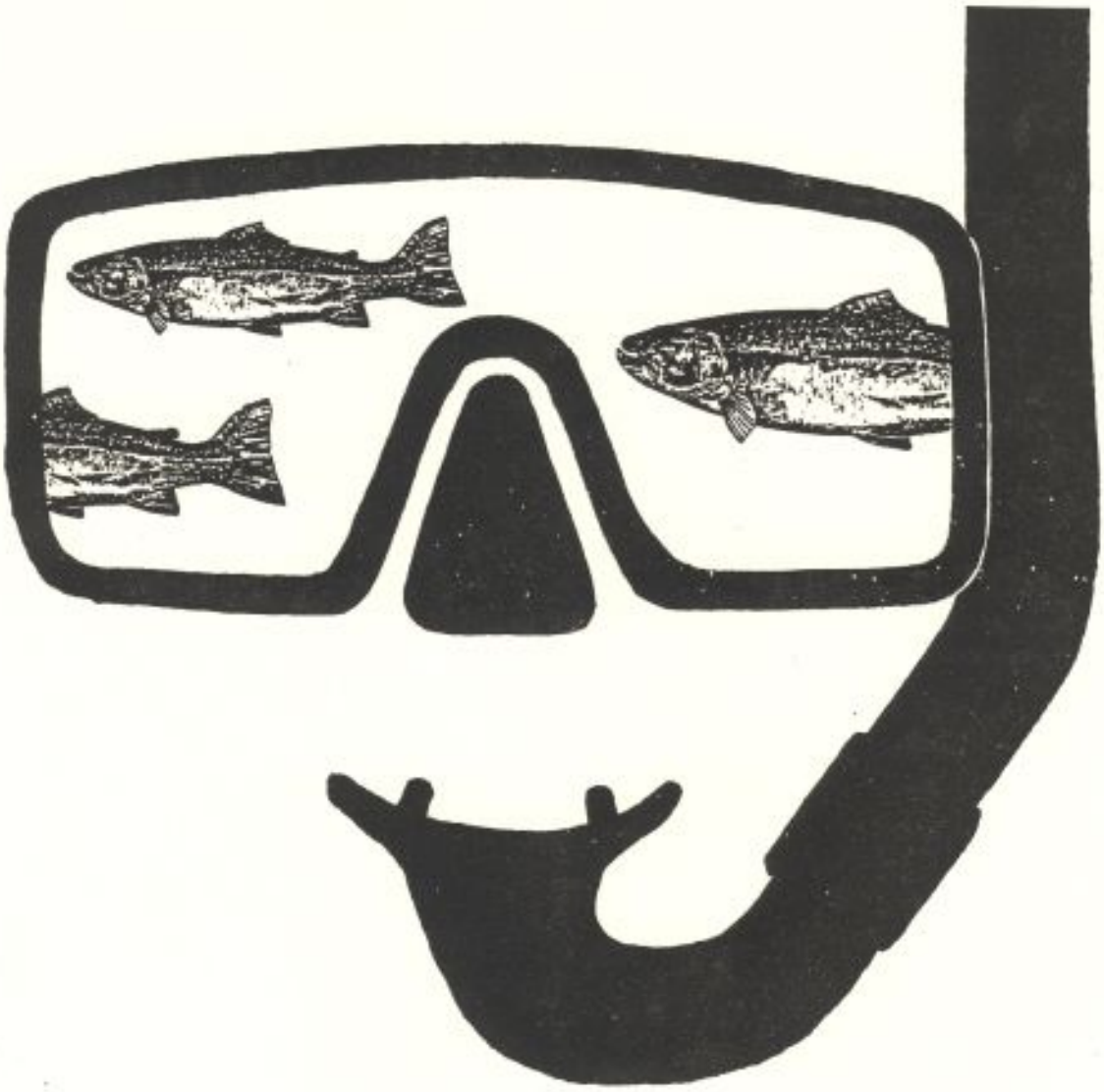
Development Of Habitat Preference Criteria For Anadromous Salmonids Of The Trinity River



Fish and Wildlife Service

U.S. Department of the Interior

DEVELOPMENT OF HABITAT PREFERENCE CRITERIA FOR ANADROMOUS SALMONIDS OF THE TRINITY RIVER

By

Mark Hampton
Trinity River Flow Evaluation Program
U.S. Fish and Wildlife Service
P.O. Box 174
Lewiston, California 96052

May 1988

U.S. Fish & Wildlife Service
Division of Ecological Services
2800 Cottage Way, Room E-1803
Sacramento, California 95825

This report should be cited as:

Hampton, M. 1988. Development of Habitat Preference Criteria for Anadromous Salmonids of the Trinity River. U.S. Dept. Int., Fish Wildl. Serv., Div. Ecol. Serv., Sacramento, California. 93pp.

ABSTRACT

Direct observation techniques using a mask and snorkel were used to collect microhabitat suitability criteria describing depth, velocity, cover, and substrate used by anadromous salmonids of the Trinity River in Northern California. Category II criteria (utilization) are presented for fry, juvenile, and spawning lifestages of chinook and coho salmon and steelhead trout. Available habitat for the upper Trinity River was obtained through the use of the IFG-4 program of the Instream Flow Incremental Methodology (IFIM). Category III criteria (preference) are developed for fry, juvenile, and spawning lifestages of chinook and coho salmon and for juvenile and spawning lifestages of steelhead trout in the upper Trinity River. Preference criteria could not be developed for fry steelhead trout because of a limited sample size.

Utilization and preference criteria descibing water velocity suitabilities for juvenile steelhead trout may not accurately describe microhabitat requirements when focal point velocities, either taken as mean column velocities or as nose velocities, are measured during use data collection. Focal point water velocities fail to measure the presence of shear water velocity zones that are located adjacented to either side of the focal point. It is the presence of these shear zones that provide the target species with optimum feeding stations.

ACKNOWLEDGMENTS

Special appreciation is owed to the entire staff of the Lewiston Field Office of the Trinity River Flow Evaluation Study for their assistance, which made the completion of this study possible. They are fishery biologists Andrew Hamilton, Richard Macedo, Phillip North, William Somer, Randy Brown, and supervisor Mike Aceituno. Further thanks are also extended to biologist Melanie McFarland and laborer Richard Williams of the Sacramento Field Office for their help on various occasions throughout the study.

California Department of Fish and Game biologist Ed Miller provided valuable first hand knowledge of the Trinity River, which assisted in our preproject scoping. The staff at Trinity Hatchery were of help on several occasions and their cooperation and assistance is appreciated.

A very warm thanks goes to Fish and Wildlife Service biologist Jody Hoffman for all his efforts and support in getting this study authorized and underway.

Finally, I would like to express my gratitude to Gwyn Hampton who spent many hours entering field data into computer files.

CONTENTS

	Page
ABSTRACT	i
ACKNOWLEDGMENTS	ii
CONTENTS	iii
LIST OF FIGURES	iv
LIST OF TABLES	vii
INTRODUCTION	1
STUDY SITE	3
METHODS	4
Habitat Utilization	4
Habitat Availability	8
Data Analysis	9
RESULTS	13
DISCUSSION	32
REFERENCES	49
APPENDIX A	53
APPENDIX B	72
APPENDIX C	73
APPENDIX D	76
APPENDIX E	78

LIST OF FIGURES

Page

Figure 1. Map of Trinity River Flow Study Sites.....2

Figure 2. Observed frequencies for mean column velocities selected by spawning chinook salmon in the Trinity River, CA.....10

Figure 3. Percent of observations conducted on fry and juvenile chinook and coho salmon and steelhead trout that were found in surface turbulence, Trinity River.....13

Figure 4. Habitat preference criteria for total depths and mean column velocities selected by chinook salmon fry in the upper Trinity River, CA.....16

Figure 5. Habitat preference criteria for cover and substrates selected by chinook salmon fry in the upper Trinity River, CA.....17

Figure 6. Habitat preference criteria for total depths and mean column velocities selected by chinook salmon juveniles in the upper Trinity River, CA.....18

Figure 7. Habitat preference criteria for cover and substrates selected by chinook salmon juveniles in the upper Trinity River, CA.....19

Figure 8. Habitat preference criteria for total depths and mean column velocities selected by spawning chinook salmon in the upper Trinity River, CA.....20

Figure 9. Habitat preference criteria for cover and substrates selected by spawning chinook salmon in the upper Trinity River, CA.....21

Figure 10. Habitat preference criteria for total depths and mean column velocities selected by coho salmon fry in the upper Trinity River, CA.....22

Figure 11. Habitat preference criteria for cover and substrates selected by coho salmon fry in the upper Trinity River, CA.....23

Figure 12. Habitat preference criteria for total depths and mean column velocities selected by coho salmon juveniles in the upper Trinity River, CA.....24

Figure 13. Habitat preference criteria for cover and substrates selected by coho salmon juveniles in the upper Trinity River, CA.....25

Figure 14. Habitat preference criteria for total depths and mean column velocities selected by spawning coho salmon in the upper Trinity River, CA.....26

Figure 15. Habitat preference criteria for cover and substrates selected by spawning coho salmon in the upper Trinity River, CA.....27

Figure 16. Habitat preference criteria for total depths and mean column velocities selected by steelhead trout fry in the upper Trinity River, CA.....28

Figure 17. Habitat preference criteria for cover and substrates selected by steelhead trout juveniles in the upper Trinity River, CA.....29

Figure 18. Habitat preference criteria for total depths and mean column velocities selected by spawning steelhead trout in the upper Trinity River, CA.....30

Figure 19. Habitat preference criteria for cover and substrates selected by spawning steelhead trout in the upper Trinity River, CA.....31

Figure 20. Habitat use and preference criteria for total depth and mean column velocity for spawning chinook and coho salmon and steelhead trout in the upper Trinity River, CA.....33

Figure 21. Original preference criteria and modified preference criteria, developed from use data after 90% tolerance limits were applied, for mean column velocities selected by spawning anadromous salmonids in the upper Trinity River, CA.....34

Figure 22. Original and modified preference criteria for total depths selected by chinook salmon and steelhead trout juveniles in the upper Trinity River, CA.....36

Figure 23. A comparison of preference criteria developed in the upper Trinity River with category I criteria developed by Bovee (1978) and Raleigh et al. (1986) for spawning chinook salmon.....38

Figure 24. A comparison between preference criteria developed in the upper Trinity River with use criteria developed by other researchers for mean column velocities selected by spawning chinook salmon.....39

Figure 25. A comparison between use criteria of fish nose velocities selected by spawning chinook salmon in the upper Trinity River with spawning chinook salmon observed by other researchers.....39

Figure 26. Mean fork lengths of tagged adult chinook salmon that returned to Trinity River Hatchery in 1985, California Department of Fish and Game, Trinity Co., CA.....40

Figure 27. A comparison of preference criteria developed in the upper Trinity River with category I criteria developed by Bovee (1978) for spawning coho salmon.....41

Figure 28. A comparison of preference criteria developed in the upper Trinity River with suitability criteria developed by other researchers for chinook salmon fry.....43

Figure 29. A comparison of preference criteria developed in the upper Trinity River with category I criteria developed by Bovee (1978) and Raleigh et al. (1986) for chinook salmon juveniles.....44

Figure 30. A comparison of preference criteria developed in the upper Trinity River for coho salmon fry and juveniles with category I criteria developed by Bovee (1978) for coho salmon fry.....46

LIST OF TABLES

Page

Table 1. Cover code descriptions used to develop habitat suitability criteria for the Trinity River Flow Evaluation, Trinity Co., CA.....6

Table 2. Substrate classifications used for habitat utilization criteria development, Trinity River Flow Evaluation, Trinity Co., CA.....7

Table 3. Method of selecting available habitat measurements from an IFG-4 model output to obtain an estimate of habitat availability on the Trinity River, CA.....9

Table 4. Summary of habitat suitability data collected through direct observation in the Trinity River, CA.....13

INTRODUCTION

The Trinity River Basin drains approximately 2,965 square miles of Trinity and Humboldt counties in Northwestern California. As the largest tributary to the Klamath River, the Trinity has historically been recognized as a major producer of chinook salmon (Oncorhynchus tschawytscha), coho salmon (O. kisutch) and steelhead trout (Salmo gairdneri). Chinook and coho salmon produced within the Trinity River contribute substantially to the offshore commercial troll industry and to both the offshore and inriver sport fishery. The Hoopa Valley Indian Reservation borders the lower twelve miles of the Trinity River, where the Hupa Indians maintain a net fishery to fulfill their subsistence and ceremonial needs. The Trinity Basin also supports other important resource based industries, of which timber, mineral, and water resources hold vast economic importance to the region.

The Trinity River Division of California's Central Valley Project, operated by the U.S. Bureau of Reclamation, is the only major water development project in the Trinity Basin. The project's primary purpose is to divert water from the Trinity Basin to California's Central Valley. As a secondary benefit, hydroelectric power plants produce electricity at various locations throughout the water diversion system. Of the natural spawning area available to chinook salmon in the Trinity River above the North Fork Trinity River confluence approximately 50% was found above the sites of Trinity and Lewiston Dams (Moffet and Smith 1950). The California Department of Fish and Game estimated that 64% of the total habitat once available to steelhead trout had also been lost in the Trinity River as a result of dam construction in 1957 (Hubbel 1973). As partial mitigation for these upstream losses the Trinity River Fish Hatchery was constructed at the base of Lewiston Dam. In addition to hatchery operations, minimum downstream flow releases were provided to maintain fishery resources.

Coincident with the construction and operation of the Trinity River Division, logging accelerated within the Trinity Basin. High watershed erosion rates combined with reduced river flows below Lewiston Dam resulted in extensive sedimentation of fish habitat in the Trinity River below Lewiston. Reduced river flow also allowed riparian vegetation to encroach along the river banks forming a confined U shaped channel eliminating wide gravel bars, resulting in a loss of both valuable spawning and juvenile rearing habitat. Maintenance of minimum river flows and the operation of Trinity Fish Hatchery were not sufficient mitigation to sustain fishery populations. In some stocks, notably steelhead, escapement declines have exceeded 90% in some years.

In response to fishery declines and to aid in the rehabilitation of the anadromous fishery the U.S. Fish &

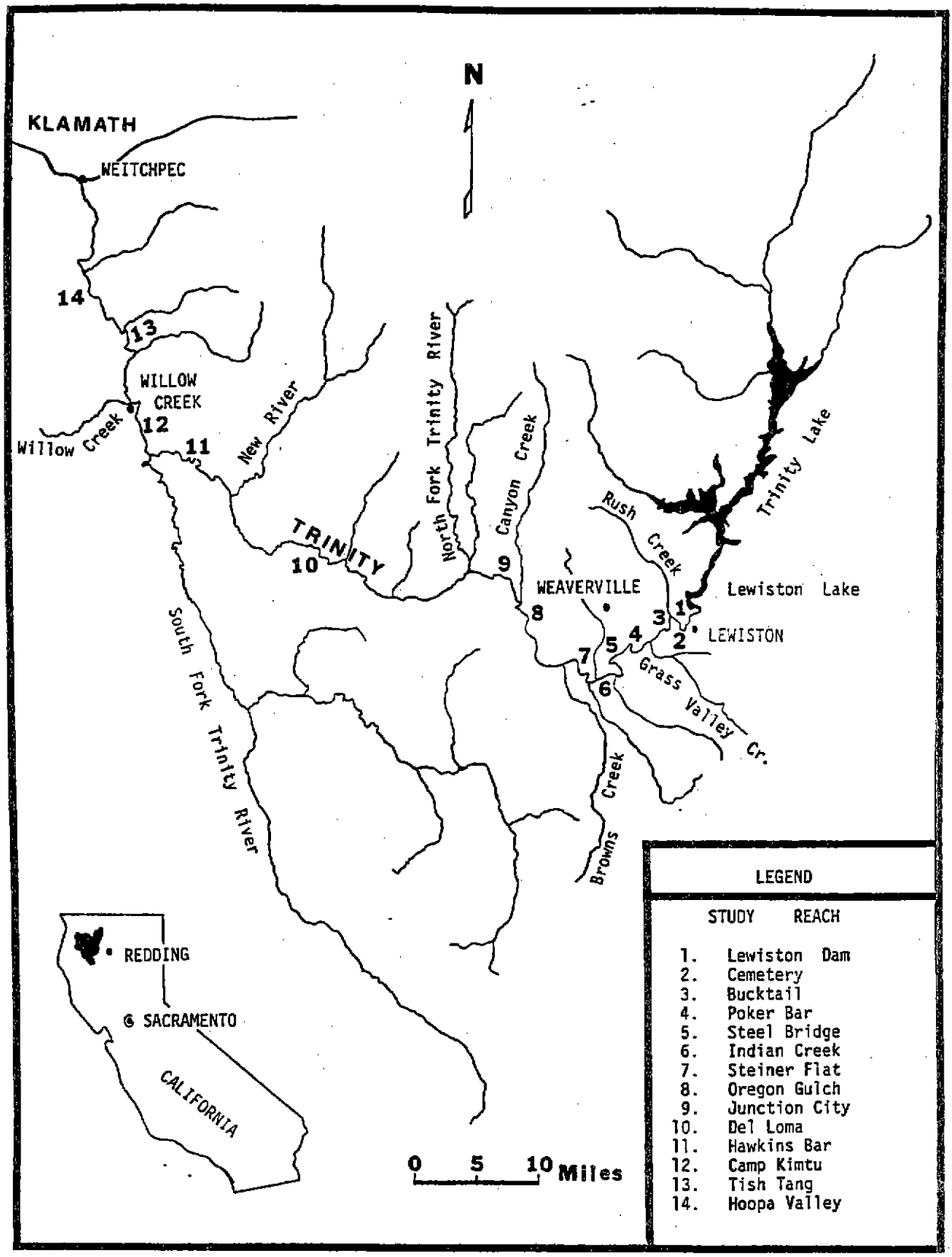


Figure 1. Trinity River Basin with habitat preference study site locations depicted.

Wildlife Service and the U.S. Bureau of Reclamation reached an agreement in December of 1980 to increase flow releases to the Trinity River below Lewiston Dam. The agreement was approved by the Secretary of the Interior in January of 1981. In addition to increasing flow releases for fishery purposes, the agreement provided for a 12-year study to monitor the fishery response to these increased flows. The resulting Trinity River Flow Evaluation was developed and a field office was established in Lewiston.

The study uses the Instream Flow Incremental Methodology (IFIM) created by the Instream Flow and Aquatic Systems Group of the U.S. Fish & Wildlife Service (Bovee 1982) to monitor habitat changes. A key element to the IFIM is the development of habitat suitability criteria describing either habitat use or preference for the target species of concern. Habitat suitability criteria may be separated into three categories dependent on the origin from which the criteria is developed. Category I criteria are based on professional judgment or on information gathered from extensive literature review. Category II criteria (utilization) are developed from observations on the target species taken in the field. These criteria may not represent actual microhabitat preference since they are dependant on the environmental conditions that were available to the target species at the time in which the observations were made. Category III criteria (preference) attempt to eliminate the habitat bias present in use criteria by adjusting them for available habitat. The resulting preference criteria tend to be much less site specific and theoretically may be transferred to other habitats outside the original area of study.

This report deals specifically with the development of use and preference criteria for fry, juvenile, and spawning lifestages of chinook and coho salmon and steelhead trout of the mainstem Trinity River.

STUDY SITE

Fourteen study sites were selected within three major study reaches between Lewiston Dam and Weitchpec (Figure 1). The upper reach, from Lewiston Dam downstream to the North Fork Trinity River confluence, is the most important reach for salmon and trout production. This section has been affected most by reduced river flows below Lewiston Dam. Riparian vegetation has encroached along both river banks throughout this reach steepening banks and reducing habitat area for salmonids. The substrate is composed of granitic sand, gravel, and cobble, with small areas of bedrock. Many tributary streams join the river in this reach, some of which provide important habitat for spawning and rearing steelhead trout. Nine study sites have been selected to represent this

section.

The middle reach of the river flows from the North Fork Trinity River confluence downstream to the South Fork Trinity River confluence at Salyer. Two study sites, one at Del Loma and one at Hawkins Bar, were selected to represent this reach. The riparian vegetation common in the upper reach disappears almost immediately below the North Fork Trinity River confluence. Seasonal variations in stream flow from the North Fork Trinity River influence the mainstem to a large enough degree to keep the riparian vegetation in check. This section generally follows a bedrock formed channel and contains several deep pools interspersed by long runs and short riffles or chutes. A steep white-water gorge is located between Cedar Flat and Gray Falls. The New River, a fairly large uncontrolled tributary, joins the Trinity in this section. The gorge area was not sampled during the study because of logistics and safety considerations.

The lower river reach extends from the South Fork Trinity River confluence downstream to the Klamath River at Weitchpec and is represented by three additional study sites. This lower reach is characterized by two major habitat types, valleys and canyons. At Willow Creek and Hoopa the river meanders through two valleys where large gravel and cobble bars are present. The remainder of the lower reach typically flows through steep sided canyons and is characterized by deep bedrock pools and glides alternating with short white-water riffles and chutes.

METHODS

Habitat use data was collected for all lifestages of chinook and coho salmon, and steelhead trout. Sampling methods included direct observation with mask and snorkel, from the bank, or from a raft during float trips.

Habitat Utilization

Direct observation made with a mask and snorkel required two persons, one person as the snorkel observer watching fish and one support person to record data, operate the flow meter, and control the raft. Sampling was conducted in a downstream direction at each study site. Sampling in an upstream direction proved to be impossible because of the size of the river and the presence of high water velocities. The observer would work in a zig-zag pattern across the river channel from bank to bank. At each bank sampling in an upstream direction for short distances was done where water velocities permitted. This sampling technique allowed nearly complete coverage of each study site. When fish were

spotted, the observer determined the species, lifestage, behavior, and focal point. The support person was then signaled to approach and the observation was completed. When fish were spotted where water was either to deep or swift to stand, the observer would float motionless past the target fish until downstream and out of sight. The observer would then carefully approach the fish from the rear or side and determine whether the fish had been startled. If the observer believed that the fish was not startled, an observation was then made with the assistance of the raft or rope.

When schools of juvenile salmon were encountered, the number of fish in the school was determined and the observation was made at the focal point of the school. When one school of fish was found to occupy more than one microhabitat, additional observations were made in order to accurately represent those microhabitats used.

Habitat measurements for spawning salmon and trout were taken 0.5 feet upstream of the redd in an attempt to simulate prespawning hydraulic and substrate conditions. Fish nose velocities were taken at 0.4 feet from the bottom for all spawning observations (Smith 1973). It was not considered a prerequisite that data only be taken on active redd sites. Data were taken on newly completed redds, unless there was doubt as to which species had constructed the redd in question, in that case, data were not collected. When more than one species was known to be spawning at the same time, data collection was limited to those active redd locations where positive species identification was possible.

Direct observation from a raft proved to be an effective method for data collection of spawning salmonids. The majority of redds were visible from above the water surface since most of the spawning was done in water less than three feet deep. Snorkel observations were still conducted on a periodic basis to verify spawning use in areas that were not easily seen from the raft, such as in deep or turbulent water.

Fourteen parameters were recorded for each microhabitat use observation. The species and lifestage were determined. Fish less than or equal to 50 mm in forklength were considered fry. Fish greater than 50 mm and less than or equal to 200 mm were considered juveniles, and fish greater than 200 mm were considered adults. An estimate of forklength was obtained with the aid of an underwater slate which had a centimeter scale marked on it. Fish behavior was categorized as either holding, roving, feeding or spawning. The total depth and depth of fish were both measured as the distance above the bottom in feet. The depth of fish was measured as the distance from the bottom to the focal point of an individual fish or school of fish. Two water velocities were taken at each observation, a mean column

water velocity and a fish nose water velocity. Mean column water velocity was measured at 0.6 tenths from the water surface for water less than 2.5 feet deep; and the average of the velocities measured at 0.2 and 0.8 tenths from the surface for water greater than or equal to 2.5 feet deep. Water velocities were measured with either a Marsh-McBirney model 201 flow meter or a Price "AA" current meter. Depths were measured with a top setting wading rod.

Seven separate cover types were selected to describe cover use (Table 1). A three digit code descriptor was used to describe the cover types present as well as provide a cover quality estimate. The first digit in the code describes the dominant cover type present while the second digit describes the subdominant type, if present. The third code value, which follows a decimal, describes the quality of the cover types present as either poor, moderate, good, or excellent.

Table 1: Cover code descriptions used to develop habitat suitability criteria for the Trinity River Flow Evaluation, Trinity Co., California, 1985-1987.

Code	Cover Type	Description
0	No cover	gravel less than 75mm or any larger material which is embedded to the extent that no cover is available.
1	Cobble	75 - 300mm in size and clear of fines.
2	Boulders	300mm and larger.
3	Small woody debris	brush and limbs less than 9 inches in diameter.
4	Large woody debris	logs and rootwads greater than 9 inches in diameter.
5	Undercut bank	undercut at least 0.5 feet.
6	Overhanging vegetation	within 1.5 feet of the water surface
7	Aquatic vegetation	

recorded as DS.Q where D = Dominant cover type
S = Subdominant cover type
Q = Quality of cover

The substrate compositions present beneath observed fish were described using the Brusven index (Brusven 1977). The Brusven index is composed of a three digit descriptor of dominant substrate, subdominant substrate and percent embedded in fines (DS.%E). The substrate size categories selected for this study are listed in Table 2.

Table 2. Substrate classifications used for habitat utilization criteria development, Trinity River Flow Evaluation, Trinity Co., California, 1985-1987.

Code	Substrate type	Size Range (mm)
0	Fines	< 4mm
1	Small Gravel	4 - 25mm
2	Medium Gravel	25 - 50mm
3	Large Gravel	50 - 75mm
4	Small Cobble	75 -150mm
5	Medium Cobble	150 -225mm
6	Large Cobble	225 -300mm
7	Small Boulder	300 -600mm
8	Large Boulder	> 600mm
9	Bedrock	

Recorded as DS.E, Where D = Dominant particle size
S = Subdominant particle size
E = Percent embedded in fines

Stream characteristics present at each observation were categorized into nine habitat types: pool, run, riffle, side channel, beaver pond, backwater, waters edge, pocket, and bar. Surface turbulence was noted as either present or absent for each observation. The percentage of sky blocked by riparian canopy was estimated for each observation. Additional data recorded for each sampling day included water visibility (estimated in feet), stream discharge, study site, water temperature, weather conditions, observers present, and the date and time of sampling.

Habitat Availability

Available habitat information was obtained through the IFG-4 program component of the IFIM (Milhous et al. 1984). For each discharge and study site sampled the IFG-4 program of the IFIM was run. The results of each run were then used to estimate habitat availability for total water depth, mean water column velocity, cover, and substrate. The total area represented by each transect within the study site was calculated by multiplying the transect weighting factors, both upstream and downstream, by the distance between transects to obtain a total length. The length was then multiplied by the transect width to obtain the area represented by each transect. This transect area was then divided by the total study site area, yielding the proportion of habitat represented by each transect within the study site. Since the transect cells which make up each transect are not always of equal surface area, habitat availability data could not be obtained directly from each cell without some bias. Rather than calculating another proportional value for each cell within the transect, as was done for each transect within the study site, random samples were taken. For each discharge sampled, the wetted width of each transect was normalized to values between 0 and 100. A random number generator was then used to pick points along the wetted width of each transect. The transect cell located at each randomly selected point was then used to obtain the necessary habitat information. The number of random distances to select for each transect was determined by multiplying the proportional area represented by that transect by 250. This procedure provided 250 habitat availability measurements per study site at each discharge sampled (Table 3).

Use of habitat availability estimates generated from IFG-4 program output allowed greater effort to be focused on habitat use data collection in the last year of the study. Effort also shifted to the upper Trinity River, above the North Fork Trinity River confluence, because accurate discharge estimates were not obtained during lower river sampling in the previous year. Without these discharge estimates modeling of lower river habitat availability was impossible. Fortunately this did not affect any significant sampling effort for 1985 since lower river habitats were rarely sampled because of unfavorable conditions such as high water and low water visibility. Use observations that were collected in the lower Trinity River were not included in preference criteria development.

Aceituno and Hampton (1987) compared habitat availability generated from standard random sampling methods with habitat availability generated from the IFG-4 program. They found that for most study sites the two differing methodologies provided similar estimates of habitat availability.

TABLE 3. Method of selecting available habitat measurements from an IFG-4 model output to obtain an estimate of habitat availability on the Trinity River, CA. 1987

XSEC	WEIGHT FAC. UP	DOWN	LEN.	CELL WEIGHTED LENGTH UP	DOWN	TOTAL	XSEC WIDTH	XSEC AREA	% AREA	* 250
1	0.0	0.5	440	0	220	220	91	20020	0.0850	21
2	0.5	0.5	220	220	110	330	77	25410	0.1079	27
3	0.5	0.5	524	110	262	372	87	32364	0.1375	34
4	0.5	0.5	135	262	67.5	329.5	112	36904	0.1568	39
5	0.5	0.5	164	67.5	82	149.5	63	9418	0.0400	10
6	0.5	0.5	194	82	97	179	97	17363	0.0737	18
7	0.5	0.5	349	97	174.5	271.5	85	23077	0.0980	25
8	0.5	0.3	110	174.5	33	207.5	101	20957	0.0890	22
9	0.7	0.5	151	77	75.5	152.5	93	14182	0.0602	15
10	0.5	0.5	375	75.5	187.5	263	82	21566	0.0916	23
11	0.5	0	0	187.5	0	187.5	75	14062	0.0597	15

Data Analysis

Initial data frequencies of habitat use by each species and lifestage were constructed following the guidelines presented by Bovee and Cochnauer (1977). Frequency distributions derived from continuous data seldom result in smooth curves (Figure 2). One method of alleviating inconsistencies is to increase the interval width. To what extent the intervals should be increased, however, is often unclear. Larger intervals result in smoother histograms, but as a result some accuracy may be lost from the original distribution (Bovee 1986). For construction of depth and velocity utilization curves the interval size used for each frequency distribution was calculated using Sturges Rule as cited by Cheslak and Garcia (1987). Sturges Rule provides an estimate of optimum interval size based on data provided as follows:

$$I = \frac{R}{1 + 3.908 \times \text{Log } N}$$

where: I = Optimum interval size

R = Range of observed values

N = Number of observations taken

For example, if data for total depth were collected at an accuracy level of tenths of feet and 100 fish were observed using depths ranging from 0.5 to 2.5 feet, then R would equal 2.0 feet and N would equal 100. The equation would then yield 0.2 feet as the optimum interval or bin width.

Cheslak (pers. comm.) has since informed me that the minor modifications that were presented in a symposium by him to the Sturges formula may violate the theoritical assumptions of the equation. Therefore, future use of the Sturges equation to determine interval sizes should utilize 3.322 in the denominator rather than 3.908 as is presented here. Time constraints did not allow me to verify whether this change would have appreciable effects on the results that are presented here. However, I do not feel that any noticeable changes in the use of the actual Sturges equation would be evident in the final preference criteria because of the application of the running mean curve smoothing techniques explained as follows.

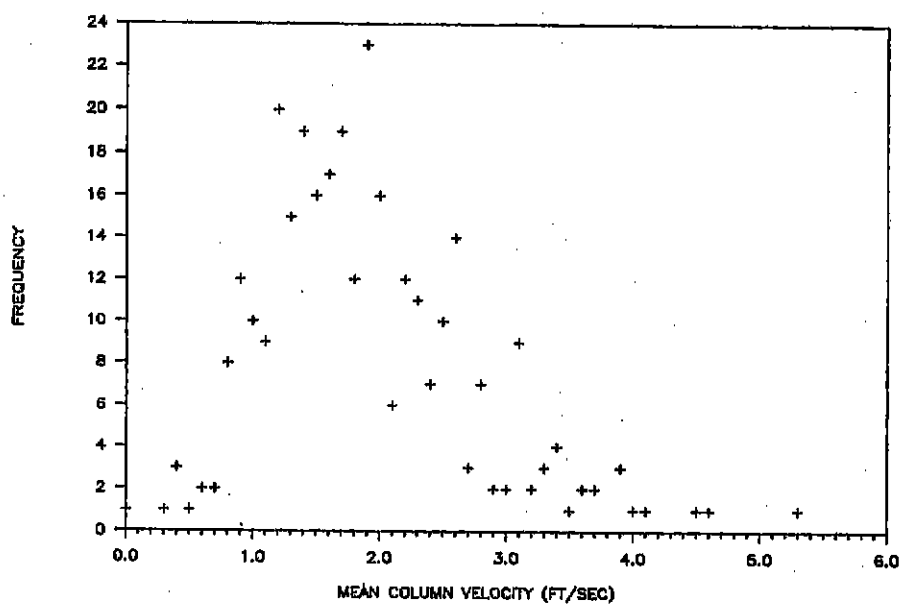


Figure 2. Observed frequency distribution of mean column velocities selected by spawning chinook salmon in the Trinity River, California, 1985-1987.

Once the interval widths were determined, a frequency bar histogram was constructed. The midpoints of each interval were then connected by a straight line. The resulting curve was then subjected to two series of three point running mean filters in order to reduce any noise in the form of large

deviations between adjacent intervals if necessary. The interval containing the largest number of observations was assigned a value of one and each of the remaining intervals were given a value proportional to its relative occurrence.

For cover, a simple frequency bar histogram was constructed. The variate with the greatest number of observations was assigned a value of one and each remaining variate was assigned a value proportional to its relative occurrence.

Habitat use criteria for substrate were developed using two different techniques. Dominant substrate, subdominant substrate, and percent embedded in fines were analyzed separately for each species and lifestage. Frequency histograms were constructed for each component of substrate, with the greatest number of observations in an interval receiving a value of one with each remaining interval assigned a value proportional to its relative occurrence. All three of the resulting curves, dominant substrate, subdominant substrate, and percent embedded in fines, were plotted for each species and lifestage for easy comparison. For spawning lifestages of each species substrate was also analyzed using the Brusven index in its entirety. Again, the substrate category or interval with the greatest number of observations were assigned a value of one, and the remaining intervals were assigned a value proportional to their relative occurrence. Because the Brusven index is composed of three digit descripter there were a large number of different substrate compositions possible. As a result, since the distribution is discrete, there were a large number of intervals to work with when the frequency distribution was tabulated. With such a large number of possible combinations there were many incomplete sections in the resulting distribution, unless the data base was very large or the target species used a narrow or well defined range of substrate types. In this study only those substrates used by spawning salmon and trout were defined well enough to develop criteria with the Brusven index. A much larger data base would be necessary before the Brusven index could effectively be used to describe substrate utilization by fry and juvenile lifestages.

Analysis of available habitat data was conducted using the same methods described for analyzing habitat use data.

Preference criteria were computed with the following function:

$$P_i = \frac{U_i}{A_i}$$

where: P_i = an unnormalized index of preference at x_i

U_i = the relative frequency of fish observations at x_i

A_i = the relative frequency of available habitat at x_i

X_i = the interval of the variable (x)

Curve smoothing techniques were applied to those criteria which still exhibited large deviations between adjacent intervals that were thought not to represent actual behavior preferences. Resulting preference criteria were then normalized to values between 0.0 and 1.0.

RESULTS

A summary of data collection achieved by direct observation in the Trinity River is presented in Table 4. Use criteria for fry, juvenile, and spawning lifestages of chinook and coho salmon and steelhead trout are illustrated in Appendix A. A comparison between spawning use curves for mean water column velocity and fish nose velocity for chinook and coho salmon and steelhead trout is presented in Appendix B. Use of the Brusven index to describe substrate utilization for spawning salmon and steelhead trout produced criteria with some discrepancies. In an effort to reduce these inconsistencies I used a combination of professional judgment and running averages for each distribution. Appendix C contains both the untouched and adjusted substrate utilization criteria for spawning chinook and coho salmon and steelhead trout as described with the Brusven index.

Results of available habitat estimates for total depth, mean water column velocity, cover, and substrate for all study sites and sampled discharges is presented in Appendix D.

Table 4. Summary of habitat suitability data collected through direct observation in the Trinity River, California, 1985-1987.

Species	Life Stage	Number of Focal Point Observations	Number of Fish Observed
Chinook	Fry	389	5988
	Juvenile	345	6352
	Spawning	311	378
Coho	Fry	130	913
	Juvenile	81	813
	Spawning	107	206
Steelhead	Fry	33	117
	Juvenile	325	832
	Spawning	88	72

Figure 3 displays the percentage of observations which were made in surface turbulent water for fry and juvenile lifestages of chinook and coho salmon and steelhead trout. Juvenile chinook salmon exhibited an increased use of turbulent water as they grew. Coho salmon juveniles showed no significant shift in turbulent water use. This tended to reinforce the finding of coho salmon juveniles to use slow water habitats where no surface turbulence is found, such as backwaters and slow edge habitat types. The strongest shift

in use of turbulent water was displayed by steelhead trout. Almost 16 % of the observations conducted on steelhead trout fry were found in turbulent water habitats, while 37.2 % of the observations on steelhead juveniles were conducted in turbulent water.

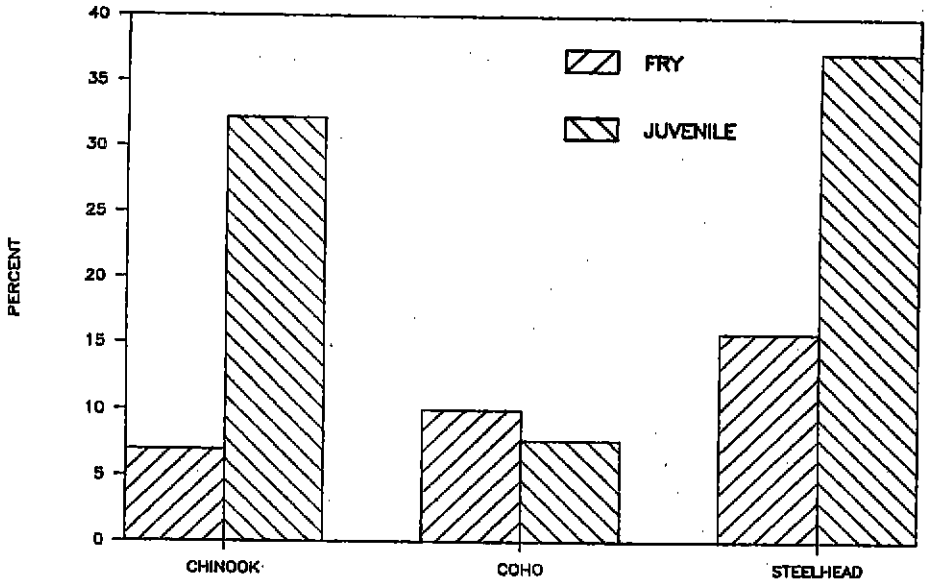
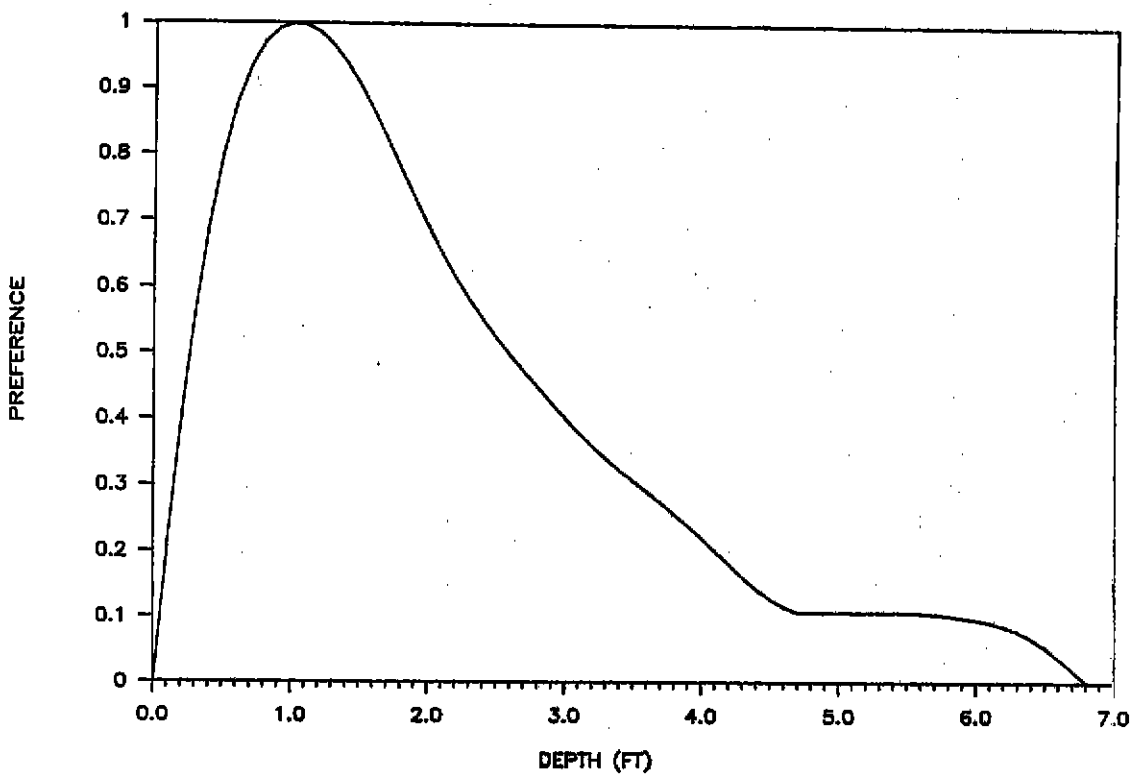


Figure 3. Percent of observations conducted on fry and juvenile chinook and coho salmon and steelhead trout that that were found in surface turbulence, Trinity River, California, 1985-1987.

During the fall months, when water temperatures fell below 48 - 50 degrees Fahrenheit, we found juvenile salmon and trout began to seek shelter by either burrowing under cobble substrates or concealing themselves in areas of thick cover, such as aquatic vegetation or woody debris. Direct observation of juvenile salmonids during these periods was largely unsuccessful. We soon discovered that the juvenile fish we were trying to observe could move through the interstitial substrate cavities at a much faster rate than we could dig through the substrate with our hands. Determination of focal point locations and species identification thus became virtually impossible to obtain under these conditions. As an alternate sampling method, a back pack electrofisher was used and worked well for locating juvenile salmonids in these over-wintering microhabitats. Use of an electrofisher as a microhabitat sampling tool does have some disadvantages. With a back pack electrofisher sampling is limited to habitats that are waist deep or less. There is also the possibility of herding fish away from their prefered holding locations thus biasing any results, however, when sampling during the winter months unwanted fish movement

is limited because their focal points are located beneath cobble substrates were lateral movement is difficult. Substrates composed of cobbles and thick woody debris appeared to be one of the most important habitat variables present in our winter sampling of juvenile salmonids.

Preference criteria for fry, juvenile, and spawning chinook salmon is presented in Figures 4 through 9. Preference criteria for fry, juvenile, and spawning coho salmon is presented in Figures 10 through 15. Preference criteria were not developed for fry steelhead trout because the limited number of observations obtained were not felt adequate to describe the preference function with confidence. Preference criteria for juvenile and spawning steelhead trout is presented in Figures 16 through 19. An attempt was made to develop habitat preference criteria using the Brusven Index to describe preferred spawning substrates for chinook and coho salmon and steelhead trout, however, the resulting preference functions were incomplete, and did not present adequate results.



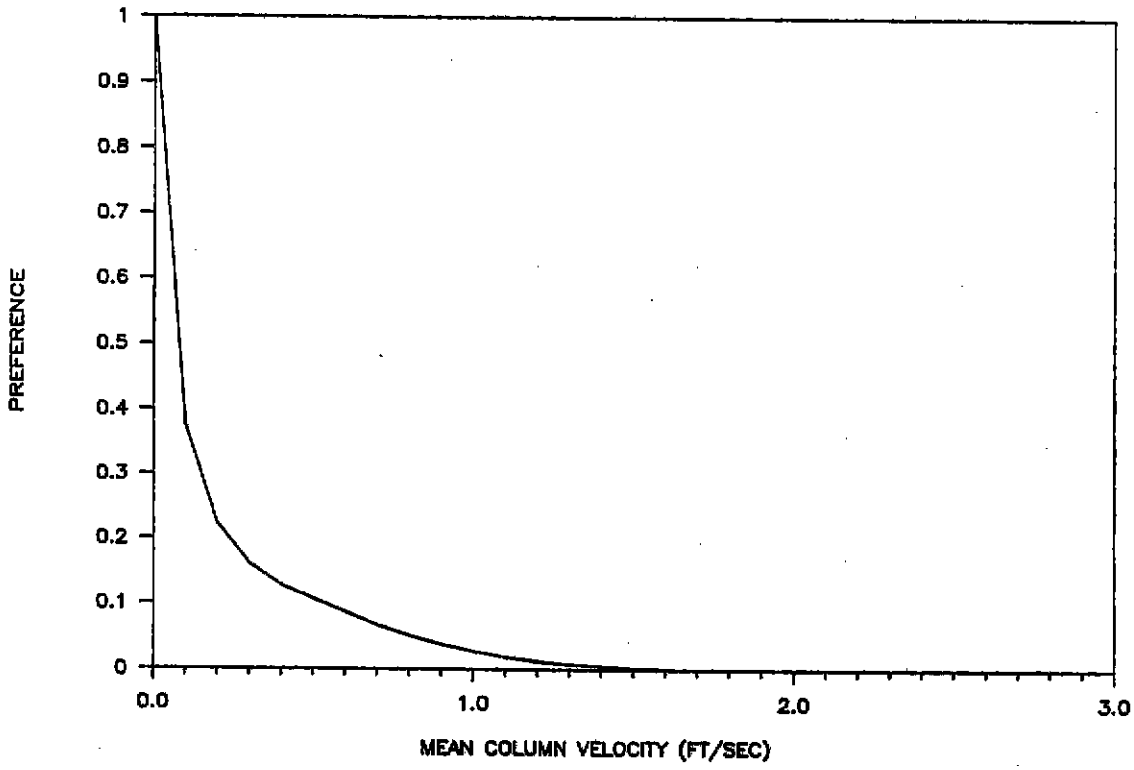


Figure 4. Habitat preference criteria for total depths and mean column velocities selected by chinook salmon fry in the upper Trinity River, CA., 1985-1987.

