PART 3

Juvenile Salmon Rearing Suitability Criteria

JUVENILE SALMON REARING SUITABILITY CRITERIA

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ABSTRACT

Changes in flow regimes in the Susitna River may affect the habitat used by rearing juvenile salmon. In order to model changes in habitat usability, data were collected for development of suitability criteria for the habitat attributes of cover, velocity, and depth used by juvenile chinook, coho, sockeye, and chum salmon. Representative sites between the Chulitna River confluence and Devil Canyon were sampled for juvenile salmon and habitat attributes were measured. Analysis was primarily univariate and data were pooled over site and season. Turbidity was apparently used by chinook salmon as cover prompting development of suitability criteria for clear (<30 NTU) and turbid (>30 NTU) conditions. Catches were insufficient for analysis of the other species by turbidity level. Suitability criteria for percent cover, cover type, velocity, and depth were developed for all four species of salmon. Composite weighting factors were formulated and correlated or compared with observed fish catch. Limitations of the suitability criteria and possible uses in habitat analysis are discussed.

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1.0 INTRODUCTION

Studies to date (ADF&G 1983a) of the rearing salmon species which occur between the Chulitna River confluence and Devil Canyon, indicate that successful rearing is dependent on a variety of physical parameters. The instream flow incremental methodology has been developed for use in evaluating fish habitat (Bovee 1982) and can be used in the Susitna River basin to evaluate effects of mainstem discharge on sites used by rearing juvenile salmon. In order to implement this methodology, habitat suitability criteria need to be developed which express the optimum, marginal, and unusable ranges of habitat variables on a one (optimum) to zero (unusable) basis. These criteria are then coupled with hydraulic models by using a system of computer programs called the Physical Habitat Simulation (PHABSIM) system (Bovee 1982). Output from PHABSIM includes calculations of the amount of equivalent optimum habitat called weighted usable area.

The present work develops suitability criteria for four species of juvenile salmon in the Chulitna River to Devil Canyon reach of the Susitna River for application in incremental simulations of rearing habitat as a function of mainstem flows. Criteria developed for these species are univariate suitability functions for cover type and percent cover, depth, and velocity. Functions for each of these environmental attributes were developed for juvenile chinook, coho, sockeye and chum salmon rearing. Different criteria for low and high turbidity water were developed as data permitted. Pink salmon were not considered because they do not rear in the study reach.

Suitability criteria have been formulated in a variety of ways (Bovee 1982) although most methods have been oriented towards describing the requirements for readily observable individuals in a relatively uniform or predictable macrohabitat. Since rearing juvenile salmon are neither easily observed nor sampled in the Susitna River's diverse glacial environment and related salmon rearing habitats, alternate criteria development techniques were used in this study. The criteria developed are specific to the Susitna River reach between the Chulitna River confluence and Devil Canyon.

The criteria developed in this report have been used with hydraulic models for seven sites on the Susitna River to provide weighted usable area projections at a wide variety of discharges (see Part 7 of this volume). They also have been used to study changes in the usability of habitat at six habitat model sites as natural mainstem discharge changes (see Part 4 of this volume). These results will be used in combination with other information to develop estimates of total usable rearing area for the Chulitna confluence to Devil Canyon reach of river at incremental levels of mainstem discharges.

2.0 METHODS

2.1 Study Locations

Locations selected as fish preference sites had substantial numbers of rearing juvenile salmon in 1981 and 1982 or were thought to be typical sites having the potential for juvenile rearing. The sites are located on the Susitna River reach between Whiskers Creek (RM 101.2) and Portage Creek (RM 148.8). Seven tributary sites, two upland sloughs, and 12 other sites which naturally oscillate between being side sloughs or side channels were sampled at least four times (Figure 1). There were also nine sites sampled only once and five sites sampled two or three times (see Part 2 of this report for a listing). These sites were thought to represent a wide cross section of habitat conditions experienced by rearing juvenile salmon in this reach of the Susitna River since tributaries, upland sloughs, side sloughs, and side channels were all intensively sampled. A limited amount of sampling was done in the mainstem channel and large side channels because of the difficulty in sampling these areas and because we believed high velocities limit juvenile rearing habitat.

2.2 Field Data Collection

2.2.1 Biological

Detailed descriptions of the site layout and data collection techniques are available in other reports (ADF&G 1984, and Part 2 of this report). Eight to 10 day field samplings were made twice monthly between May and October 1983. Twenty-three sites were sampled from three to seven times while the other 12 sites were only incidentally sampled once or twice. About eight staked transects from 75 to 200 feet apart were established across the study site. Upstream from each transect, sampling cells 50 feet long by six feet wide (300 ft^2) were delineated along each shoreline. Another mid-channel cell was located between the shoreline cells. The grid of transects and cells was normally located in areas of relatively uniform water temperature, pH, dissolved oxygen, conductivity, and turbidity. Transects were placed to maximize within site variability of habitat types sampled while also attempting to maintain uniform physical habitat within individual sampling cells. Cells were selected to represent a wide range of habitat types and approximately 20 cells were sampled per day.

During the field season, we directed sampling effort towards sites where rearing fish were numerous based on knowledge of seasonal movements. Sampling frequency was reduced if efforts to catch 30 or more juveniles of a species in a grid of transects were unsuccessful. Backpack electrofishing units and 1/8" mesh beach seines were used to sample the entire cell for fish. Typically, beach seining was limited to turbid water samplings and electrofishing to clear water conditions. Electrofishing was the preferred sampling method, but was found to be ineffective in turbid water. Each captured fish was identified to species and measured in total length to the nearest millimeter. Those cells sampled for fisheries data were subsequently individually characterized by a set of habitat measurements even if no fish were captured.

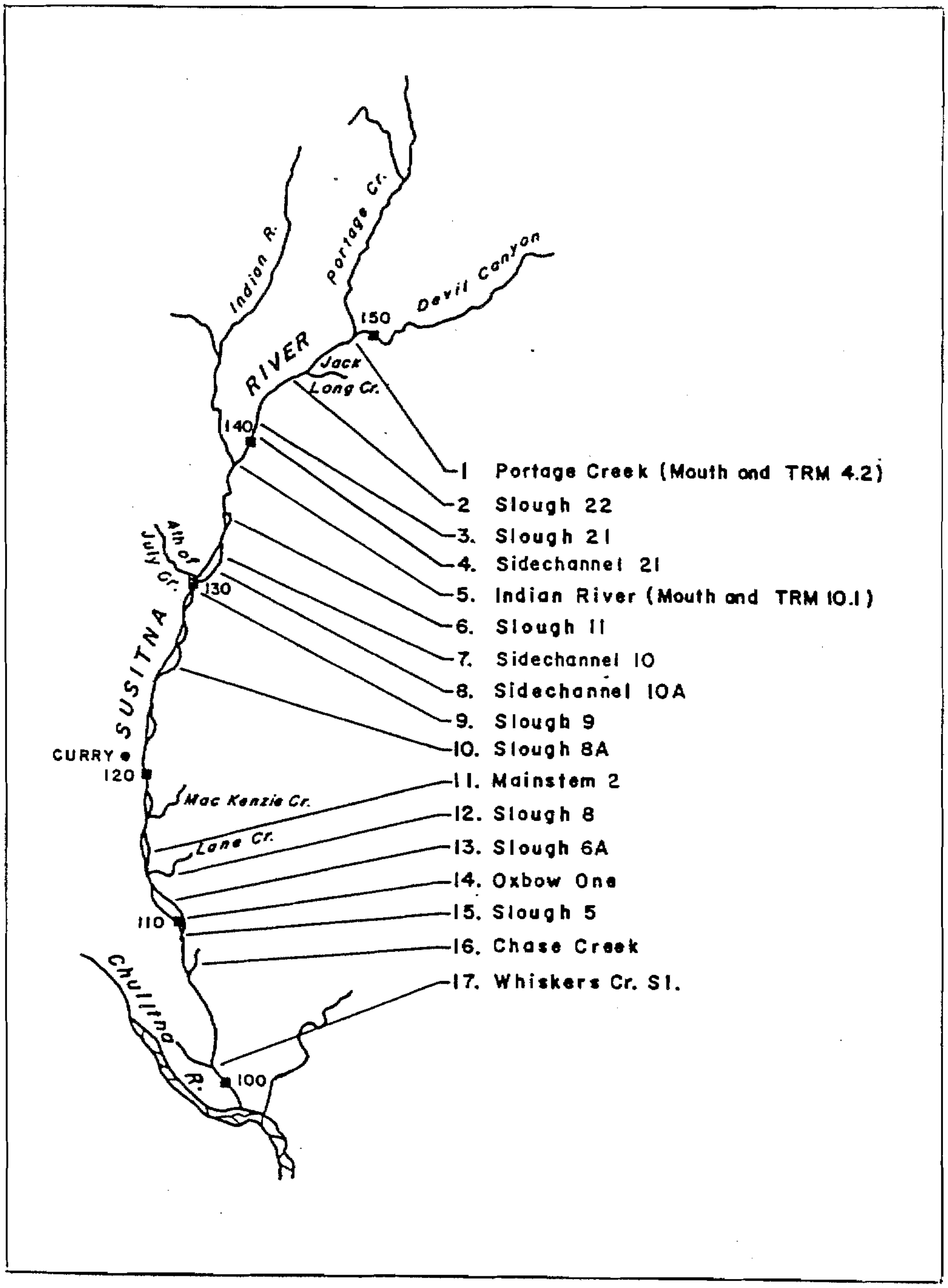

Figure 1. Location of the study sites sampled more than three times for juvenile salmon suitability criteria development, May through October, 1983.

2.2.2 Physical

We determined an average depth and velocity, and also estimated the total amount of available cover (expressed in percent areal coverage), and the dominant type of cover available for juvenile salmon in each cell. Codes for nine cover types and six categories of percent cover were developed (Table 1). Prior to the sampling season, a field trip was made to promote consistent ratings among the raters. Estimates of cover were made on the basis of cover specifically available to juvenile salmon for concealment or protection. Cells without objective cover (cover type group #1) will be referred to as "no cover" or "zero cover" cells.

Table 1. Percent cover and cover type categories.

Group #	% Cover	Group #	Cover Type
1	0-5%	1	No object cover
2	6-25%	2	Emergent vegetation
3	26-50%	3	Aquatic vegetation
4	51-75%	4	Debris or deadfall
5	76-96%	5	Overhanging riparian vegetation
6	96-100%	6	Undercut banks
		7	Gravel (1" to 3" diameter)
		8	Rubble (3" to 5" diameter)
		9	Cobble (larger than 5" diameter)

Water temperature, dissolved oxygen, pH, conductivity, and turbidity were measured at one point in the grid. If an obvious water quality gradient existed across the grid, another measurement of these parameters was taken. Detailed descriptions of the water chemistry measurement procedures are available in ADF&G (1984).

2.3 Data Analysis

Data were separated by gear type because both beach seining and electrofishing effectiveness are influenced by water quality and hydraulic attributes and because each gear was used selectively, dependent upon the sampling conditions. Since no resources were available for a major study of gear effectiveness, we did not attempt to quantify gear efficiency under various sampling conditions. Beach seines were used because backpack electrofishing is ineffective in highly turbid water. The bias inherent in both gear types influenced our pathway of analysis and affected our interpretation of results and subsequent conclusions. Figure 2 details the data analysis pathways and final products of criteria development as presented in the results section.

