result in different limiting factors on the population. These factors interact in a nonadditive manner because fishes can make choices; in a sense, they change strategies. If cover is more limiting than flow, flow will be the variable that will contribute most to the explanation of habitat use. We will explore in the next chapter how variations in habitat (differences in habitat availability) affect habitats used. Recall that neither flow, nor discharge, nor depth was found to be a variable that weighted heavily in defining habitat quality for cutthroat trout; yet these are important variables to the Incremental Methodology.

THE INFLUENCE OF AVAILABILITY UPON HABITAT SELECTION

Introduction

This aspect of the study was designed to document and quantify habitat selection by fish during different seasons. Current models of habitat quality ignore selection patterns *per se* (e.g. see Binns and Eiserman, 1979). Present models are constructed from habitat use patterns, not preferences. Variability in patterns of use along a physical gradient may reflect that fish select habitats in a non-additive fashion and that they settle for the "best mix" of factors under given circumstances, although these conditions may not be optimal. This aspect of fish behavior must be examined before we can develop an adequate model of habitat assessment with which to predict impacts of small-scale dams on fish communities. The redside shiner (*Richardsonius balteatus*) was selected as target species for this study because it is a habitat generalist inhabiting lakes and streams (Scott and Crossman, 1973; Wydowski and Whitney, 1979); it is common in the Willamette drainage; and changes to the habitat can result in the shiner displacing economically important salmonids (Reeves, Everest, and Hall, in preparation).

The purpose was to restrict, although we could not eliminate, the influence of biological interactions on habitat selection and to examine habitat factors as units or patches. This was achieved by studying a number of reaches of a small stream where the number of species was constant. Habitat factors comprise one dimension of the ecotope, the other being niche (Whittaker et al., 1973). Niche dimension is similar in concept to the realized niche of Hutchinson (1958). The habitat dimensions are formed from the number of factors which comprise the physicochemical environment.

Habitat units are homogenous patches of different qualities (Fretwell and Lucas, 1970; Fretwell, 1972). The theory of habitat distribution proposed by Fretwell (1972) suggests that animals can assess patch suitability and select from the array that is available. Differences in distribution of habitats then, result in differences in species density over a given area. Likewise, the degree of environmental patchiness and dynamic resource availability can affect habitat utilization patterns (Dueser and Shugart, 1978). It is only recently that the process of habitat selection has been examined for fishes (Finger, 1982; Smith and Li, 1983).

Study Area

Greasy Creek is a small, fourth order stream located 12 kilometers west of Corvallis, Benton County, Oregon (shown in Figure 9). Greasy Creek is a major tributary to the Marys River system of the Willamette drainage basin, and originates on the southern slope of Marys peak. Starting at an elevation of 150 meters, Greasy Creek flows eastward 13 kilometers through a narrow agricultural valley to its confluence with the Marys River near Philomath. The total drainage area of

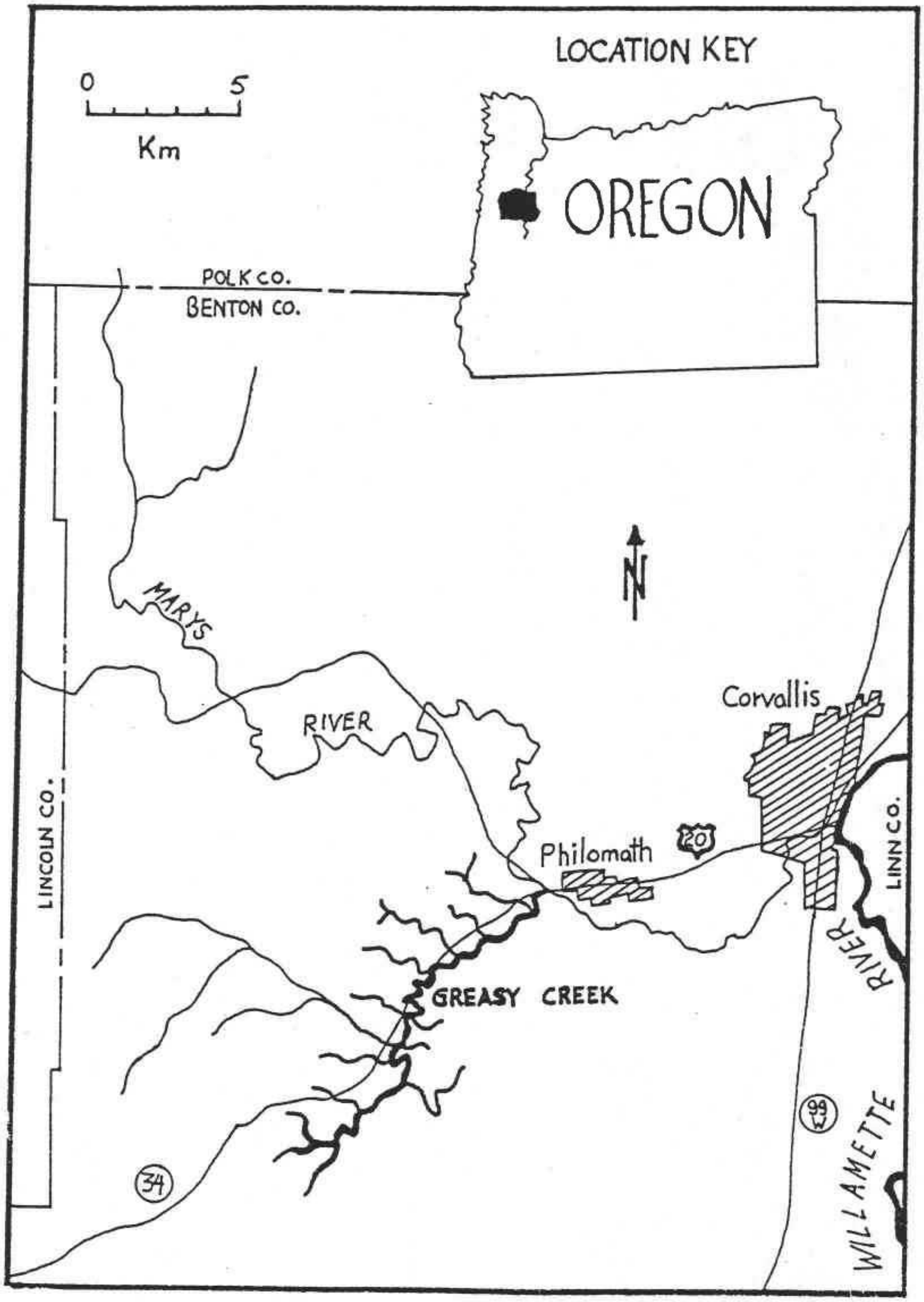


Figure 9. Location Map of Greasy Creek, Oregon

the stream is approximately 100 square kilometers.

Greasy Creek receives an annual precipitation of 175 to 200 cm, most of it falling as rain between October and May. Impervious sedimentary formations and shallow soils in the upper watershed provide little volume of water storage and little capacity for buffering stream discharge. Stream flow therefore closely follows the rainfall pattern. Mean daily discharge varies from less than 5 cfs in late summer to over 100 cfs during winter freshets. Storm events result in mass substrate movement, tree fall, streambank erosion, formation of debris jams, and high turbidities. Wide fluctuations in streamflow are thus characteristic during winter months while severe water shortages characterize summer periods. Main channel water temperatures seasonally range from a recorded maximum of 23.5 C in August to a minimum value of 3 C during December and January.

Twelve species of fishes were found in Greasy Creek, of which only five were abundant: redside shiner, speckled dace (*Rhinicthys osculus*), reticulate sculpin (*Cottus perplexus*), torrent sculpin (*C. rotheus*), and cutthroat trout.

Methods

Ten sites were selected along a longitudinal gradient. Each site was representative of the available reaches along the gradient. Each was 20 m in length and comprised a straight and meandering reach.

Surveys were conducted during three different discharge regimes: 1) summer low flows (August-September), 2) winter high flows (January-March), and 3) decreasing transitional flows (May-July). Summer and transitional habitat use was enumerated by snorkeling along transects. This is a rapid, effective, method that has minimal disruptive effects on fish behavior (Northcote and Wilkie, 1963; Goldstein, 1978). A comparison of snorkling and seining techniques was conducted to ensure reliability of the estimates. Observations were made in midday between 1000 and 1500 hr, to maximize illumination. Diel observations were made in a supporting study to note changes in day/night activities and potential differences in habitat use.

During the winter, snorkling was not feasible because of poor water clarity, high water velocities and low temperatures. Stunning fish by electroshocking was the only effective sampling technique.

Focal sampling was employed during the snorkling surveys. Fish were observed for 1 to 3 minutes to estimate the focal point or location where a fish spends most of its time (Wickham, 1967; Bovee and Cochnauer, 1977). Shiners were categorized into two groups, young (less than 25 mm TL), and adults (greater than 24 mm TL). Coded markers were placed at each sighting location and measurements of substrate composition, depth, current velocity, parameters considered by Gorman and Kar (1978) to be most important to microhabitat specialization of stream fishes, were taken at those loci. Forms of instream cover (any submerged object that increases relief), overhead cover (objects which increase shade, including tree canopy and undercut banks), and stream turbulence were quantified at these sites, as the distribution of stream fishes has been positively correlated with different forms of cover (Boussu, 1954; Butler and Hawthorne, 1968; Lewis, 1969; Bustard and Narver, 1975).

Habitat availability was determined by measuring those variables while mapping transects of 2 m gridded intervals of the entire study section. Mapping of available habitat was conducted less than 24 hr after focal sampling to ensure that changes of stream habitats would be minimal. Data from focal samples (use) and mapping (availability) collected for each season were separately pooled and analyzed.

At the beginning of each sampling period, air temperature, water temperature, and dissolved oxygen were recorded with a temperature/oxygen meter (Yellow Spring, model 54A). Pilot tests showed that these parameters did not vary during the sampling period. Substrate composition was visually estimated, size classes were based on the Wentworth Particle size Scale. Depth of the water column was measured with a graduated staff. Surface, bottom, and mean water (0.4 of the depth measured from the stream bottom) flow was measured with a Marsh-McBirney electronic current meter (model 201).

A discriminant function analysis and classification was used to derive an unbiased basis for weighting the relative importance of each habitat variable to group differentiation of habitat type (Klecka, 1975). It was used as a statistical tool to describe available and occupied habitat types and not as a predictive model _per se_. A stepwise approach was used to determine which variables contributed most effectively to habitats selected by different life-stages of the shiner. Variables were incorporated or eliminated from the classification based on the Wilks lambda statistic. This technique maximizes overall group differences (Klecka, 1975). The particular discriminant procedure used was considered "unbiased" because the computer was programmed to randomly select 75% of the original cases from each group for the analysis and ensuing discriminant functions. The remaining cases were reserved to test the classification; thus, the test was independent of circularity. The classification was considered sufficient to describe group differences when the percentage of correct classifications was 75%.

This technique is not restricted by the assumption of independence among variables. Assumptions and limitations of multivariate statistical techniques in empirical and ecological studies are discussed by Green (1971, 1980), Morrison (1976), and Pimentel and Frey (1978). Pimentel and Frey (1978) suggest that discriminant methods are robust; the analysis should be valid even if data are not multidimensional normal.

Results

Summer Habitats

Summer habitats were characterized by low stable flows, clear water and water temperatures ranging from 12.5 to 22.0 C in the main channel. Most of the sampling occurred between 15 and 18 C and dissolved oxygen values were at or near saturation. Shiners occurred in all study sections. Young-of-the-year (YOY), fish born that year, were highly aggregated (mean group size = 18 ± 9) and occuped shallow areas of slow water and small particle substrates. Adults were found in areas of faster, deeper water, higher surface turbulence, a greater proportion of gravel, cobble, and undercut banks (see Table 5). Group size was typically smaller than YOY (9 ± 6). Adults were found at all depths, whereas YOY were found near the surface. Most shiners of the same age-group occupied similar habitats throughout the 24-hr cycle.

Variables important to the discriminant function separating life stages were mean water velocity and depth at focal points (see Table 6). Adults had higher positive loadings on both variables, reflecting faster, deeper microhabitats. The percentage of correct classifications of independent cases was 93%.

YOY selected slower waters with less gravel and bedrock, and more instream cover than was generally available (see Table 7). A value of 75% suggests selection for these habitats and this discriminant classification is weak. Adult shiners selected microhabitats which were deeper, had more cobble and surface turbulence than was generally available (see Table 8). A classification value of 81% suggests strong preference for these habitats.

Table 5. Habitat variables measured at summer locations of redside shiners and corresponding available stream habitats.

Variable	Young shiners (n=327)	Adult shiners (n=125)	Available (area=1575 m^2)
Depth ($\bar{x}$ ± 95% CI)	31.4cm ± 6.7	55.7cm ± 8.8	34.3cm ± 2.3
Mean Velocity ($\bar{x}$ ± 95% CI)	5.4cm/sec ± 1.7	20.0cm/sec ± 5.5	16.5cm/sec ± 1.7
Substrate Composition (% occurrence)			
Sand/silt/clay	46.4	23.6	25.1
Small Gravel	17.6	33.3	38.9
Gravel	8.5	21.5	16.2
Cobble	3.6	4.7	4.2
Rubble	1.9	0.0	0.9
Boulders	5.9	4.6	1.8
Bedrock	6.0	2.4	6.0
Woody Debris	10.1	9.9	6.9
Cover Forms (% occurrence)			
Instream	100	88	95
Overhead	39	58	54
Undercut Banks	11	25	11
Surface Turbulence	11	46	32

Table 6. Variable loadings and unbiased classification results for habitat discrimination by life stages.

Variables	Loadings Young	/ Adults	Wilk's Lambda	Classification (%)
Summer				
Depth	0.115	0.215	0.411	93.3
Mean Velocity	0.120	0.404		
Winter				
Depth	0.100	0.148	0.763	86.1
Transitional				
Depth	0.503	1.912	0.323	95.2
Mean Velocity	0.195	0.771		
Sand/silt/clay	0.863	0.312		
Small Gravel	0.354	1.230		

Table 7. Variable loadings and unbiased classification results for habitat selection by young redside shiners.

Variables	Loadings Young	/ Adults	Wilk's Lambda	Classification (%)
Summer				
Mean Velocity	-0.009	0.052		
Small Gravel	0.031	0.066	0.722	73.5
Boulders	0.058	0.078		
Instream Cover	44.099	41.682		
Winter				
Turbulence	-0.098	3.989		
Small Gravel	-0.001	0.067	0.385	90.2
Mean Velocity	0.005	0.047		
Transitional				
Depth	0.032	0.118		
Small Gravel	0.017	0.098	0.430	89.1
Woody Debris	0.087	-0.009		

Table 8. Variable loadings and unbiased classification results for habitat selection by adult redside shiners.

Variables	Loadings Young	/ Adults	Wilk's Lambda	Classification (%)
Summer				
Depth	0.175	0.093		
Gravel	0.107	0.065	0.638	80.2
Turbulence	2.937	1.957		
Winter				
Depth	0.137	0.088		
Mean Velocity	0.021	0.060	0.466	88.0
Small Gravel	-0.043	0.000		
Transitional				
Depth	0.198	0.101	0.618	82.8

Winter Habitats

Marked seasonal changes in stream habitats were observed during the 9-week period of 17 January to 19 April 1981. Intermittent floods and high stream flows modified previously available habitats and created new habitats by channel expansion and deepening. Winter habitat availability could not be predicted from summer low flow surveys. Main-channel water temperatures were stable, ranging from 4.5 C to 8.0 C. Dissolved oxygen values were always at or near saturation.

Classes of discrete habitat were observed, rather than focal points because of the marked patterns and due to the difficulty of sampling (see Table 9). Only five study sites could be sampled; fish were located in just three of them. When shiners were not located in a sampling section, they were usually observed a short distance upstream or downstream of it in association with cover.

Both YOY and adult shiners selected discrete microhabitats corresponding to increased stream flows and lowered water temperatures. YOY occurred primarily in backwater areas including sidepools and quiet water areas (see Table 7). Adults were associated with a greater variety of habitat types, especially areas where bank failures and backwater areas were present. Both YOY and adult fish were located in areas with minimal water velocity, containing substrates dominated by very small particles (sand, silt, or clay) and woody debris (see Table 10). All shiner microhabitats were

Table 9. Stream habitat types selected by redside shiners during winter periods.

Habitat Types	Numbers (% of total) Young (n=278)		Adults (n=280)	
Undercut banks (with tree roots or woody debris)	0	(0)	21	(7.5)
Root wads (provided by a fallen tree)	0	(0)	36	(12.9)
Fallen trees (without root wads present)	65	(23.4)	16	(5.7)
Bank failure (with debris accumulation)	37	(13.3)	106	(38.0)
Backwater areas (including quiet sidepools)	176	(63.3)	101	(35.9)

Table 10. Habitat variables measured at winter locations of redside shiners and corresponding available stream habitats.

Variable	Young shiners (n=222)	Adult shiners (n=119)	Available (area=1060m^2)
Depth ($\overline{x}$ ± 95% CI)	54.8cm ± 2.8	83.0cm ± 4.6	51.3cm ± 3.3
Mean Velocity ($\overline{x}$ ± 95% CI)	2.2cm/sec ± 0.2	4.1cm/sec ± 0.5	47.8cm/sec ± 4.6
Substrate Composition (% occurrence)			
Sand/silt/clay	57.5	63.5	26.8
Small Gravel	0.0	3.5	39.0
Gravel	0.0	2.2	17.3
Cobble	0.0	0.2	4.2
Rubble	0.0	0.0	0.3
Boulders	0.0	0.0	0.0
Bedrock	18.0	5.4	5.1
Woody Debris	24.5	25.2	7.3
Cover Forms (% occurrence)			
Instream	100	100	99
Overhead	86	92	44
Undercut Banks	14	27	11
Surface Turbulence	0	8	66

ususally associated with both instream and overhead cover forms.

Habitat segregation among life stages was distinct, as adults utilized deeper areas containing undercut banks and surface turbulence to a greater extent than did the YOY. Adults were distributed according to the location of root masses and debris in the water column. Young shiners always occurred near the surface.

Similar-sized shiners were found together. The largest were found deeper with cover for any particular type of structure than smaller ones. Mean group size for YOY was large when compared to adult groups (37 ± 22 vs. 8 ± 3). All adult shiners were inactive, extremely dark in coloration, and appeared thin or emaciated. Shiners remained closely associated with winter microhabitats until stream flows decreased and main channel temperatures rose about 9-10 C.

The difference between YOY and adult habitats could be statistically distinguished with a single variable (see Table 6). Adult shiners inhabited deeper water than young fish, as reflected by a higher positive loading on depth of adult habitats. We inferred from the statistic that 86% of the cases were properly classified that adults and juveniles preferred different habitats.

Negative loading values for the variables of surface turbulence, percent small gravel, and mean water velocity (see Table 7) suggest that YOY select areas of low turbulence, slow water and small gravel. The classification value of 90% denotes habitat selection by YOY.

Loading values for the variables of depth, mean water velocity and percent small gravel suggest selection by adult shiners for deep, slow water (see Table 8). Strong selection is suggested by a correct classification of 88% of habitats placed in the correct class.

Habitats During Transitional Periods

The transitional period, occurring from 10 May to 15 July 1981, was characterized by decreasing flow and increasing water temperatures. April 14 was the first day when recorded temperatures exceeded 10 C in the main channel. The water temperatures ranged from 10.0 to 17.5 C during this sampling period. Dissolved oxygen was always saturated and water clarity was very good (1-2 m visibility). Fish were found in all 5 sampling sites examined. Size of YOY ranged from 24 to 28 mm and most adults exceeded 60 mm in total length. Focal sampling and stream mapping were completed on 1 July and newly emerged YOY were first seen in shallow margins of the stream on 15 July.

YOY shiners inhabited shallow margins of the stream where the substrate was characterized by small gravel and sand particles, by woody debris, and by slow water (see Table 11). Mean group size was 22 ± 17. Adult shiners were brightly colored, and found in small groups of 1 to 5 fish, with 3 being the typical number of similar sized fish in deep, fast water running over gravel substrates (see Table 11).

