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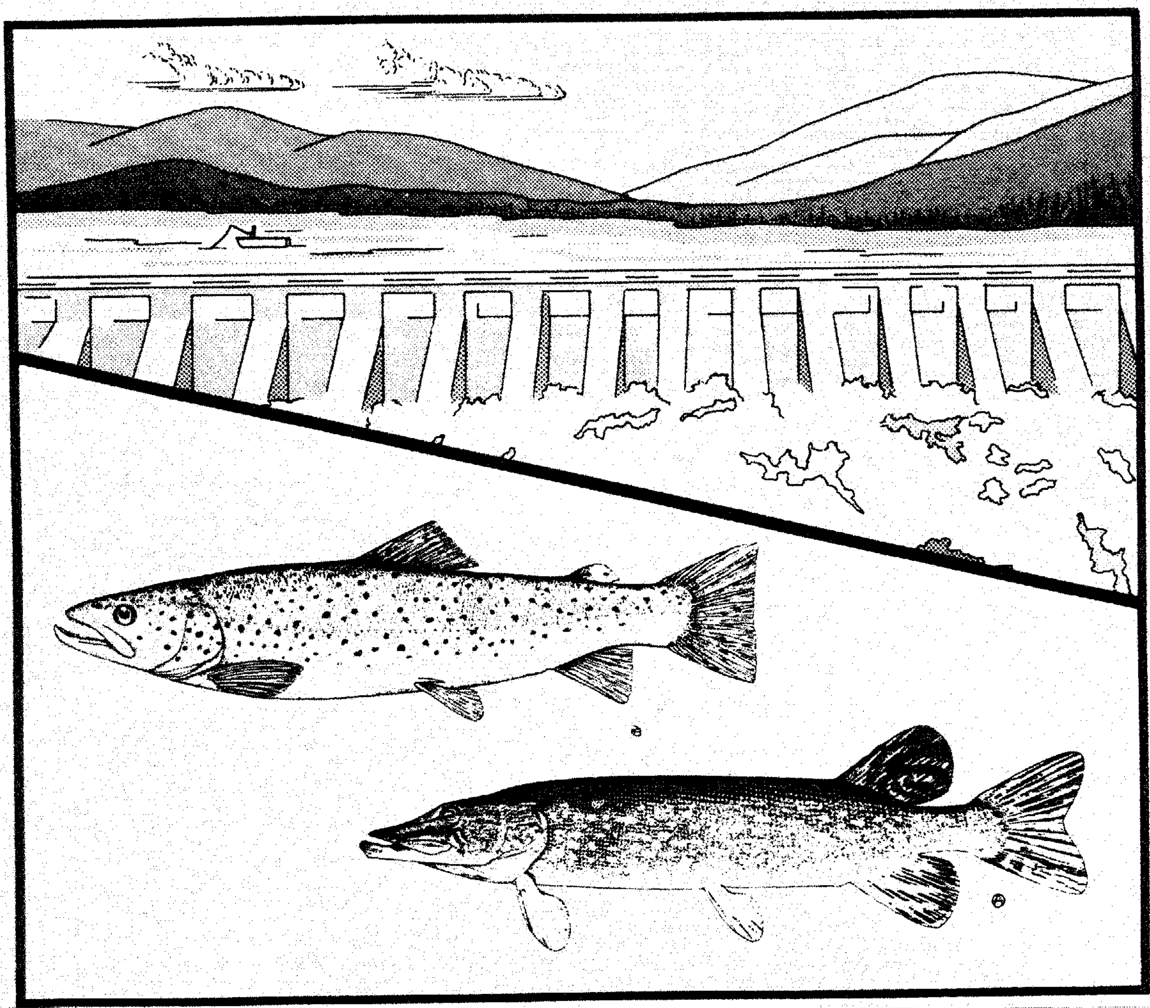
HABITAT SUITABILITY INDEX MODELS: REGRESSION MODELS BASED ON HARVEST OF COOL AND COLDWATER FISHES IN RESERVOIRS