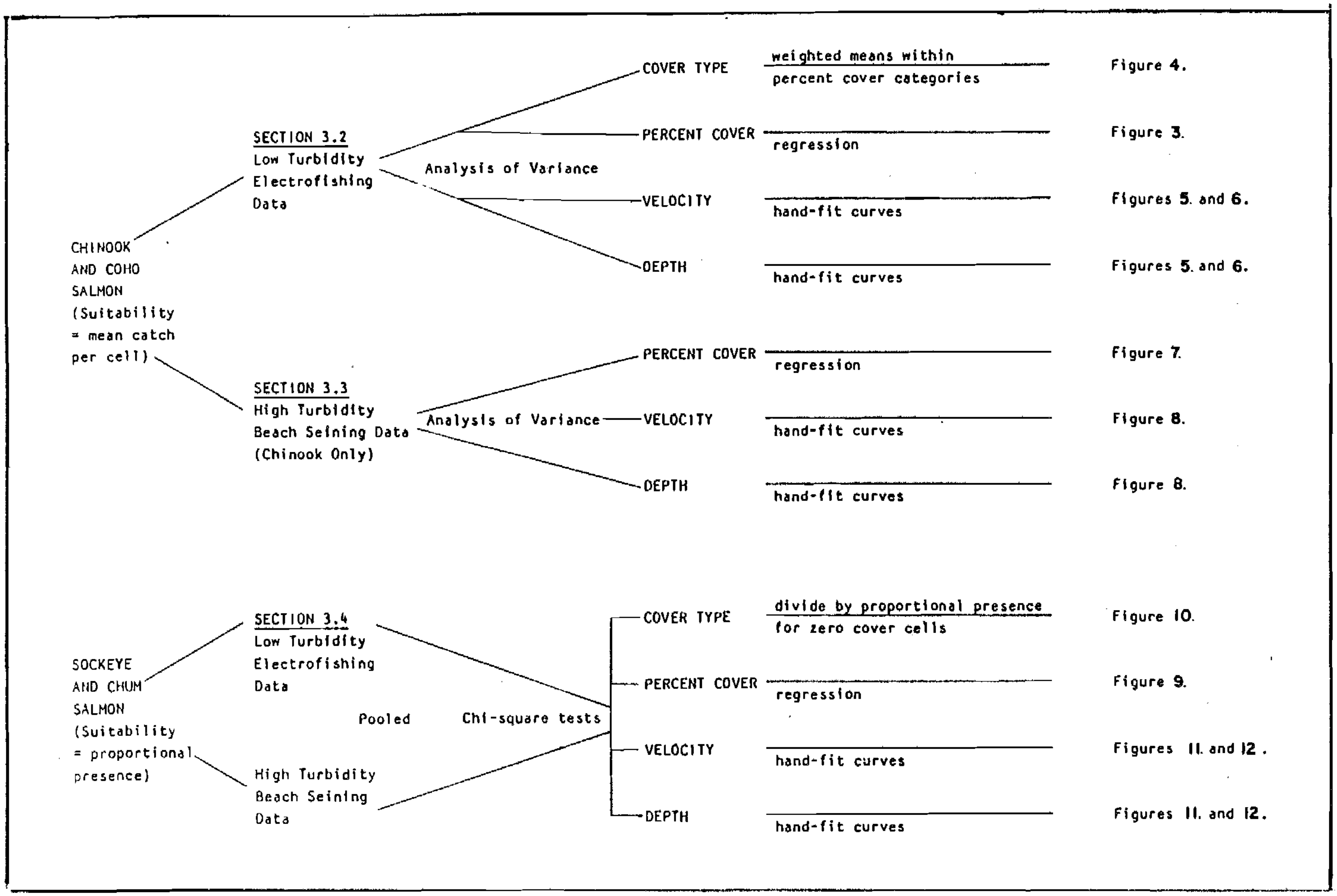

Figure 2. Outline of data analysis pathways for determination of juvenile salmon suitability criteria.

We used different types of analyses for chinook and coho salmon in comparison to sockeye and chum salmon. Chinook and coho salmon are territorial or at least exhibit some forms of agonistic behavior (Stein et al. 1972) and normally disperse themselves as individuals while sockeye and chum salmon are usually distributed in schools which move about as a cohesive social unit.

Suitability was derived for chinook and coho salmon by taking total fish catch for each value of attribute (utilization) and dividing by the number of cells fished having the same attribute value (effort). For example, if 50 chinook salmon fry were captured in 25 cells of 0.0 velocity sampled, mean catch per cell (suitability) was 50/25 = 2.0 for 0.0 velocity cells. Fish density was assumed to be a function of mean catch per cell. Differences in mean catch per cell by habitat attribute value were analyzed with analysis of variance and least squares regression.

Sockeye and chum salmon suitability was derived by taking the total number of cells with fish present by value of habitat attribute (utilization) and dividing by the number of cells fished (effort). For example, if chum salmon fry were captured in 10 of 50 cells of 0.0 velocity fished, then proportional presence (suitability) was 10/50 = 0.2 for 0.0 velocity cells. Suitability was derived differently for sockeye and chum salmon because these fish school normally and capture of a large school within a cell might disproportionately affect mean catch per cell as the habitat might be only as good as another cell nearby without any fish but the cell with fish would be ranked much higher than if rated on a proportional presence basis. Differences in proportional presence by habitat attribute value were analyzed with chi-square tests of association.

Data from all sites over the entire season were pooled by species for analysis. Data from tributary sites where no major runs of sockeye salmon are present were excluded from the sockeye suitability criteria development, as were data collected between May 1 and 15, when only a small percentage of sockeye had emerged. Since the vast majority of chum salmon outmigrate from the upper Susitna River prior to July 15 (ADF&G 1983b), only data collected before July 15 were used to develop suitability relationships for this species.

Statistical analyses used included analysis of variance, linear regression and chi-square tests of association. Most statistical analyses were conducted using the Statistical Package for the Social Sciences (SPSS) (Nie et al. 1975). Transformations by natural log (X+1) were used to help equalize variances and normalize catch per cell of chinook and coho salmon for analysis of variance (Dixon and Massey 1969). Chi-square tests of association were used to examine proportional presence data for differences in use of categories of habitat attributes by sockeye and chum salmon. Expected values in these tests were calculated with standard contingency table techniques. Kendall rank-order correlations were carried out between the habitat variables to check for intercorrelations. The particular procedure utilized in each analysis is presented within the appropriate results section.

Most of the analysis was geared toward a univariate analysis and development of suitability criteria but some multivariate comparisons were made. Multiway analyses of variance were conducted to find if interaction effects were significant. All velocity and depth criteria were fit to the data by hand using professional judgement to give the best fit. The rationale and judgements used for criteria development are discussed according to the individual relationship.

2.3.1 Cover analysis

Cover is an important factor influencing the distribution of juvenile salmon (Reiser and Bjornn 1979). Rocks, debris, and vegetation are types of object cover; turbidity is another form of cover. We examined the effects of both the type and amount of object cover on the distribution of juvenile salmon. Turbidity effects were inferred from differences in catch in cells without object cover over the range of turbidities sampled. We pooled percent object cover categories 76-95% and 96-100% for the analysis because of small sample sizes and then regressed percent cover categories against catch per cell for chinook and coho salmon. The proportion of cells with fish present were regressed against the percent cover categories for sockeye and chum salmon.

The relative importance of object cover type for chinook and coho salmon in clear water was addressed by examining mean catch per cell by cover type within each percent cover category. Each mean catch/cell for a cover type within a percent cover category was divided by the mean catch for that percent cover category for all cover types combined. These ratios were then pooled over all percent cover categories for a cover type by taking a weighted mean adjusted by the number of cells of that cover type within each percent cover category to give an average effect of cover type. The weighted mean was then used to rank cover types by suitability on a scale from 0 to 1. The equations used and an example are given in Appendix A. Cover type suitability differences were not addressed with the beach seine data since we believed seine effectiveness was strongly affected by cover type.

Because of the smaller sample sizes and use of proportional presence data, cover type suitability differences were calculated in a different way for chum and sockeye salmon. Sockeye and chum cover type suitability differences were addressed by pooling the incidence of catch by cover type over all percent cover categories and then dividing through by the proportional presence for cells without object cover. Sometimes, the proportional presence for some cover types was less than the proportional presence for zero cover cells. In these instances, cover type was assumed to have no effect on distribution and was ranked with the zero cover type in the suitability ratings. The equation used and an example are given in Appendix B.

2.3.2 Velocity and depth analysis

Velocity and depth were measured in intervals of 0.1 ft/sec and 0.1 ft, respectively. Since sample sizes were small and variances were high, these values were pooled into groups (Table 2). Baldridge and Amos (1983) listed a number of criteria of use in grouping data for criteria development but since we analyzed four species of salmon, one standard grouping interval was used for all criteria development.

Table 2. Velocity and depth groupings for suitability criteria development.

Group #	Velocity (ft/sec) Grouping	Group #	Depth (ft) Grouping
1	0	1	0.1 - 0.5
2	0.1 - 0.3	2	0.6 - 1.0
3	0.4 - 0.6	3	1.1 - 1.5
4	0.7 - 0.9	4	1.6 - 2.0
5	1.0 - 1.2	5	2.1 +
6	1.3 - 1.5		
7	1.6 +		

Mean catch/cell was again used as the measure of suitability for chinook and coho criteria development. Sockeye and chum suitability was measured using proportional presence.

2.3.3 Tests of data fit

In the PHABSIM system, univariate suitability indices are combined to provide a composite weighting factor which reflects the habitat potential of a cell at a given discharge (Bovee 1982). Suitability criteria are normally combined by multiplying suitability indices together to formulate these weighting factors but other combinations are possible (Milhous et al. 1981). Regardless of the composite weighting factor formulation used, one of the assumptions of the instream flow incremental methodology is that there is a positive linear relationship between weighted usable area and habitat use (Orth and Maughan 1982). We attempted to evaluate various combinations of univariate suitability indices by comparison with observed fish catches.

For chinook and coho salmon, we compared observed catches by cell with composite weighting factors calculated using suitability indices from various combinations of habitat attributes. Pearson correlation coefficients were calculated between various composite weighting factor indices and coho and chinook catch per cell. We again transformed catch per cell with natural log (X+1) to normalize the data. Since proportional presence was used as a measure of suitability for chum and sockeye salmon, correlation coefficients could not be used to test for data fit. Instead, we calculated several composite weighting factors using only a few combinations of univariate suitability indices and then divided the data into four groups of approximately equal size by value of composite weighting factor. Chi-square tests were then run to see if proportional presence was associated with the composite weighting factor value intervals.

3.0 RESULTS

3.1 Sampling Effort and Catch

Fish suitability criteria data were collected at a total of 1,260 cells over the entire season, with about 70 percent of the sampling done with backpack electrofishing gear and 30 percent with beach seines (Table 3). Some of the cells fished were subsequently eliminated from the sockeye and chum suitability criteria development because of seasonal and site factors discussed in the methods section.

Table 3. Sampling effort (number of cells fished) and catch by gear type.

	Electrofishing		Beach Seining		Total	
	Effort (cells fished)	Catch all age classes	Effort (cells fished	Catch all age classes	Effort	Catch
Chinook	871	3066	389	1329	1260	4395
Coho	871	1907	389	113	1260	2020
Sockeye	658	814	355	192	1013	1006
Chum	408	1152	106	5	514	1157

Field observations and examination of the catch data indicated that chinook salmon distribution was very different in turbid water than in clear water. Scatter plots of juvenile salmon catch by species in cells without object cover versus turbidity were examined. An inflection point at approximately 30 NTU was noted for juvenile chinook salmon. The catch rate at turbidities greater than 30 NTU was much higher than the catch rate below 30 NTU, indicating that turbidity is used for cover in lieu of object cover. Sample sizes for the other species were too small to indicate whether other inflection points were evident. Subsequently, mean catch/cell was examined for cells without object cover for each of the four species both above and below 30 NTU (Table 4). Catches of chinook were significantly higher in high turbidity cells without object cover than in similar cells with turbidities of less than 30 NTU. Chum salmon were caught in significantly higher numbers in clear water.

Table 4. Comparison of mean catch per cell for cells without object cover above and below 30 NTU turbidity.