Table 11. Habitat variables measured at during periods of changing discharge between seasons (transitional habitats).

Variable	Young shiners (n=66)	Adult shiners (n=72)	Available (area=1016m^2)
Depth ($\bar{x} \pm$ 95% CI)	20.8cm $\pm$ 4.5	76.5cm $\pm$ 2.8	39.3cm $\pm$ 2.7
Mean Velocity ($\bar{x} \pm$ 95% CI)	3.2cm/sec $\pm$ 1.1	41.0cm/sec $\pm$ 6.2	43.9cm/sec $\pm$ 3.8
Substrate Composition (% occurrence)			
Sand/silt/clay	63.6	21.9	16.9
Small Gravel	1.4	51.2	51.0
Gravel	6.8	15.3	15.5
Cobble	0.0	2.0	4.0
Rubble	0.0	0.0	1.0
Boulders	0.0	2.5	3.3
Bedrock	0.0	1.3	2.9
Woody Debris	28.2	5.8	5.4
Cover Forms (% occurrence)			
Instream	100	100	99
Overhead	9	47	34
Undercut Banks	0	14	9
Surface Turbulence	0	71	65

Presence of adults was associated wtih surface turbulence and overhead cover.

Statistical separation of YOY and adult shiners was based on the following variables: depth, relative proportions of sand, silt, and clay; small gravel; and mean water velocity (see Table 6). Loading values reflect YOY preference for substrates of small particle sizes, and shallow, slow water in contrast to the preferences of the adults. The habitats used by different life stages is very distinct as suggested by the classification value of 92%.

The discriminant analysis for habitat selection indicated that YOY preferred shallower areas with more woody debris and less small gravel in the substrate than is generally available in the typically available habitat (see Table 7). The classification value was 89%.

Adult shiners selected deep water as revealed by the single variable, discriminant function (see Table 8). 83% of the cases were properly classified by this function.

Discussion

Redside shiners inhabited a variety of Greasy Creek habitats and exhibited different behaviors depending on the size of the fish, the array of habitats available, and seasonal shifts in habitat availability. Both YOY and adult shiners were selective in habitats occupied throughout the year. Variables of the greatest statistical significance in distinguishing selected from available habitat varied with season and life stage.

Throughout the year, depth was the most important variable in describing habitat selection. Habitat for YOY shiners changed seasonally and comprehensive descriptions depend upon larger arrays of variables, the relative importance of which also changed seasonally. The lowest classification value for habitat selection by YOY was recorded during the summer period. This value of 74% may be indicative of weak habitat specialization or that habitat usage was proportional to habitat availability. These results are especially interesting because YOY used similar stream habitats throughout the year regardless of the array of habitat types available. The changing availability of stream microhabitats through seasons resulted in the variety of selection variables chosen for analysis.

Past studies relating distribution of stream fishes with habitat variables have not measured the availability of microhabitats (e.g. Binns and Eiserman, 1979; Orth and Maughan, 1982). These studies considered the relationship of habitat variables to habitat quality as a fixed pattern. Recently, a few studies have considered the problem of habitat availability (Finger, 1982; Smith and Li, 1983) but did not treat it in a multivariate approach. As demonstrated in the present study, there are more inclusive assumptions pertaining to habitat selection: 1) habitats differ in availability, 2) habitats differ in basic suitability, and organisms use the most suitable habitats available to them. Therefore, fishes may occur in high densities in areas that are suboptimal, but the best of that available. If stream habitats are subject to dynamic flux, factors influencing habitat selection will change, as witnessed by seasonal changes in habitat selection.

The analytical results of this study suggest that four components of stream habitat (depth, current velocity, substrate composition, and various forms of cover) acting alone or together provided enough information to describe the seasonal habitats of the redside shiner in Greasy Creek, to differentiate habitats occupied by different life stages, and to document the degree of habitat selection occurring. The numbers of redside shiners in Greasy Creek were less than those observed in larger streams or reported for lake systems in British Columbia (Lindsey and Northcote, 1963). The availability of large, deep pools and lake-like habitats may be limiting in Greasy Creek and other small streams. Within the larger strreams examined, adult shiners exhibited both aggregating behavior associated with pools and territorial behavior associated with faster, shallower water. Young shiners in larger streams occupied both stream margins and large pools with adults. Therefore, we do not suggest that the derived discriminant functions provide a model of redside shiner habitat selection which can be applied to every stream inhabited by this species. We believe that the selection pattern may vary from stream to stream, depending upon the availability of habitats and other factors which impose limitations upon the population.

This part of the study is autecological and is incomplete in the sense that species distributions cannot be explained completely by physicochemical factors. Biological factors, that include interactions among species, competition, diseases, and predation may exclude fishes from habitats which are physiologically tolerable. Additional stream observations and laboratory "removal" experiments should help evaluate the importance of biological interactions to habitat selection by redside shiners. These biological interactions can be incorporated to define the ecotype which describes the full range of adaptations to external factors concerning both niche and habitat (Whitaker et al., 1973). Expansion of the present model to incorporate niche parameters is the next step for greater comprehension of habitat selection by the redside shiner.

Implications for Small-Scale Hydropower Development

This part of the study addressed the first three objectives. Objective 1 was to increase the understanding of habitat requirements for important fish species in the Willamette drainage. The redside shiner is common in the drainage and can be an important competitor to steelhead trout juveniles if flows decrease and water temperatures increase (Reeves, Everest, and Hall, in preparation). We found that depth, not flow, was the most important variable influencing habitat selection for adult redside shiners, and that a host of factors, the number and weighted importance of which change seasonally, influenced the selection of habitats by the juveniles. This finding addresses objective 2: the Incremental Method of the Instream Flow Group is inadequate to predict habitat quality for the redside shiner. We have found that describing important habitats by describing important use patterns in relation to availability is very instructive and indicates that this technique should be incorporated in the next generation of habitat models. This satisfies objective 3.

DISTRIBUTION OF RESIDENT FISHES ABOVE AND BELOW SMALL IMPOUNDMENTS IN TWO STREAM SYSTEMS

Introduction

We did not believe we could predict the impact of small-scale hydroelectric dams using either of the habitat assessment approaches because evidence from the first parts of our study suggested they were faulty. Ideally, use of the models would have made impact assessment logistically easier because they demand physicochemical data samples without the corresponding biological information. We decided to assess the impacts of small-scale dams by direct measurement. Therefore, the objective of this part of the study was to document changes in species composition of resident fishes and changes of associated physical habitat characteristics at different sites along the longitudinal gradient of streams impounded by small-scale dams. We had hoped to pair unimpounded streams as study controls for similar types of impounded streams. Unfortunately, the distribution of the small-scale dams did not allow this type of study design. We sampled systematically along the longitudinal gradient of the stream at different distances away from the dam. We expected species richness to increase downstream, presumably because the habitat would be more stable and more diverse (Sheldon, 1968; Horwitz, 1978; Schlosser, 1982). When we observed discontinuities in the longitudinal gradient of either species composition or physical habitat, we inferred an impact by the dam.

Study Areas

This part of the report covers two stream systems, one draining from the Coast Range and the other from the Cascade range: the Rock Creek drainage and the Calapooia River, respectively. These are shown in Figure 10. This provided two contrasts because the streams from the Coast Range tend to be "flashier," more subject to quick variation in discharge, than streams from the Cascades.

The Rock Creek drainage is located 5 miles west of the city of Philomath, Oregon (see Figure 10). The study area lies within the City of Corvallis Watershed. Two forks of Rock Creek were examined, the North Fork and the South Fork. Both forks are spring fed, have similar gradients, as determined from USGS 15-minute topographic maps, are impounded, and are subject to potential colonization by the same kinds of species. The South Fork has a concrete diversion dam 0.5 m high. The North Fork is impounded by a large earth-filled storage dam. This is the source of the domestic water supply of the city of Corvallis, by means of a transmission line from the dam.

The major differences between the two streams are the nature of the impoundments on them and the management policies applied to them. Water is diverted from the South Fork dam to the larger impoundment on the North Fork. Deposition

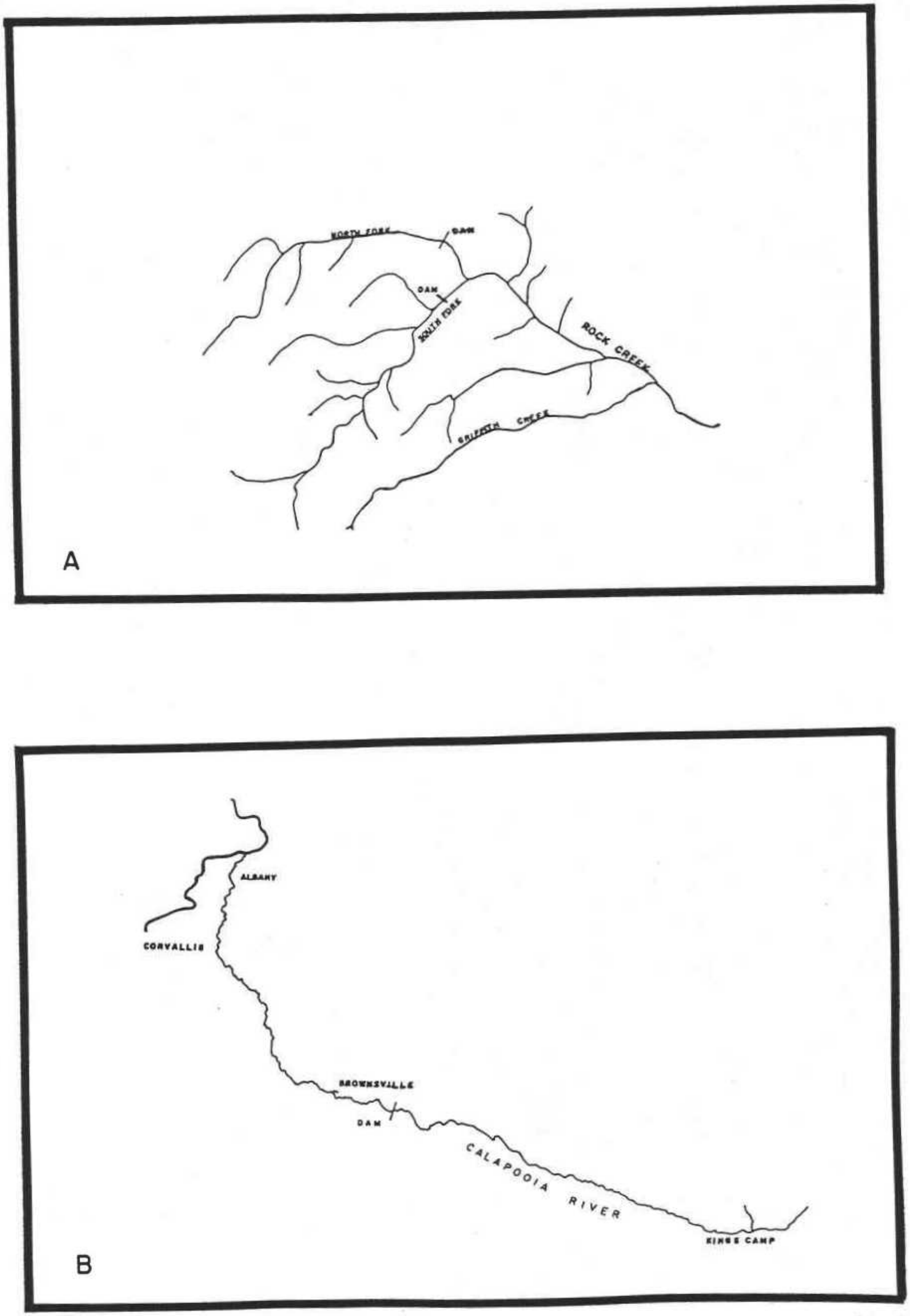


Figure 10. Location Map of Rock Creek and Calapooia River dams

of stream materials behind this small dam during the spring and early summer necessitates periodic clearing with a backhoe to remove deposited fines and gravels. The spoils are deposited below the dam in the channel. Copper sulfate is applied irregularly through the years to control nuisance algae in the impoundment behind the North Fork dam. The outflow of the North Fork dam extends approximately 90 m, joining the South Fork to form Rock Creek proper. The municipality plans to retrofit bulb turbines in the discharge line to generate hydroelectricity from these dams.

The Calapooia River is impounded approximately 8 miles upstream from Brownsville (see Figure 10). The dam is a wood and concrete structure approximately 3 m in height. Timber is harvested in the Calapooia headwaters near King Camp and the drainage has been mined extensively for gold.

Methods

Each stream was sampled along a longitudinal gradient. For the South Fork of Rock Creek, sampling stations were established at distances of 450 m, 200m, 100 m, and 10 m above the diversion dam and at 50 m, 250 m, and 600 m below this diversion. Four sites were sampled on the North Fork of Rock Creek: 150 m and 50 m above the reservoir and 10 m and 50 m below the impoundment dam. The sampling stations were approximately 25 m long and were adjusted slightly so that the best representative sites would be sampled. Estimates of fish density in the Rock Creek drainage were assessed using the DeLury Method because of the basin's small size (Ricker, 1958). Sections were blocked off at the upstream and downstream margins of the reach to be sampled. Three to five passes were made with an electroshocker (Coefeldt model BP-3). Fishes were identified, counted, weighed, and measured after each pass. All fish were held in buckets until the sampling was finished; they were then released back into the stream.

Because of its large size, the Calapooia could not be sampled in the same way. Study sites were approximately 50 to 100 m in length. The study sites were 32 km, 27 km, 18.5 km, 3.2 km and 0.4 km above the dam and 4 m, 7 m, 8 m, and 300 m below the dam. The fishes were enumerated by visual observation, using the snorkling techniques previously described, in all microhabitats except shallow riffles where electroshocking techniques were used to gather relative frequencies of fishes.

Measurement of microhabitats available were done slightly differently in each system because of size. In the Rock Creek drainage, physical characteristics of the sampling sites were recorded along a series of cross-sectional transects spaced 2 m apart. In the Calapooia River, we sampled microhabitat patches, defined by us as homogenous sections of stream with respect to substrate, current velocity, surface turbulence, and depth. We made physical measurement of those

Table 12. Summary of selected hydrographic features above and below small-scale dams on the North Fork and the South Fork of the Rock Creek drainage.

Site	Location	Distance from Dam (m)	Reach Length (m)	Surface Area (m^2)	$\bar{x}$ (m) Width	$\bar{x}$ (cm) Depth	Average Mean Vel. (cm/sec)	Discharge Estimated m^3/sec	Discharge Estimated ft^3/sec
1a	N. Fork Rock Cr.	10 below	20	56	3.6	11	23	0.03	3.2
2a	"	50 below	20	69.2	4.9	16	14	0.11	3.9
3a	"	inlet 50 above	25	90.6	3.5	21.8	21	0.16	5.7
4a	"	150 above	25	74.4	2.7	17	22	0.10	3.6
1b	S. Fork Rock Cr.	600 below	25	57.2	2.8	10	10	0.03	1.0
2b	"	400 below	25	42.9	2.1	13	9	0.02	0.9
3b	"	200 below	25	64.0	3.2	14	6.0	0.03	1.0
4b	"	50 below	25	52.8	2.6	11	8.0	0.02	0.8
5b	"	10 above	32	147.6	4.3	83.6	6.0	0.22	7.6
6b	"	100 above	50	519.4	7.9	15.2	25.0	0.30	10.6
7b	"	200 above	30	115.8	3.9	29.7	12.4	0.14	5.1
8b	"	450 above	25	83.2	4.2	20	11.5	0.10	3.4

Table 13. Summary of selected physical parameters at study sites above and below Brownsville Dam (Calapooia River).

Site	Transect	Distance from dam (m)	Patch length (m)	Mean width (m)	Surface area (m^2)	Mean depth (cm)	Mean water velocity (cm/sec)
1	a	32000	46	22	1012	55	22
	b	"	75	26	1950	80	50
2	a	27400	60	16	960	132	3
	b	"	12	25	300	23	60
	c	"	50	13	650	223	5
3	a	18500	24	20	480	62	20
	b	"	18	19	342	26	56
4	a	3200	21	13	273	39	50
	b	"	33	8	264	81	37
	c	"	28	11	308	80	40
	d	"	28	17	476	100	22
5[1]	a	400	400	15	6000	2896	5
6[2]	s	4	22	6	132	78	36
	b	8	11	22	242	90	19
	c	7	11	14	154	47	73
	d	8	5	13	65	73	70
	e	7	1	7	7	31	63
7	a_1	300	1	13	13	40	82
	a_2	"	1	13	13	25	2

[1]reservoir

[2]plunge pool

Table 14. Substrate composition at study sites on the Calapooia River.*

		% Substrate composition							Presence of instream cover			
Site	Transect	A	B	C	D	E	F	G	H	I	J	K
1	a			10	43	47			-	-	-	-
	b					30		70	-	-	-	-
2	a	28	3	3	3	22	3	33	-	-	+	-
	b		13	37	27	23			-	-	-	-
	c		27		33	3	3	33	+	+	-	-
3	a	23	10	7	12	25		23	-	-	-	-
	b	2	5	13	18	65			-	-	-	-
4	a	10	42	22	27				-	-	-	-
	b	17			3		13	66	-	-	-	-
	c	14	2	2	5	11	33	33	-	-	-	-
	d	10	47	22	8	7	2		-	-	-	-
5[1]	a	100							-	+	+	-
6[2]	a		34				37	28	-	+	+	-
	b	27	7					66	-	-	-	-
	c		2			17	80		+	-	-	-
	d		16		10	37	37		-	-	-	-
	e	2	13		28	53			+	+	+	-
7	a[1]						99		-	-	-	-
	a[2]	13	15		25	47			+	-	-	-

* A = sand, silt, clay; B = small gravel < 2.5cm; C = large gravel 2.5-7.5cm D = cobble 7.5-15cm; E = rubble 15-30cm; F = boulder > 30cm; H = woody debris; I = undercut banks; J = root wads and boles; K = rooted vegetation.

[1] reservoir

[2] plunge pool

Table 15. Patterns of substrate distribution above and below small-scale dams on the north fork and the south fork of the Rock Creek drainage.

Location	Site	Distance from Dam (meters)	% Substrate A	B	C	D	E	F	G	H
N. Fork Rock Cr.	1a	10 below	11	17	20	30	22	0	0	0
"	2a	30 below	12	21	36	27	4	0	0	0
"	3a	inlet 150 above	40	26	14	5	2	0	13	0
"	4a	150 above	9	23	50	8	3	1	6	0
S. Fork Rock Cr.	1b	600 below	4	20	14	18	32	0	12	0
"	2b	400 below	2	15	18	23	37	0	0	0
"	3b	200 below	10	15	15	17	30	13	0	0
"	4b	50 below	13	28	22	19	18	0	0	2
"	5b	10 above	39	4	2	3	0	42	0	0
"	6b	100 above	6	15	28	28	20	3	0	0
"	7b	200 above	14	12	15	14	35	4	0	0
"	8b	450 above	6	19	21	27	26	0	1	0

ameters along several transects across the width of each patch; the number varied in relation to its size.

The following procedures were common to the sampling programs for the Rock Creek Drainage and the Calapooia River. Each transect was sampled at three loci: 0.25, 0.50, and 0.75 of the wetted width of the channel. At each locus, the following physical parameters were measured: substrate composition; water velocity at the surface and the geometric mean velocity; depth; and instream and overhead cover. Temperature and dissolved oxygen were measured at 1200 hr. $\pm$ 1 hr. Percent substrate was visually estimated using a viewing box. The Wentworth Scale was used to classify particle sizes. Water velocity was measured using an electromagnetic flow meter (Marsh-McBirney model 201). Water temperature and oxygen were measured using a YSI model 54A meter.