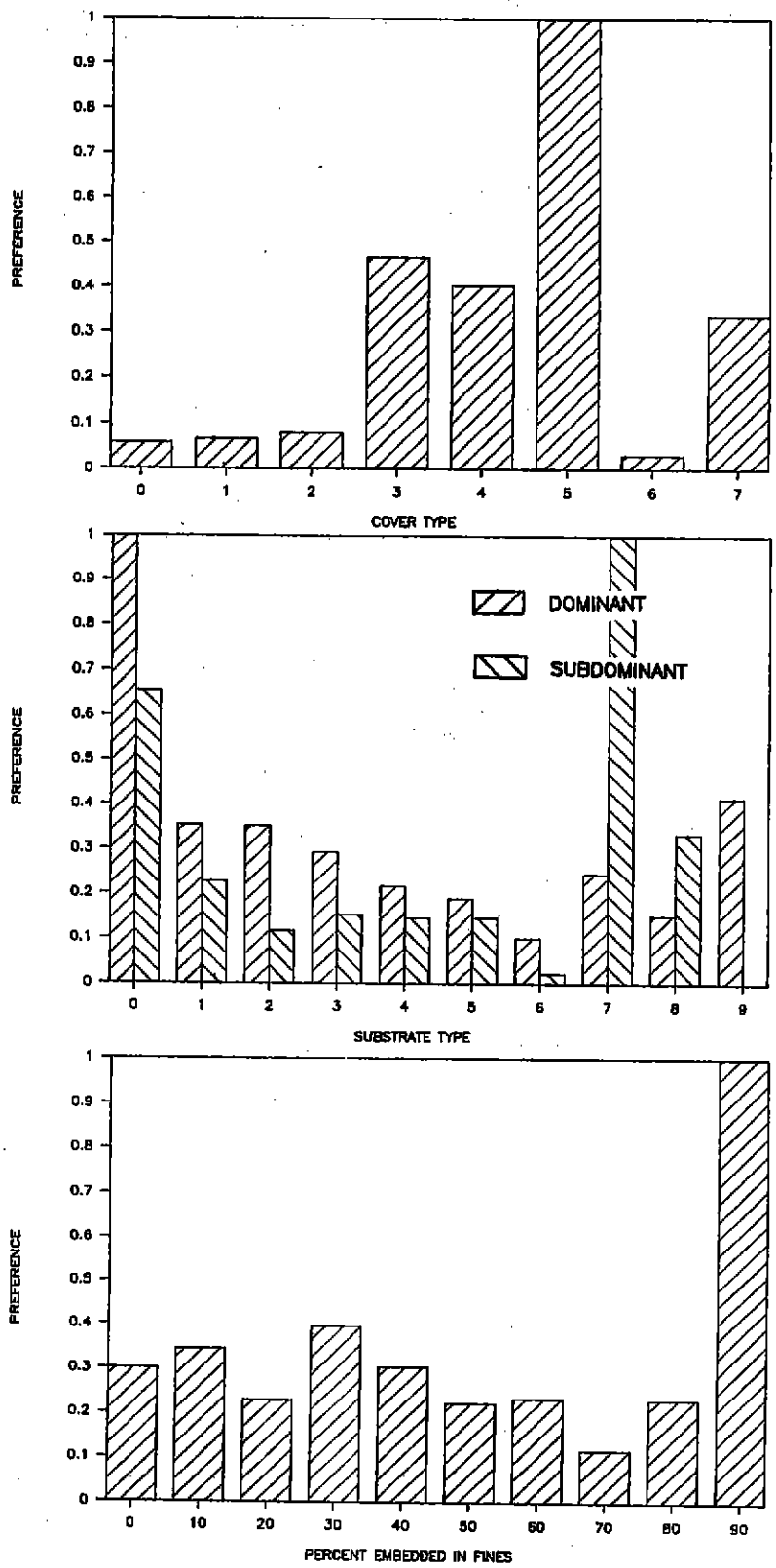


Figure 5. Habitat preference criteria for cover and substrates selected by chinook salmon fry in the upper Trinity River, CA., 1985-1987.

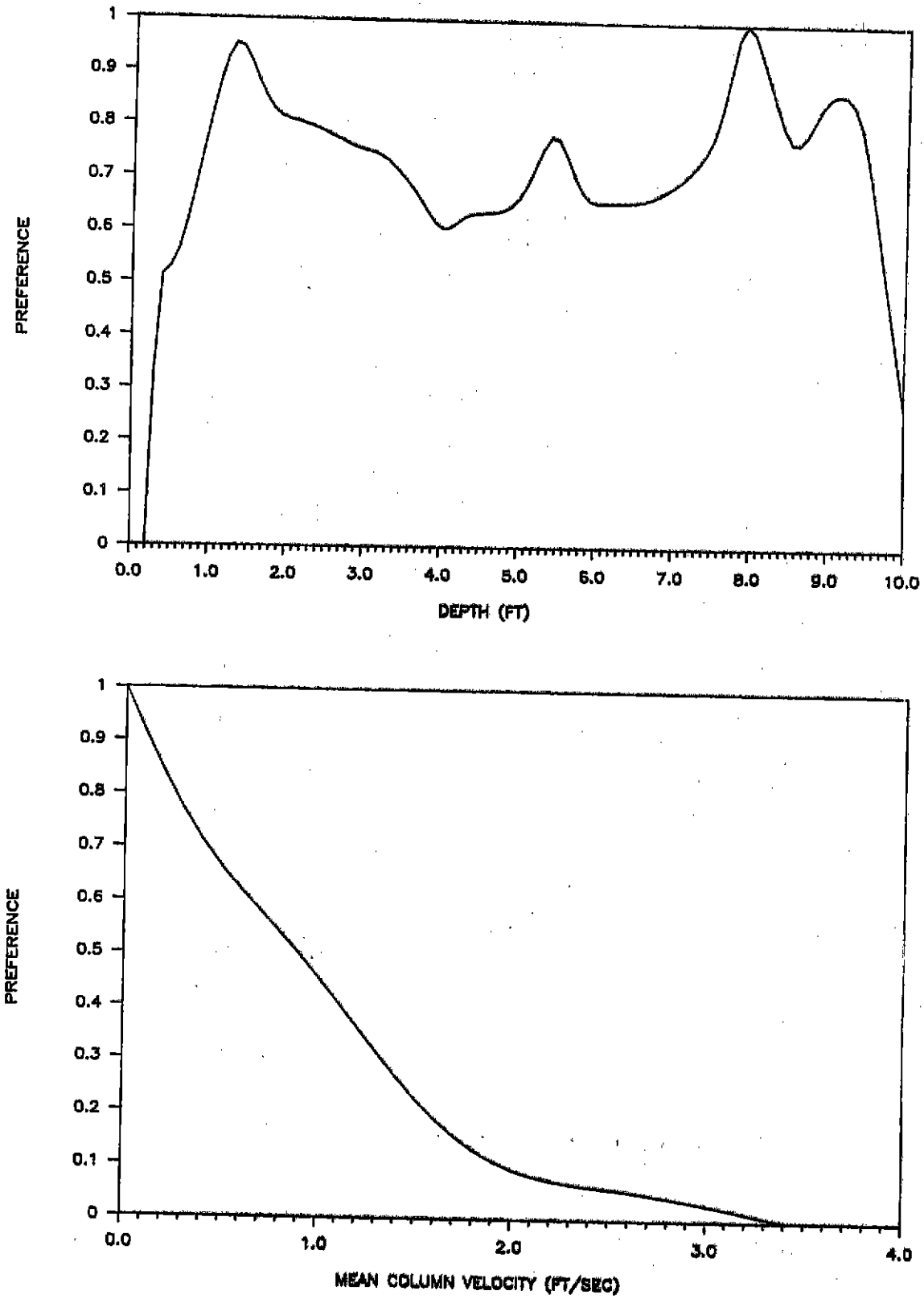


Figure 6. Habitat preference criteria for total depths and mean column velocites selected by chinook salmon juveniles in the upper Trinity River, CA., 1985-1987.

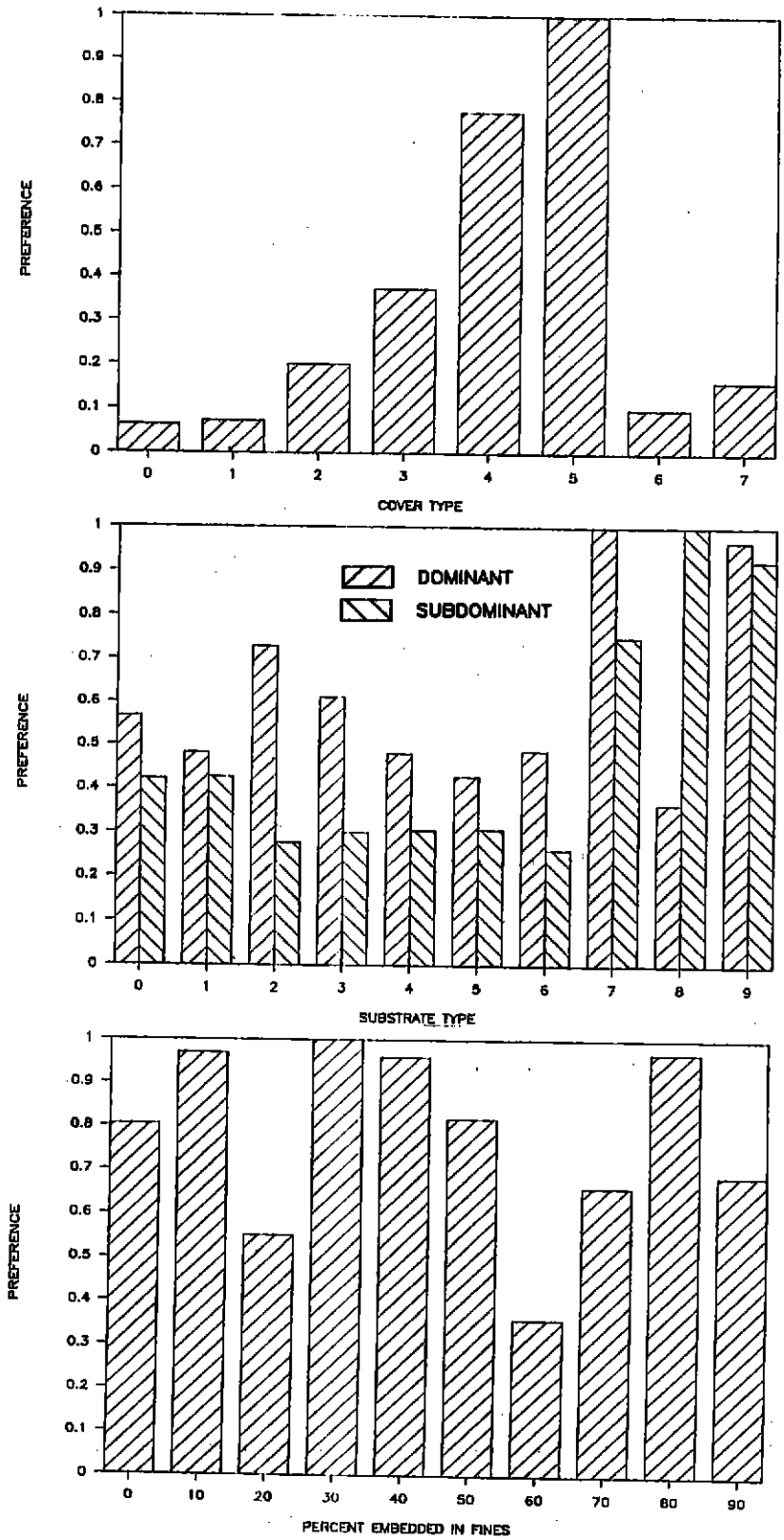
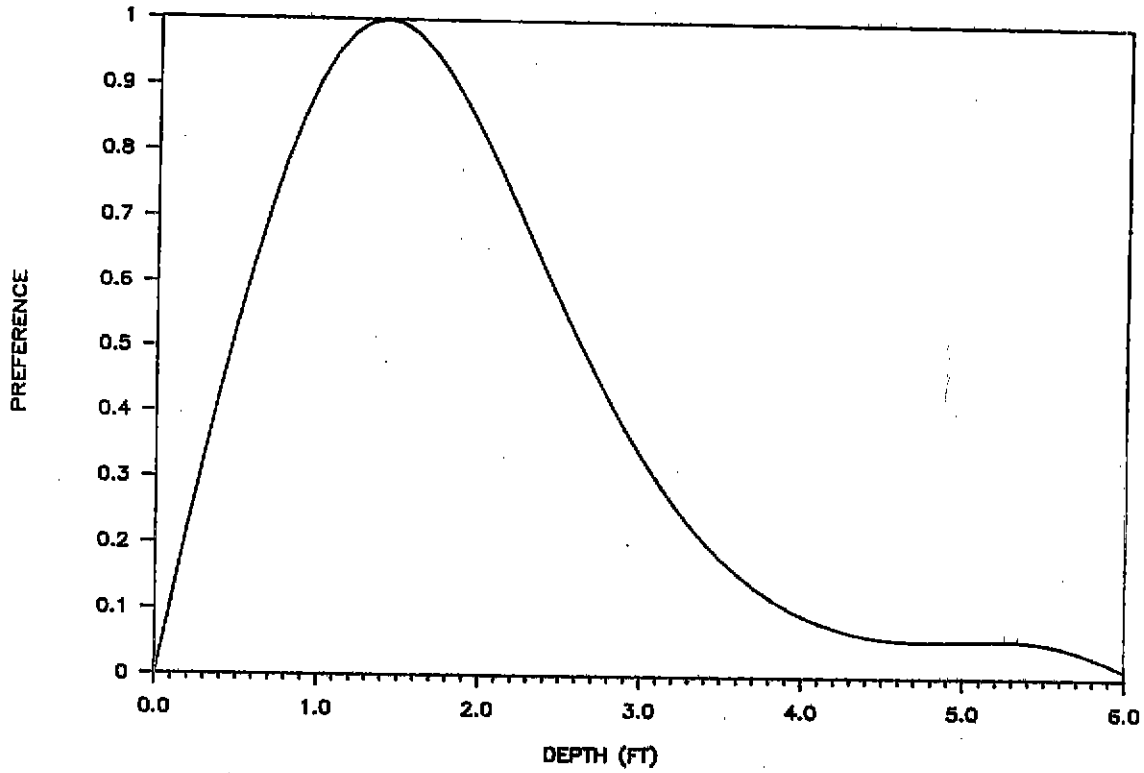


Figure 7. Habitat preference criteria for cover and substrates selected by chinook salmon juveniles in the upper Trinity River, CA., 1985-1987.



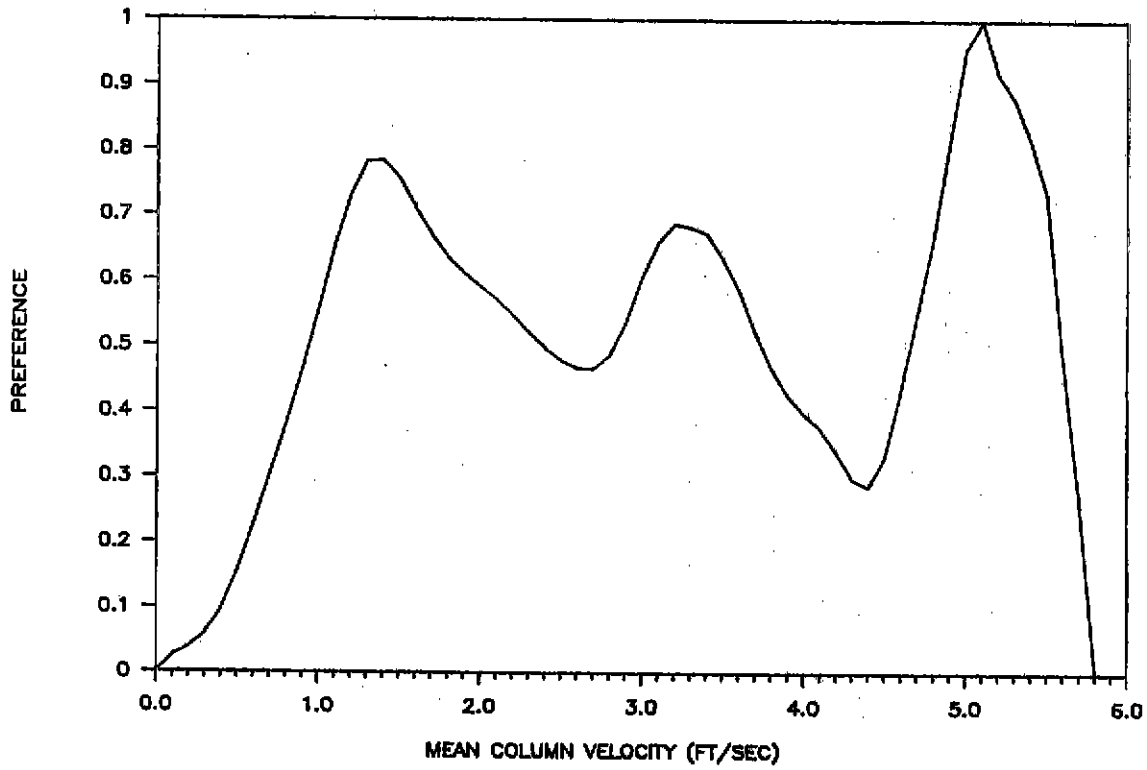


Figure 8. Habitat preference criteria for total depths and mean column velocities selected by spawning chinook salmon in the upper Trinity River, CA., 1985-1987.

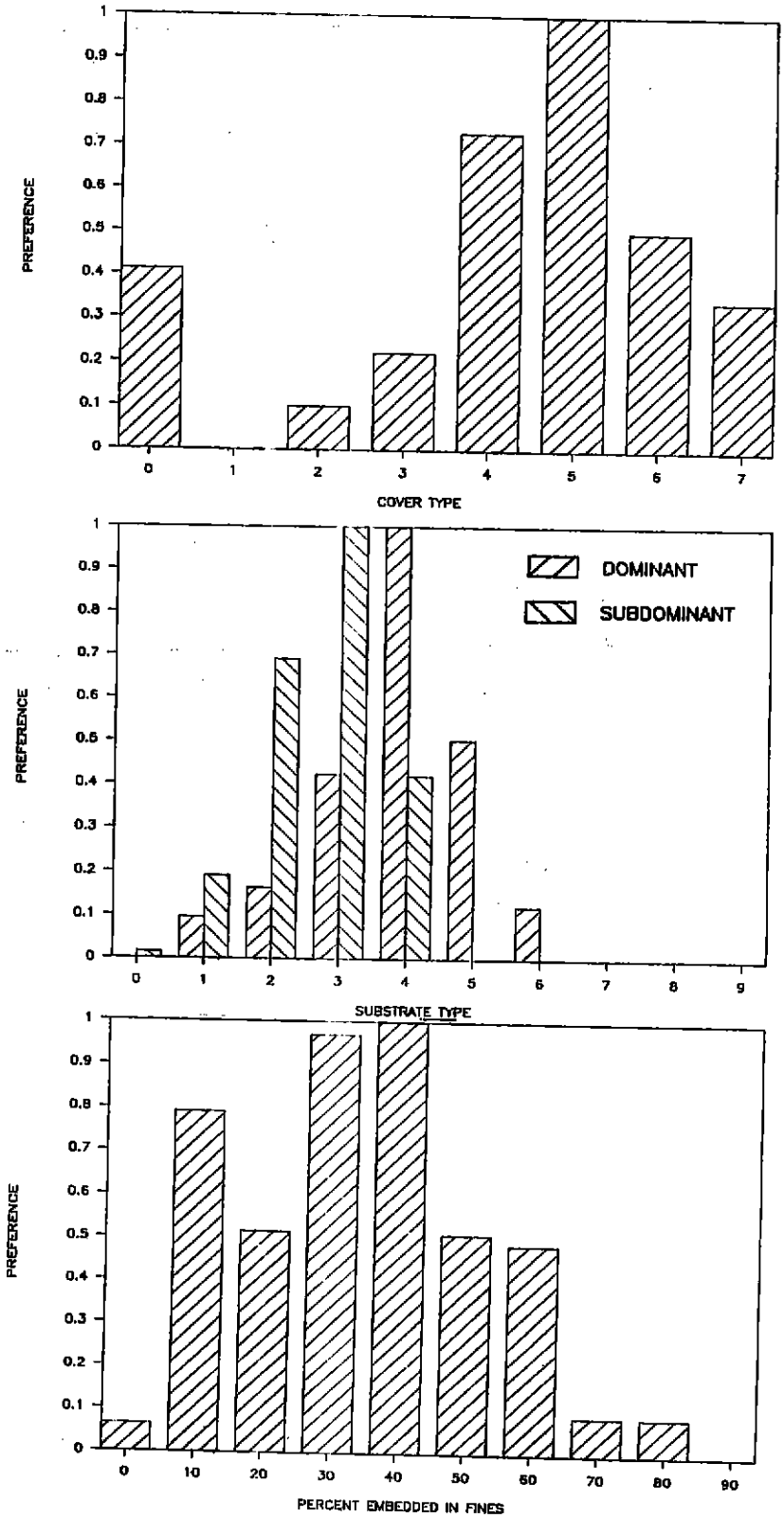
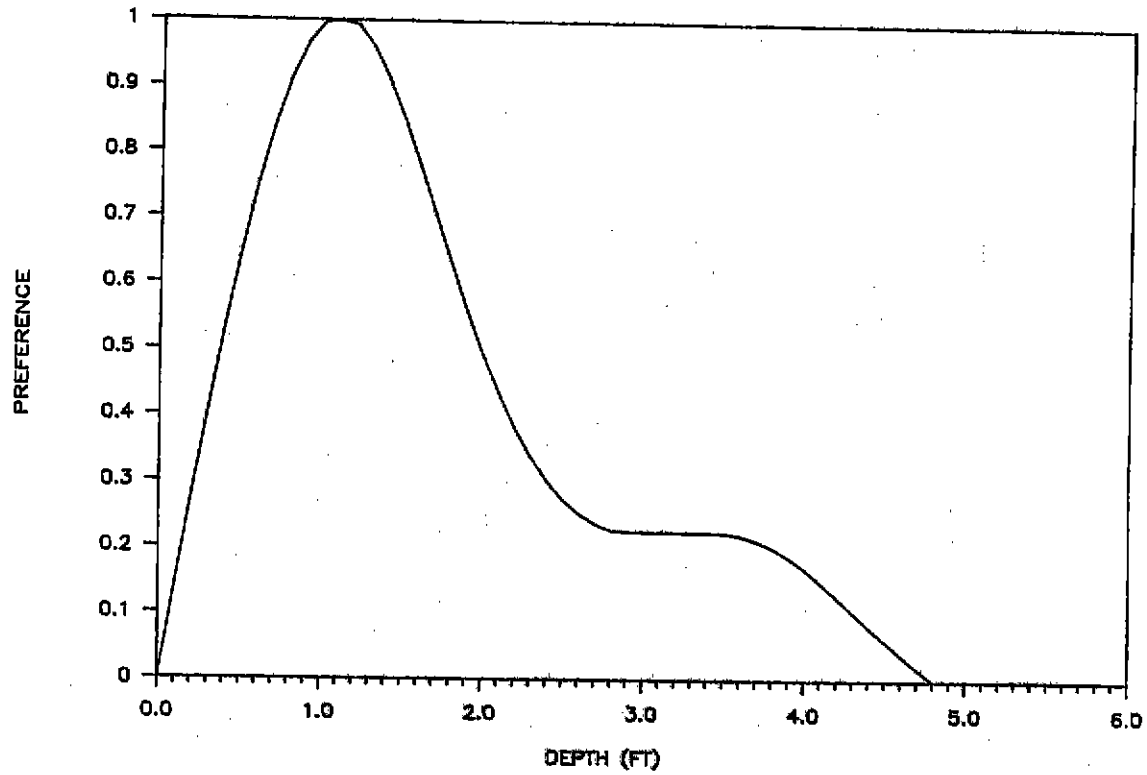


Figure 9. Habitat preference criteria for cover and substrates selected by spawning chinook salmon in the upper Trinity River, CA., 1985-1987.



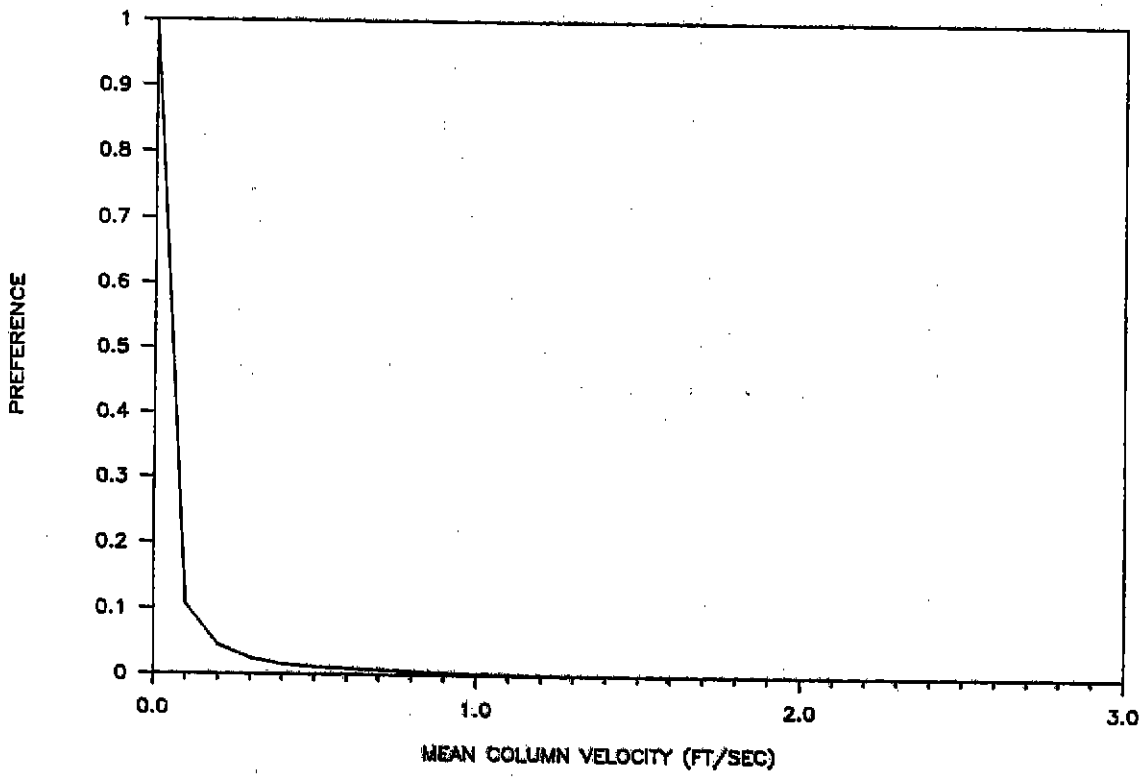


Figure 10. Habitat preference criteria for total depth and mean column velocities selected by coho salmon fry in the upper Trinity River, CA., 1985-1987.

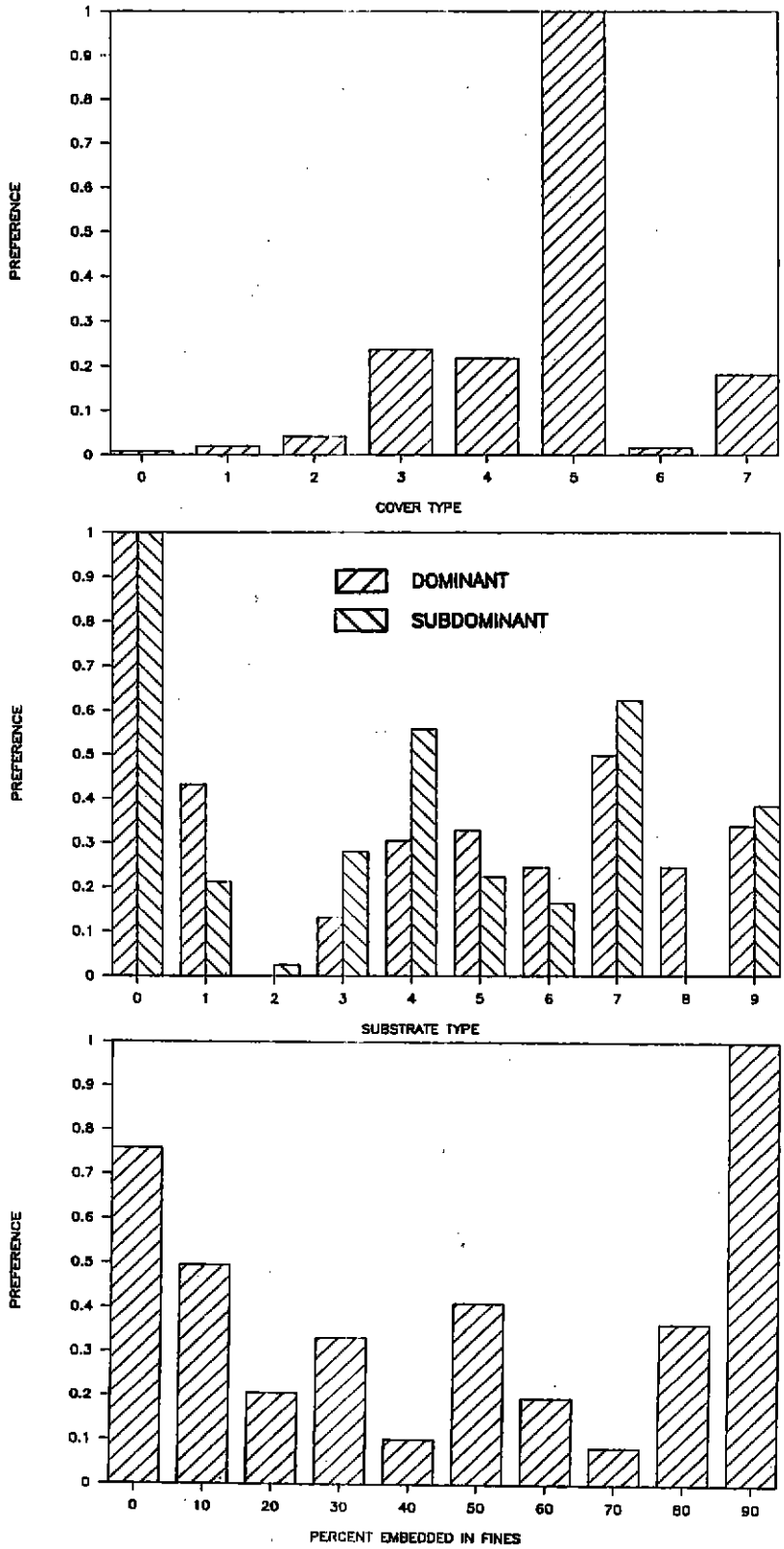


Figure 11. Habtat preference criteria for cover and substrates selected by coho salmon fry in the upper Trinity River, CA., 1985-1987.

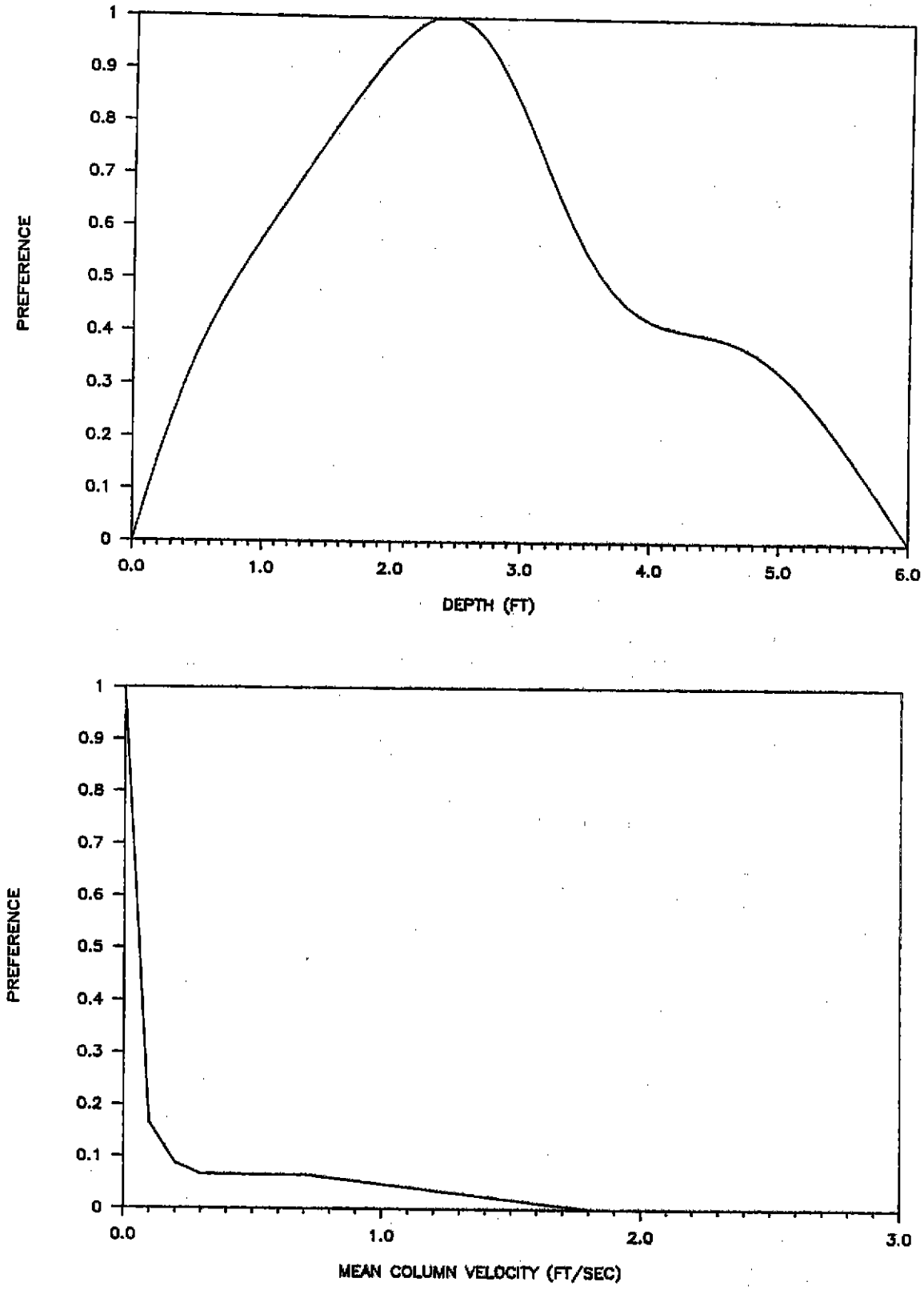


Figure 12. Habitat preference criteria for total depths and mean column velocities selected by coho salmon juveniles in the upper Trinity River, CA., 1985-1987.

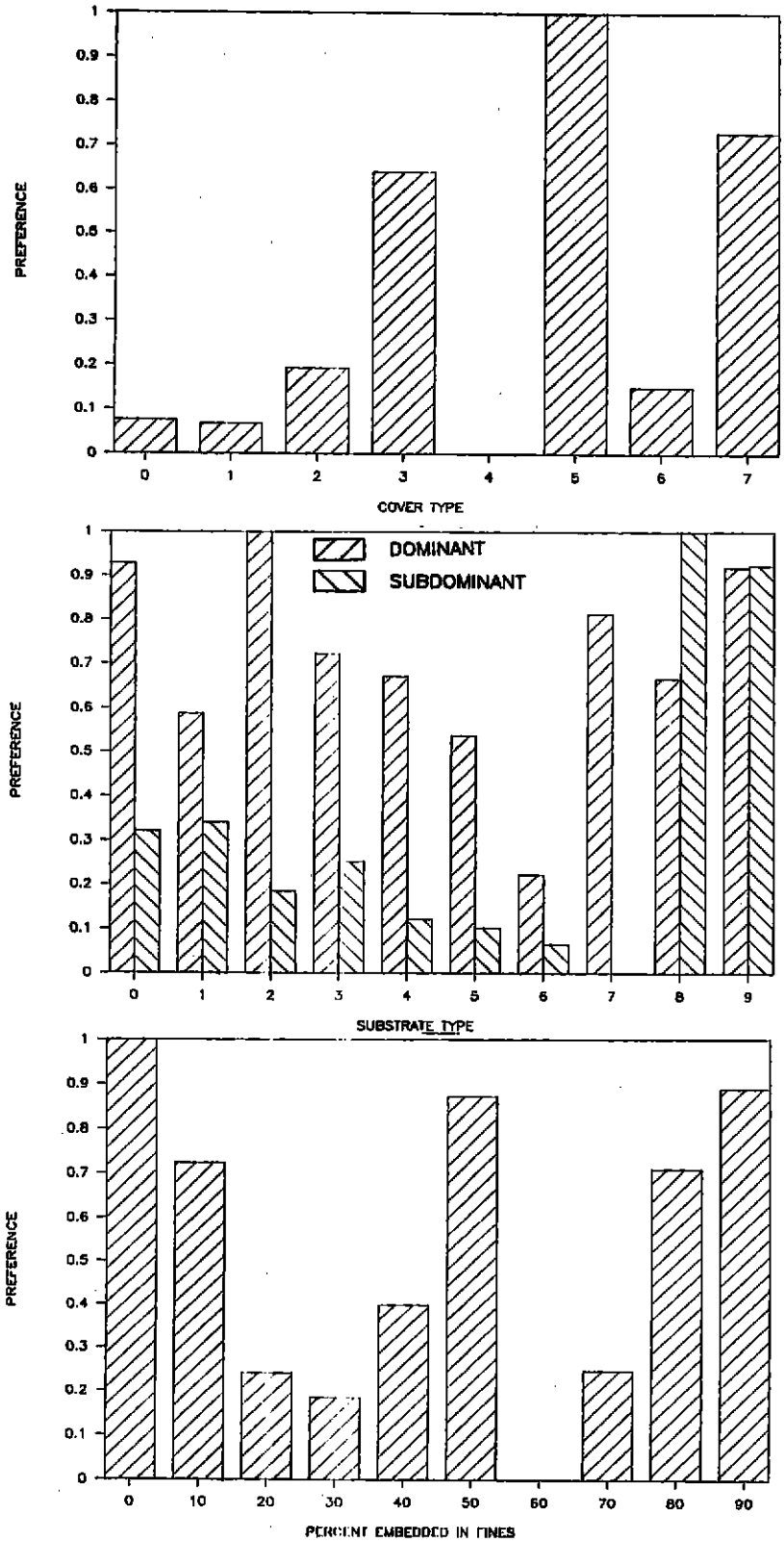
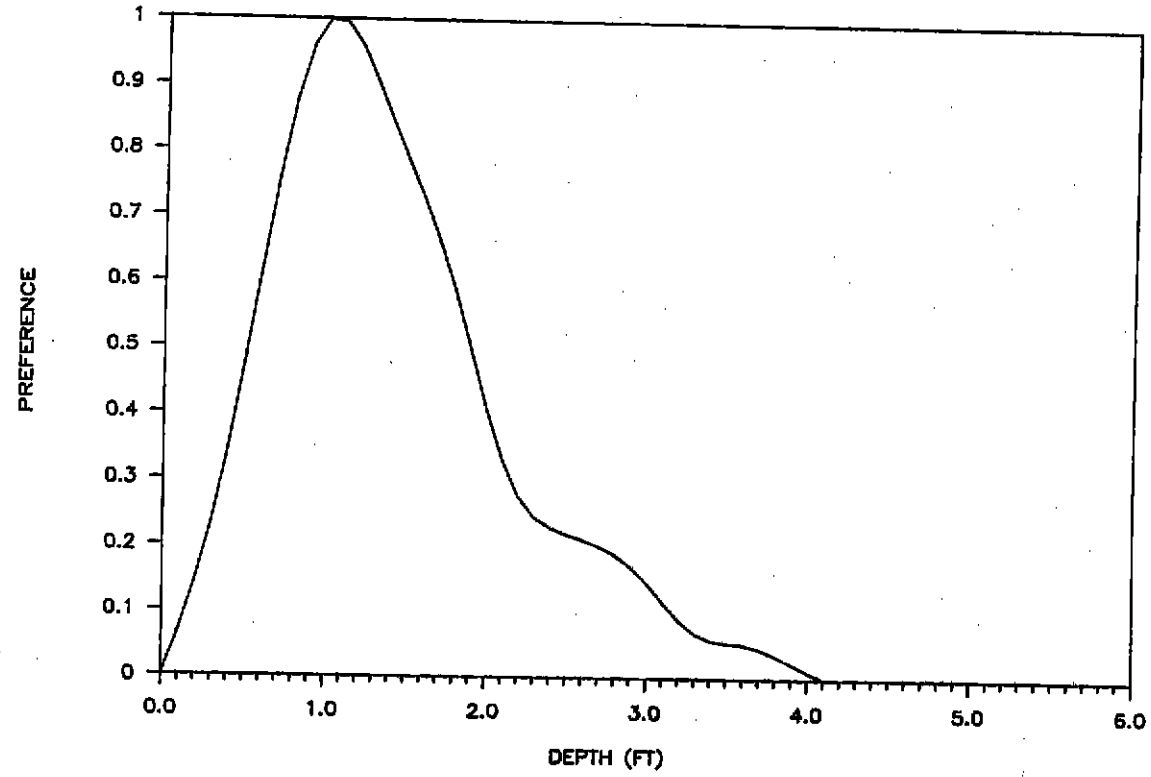


Figure 13. Habitat preference criteria for cover and substrates selected by coho salmon juveniles in the upper Trinity River, CA., 1985-1987.



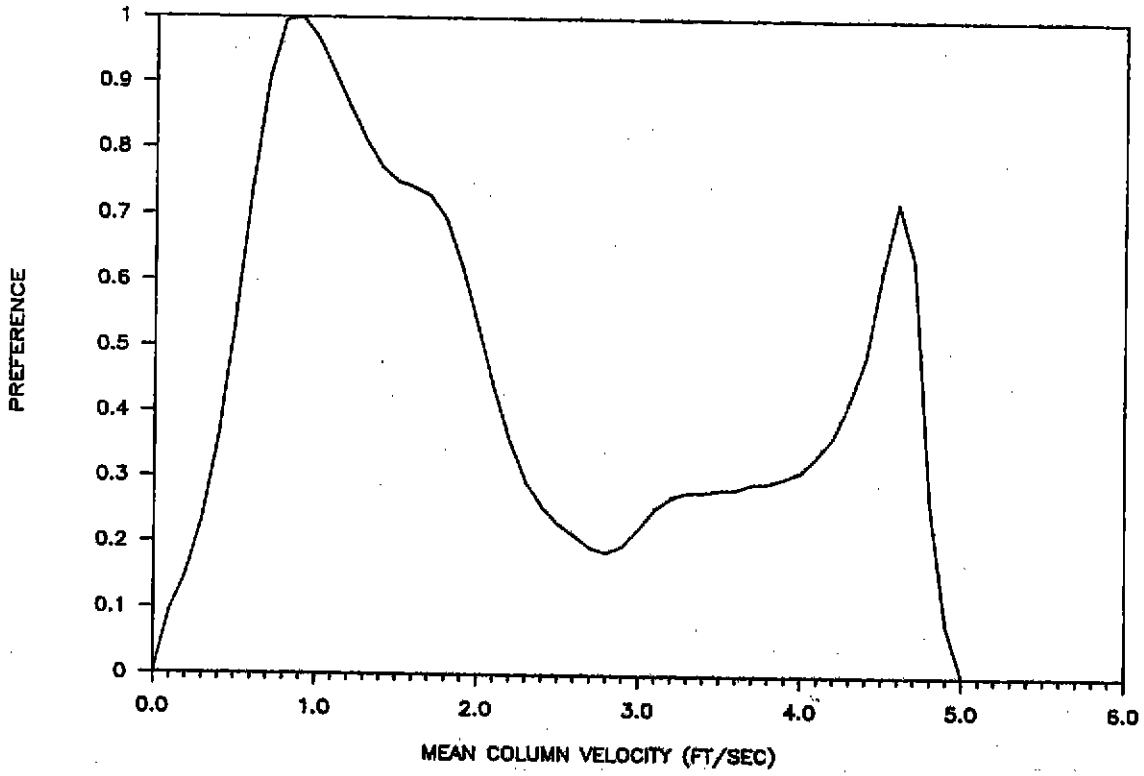


Figure 14. Habitat preference criteria for total depths and mean column velocities selected by spawning coho salmon in the upper Trinity River, CA., 1985-1987.

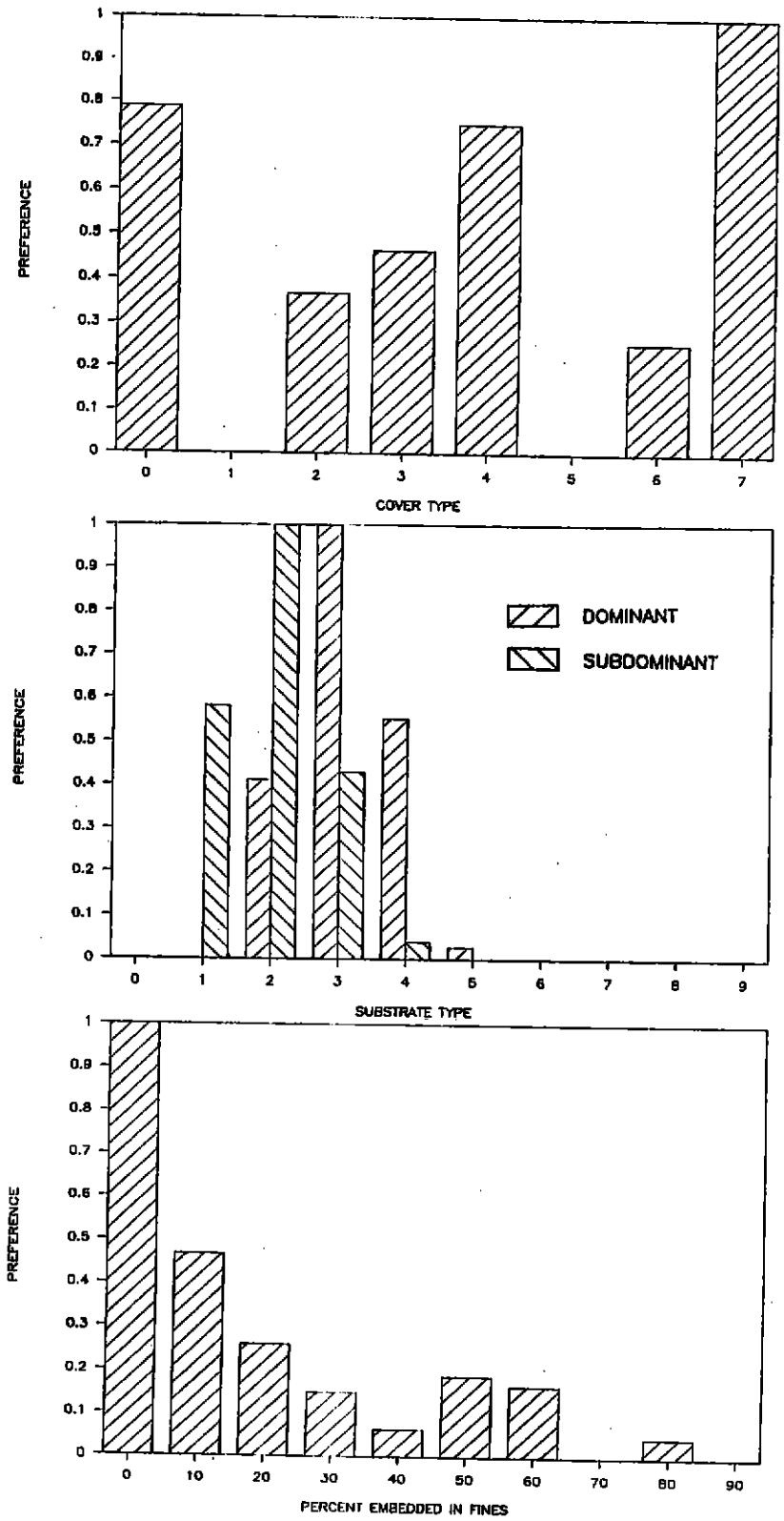


Figure 15. Habitat preference criteria for cover and substrates selected by spawning coho salmon in the upper Trinity River, CA., 1985-1987.