	Total catch in zero cover cells	Total zero cover cells fished	Mean catch ≤30 NTU	Mean catch >30 NTU	t	Significance
Chinook	312	155	0.19(N=42)	2.69(N=113)	14.99	<0.001
Coho	5	155	0.00(N=42)	0.04(N=113)	1.35	0.25
Sockeye	64	144	0.23(N=35)	0.51(N=109)	0.76	0.39
Chum	52	57	1.81(N=21)	0.39(N=36)	5.15	0.03

Since the distribution of chinook is different in waters with turbidities greater than 30 NTU, when compared to clearer water, we grouped the data by both turbidity level and gear type (Table 5). The only data set deemed sufficient in size for suitability criteria development in high turbidity conditions was the chinook beach seine data. Although chum salmon may have a different distribution in turbid water, sample sizes were insufficient for suitability criteria development. Coho catches were very small in turbid water and no turbidity dependent suitability criteria could be generated from the data. The electrofishing data in clear water cells was ample for criteria development, and therefore the small amount of beach seine data were not pooled with the electrofishing data. Similarly, chinook electrofishing data from clear water were used exclusively for low turbidity criteria development.

Small sample sizes made it necessary for gear types and turbidity levels to be pooled for development of chum and sockeye suitability criteria development for two reasons. The amount of electrofishing data for sockeye and chum salmon was smaller than for chinook and coho salmon because some cells fished were eliminated due to season or spawning distribution as previously discussed in the methods. Also since proportional presence was used as the measure of suitability, sample sizes need to be large for good estimates of proportions. We therefore assumed that seining and electrofishing were equally effective at catching at least one fish in a cell if fish were present. Table 6 summarizes the data sets used for criteria development.

Table 5. Sampling effort and catch by gear type and turbidity level.

Clear (Turbidity ≤ 30 NTU)

	Electrofishing Effort	Electrofishing Catch	Beach Seine Effort	Beach Seine Catch
Chinook	813	2574	41	39
Coho	813	1699	41	62
Sockeye	611	757	24	84
Chum	366	1107	16	1

Turbid (Turbidity > 30 NTU)

	Electrofishing Effort	Electrofishing Catch	Beach Seine Effort	Beach Seine Catch
Chinook	44	61	320	1241
Coho	44	206	320	23
Sockeye	44	57	303	101
Chum	29	44	90	4

Note - Cells where turbidity was not recorded (14 electrofished cells and 28 beach seined cells) were excluded from this data set.

Table 6. Data sets used for suitability index development.

Species	Turbidity Level*	Gear Type	Suitability Measure	Number of cells Fished
Chinook	Clear Turbid	Electrofishing Beach Seine	Catch/cell Catch/cell	813 320
Coho	Clear	Electrofishing	Catch/cell	813
Sockeye	Both	Pooled	Proportion of cells with catch	1013
Chum	Both	Pooled	Proportion of cells with catch	514

* Clear - Turbidity ≤ 30 NTU
Turbid - Turbidity > 30 NTU

Correlations among the values of habitat attributes and catch were examined for the data sets used in criteria development. The resulting Kendall rank-order correlation coefficients are listed in Table 7 for the low turbidity electrofishing data. There are a number of statistically significant correlations among the habitat attributes but none are greater in absolute value than 0.18. Correlations between the habitat attributes and fish catch are also small, none being over 0.22 in absolute value. Large correlations among the habitat variables would necessitate a multivariate approach or elimination of selected habitat attributes from consideration.

Table 7. Kendall correlation coefficients between habitat variables and chinook and coho catch by cell (N=813) in clear water for electrofishing data.

	Percent cover	Cover type	Velocity	Depth	Chinook
Percent cover	1.00				
Cover Type	0.11**	1.00			
Velocity	0.13**	0.18**	1.00		
Depth	0.03	-0.11**	-0.17**	1.00	
Chinook	0.21**	0.18**	0.20**	-0.04	1.00
Coho	0.22**	-0.18**	0.02	0.21**	0.20**

*Significantly different from 0 at $p < 0.05$
**Significantly different from 0 at $p < 0.01$

Kendall rank-order correlations among the high turbidity beach seine data were very similar to the electrofishing data (Table 8). The correlation between percent cover and cover type was fairly high (0.40) but small sample sizes and beach seine inefficiency in high object cover conditions caused the analysis of cover type in turbid water to be only qualitative.

Table 8. Kendall correlation coefficients between habitat variables and chinook catch in turbid water by cell (N=320) for beach seine data.

	Percent cover	Cover type	Velocity	Depth
Percent cover	1.00			
Cover Type	0.40**	1.00		
Velocity	0.12**	0.20**	1.00	
Depth	0.01	-0.05	0.08*	1.00
Chinook	0.12**	-0.02	-0.19**	0.12**

*Significantly different from 0 at $p < 0.05$
**Significantly different from 0 at $p < 0.01$

3.2 Analysis of Chinook and Coho Distribution in Low Turbidity Waters

3.2.1 Cover

Two-way analyses of variance (using the regression approach) were run on the catch/cell data to examine the effects of cover type and percent cover on the transformed chinook and coho catch/cell (Table 9). The effects of both cover type and percent cover were significant but the amount of explained variation was small.

Table 9. Analysis of variance in clear water between cover type, percent cover, and chinook or coho catch transformed by ln (x+1). Due to empty cells or a singular matrix, interactions could not be calculated.

Chinook Source of Variation	Sum of Squares	df	Mean Square	F	Significance of F
Main Effects	113.852	12	9.488	10.805	< 0.001
Cover type	45.871	8	5.734	6.530	< 0.001
Percent cover	54.897	4	13.724	15.630	< 0.001
Explained	113.852	12	9.488	10.805	< 0.001
Residual	702.482	800	0.878		
Total	816.334	812	1.005		

Coho Source of Variation	Sum of Squares	df	Mean Square	F	Significance of F
Main Effects	90.738	12	7.561	11.402	< 0.001
Cover type	56.793	8	7.099	10.705	< 0.001
Percent cover	35.058	4	8.765	13.216	< 0.001
Explained	90.738	12	7.561	11.402	< 0.001
Residual	530.550	800	0.663		
Total	621.288	812	0.765		

Least squares regressions were then run between chinook and coho catch per cell and the percent cover categories to quantify the relationship to cover categories where there is only a small amount of data. The fit of the regression to the actual mean catches and derived suitability indices by cover category is shown in Figure 3. The effects of cover type by species were then quantified by taking a weighted mean of the effect of cover type over all percent cover categories to derive a suitability index for cover type (Figure 4).

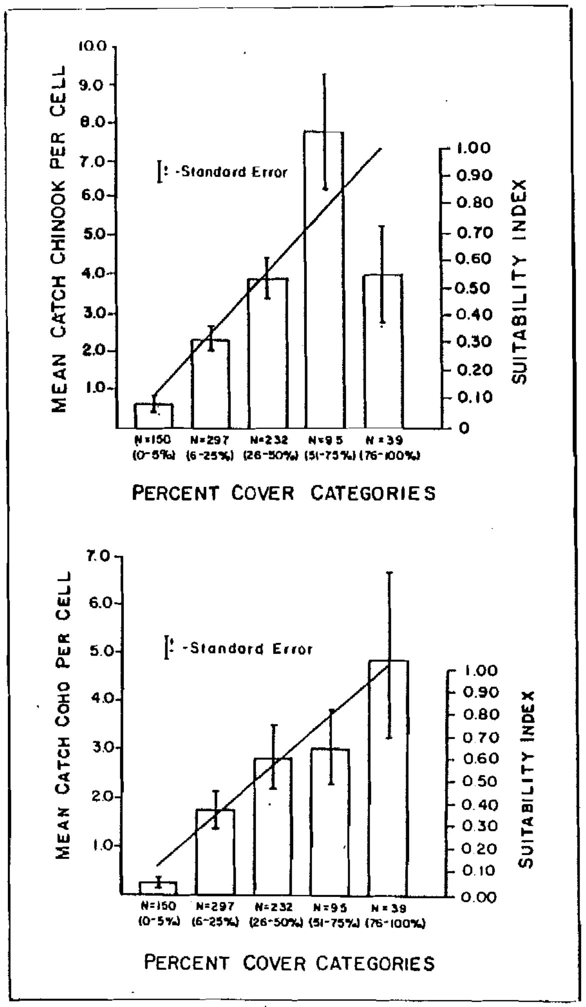

Figure 3. Mean catch of juvenile chinook and coho salmon per cell by percent cover category (bars) and fitted suitability index (lines) in low turbidity waters, Chulitna River to Devil Canyon reach of the Susitna River.

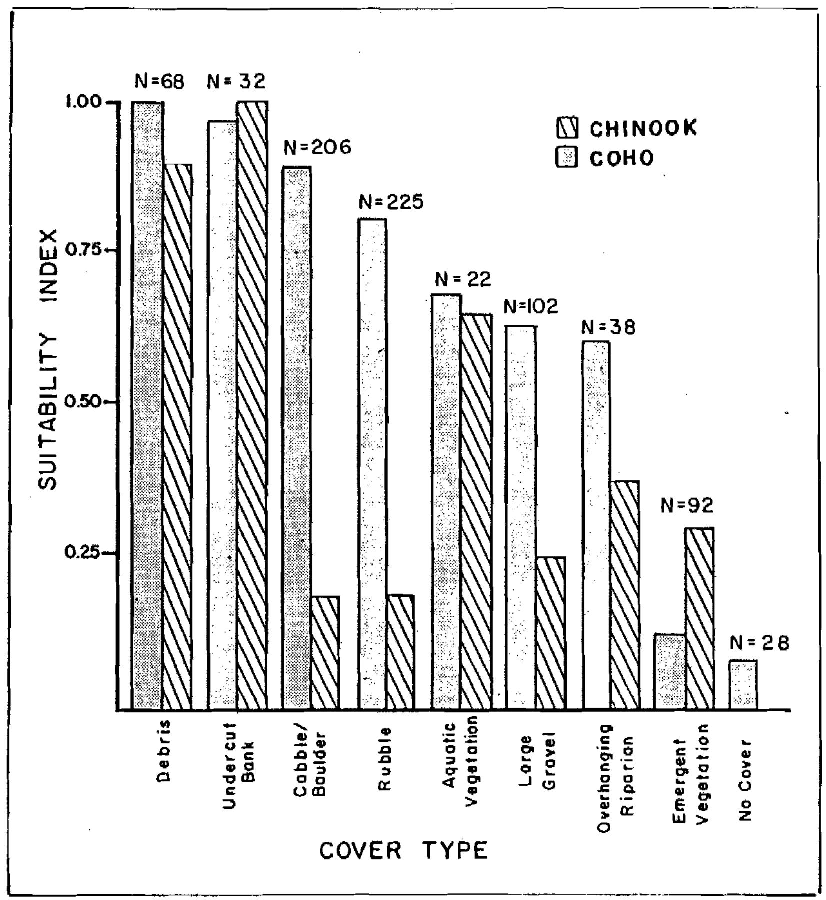

Figure 4. Comparison of cover type suitability indices for juvenile chinook and coho salmon in low turbidity waters, Chulitna River to Devil Canyon reach of the Susitna River.

3.2.2 Depth and velocity

Since depth and velocity were not expected to be linearly related to fish habitat suitability, depth and velocity effects were analyzed in a two-way analysis of variance for chinook and coho catch per cell (Table 10). Depth and velocity were singly not significant for chinook at the 0.05 significance level after adjusting for the effects of the other, but taken together, they were significant for chinook as was the interaction between depth and velocity. Depth, velocity, and the interaction between these two attributes were all significant for coho. The total amount of explained variation was again relatively small for both species.

Table 10. Analysis of variance in clear water between depth, velocity, and chinook or coho catch transformed by ln (x+1).