Results

The physical data are summarized in Tables 12, 13, 14, and 15. The common pattern to be noted is the large amount of fines deposited in the reaches just above the dam (site 5a in Table 14, and sites 3a and 5b in Table 15). This is accompanied by a decrease in the average mean velocity in those sections. In the South Fork of Rock Creek, this extended downstream because of diverted water.

Five species of fishes were found in Rock Creek: cutthroat trout, riffle sculpin, Piute sculpin (C. beldingii), the reticulate sculpin, and specled dace. The most obvious

Table 16. Density estimates of resident fishes made above and below small-scale dams on north and south forks of the Rock Creek Drainage.*

Species	Site	Location	Catch	Time	Pop.Est.	#/m^2
		North Fork				
Salmo clarki	1a	10m below dam	6	0.02	9	0.16
"	2a	50m below dam	8	0.01	16	0.23
"	3a	50m above inlet	2	0.01	2	0.02
"	4a	150m above inlet	3	0.01	3	0.04
		South Fork				
"	1b	600m below dam	12	0.04	13	0.28
"	2b	400m below dam	12	0.04	15	0.35
"	3b	200m below dam	15	0.07	18	0.28
"	4b	50m below dam	2	0.09	2	0.04
"	5b	10m above dam	25	4 seine hauls	25	0.17
"	6b	100m above dam	19	0.05	26	0.05
"	7b	200m above dam	11	0.05	11	0.10
"	8b	450m above dam	7	0.01	7	0.08
		North Fork				
Cottus rotheus	1a	10m below dam	1	0.003	NA	0.02
"	2a	50m below dam	1	0.001	NA	0.01
"	3a	50m above inlet	2	0.01	NA	0.02
"	4a	150m above inlet	6	0.02	7	0.08
		South Fork				
"	1b	600m below dam	7	0.02	NA	0.12
"	2b	400m below dam	10	0.03	10	0.23
"	3b	200m below dam	3	0.01	NA	0.05
"	4b	50m below dam	3	0.14	3	0.06
"	5b	10m above dam	0	NA	NA	NA
"	6b	100m above dam	6	0.02	NA	0.01
"	7b	200m above dam	3	0.01	NA	0.03
"	8b	450m above dam	3	0.004	NA	0.04
		North Fork				
Cottus beldingii	1a	10m below dam	1	0.003	NA	0.02
"	2a	50m below dam	0	-	NA	-
"	3a	50m above inlet	1	0.01	NA	0.01
"	4a	150m above inlet	7	0.02	9	0.09
		South Fork				
"	1b	600m below dam	4	0.01	4	0.07
"	2b	400m below dam	1	0.03	1	0.02
"	3b	200m below dam	0	-	NA	-
"	4b	50m below dam	0	-	NA	-
"	5b	10m above dam	0	-	NA	-
"	6b	100m above dam	4	0.01	NA	0.01
"	7b	200m above dam	4	0.02	NA	0.03
"	8b	450m above dam	5	0.01	NA	0.06
		North Fork				
Cottus perplexis	1a	10m below dam	8	0.03	NA	0.14
"	2a	50m below dam	8	0.02	12	0.20
"	3a	50m above inlet	24	0.12	18	0.26
"	4a	150m above inlet	9	0.03	NA	0.12
		South Fork				
"	1b	600m below dam	5	0.02	7	0.04
"	2b	400m below dam	1	0.03	1	0.02
"	3b	200m below dam	1	0.04	NA	0.02
"	4b	50m below dam	0	-	-	-
"	5b	10m above dam	0	-	-	-
"	6b	100m above dam	0	-	-	-
"	7b	200m above dam	0	-	-	-
"	8b	450m above dam	2	0.03	NA	0.00

*NA = Not applicable

Table 17. Mean densities of fishes collected at study sites on the Calapooia River.

Site	Transect	Species: Speckled dace (ad)	Speckled dace (juv)	*Cottus perplexus* (ad)	*C. rotheus* (ad)	*C. beldingi* (ad)	Largescale sucker (ad)	Largescale sucker (juv)	Redside shiner (ad)	Longnose dace (ad)	Cutthroat trout (ad)	Cutthroat trout (juv)	Rainbow trout (ad)	Whitefish (ad)	Squawfish (ad)
1	a					.002					.016	.026			
	b						.002				.014		.001	.001	
2	a	.002	.104				.015				.001				
	b				.003	.037				.007					
	c		.615					.308			.015	.003			
3	a	.006			.008	.015				.021					
	b	.044	.009	.009	.006		.006			.018					
4	a	.055	.029	.011	.022		.011		.026	.011		.004			.015
	b								.023	.004					
	c	.097	.974	.006					.016						
	d				.008										
5	a														
6	a	1.061		.015			.030		.303		.008				.174
	b								.083						
	c	.032			.052					.039					
	d				.015										
7	a_1														
	a_2	.538	.692	.077	.077				.077	.308					

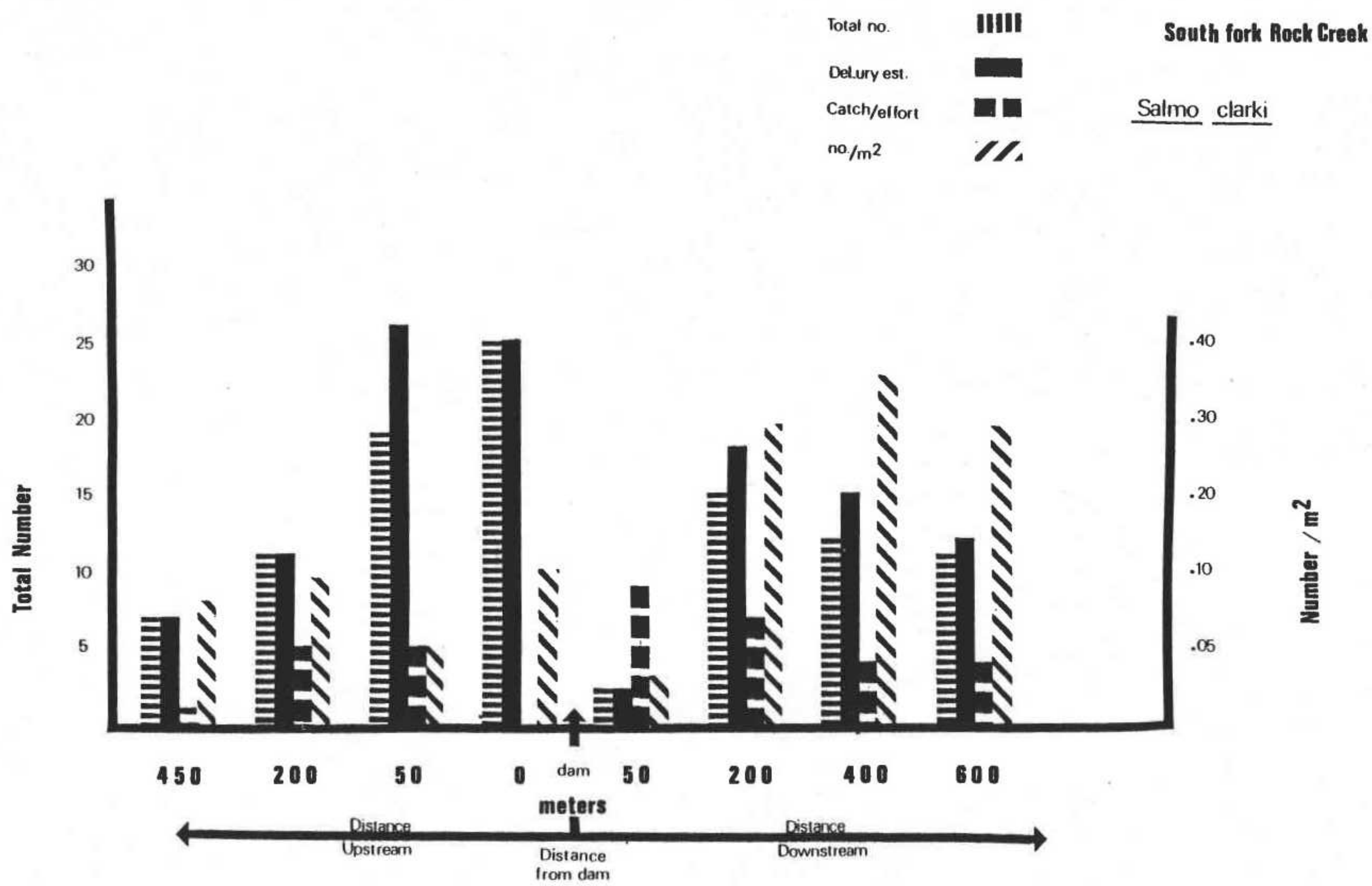


Figure 11. Cutthroat Trout Densities Upstream and Downstream of South Fork Rock Creek Dam

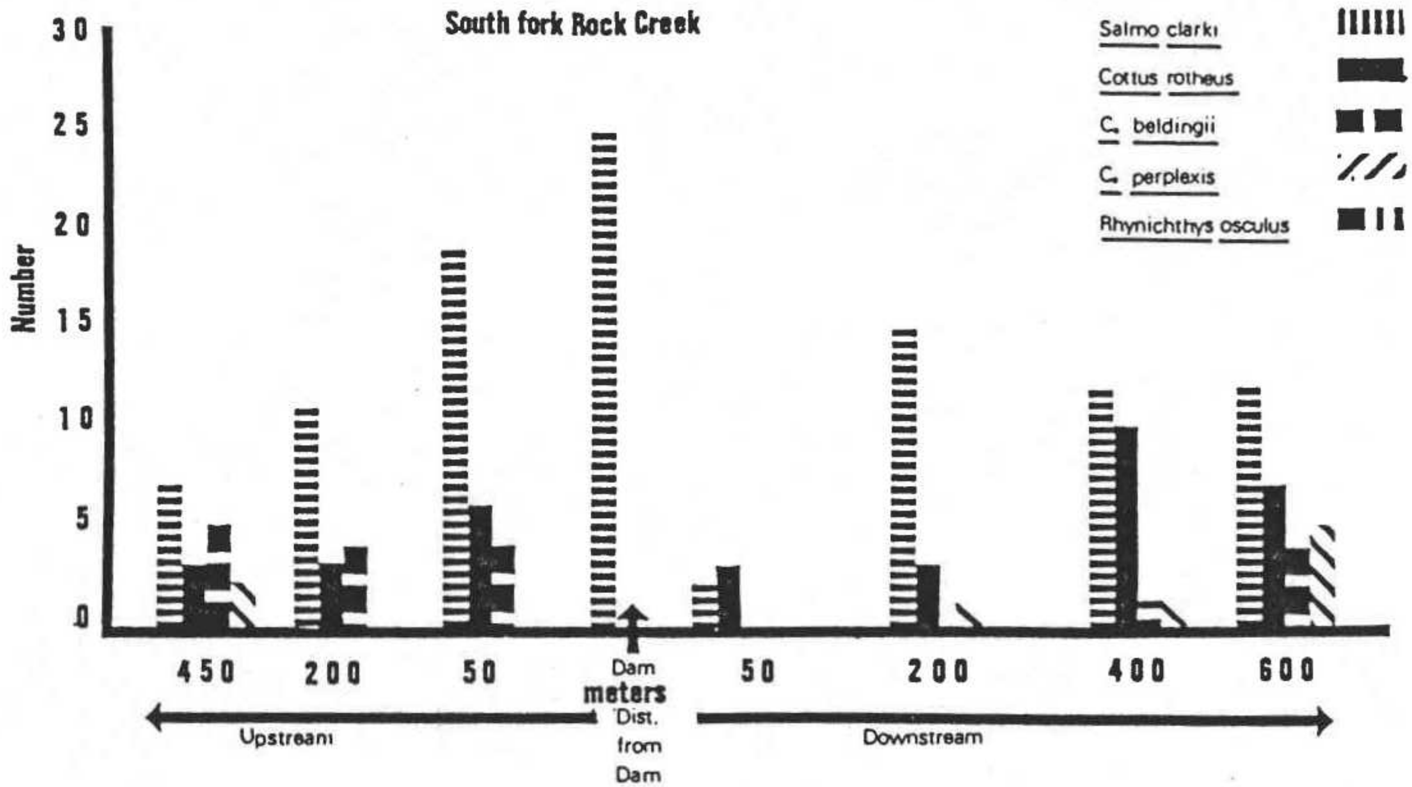


Figure 12. Fish Densities Upstream and Downstream of South Fork Rock Creek Dam

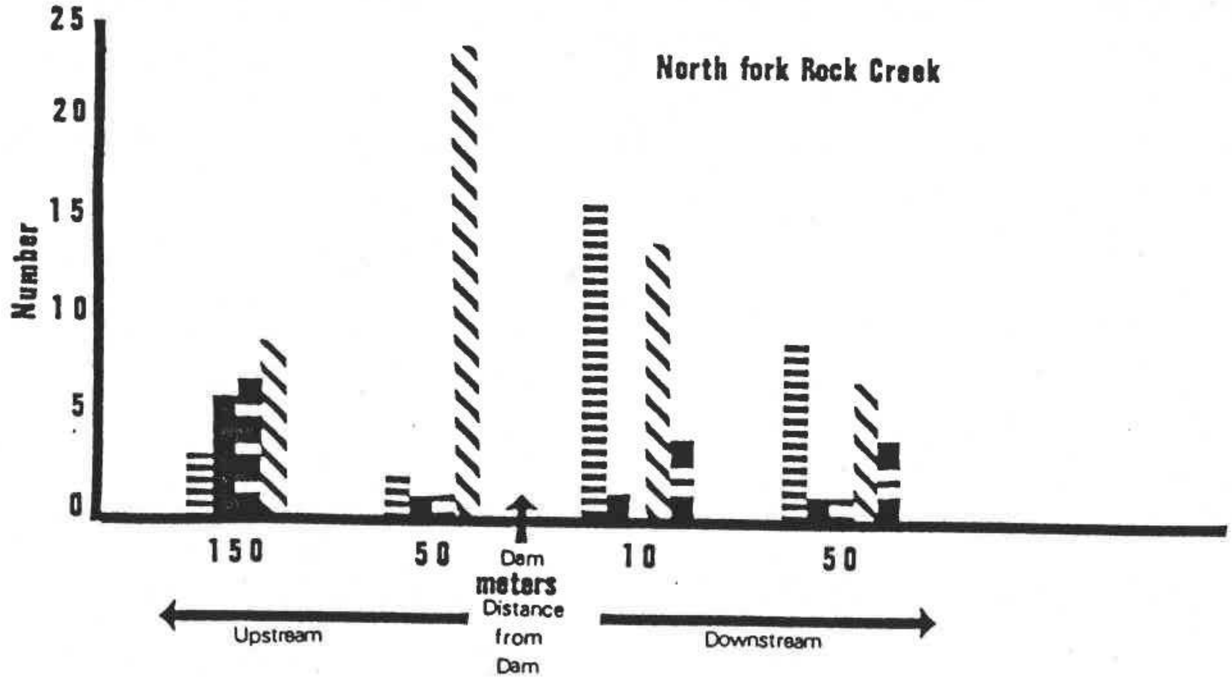


Figure 13. Fish Densities Upstream and Downstream of North Fork Rock Creek Dam

impacts in the South Fork of Rock Creek are: (1) that the sculpins are not found in the impounded reach of the South Fork, but are found above and below that section (see Table 16 and Figures 11, 12, and 13), and that the impact of the dam extended at least 50 m downstream. In the North Fork, greater numbers of the reticulate sculpin were found in the reach 50 m above the inlet. This section was characterized by a high percentage of silt, which suggested that it is aggrading and is poor habitat for sculpins. The speckled dace is found only below the earth-filled dam on the North Fork of Rock Creek and in the confluence of the two forks. Interestingly, the small 0.5 m dam on the South Fork of Rock Creek supported the highest density of cutthroat trout, acting as a refuge during the low-flow summer period because the creek was dimninished in size and pool habitat was limited. In contrast, the numbers of cutthroat trout declined and were at their lowest densities just 50 m from the impoundment in the North Fork (see Figures 11, 12, and 13). Only sculpins were found in the impoundment of the large earth-filled dam.

The most significant impact of the dam on the Calapooia River was the seeming lack of fishes in the impoundment behind the dam (see Table 17). We had observed redside shiners in 1980, but no fishes in 1981 during the four transects conducted. The second impact was an increase of adult squawfish in the tailrace below the dam. There was also a decrease in cutthroat trout and an increase in the numbers of redside shiners and speckled dace below the dam. We cannot determine whether this was due to longitudinal stream effects such as a shift in species composition that would naturally occur due to the position of that reach within the stream system (i.e. Schlosser, 1982) or to the dam itself.

Discussion

The structure of the communities was different above and below the dams. Although more work needs to be done, we suggest the following. Dams may have fewer detrimental impacts if placed higher up in a drainage. This is for two reasons. The first reason is that fewer species are found in the headwaters than are found further downstream; species of fishes are abstracted from the system as one goes up the stream to the headwaters. Therefore, fewer species will be impacted. Willamette drainage fishes found highest up in the system are cutthroat trout and different species of sculpins. The second reason is that dams at high elevations are not going to impact as many migrating fishes, especially anadromous salmonids. In these small systems, the impact of a few widely dispersed small-scale dams found near the headwaters may only be local. Some of the impacts may be beneficial, offering refuge for cutthroat trout in the nature of pools during the low summer flows. We do not know what the cumulative impact of numerous small dams may be, but the interception of gravels and organic materials is a subject area that should be examined. From casual observations on the South Fork of Rock Creek, the decision of whether to dredge out the impoundment periodically may be critical.

Local impacts include a reduced number of native fishes in the impoundment itself. The larger embayments, North Fork of Rock Creek and the Brownsville Dam on the Calapooia River, supported low densities of native fish. This should not surprise us, as all the native fishes have evolved in streams. The attraction of large squawfish to the tailrace area below a dam raises an issue on dams downstream in the larger streams, such as the South Santiam and McKenzie rivers. Buchanan et al. (1981) suggest that squawfish predation below dams may be a bottleneck on migratory juvenile salmonid fishes. This is a negative impact.

SUMMARY AND CONCLUSIONS

We do not believe that the current generation of fish habitat models are adequate to predict how dams will change habitat quality for many species. This is unfortunate because, if reliable, these approaches would save time, money, and labor in determining good sites from bad sites from a biological point of view and might suggest mitigation measures. We observed from our studies that interactions among species could affect species distributions not predicted by models that rely entirely upon physical characteristics of habitat. Our work suggested that differences in habitat diversity among streams might limit species differently in various stream systems because the availability of microhabitats would differ. We found the concept of defining selection and availability in habitat models to be a quite useful approach and might be useful in a regional, hierarchical classification of stream systems as advocated by Warren (1979), and Warren and Liss (1983).

We suggest that the impacts of single small-scale dams may be highly localized. We found that the physical factors which changed were the large amonts of silt building up in the reaches above the dam and in the area of impoundment and the reduction in water flow. The impacts of the dams may be related to location and size. There may be less impact on dams higher up in the watershed because fewer fishes inhabit headwaters (Sheldon, 1968; Small, 1975; Schlosser, 1982). Near King Camp in the upper reaches of the Calapooia, only cutthroat trout, and the Piute sculpin are present out of the total Willamette fish fauna. In the headwaters of Greasy Creek, only the cutthroat trout, the reticulate sculpin, the Piute sculpin and the torrent sculpin are found. In the upper reaches, small impoundments may increase pool refuges during the summer low flow. We caution that small streams and intermittent streams are important. Summer steelhead prefer to use intermittent and small streams to spawn in the Umpqua, the Rogue, the Smith and the Trinity Rivers (T. Roeloffs, pers. communication). Here the point is made that high-elevation sites will interfere less with fish migrations than will lower-elevation sites. There were few fishes inhabiting the impoundment itself. This makes intuitive sense, as native fishes of the Willamette drainage are adapted to free-flowing conditions. As a consequence, the larger the impoundment, the greater will be the amount of habitat lost. This can lead to another undesirable condition: the introduction of exotic fish species that are lake dwellers, in an attempt to mitigate fish losses. Exotics have often caused more problems than they have solved (Moyle, 1976; Zaret, 1979; Li and Moyle, 1981). We have observed the concentration of squawfish in tailrace areas at the Brownsville Dam, a dam at lower elevation on a high-order stream. Squawfish concentrations below dams may form a significant bottleneck to the survival of migrating juvenile salmonid fishes in the Willamette River (Buchanan et al., 1981).