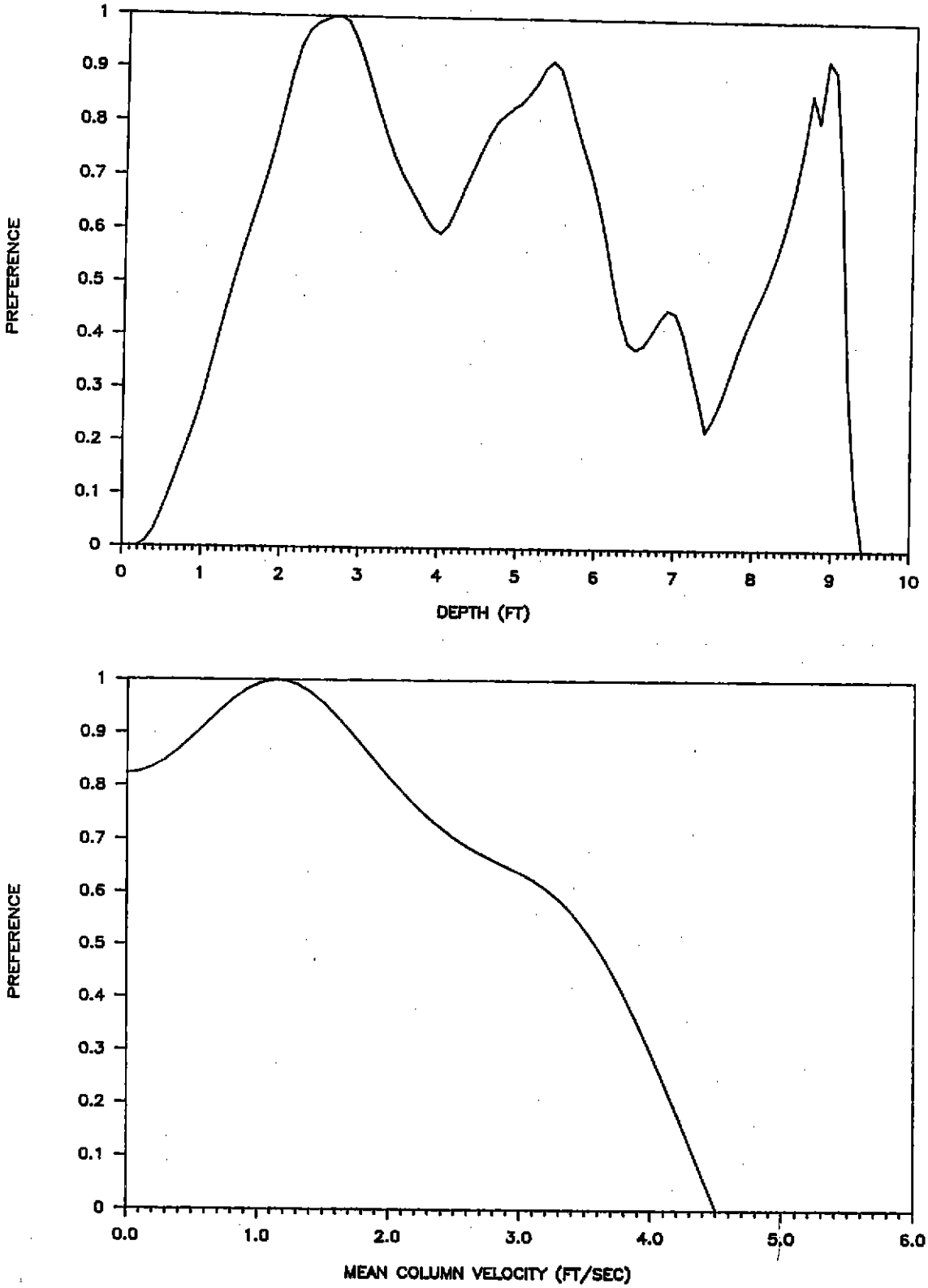


Figure 16. Habitat preference criteria for total depths and mean column velocities selected by steelhead trout juveniles in the upper Trinity River, CA., 1985-1987.

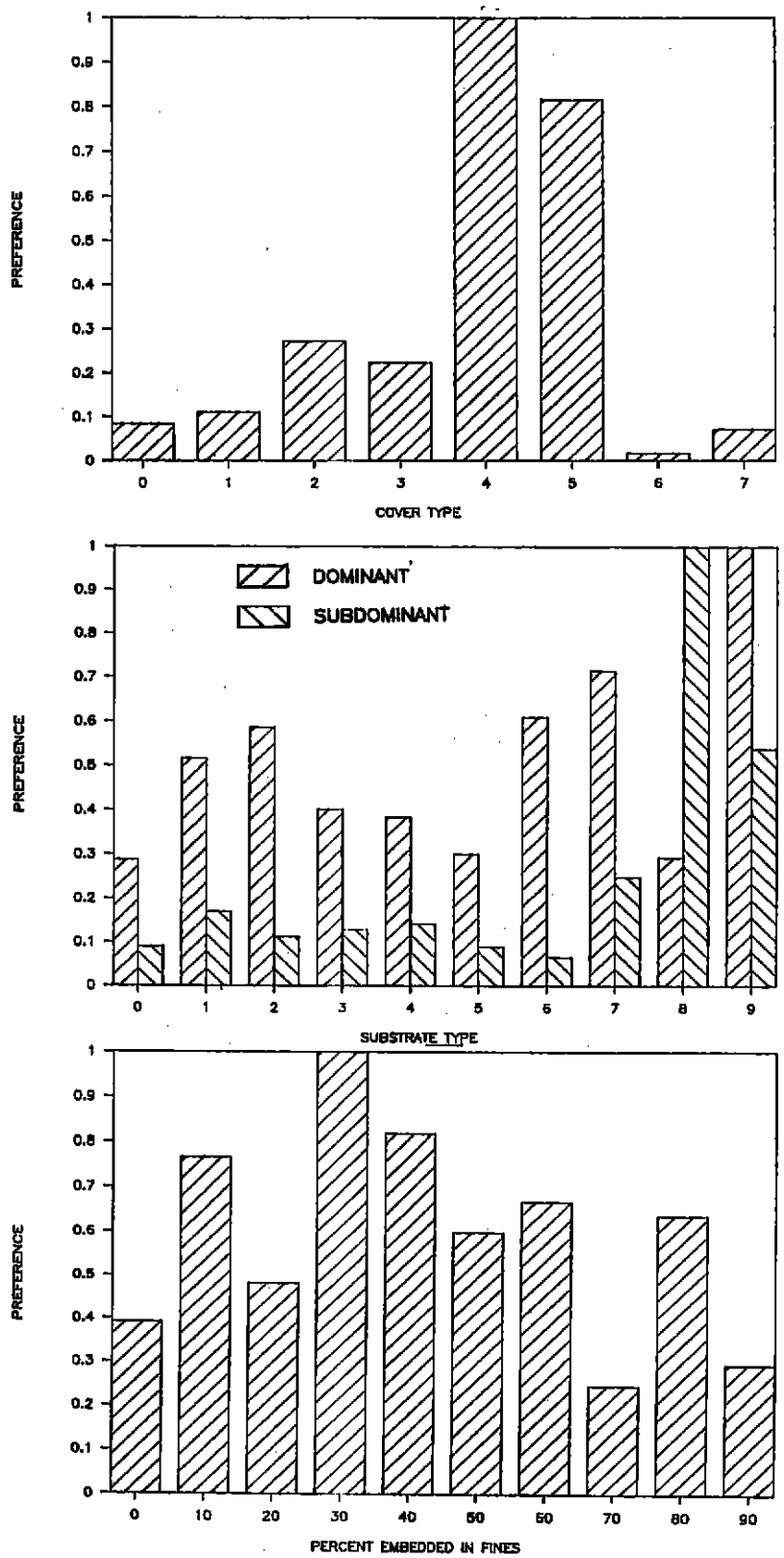


Figure 17. Habitat preference criteria for cover and substrates selected by steelhead trout juveniles in the upper Trinity River, CA., 1985-1987.

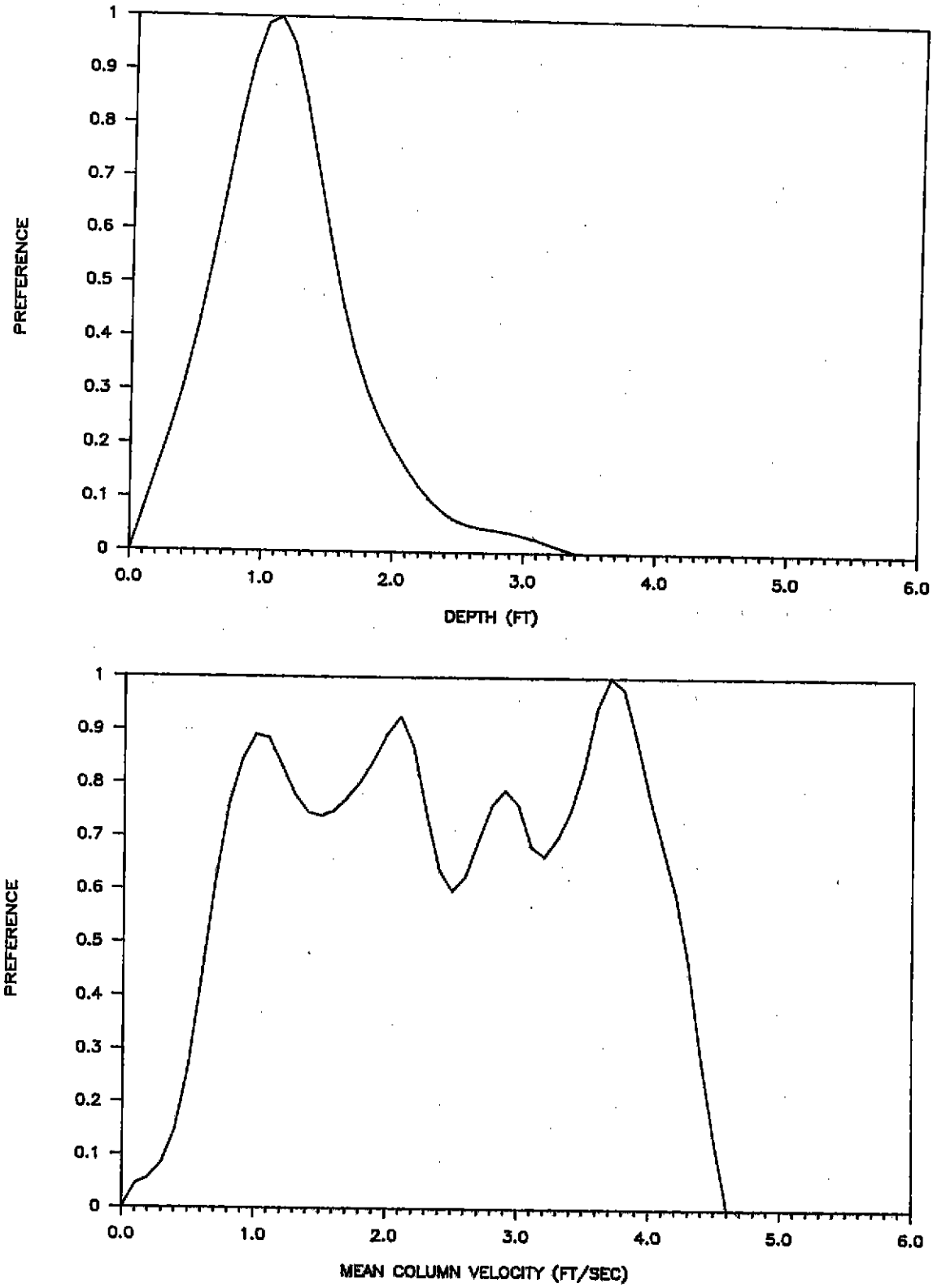


Figure 18. Habitat preference criteria for total depths and mean column velocites selected by spawning steelhead trout in the upper Trinity River, CA., 1985-1987.

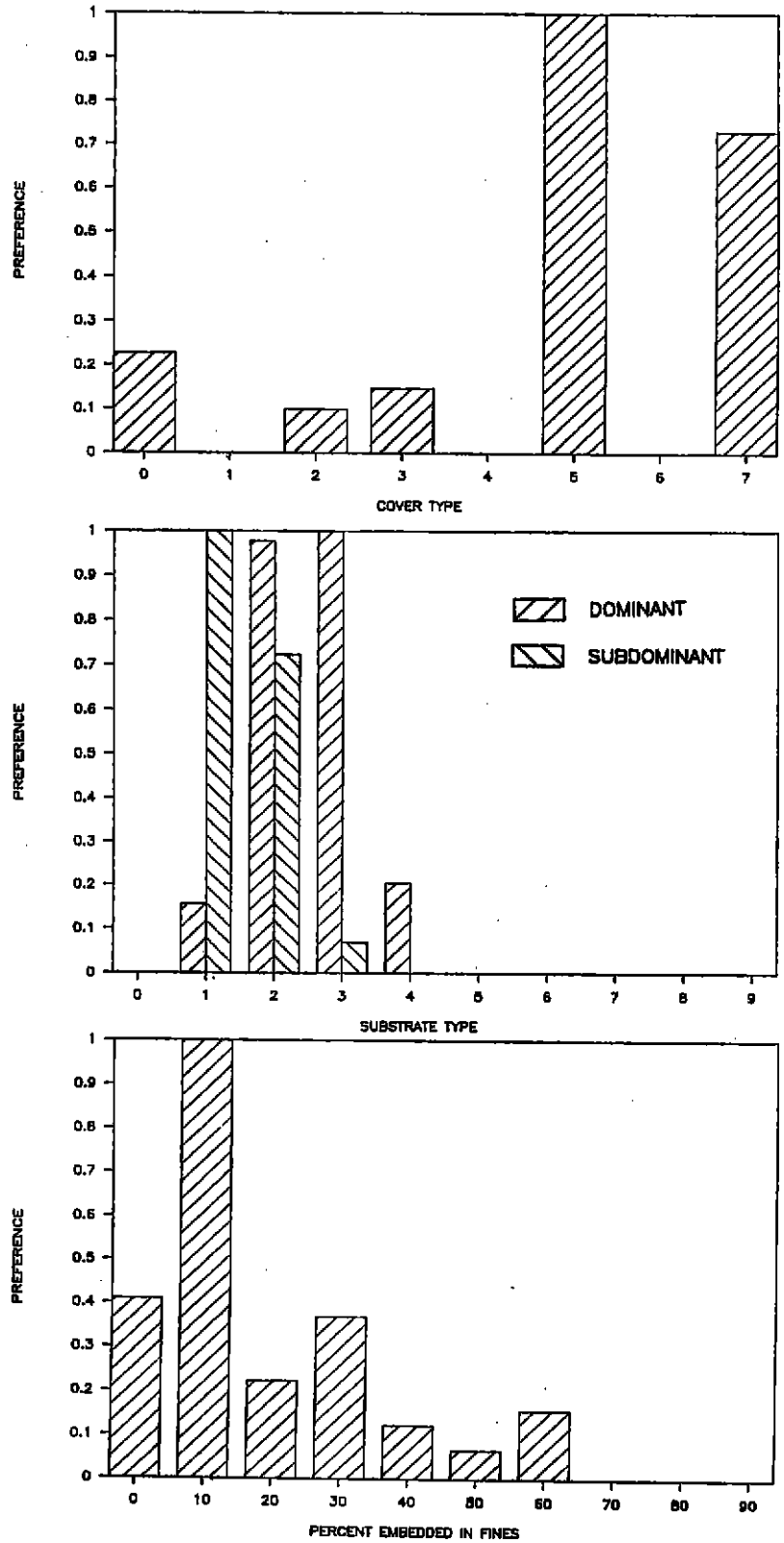


Figure 19. Habitat preference criteria for cover and substrates selected by spawning steelhead trout in the upper Trinity River, CA., 1985-1987.

DISCUSSION

A comparison between use criteria and preference criteria describing depths and mean column velocities selected by spawning chinook and coho salmon and steelhead trout is presented in Figure 20. Preference criteria describing mean column velocities preferred by chinook salmon and steelhead trout deviate significantly from the representative utilization criteria. The preference and utilization criteria developed on velocities chosen by coho salmon exhibit similar suitabilities until velocities begin to exceed 2.8 feet per second, at which point preference values start to increase rapidly and utilization values decrease into the tail end of the distribution. For all three species, high preference values correspond with low utilization values located in the upper limits of each utilization distribution where high water velocities are present. A closer examination of the spawning velocity use data revealed the source of these high preference values. When mean column water velocities begin to exceed about 3.0 feet per second, both the utilization and availability distributions begin to approach zero. This resulted in small probability ratios for both utilization and preference as can be expected, however, the ratio between use and availability ($P_i = U_i/A_i$) remained fairly large. Therefore, a large preference value resulted. In this situation it appears that the behavioral selection of one individual within the population yielded a misrepresentation of the actual preference for the majority of the population. When both the use and availability distributions simultaneously enter the limits of their distributions there is a danger of misrepresenting actual preference simply because of small probability ratios involved. In these instances it is important that the investigator has a good understanding for the species under study so that any extraneous preference values can be recognized and corrected. In order to eliminate the influence of these outliers within the spawning velocity distributions for each species, I applied nonparametric tolerance limits to each frequency distribution which would include 90% of the use observations at a 90% confidence level. Tolerance limits were obtained from a table developed by Somerville as presented by Bovee (1986). Utilization and preference criteria were then recalculated using those frequency values that fell within the 90% tolerance levels established. A comparison of adjusted preference criteria for spawning velocities with the original preference criteria developed is presented in Figure 21. The adjusted preference criteria for spawning velocities selected by salmonids in the Trinity River compare favorably with utilization criteria developed for spawning velocities actually used and probably represent a more accurate description of true preference.

Habitat preference criteria describing depth selection for juvenile chinook salmon and steelhead trout fluctuate

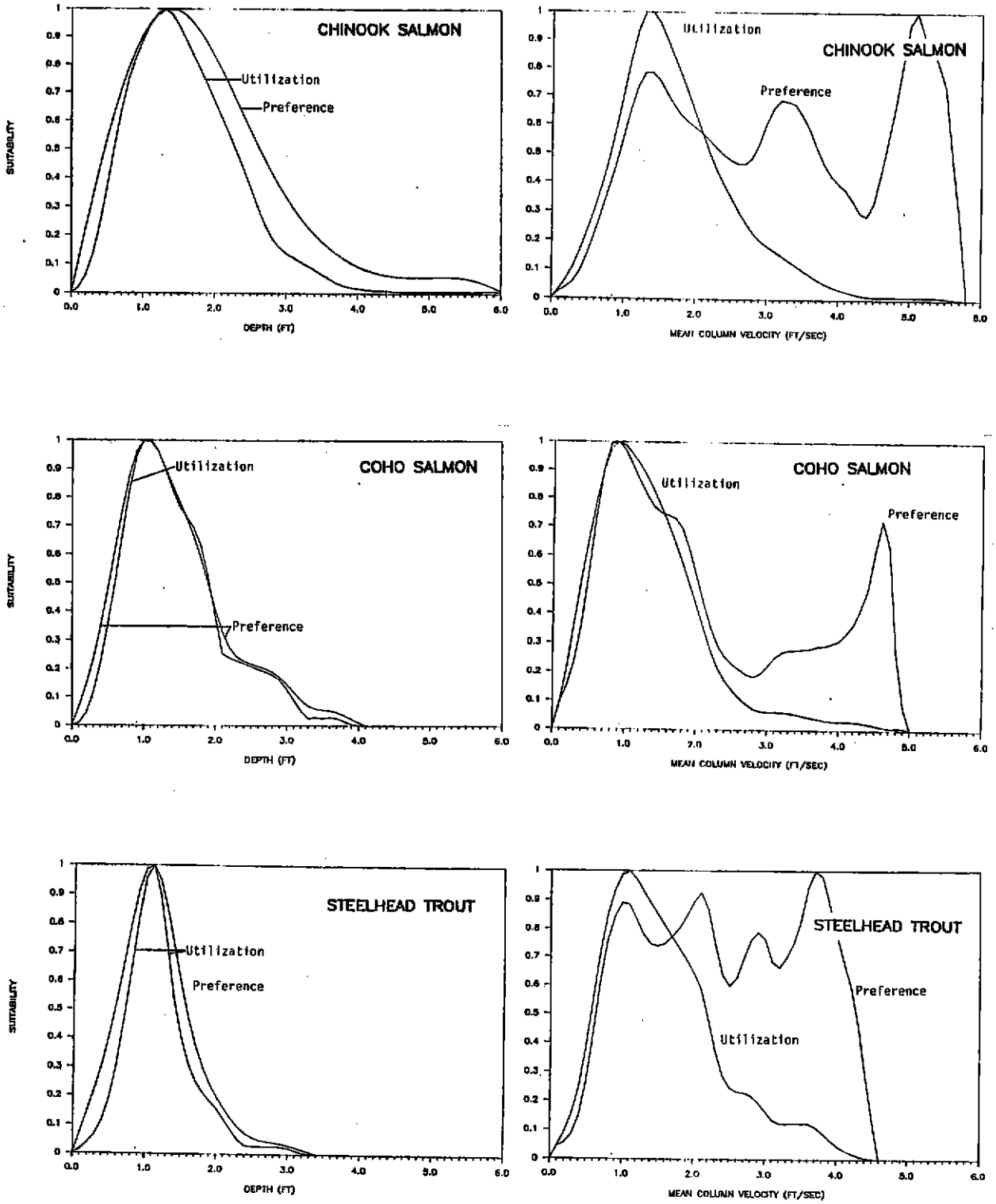


Figure 20. Habitat use and preference criteria for total depth and mean column velocity for spawning chinook and coho salmon and steelhead trout in the upper Trinity River, CA., 1985-1987.

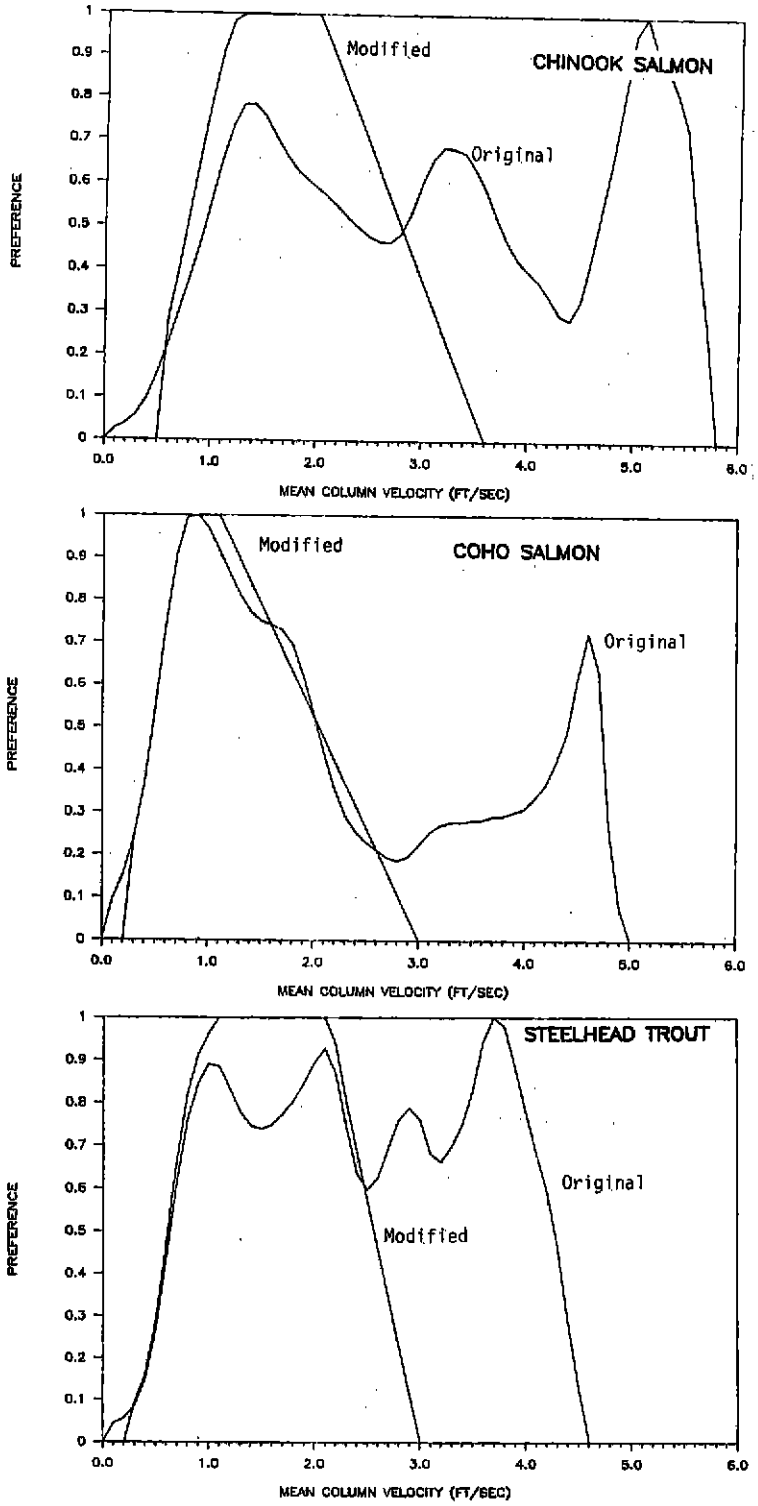


Figure 21. Original preference criteria and modified preference criteria, developed from use data after 90% tolerance limits were applied, for mean column velocities selected by spawning anadromous salmonids in the upper Trinity River, CA., 1985-1987.

greatly. It appears that juvenile chinook salmon and steelhead trout do not exhibit a strong preference for a particular depth range. Observations in the field have led me to believe that water velocity is the critical hydraulic parameter that determines final microhabitat selection for these two species and lifestages during the spring, summer, and early fall months. This would explain the wide range of depths that are described by the final preference criteria. Figure 22 presents modifications to depth preference criteria for juvenile chinook salmon and steelhead trout that were made by professional judgment.

Trinity River chinook salmon are composed of two major stocks, the spring and fall runs. The spring run chinook ascend the river on their spawning migration from April through October, with the majority of fish reaching the upper river by the end of July. The fall run chinook migration begins in September and continues into November. Moffett and Smith (1950) described three distinct seasonal migrations of chinook salmon past Lewiston before the Trinity River Division of the Central Valley Project was built. A spring run past Lewiston in June and July, A summer run in August and September, and the fall run from October to November. The spring and summer fish spawned between Grass Valley Creek and Stuarts Fork in early October and by mid-October spawning spread from the North Fork Trinity River upstream to The East Fork Trinity River. The fall run fish spawned later usually after the early fall freshets had increased river flow opening up new spawning areas further upstream where spring and summer run adults were unable to reach. Under historic uncontrolled flow conditions these differences in the time of spawning provided spatial segregation through increased habitat gains further upstream as a result of higher flows. Under the current controlled flow management scheme the only mechanism for maintaining the genetic integrity between the two runs is time of spawning, in which some overlap does occur. With the presence of Lewiston Dam and controlled flow, the habitat areas available to each run are equal. As a result, the available spawning areas below Lewiston Dam experience heavy use by both runs of chinook salmon and by coho salmon and steelhead trout. This constant pressure on the available habitat leads to a large percentage of superimposition of redds throughout the spawning season. I chose not to develop separate habitat suitability criteria for the spring and fall runs of chinook salmon, since the habitat available to each run is equal.

Spawning chinook salmon in the Trinity River preferred mean column velocities from 1.2 to 2.0 feet per second, in water 1.4 feet deep. Category I criteria developed by Bovee (1978) for spawning chinook salmon suggested a range of optimum mean column velocities from 1.0 to 1.7 feet per second in depths from 0.8 to 1.0 feet for spring run chinook and mean column velocities from 1.5 to 1.7 feet per second and depths from 0.7 to 1.0 feet for fall run chinook. Raleigh et al. (1986)

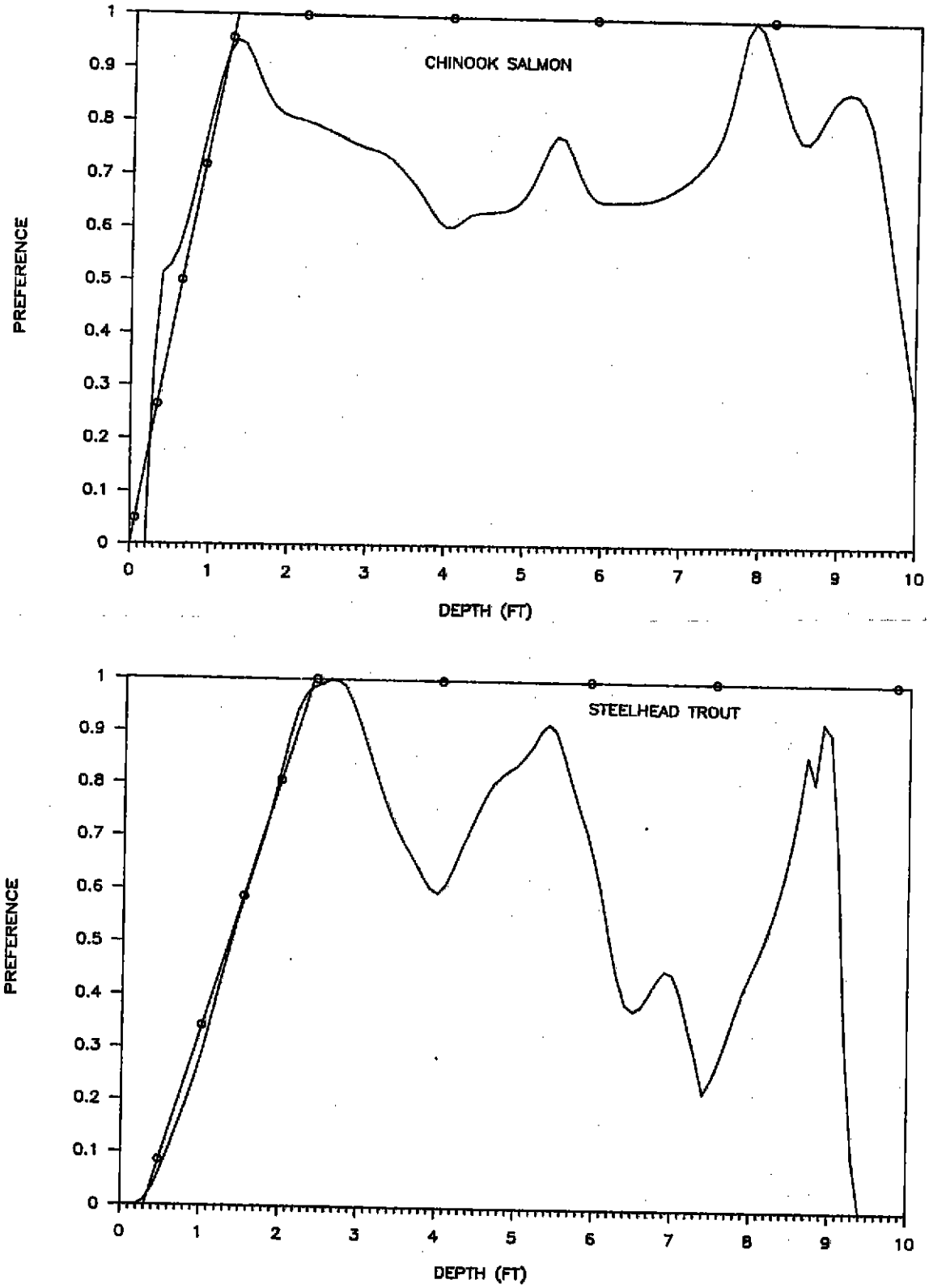


Figure 22. Original (——) and modified (—o—) preference criteria for total depths selected by chinook salmon and steelhead trout juveniles in the upper Trinity River, CA., 1985-1987.

developed category I criteria presenting optimum mean column velocities from 1.5 to 2.4 feet per second and optimum depths as 1.0 feet or greater (Figure 23). A comparison of preference criteria developed in this study with published use criteria describing mean column velocities selected by spawning chinook salmon is present in Figure 24. Trinity River chinook salmon preferred comparable mean column velocities with use criteria reported by other researchers with the exception of use criteria reported by Stempel (1984). On the Yakima River, Stempel found that mean water column velocities from 1.9 to 2.8 feet per second provided the greatest suitability for spawning spring chinook salmon averaging from 85 -100 cm in length. This compares with mean column velocities from 1.2 to 2.0 feet per second that were preferred by spawning chinook salmon in the Trinity River. A comparison of use criteria developed for nose velocities selected by spawning chinook salmon in the Trinity River with use criteria developed by Vogel (1982) and Kurko (1977) is presented in Figure 25. Vogel and Kurko measured nose velocities at 0.5 feet. Spawning chinook salmon in the Trinity River selected the slowest nose velocities. These differences in selection may be a factor of sampling methods, equipment used, fish size or behavior differences that exist.

Trinity River chinook salmon have historically been recognized as physically smaller in size. Average fork lengths of returning adult chinook salmon to Trinity River Hatchery are presented in Figure 26. Physically smaller adults may account for selection of slower water velocities for redd construction by Trinity River chinook salmon. Mills (pers. comm.) measured nose velocities at 0.4 feet and found that spawning fall chinook salmon in the South Fork Trinity River most often selected nose velocities of 2.1 feet per second. The reasons for the discrepancies between nose velocities selected by South Fork Trinity River and mainstem Trinity River chinook salmon may be an artifact of habitat availability differences between the two rivers. The South Fork Trinity River still exhibits a natural flow regime and has many wide point bars. The mainstem Trinity River has experienced several years of reduced controlled flow which allowed riparion vegetation to encroach along the banks eliminating these habitat types.

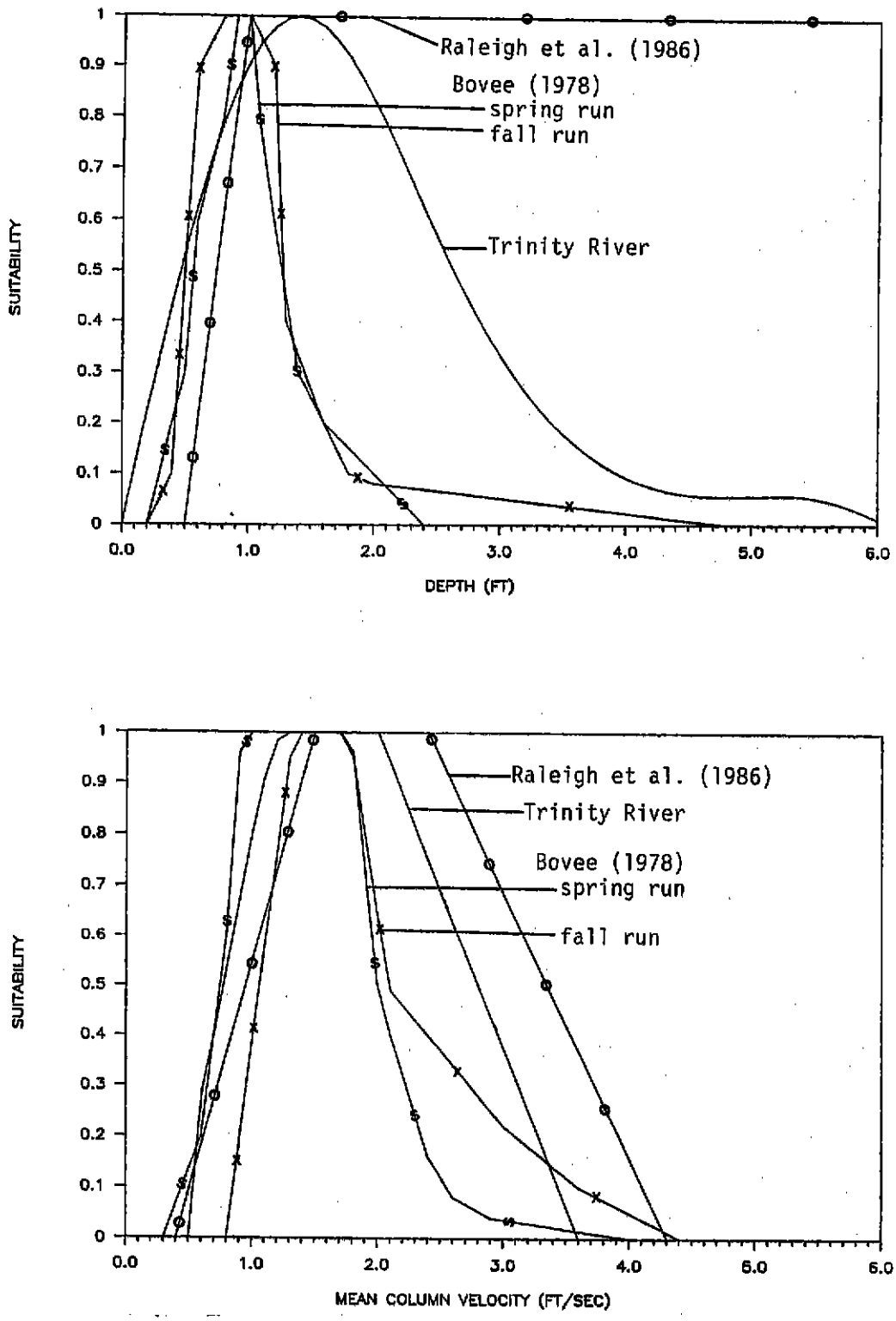


Figure 23. A comparison of preference criteria developed in the upper Trinity River with Category I criteria developed by Bovee (1978) and Raleigh et al. (1986) for spawning chinook salmon.

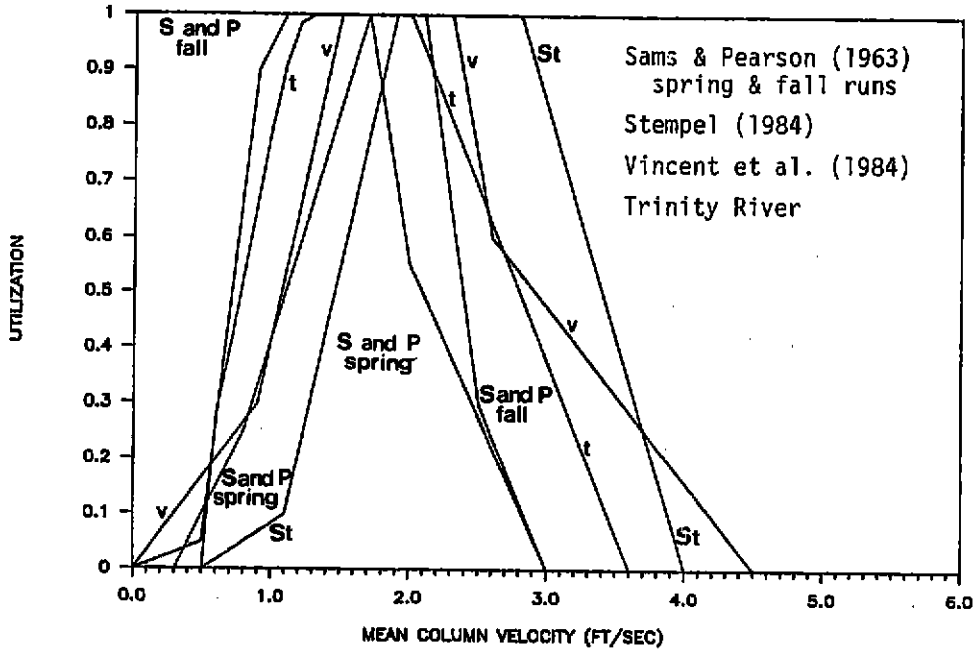


Figure 24. A comparison between preference criteria developed in the upper Trinity River with use criteria developed by other researchers for mean column velocities selected by spawning chinook salmon.

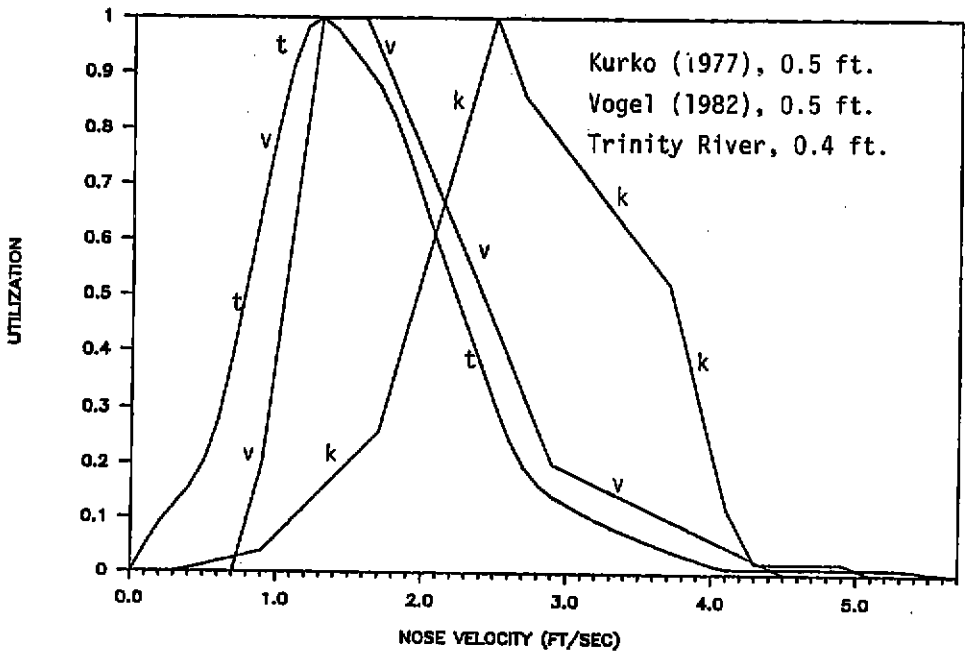


Figure 25. A comparison between use criteria of fish nose velocities selected by spawning chinook salmon in the upper Trinity River with spawning chinook salmon observed by other researchers.

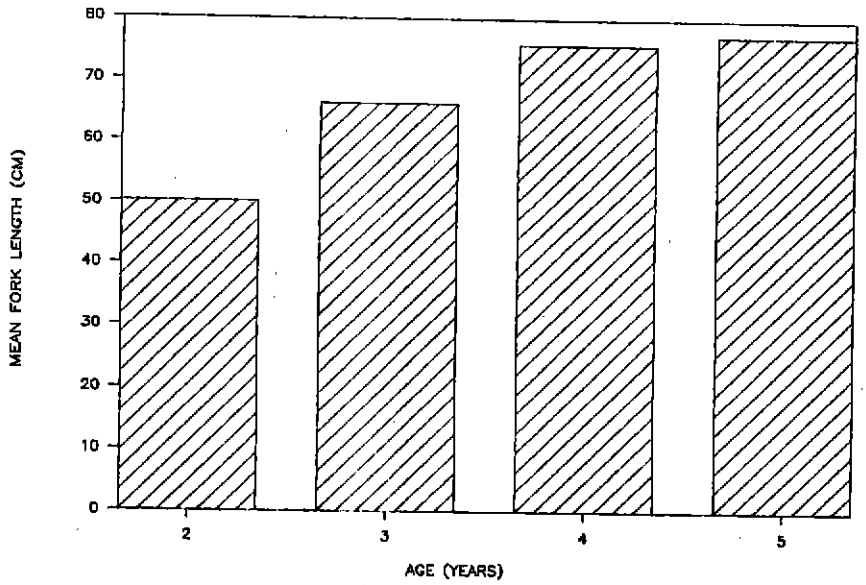
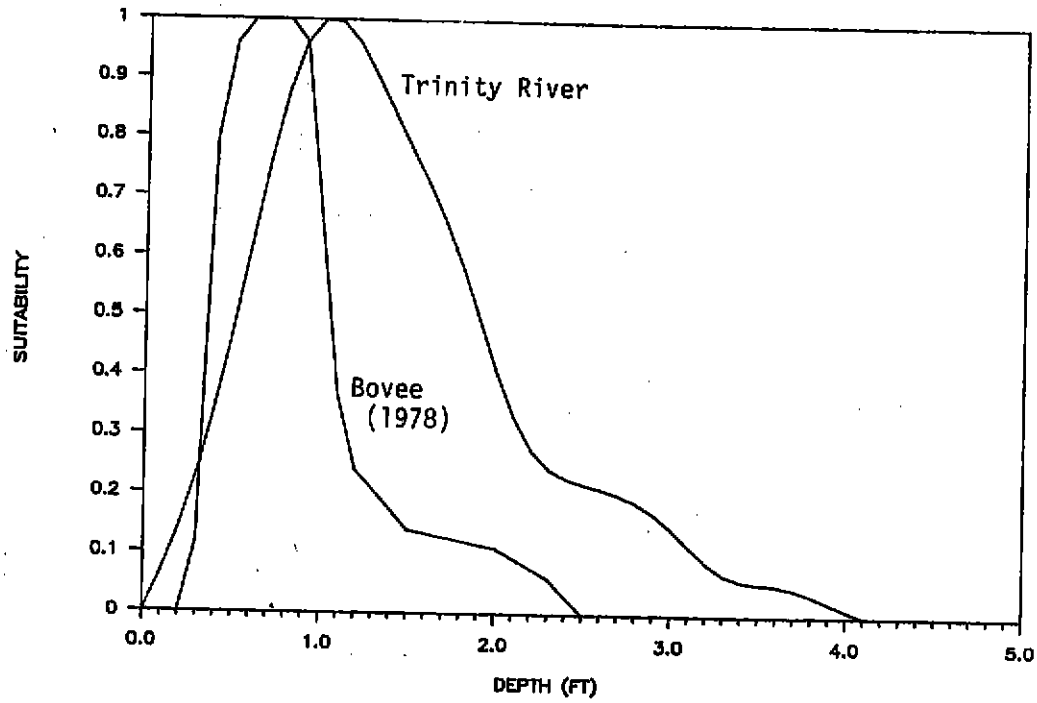


Figure 26. Mean fork lengths of tagged adult chinook salmon that returned to Trinity River Hatchery in 1985, California Department of Fish and Game, Trinity Co., California.