h and Wildlife Service

S. Department of the Interior

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HABITAT SUITABILITY INDEX MODELS: REGRESSION MODELS BASED ON HARVEST OF COOLWATER AND COLDWATER FISHES IN RESERVOIRS

by

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PREFACE

The methods presented in this report are designed to permit habitat classification of reservoirs, containing coolwater, coldwater, and seasonal two-story fisheries, based on harvest of selected coolwater and coldwater sport fishes. Multiple regression equations describing relations between reservoir environmental characteristics and biomass harvest of selected sport fish species or groups are presented. Cumulative Frequency (CF) plots of known harvest estimates from the various classes of reservoirs are presented to facilitate conversion of harvest predictions to Habitat Suitability Indices (HSI's). Detailed descriptions and limitations of the procedures are discussed.

The predictive capability of the regression equations is likely to vary depending on the environmental conditions present. The U.S. Fish and Wildlife Service encourages model users to convey comments and suggestions that might help us increase the utility and effectiveness of this habitat-based approach to planning. Please send comments to:

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REGRESSION MODELS BASED ON HARVEST OF COOLWATER AND COLDWATER FISHES IN RESERVOIRS

INTRODUCTION

Since 1963, the National Reservoir Research Program (NRRP) has served as a repository for fish standing crop, angler use and harvest, and environmental data from United States reservoirs with surface areas of 500 acres or larger. These data are collated, periodically updated, and analyzed to provide broader insight into the effects of environmental factors on standing crop and harvest of reservoir fishes. Correlation and multiple regression analysis have been the primary analytical techniques used to define important biological-environmental relations based on field data. They also have been used to develop simple mathematical expressions to predict reservoir standing crop and harvest, including an assessment of precision or reliability (Jenkins 1967; Jenkins and Morais 1971; Jenkins 1974, 1976, 1977, and 1982). These techniques mesh closely with the objectives of the Habitat Evaluation Procedures Group of the U.S. Fish and Wildlife Service's Western Energy and Land Use Team, which are to provide biologists with methods to more accurately quantify changes in fish and wildlife habitat associated with changes in land and water use.

In a previous analysis, Aggus and Morais (1979) developed regression formulas to predict standing crops of fishes in warmwater impoundments and cumulative frequency distribution plots to equate these predicted standing crops to Habitat Suitability Indices (HSI's), as required in the 1978 draft version of Habitat Evaluation Procedures (HEP) (U.S. Fish and Wildlife Service 1978). The standing crop estimates were based on cove rotenone data. The cove rotenone technique is not effective in reservoirs where summer water temperatures remain below 24-25°C; therefore, many coolwater and coldwater fishes were not included in that analysis. Estimates of angler harvest offer the largest source of stock assessment data in those impoundments.

The terms "coolwater fishes" and "coldwater fishes" are not clearly defined. For the purposes of this report, coolwater fishes are designated as members of the perch (Percidae) and pike (Esocidae) families, whereas coldwater forms are members of the trout and salmon family (Salmonidae).

Information is provided for coho salmon (*Oncorhynchus kisutch*), kokanee salmon (*Oncorchynchus nerka*), cutthroat trout (*Salmo clarki*), rainbow trout (*Salmo gairdneri*), brown trout (*Salmo trutta*), brook trout (*Salvelinus fontinalis*), lake trout (*Salvelinus namaycush*), northern pike (*Esox lucius*), muskellunge (*Esox masquinongy*), yellow perch (*Perca flavescens*), sauger (*Stizostedion canadense*), and walleye (*Stizostedion vitreum vitreum*).

HABITAT SUITABLITY INDEX MODELS

Model Applicability

The objective of this report is to develop HSI models for selected coolwater and coldwater fishes in reservoirs. The models, based on estimates of harvest, are designed for use in existing and proposed coolwater and coldwater reservoirs in the contiguous United States.