Chinook Source of Variation	Sum of Squares	df	Mean Square	F	Significance of F
Main Effects	27.426	10	2.743	2.990	< 0.001
Depth	8.099	4	2.025	2.207	0.067
Velocity	7.549	6	1.258	1.372	0.223
Interaction Effects	25.216	16	1.576	1.718	0.039
Explained	95.271	26	3.664	3.994	< 0.001
Residual	721.062	786	0.917		
Total	816.334	812	1.005		

Coho Source of Variation	Sum of Squares	df	Mean Square	F	Significance of F
Main Effects	35.505	10	3.551	5.242	< 0.001
Depth	8.318	4	2.079	3.070	0.016
Velocity	19.343	6	3.224	4.760	< 0.001
Interaction Effects	40.079	16	2.505	3.699	< 0.001
Explained	88.957	26	3.421	5.052	< 0.001
Residual	532.331	786	0.677		
Total	621.288	812	0.765		

Since the data base was not large enough, given the amount of variability in the data, to fit a multivariate function with any confidence, we examined depth and velocity only on a univariate basis. Professional judgement was used to fit a curve to the data by hand and suitability indices were normalized to the fitted data (Figures 5 and 6). The functions were fit so that they followed the means most closely over the intervals where sample sizes were greatest. On the depth curves, we

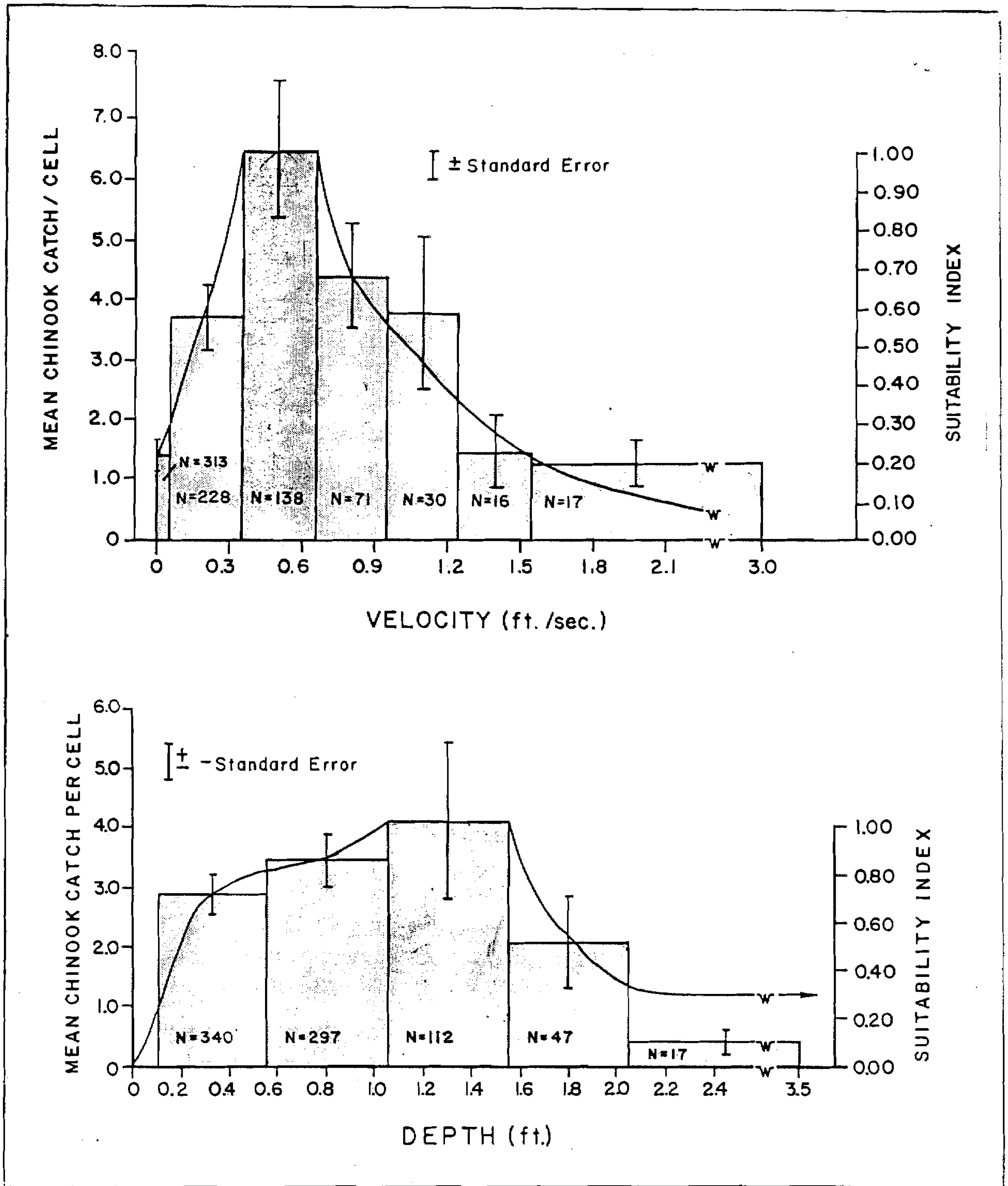

Figure 5. Mean catch of juvenile chinook salmon per cell by velocity and depth intervals (bars) in low turbidity waters, Chulitna River to Devil Canyon reach of the Susitna River. Suitability indices (lines) fitted by hand.

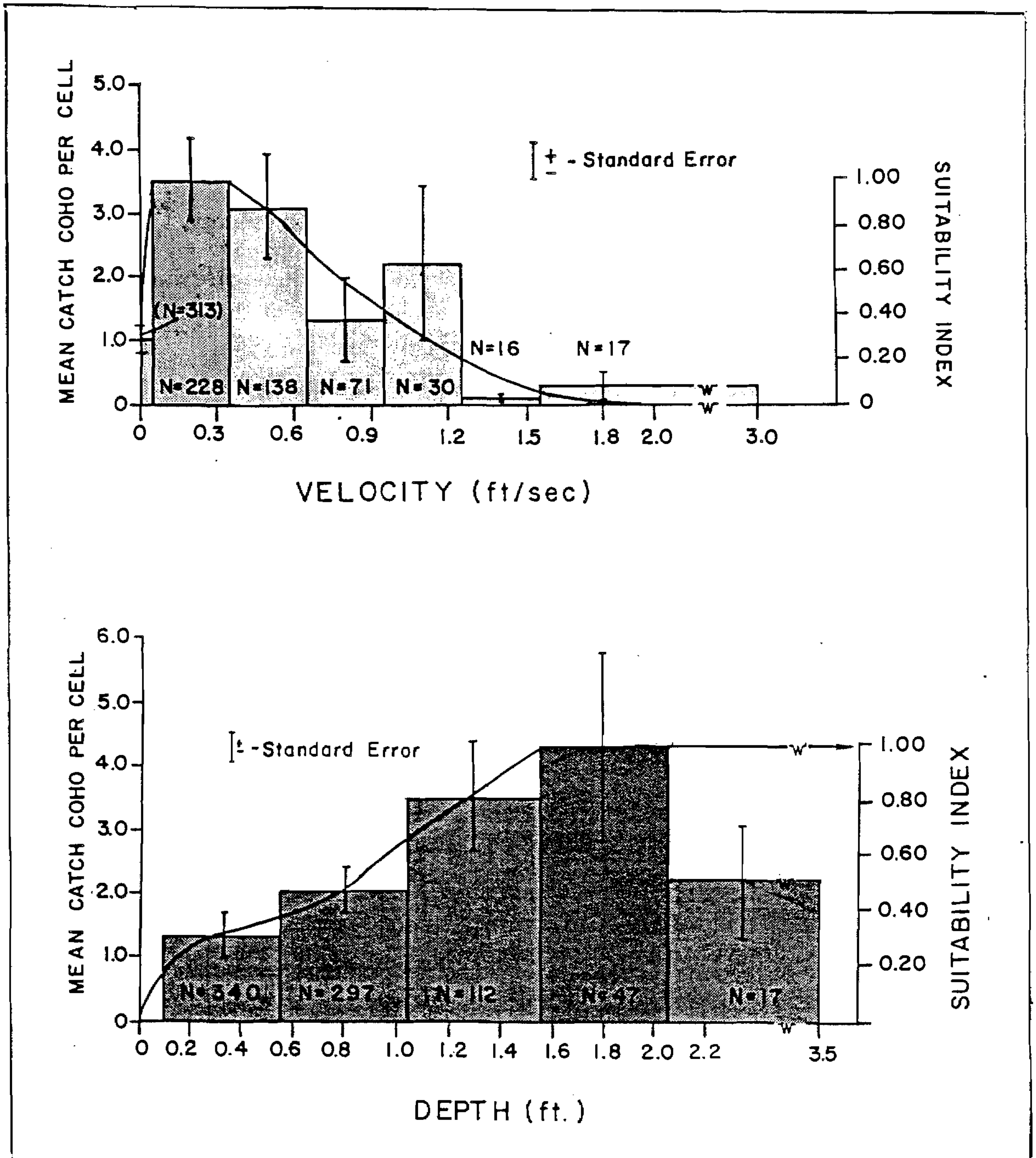

Figure 6. Mean catch of juvenile coho salmon per call by velocity and depth intervals (bars) in low turbidity waters, Chulitna River to Devil Canyon reach of the Susitna River. Suitability indices (lines) fitted by hand.

believed that gear inefficiency was becoming a factor at the greatest depths sampled and therefore the curves were drawn in at a higher suitability than a close fitting of the data would warrant. The depth curves did not drop off to zero at the high ranges because we thought depths did not limit juvenile distribution and we had no data for large depths.

3.3 Analysis of Chinook Salmon Distribution in High Turbidity Waters Using Beach Seine Data

3.3.1. Cover

Cover analysis of beach seine catch data is complicated by the fact that gear effectiveness is reduced by the amount and type of object cover. A least squares regression line was taken as a reasonable estimate of the relationship between suitability and percent cover, however, and a suitability index was normalized to the regression line (Figure 7). We did not try to analyze the effect of object cover type on suitability for chinook as it was obvious that the chinooks were using turbidity for cover and thus the type of object cover present was probably not as important.

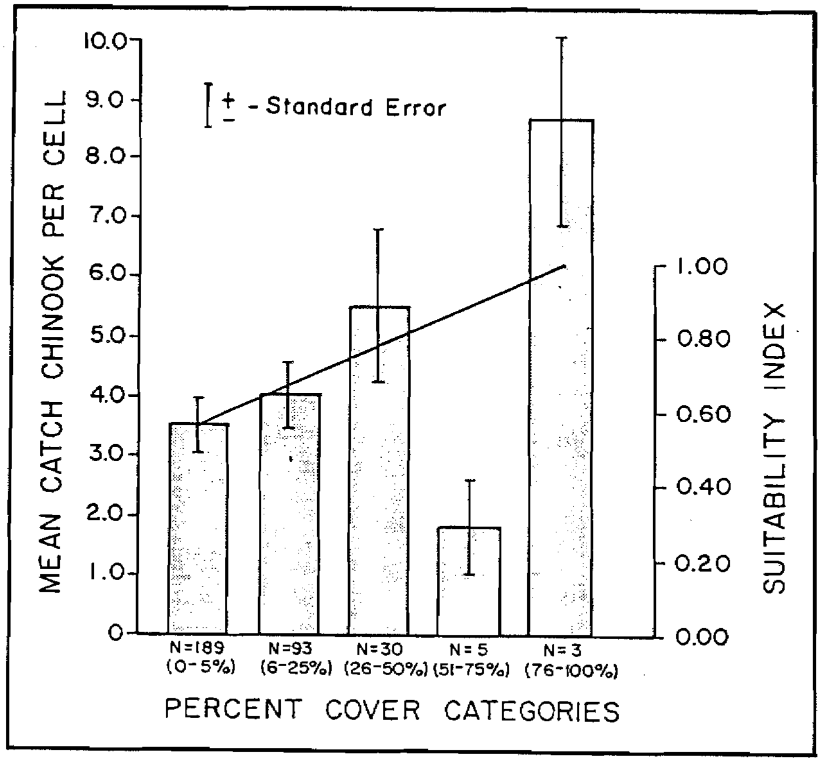

Figure 7. Mean catch of juvenile chinook salmon per cell by percent cover categories (bars) and fitted suitability index (line) in high turbidity waters, Chulitna River to Devil Canyon reach of the Susitna River.