We need to survey more systems with a study design to accomodate our new view of habitat models. We now conceive microhabitat to be homogenous units of substrate, flow, depth, and turbulence which are similar to runs, riffles, and pools, except that we define them statistically, not typologically. We envision that some systems might have types of microhabitats that are unavailable in other systems and that this would result in a community different in character from the others. In essence, we can cluster the patches of microhabitats based upon physical properties, using cluster analysis, and classify them statistically using discriminant function analysis. We can ordinate the species composition found in these patches, thus defining the kinds of communities that inhabit the different microhabitats. We can then rank the suitability of various species to different microhabitats as they are arranged longitudinally within the stream. This can be done for redside shiners and cutthroat trout, two ecologically important species for which standing-crop estimates were easy to obtain. In this way, we can observe the effect of differences of habitat diversity between stream systems on habitats selected by different species and can more carefully dissect confounding patterns of the abiotic and biotic environment on habitat quality.

LITERATURE CITED

Allee, B.J. 1974. Spatial requirements and behavioral interactions of juvenile coho salmon (Oncorhynchus kisutch) and steelhead trout (Salmo gairdneri). Ph.D. thesis. University of Washington, Seattle, 160 pp.

Andrusak, H. and T.G. Northcote. 1971. Segregation between adult cutthroat trout (Salmo clarki) and Dolly Varden (Salvelinus malma) in small coastal British Columbia lakes. J. Fish. Res. Board Can. 28:1259-1268.

Baxter, R.M. 1977. Environmental effects of dams and impoundments. Ann. Rev. Ecol. Syst. 8:255-283.

Binns, N.A. and F.M. Eiserman. 1979. Quantification of fluvial trout habitat in Wyoming. Trans. Amer. Fish. Soc. 108:215-228.

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

Bovee, K.D. and R. Cochnauer. 1977. Developoment and evaluation of weighted criteria, probability of use curves for instream flow assessments: fisheries. Instream Flow Information Paper No. 3. Cooperative Instream Flow Service Group, Ft. Collins, Colo. 39 p.

Buchanan, D.F., R.M. Hooton, and J.R. Moring. 1981. Northern squawfish (Ptychocheilus oregonensis) predation on juvenile salmonids in section of the Willamette River Basin, Oregon. Can J. Fish. Aquat. Sci. 38:360-364.

Bustard, D.R. and D.W. Narver. 1975. Aspects of winter ecology of juvenile coho salmon (Oncorhynchus kisutch) and steelhead trout (Salmo gairdneri). J. Fish. Res. Board Can. 22:405-409.

Butler, R.L. and V.M. Hawthorne. 1968. The reactions of dominant trout to changes in overhead artificial cover. Trans. Amer. Fish. Soc. 97:37-41.

Dueser, R.D., and H.H. Shugart. 1978. Microhabitats in a forest-floor small mammal fauna. Ecology 59:89-98.

Erman, D.C. 1973. Upstream changes in fish populations following impoundment of Sagehen Creek, California. Trans. Amer. Fish. Soc. 103:626-629.

Finger, R.R. 1982. Interactive segregation among three species of sculpins (Cottus). Copeia. 1982:680-694.

Fretwell, S.D. 1972. Populations in a seasonal environment. Princeton Univ. Press, Princeton, N.J.

________ and H.L. Leucas, Jr. 1970. On territorial behavior and other factors influencing habitat distribution in birds. I. Theoretical development. Act. Biot. XIX:16-36.

Geen, G.H. 1974. Effects of hydroelectric development in western Canada on aquatic ecosystems. J. Fish. Res. Board Can. 31:913-927.

Glova, T. Dept. Oceans and Fisheries, Nanaimo, British Columbia, pers. comm.

Goldstein, R.M. 1978. Quantitative comparison of seining and underwater observation for stream fishery surveys. Prog. Fish Cult. 40:108-111.

Gorman, O.T. and J.R. Karr. 1978. Habitat structure and stream fish communities. Ecology 59:507-515.

Green, R.H. 1971. A multivariate approach to the Hutchinsonian niche: bivalve molluscs of central Canada. Ecology 52:543-556.

________. 1980. Multivariate approaches in ecology: the assessment of ecologic similarity. Ann. Rev. Ecol. Syst. 11:1-14.

Holden, P.B. 1979. Ecology of riverine fishes in regulated stream systems with emphasis on the Colorado River, p. 57-74. In: The ecology of regulated streams. J.V. Ward and J.A. Stanford (Eds). Plenum Press, New York.

Horwitz, R.J. 1978. Temporal variability patterns and the distributional patterns of stream fishes. Ecol. Monogr. 48:307-321.

Hutchinson, G.E. 1958. Concluding remarks. Cold Springs Harbor Symposium Quant. Biol. 22:415-427.

Klecka, W.R. 1975. Discriminant analysis. p. 434-467. In: Statistical package for the social sciences. Nie et al. (eds.). McGraw-Hill, New York.

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

Li, H.W. 1975. Competition and coexistence in stream fishes, p. 19-30. In: Symposium on trout/non-game fish relationship in streams, P.B. Moyle and D. Koch (eds.). Desert Res. Inst. Water Res. Center Rpt. 17.

________ and P.B. Moyle. 1981. Ecological analysis of species introductions into aquatic systems. Trans. Amer. Fish. Soc. 110:772-783.

Lindsey, C.C. and T.,G. Northcote. 1963. Life history of redside shiners, Richardsonius balteatus, with particular reference to movements in and out of Sixteenmile Lake streams. J. Fish. Res. Board Can. 20:1001--1030.

Lotrich, V.A. 1973. Growth, production, and community composition of fishes inhabiting a first-, second-, and third-, order stream of eastern Kentucky, Ecol. Monogr. 43:377-397.

Milhous, R.T. 1979. The PHABSIM system for instream flow studies, p. 440-446. In: Proceedings of the 1979 summer computer simulation conference. Toronto, Canada.

Morrison, D.F. 1976. Multivariate statistical methods. McGraw-Hill, New York, N.Y.

Moyle, P.B. 1976. Inland fishes of California. Univ. Calif. Press, Berkeley, CA.

Nickelson, T. 1976. A proposed methodology for evaluating in-stream flows for salmonid rearing, p. 588-596. In: Instream flow needs, vol. 2. J.F. Orsborn and C.H. Allman (eds.). Western Division Amer. Fish Soc.

________ and W.M. Beidler. 1978. Willamette Basin streamflow studies. Federal Aid Progr. Rept. Project no. 2-4-8-20-02, Research and Development Section, OR Dept. Fish Wildl., Portland, OR. 28 p.

________ and R.E. Hafele. 1978. Streamflow requirements of salmonids. Federal Aid Prog. Rept. Project no. AFS-62, Research and Development Section, OR Dept. Fish Wildl., Portland, OR. 28 p.

Northcote, T.G. and D.W. Wilkie. 1963. Underwater census of stream fish populations. Trans. Amer. Fish. Soc. 92: 146-151.

Oregon's Environment. 1980. Water Resources Research Institute, Oregon State Univrsity, Corvallis, OR 97331, 16 p.

Orth, D.J. and O.E. Maughan. 1982. Evaluation of the incremental methodology for recommending instream flows for fishes. Trans. Amer. Fish. Soc. 111:413-445.

Pimentel, R.A. and D.F. Frey. 1978. Multivariate Analysis of Variance and Discriminant Analysis, p. 247-274. In: Quantitative ethology. P.W. Colgan (ed). John Wiley and Sons, New york.

Ricker, W.E. 1958. Handbook of computations for biological statistics of fish populations. Fish. Res. Board Can. Bull. No. 119:1-300.

Roeloffs, T. Dept. Fisheries and Wildlife, Humboldt State Univ., Pers. comm.

Schlosser, I.J. 1982. Fish community structure and function along two habitat gradients in a headwater stream. Ecol. Monogr. 52:398-414.

Scott, W.B. and E.J. Crossman. 1973. Freshwater fishes of Canada. Fish. Res. Board Can. Bull. No. 184:1-966.

Sheldon, A.L. 1968. Species diversity and longitudinal succession in stream fishes. Ecology 49:193-198.

Skud, B.E. 19082. Dominance in fishes: the relation between environment and abundance. Science 216:144-149.

Small, J.W. 1975. Energy dynamics of benthic fishes in a small Kentucky stream. Ecology 56:827-840.

Smith, J.J. and H.W. Li. 1983. Energetic factors influencing foraging tactics of juvenile steelhead trout, Salmo gairdneri, p. 173-180. In: Preadators and prey in fishes. D.L.G. Noakes et al. (eds.). Dr. W. Junk, The Hague, Netherlands.

Spence, J.A. and H.B.N. Hynes. 1971. Differences in fish populations upstream and downstream of a mainstram impoundment. J. Fish. Res. Board Can. 28:45-46.

Stein, R.A. 1979. Behavioral response of prey to fish predators, p. 343-354. In: Predator-prey systems in fisheries management, R.H. Stroud and JH. Clepper (eds.). Sport Fishing Institute, Washington, D.C.

U.S. Fish and Wildlife Service. 1981. Standards for the development of Habitat Suitability Index Models. 103 ESM. USDI, Fish Wild. Service Div. Ecol. Serv.

Vanicek, C.D., R.H. Kramer, and D.R. Franklin. 1970. Distribution of Green River fishes in Utah and Colorado following closure of Flaming Gorge Dam. Southwest Natur. 14:297-315.

Vannote, R.L., G.W. Minshall, K.W. Cummins, J.R. Sedell, and C.E. Cushing. 1980. Can. J. Fish. Aquat. Sci. 37:130-137.

Warren, C.E. 1979. Toward classification and rationale for watershed management and stream protection. Ecological Research Series, U.S. Environmental Protection Agency, EPA-600/3-79-0.

________ and W.J. Liss. 1983. Systems classification and modeling of streams. Report U.W. Environmental Protection Agency, CR807187 and U.S. Forest Service RM-80-144-CA.

Werner, E.E. 1977. Species packing and niche complementarity in three sunfishes. Am. Nat. 111:553-578.

________ and D.J. Hall. 1976. Niche shifts in sunfishes: experimental evidence and significance. Science. 191: 404-406.

Whittaker, R.H., S.A. Levins, and R.B. Root. 1973. Niche, habitat, and ecotope. Am. Nat., 197:321-338.

Wickham, M.G. 1967. Physical microhabitat of trout. Unpubl. Master's thesis. Colorado State Univ., Fort Collins.

Zaret, T.M. 1979. Predation in freshwater communities. p. 135-144. In: Predator-prey systems in fisheries management, R.H. Stroud and H. Clepper (eds.). Sport Fishing Institute, Washington, D.C.