Adult coho salmon begin their migration up the Trinity River in October and spawning activity occurs from November through January. The majority of coho salmon that spawn in the mainstem do so in the upper reaches directly below Lewiston Dam. Spawning coho salmon preferred microhabitats containing mean column water velocities from 0.9 to 1.1 feet per second in water depths of 1.0 to 1.1 feet. Bovee (1978) presents category I criteria for spawning coho salmon as optimum for mean column velocities from 1.2 to 1.4 feet per second and depths from 0.6 to 0.8 feet (Figure 27). Trinity River coho salmon preferred slower velocities and slightly deeper water for spawning than the category I criteria provided by Bovee (1978).

Collection of habitat use data for adult steelhead trout was complicated by poor sampling conditions and low escapement levels. Adult steelhead migration occurs from November through April when winter storms commonly cause high river flows and turbidity levels which prevent effective sampling by direct observation. Returns of adult steelhead to Trinity Hatchery during the sampling period from 1985 through 1987 were 142, 461, and 3,780 respectively. The presence of a fairly good run in 1987, combined with good sampling conditions gave us the opportunity to obtain enough spawning data to develop utilization and preference criteria. Steelhead trout preferred mean column velocities from 1.1 to 2.1 feet per second in depths from 1.0 to 1.1 feet for spawning.



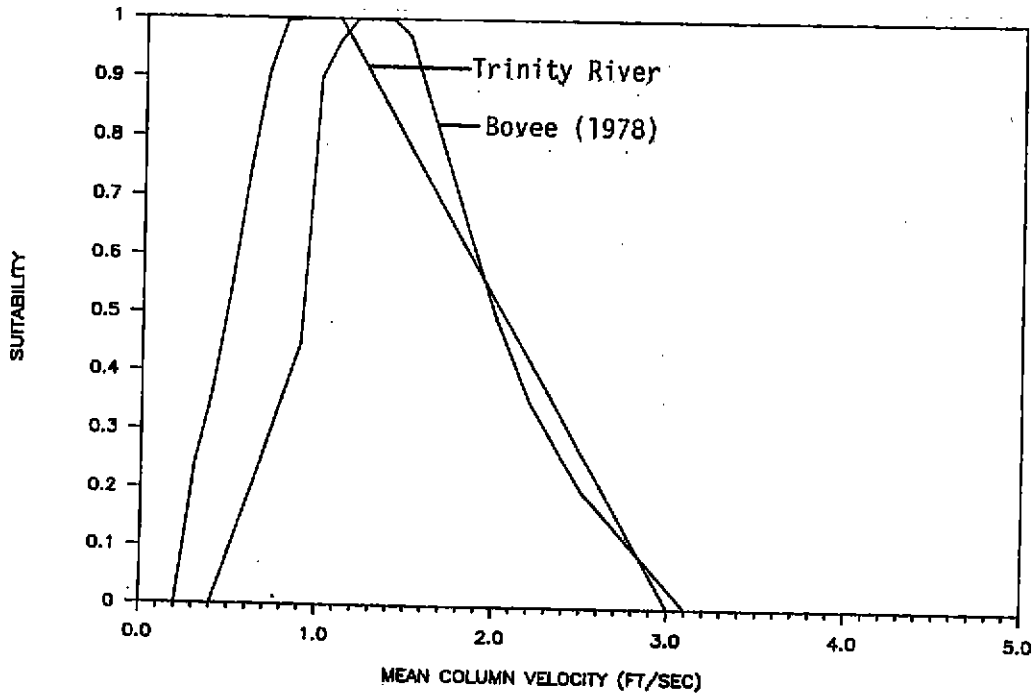
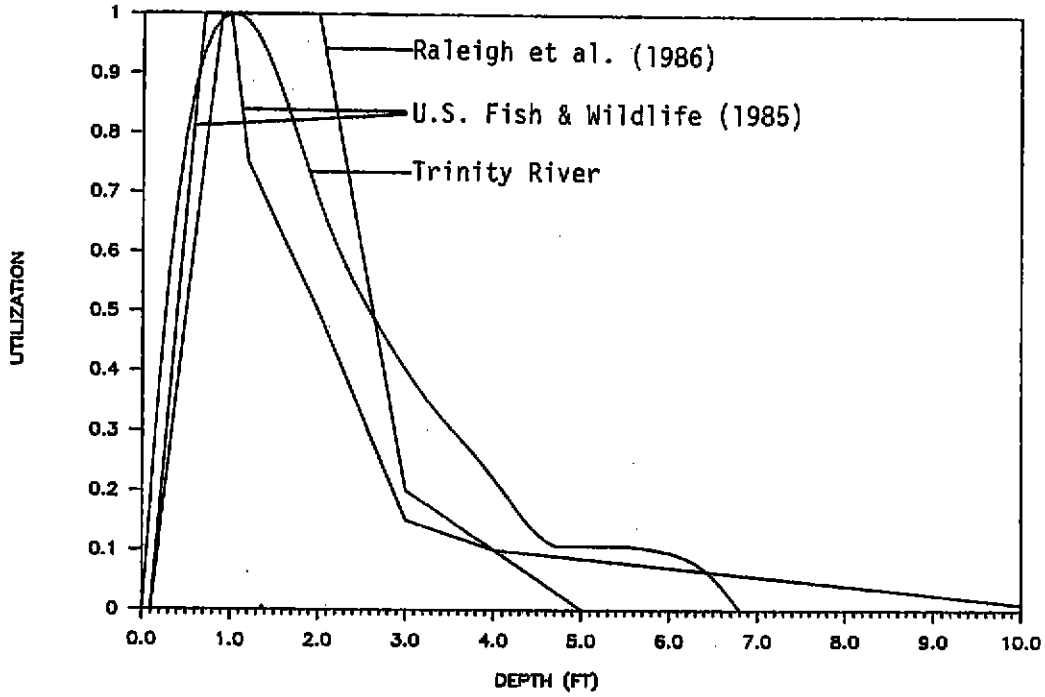


Figure 27. A comparison of preference criteria developed in the upper Trinity River with category I criteria developed by Bovee (1978) for spawning coho salmon.

Emergence of fry chinook salmon begins in December and continues into Mid-April (Leidy and Leidy, 1984). This lengthy timing in emergence accounted for large differences in size within chinook salmon observed during the Spring months. After emergence, fry chinook salmon occupied stream margins where slow velocities and abundant cover types were present. Woody debris, cobble substrates clear of fine sediments, and undercut banks provided critical escape cover from surface feeding predators, such as herons and mergansers. Preference criteria developed for fry chinook salmon showed optimum suitability for water 1.0 feet deep in mean column velocities of 0.0 feet per second. Utilization criteria developed for fry chinook salmon showed heaviest use of water depths from 1.2 to 1.3 feet also in zero velocity water. Category I criteria developed by Raleigh et al. (1986) show optimum habitat for fry chinook salmon as depths from 0.9 to 2.0 feet with mean column water velocities 0.2 to 0.3 feet per second (Figure 28). Burger et al. (1982) developed use criteria describing mean column velocities used by fry chinook salmon in Alaska and found that the greatest use occurred in 0.1 feet per second. Category I criteria developed by USFWS (1985) present depths from 0.7 to 1.0 feet as most suitable for fry chinook salmon. Trinity River fry chinook salmon preferred slower velocities and similiar depths as chinook salmon fry reported by other researchers.

As chinook salmon grew larger they became less dependent on stream margins and began to use areas with faster velocities in deeper water. Object cover in the form of fallen alders or willows were heavily utilized, both as protection from predators and as velocity shelters. A comparison of use criteria developed for juvenile chinook salmon on the Trinity River with category I criteria developed by Bovee (1978) and Raleigh et al. (1986) is presented in Figure 29. Juvenile chinook salmon in the Trinity River utilized similar depths and slower velocities as those presented by both Bovee (1978) and Raleigh et al. (1986). Stempel (1984) found that juvenile chinook salmon in the Yakima river basin selected depths from 2.3 to 2.7 feet with mean column velocities ranging from 0.4 to 0.5 feet per second. Chinook salmon juveniles on the Trinity River preferred slow water habitat in depths greater than 1.0 feet. Field observations confirm the importance of velocity as the determining factor in habitat selection over total depth by juvenile chinook salmon. Juvenile chinook salmon were observed in a wide range of depths as long as slow water velocities were available. Substrate only appeared to be an important factor for habitat selection when large cobbles or boulders could be used as velocity shelters in riffles and runs. In deep pool habitats, schools of juvenile chinook salmon positioned themselves in relationship to ever changing eddies and shear velocity zones where food items could be easily taken in the drift. In pools, the majority of juvenile salmon would feed near the water surface and would flee to deep water when frightened from above. At night fry and juvenile chinook



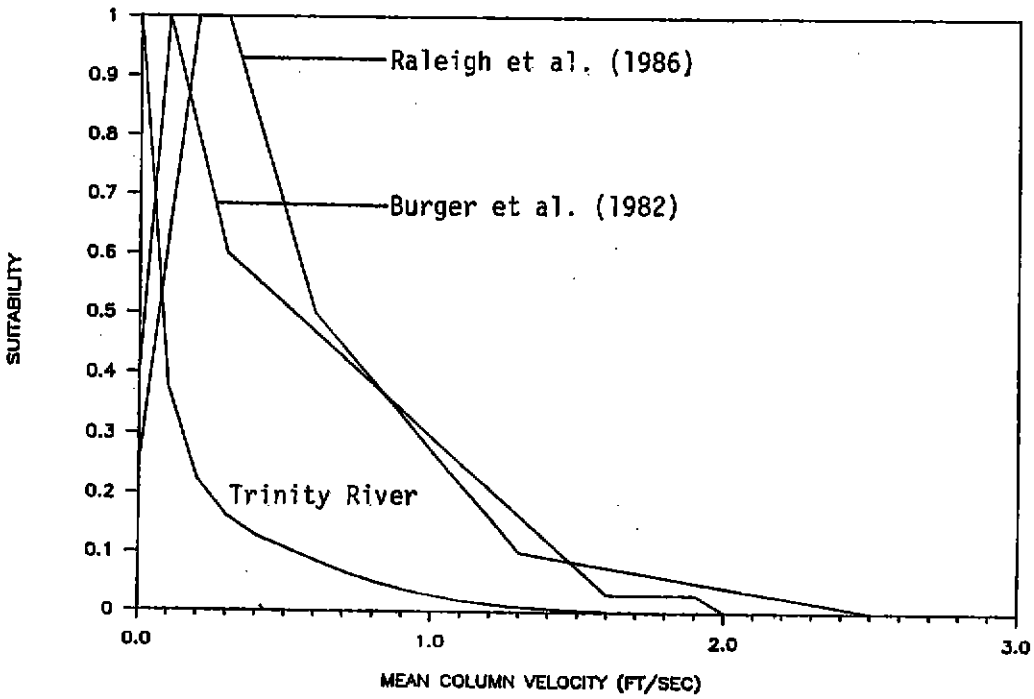
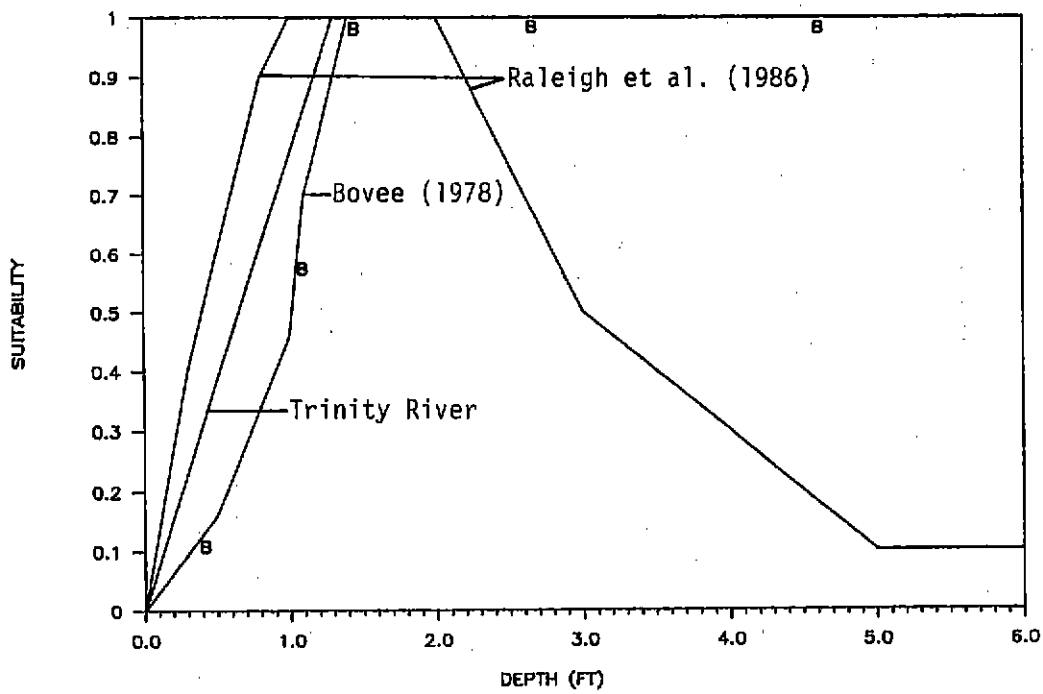


Figure 28. A comparison of preference criteria developed in the upper Trinity River with suitability criteria developed by other researchers for chinook salmon fry.



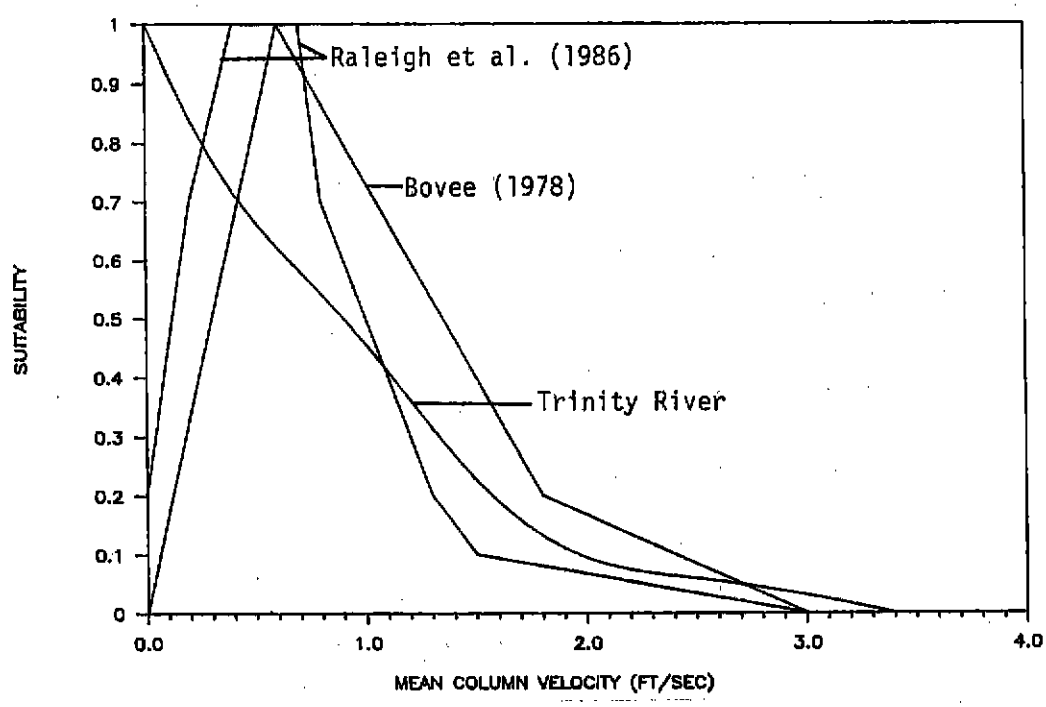


Figure 29. A comparison of preference criteria developed in the upper Trinity River with category I criteria developed by Bovee (1978) and Raleigh et al. (1986) for chinook salmon juveniles.

salmon congregated into slow velocity habitats in close proximity to river substrates or cover items.

Coho salmon fry emerged from February to May and were found to use the same habitats as fry chinook salmon along the stream margins. Juvenile coho salmon did not shift their habitat selection to areas of faster water as did juvenile chinook salmon, rather they tended to seek out slow water habitats that were present in backwaters, sidechannels and stream margins adjacent to large slow runs or pools. Fry and juvenile coho salmon showed a strong preference for slow water velocities. Fry coho salmon preferred depths from 0.9 to 1.2 feet, while juvenile coho salmon preferred depths from 2.3 to 2.5 feet. Category I criteria developed for fry coho salmon by Bovee (1978) present mean column velocities of 0.5 feet per second in water from 1.7 to 2.0 feet deep as optimum (Figure 30). Cover seemed to play a more important role in habitat selection for both fry and juvenile coho salmon. The habitats that were selected usually contained areas of quality cover types, such as brush or logs, over hanging vegetation or thick clusters of aquatic vegetation.

Lister and Genoe (1970) noted that both chinook and coho salmon juveniles on the Big Qualicum River occupied habitat of progressively higher velocities as they grew and spatial segregation apparently resulted from size differences caused by differences in emergence timing, size of emergent fry, and growth rate. In the Sixes River, Stein et al. (1972) found that chinook and coho salmon emerged at similar times, utilized similar habitats and interacted. Microhabitat segregation based on size difference did not occur. They also found that the distributions of the two species changed as temperatures in the main river increased, and speculated, that as temperatures increased, coho salmon left the main river in search of cooler water in the tributaries or died. On the Trinity River, fry and juvenile chinook salmon greatly outnumbered fry and juvenile coho salmon during the study period. As fry, both species were found to interact often and were commonly found together in one school. Antagonistic behavior between the two species was rarely observed, and it appeared that as each species grew their differences in habitat selection provided for spatial segregation between the two species. It is also possible that coho salmon are less tolerant of crowded conditions caused by high densities of chinook salmon, and therefore, sought out habitat types that were less utilized by juvenile chinook salmon.

The low numbers of adult steelhead trout that entered the Trinity River on their spawning migration in 1985 and 1986 greatly hindered our ability to gather fry steelhead use data in the subsequent years. There was never any problem in obtaining use data on juvenile steelhead during the study period, probably because many of these larger juveniles reared in tributary streams as fry. Steelhead trout fry were usually found along stream margins adjacent to runs and

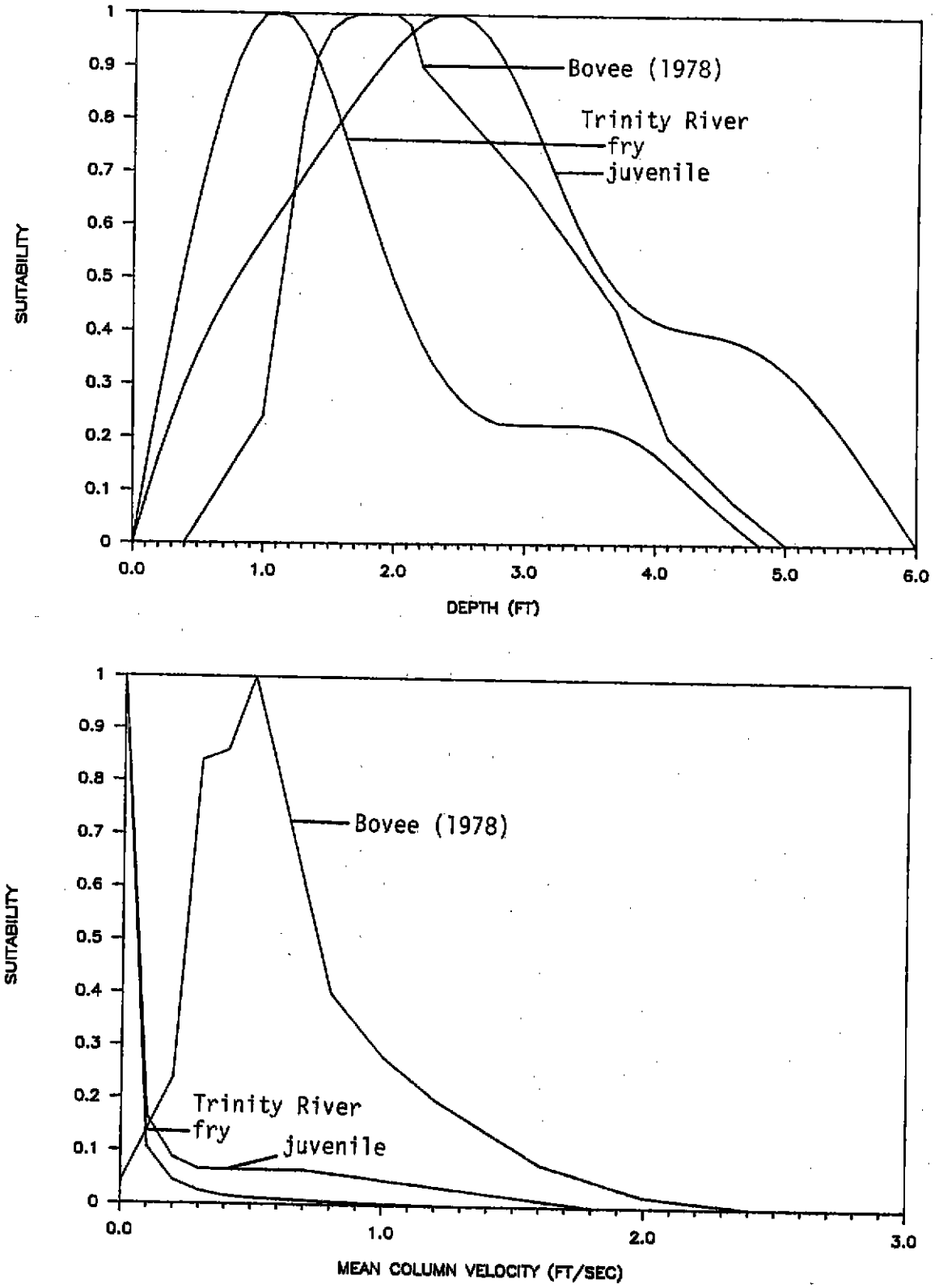


Figure 30. A comparison of preference criteria developed in the upper Trinity River for coho salmon fry and juveniles with category I criteria developed by Bovee (1978) for coho salmon fry.

riffles or along the edges of transition habitats between riffles and pools. Fry assumed focal points on or very near the stream bottom between cobbles or within woody debris. Juvenile salmon were frequently observed in the water column above fry steelhead trout in the same microhabitats. Unlike fry chinook or coho salmon, fry steelhead were often found in turbulent water present in shallow riffles. Their association with velocity shelters on or near the stream bottom allowed them to use these more turbulent microhabitats. Fry steelhead were rarely observed in monotypic habitats present in long slow runs or pools.

Juvenile steelhead trout preferred run, riffle, and riffle-pool transition habitats that provided a high degree of velocity diversity. Preferred depths from 2.0 feet and greater with mean column velocities from 1.0 to 1.3 feet per second. Juvenile steelhead actively defended feeding stations in riffles and across the tail end of run habitats. Object cover, boulders, large cobbles or woody debris, played an important role by providing velocity shelters where juvenile steelhead could establish feeding stations with little effort. When found in riffle-pool transition habitats groups of juvenile steelhead were often seen feeding in the same locations without displaying any aggressive behavior among themselves. In these microhabitats steelhead were usually positioned underneath areas of high surface water velocity along the ledge located at the upper boundary of the pool. In these locations juvenile steelhead could maintain focal points in near zero velocity water and still take advantage of drift organisms originating in the riffle upstream. Cover objects were seldom present in these riffle-pool transition habitats, however, surface turbulence did provide concealment from surface predators.

Shear velocity zones, areas of rapid velocity change, proved to be a critical hydraulic characteristic present in the microhabitats selected by juvenile chinook salmon and steelhead trout. These shear zones provided opportunistic feeding stations for juvenile salmon and trout where focal points could be established in slow velocity areas and yet still be in close proximity to higher velocity areas where food, available in the form of drift, is more easily accessible and more abundant. Net energy gain in these microhabitats is probably optimized because less energy is used to maintain focal points and distances traveled to capture prey items are reduced. Lisle (1981) describes the importance of large roughness elements (boulders and woody debris) as a key resource to fish habitat by providing a diversity of channel form and substrate conditions. These same roughness elements also provide important rearing habitat for anadromous salmonids by increasing velocity diversity through the formation of shear velocity zones. Habitat suitability criteria based on focal point velocities, either taken as mean column water velocities or as fish nose velocities, fail to measure the presence of these shear

velocity zones that are located adjacent to focal points and, therefore, may misrepresent actual fish habitat preferences for rearing salmonids. A form of preference criteria that considers both focal point velocities and adjacent cell velocities would be a better measure of fish preference in these instances.

Future habitat suitability studies can alleviate this problem by developing criteria that not only describe focal point velocities, but also quantify the distances traveled by the target species to capture prey items as well describing the velocities that are present at the location where prey items are captured. Quantification of these two additional parameters may then be input into the HABTAV program of the IFIM to predict a more accurate weighted useable area versus discharge relationship for those species and lifestages that utilize shear velocity zones.

The concept that preference criteria, by eliminating habitat bias, may be transferred to other streams or rivers is questionable. Development of preference criteria is dependent on the available habitat present within the area of study. Therefore, if a habitat type is not present within the study area the influence of that habitat type on the target species habitat selection will not be represented in the resulting preference criteria. Based on this fact, it is important that other researchers validate that the available habitat in the system where the preference criteria are being considered for use is similar to the available habitat present in the system where the preference criteria were developed. Only after the available habitats of the two systems have been found to be similar should preference criteria be transferred.

Appendix E presents habitat preference criteria judged at this time to be best suited for habitat studies in the Trinity River. The limitaions of these criteria should be clearly understood before they are utilized in other streams or rivers for similiar type studies.

REFERENCES

Aceituno, M.E., and M. Hampton. Validation of habitat availability determinations by comparing field observations with hydraulic model (IFG-4) output. pp. 322-334 in K. Bovee and J.R. Zuboy, eds. Proceedings of a workshop on the development and evaluation of habitat criteria. U.S. Fish Wildl. Serv. Biol. Rep. 88(11). 407 pp.

Bovee, K.D. 1978. Probability of use criteria for the family salmonidae. Instream Flow Information Paper No. 4. U.S. Fish Wildl. Serv. FWS/OBS-78/07

Bovee, K.D. 1982. A guide to stream habitat analysis using the instream flow incremental methodology. Instream Flow Information Paper No. 12. U.S. Fish Wildl. Serv. FWS/OBS-82/26

Bovee, K.D. 1986. Development and evaluation of habitat suitability criteria for use in the instream flow incremental methodology. Instream Flow Information Paper No. 21. U.S. Fish Wildl. Serv. Biol. Rep. 86(7). 235 pp.

Bovee, K.D., and T. Cochnauer. 1977. Development and evaluation of wieghted criteria, probability - of - use curves for instream flow assessments: fisheries. Instream Flow Information Paper No. 3. U.S. Fish Wildl. Serv. FWS/OBS-77/63

Brusven, M.A. 1977. Effects of sediments on insects. Page 43 in D.L. Kibbee (ed.). Transport of granitic sediments in streams and its effects on insects and fish. USDA Forest Sevice. Forest, Wildl., and Range Exp. Sta. Bull. 17. Univ. Idaho, Moscow, ID.

Cheslak, E., and J. Garcia. 1987. Sensitivity of PHABSIM model output to methods for fitting functions of curves to species preference data. in K.D. Bovee, and J. Zuboy, eds. Proceedings of a workshop on the development and evaluation of habitat criteria for fish. U.S. Fish Wildl. Serv. Biol. Rep. (in press)

Cheslak, E., EA Engineering, Science, and Technology, Inc. February 2, 1988. Personal Communication.

Hubbel, P.M. 1973. A program to identify and correct salmon and steelhead problems in the Trinity River Basin. Calif. Dept. of Fish and Game. Report to the Trinity River Basin Fish & Wildlife Task Force, Sacramento, Calif. 70 pp.

Kurko, K.W. 1977. Investigations on the amount of potential spawning area available to chinook, pink, and chum salmon in the upper Skagit River, Washington. M.S. Thesis. University of Washington, Seattle. 76 pp.

Leidy, R.A., and G.R. Leidy. 1984. Life stage priodicities of anadromous salmonids in the Klamath River Basin, Northwestern California. U.S. Fish Wildl. Serv., Division of Ecological Services, Sacramento, California. 21 pp.

Lisle, T.E. 1981. Roughness elements: a key resource to improve anadromous fish habitat. in T.J. Hassler ed. Proceedings: propagation, enhancement, and rehabilitation of anadromous salmonid populations and habitat symposium. October 15-17, 1981, Humboldt State University, Arcata, California.

Lister, D.B., and H.S. Genoe. 1970. Stream habitat utilization by cohabiting underyearlings of chinook (Oncorhynchus tshawytscha) and coho (O. kisutch) salmonids. J. Fish. Res. Board Can. 27:1215-1224.

Milhous, R.T., D.L. Wegner, and T. Waddle. 1984. User's guide to the Physical Habitat Simulation System. Instream Flow Information Paper 11. U.S. Fish Wildl. Serv. FWS/OBS-81/43 Revised. 475pp.

Mills, T. J., Cailfornia Department of Fish and Game. February 3, 1988. Personal Communication.

Moffett, J.W., and S.H. Smith. 1950. Biological investigations of the fishery resources of Trinity River, Calif. U.S. Fish Wildl. Serv. Special Scientific Report - Fisheries No. 12 71 pp.

Raleigh, R.F., W.J. Miller, and P.C. Nelson. 1986. Habitat suitability index models and instream flow suitability curves: chinook salmon. U.S. Fish Wildl. Serv. Biol. Rep. 82(10.122) 64 pp.

Reimers, P.E. 1968. Social behavior among juvenile fall chinook salmon. J. Fish. Res. Bd. Canada, 25(9):2005-2008

Sams, R.E., and L.S. Pearson. 1963. Methods for determining spawning flows for anadromous salmonids. Oregon Fish Commission Draft Report. 68 pp.

Stein, R.A., P.E. Reimers, and J.D. Hall. 1972. Social interaction between juvenile coho (Oncorhynchus kisutch) and fall chinook salmon (O. tshawytscha) in Sixes River, Oregon. J. Fish. Res. Bd. Canada 29:1737-1748

Smith, A.K. 1973. Development and application of spawning velocity and depth criteria for Oregon salmonids. Trans. Amer. Fish. Soc., 102(2):312-316

Stempel, J.M. 1984. Development of fish preference curves for spring chinook and rainbow trout in the Yakima River Basin. U.S. Fish Wildl. Serv., Ecological Sevices, Moses Lake, WA. 20 pp.

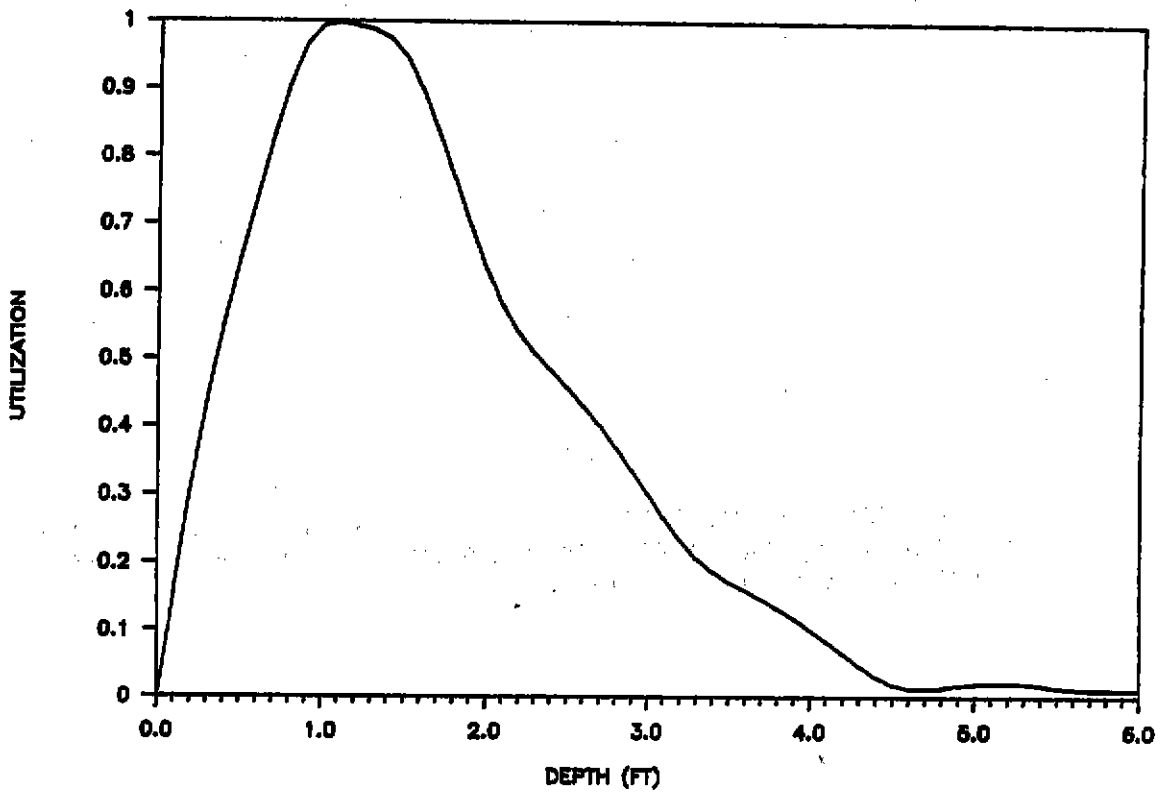
U.S. Fish & Wildlife Service. 1985. Life history information on juvenile chinook salmon in the lower American River. Report to the Bureau of Reclamation, American River Studies. U.S. Fish Wildl. Serv., Division of Ecological Services, Sacramento, CA.

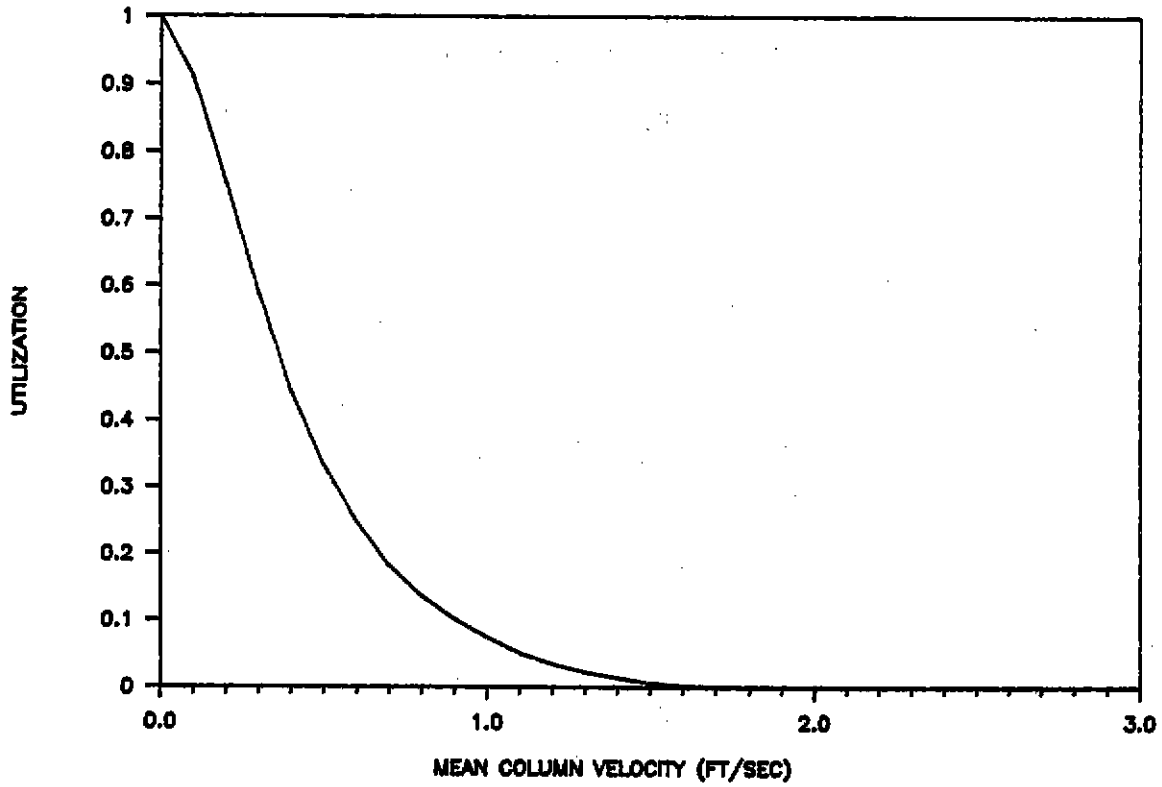
Vincent-Lang, D., A. Hoffman, A. Bingham, and C. Estes. 1984. Habitat suitability criteria for chinook, coho, and pink salmon spawning in tributaries of the middle Susitna River. Chapter 9 in C.C. Estes, and D.S. Vincent-Lang, eds. Aquatic habitat and instream flow investigations (May-October 1983). Alaska Dept. Fish Game Susitna Hydro Aquatic Studies Report No. 3, Anchorage.

Vogel, D.A. 1982. Preferred spawning velocities, depths, and substrates for fall chinook salmon in Battle Creek, California. USDI Fish Wildl. Serv., Fisheries Assistance Office, Red Bluff, CA. 8 pp.

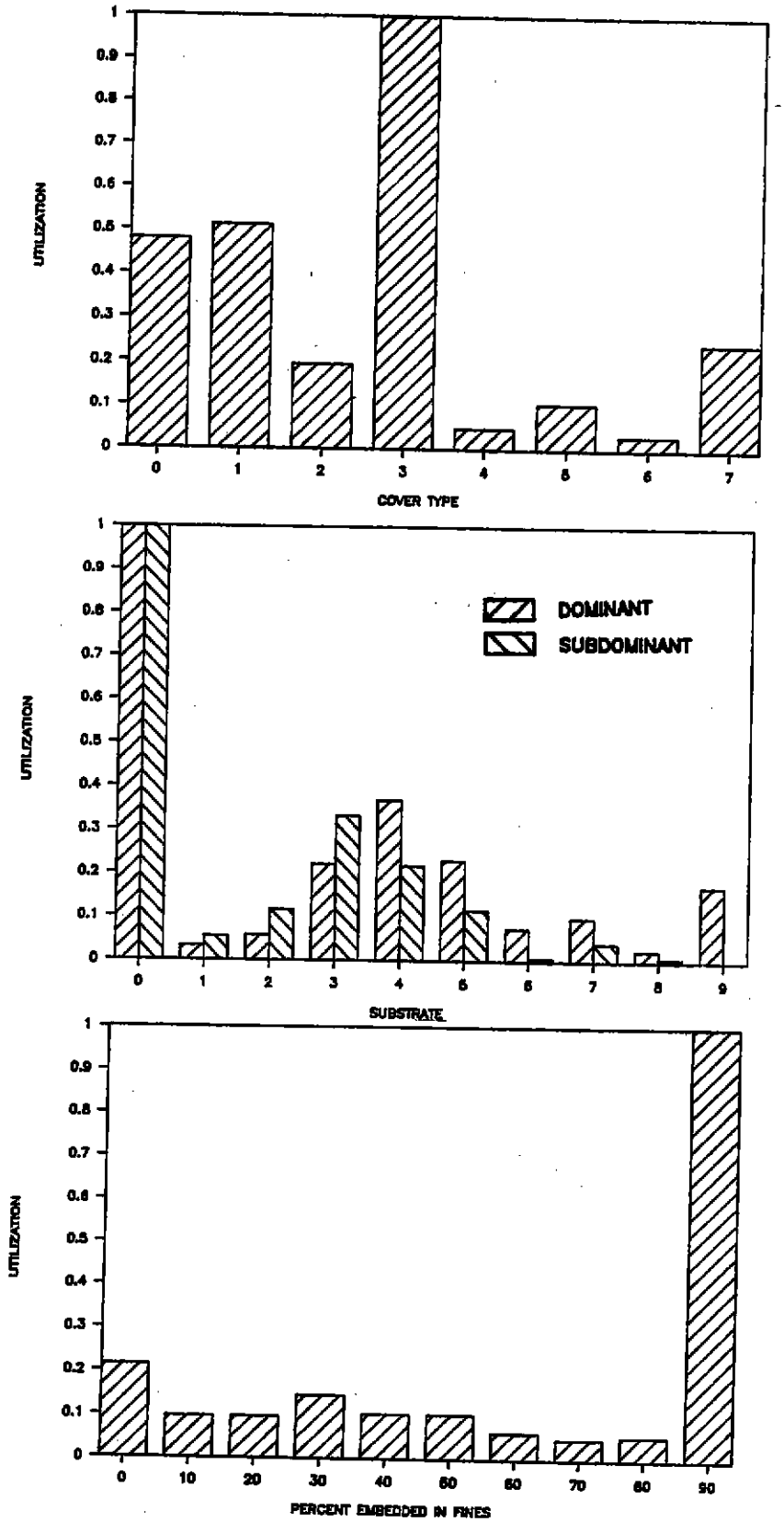
APPENDIX A

HABITAT UTILIZATION CRITERIA FOR FRY, JUVENILE, AND SPAWNING LIFESTAGES OF THE ANADROMOUS SALMONIDS OF THE UPPER TRINITY RIVER, CALIFORNIA, 1985-1987.



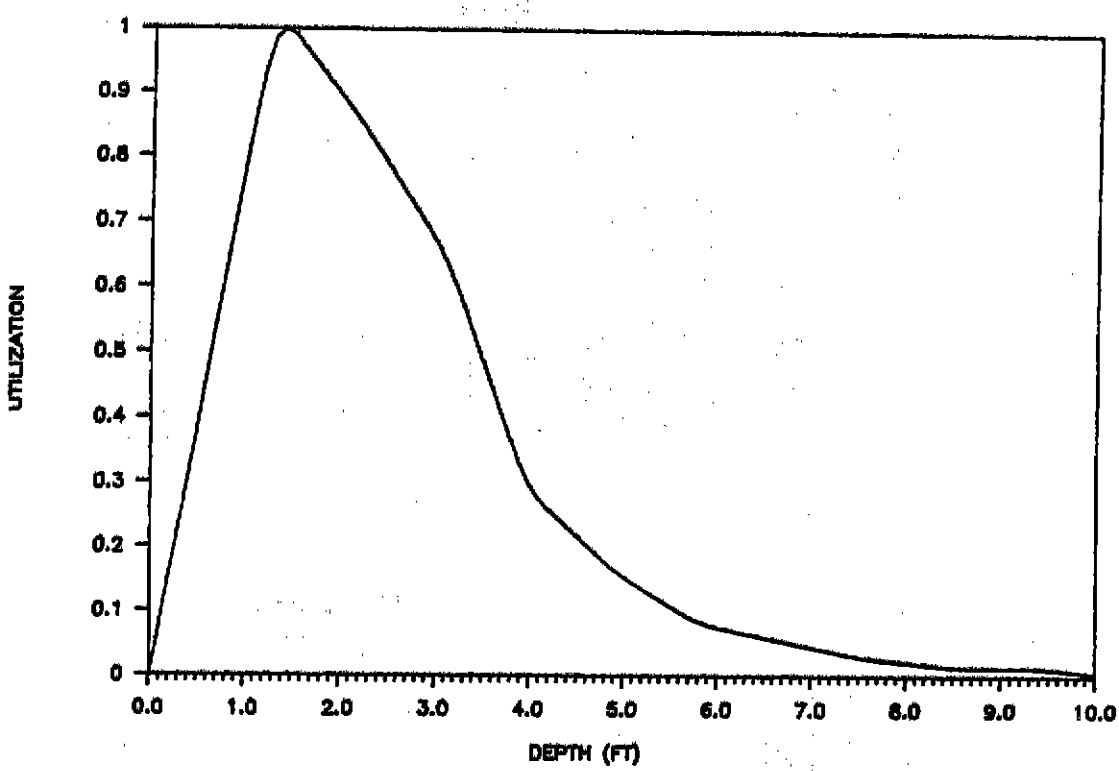


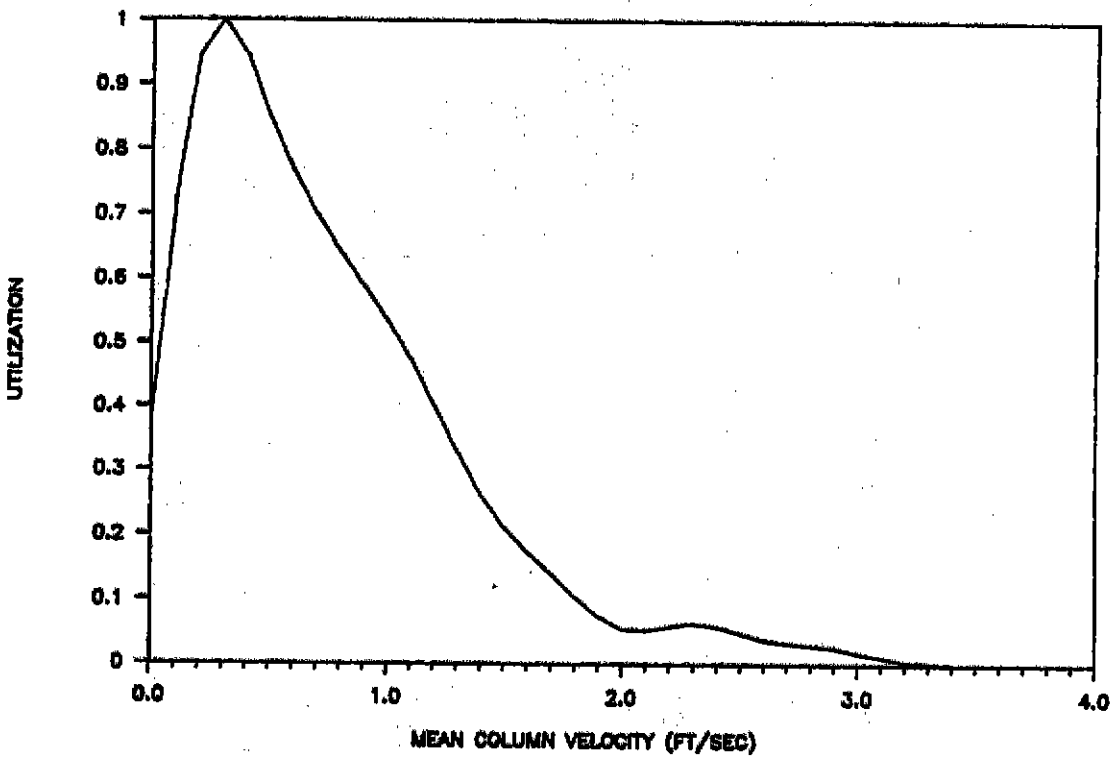
Habitat utilization criteria describing total depths and mean column velocites selcted by chinook salmon fry in the upper Trinity River, CA., 1985-1987.