3.3.2 Depth and velocity

Depth and velocity have much less effect on beach seine effectiveness than does the amount and type of cover within the range sampled and so analysis of depth and velocity was identical to that used for the electrofishing data. A two-way analysis of variance between depth, velocity and catch per cell showed velocity to be significant (Table 11). Depth was not significant by itself as an effect and interactions could not be assessed due to empty cells (in the analysis of variance table classification).

Table 11. Analysis of variance between depth, velocity, and chinook catch transformed by ln (x+1) in high turbidity water. Due to empty cells or a singular matrix, interactions could not be calculated.

Chinook Source of Variation	Sum of Squares	df	Mean Square	F	Significance of F
Main Effects	43.617	10	4.362	5.160	< 0.001
Depth	5.965	4	1.491	1.764	0.136
Velocity	35.617	6	5.936	7.022	< 0.001
Explained	43.617	10	4.362	5.160	< 0.001
Residual	261.212	309	0.845		
Total	304.828	319	0.956		

Even though depth was not statistically significant by itself, a curve was fit by hand to the data for depth using professional judgement because a trend was evident (Figure 8). A curve was also fit to the velocity data by hand using professional judgement and a suitability index derived (Figure 8). The data indicate that in turbid water, chinook use shallower and slower moving water than they do in clear water.

3.4 Analysis of Sockeye and Chum Salmon Proportional Presence Using Pooled Electrofishing and Beach Seining Data

3.4.1. Cover

Since proportional presence was used as a measure of suitability instead of catch per cell, standard analysis of variance techniques were not used. Instead, chi-square tests of association were used to test for differences in proportional presence among categories of percent cover and cover type (Table 12). All these tests were significant and suitability criteria were fit to the data. The five points of proportional

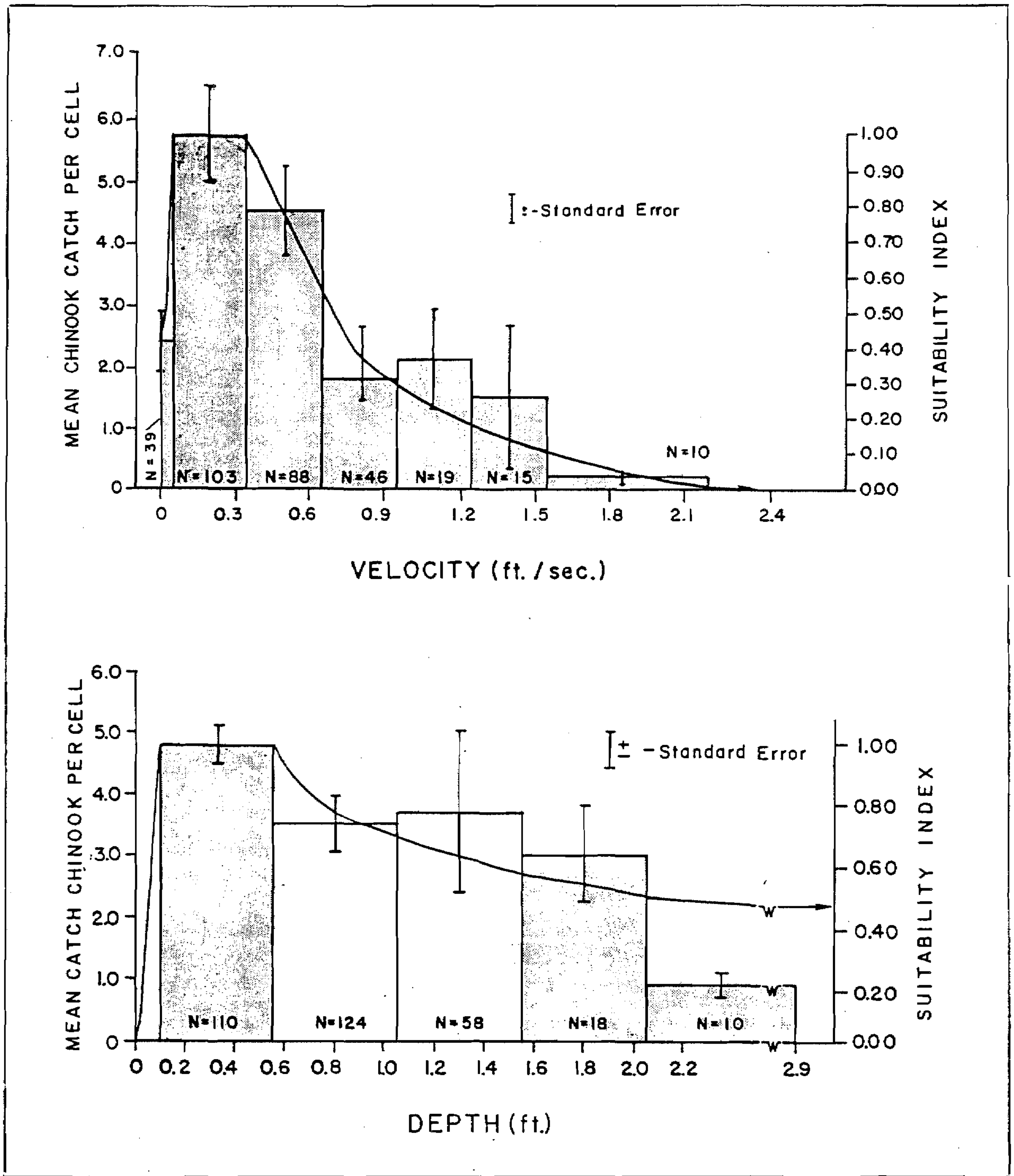

Figure 8. Mean catch of juvenile chinook salmon per cell by velocity and depth intervals (bars) in high turbidity waters, Chulitna River to Devil Canyon reach of the Susitna River. Suitability indices (lines) fitted by hand.

presence were regressed to the percent cover categories and the regression line was normalized to a suitability index (Figure 9). Cover type suitability criteria were formed by dividing through by the percent presence for zero cover cells and then normalizing (Figure 10). Some cover types were not any more suitable than the zero cover cells.

Table 12. Chi-square tests for differences in proportions of sockeye or chum presence between habitat attribute groupings of percent cover, cover type, velocity and depth.

Species	Habitat Attribute	df	Chi-square
Sockeye			
	Cover type	8	41.11**
	Percent cover	4	19.05**
	Velocity	6	28.68**
	Depth	4	15.73*
Chum			
	Cover type	8	21.18*
	Percent cover	4	23.65**
	Velocity	5	11.06*
	Depth	3	20.09**

*Significant at $p < 0.05$
**Significant at $p < 0.01$

3.4.2 Depth and velocity

Chi-square tests indicated that the depth and velocity group intervals were associated with both sockeye and chum proportional presence (Table 12). Curves were fit to the data by hand using professional judgement (Figures 11 and 12) and suitability indices normalized to the lines.

Velocity criteria were similar for both species but the depth criteria indicated that sockeye salmon found deeper water more suitable while chum used shallower water.

3.5 Tests of Fitted Habitat Values to Observed Fish Catches

3.5.1 Chinook and coho salmon

Once suitability indices were fitted to the data, various formulations of composite weighting factors were correlated with actual fish catches to evaluate their fit. Catches were transformed by ln (X+1) and Pearson correlations were then run between the transformed catch and various composite weighting factor combinations of habitat variables (Table 13).

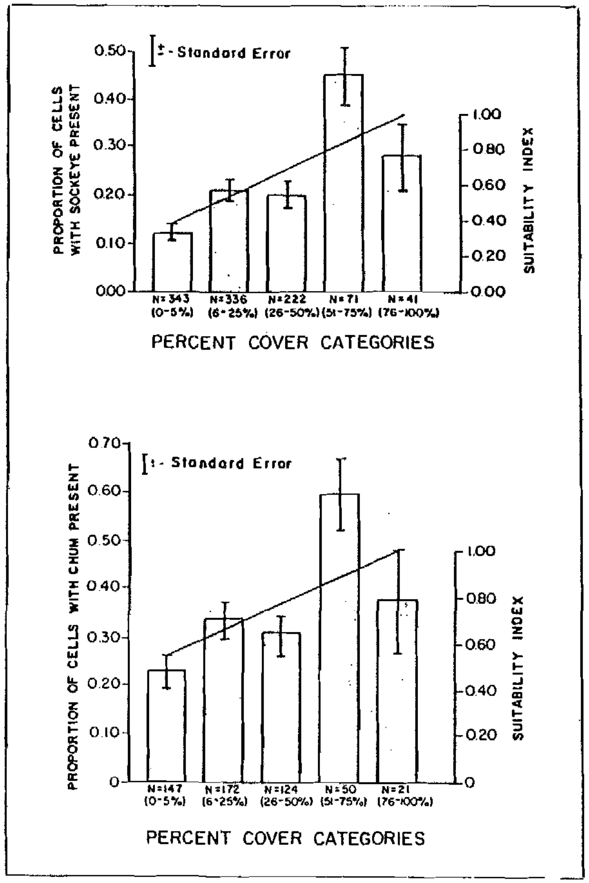

Figure 9. Proportion of cells with juvenile sockeye and chum salmon present by percent cover category (bars) and fitted suitability indices (lines), Chulitna River to Devil Canyon reach of the Susitna River.

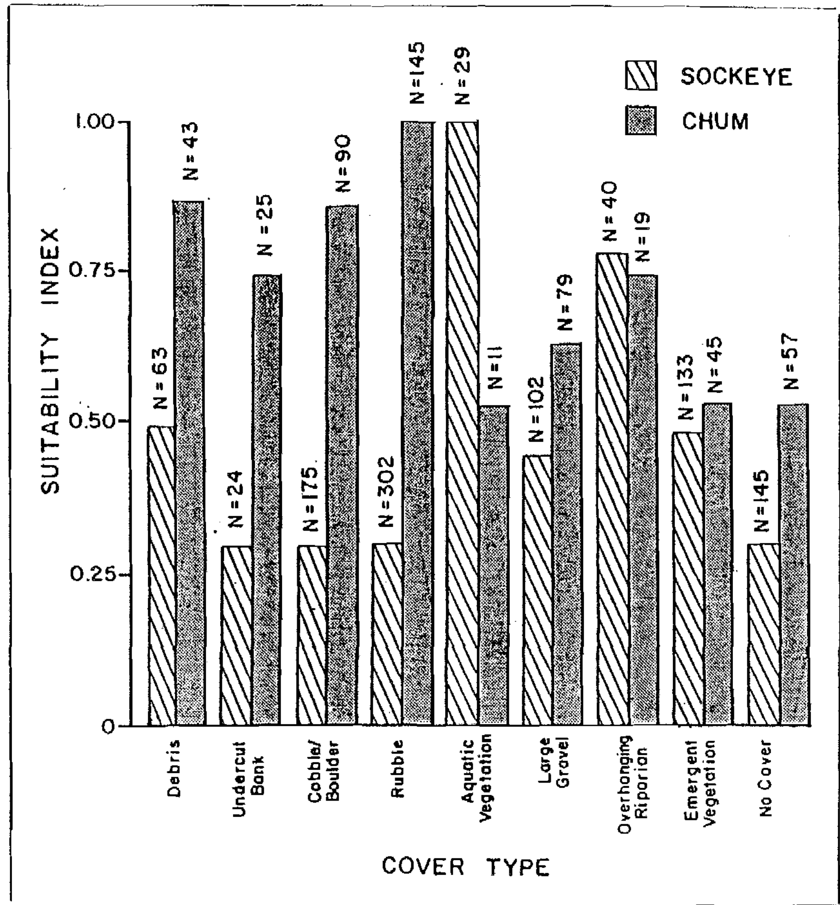

Figure 10. Comparison of cover type suitability indices for juvenile sockeye and chum salmon, Chulitna River to Devil Canyon reach of the Susitna River.