CUTTHROAT TROUT

ADULTS

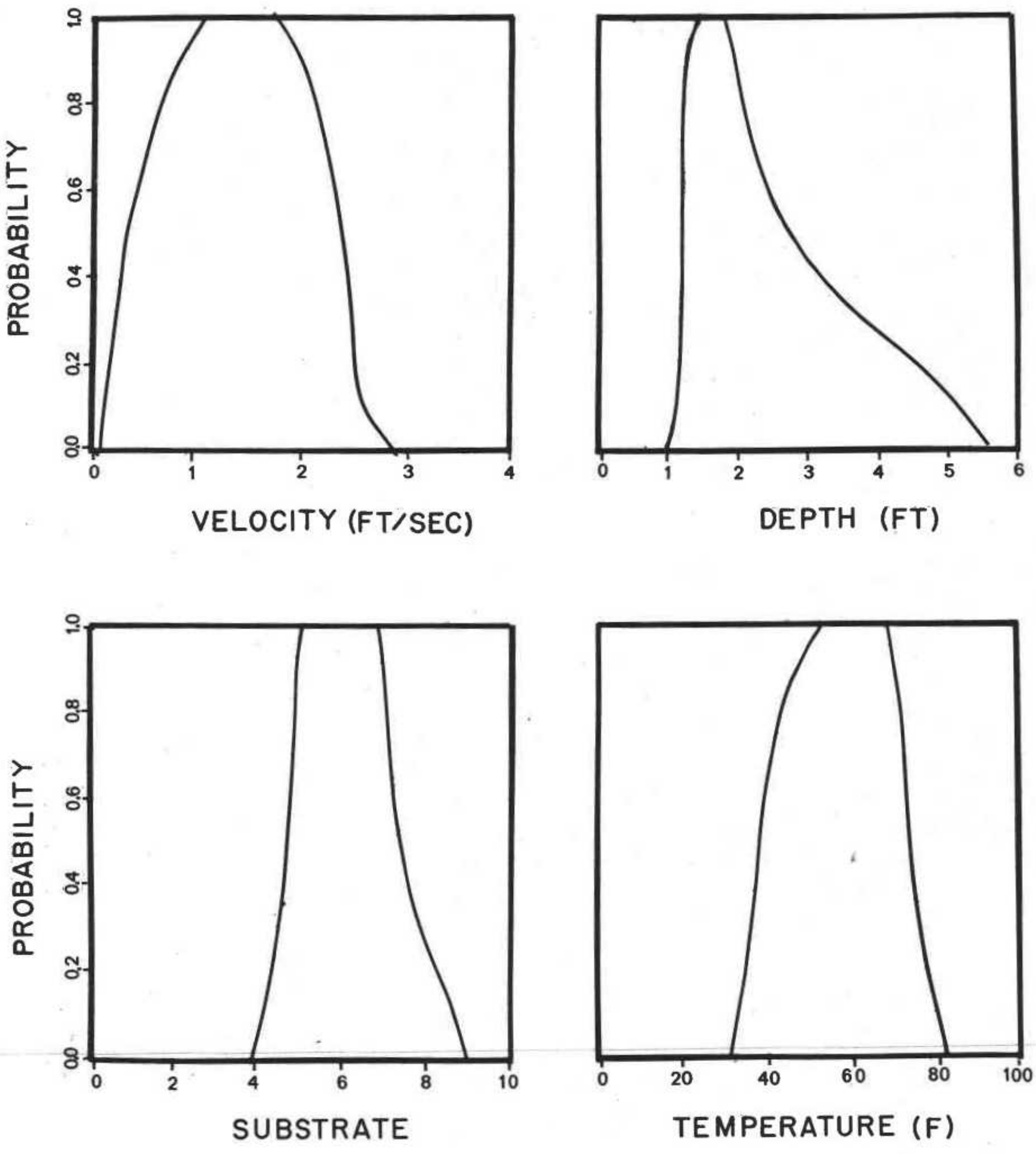


Figure 1. Examples of Habitat-Suitability Curves

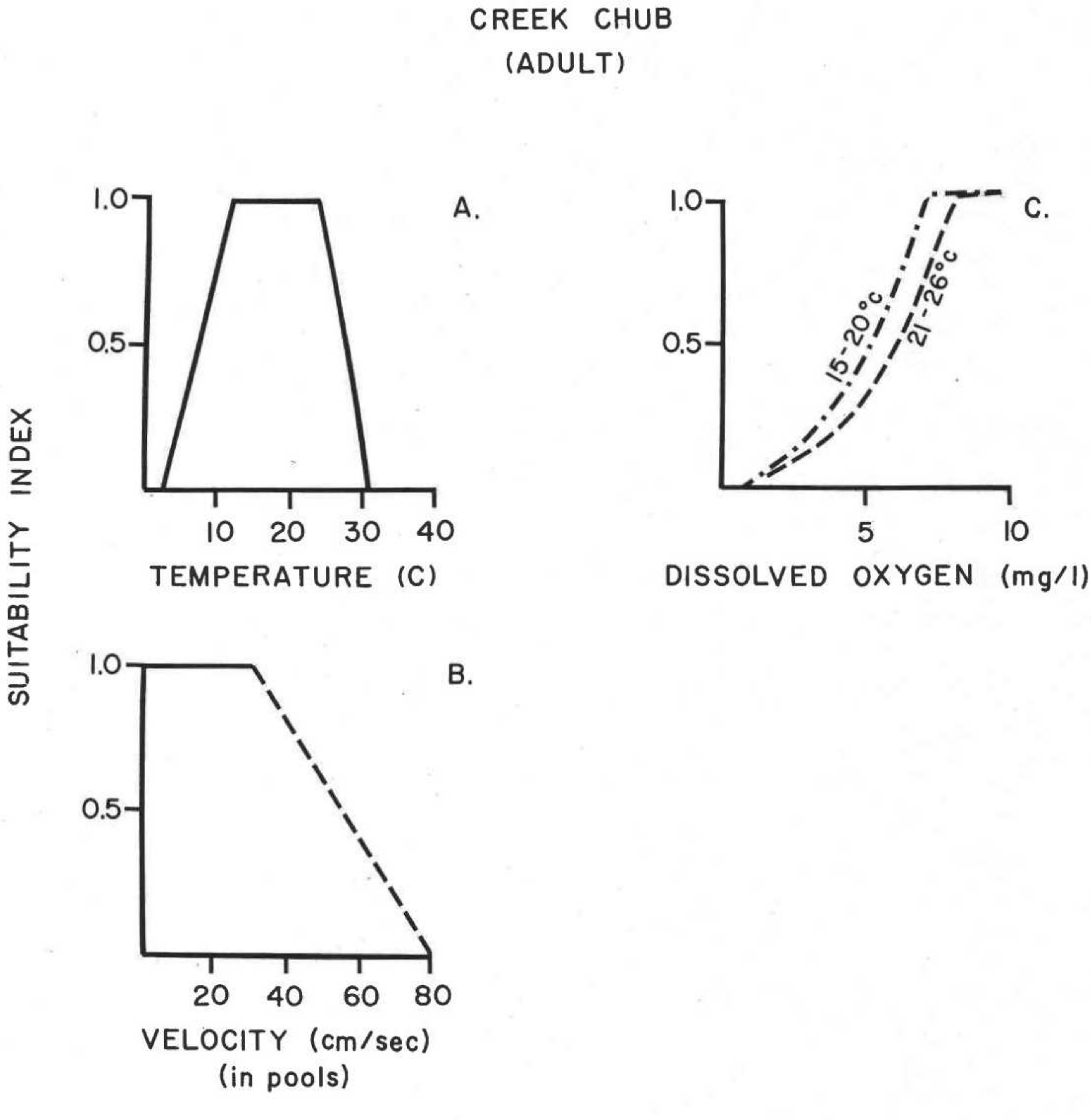


Figure 2. Examples of Suitability Index Curves

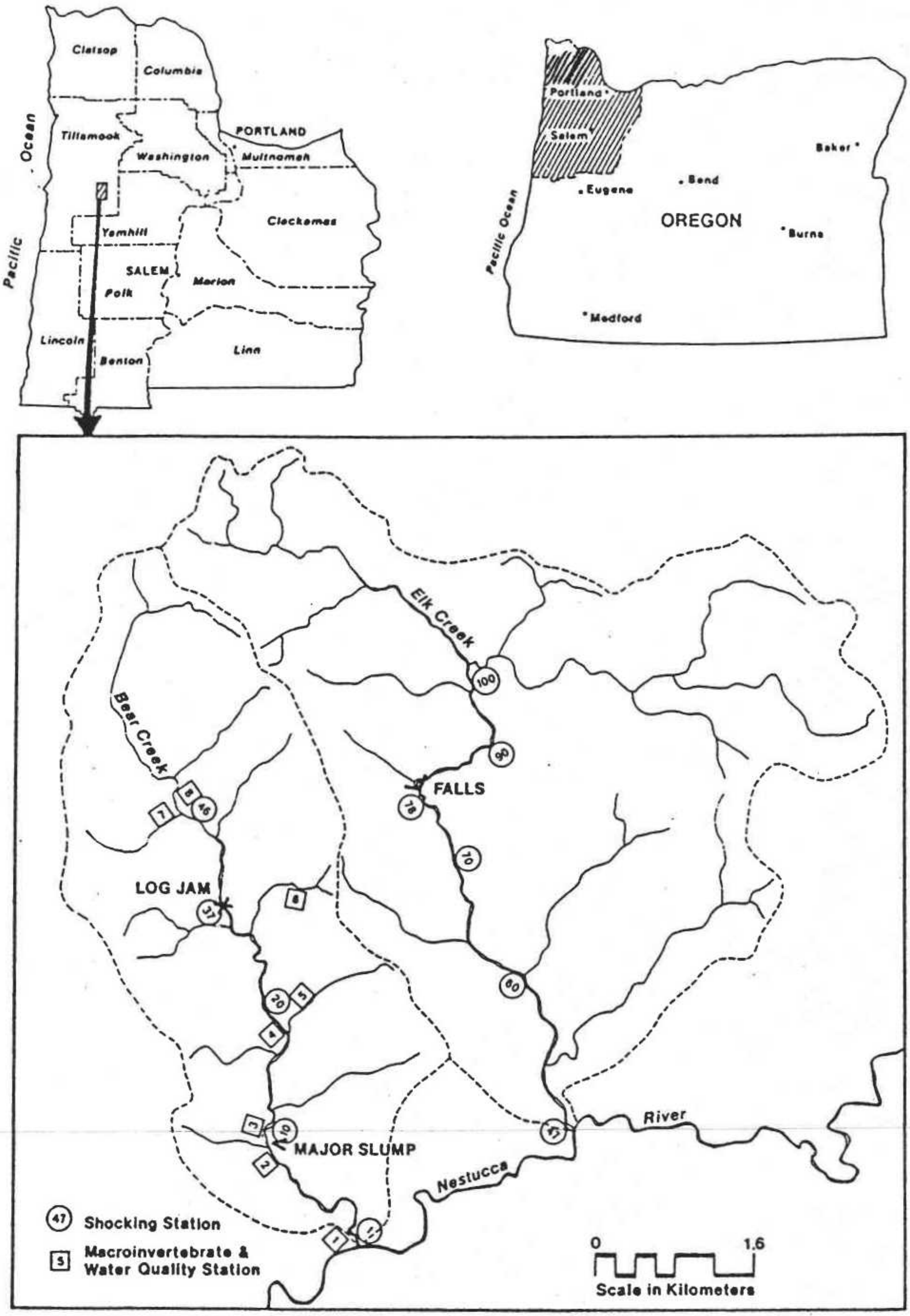
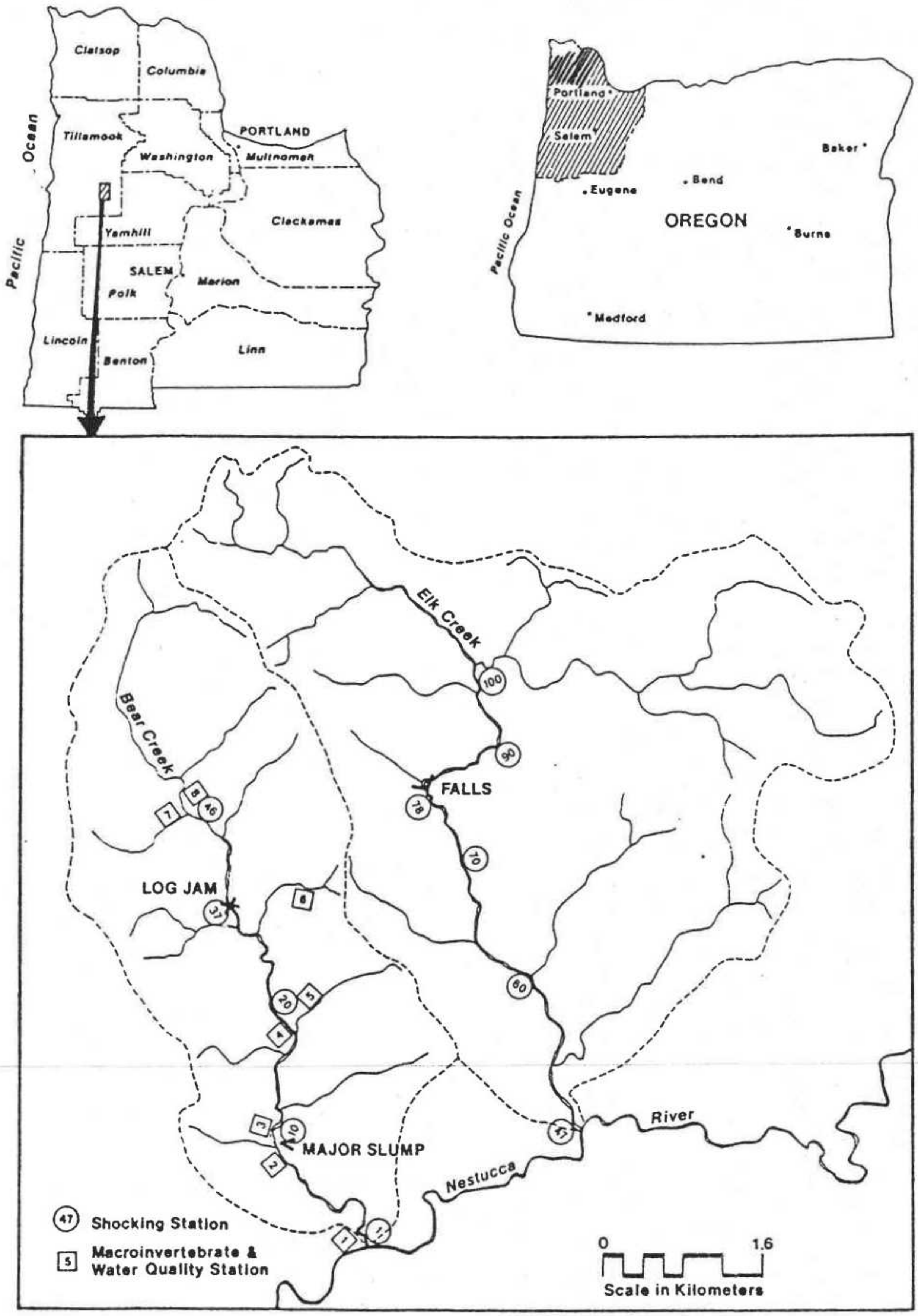


Figure 3. Location Map of Bear and Elk Creek Drainages, Oregon



Clatsop
Columbia
Tillamook
Washington
PORTLAND
Multnomah
Clackamas
Yamhill
SALEM
Polk
Marion
Lincoln
Benton
Linn
Pacific Ocean
Portland
Salem
Baker
Bend
Eugene
OREGON
Burns
Medford
Pacific Ocean
Elk Creek
Bear Creek
FALLS
LOG JAM
MAJOR SLUMP
Nestucca River
Shocking Station
Macroinvertebrate & Water Quality Station
0 1.6
Scale in Kilometers

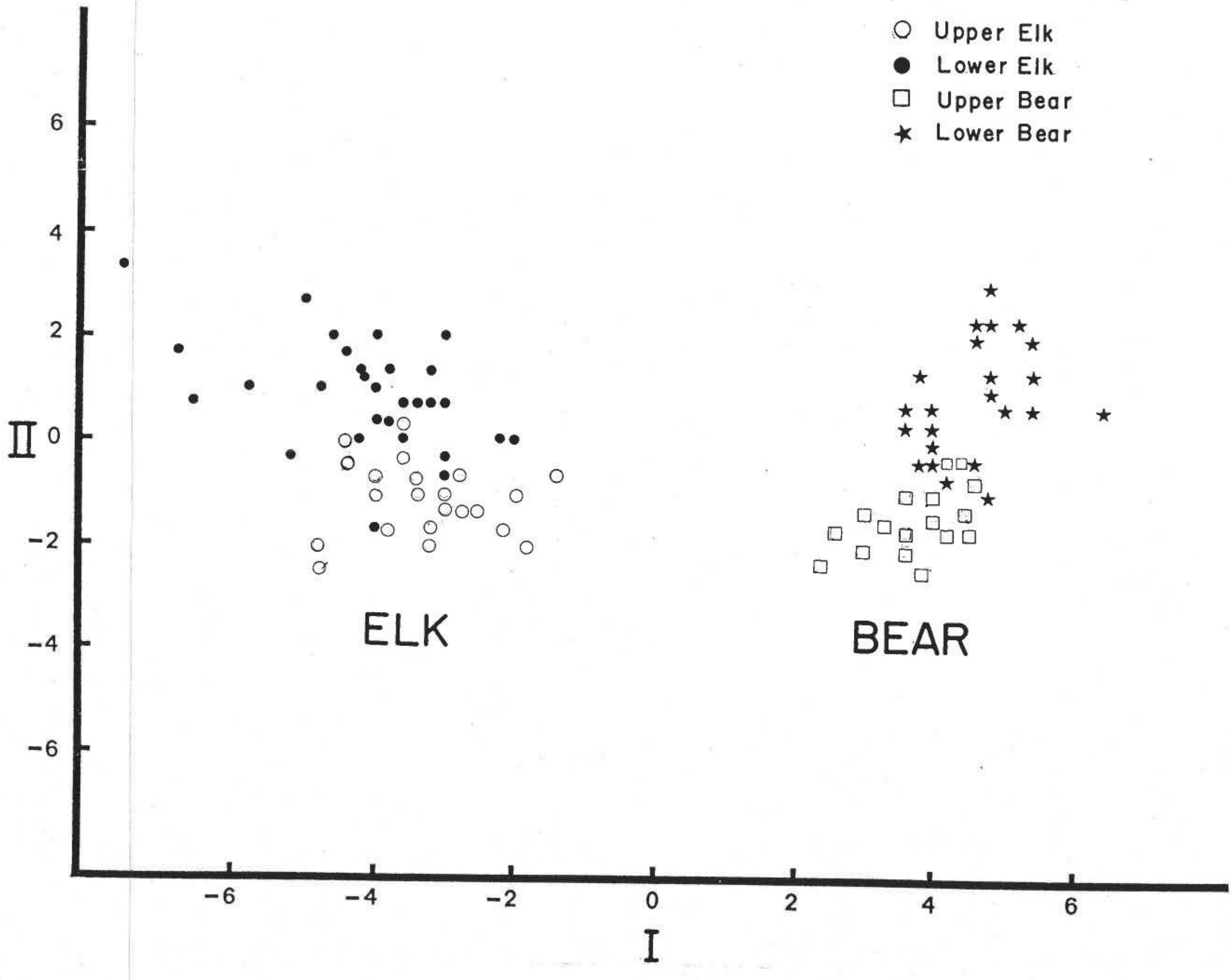


Figure 4. Reaches of Elk Creek and Bear Creek Clustered along Canonical Discriminant Functions I and II

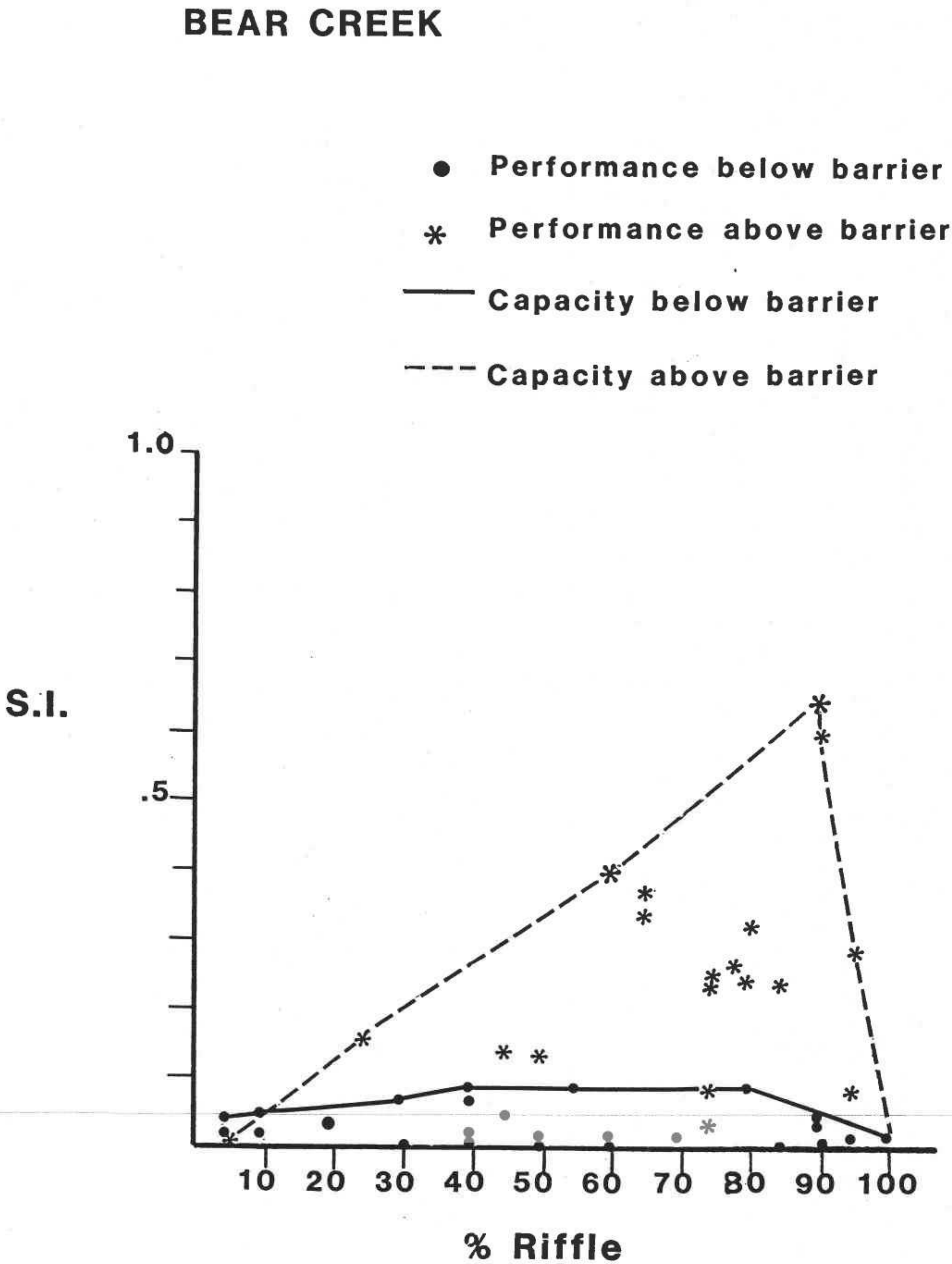
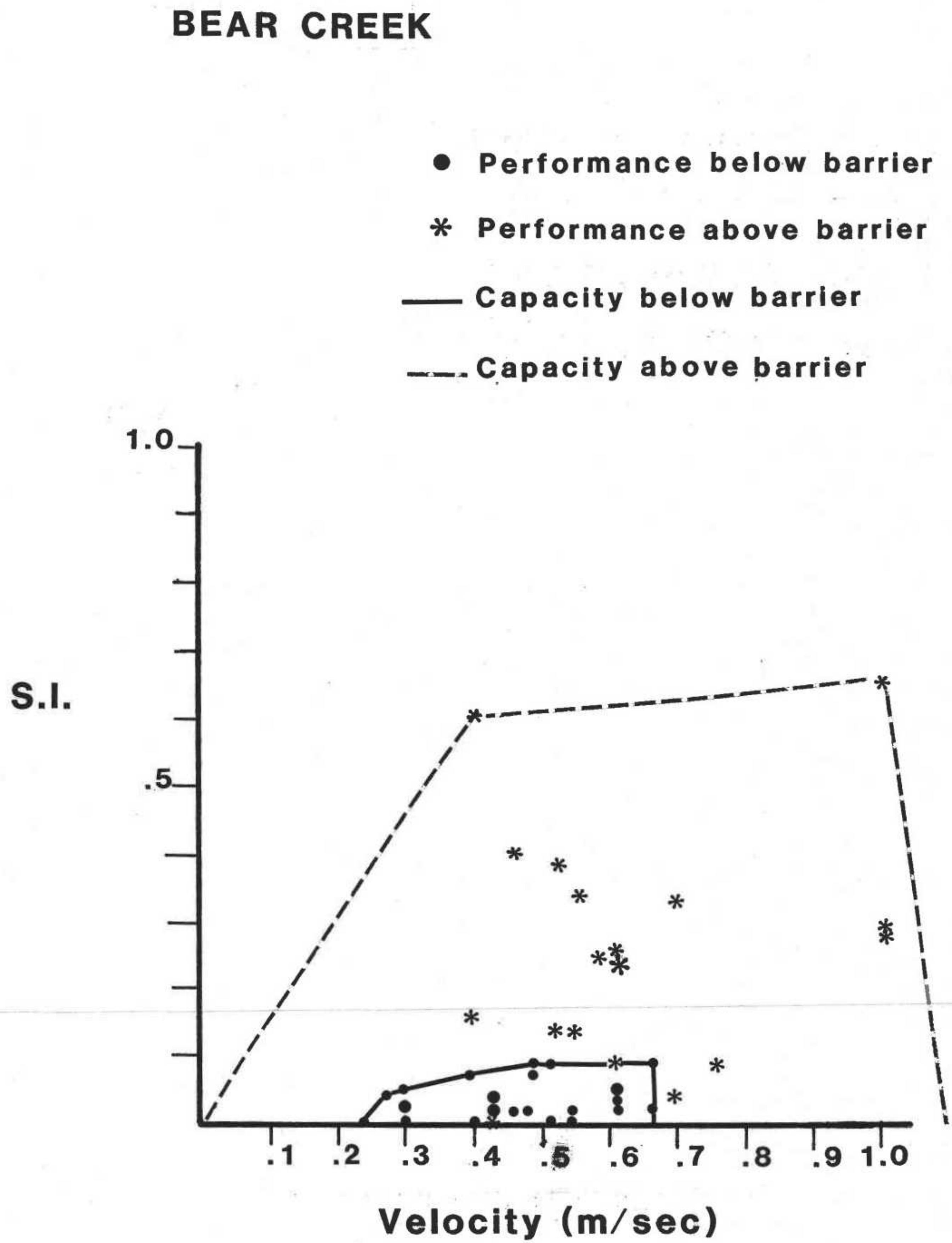


Figure 5. Cutthroat Trout Suitability Index vs. Riffles in Bear Creek


BEAR CREEK
Performance below barrier
Performance above barrier
Capacity below barrier
Capacity above barrier
1.0
.5
S.I.
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
Velocity (m/sec)