Habitat utilization criteria describing cover and substrates selected by chinook salmon fry in the upper Trinity River, CA., 1985-1987.

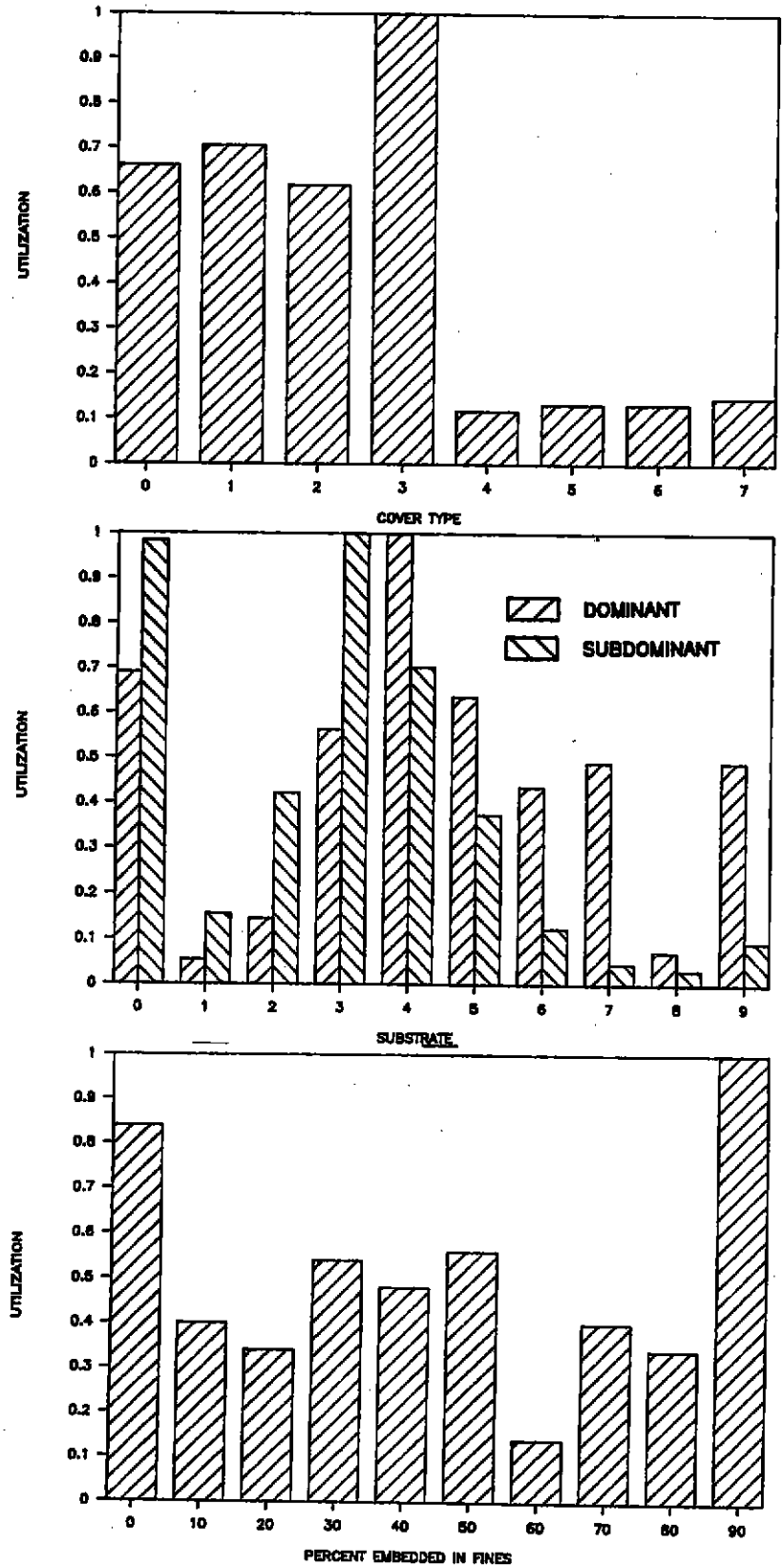
APPENDIX A



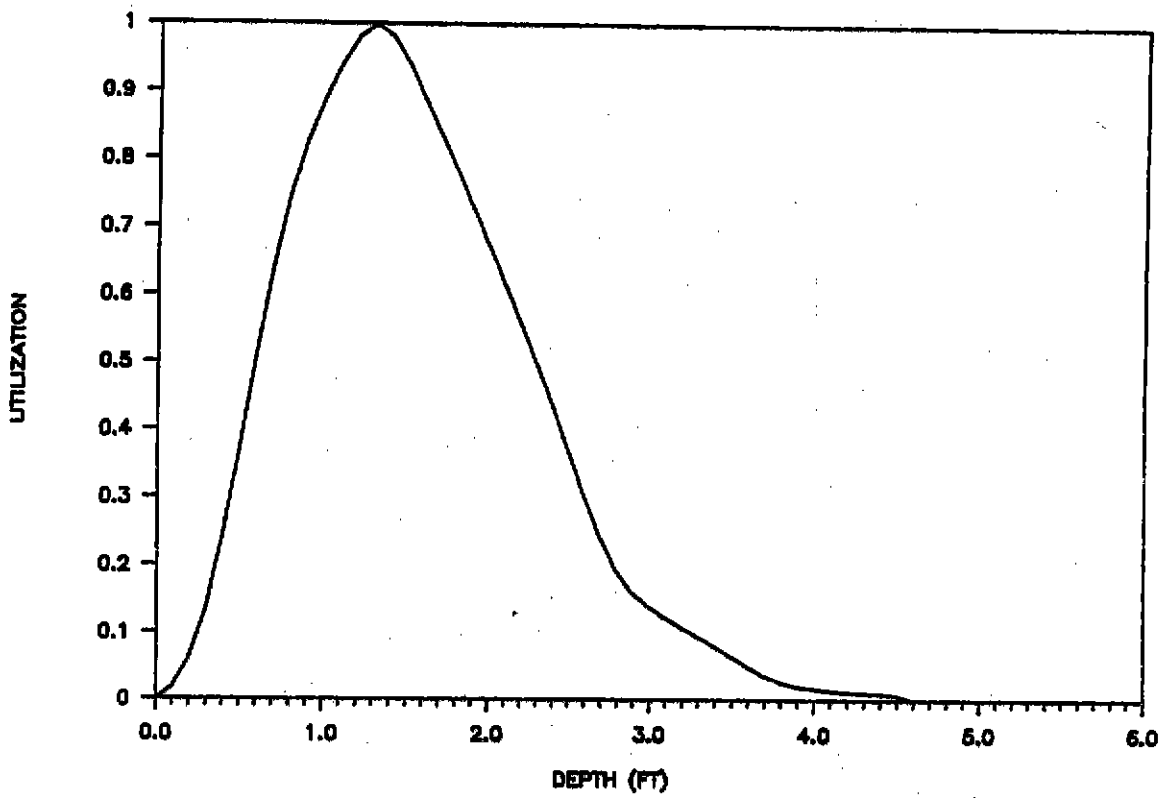


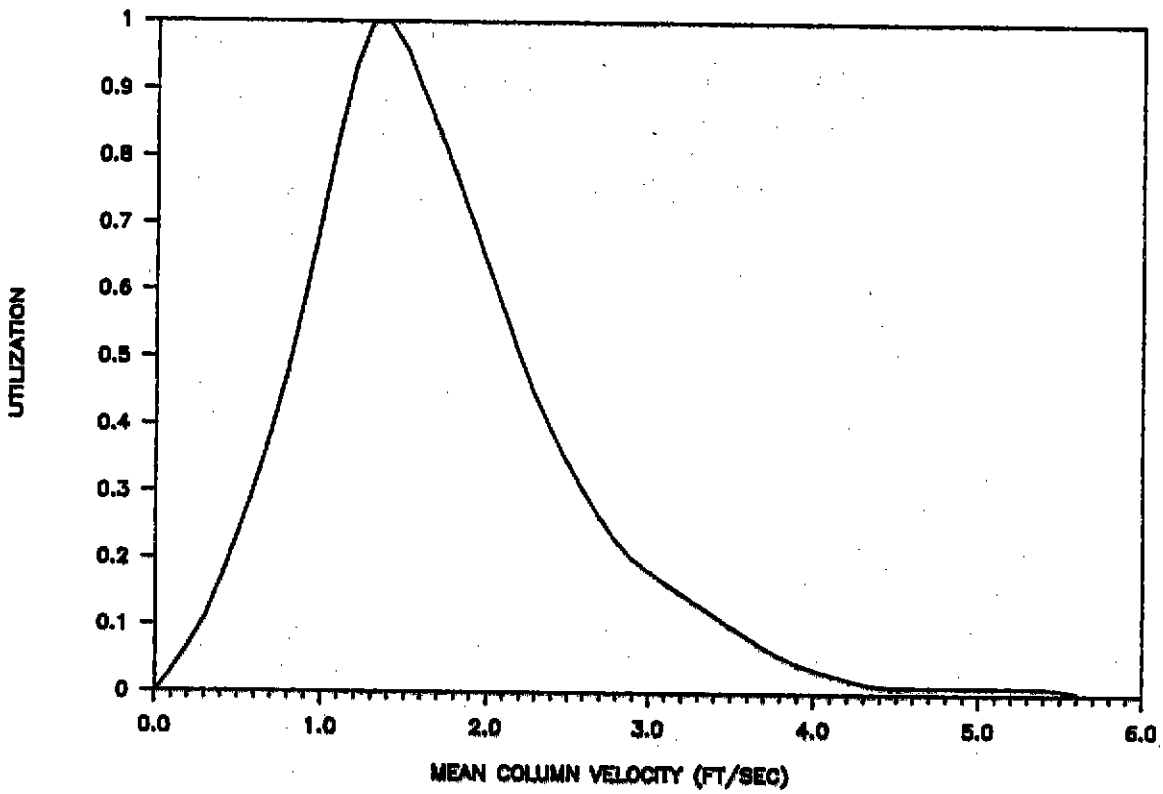
Habitat utilization criteria describing total depths and mean column velocites selcted by chinook salmon juveniles in the upper Trinity River, CA., 1985-1987.

APPENDIX A

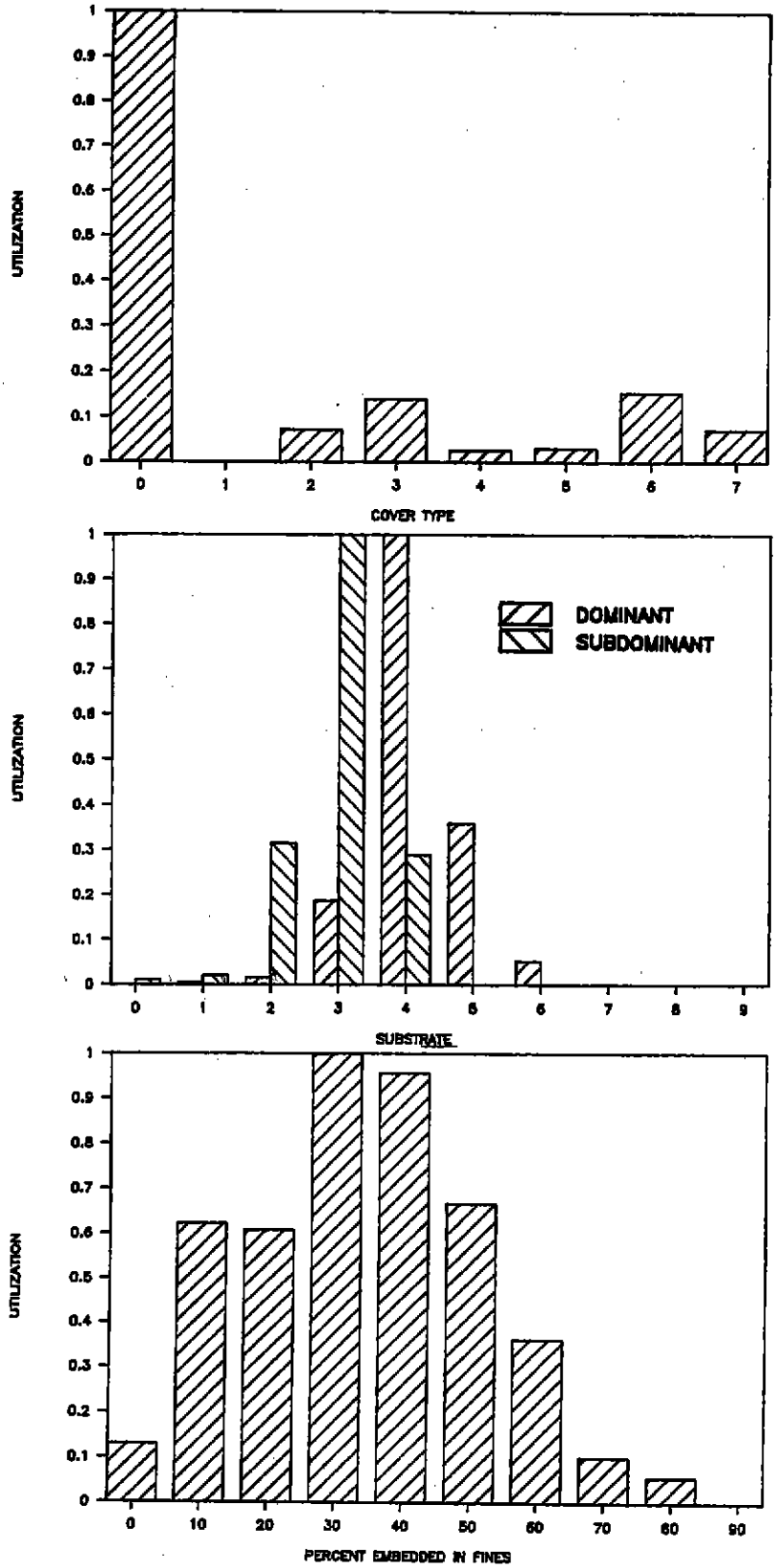


Habitat utilization criteria describing cover and substrates selected by chinook salmon juveniles in the upper Trinity River, CA., 1985-1987.

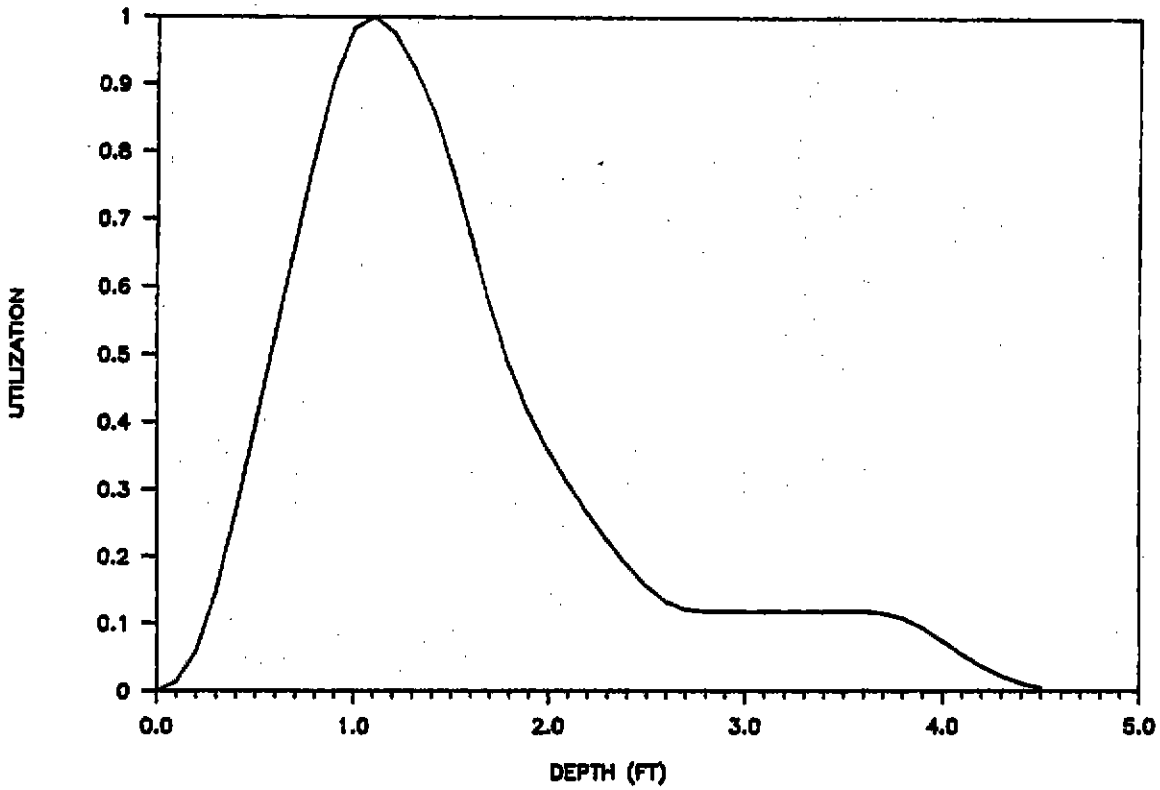


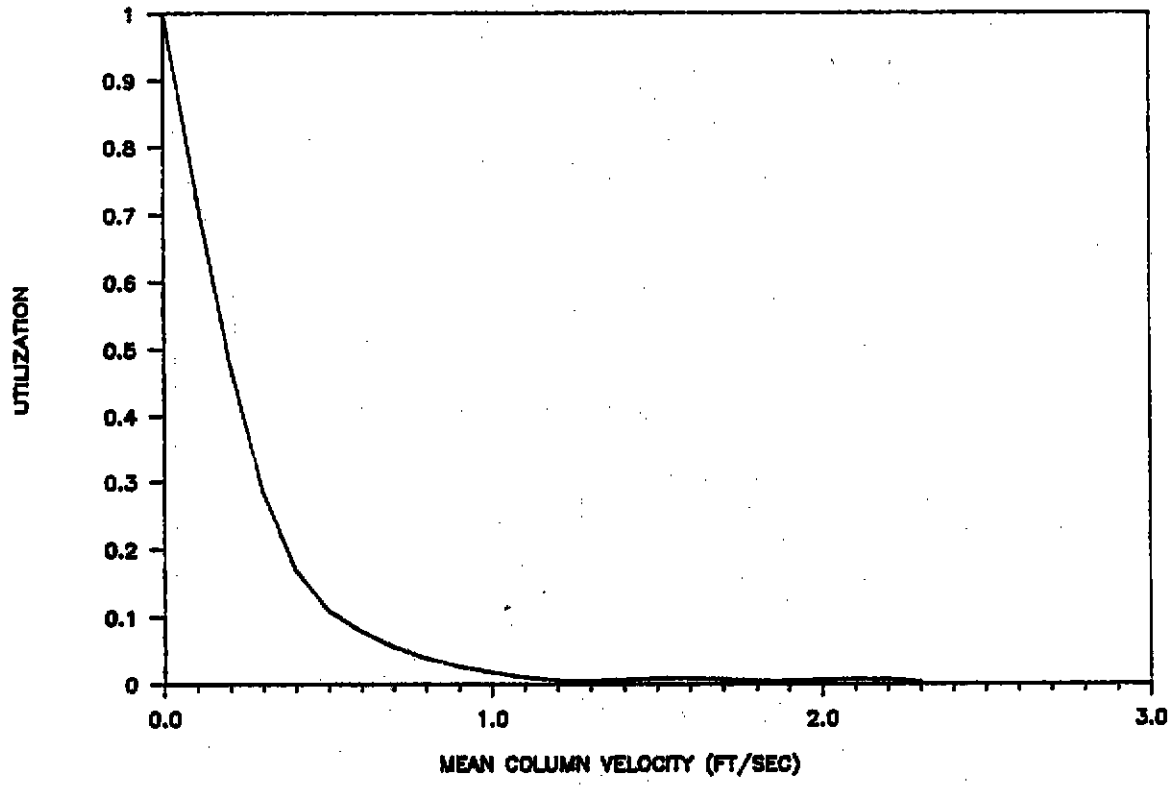


Habitat utilization criteria describing total depths and mean column velocites selcted by spawning chinook salmon in the upper Trinity River, CA., 1985-1987.

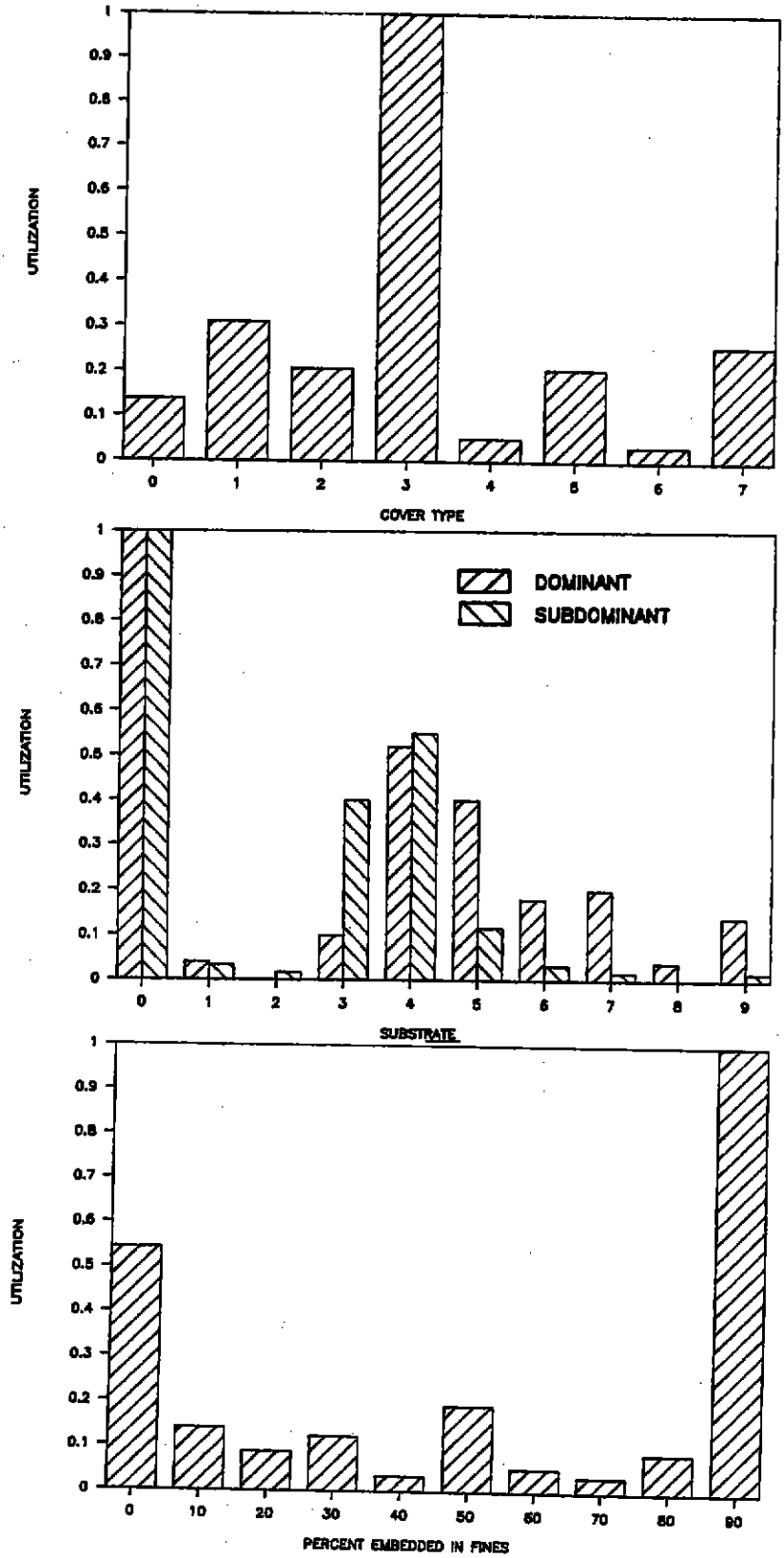


Habitat utilization criteria describing cover and substrates selected by spawning chinook salmon in the upper Trinity River, CA., 1985-1987.



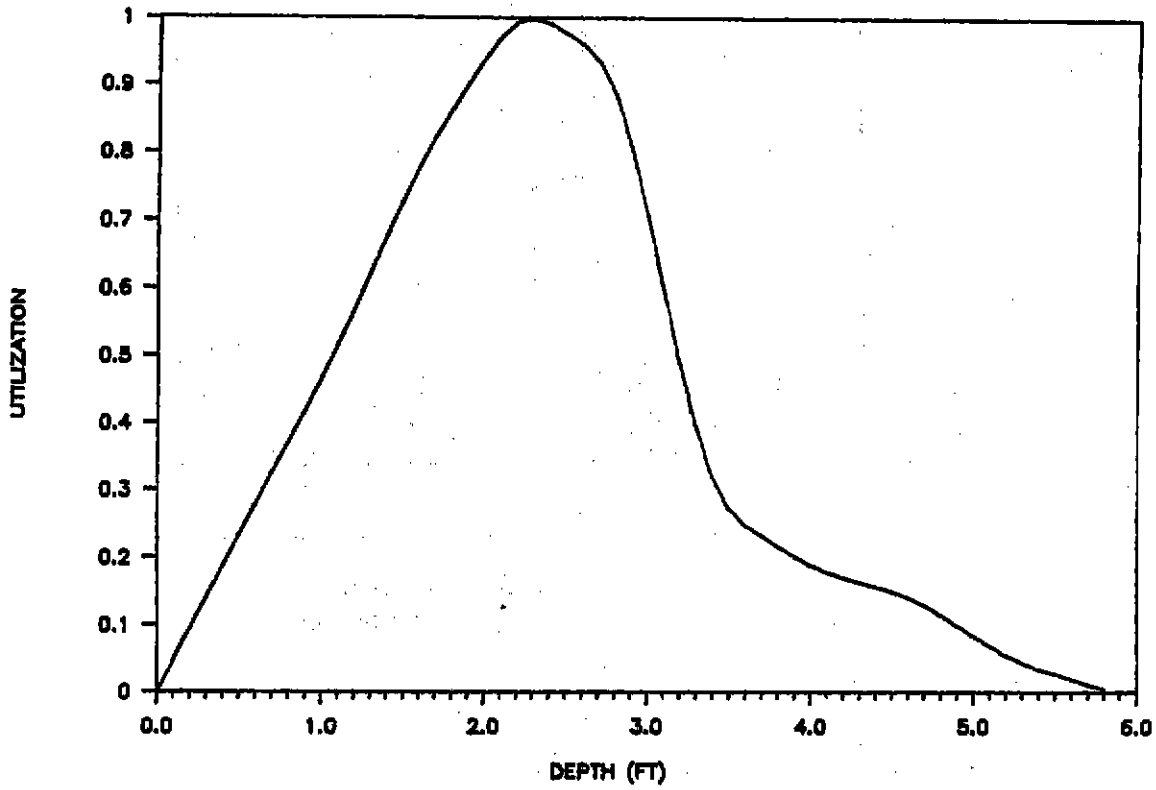


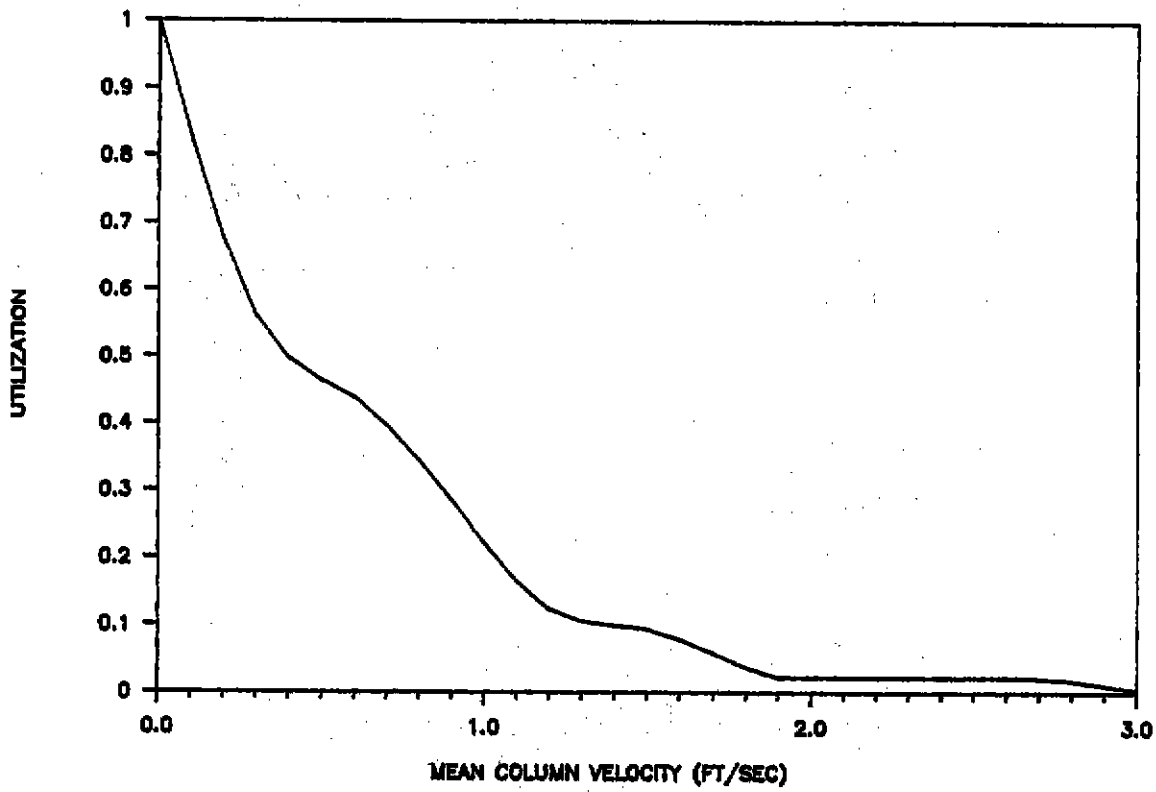
Habitat utilization criteria describing total depths and mean column velocites selcted by coho salmon fry in the upper Trinity River, CA., 1985-1987.



Habitat utilization criteria describing cover and substrates selected by coho salmon fry in the upper Trinity River, CA., 1985-1987.

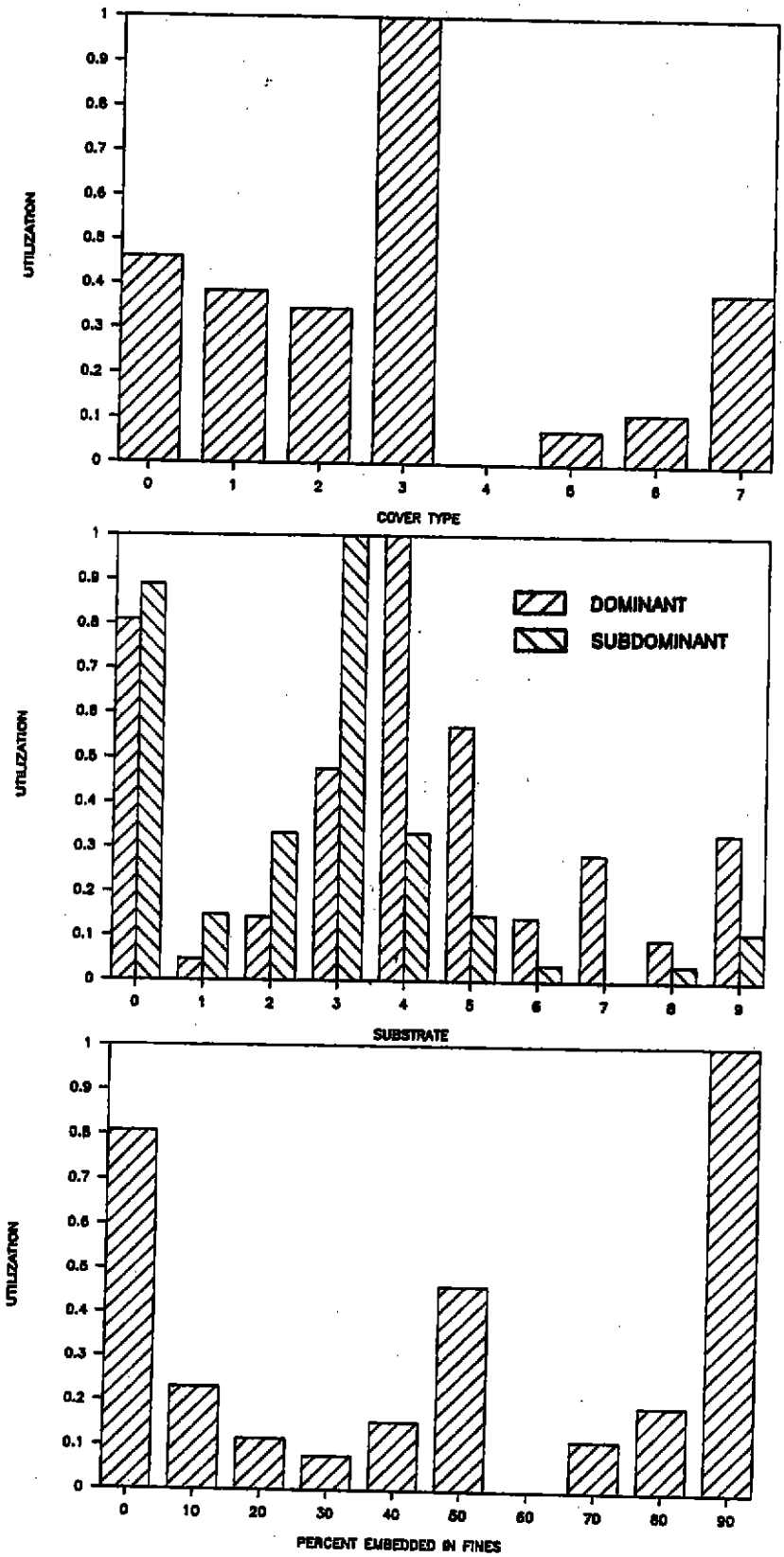
APPENDIX A



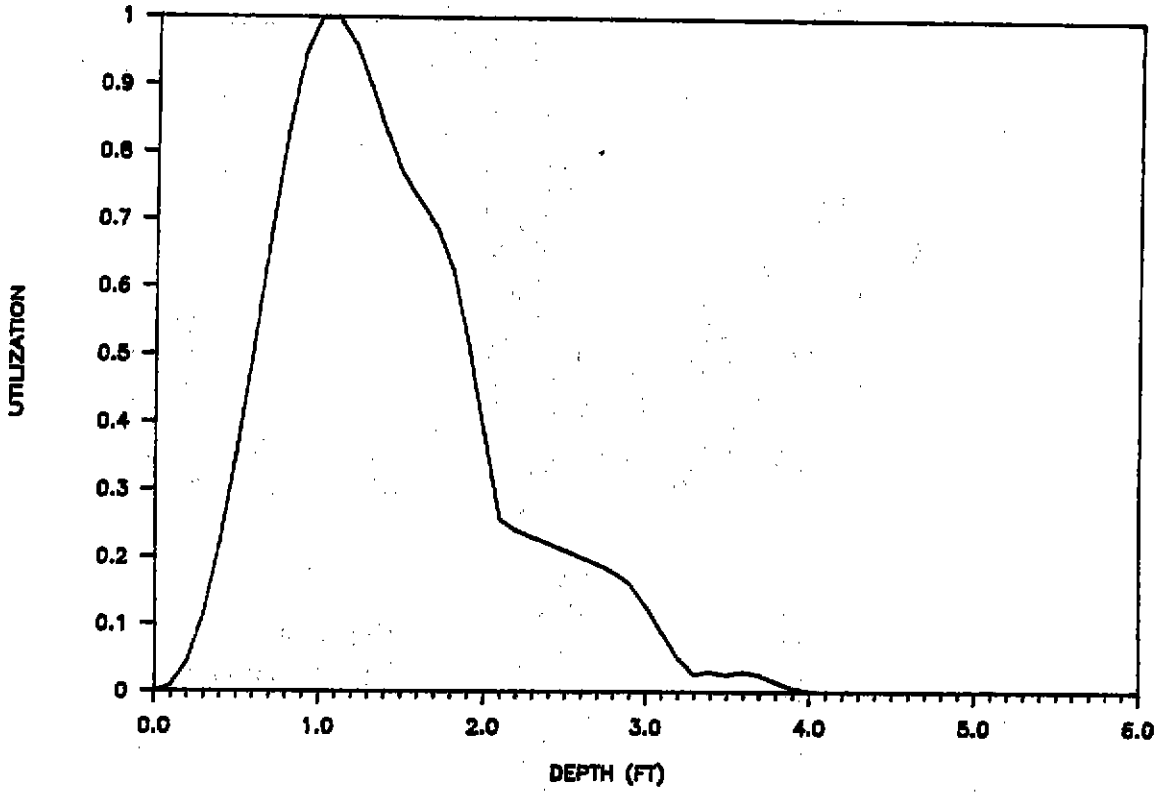


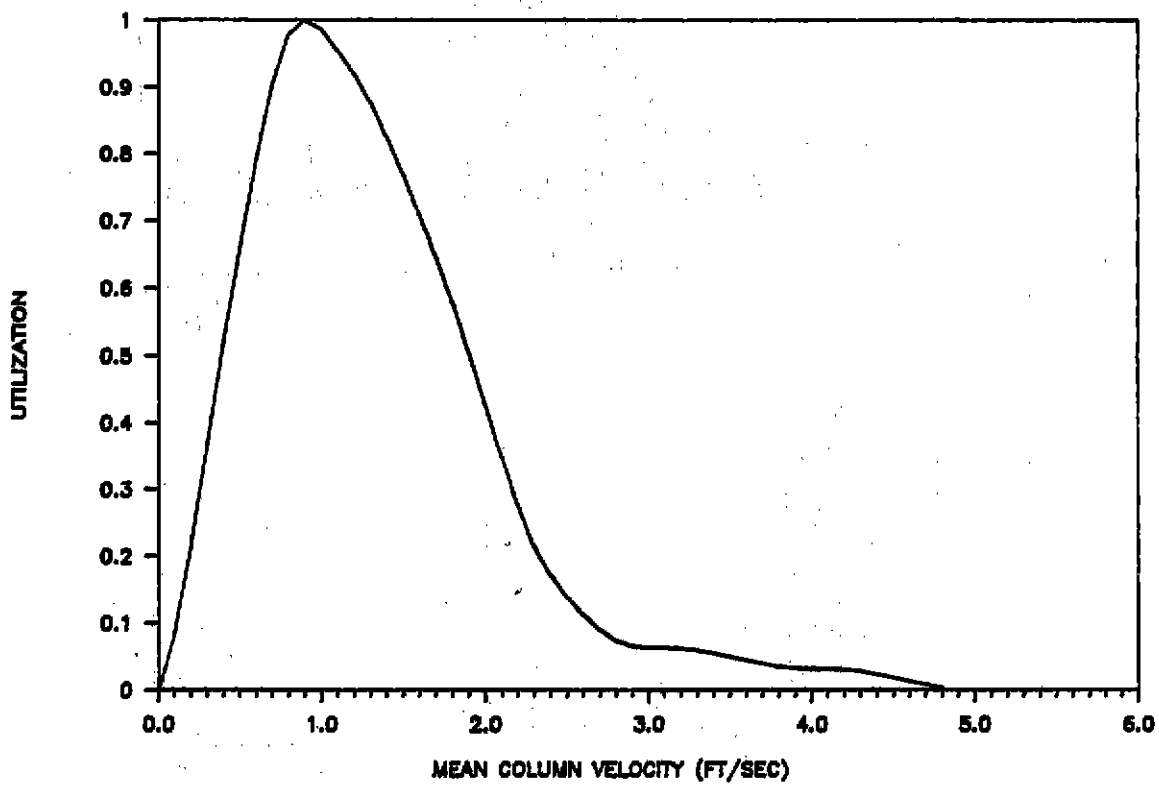
Habitat utilization criteria describing total depths and mean column velocites selcted by coho salmon juveniles in the upper Trinity River, CA., 1985-1987.

APPENDIX A



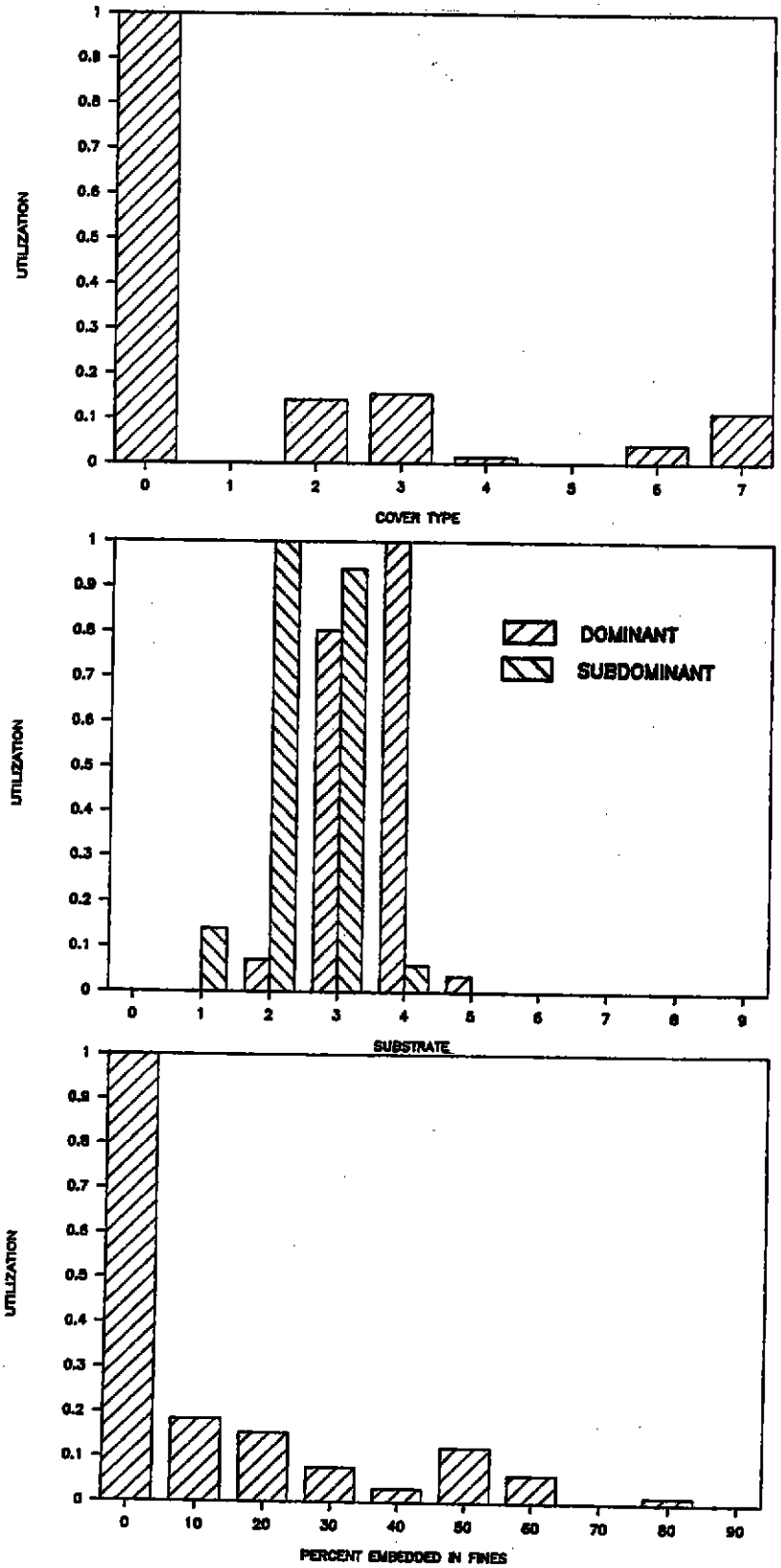
Habitat utilization criteria describing cover and substrates selected by coho salmon juveniles in the upper Trinity River, CA., 1985-1987.