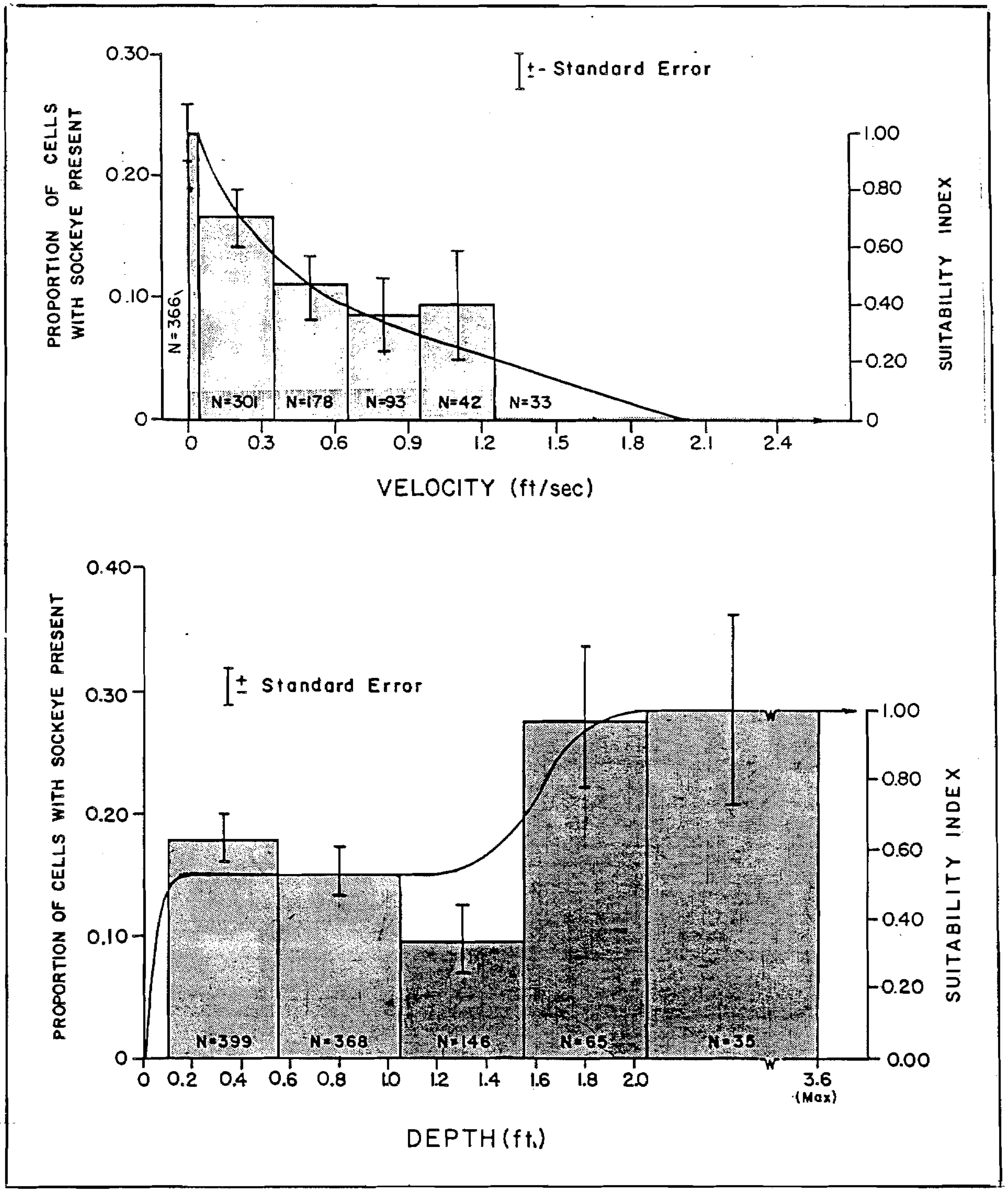

Figure 11. Proportion of cells with juvenile sockeye salmon present by velocity and depth intervals (bars), Chulitna River to Devil Canyon reach of the Susitna River. Suitability indices (lines) fitted by hand.

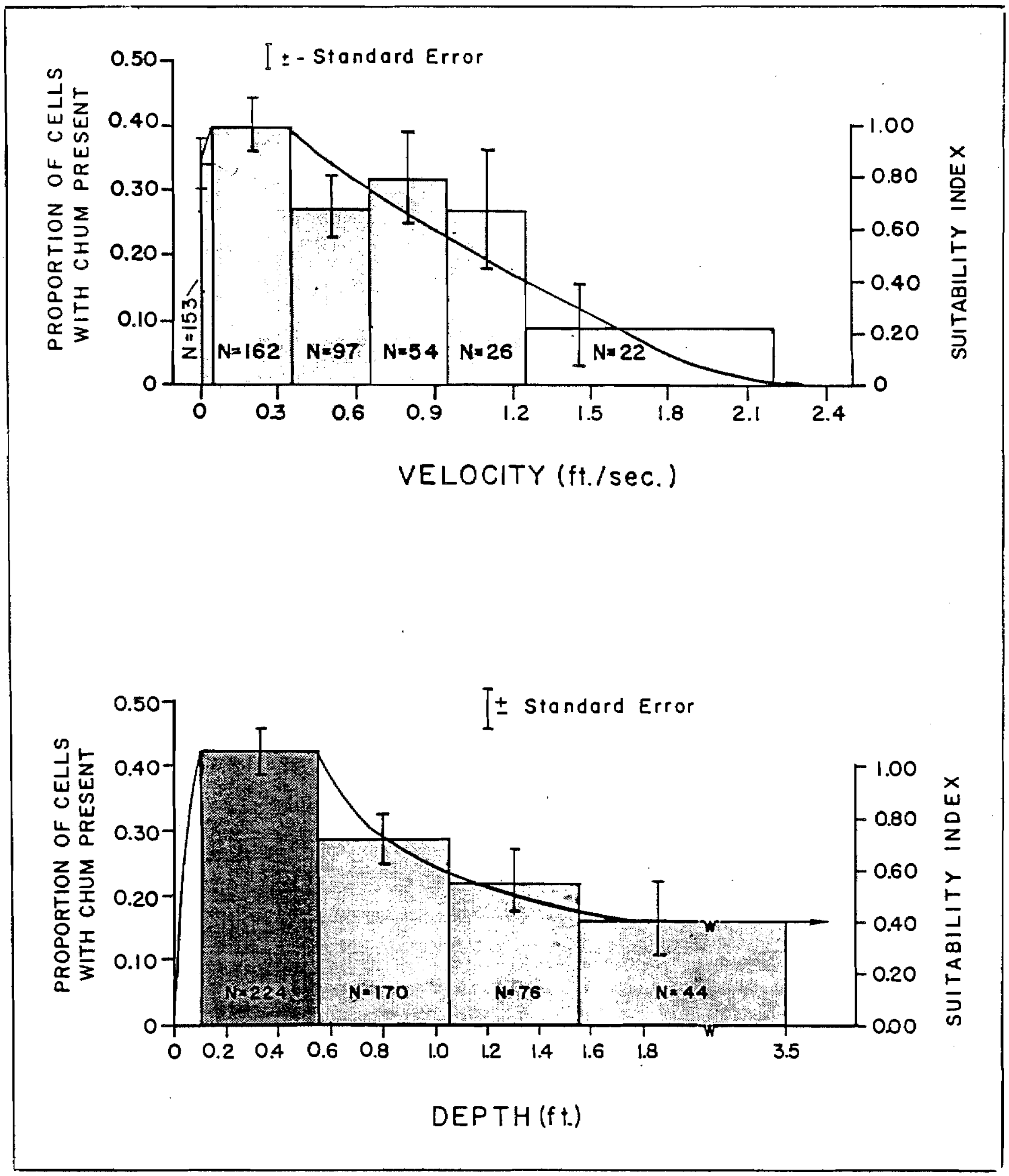

Figure 12. Proportion of cells with juvenile chum salmon present by velocity and depth intervals (bars), Chulitna River to Devil Canyon reach of the Susitna River. Suitability indices (lines) fitted by hand.

The correlations range from 0.16 to 0.42, and all were statistically greater than zero.

Table 13. Correlations between composite weighting factors generated using various combinations of suitability indices and transformed [ln (X+1)] chinook and coho catch.

Composite Weighting Factor Calculation	Pearson correlations (r)* Chinook (clear)	Coho (clear)	Chinook (turbid)
(Percent cover)x(cover type)x(velocity)x(depth)	0.42	0.36	0.31
(Percent cover)x(cover type)x(velocity)	0.41	0.38	0.30
(Percent cover)x(cover type)	0.35	0.37	0.16
(Velocity)x(depth)	0.28	0.30	0.28
Limiting factor (minimum of (percent cover x cover type), (velocity), or (depth) taken as weighting factor)	0.43	0.39	0.32
	N=813	N=813	N=813

* All correlations significantly greater than zero at the 0.01 significance level.

Combinations of habitat variables with the highest correlations are the most likely candidates for applications in habitat modelling studies. The low correlations are due to the fact that actual fish numbers are influenced greatly by other factors such as season and site.

3.5.2 Sockeye and chum salmon

Sockeye and chum salmon proportional presence increased significantly with increased magnitude of several composite weighting factor intervals (Table 14). The largest composite weighting factor interval had an associated proportional presence which was three to seven times the proportional presence associated with the lowest composite weighting factor interval.

Table 14. Proportional presence of sockeye and chum salmon fry associated with several composite weighting factors.

Species	Composite Weighting Factor Calculation	Composite Weighting Factor Interval	Total No. of cells	Proportion with Fish Present	Chi-Square
Sockeye	Minimum factor of (percent cover x cover type), (velocity) or (depth)	0.0-0.12	269	0.12	62.9*
		0.12-0.20	321	0.08	df=3
		0.20-0.33	312	0.22	
		0.33+	111	0.38	
Sockeye	(Percent cover) x (cover type) x (velocity) x (depth)	0.0-0.04	312	0.09	49.6*
		0.04-0.08	260	0.13	df=3
		0.08-0.17	330	0.20	
		0.17 +	111	0.36	
Sockeye	(Percent cover) x (cover type) x (velocity)	0.0-0.08	341	0.09	50.8*
		0.08-0.14	253	0.12	df=3
		0.14-0.30	308	0.22	
		0.31 +	111	0.35	
Chum	Minimum factor of (percent cover x cover type) (velocity), or (depth)	0.0-0.33	79	0.18	32.6*
		0.33-0.50	177	0.25	df=3
		0.50-0.67	178	0.37	
		0.67+	80	0.55	
Chum	(Percent cover) x (cover type) x (velocity) x (depth)	0.0-0.17	77	0.09	49.6*
		0.17-0.31	171	0.26	df=3
		0.31-0.53	177	0.37	
		0.53 +	89	0.56	
Chum	(Percent cover) x (cover type) x (velocity)	0.0-0.26	71	0.14	32.7*
		0.26-0.44	183	0.27	df=3
		0.44-0.64	175	0.36	
		0.64 +	85	0.54	

* All significant at $p < 0.001$

4.0 DISCUSSION

Suitability criteria for juvenile salmon in the Susitna River have been developed by integrating statistical methods with professional judgement. Somewhat novel design and analysis methods were used to overcome problems that prevented the use of traditional applications in the Susitna River system. Bovee (1982) reviewed the popular methods of describing preference curve construction. The methods range from the binary criteria used by Collings et al. (1972) to multivariate suitability techniques explored by Voos (1981) and Prewitt (1982). Perhaps the most widely used methods have been the probability-of-use curves construction techniques described by Bovee and Cochnauer (1977).