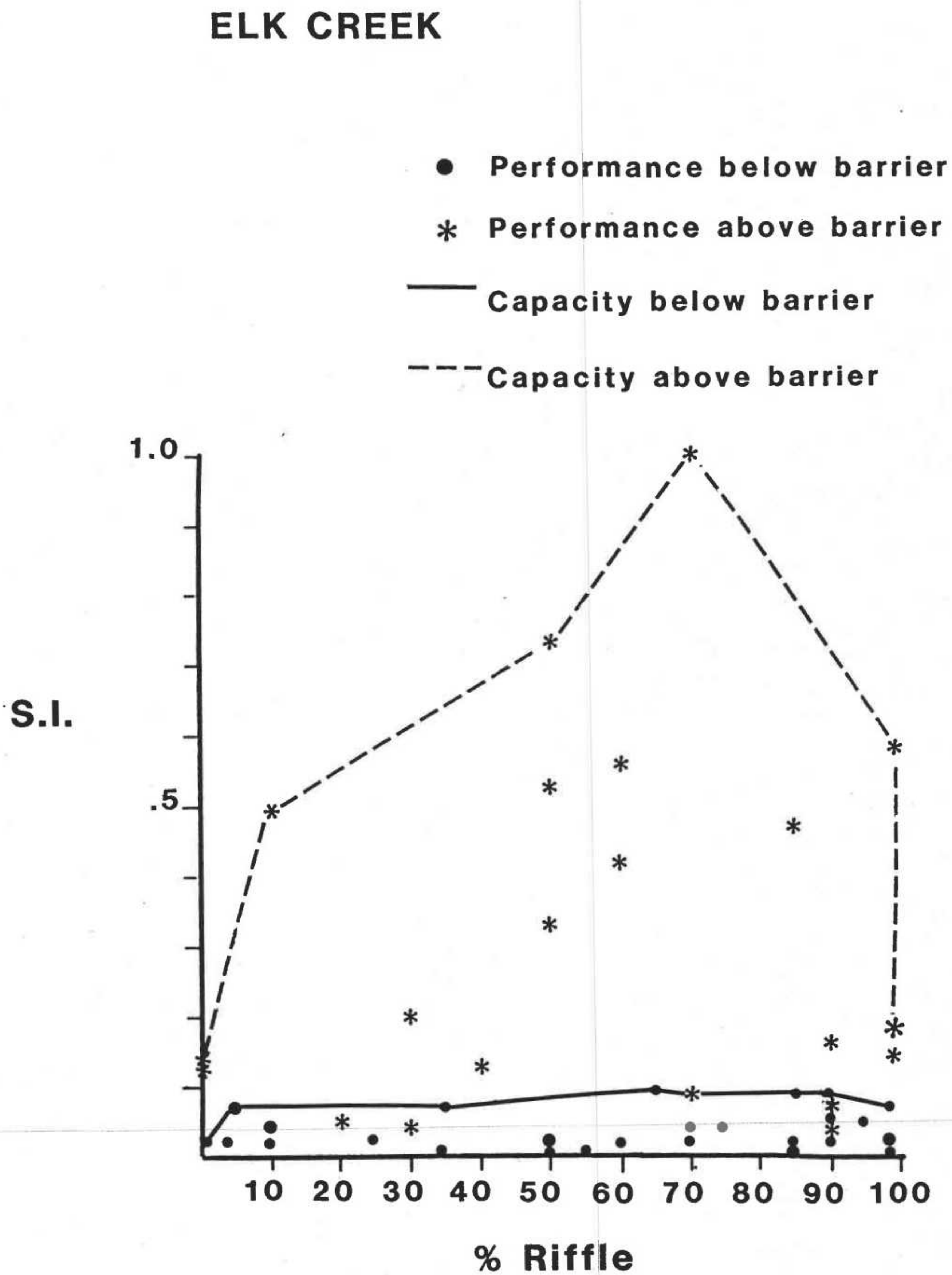
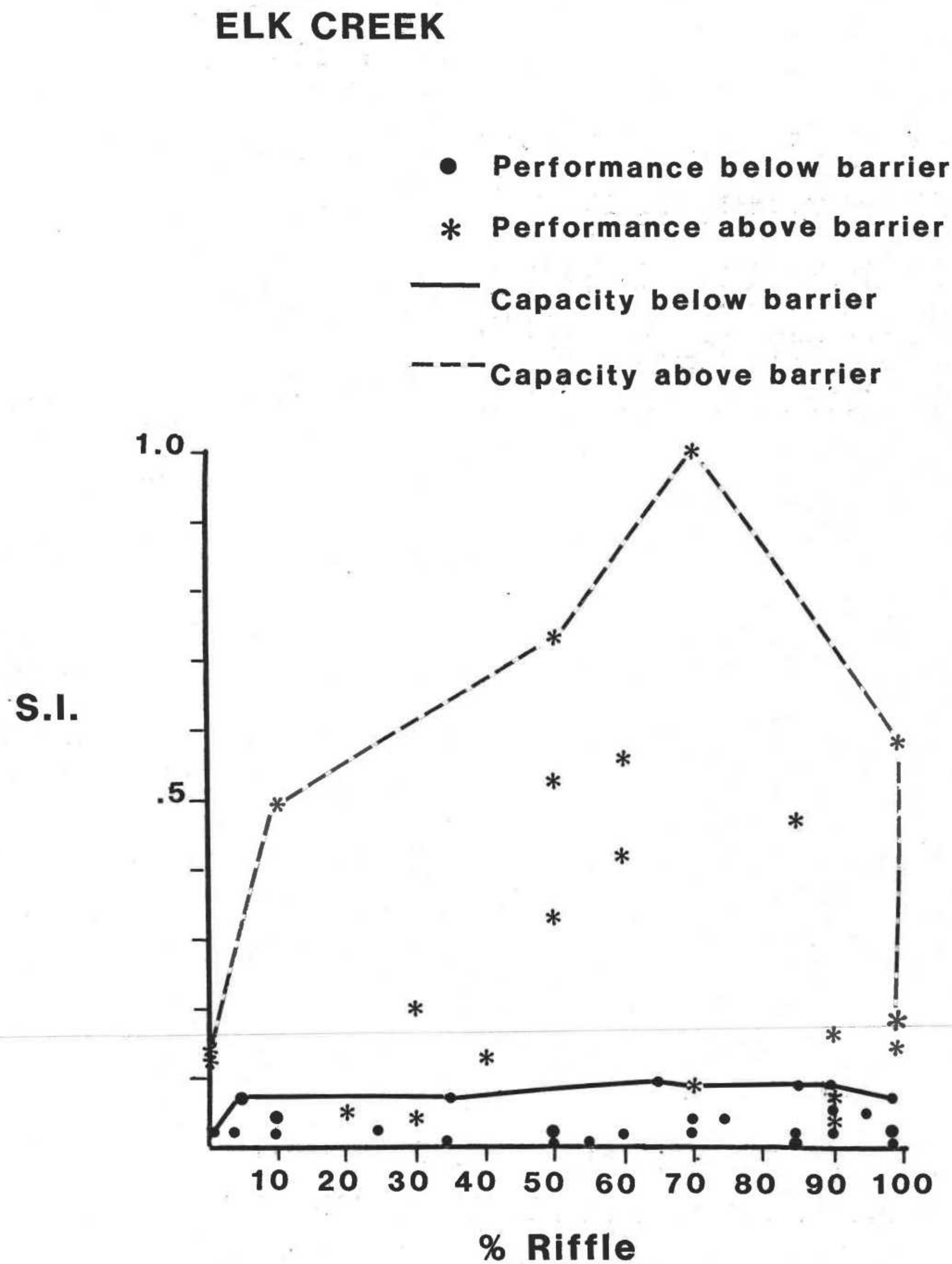


Figure 6. Cutthroat Trout Suitability Index vs. Riffles in Elk Creek


ELK CREEK
Performance below barrier
Performance above barrier
Capacity below barrier
Capacity above barrier
1.0
.5
S.I.
10
20
30
40
50
60
70
80
90
100
% Riffle

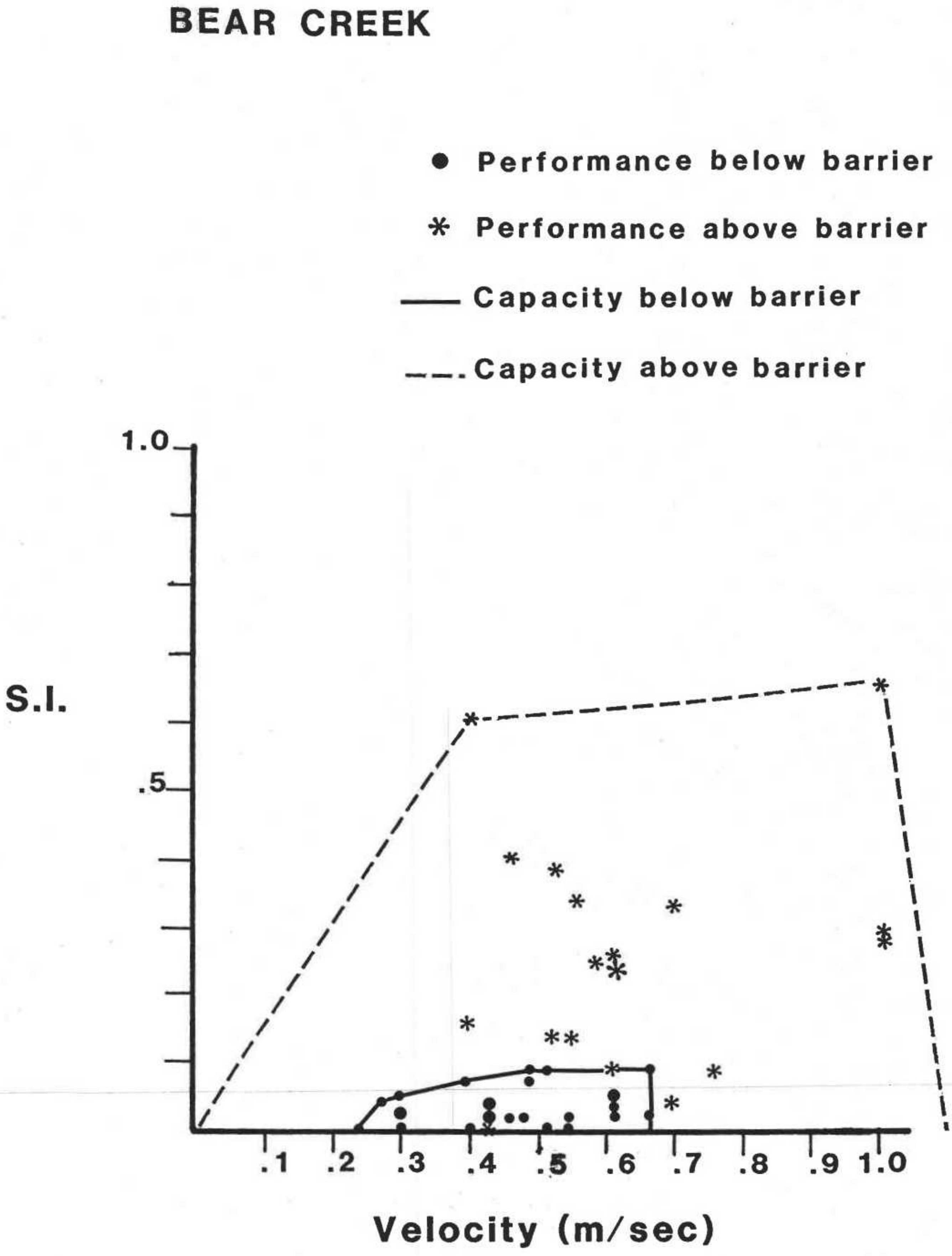
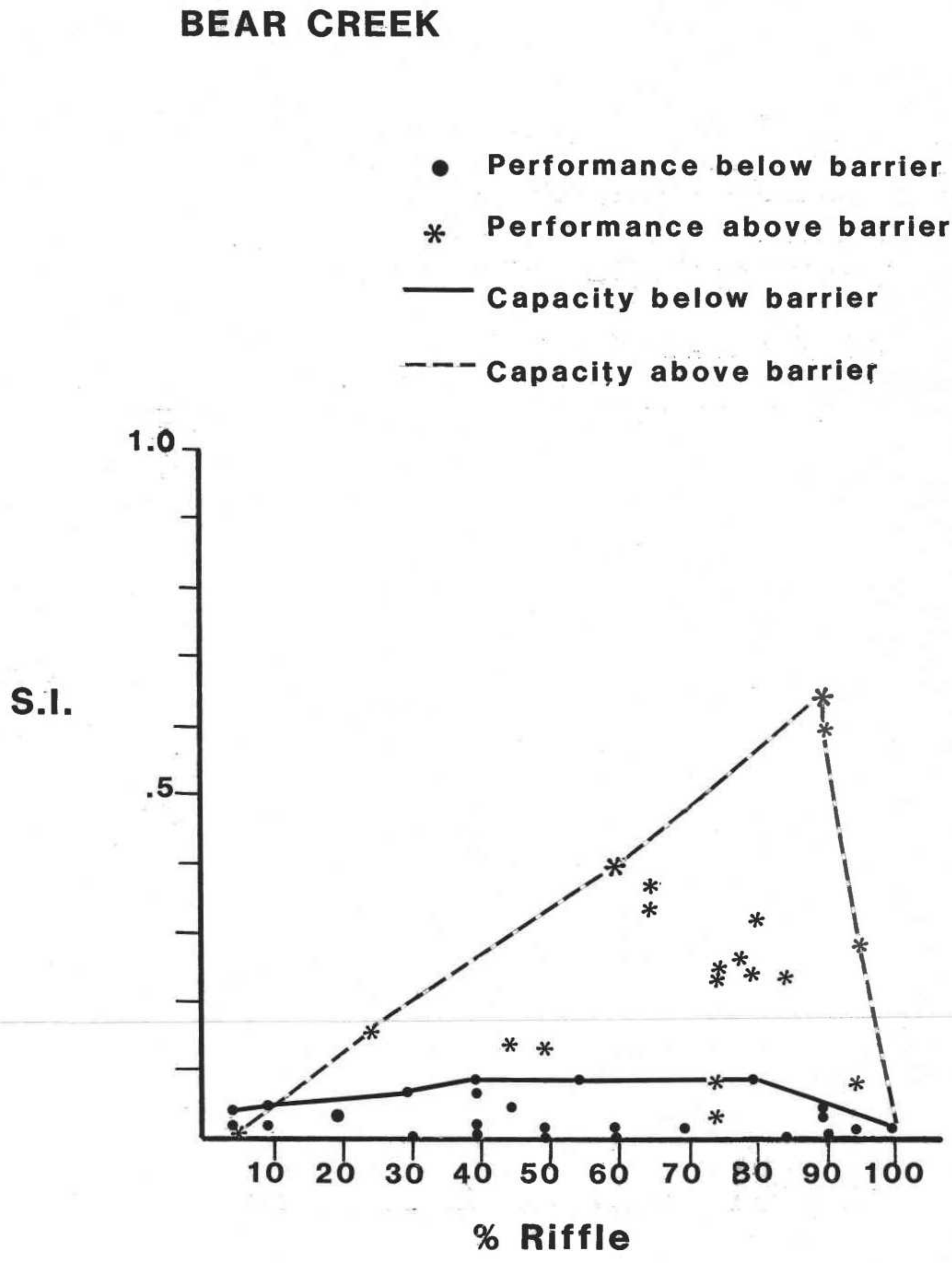


Figure 7. Cutthroat Trout Suitability Index vs. Current (cm/sec) in Bear Creek


BEAR CREEK
Performance below barrier
Performance above barrier
Capacity below barrier
Capacity above barrier
1.0
.5
S.I.
10 20 30 40 50 60 70 80 90 100
% Riffle

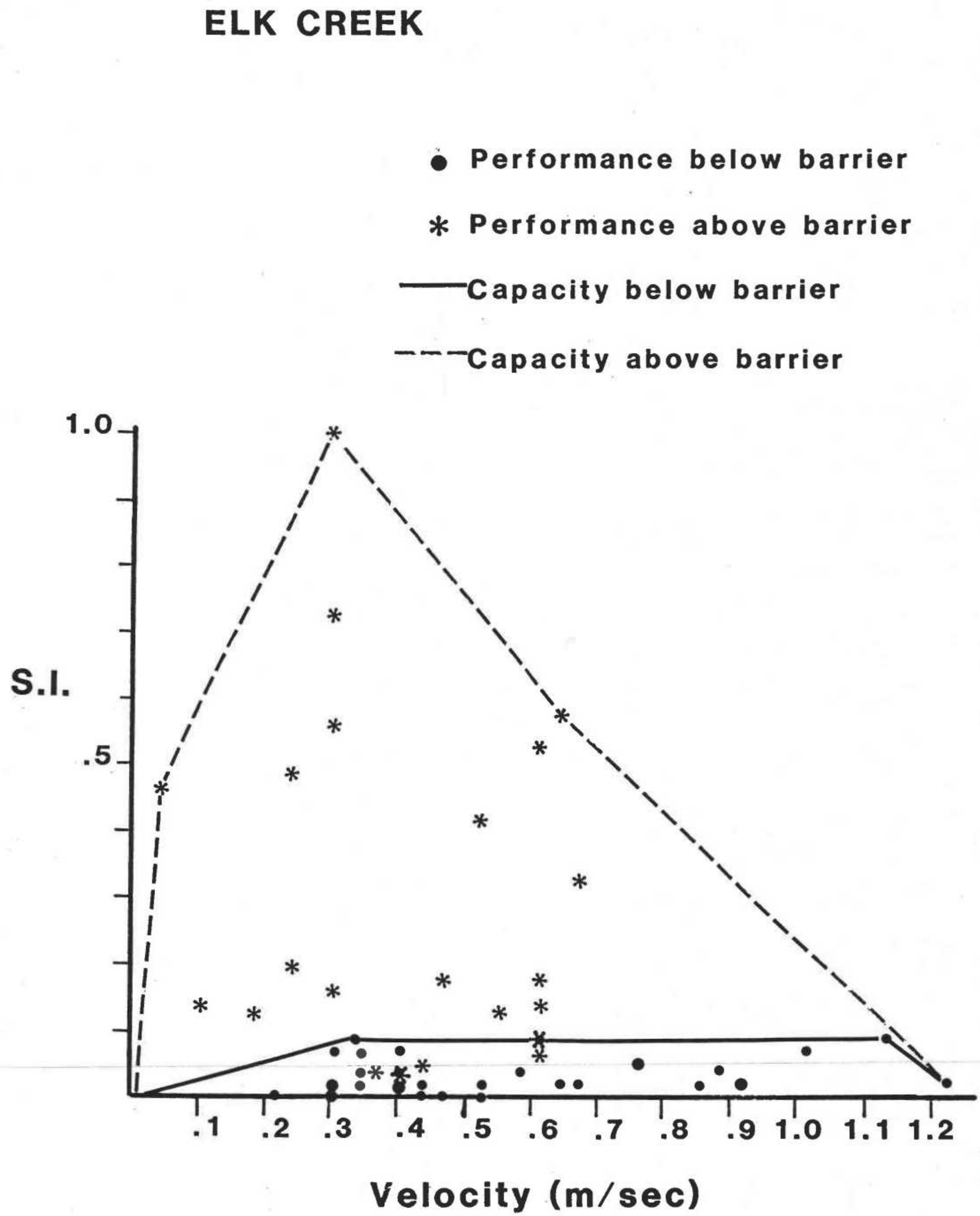
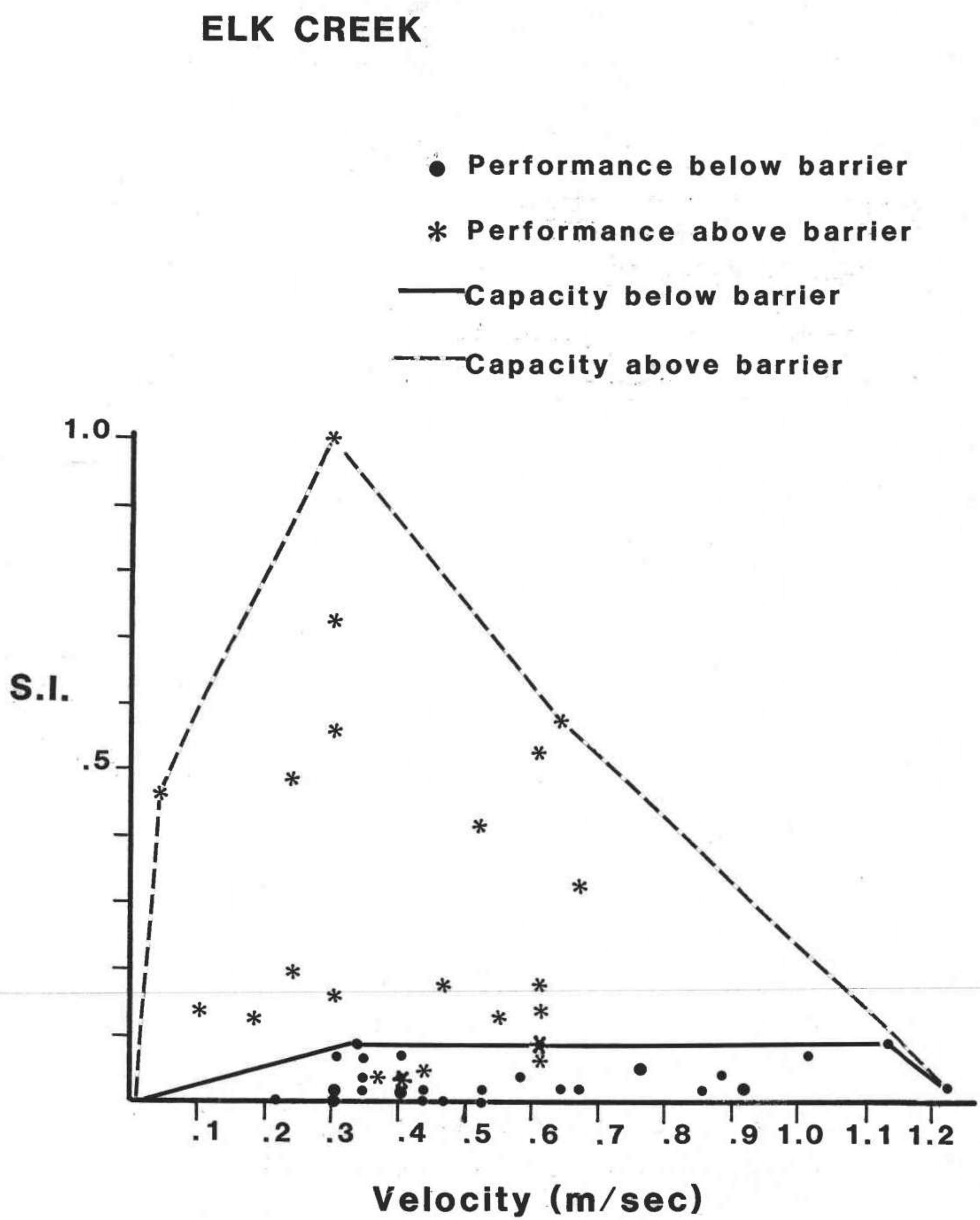