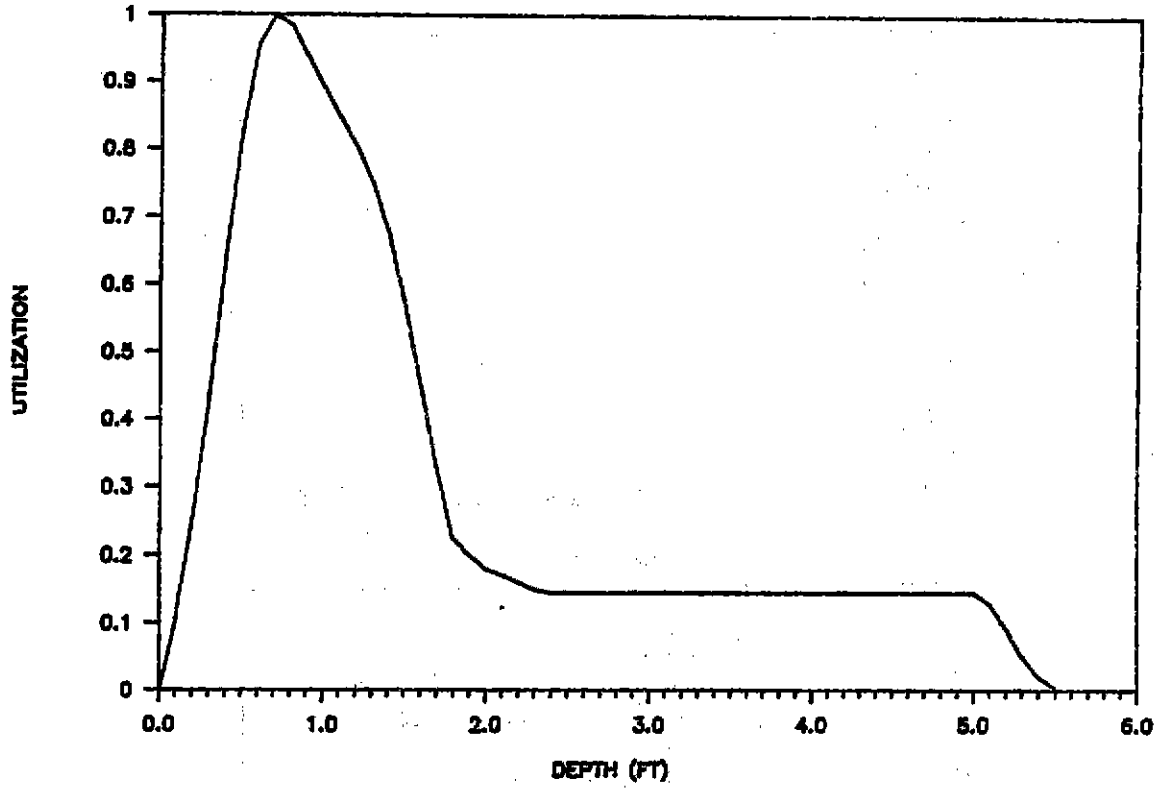


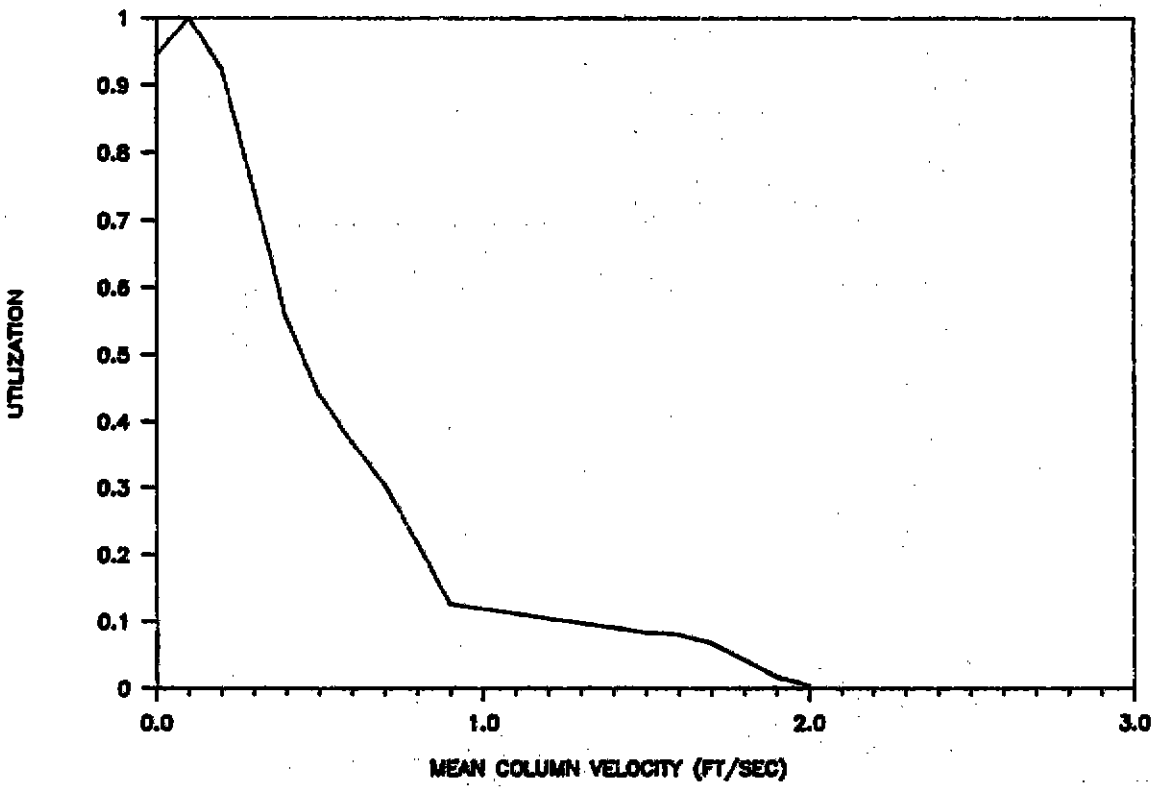
Habitat utilization criteria describing total depths and mean column velocites selcted by spawning coho salmon in the upper Trinity River, CA., 1985-1987.

APPENDIX A

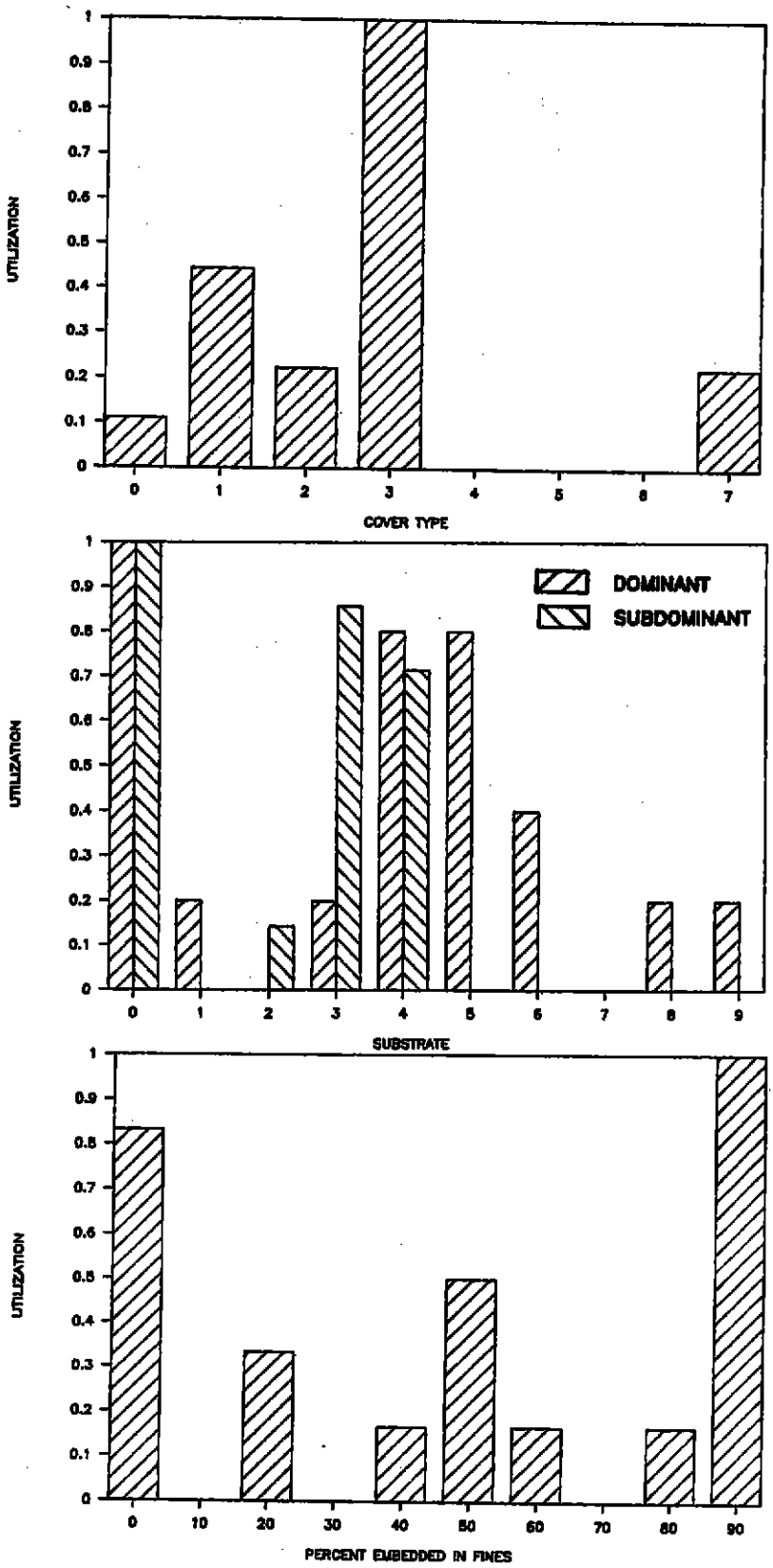


Habitat utilization criteria describing cover and substrates selected by spawning coho salmon in the upper Trinity River, CA., 1985-1987.

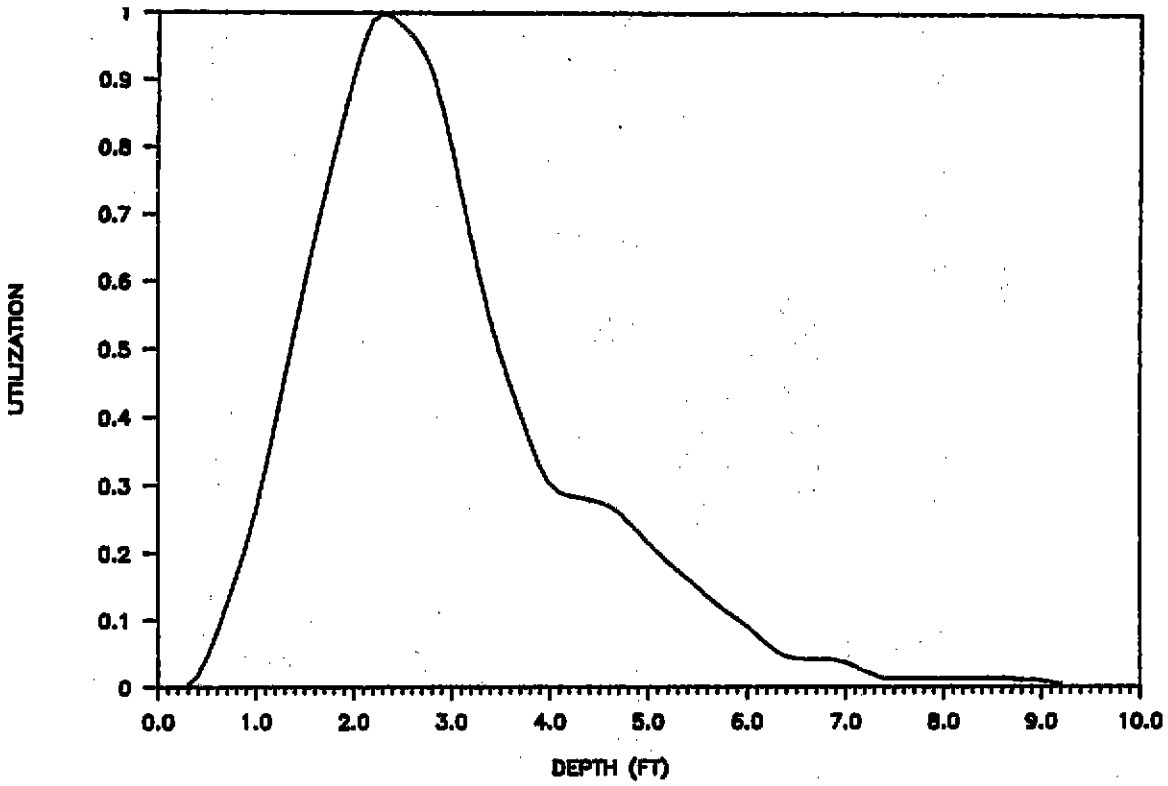


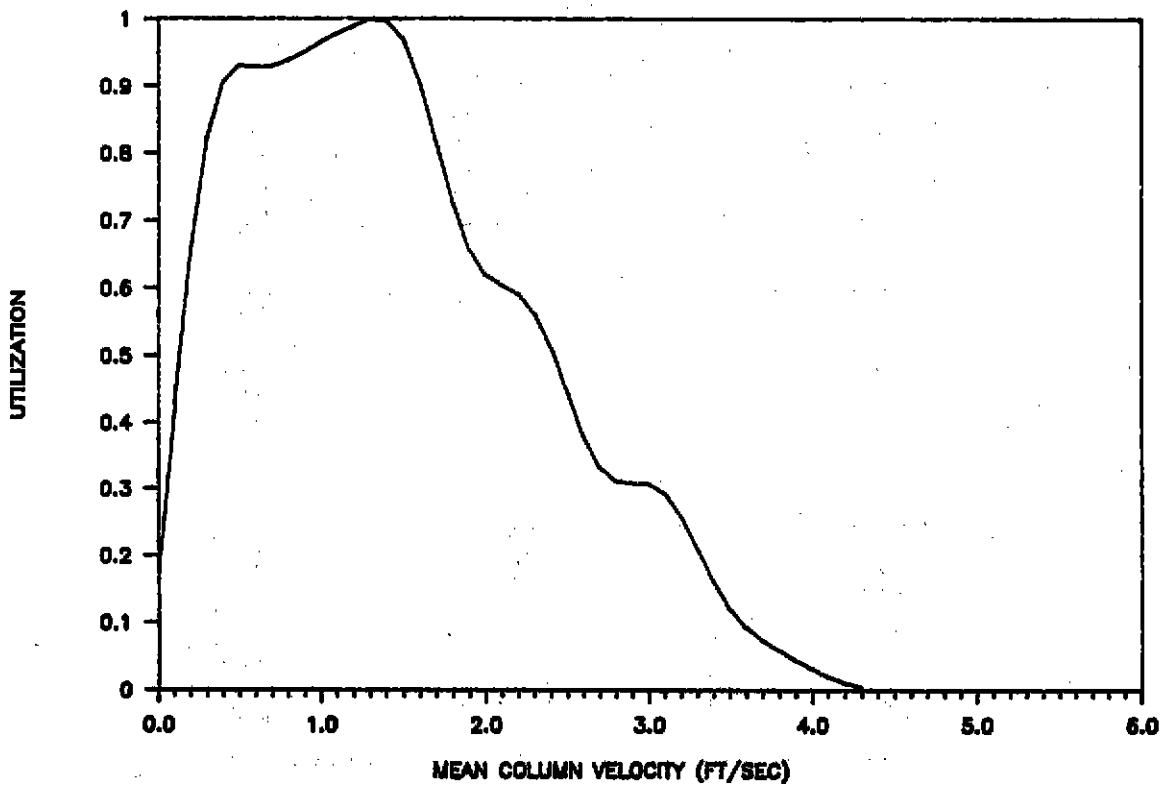


Habitat utilization criteria describing total depths and mean column velocites selcted by steelhead trout fry in the upper Trinity River, CA., 1985-1987.



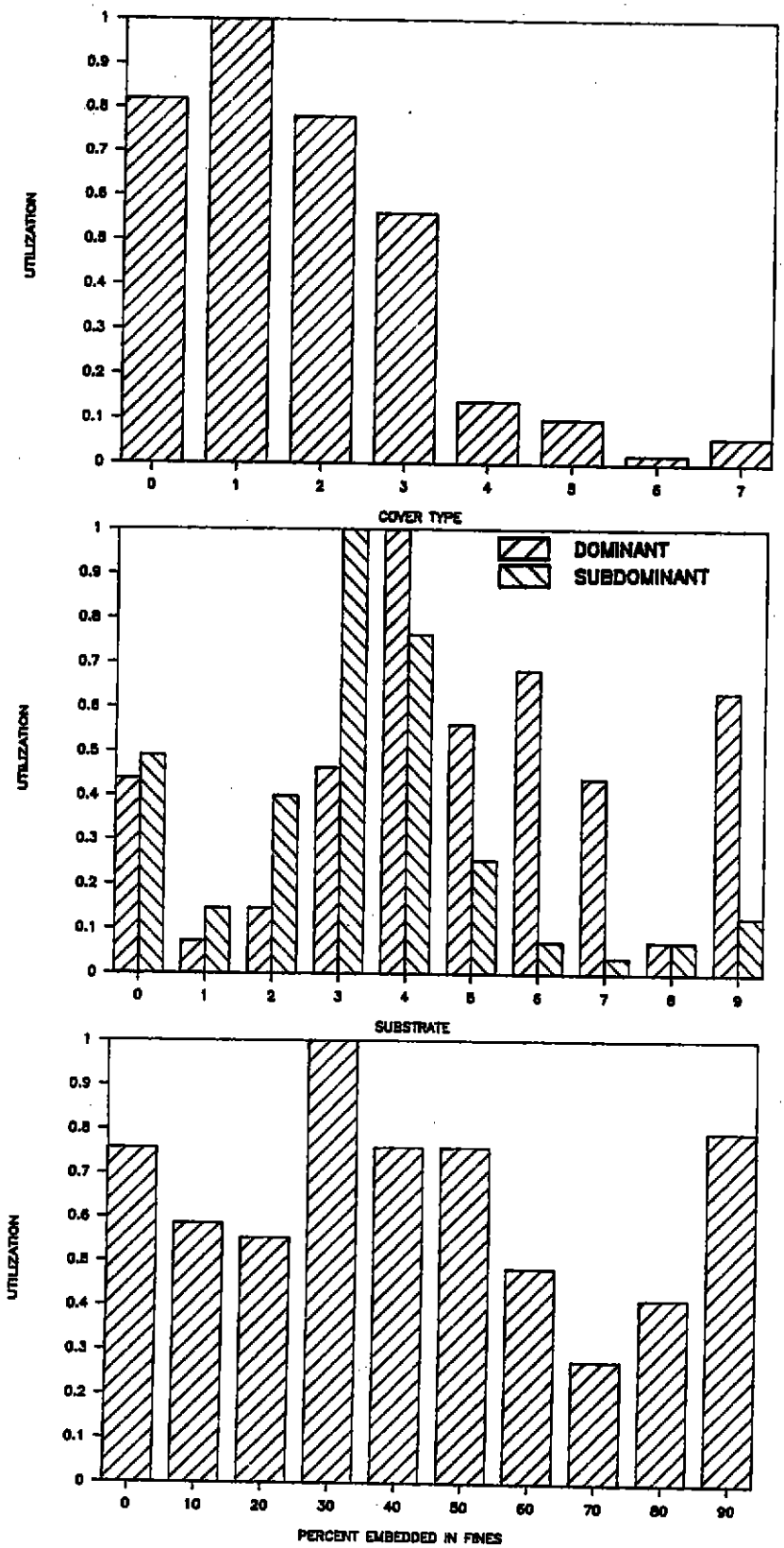
Habitat utilization criteria describing cover and substrates selected by steelhead trout fry in the upper Trinity River, CA., 1985-1987.





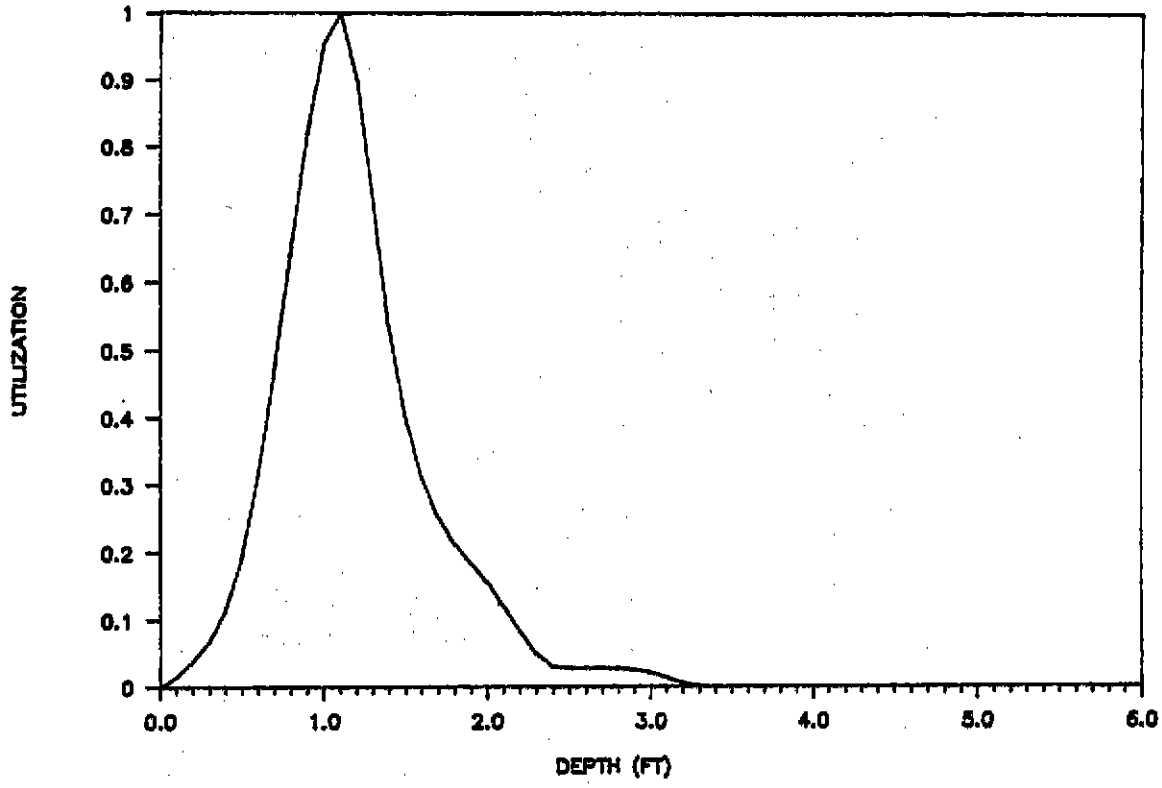
Habitat utilization criteria describing total depths and mean column velocites selcted by steelhead trout juveniles in the upper Trinity River, CA., 1985-1987.

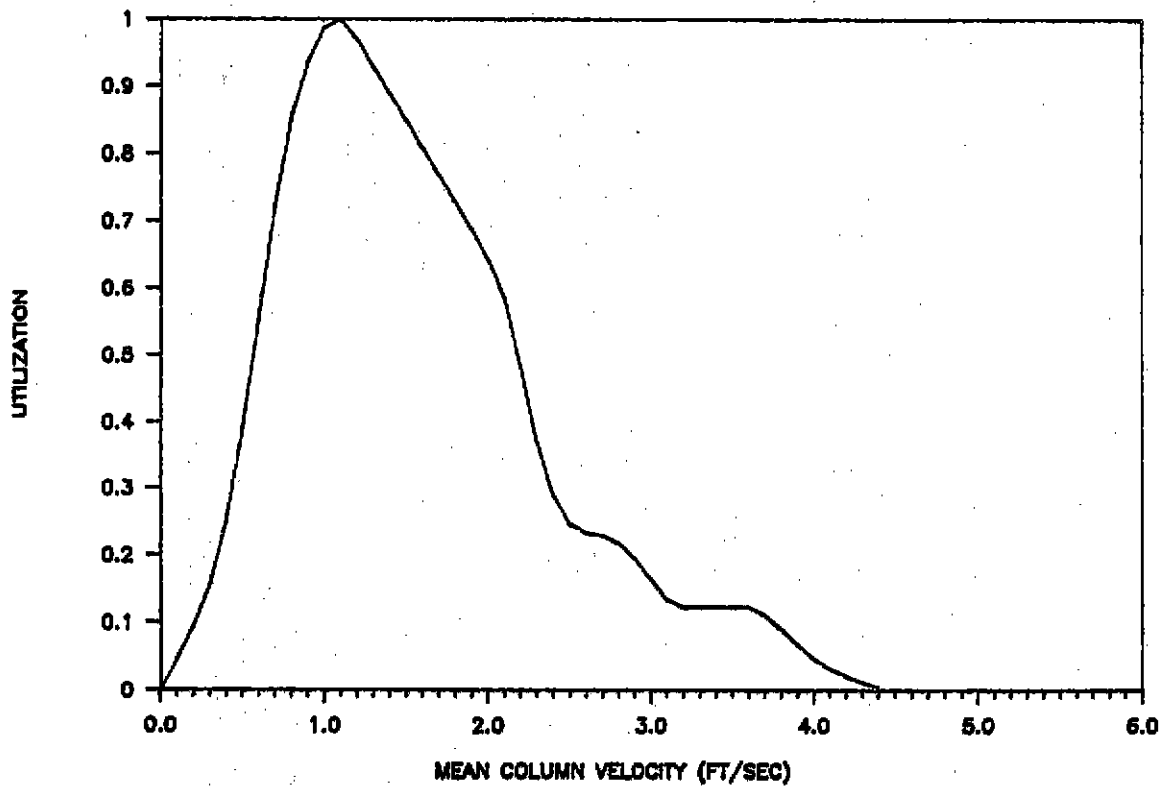
APPENDIX A



Habitat utilization criteria describing cover and substrates selected by steelhead trout juveniles in the upper Trinity River, CA., 1985-1987.

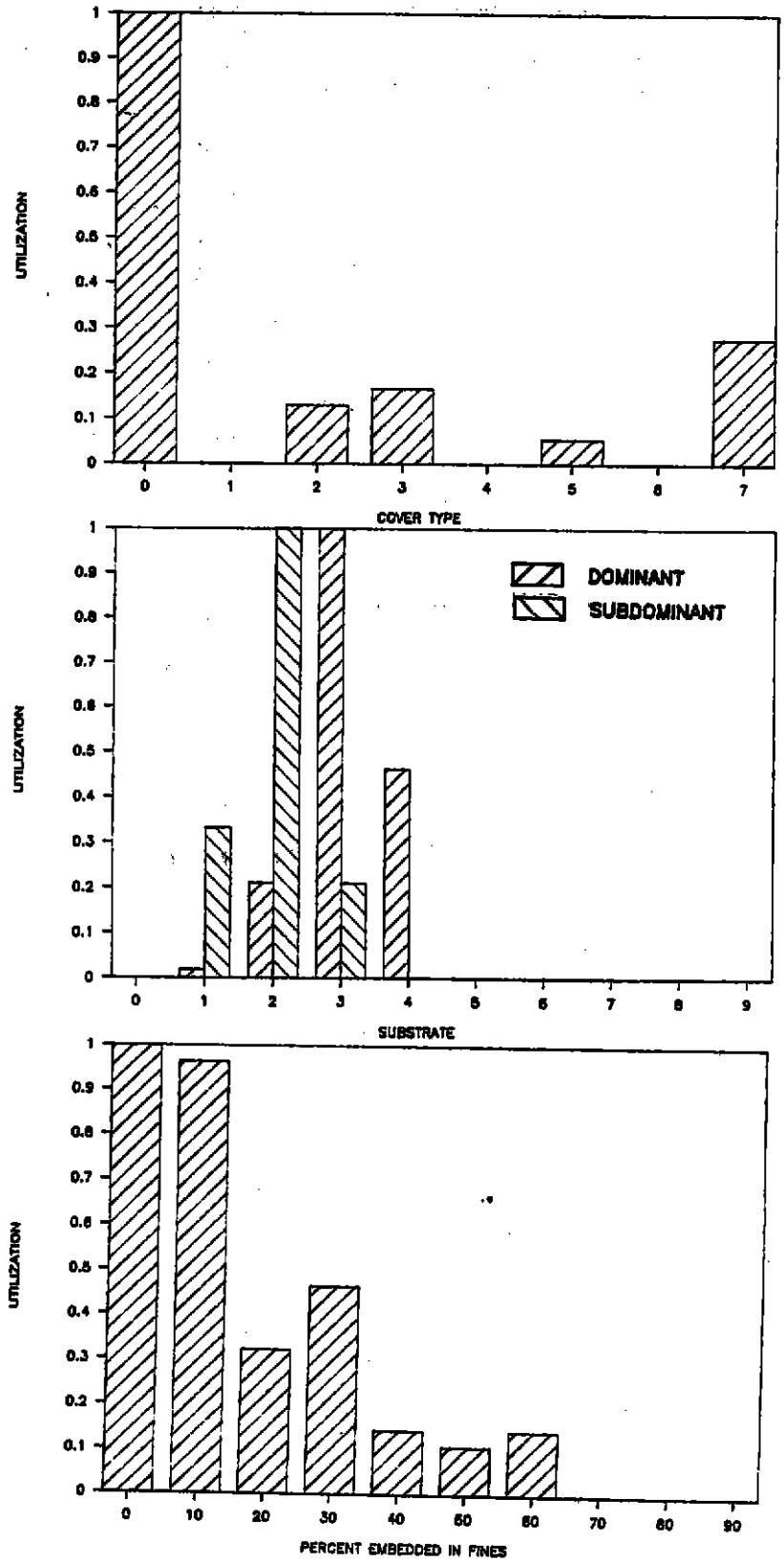
APPENDIX A



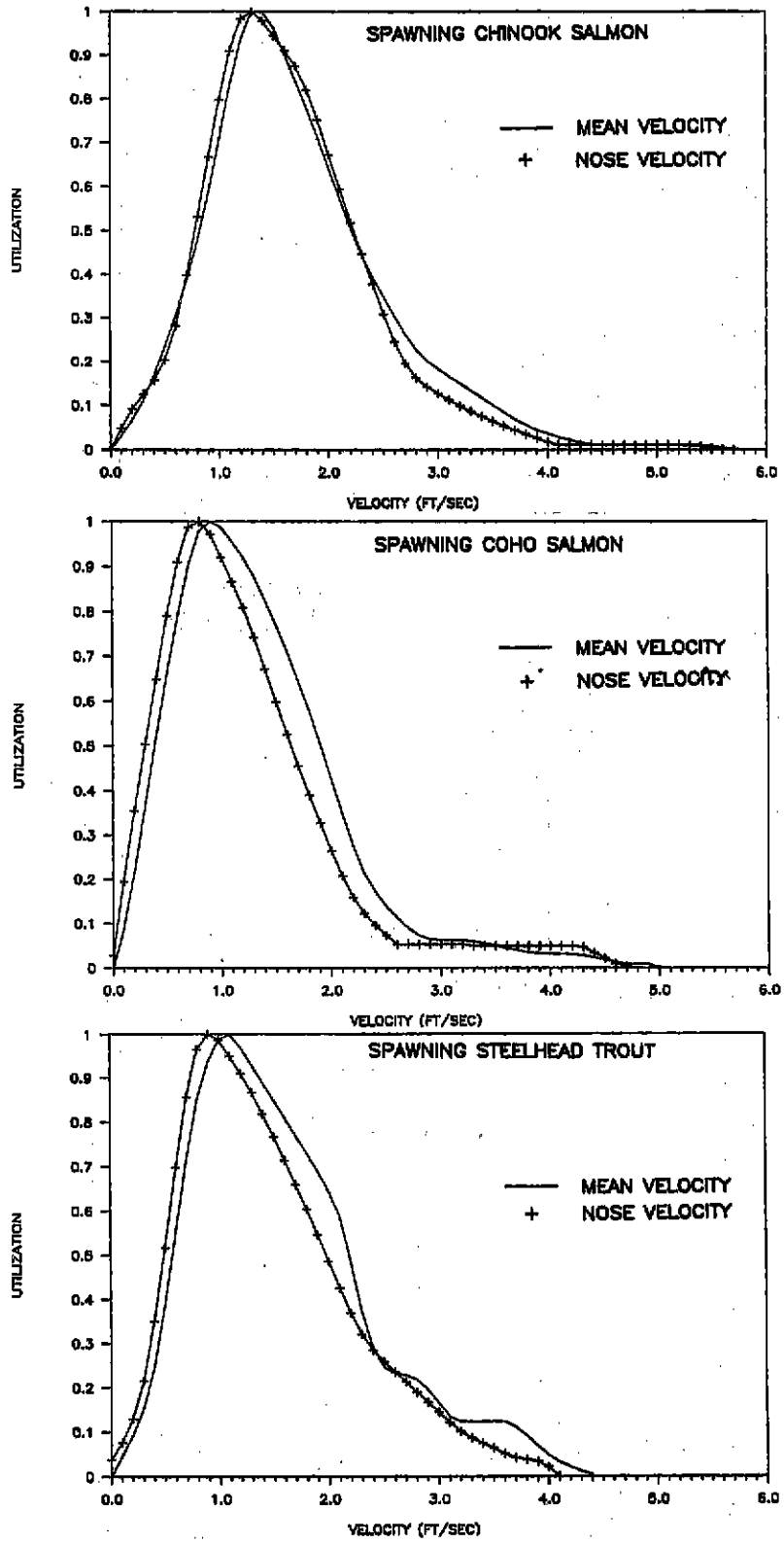


Habitat utilization criteria describing total depths and mean column velocites selcted by spawning steelhead trout in the upper Trinity River, CA., 1985-1987.

APPENDIX A



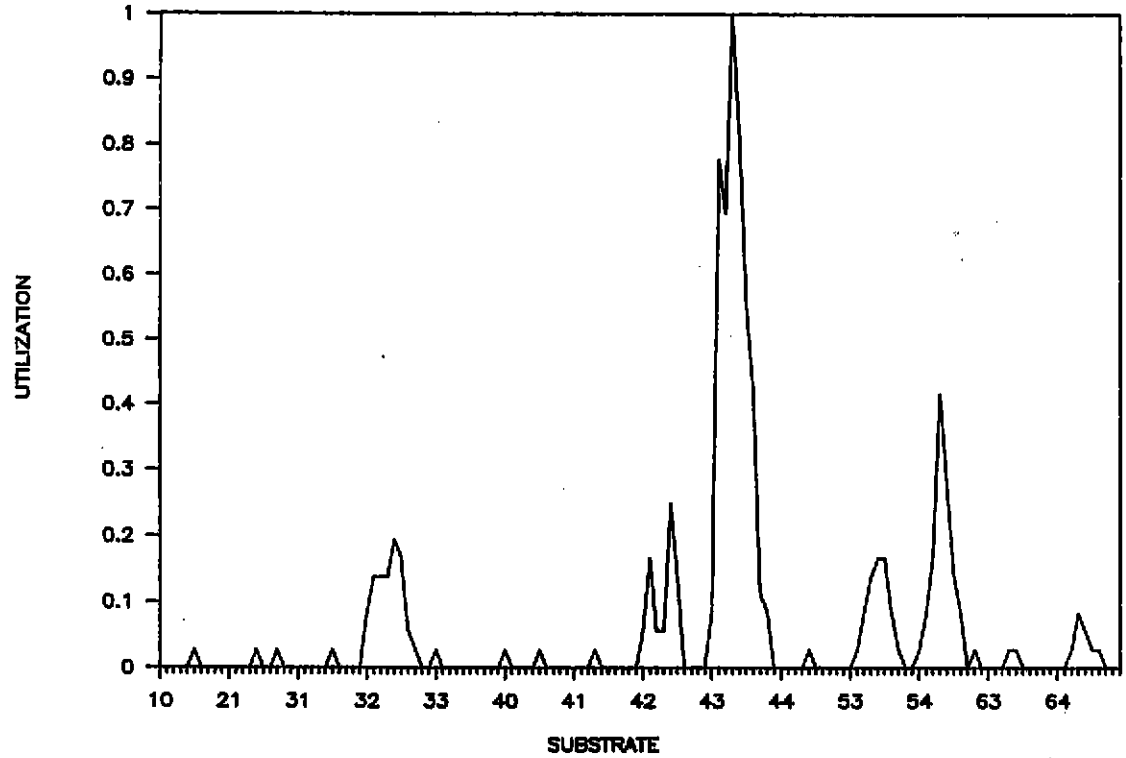
Habitat utilization criteria describing cover and substrates selected by spawning steelhead trout in the upper Trinity River, CA., 1985-1987.

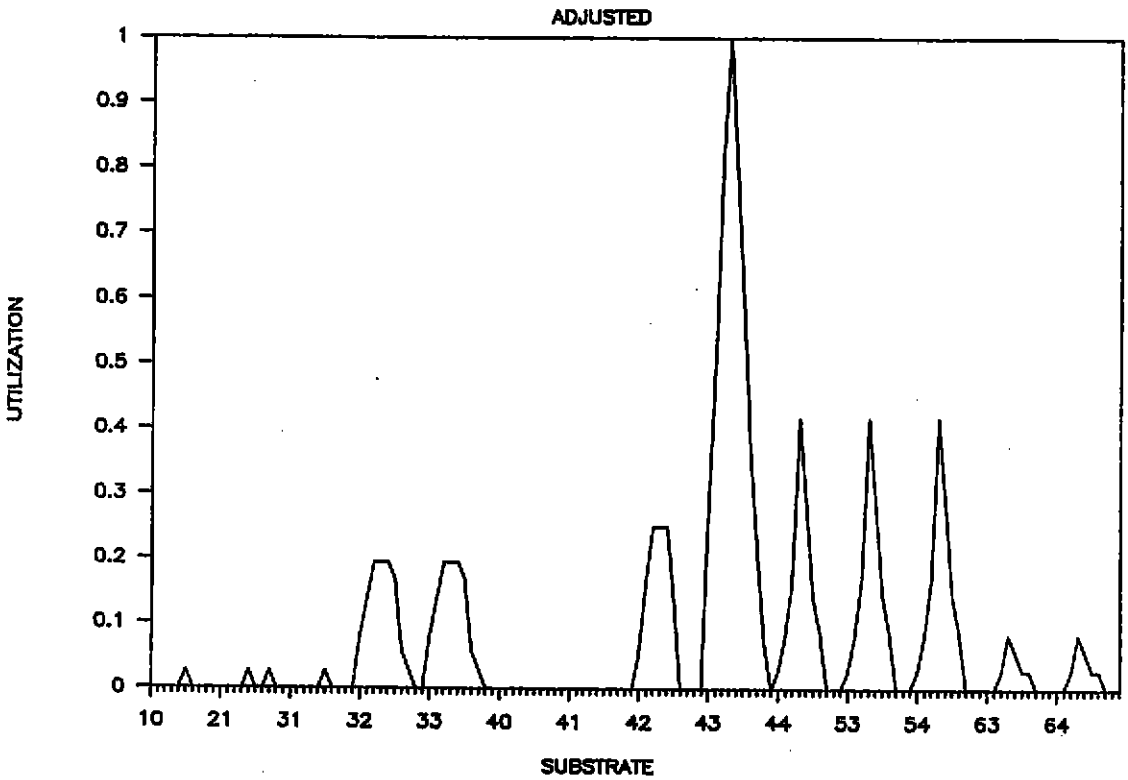


A comparison of habitat utilization criteria developed for fish nose velocities, taken at 0.4 feet, and mean column velocities selected by anadromous salmonids in the upper Trinity River, California, 1985-1987.

APPENDIX C

CHINOOK SALMON

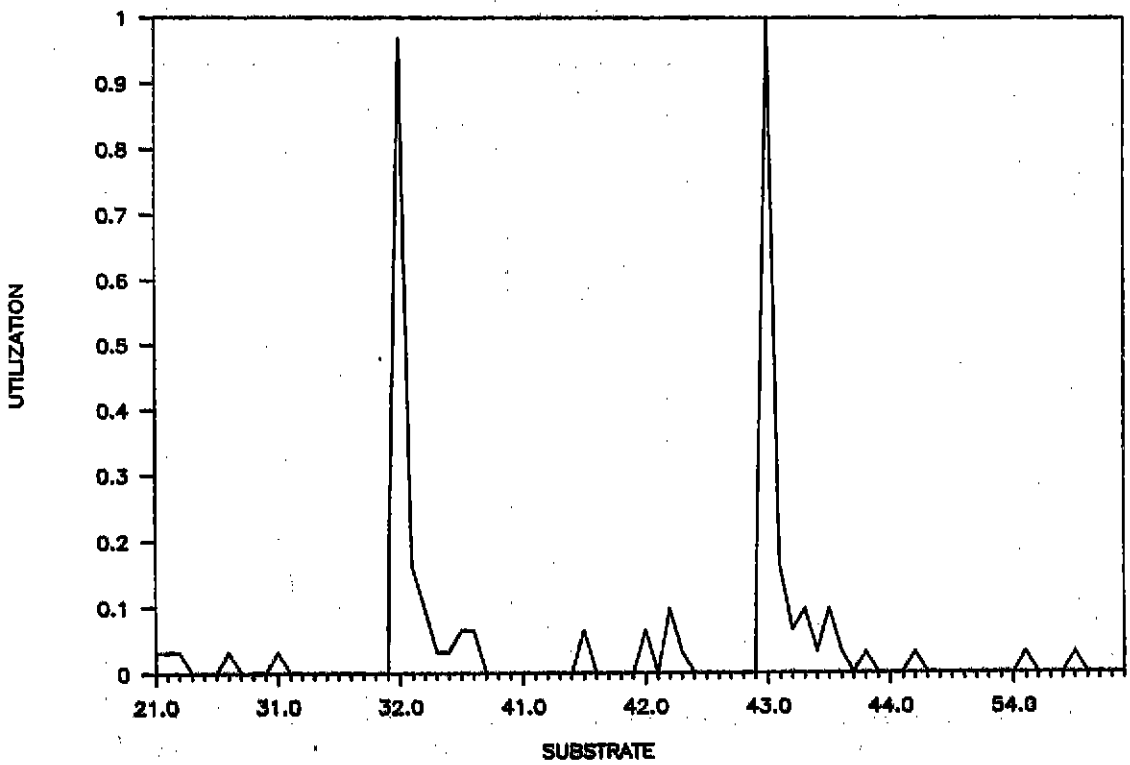




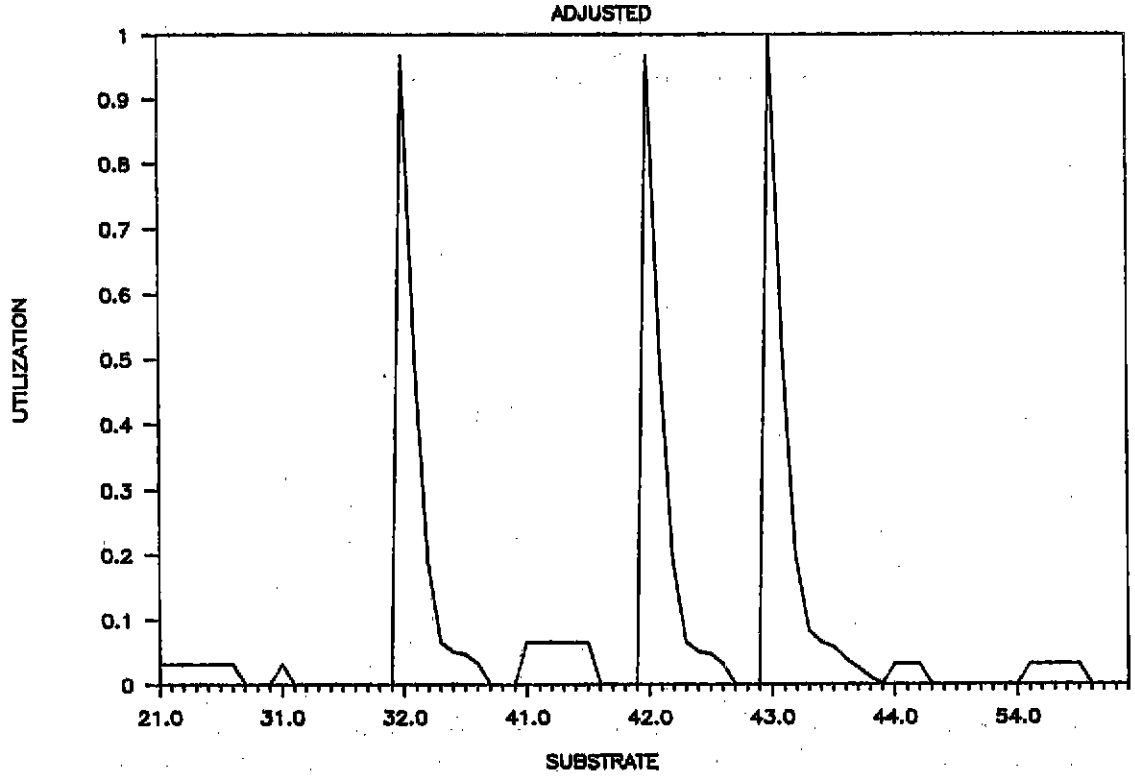
Habitat use criteria for substrates selected by spawning chinook salmon in the upper Trinity River as described with the Brusven Index. Use criteria as calculated is shown in the upper half of the Figure and adjusted use criteria is shown in the lower half of the Figure.