Baldrige and Amos (1983) have expanded Bovee and Cochnauer's approach to produce univariate suitability descriptions which minimize environmental and sampling bias. Our techniques merge these authors' concepts of environmental suitability, availability, and usability with an infrequently applied approach. Usability descriptions (defined as suitability times availability) are commonly derived from collecting point specific habitat measurements at locations where fish are observed. These data are the probability of observing a value for an environmental attribute (E), given fish (F), which is P[E/F] (Bovee 1982). This practice cannot be easily implemented for juvenile salmon in large turbid glacial systems. Instead, we have compiled the description P[N/E], the probability of one or more fish (N), given a set of environmental attribute values. This method, has the benefit of collecting fish and physical habitat data in a manner that can be used to subsequently verify model outputs. This was accomplished by establishing the grid and cell sampling scheme over important rearing areas in the reach. Bovee notes that two assumptions are made when P[N/E] distributions are calculated directly: systematic random sampling is employed and that the entire population is sampled. We view our experimental design as stratified random sampling of selected areas of the most important macrohabitats available in the reach above the Chulitna confluence. While we did not observe the whole population we believe that representative data have been collected.

4.1 Limitations of the Suitability Criteria

Not all the factors which could have a major effect on the distribution of juvenile fish were addressed in this study. We evaluated cover, depth, and velocity but such factors as water quality and food production also influence juvenile salmonid distribution (Reiser and Bjornn 1979). We may have addressed food production indirectly as Reiser and Bjornn reported that velocity, depth, and substrates are correlated with food supply. The water quality suitability differences within and between sites are probably minimal with the exception of turbidity as measured water quality attributes of dissolved oxygen and temperature normally do not vary greatly from optimum ranges presented by Reiser and Bjornn (1979).

These criteria are also specific to the Susitna River reach studied and if used outside that reach they might not be valid. The suitability criteria developed are also limited to the open-water time period from

May to mid-October. Winter rearing habitat preferences are probably different as feeding and activity of the fish are reduced. Bjornn (1971) reported that juvenile salmon enter large rubble substrate when stream temperatures drop below 4-6°C and will leave the area if this cover type is not present.

The criteria are also limited by the values of the habitat attributes which could be effectively sampled by the methods used. Velocities over three feet per second and depths over two to three feet could not be effectively sampled, for example. A preliminary experiment described in Part 2 of this report suggested that sampling efficiency also decreased slightly in cells with large amounts of cover.

Single habitat measurements used to describe a cell with diverse values of habitat attributes like depth and velocity are often inadequate descriptions. Since the curves are univariate, they also do not account for interactions between variables such as depth and velocity.

Criteria also were not developed specifically by age class; however, over 99% of the fish captured were 0+ fish and 1+ fish were pooled with these to increase sample sizes. Suitability criteria might also shift as a function of within year life history: larger fish of a given species may prefer different habitat conditions as food sources and behaviors change. (Chapman and Bjornn 1969; Everest and Chapman 1972).

4.2 Chinook and Coho Salmon

Chinook and coho salmon low turbidity suitability indices were developed from the same data set. Electrofishing is perhaps the best method for collecting juvenile fish in clear water as seining efficiency is affected strongly by cover. Because the backpack electroshocker is most effective in shallow water, the depth curves were drawn so that the suitability in deep water was actually higher than indicated by the data. Wiley and Tsai (1983) concluded that the electroshocker (and also beach seine) was more effective and consistent than seines for estimating fish populations. Dauble and Gray (1980) concluded that electrofishing was better than beach seining for sampling irregular substrates and higher velocities.

4.2.1 Chinook salmon

Chinook salmon were the only species for which enough data were collected to generate suitability indices for both clear and turbid conditions. Some shifts in preferences for habitat conditions are apparent. Lower velocity waters are preferred under turbid conditions than under clear conditions, as are shallower depths (Figures 5 and 8). Juvenile chinook salmon possibly prefer lower velocities in turbid water because when using the turbid water as cover, they have no velocity breaks to hide or rest behind. Cover might still be useful, however, as a break from velocity. A shift in depth preference may be due to the fish reacting to high suspended solid concentrations by staying near the surface (Wallen 1951 as cited in Beauchamp et al. 1983).

The preference for object cover appears stronger in clear water than in turbid water for chinook salmon because of the higher suitability for low cover cells and lesser slope of the cover regression line in turbid than in clear water. This limited preference for object cover in turbid water is partly due to gear bias as beach seining is quite ineffective where large amounts of object cover are present. However, the distribution of chinook salmon is clearly different in clear than in turbid water. In turbid waters, such factors as depth and velocity most limit and influence distribution while in clear water, object cover seems more important. MacCrimmon (1954) noted Atlantic salmon fry use of turbid water for cover.

The velocity probability-of-use curves for juvenile chinook salmon presented in Bovee (1978) and Burger et al. (1982) are almost identical with the curve developed for chinooks in clear water of the Susitna River with the peaks at approximately 0.2 to 0.6 ft /sec. Minnow trap chinook catch data from the Little Susitna River also suggest the optimum velocity for chinook salmon to be approximately 0.3 to 0.6 ft /sec with little use of velocities greater than 1.8 ft /sec (Delaney and Wadman 1979).

Depth criteria developed in other systems for juvenile chinook salmon vary significantly from those presented here, where optimum depths were 1.0 to 1.5 ft in clear water and less than 0.5 ft in turbid water. A depth probability-of-use curve presented in Bovee (1978) for chinook salmon shows an optimum range from 1.2 ft up to at least 3.0 ft in depth, while data presented in Delaney and Wadman's (1979) data suggest an optimum of 2.5 to 3.2 ft Burger et al. (1982) observed chinook fry in pools to ten feet in depth and thought depths of less than 0.2 ft were avoided. Correlations of depth with other important distributional factors which may vary from river to river probably cause much of this variation in the form of the depth suitability functions.

4.2.2 Coho salmon

In contrast to chinook salmon, coho salmon do not appear to use turbid water as cover. Bisson and Bilby (1982) reported that coho salmon avoided turbidities of 70 to 100 NTU under experimental conditions and Sigler et al. (1984) found, in a laboratory study, that more juvenile coho salmon emigrated from channels with a turbidity level of 25-50 NTU than from clear water channels. These turbidity levels are frequently exceeded during the ice free months in side channels of the Susitna River. Catches of coho salmon were very low in turbid side channels (see Part 2 of this volume). Cover types preferred by coho, i.e. debris and undercut banks, are also very scarce at these sites, however, and almost impossible to sample effectively with beach seines. It may be that coho usually leave a site when turbidities exceed a certain level.

The distribution of coho salmon fry may be limited greatly within a clear water area by the lack of suitable cover type, as very strong preferences for a few cover types were noted (Figure 4). In contrast to chinook salmon, substrate was little used as cover while preferred velocities and depths were also somewhat different. Bustard and Narver (1975) also noted that coho preferred bank cover in the form of undercut banks rather than instream cover. Social interactions between the two species could cause these differences (Stein et al. 1972) but intraspecific interactions and microhabitat preferences might be most important (Allee 1981).

Bovee (1978) presented a velocity suitability curve for coho fry very similar to that presented in this report with a slightly higher optimum of 0.5 ft /sec. and a minimum at 2.3 ft /sec. Burger et al. (1982) presented utilization curves with optimums at 0.0 ft /sec , but which then quickly dropped to very low suitabilities at velocities greater than 0.2 ft /sec. Habitat suitability criteria from the Terror and Kizhuyak Rivers for coho salmon juveniles also presented optimum velocities at 0.0 to 0.4 ft /sec (Baldridge 1981) as do those suggested by Delaney and Wadmans' (1979) data. Optimum velocities for coho derived in this report are therefore very similar to velocity criteria developed for coho in other streams.

Depth criteria, on the other hand, vary greatly from stream to stream. On the Terror and Kizhuyak rivers, optimum depths for coho fry ranged from near 0.0 ft to 1.0 ft and then declined rapidly to zero at 2.5 ft (Baldrige 1981). Data presented in Bovee (1978), however, indicate very little use until 1.0 ft in depth with an optimum at 2.0 ft and a gradual decline to zero use at 5.0 ft. In the Susitna River, the optimum suitability appeared to occur at approximately 1.6 to 2.0 ft with limited data above this depth. These conflicting data show that depth suitability may vary greatly from river to river for unknown reasons, although correlations of depth with other important factors influencing distribution are probable.

4.3 Sockeye and Chum Salmon

The sockeye and chum suitability indices are less reliable than for chinook and coho as the numbers, distribution, and seasonal use of habitat is smaller for these species. The seasonally reduced sampling and need for large sample sizes also made it necessary to pool gear types to adequately address the range of habitat conditions encountered during the study. The schooling behavior of these species also caused us to put catch on a presence-absence basis for purposes of analysis.

4.3.1 Sockeye salmon

Sockeye salmon were apparently much less dependent on cover than were chinook or coho salmon because they occur in schools and use the schooling as a means of predator avoidance. Schools of sockeye were observed ranging throughout areas which varied from heavy cover to no cover at all. Depth and velocity, therefore, could have a much larger effect on their distribution. However, from the analysis, the distribution of junvenile sockeye salmon did appear to be related with cover. The suitability curves for depth and velocity both indicate a fish that rears in a lacustrine environment. The effect of turbidity on sockeye salmon distribution is unknown. A limited review of the literature indicated that suitability criteria for stream rearing sockeye populations have not been developed. Burger et al. (1982) presented a velocity probability-of-use curve for sockeye in the Kenai River with an optimum at 0.0 ft /sec and very little use at velocities greater than 0.6 ft /sec.

Sockeye salmon have a limited distribution in the upper Susitna River basin. Most of the rearing appears to be limited to sites along the mainstem Susitna which offer lacustrine environments. However, we had no means of effectively sampling these types of habitat areas in this study.

4.3.2 Chum salmon

Of the four species of salmon which rear in the middle Susitna River, chum salmon rear for the shortest period of time (ADF&G 1983b). Little is known about the rearing requirements of chum salmon but they have been reported to use substrate as cover initially (Neave 1955) and then after schooling, use the protection of the schools (Hoar 1956). Both these behaviors of chum salmon fry were observed in the Susitna River and the suitability indices reflect a larger relative use of large substrate for cover by chum salmon than for sockeye salmon. As the amount of cover increased greatly, however, the change in use by juvenile chum salmon was very similar to sockeye salmon. Shallow depths and low velocity water were found most suitable for chum salmon fry in this study. Mean catches of juvenile chum salmon were less in cells without object cover in turbid water which suggests avoidance of turbid conditions. On the other hand, this may also have been an artifact of the influences of natal areas on distribution with clear water near emergence areas affecting the results.

4.4 Recommended Applications for the Suitability Criteria

The suitability criteria for juvenile salmon in the Susitna River reach between the Chulitna River confluence and Devil Canyon which are recommended for use in calculating weighted usable area are listed in Appendix Table C-1.

Suitability criteria, in conjunction with hydraulic models, are one means of calculating changes in habitat with changes in flow. Typically, weighted usable areas (WUA's) are calculated for a series of discharges and these are taken as representing changes in the desirability of habitat. There are several standard methods for calculating WUA's by multiplying area with composite weighting factors which are combinations of suitability indices of factors believed to have major effects on distribution. Suitability indices can be multiplied together, the geometric mean can be taken, or the lowest suitability index for attributes of importance can be used as the composite weighting factor (Milhous et al. 1981).

We have calculated composite weighting factors for various combinations of habitat attributes and compared the composite weighting factor to observed fish catch (Tables 13 & 14). The geometric mean was not used for integrating suitability indices as this implies a compensatory effect that does not seem biologically reasonable for juvenile salmonids. The correlations are very similar for various combinations and are consistently low. Other formulations of composite weighting factors are possible and these could produce better correlations, but time constraints prevented further testing.