Figure 8. Cutthroat Trout Suitability Index vs. Current (cm/sec) in Elk Creek



ELK CREEK
Performance below barrier
Performance above barrier
Capacity below barrier
Capacity above barrier
1.0
.5
S.I.
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
Velocity (m/sec)

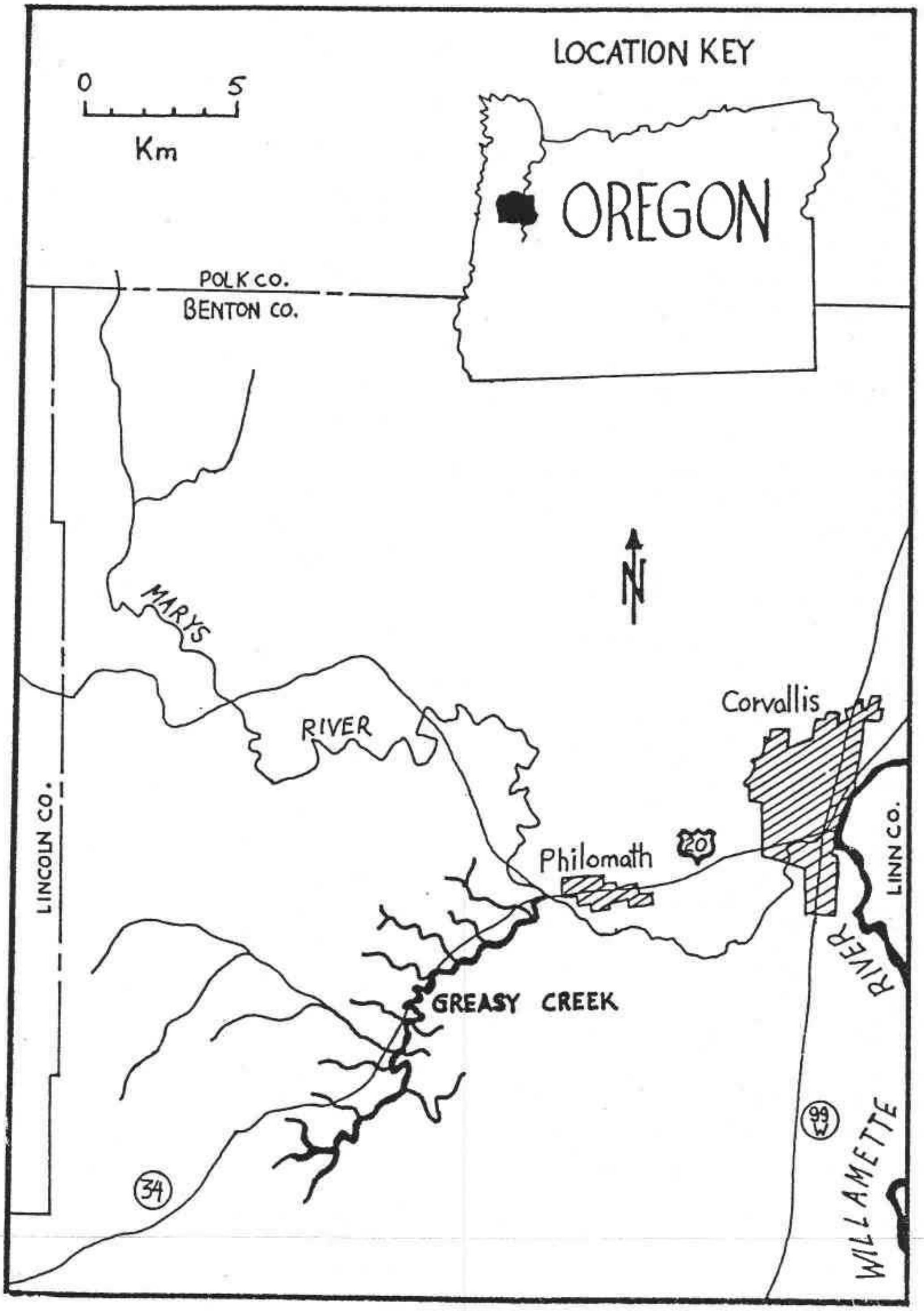


Figure 9. Location Map of Greasy Creek, Oregon

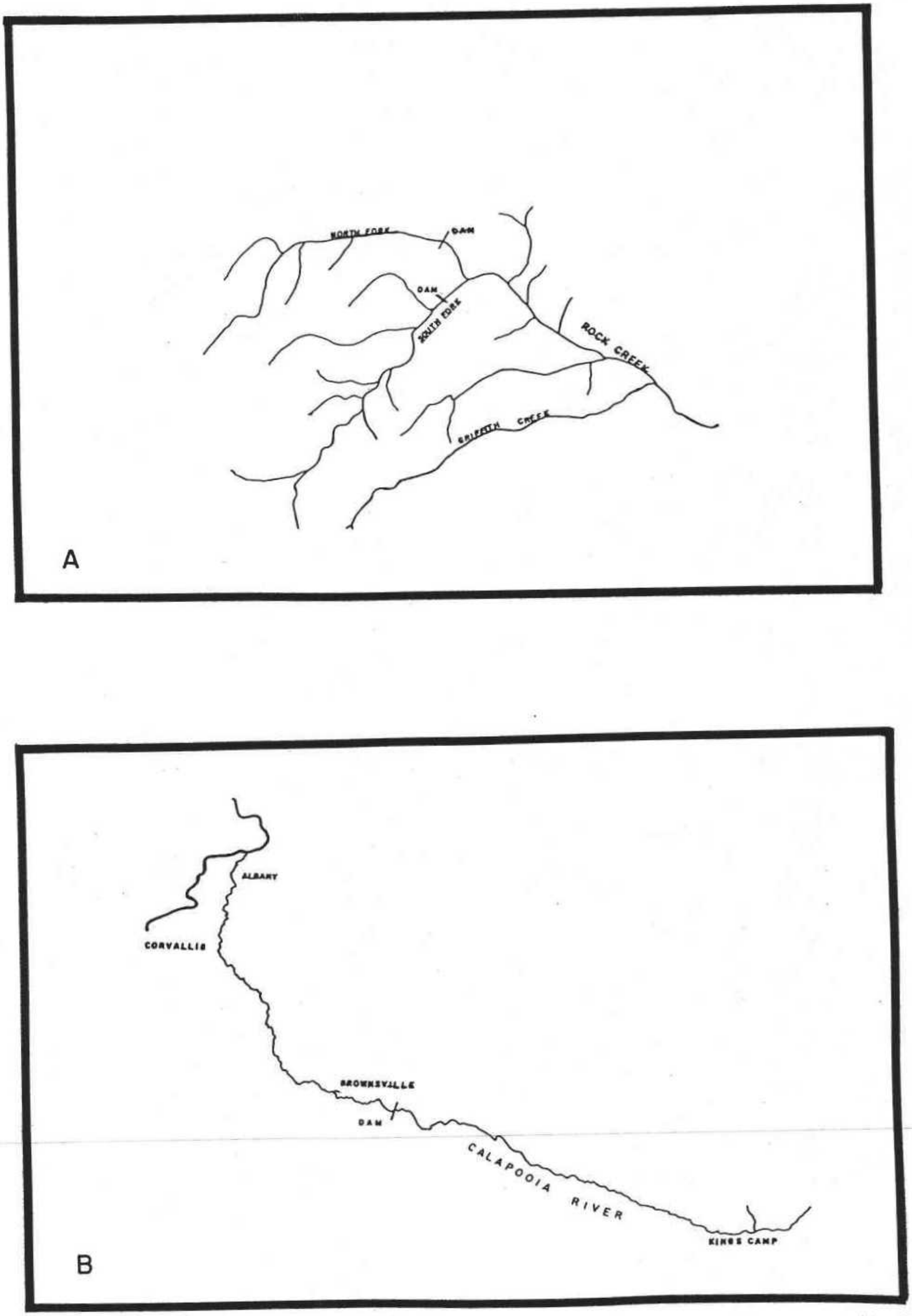
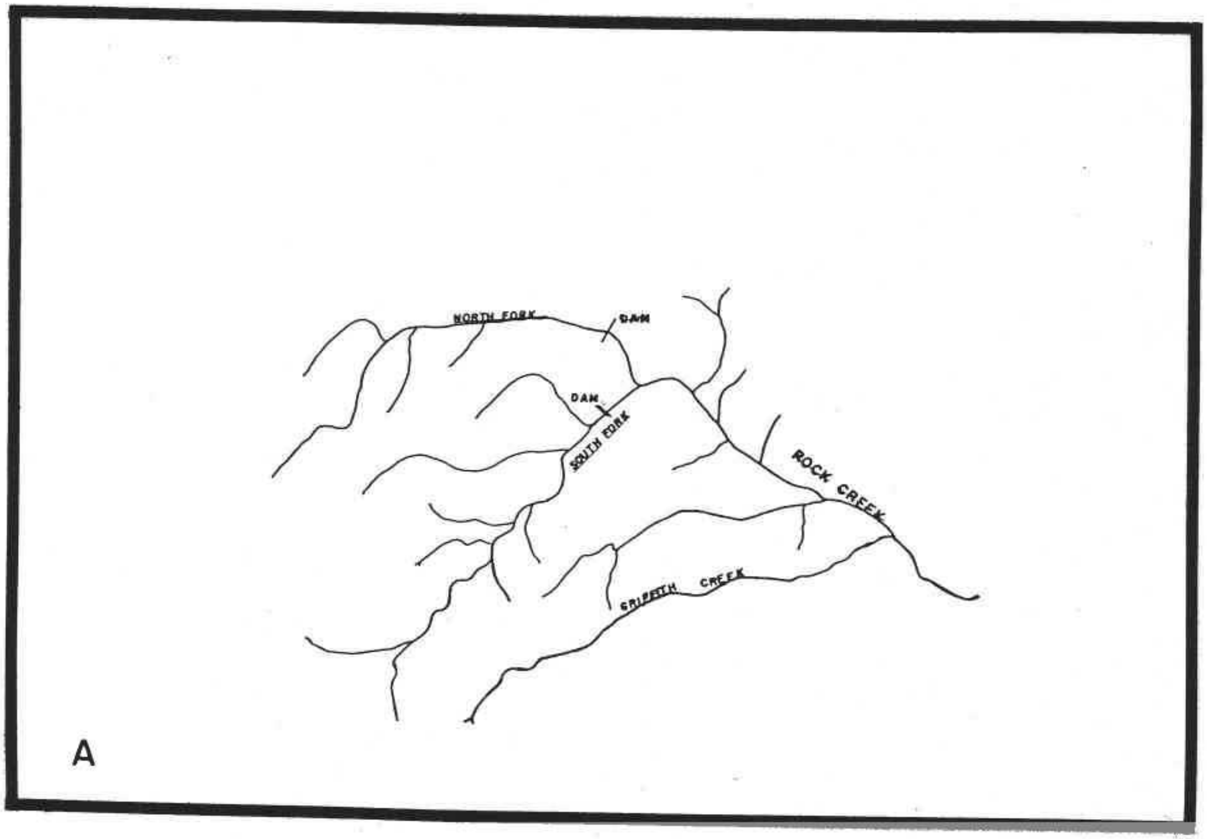
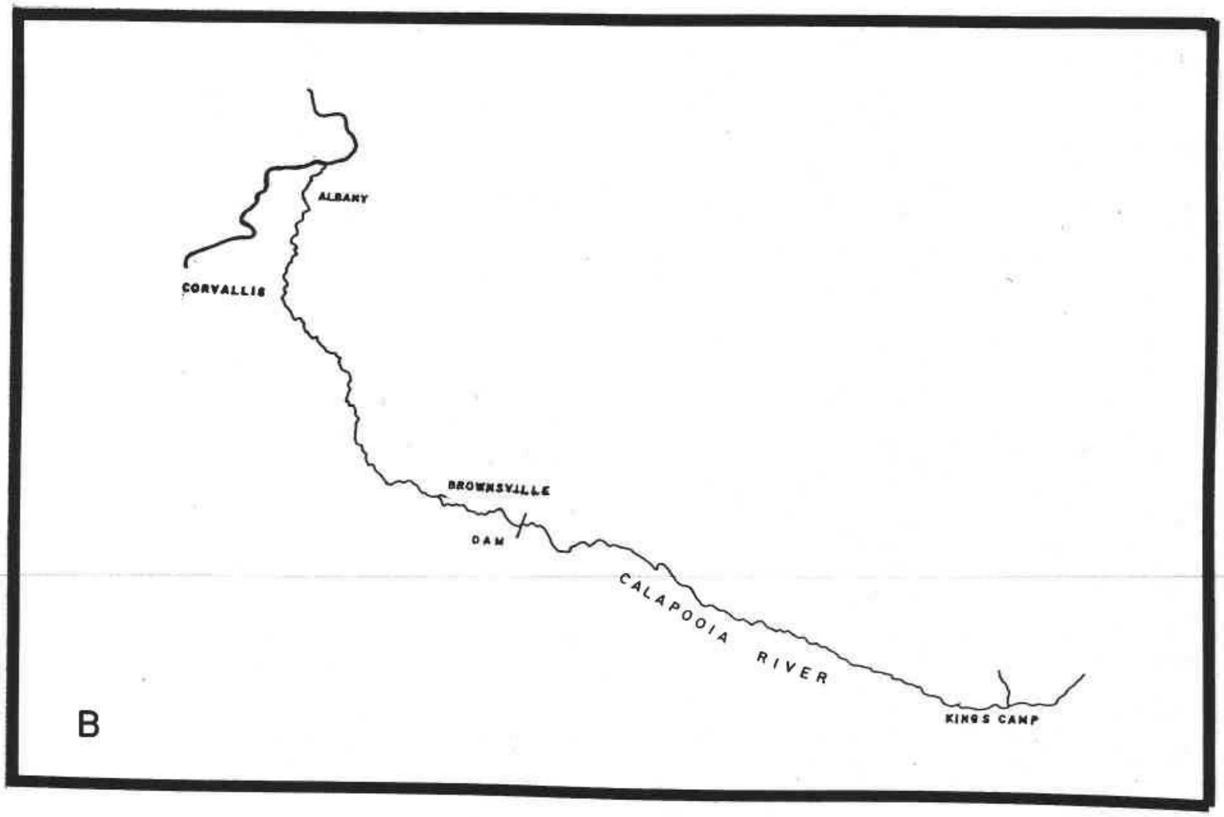


Figure 10. Location Map of Rock Creek and Calapooia River dams


NORTH FORK
DAM
DAM
SOUTH FORK
ROCK CREEK
GRIFFITH CREEK
A


ALBANY
CORVALLIS
BROWNSVILLE
DAM
CALAPOOIA RIVER
KINGS CAMP
B

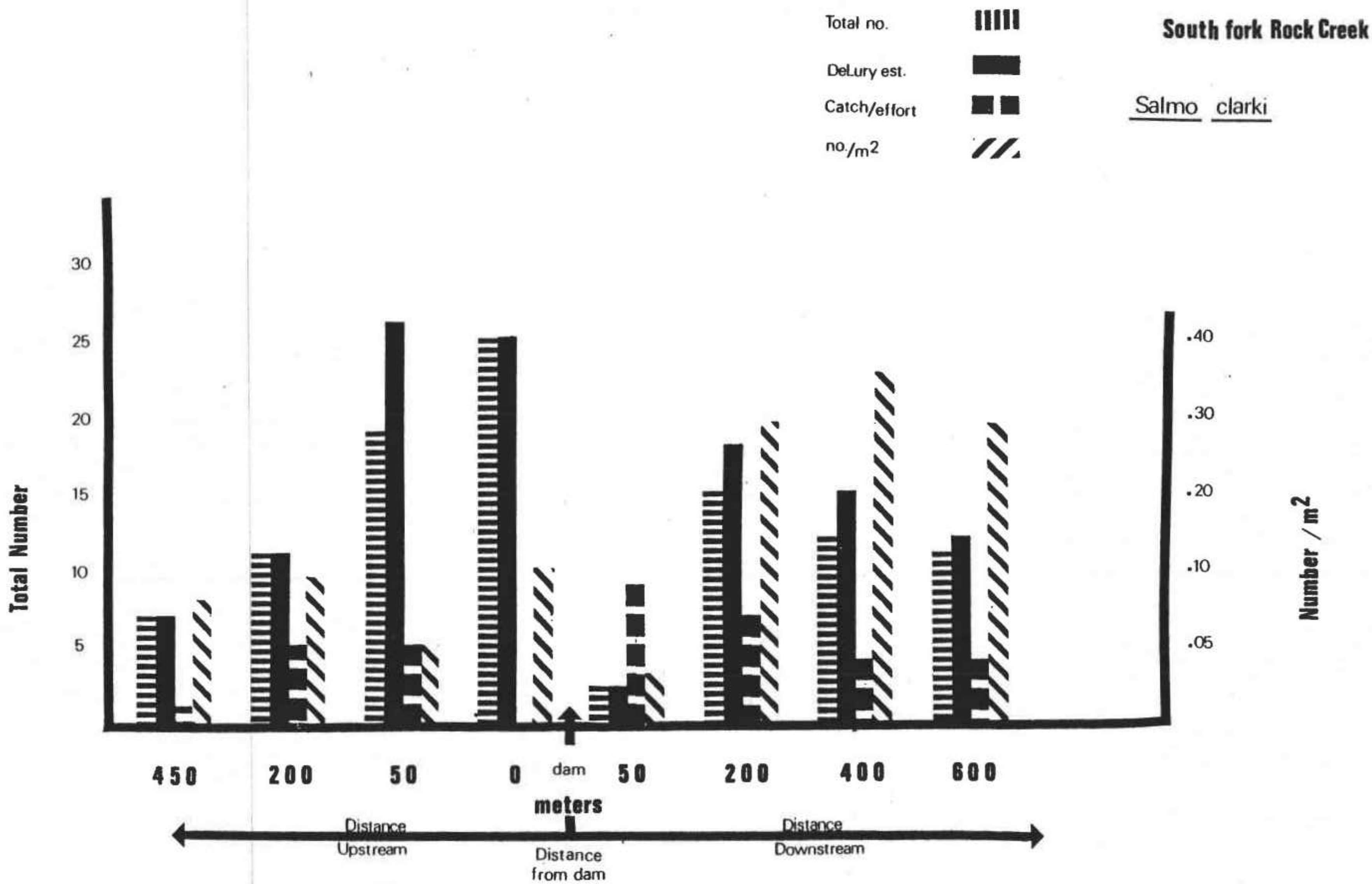


Figure 11. Cutthroat Trout Densities Upstream and Downstream of South Fork Rock Creek Dam