APPENDIX C

COHO SALMON



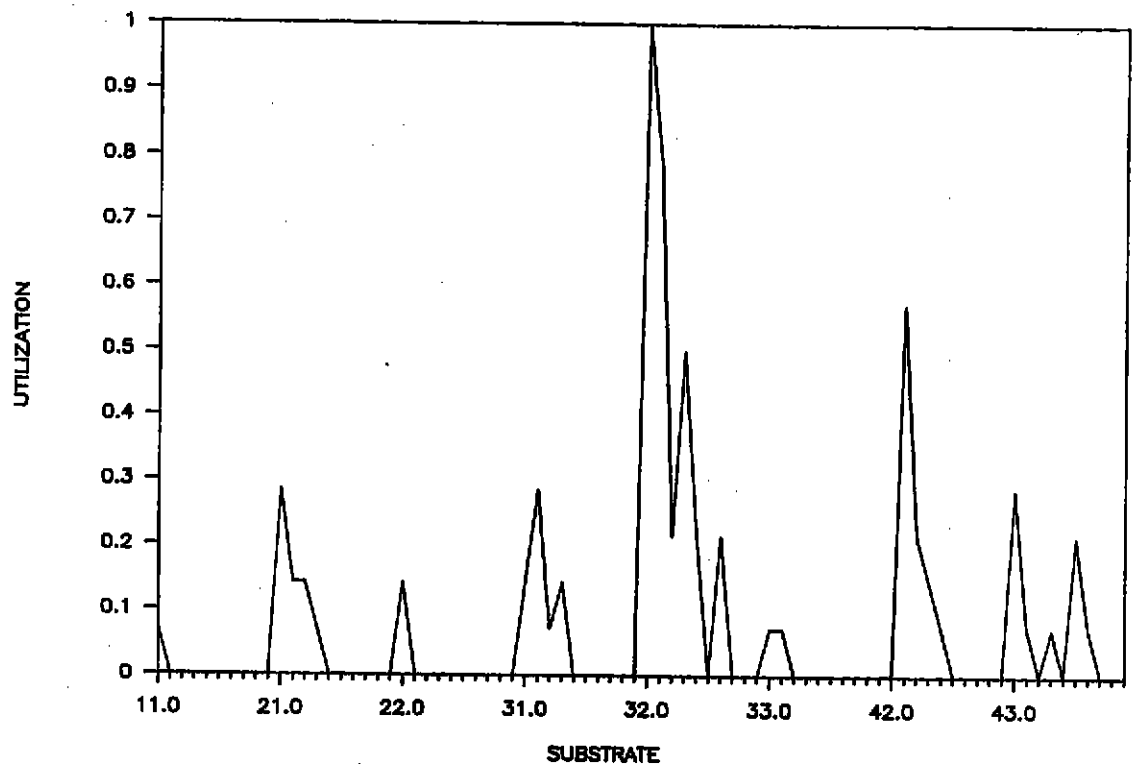
ADJUSTED

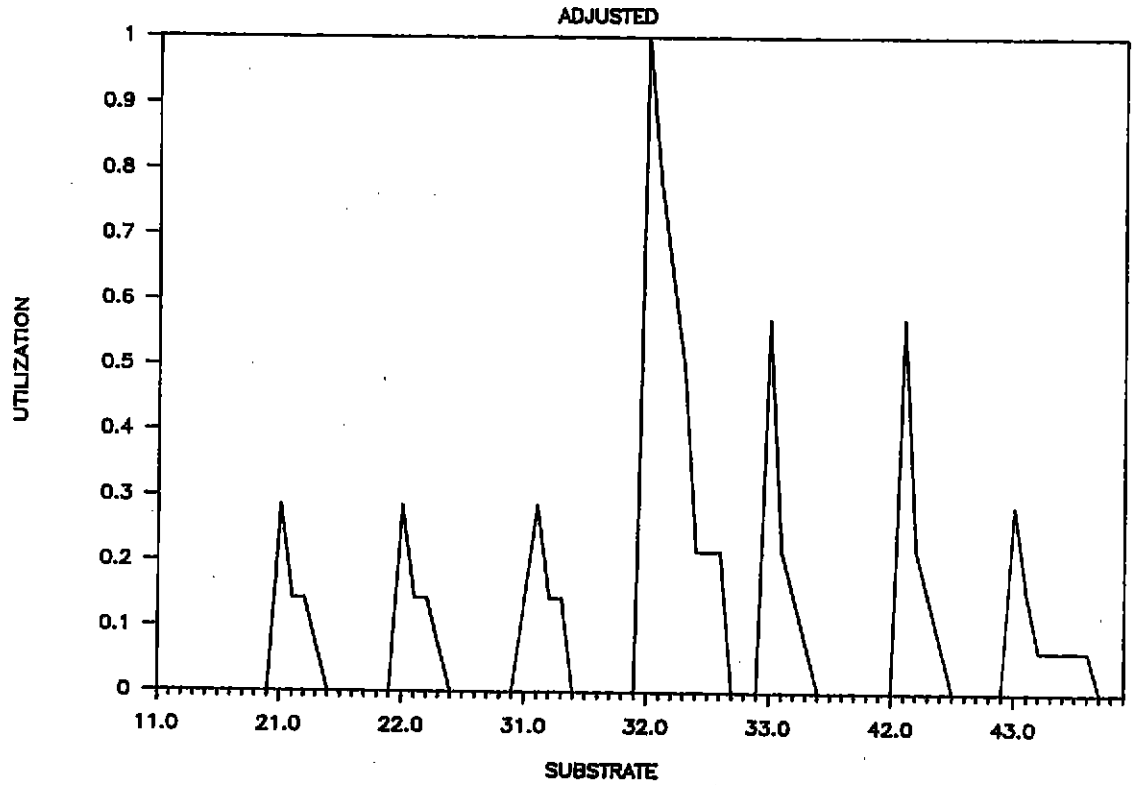


Habitat use criteria for substrates selected by spawning coho salmon in the upper Trinity River as described with the Brusven Index. Use criteria as calculated is shown in the upper half of the Figure and adjusted use criteria is shown in the lower half of the Figure.

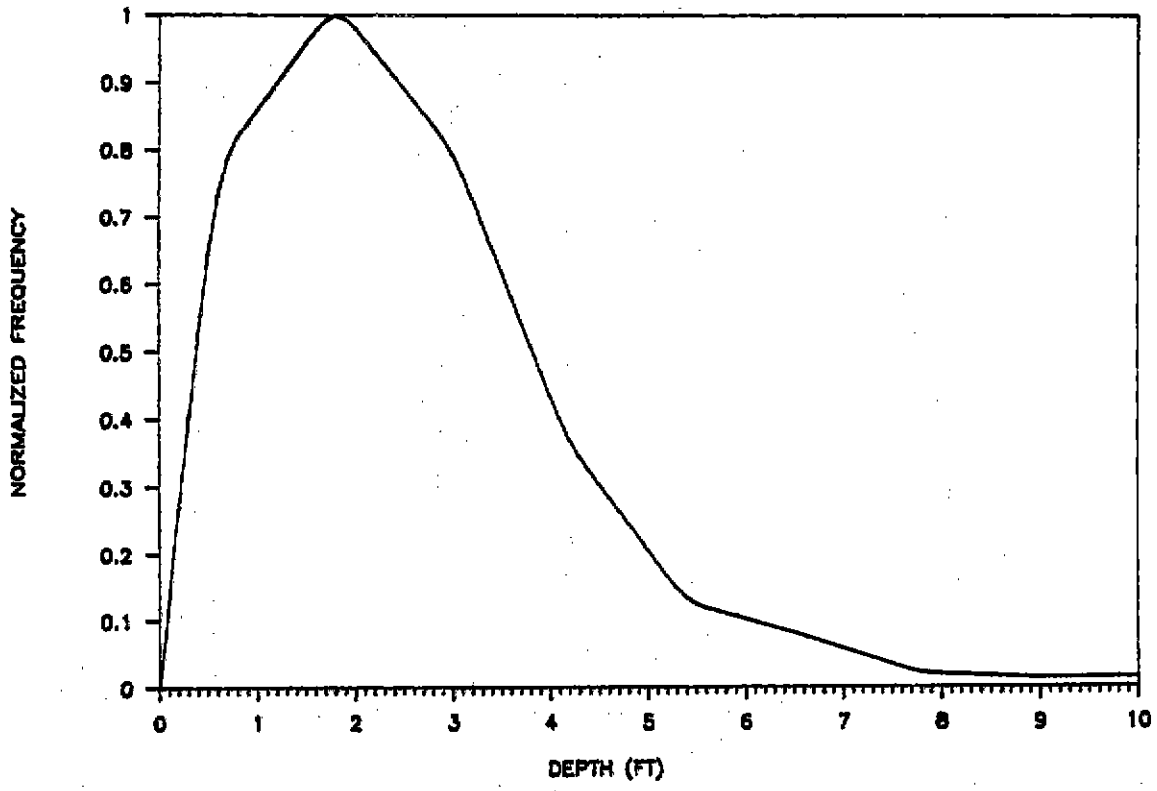
APPENDIX C

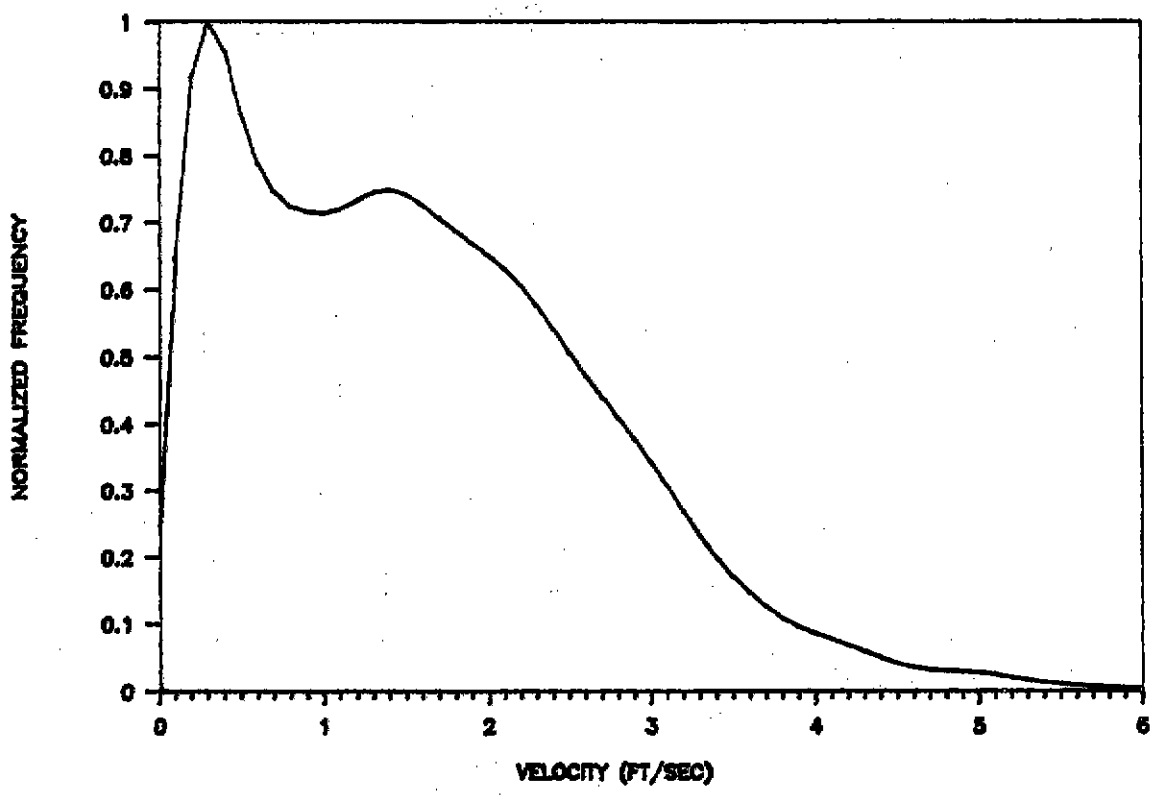
STEELHEAD TROUT





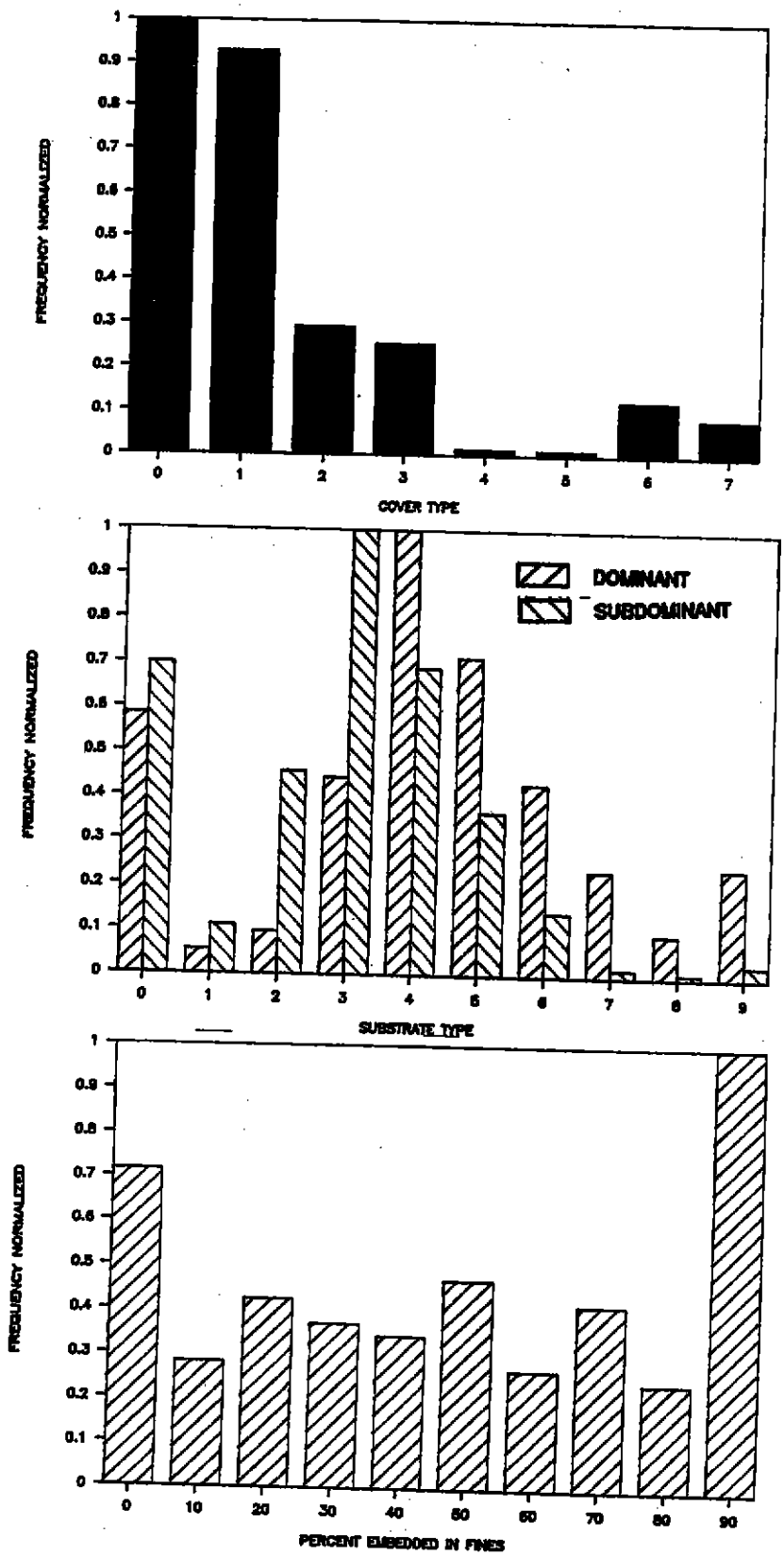
Habitat use criteria for substrates selected by spawning steelhead trout in the upper Trinity River as described with the Brusven Index. Use criteria as calculated is shown in the upper half of the Figure and adjusted use criteria is shown in the lower half of the Figure.



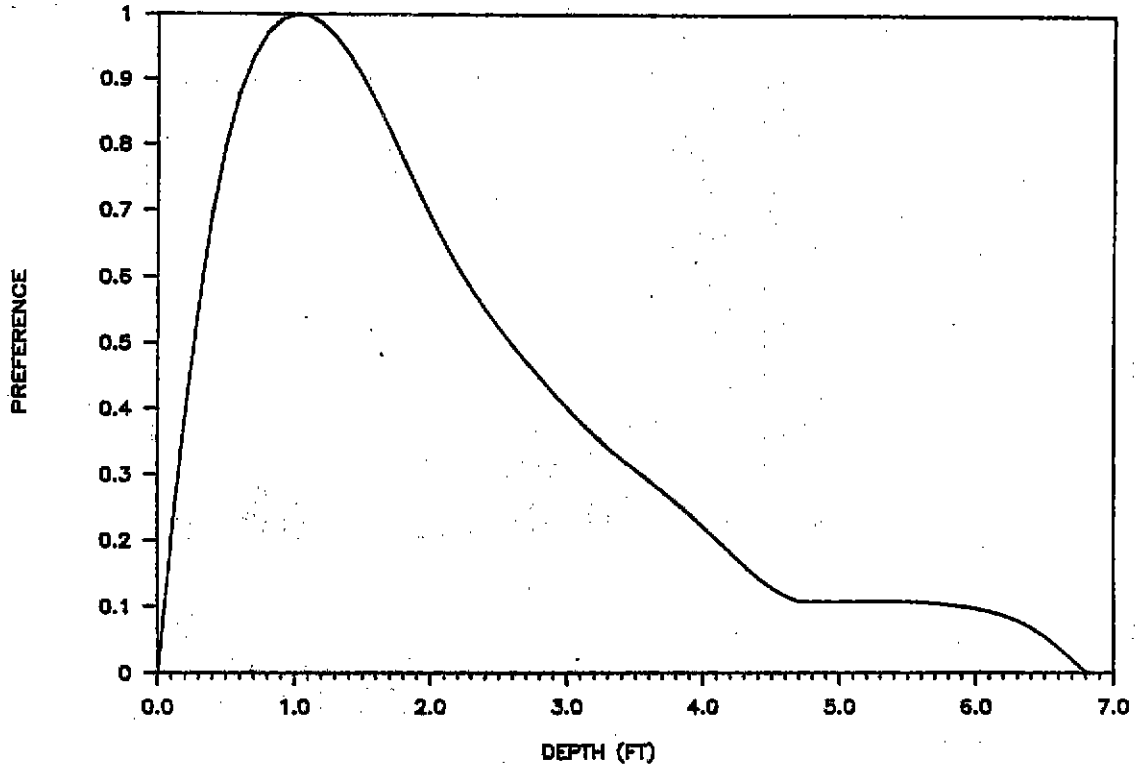


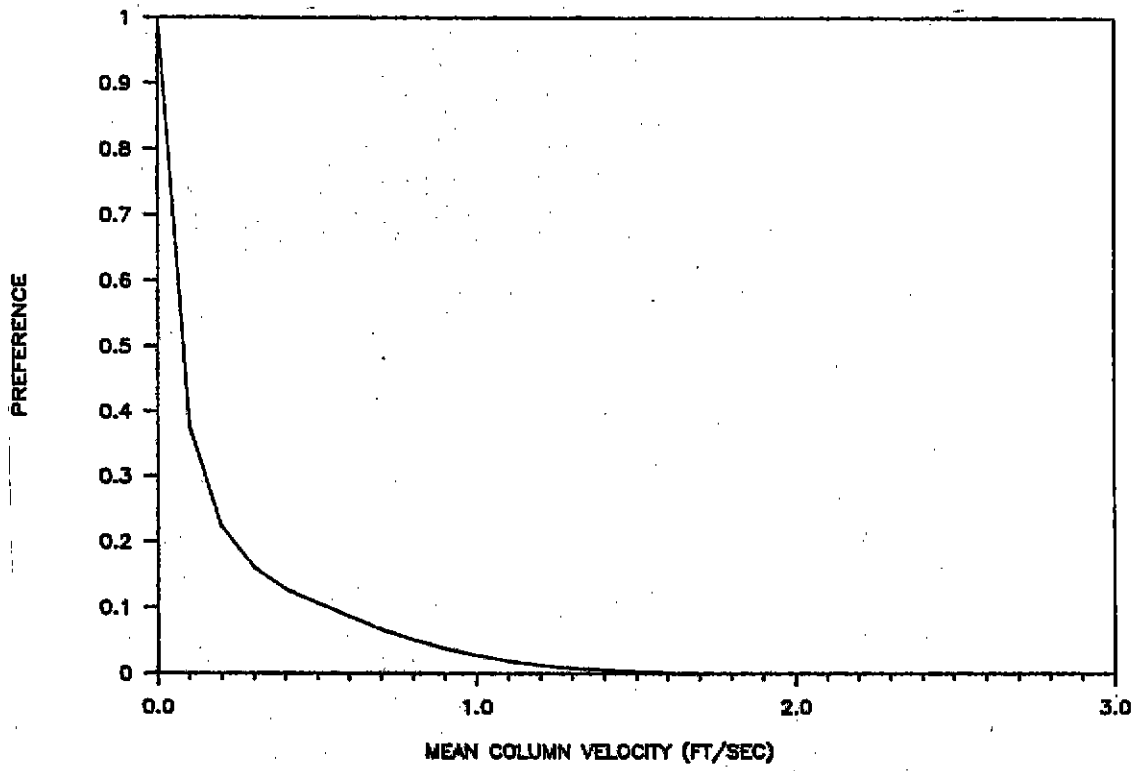
Estimates of habitat availability for total depth and mean column velocity taken from the IFG-4 program of the Instream Flow Incremental Methodology, Trinity River, CA.

APPENDIX D



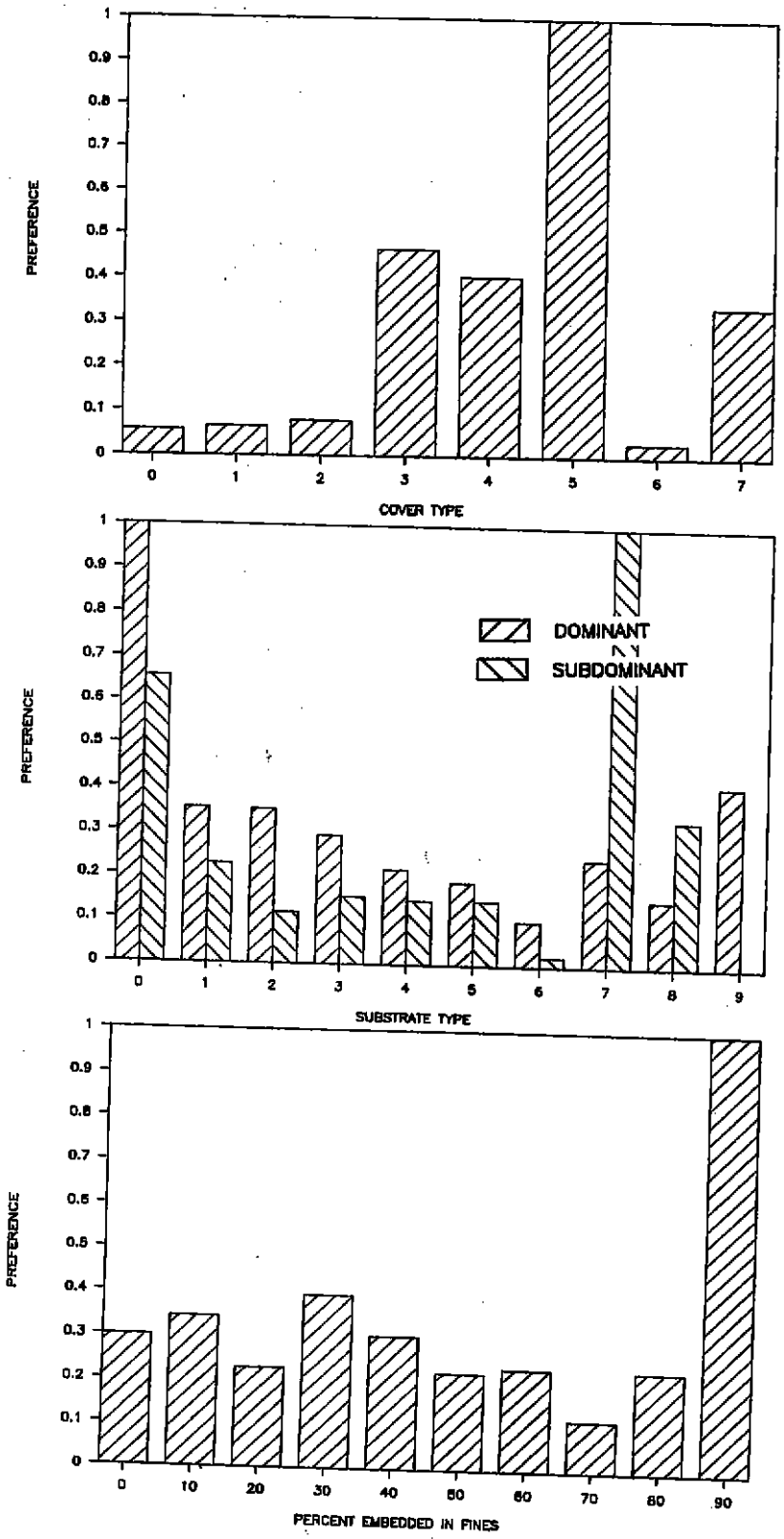
Estimates of habitat availability for cover and substrate taken from the IFG-4 program of the Instream Flow Incremental Methodology, Trinity River, CA.



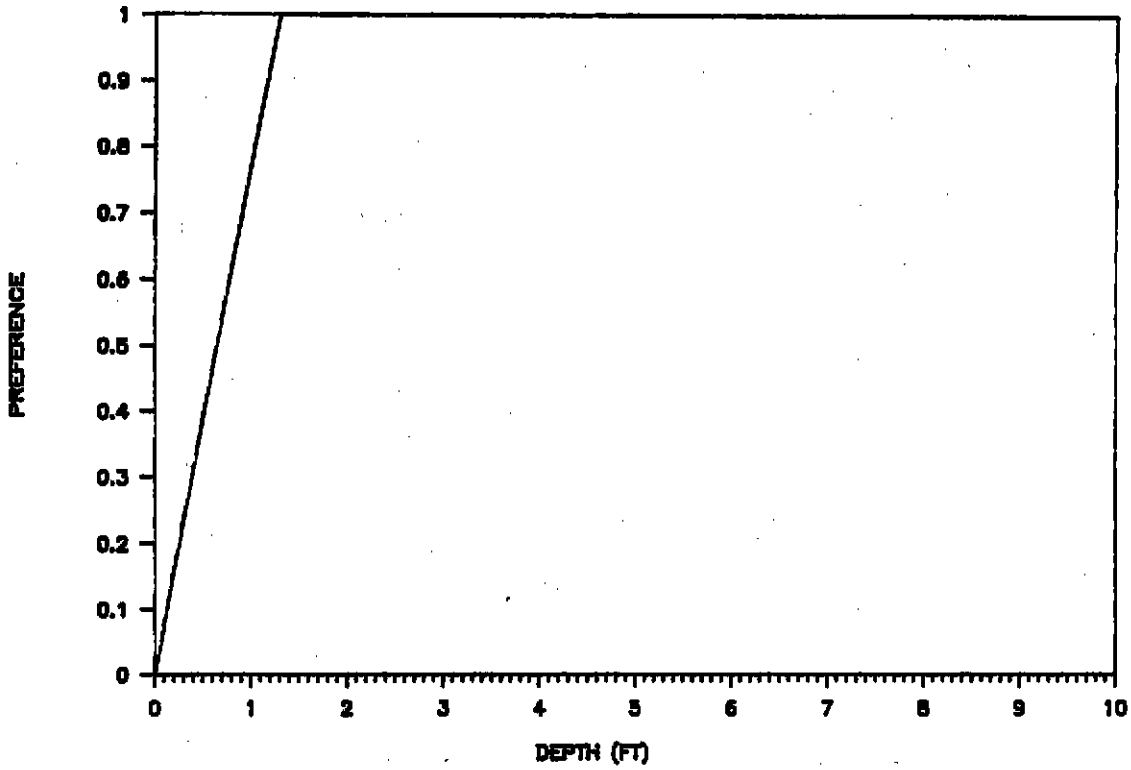


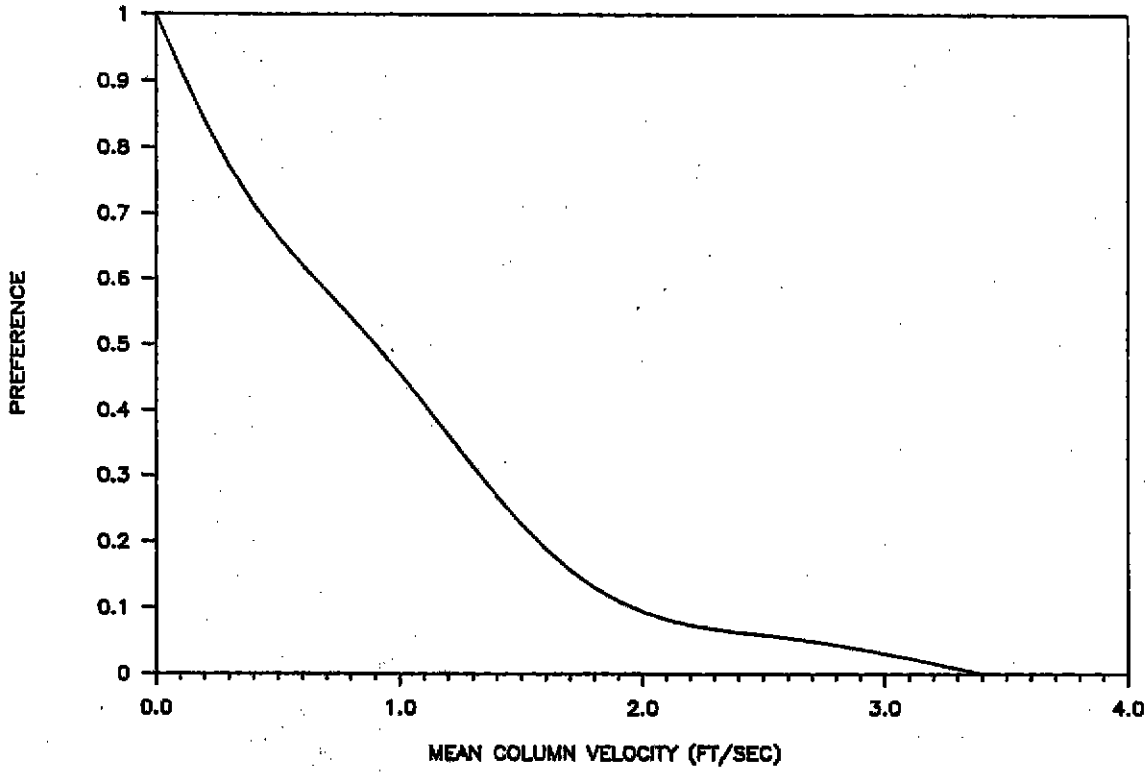
Final habitat preference criteria describing total depths and mean column velocities selected by chinook salmon fry in the upper Trinity River, CA., 1985-1987

APPENDIX E



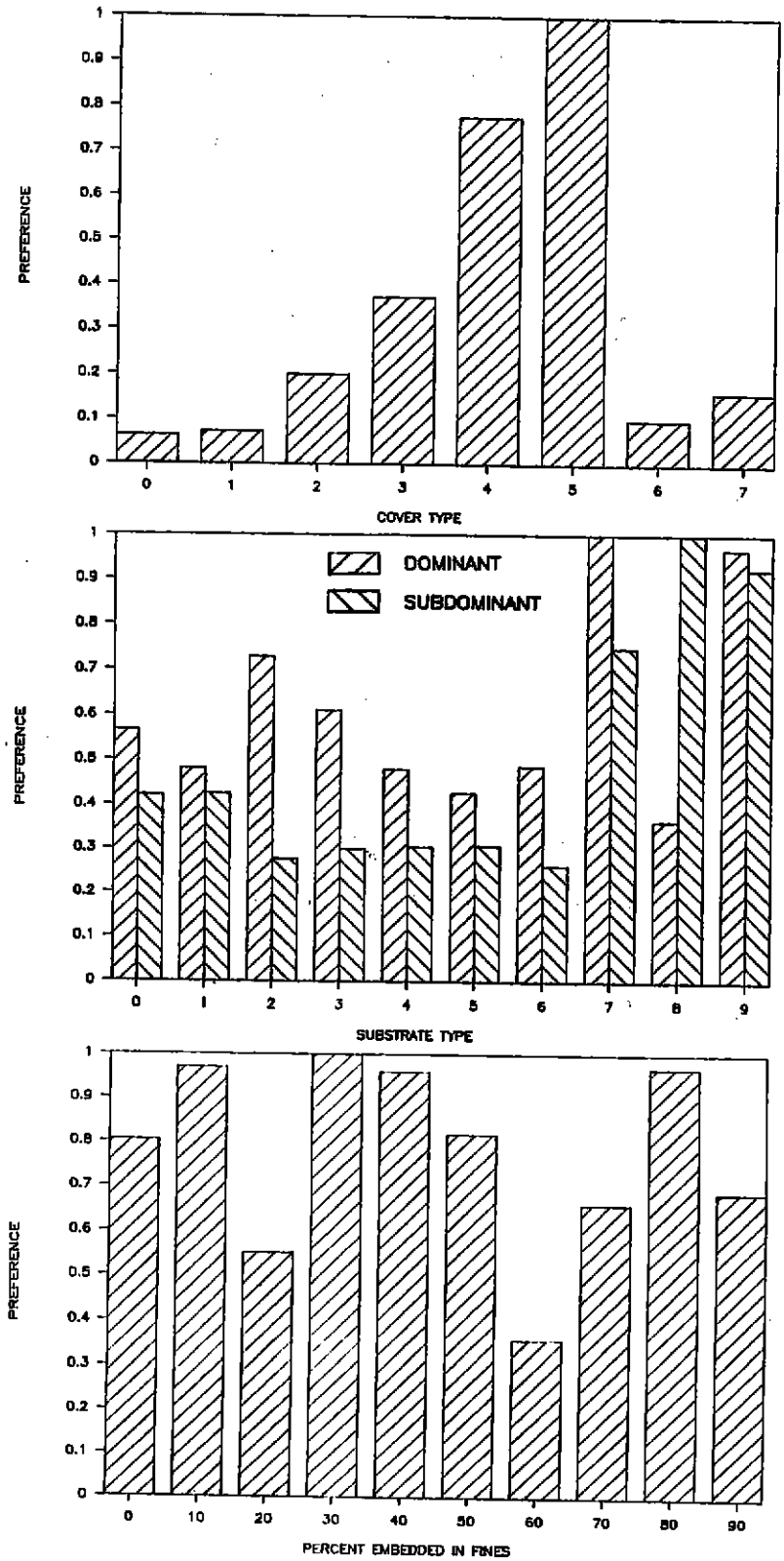
Final habitat preference criteria describing cover and substrates selected by chinook salmon fry in the upper Trinity River, CA., 1985-1987.



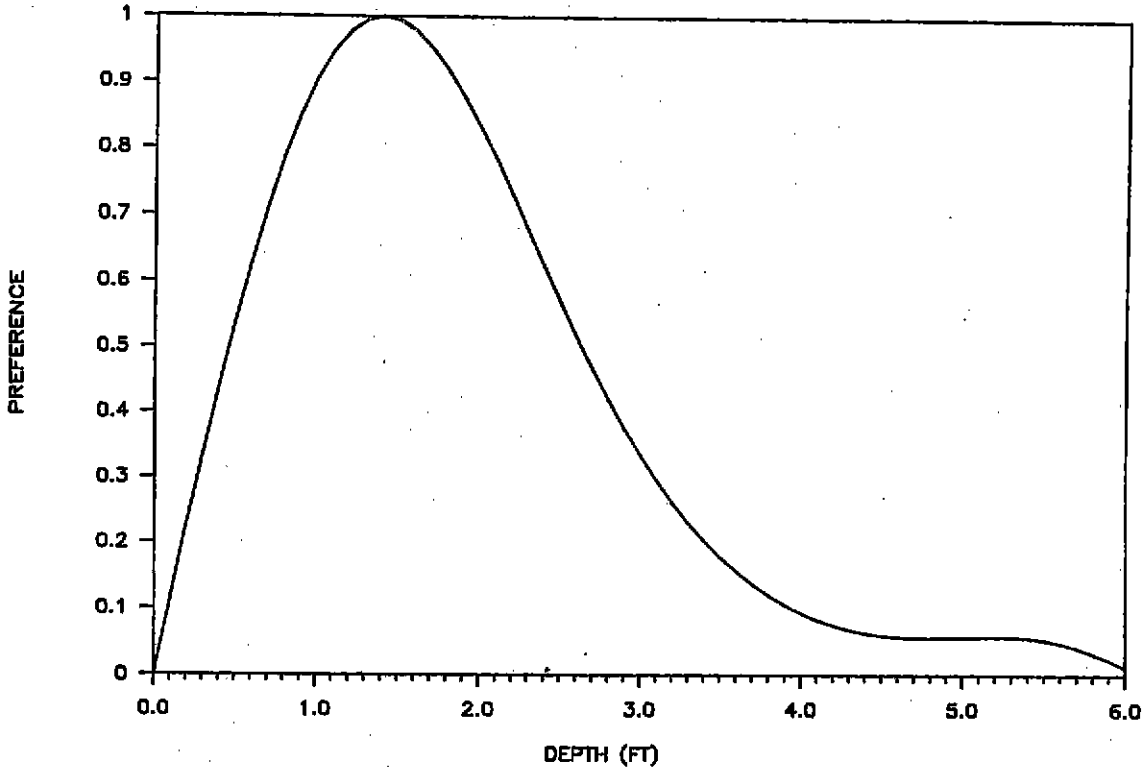


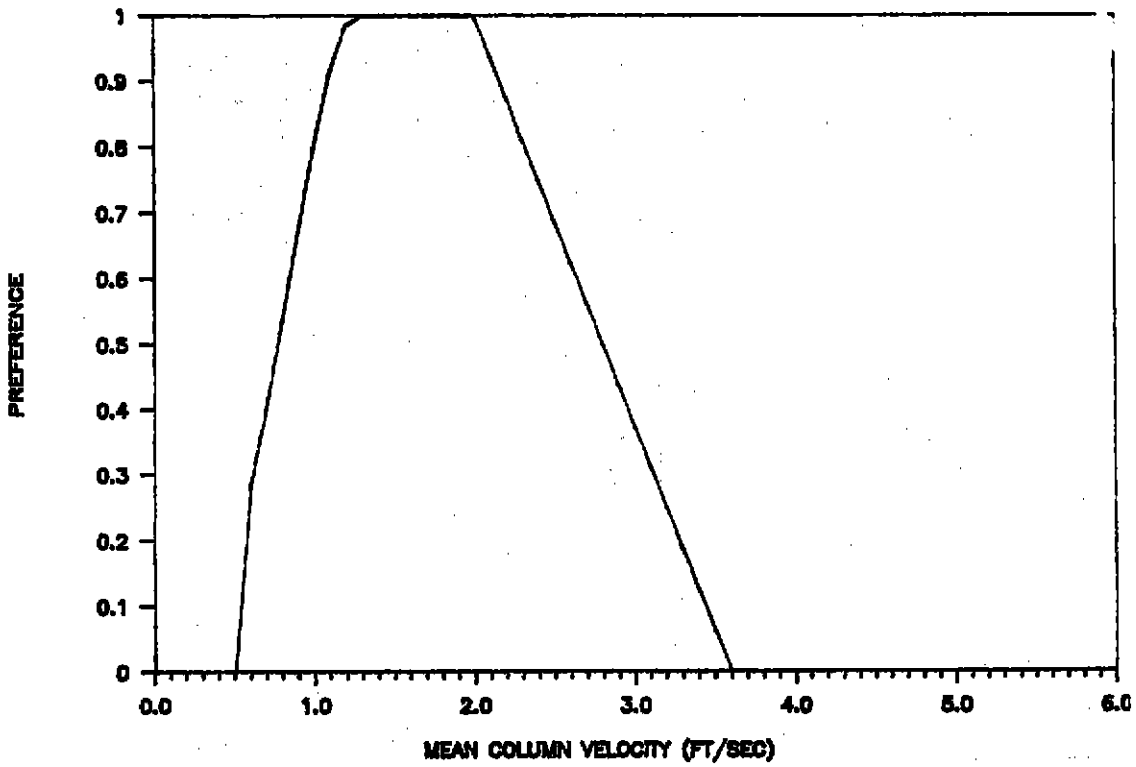
Final habitat preference criteria describing total depths and mean column velocities selected by chinook salmon juveniles in the upper Trinity River, CA., 1985-1987.

APPENDIX E



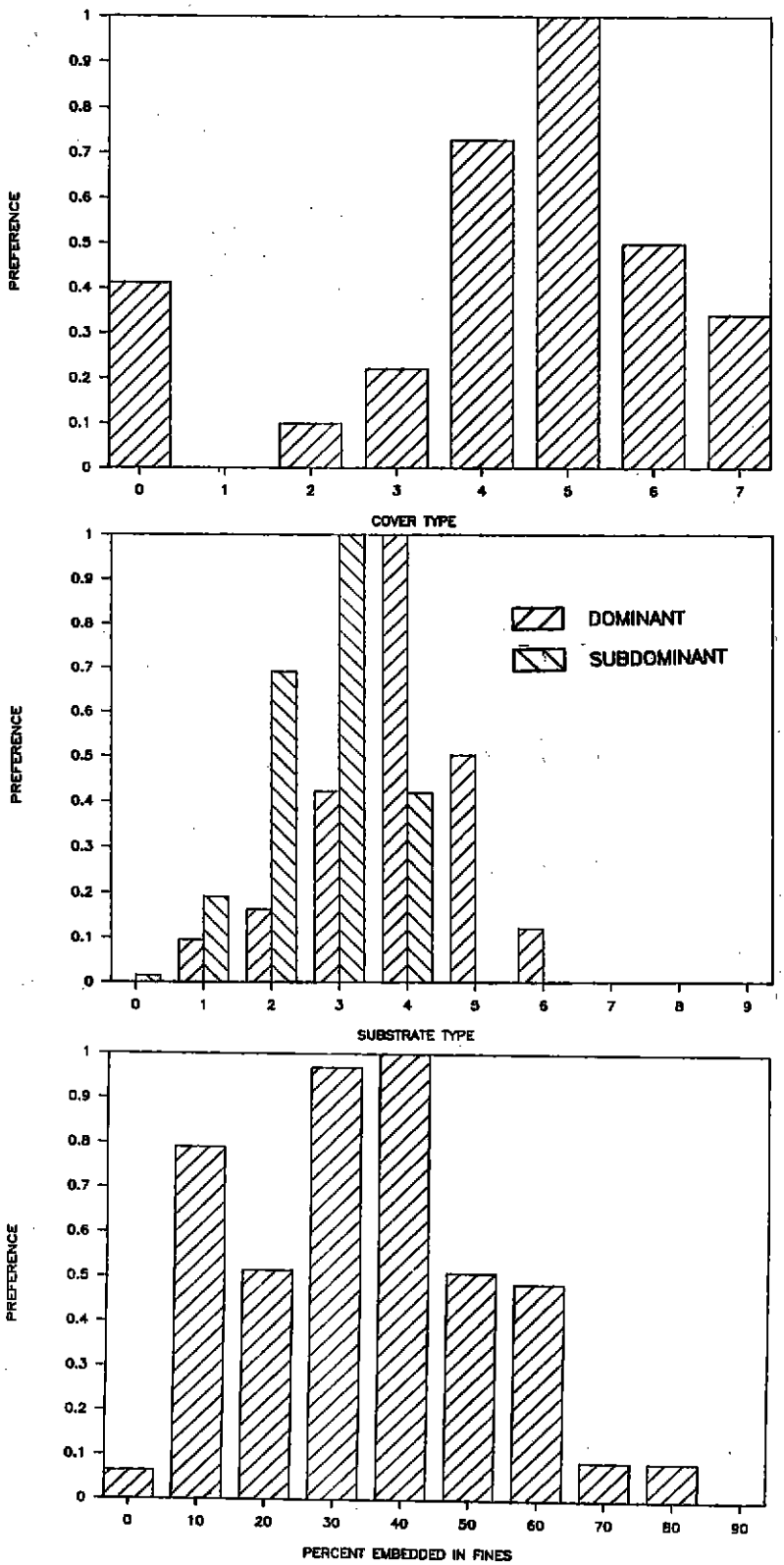
Final habitat preference criteria describing cover and substrates selected by chinook salmon juveniles in the upper Trinity River, CA., 1985-1987.