Effects of depth on the distribution of juvenile salmon are probably limited as depth typically by itself would not limit the distribution of fish. Correlations with other factors like site, season, or velocity may make depth seem more important than it is. When depth was eliminated from calculations of the composite weighting factor, little reduction in the correlations of catch with weighting factors was noted. By including depth in the calculations, however, equal weight is given to depth with cover and velocity and this weighting can drive changes in WUA with discharge as was noted in trial runs with models discussed in Part 4 of this report. Since depth is not as limiting in a behavioral or physical sense as cover and velocity are, its applicability to habitat modelling as equally weighted with velocity or cover is dubious. Analyses of variance, however, suggested that depth and velocity interactions were sometimes significant and that fish were not selecting habitat on the basis of velocity independent of depth (Table 10). Interactions of depth and velocity have been shown in at least one other study (Orth and Maughan 1982) to affect WUA's when depth and velocity were multiplied together to generate composite weighting factors.

Because the inclusion of depth in the composite weighting factors did not improve the correlation with fish density, we decided to discount the effect of depth at depths greater than 0.15 ft in the composite weighting factors which were used in projecting weighted usable area in Part 4 and Part 7 of this report. This was done by setting the suitability index to 1.0 for all depths greater than or equal to 0.15 ft. and represents a departure from the depth suitability indices presented in the results section. The 0.15 point is somewhat arbitrary, but there is little data to go on. Burger et. al (1982) as previously suggested that chinook salmon avoided depths of less than 0.2 ft. Obviously, a depth of 0.0 ft. has a suitability index of 0.0.

If turbidity is used as cover, then depth suitability is not independent of turbidity. At shallower depths, water of a given turbidity may not provide cover, while deeper waters may provide excellent cover. Secchi disc transparencies measured in Eklutna Lake decreased from 3.0 to 1.4 ft. over a turbidity range of 18 to 36 NTU (R & M Consultants, 1982). Cover for fish would be provided at shallower depths than indicated by Secchi disc readings due to their cryptic coloration. The relationship of turbidity to light penetration, water depth, and related cover value has not been quantified in the Susitna River.

The minimum factor approach which implies that the habitat is no better than the most limiting attribute is biologically reasonable. The calculated fit with the observed data was as good as the other approaches used. When the minimum factor was used as the composite weighting factor, cover was often the minimum factor for chinook and coho salmon in clear water, velocity was secondarily important, and depth was only occasionally the minimum factor. Reiser and Bjornn (1979) reviewed the importance of cover in the literature and found that salmonid abundance declined and increased as cover was removed or added to streams in a number of instances. Burger et al. (1982) reported that velocity was perhaps the most limiting factor for juvenile chinook in the Kenai River but that the fry also moved from areas where suitable cover types in the form of steep vegetated banks no longer existed. Depth was not mentioned in these studies as having much of an influence on distribution, and therefore probably should not be weighted the same as cover or velocity. If cover and velocity are weighted with equal importance and depth suitability is held constant, determinations of WUA's for juvenile salmon will perhaps be most valid.

The suitability criteria which have been developed in this paper represent a compendium of the data from the 1983 field study and three years of experience in observing and sampling these populations. Although there are limitations to the suitability criteria technique, we are confident that the curves presented are reasonably accurate for this reach of river and will lead to weighted usable area projections which are of value in predicting effects of changes in flow on juvenile salmon habitat.

5.0 CONTRIBUTORS

Field sampling was conducted by Paul Suchanek, Larry Dugan, Robert Marshall, and David Sterritt. Carol Kerkvliet drafted the figures. Allen Bingham provided assistance with the data analysis. Donna Buchholz keypunched the data and Gail Heineman organized the database. Larry Bartlett, Allen Bingham, and Kathrin Zosel reviewed the manuscript.

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APPENDIX A

Calculations of Suitability of Cover Type for Chinook and Coho Salmon in Clear Water

Calculations of suitability of cover type for chinook and coho salmon in clear water.

$$\text{Weighted mean effect of cover type } j = \frac{\sum_{i=1}^{x} \left(\frac{N_{i,j}}{K_i}\right)}{\sum_{i=1}^{x} C_{i,j}}$$

$N_{i,j}$ = Number of fish captured in percent cover category i and cover type category j

$C_{i,j}$ = Number of cells sampled in percent cover category i and cover type category j

i = Percent cover category

j = Cover type category

x = Number of percent cover categories = 5

$K_i = \sum_{j=1}^{y} N_{i,j} \Big/ \sum_{j=1}^{y} C_{i,j}$ = Mean catch for all cover types pooled in percent cover category i

y = Number of cover types = 9

Hypothetical example:

1. Sample data

Percent Cover Category	Primary Cover Type	Chinook Captured ($N_{i,j}$)	Cells Sampled ($C_{i,j}$)
1) 0-5%	1) Emergent vegetation	1	5
	2) Undercut banks	5	10
	3) Boulders	4	5

$$K_1 = \sum_{j=1}^{3} N_{1,j} \Big/ \sum_{j=1}^{3} C_{1,j} = 10 / 20 = 0.5$$

Percent Cover Category	Primary Cover Type	Chinook Captured ($N_{i,j}$)	Cells Sampled ($C_{i,j}$)
2) 6-25%	1) Emergent vegetation	5	10
	2) Undercut banks	10	10
	3) Boulders	15	10

$$K_2 = \sum_{j=1}^{3} N_{2,j} \Big/ \sum_{j=1}^{3} C_{2,j} = 30 / 30 = 1.0$$

2. Calculations of average effect of cover types on chinook distribution

Weighted mean effect of emergent vegetation =

$$\frac{\sum_{i=1}^{2} \left(\frac{N_{i,1}}{K_i}\right)}{\sum_{i=1}^{2} C_{i,1}} = \frac{\frac{1}{0.5} + \frac{5}{1.0}}{5 + 10} = 0.47$$

Weighted mean effect of undercut banks =

$$\frac{\sum_{i=1}^{2} \left(\frac{N_{i,2}}{K_i}\right)}{\sum_{i=1}^{2} C_{i,2}} = \frac{\frac{5}{0.5} + \frac{10}{1.0}}{10 + 10} = 1.00$$

Weighted mean effect of boulders $= \dfrac{\sum_{i=1}^{2} \left(\dfrac{N_{i,3}}{K_i}\right)}{\sum_{i=1}^{2} C_{i,3}} = \dfrac{\dfrac{4}{0.5} + \dfrac{15}{1.0}}{5 + 10} = 1.53$

3. Normalize to 1.0 by dividing each effect by the largest effect

	Weighted Mean Effect	Suitability
Emergent Vegetation	0.47	0.47/1.53 = 0.31
Undercut banks	1.00	1.00/1.53 = 0.65
Boulders	1.53	1.53/1.53 = 1.00

APPENDIX B

Calculations of Effect of Cover Type on Distributions of Sockeye and Chum Salmon

Calculations of effect of cover type on distributions of sockeye and chum salmon.

Effect of cover type j = $E_j = \dfrac{P_j \,/\, C_j}{R}$

If less than 1.0 then $E_j = 1.0$ = effect of no cover

P_j = Number of cells of cover type j sampled with fish present
C_j = Number of cells of cover type j sampled
$R = N_1/C_1$ = Proportional presence of fish in cells without object cover

---

Hypothetical example:

1. Sample data

Primary Cover Type	Cells Sampled (C_j)	Number of Cells Sampled with Sockeye Present (N_j)
1) No object cover	15	5
2) Emergent vegetation	20	5
3) Undercut banks	20	8
4) Boulders	50	25

2. Calculations of average effect of cover type on sockeye distribution.

$R = P_1/C_1 = 5/15 = 0.33$

$$\text{Effect of emergent vegetation} = \frac{P_2 \;/\; C_2}{R} = \frac{5 \;/\; 20}{0.33} = 0.76$$

Since less than 1.0 change to equal 1.0.

$$\text{Effect of undercut banks} = \frac{P_3 \;/\; C_3}{R} = \frac{8 \;/\; 20}{0.33} = 1.21$$

$$\text{Effect of boulders} = \frac{P_4 \;/\; C_4}{R} = \frac{25 \;/\; 50}{0.33} = 1.52$$

3. Normalize to 1.0 by dividing each effect by the largest effect

	Effect	Suitability
No cover	1.00	1.00/1.52 = 0.66
Emergent vegetation	1.00	1.00/1.52 = 0.66
Undercut banks	1.21	1.21/1.52 = 0.80
Boulders	1.52	1.52/1.52 = 1.00

APPENDIX C

Suitability indices for juvenile salmon for cover, velocity, and depth

Appendix Table C-1. Suitability indices for juvenile salmon for cover, velocity, and depth.

		Cover Suitability					
Cover type	% Cover[1]	PHABSIM Code	Chinook (high turbidity)	Chinook (low turbidity)	Coho	Sockeye	Chum
No cover	0-5%	1.1	0.45	0.01	0.00	0.11	0.29
Emergent vegetation	0-5%	2.1	0.57	0.01	0.03	0.18	0.29
	76-100%	2.5	1.00	0.12	0.29	0.47	0.53
Aquatic vegetation	0-5%	3.1	0.57	0.07	0.07	0.39	0.29
	76-100%	3.5	1.00	0.68	0.65	1.00	0.53
Debris/deadfall	0-5%	4.1	0.57	0.11	0.10	0.19	0.47
	76-100%	4.5	1.00	1.00	0.90	0.49	0.87
Overhanging riparian vegetation	0-5%	5.1	0.57	0.06	0.04	0.30	0.40
	76-100%	5.5	1.00	0.61	0.38	0.78	0.74
Undercut banks	0-5%	6.1	0.57	0.10	0.12	0.11	0.40
	76-100%	6.5	1.00	0.97	1.00	0.29	0.74
Large gravel (1-3")	0-5%	7.1	0.57	0.07	0.03	0.17	0.37
	76-100%	7.5	1.00	0.63	0.24	0.44	0.68
Rubble (3-5")	0-5%	8.1	0.57	0.09	0.02	0.12	0.54
	76-100%	8.5	1.00	0.81	0.18	0.30	1.00
Cobble or boulder (> 5")	0-5%	9.1	0.57	0.09	0.02	0.11	0.46
	76-100%	9.5	1.00	0.89	0.18	0.29	0.86

[1] With the exception of the "no cover" cover type, there are three other precent cover categories for each cover type between the 0-5% and 76-100% categories. Suitability values for these cover types are linearly interpolated from the two endpoints given. PHABSIM codes for the

Appendix Table C-1 (continued)

VELOCITY

Chinook (turbid)		Chinook (clear)		Coho		Sockeye		Chum	
Velocity (ft/sec)	Suita-bility	Velocity (ft/sec)	Suita-bility	Velocity (ft/sec)	Suita-bility	Velocity (ft/sec)	Suita-bility	Velocity (ft/sec)	Suita-bility
0.00	0.42	0.00	0.18	0.00	0.29	0.00	1.00	0.00	0.86
0.05	1.00	0.20	0.57	0.05	1.00	0.05	1.00	0.05	1.00
0.35	1.00	0.35	1.00	0.35	1.00	0.20	0.71	0.35	1.00
0.50	0.80	0.65	1.00	0.50	0.88	0.50	0.48	0.50	0.87
0.80	0.38	0.80	0.68	0.80	0.55	0.80	0.36	0.80	0.70
1.10	0.25	1.10	0.44	1.10	0.32	1.10	0.27	1.10	0.56
1.40	0.15	1.40	0.25	1.40	0.12	1.40	0.17	1.40	0.37
1.70	0.07	1.70	0.18	1.70	0.04	1.70	0.09	1.70	0.15
2.00	0.02	2.00	0.12	2.00	0.01	2.00	0.02	2.00	0.03
2.30	0.01	2.30	0.06	2.10	0.00	2.10	0.00	2.10	0.00
2.60	0.00	2.60	0.00						

DEPTH (All Species)

Depth (ft)	Suitability
0.00	0.00
0.14	0.00
0.15	1.00
10.00	1.00

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Part 3
Juvenile Salmon Rearing Suitability Criteria

ALASKA DEPARTMENT OF FISH AND GAME
SUSITNA HYDRO AQUATIC STUDIES

REPORT NO. 2

RESIDENT AND JUVENILE ANADROMOUS FISH
INVESTIGATIONS (MAY - OCTOBER 1983)

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