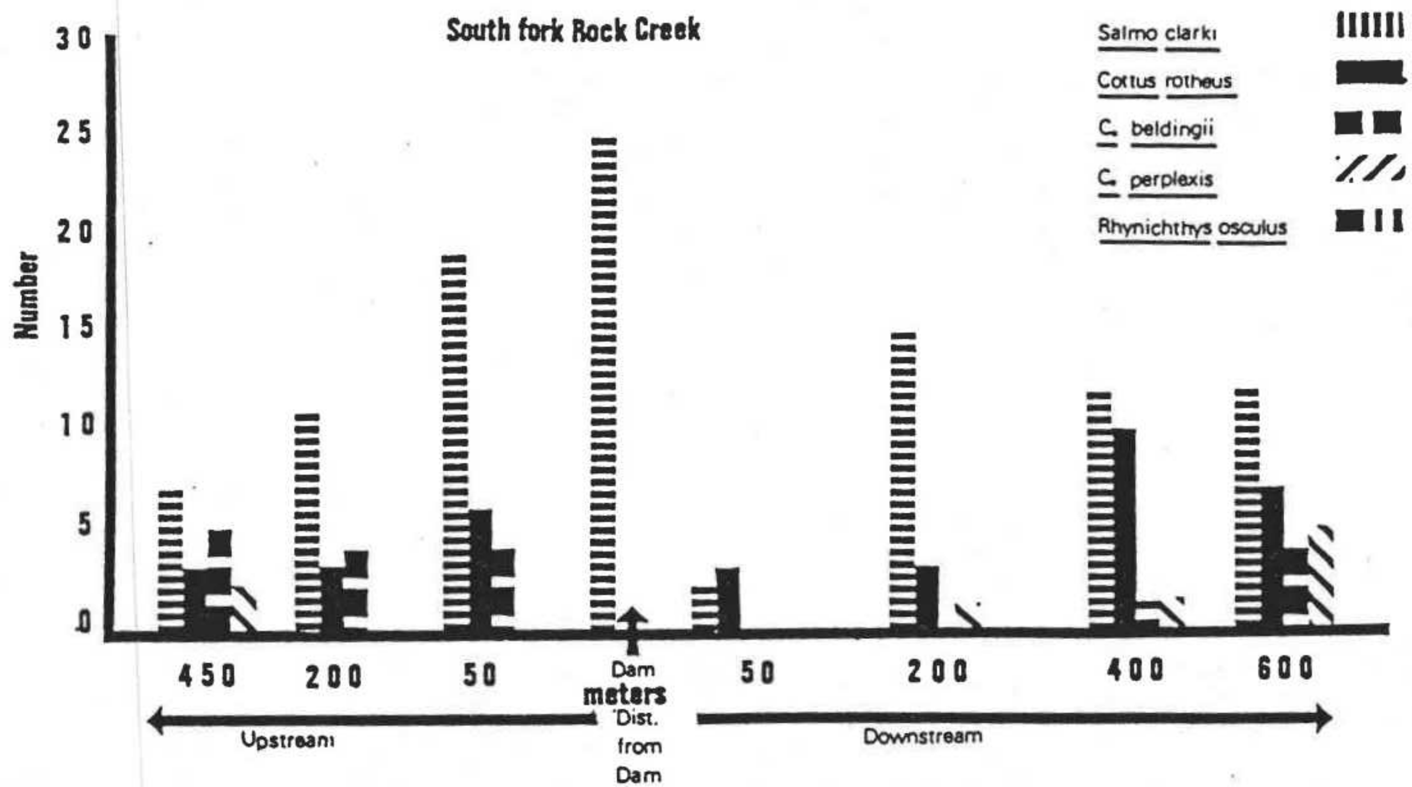
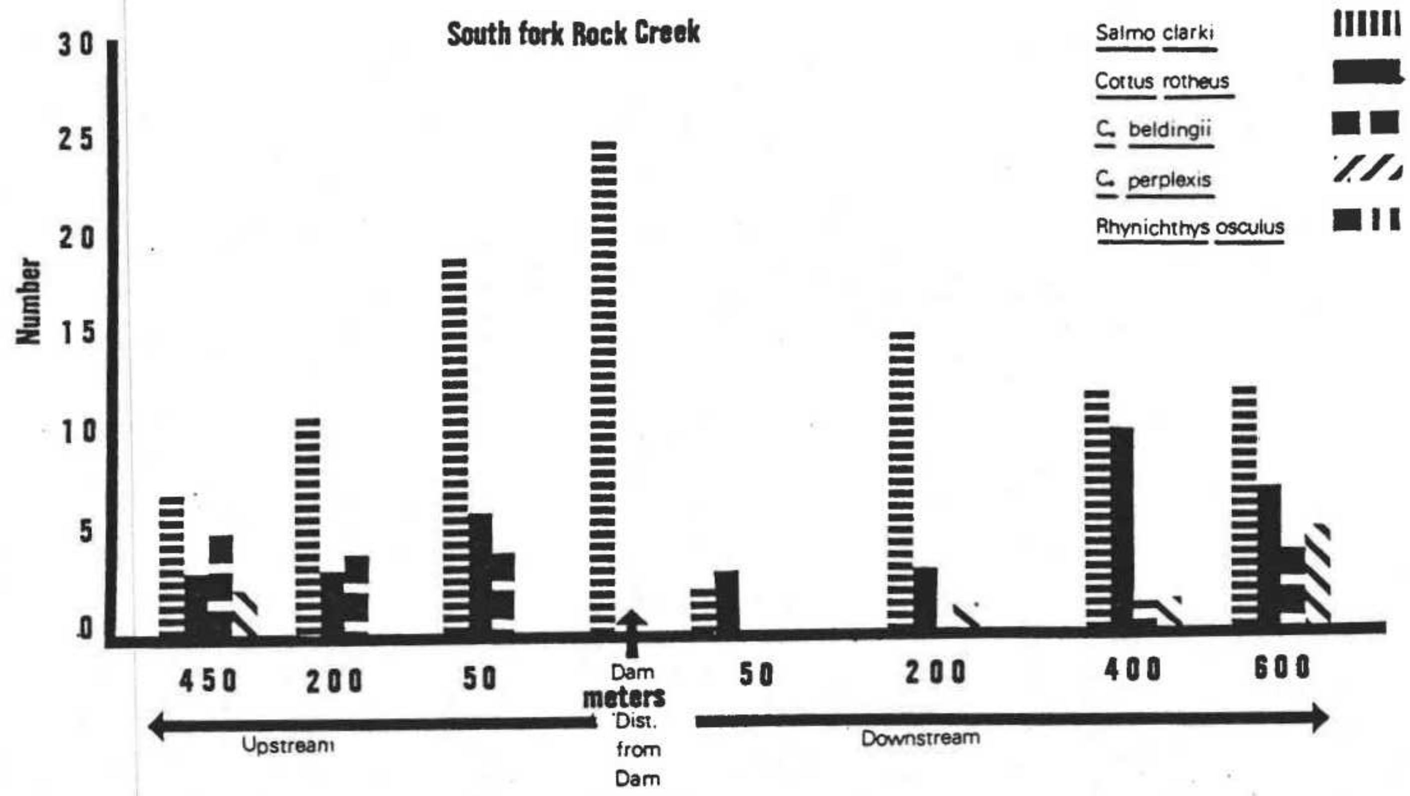


Figure 12. Fish Densities Upstream and Downstream of South Fork Rock Creek Dam


South fork Rock Creek
Number
30
25
20
15
10
5
0
450
200
50
Dam
meters
Dist. from Dam
50
200
400
600
Upstream
Downstream
Salmo clarki
Cottus rotheus
C. beldingii
C. perplexis
Rhynichthys osculus

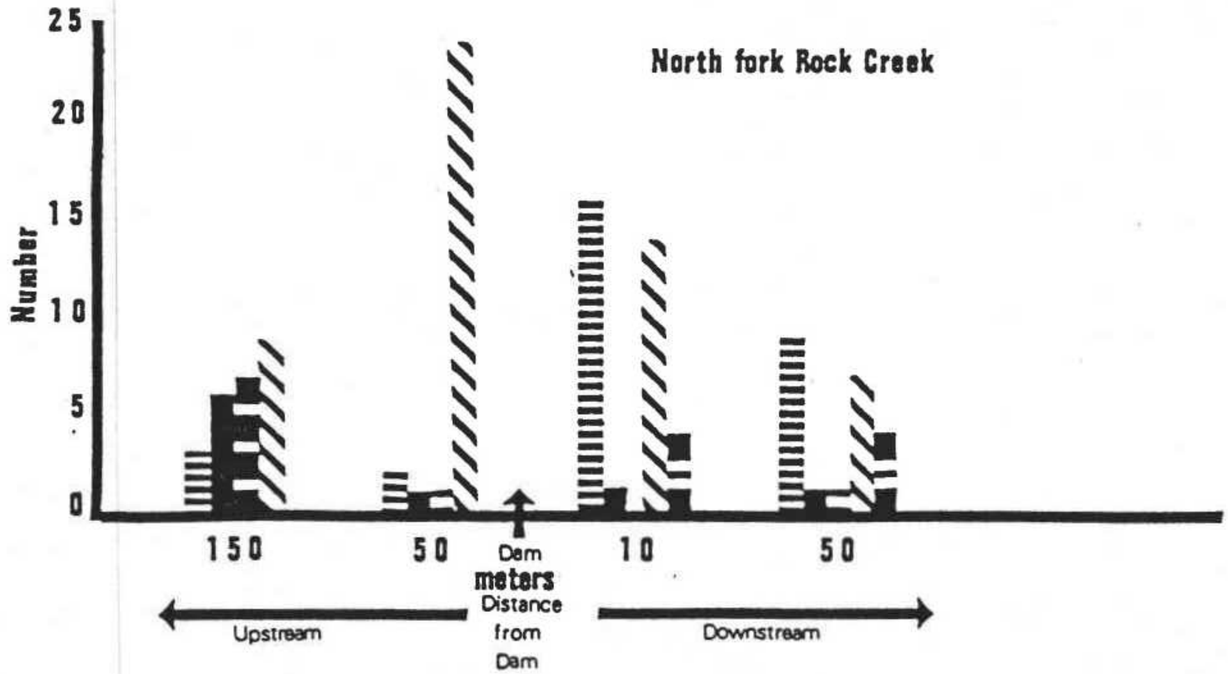
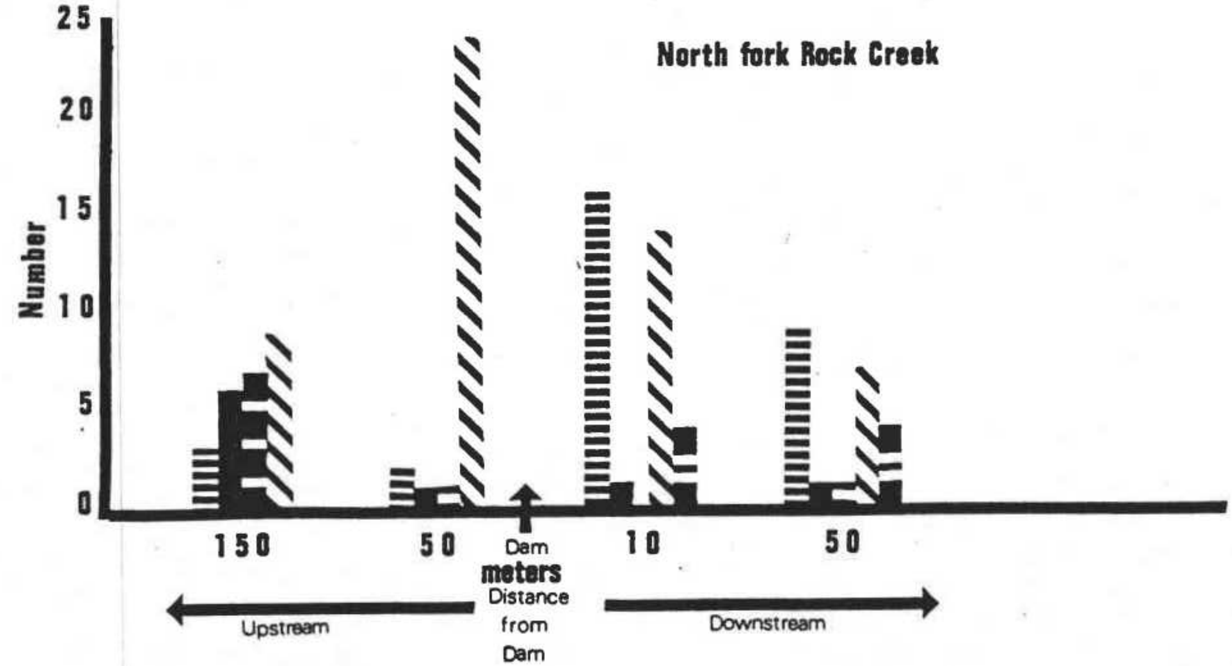
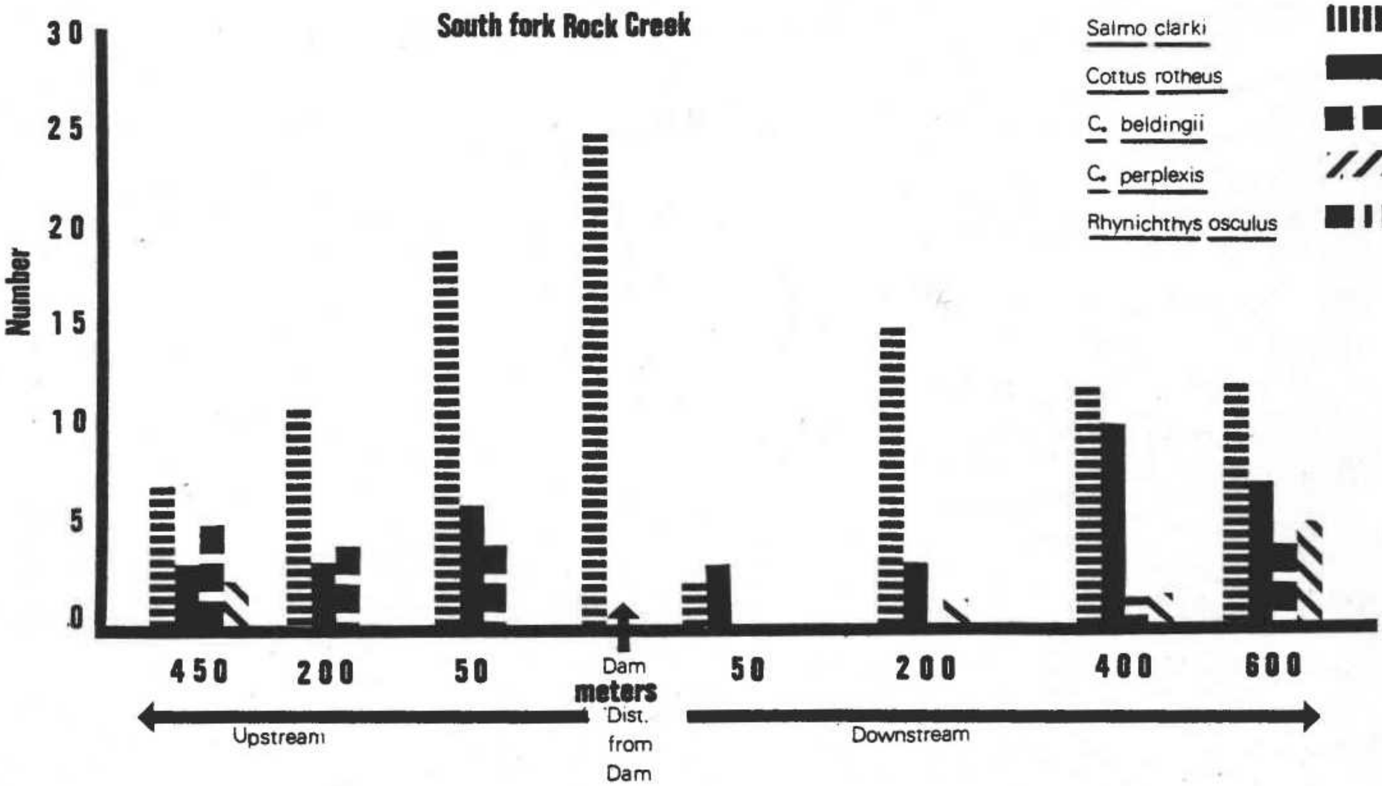
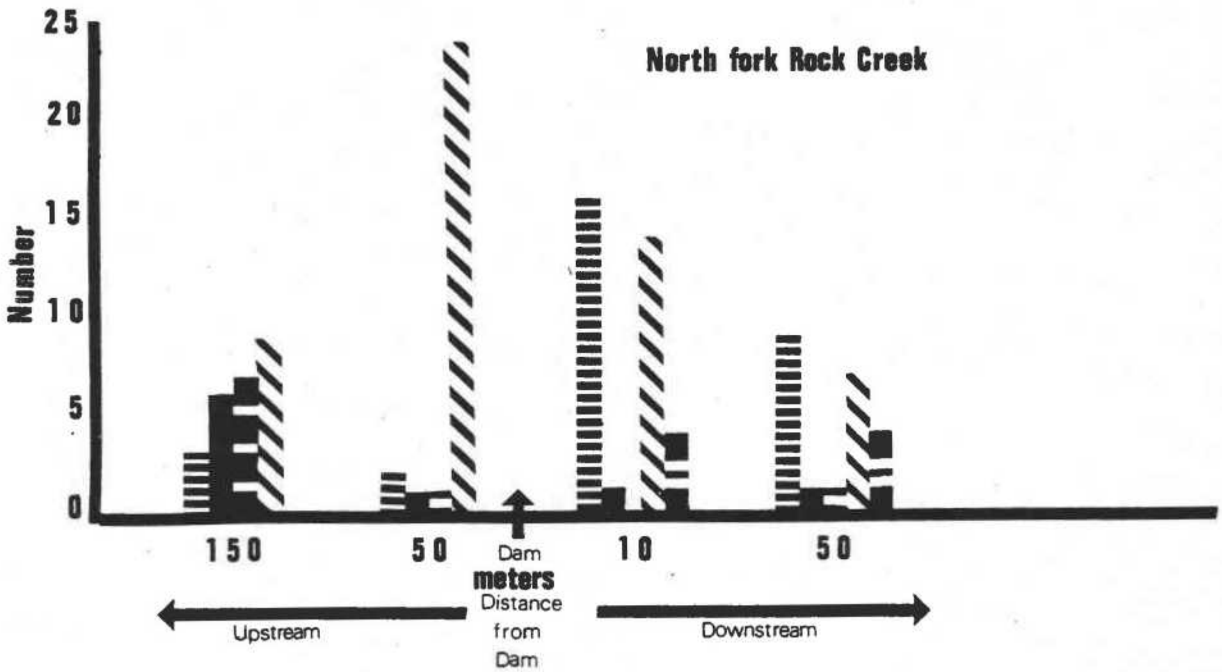


Figure 13. Fish Densities Upstream and Downstream of North Fork Rock Creek Dam


North fork Rock Creek
Number
25
20
15
10
5
0
150
50
Dam
10
50
meters
Distance
from
Dam
Upstream
Downstream


South fork Rock Creek
Salmo clarki
Cottus rotheus
C. beldingii
C. perplexis
Rhynichthys osculus
Number
30
25
20
15
10
5
0
450
200
50
Dam
50
200
400
600
meters
Dist.
from
Dam
Upstream
Downstream


North fork Rock Creek
Number
25
20
15
10
5
0
150
50
Dam
10
50
meters
Distance
from
Dam
Upstream
Downstream