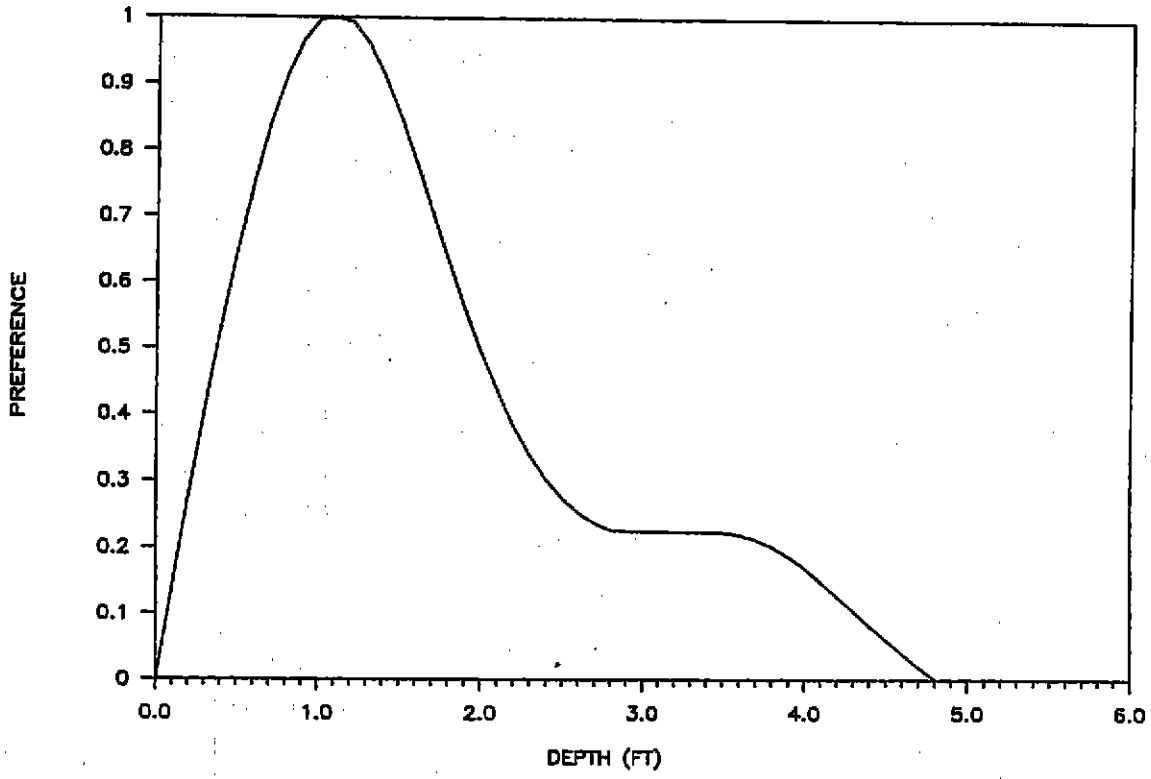


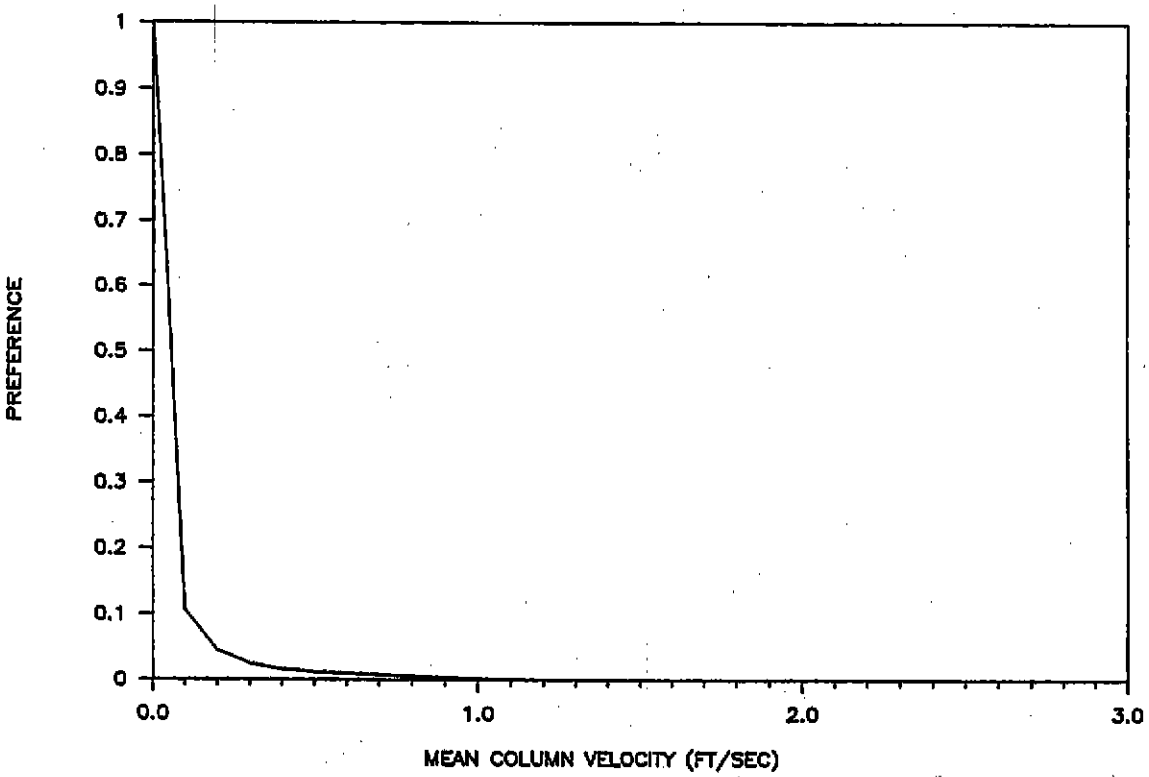
Final habitat preference criteria describing total depths and mean column velocities selected by spawning chinook salmon in the upper Trinity River, CA., 1985-1987.

APPENDIX E



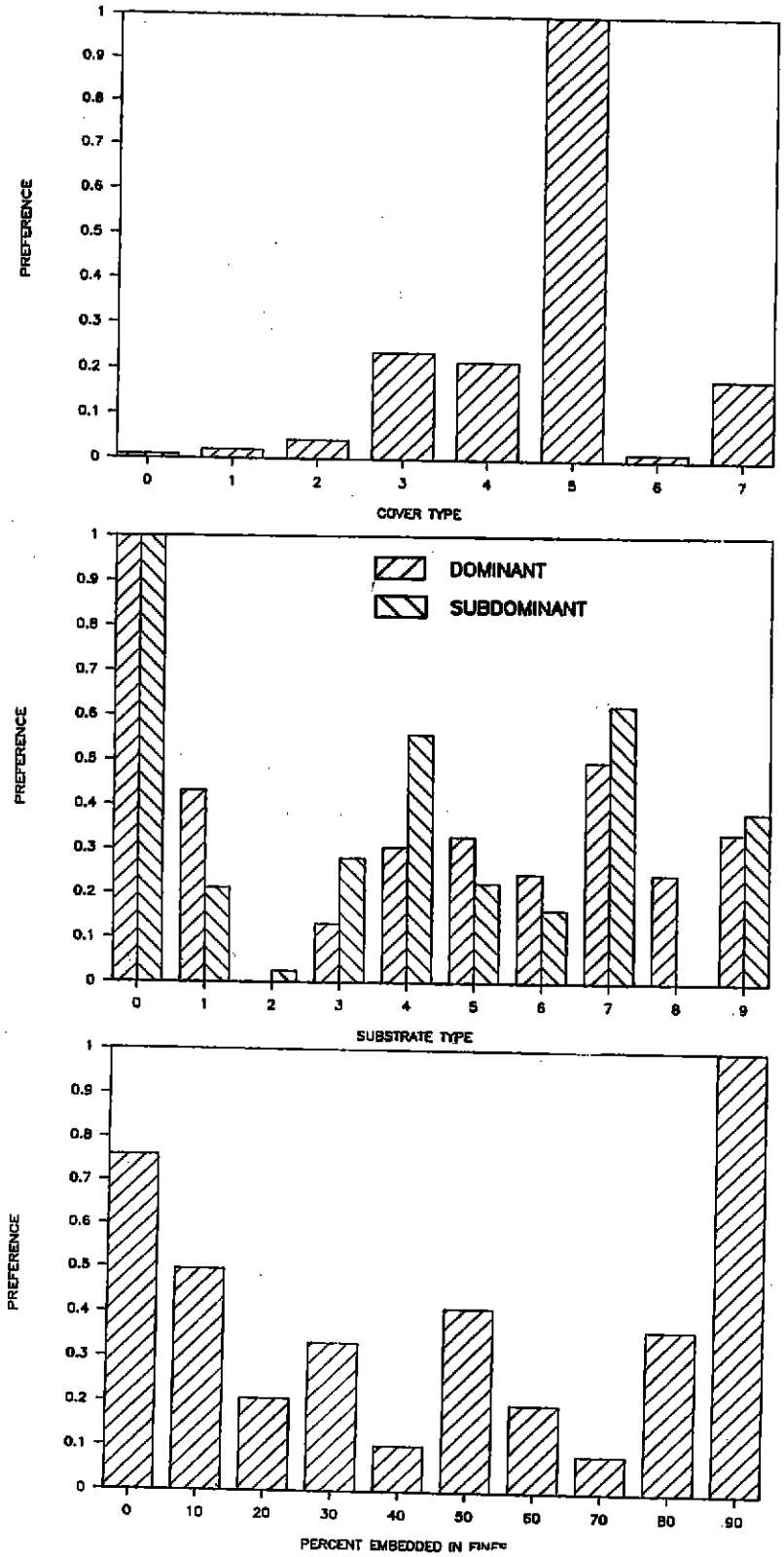
Final habitat preference criteria describing cover and substrates selected by spawning chinook salmon in the upper Trinity River, CA., 1985-1987.



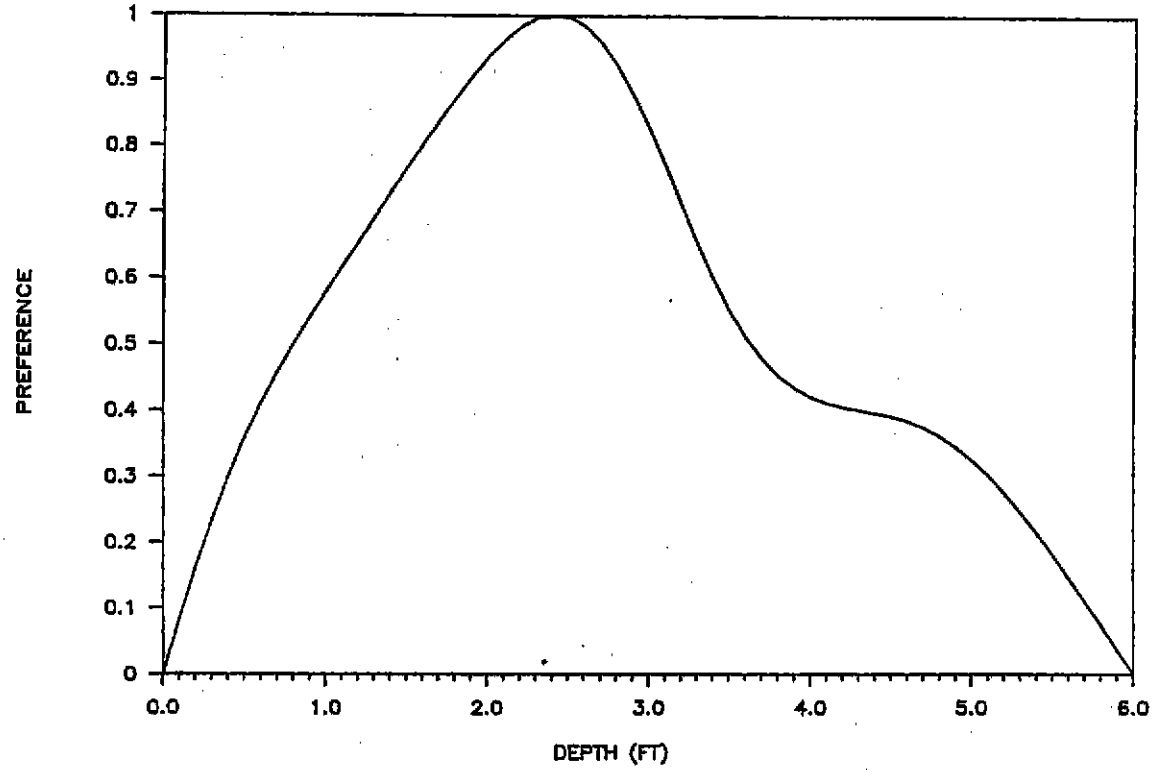


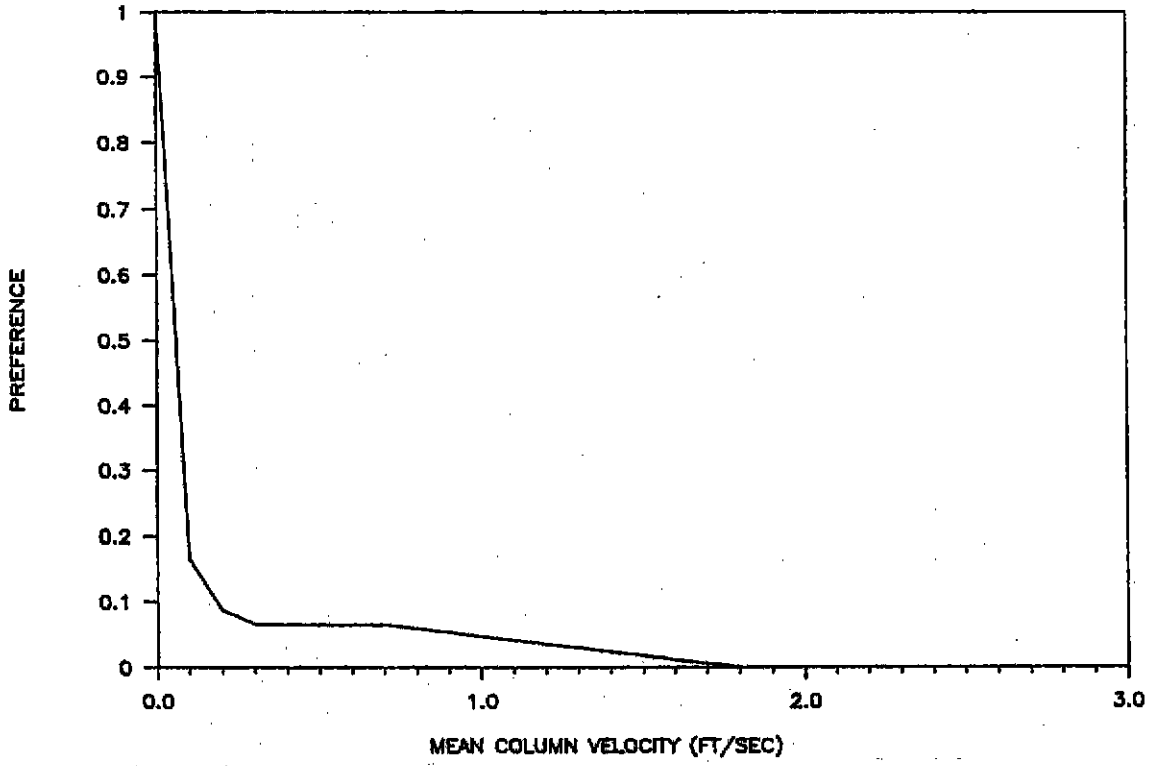
Final habitat preference criteria describing total depths and mean column velocities selected by coho salmon fry in the upper Trinity River, CA., 1985-1987.

APPENDIX E



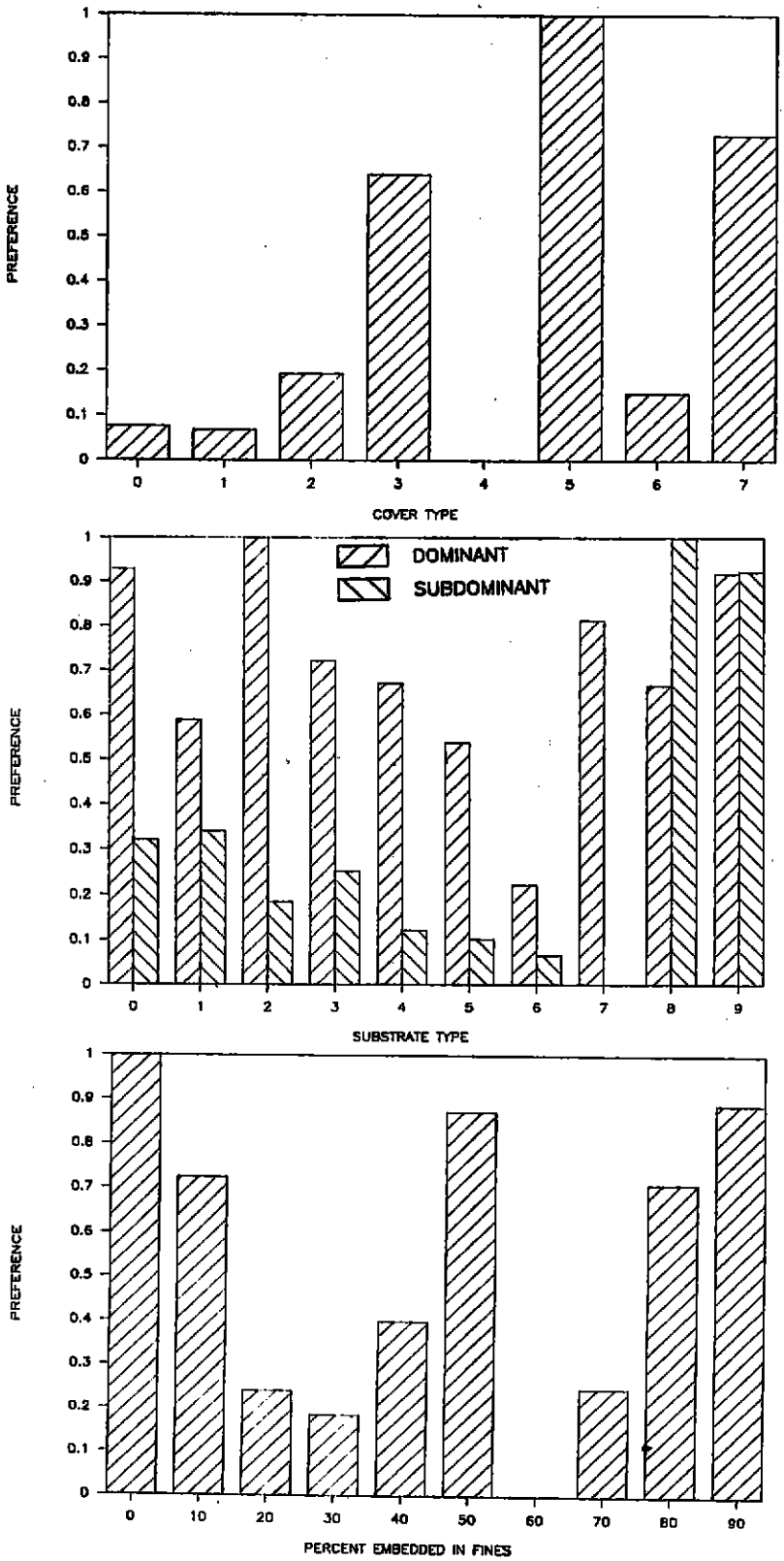
Final habitat preference criteria describing cover and substrates selected by coho salmon fry in the upper Trinity River, CA., 1985-1987.



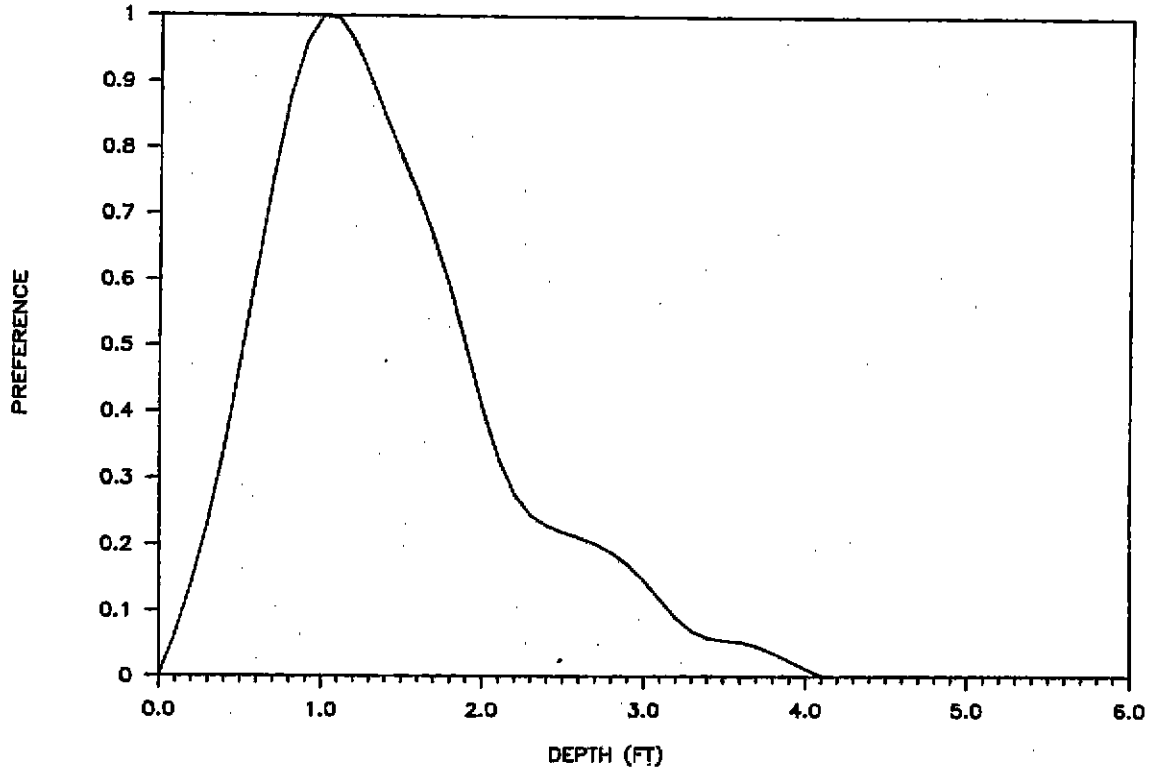


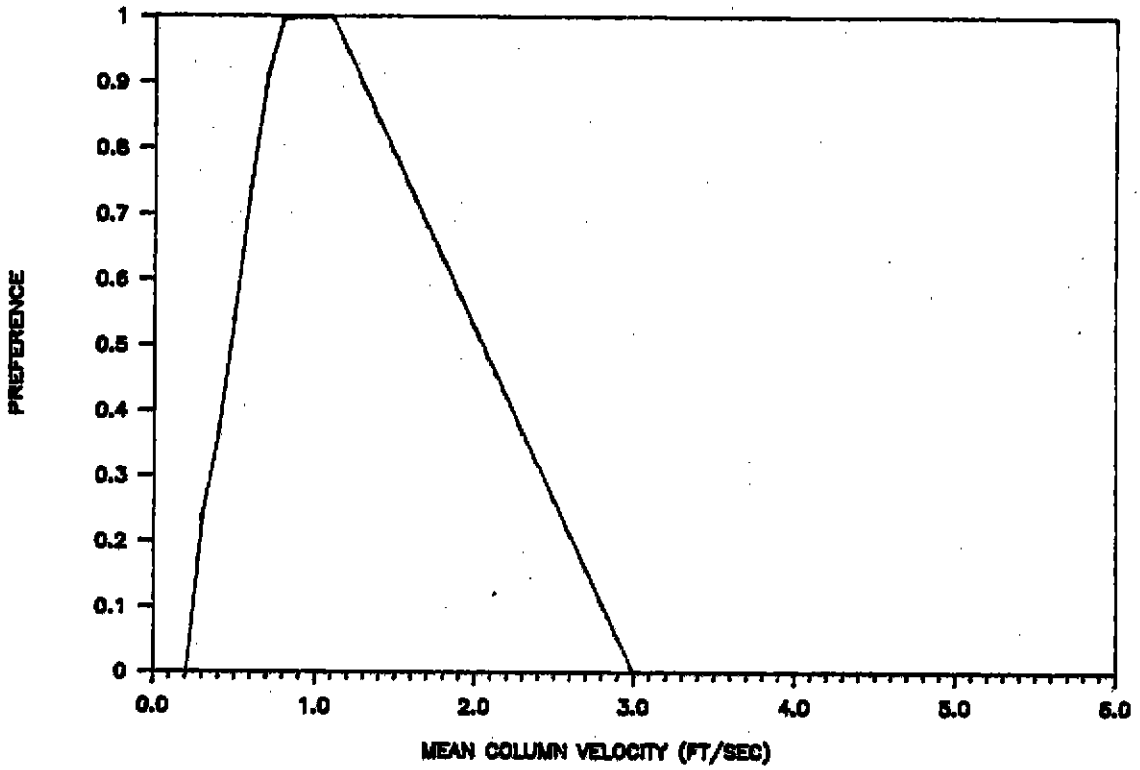
Final habitat preference criteria describing total depths and mean column velocities selected by coho salmon juveniles in the upper Trinity River, CA., 1985-1987.

APPENDIX E



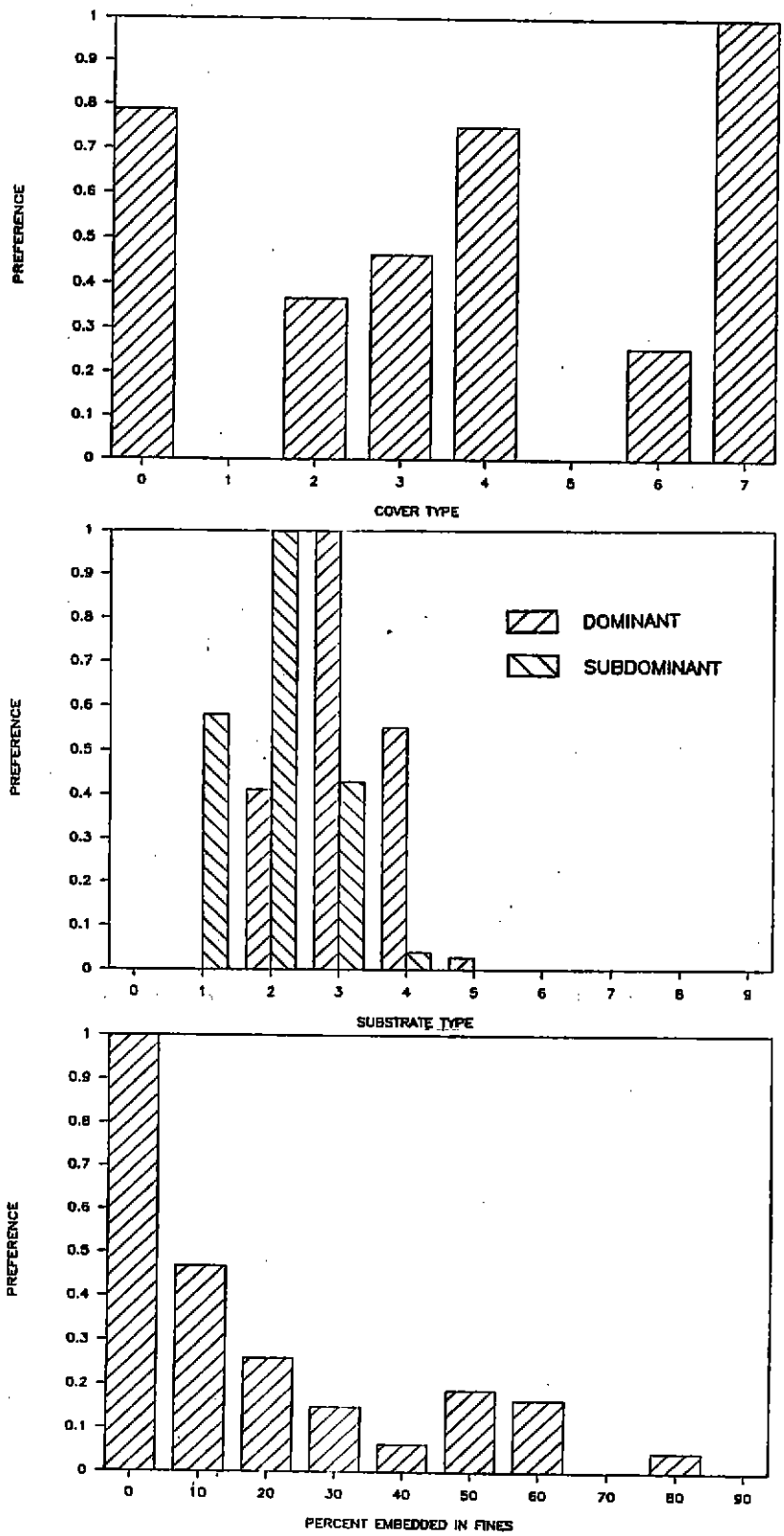
Final habitat preference criteria describing cover and substrates selected by coho salmon juveniles in the upper Trinity River, CA., 1985-1987.



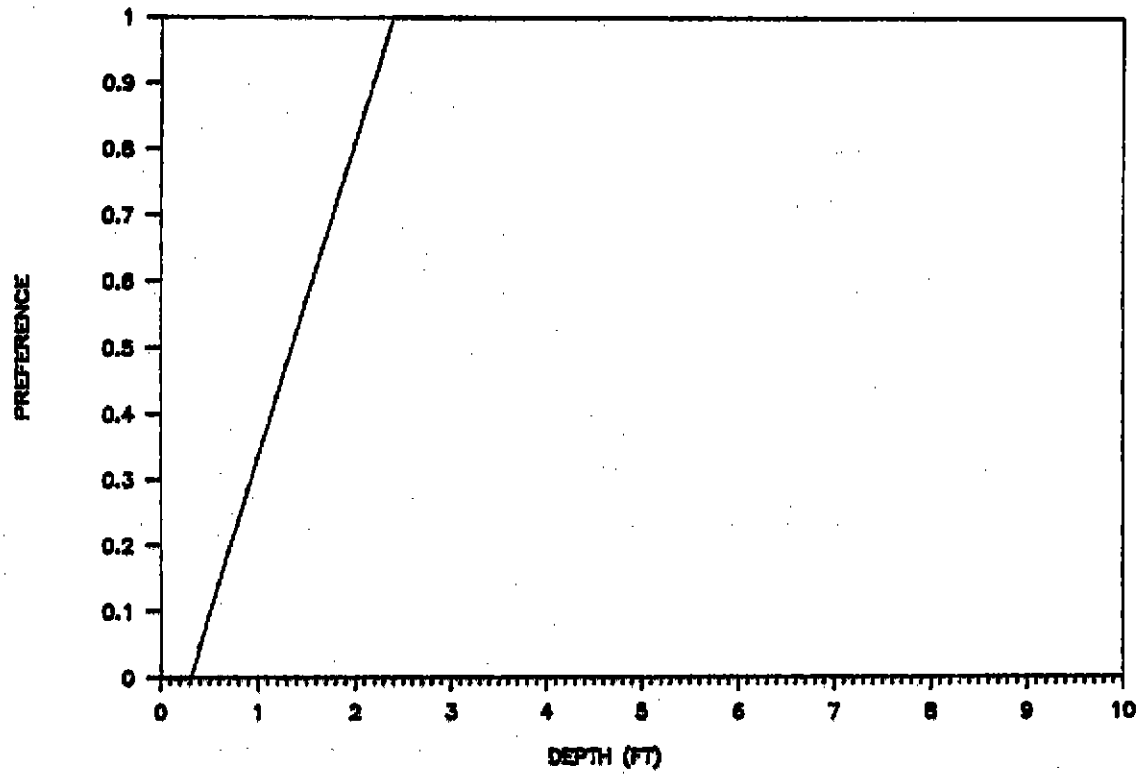


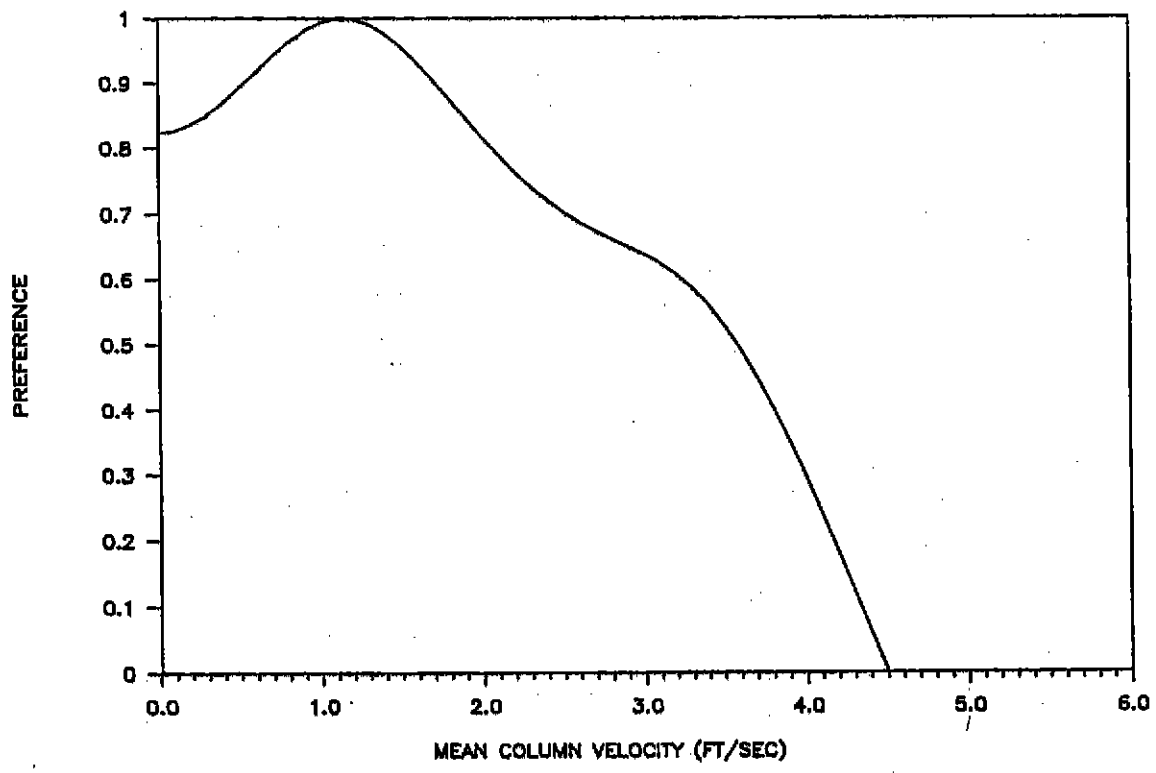
Final habitat preference criteria describing total depths and mean column velocities selected by spawning coho salmon in the upper Trinity River, CA., 1985-1987.

APPENDIX E



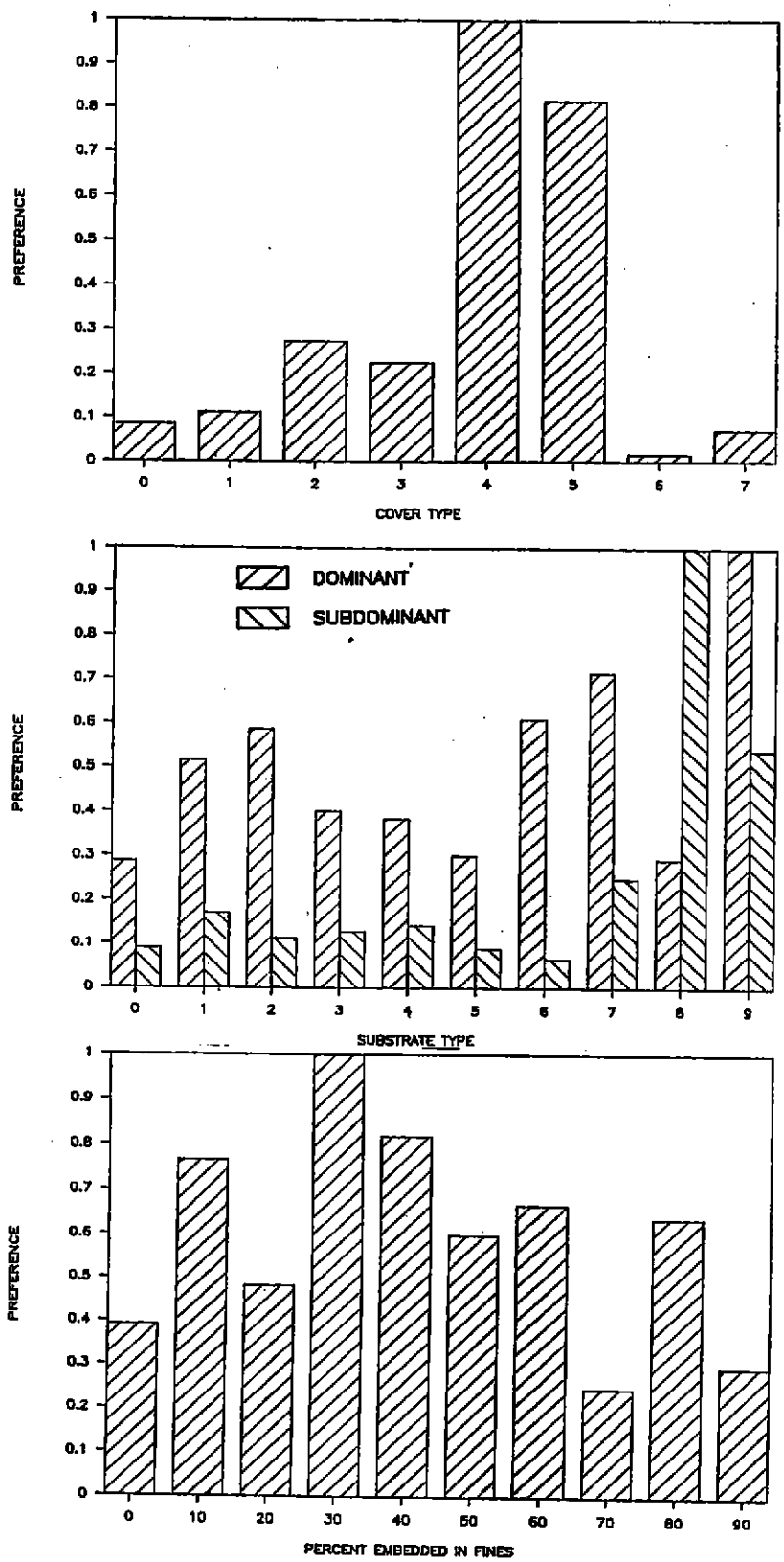
Final habitat preference criteria describing cover and substrates selected by spawning coho salmon in the upper Trinity River, CA., 1985-1987.



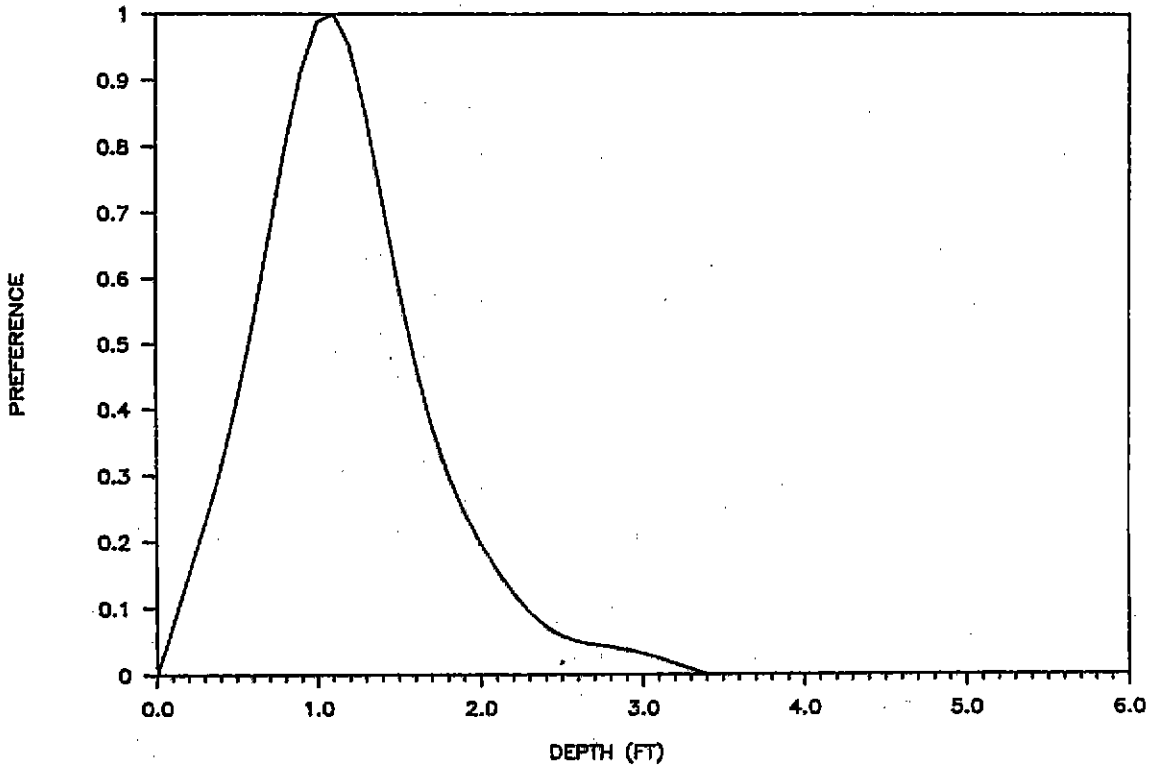


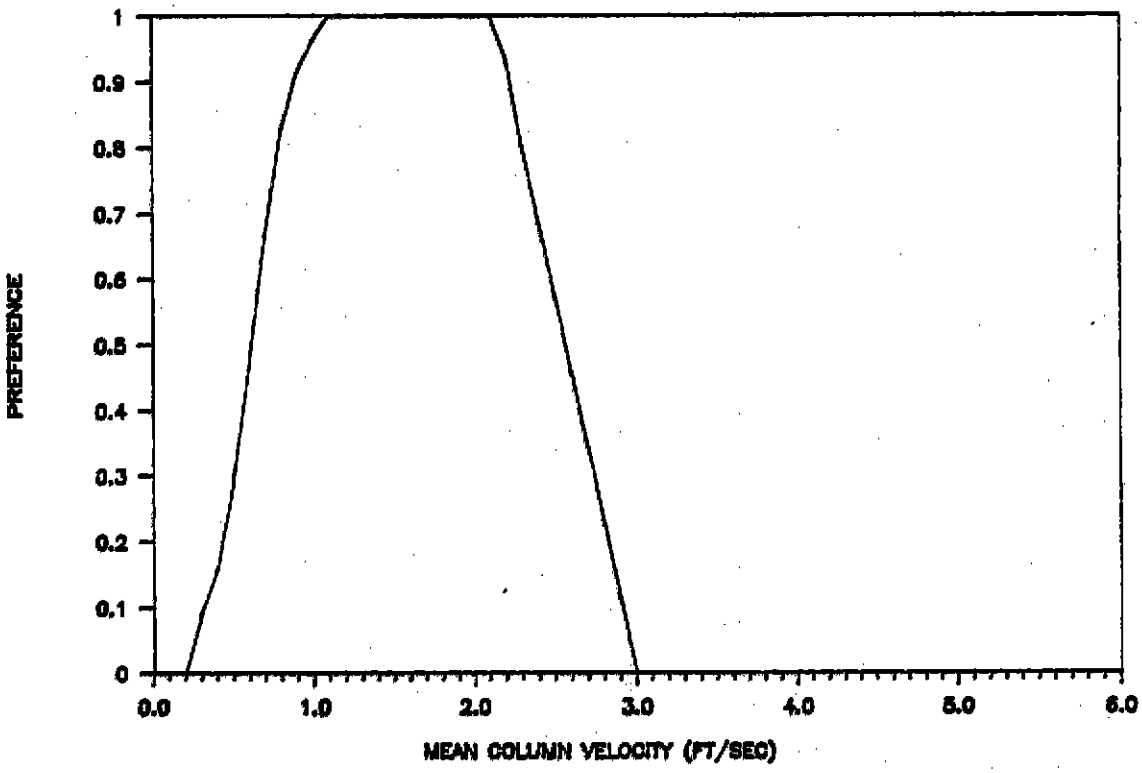
Final habitat preference criteria describing total depths and mean column velocities selected by steelhead trout juveniles in the upper Trinity River, CA., 1985-1987.

APPENDIX E



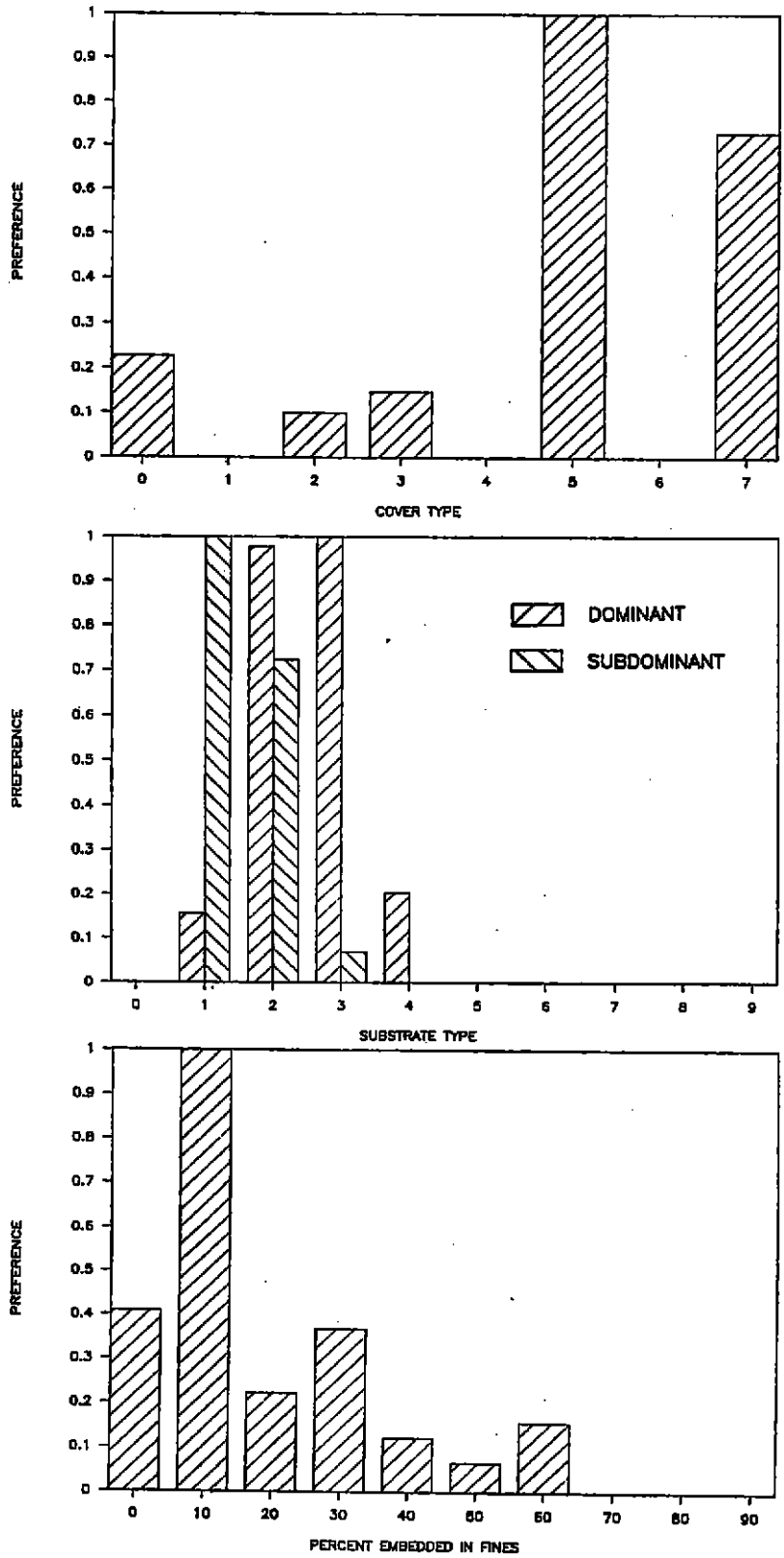
Final habitat preference criteria describing cover and substrates selected by steelhead trout juveniles in the upper Trinity River, CA., 1985-1987.





Final habitat preference criteria describing total depths and mean column velocities selected by spawning steelhead trout in the upper Trinity River, CA., 1985-1987.

APPENDIX E



Final habitat preference criteria describing cover and substrates selected by spawning steelhead trout in the upper Trinity River, CA., 1985-1987.