Selection of Variables

Harvest of fish. The Habitat Evaluation Procedures (U.S. Fish and Wildlife Service 1980) utilize two types of information to describe the suitability of aquatic habitats for animal species. One type includes direct estimates of production or abundance, whereas the other is based on indicators of habitat suitability and uses indirect estimates. The techniques employed by the NRRP use biomass of fish as direct measures of abundance. The use of harvest data to evaluate coolwater and coldwater reservoirs includes only the larger fish in a population. Use of this information to assess habitat suitability, therefore, requires the assumption that suitability of a reservoir for a particular fish species or species group will be reflected in the biomass of fish harvested.

Estimates of harvest used in this analysis are from studies conducted mostly by State fishery management agencies. These include estimates made over a 30+ year period that incorporate numerous sampling designs. No attempt was made to adjust for differences in creel census design. Estimates which included only a portion of the angler season or a fraction of the total angler effort were not used. Data, whenever possible, were analyzed at the species level; however, some fishery management agencies group fishes into broader taxonomic categories for reporting. In the case of the coolwater and coldwater fishes, these included such taxonomic groups as Esox spp. and "trout". The fish species and species groups included in this analysis are listed in Table 1. Agencies collecting the environmental data used for this analysis routinely report data in English units. To simplify use of the methodology, environmental data are reported in the most commonly measured unit (usually English). Harvest estimates are in metric units to conform with Office of Biological Services standards.

Environmental variables. The Habitat Evaluation Procedures (U.S. Fish and Wildlife Service 1980) require the assumption that habitat value for fish and wildlife can be determined relative to certain measurable characteristics of the physical environment. The Procedures also are based on the assumption that suitability of a habitat can be numerically characterized by the degree to which certain life requisites are met, as discussed by Schamberger and Farmer (1978).

In selecting environmental variables for reservoirs, we specified that a variable must: (1) be determined in the early phases of reservoir planning and designing; (2) be easily measured or affected by the design or operation of a reservoir; and (3) have some biological basis; for example, be related to the behavior or production of one or more reservoir fish species.

Since the NRRP began collating and analyzing environmental and fish standing crop and harvest data, many environmental variables meeting the above criteria have been tested. Those listed in Table 1 were selected after removal of highly correlated variables. This was accomplished by first computing a simple correlation matrix for environmental and harvest variables, then retaining the environmental variable having the highest correlation to harvest variables. The removal of highly correlated environmental variables does not greatly reduce the power of a predictive expression, but does reduce the number of measurements required to use the procedure. Variables, such as shore development, surface area, mean depth, outlet depth, and water-level fluctuation, usually are quantified during the early stages of planning for reservoir construction. Data on these variables can be obtained from planning and operating agencies. Water Resources Data, Surface Water and Water Quality Records[1] provides information needed to compute values, such as storage ratio and dissolved solids. Definitions of environmental variables used in this report are presented in Appendix A.

The data base. For this analysis, the NRRP's reservoir data banks were searched to identify available information on the harvest of coolwater and coldwater fishes in reservoirs. Lists of reservoirs and years of harvest records were separated by State and mailed to appropriate State fishery agencies. Requests for verification and additional harvest or environmental data were attached.

Upon return of these requests, new data were listed for computer entry and verified. We further separated data for coldwater fisheries into two groups and analyzed these separately: (1) reservoirs with true coldwater fisheries; and (2) reservoirs with seasonal (winter) or two-story (thermally stratified) fisheries. This effort yielded environmental and harvest data from 57 reservoirs with predominantly coldwater fisheries and 39 reservoirs where coldwater fisheries existed seasonally or beneath a warmwater (two-story) fishery. In addition, 119 reservoirs with coolwater fisheries were identified. The sample included 421 creel years of records for coolwater fisheries, 172 creel years of records for coldwater fisheries, and 110 creel years of records for seasonal or two-story fisheries (Appendix B, Tables B-1 to B-3).

Records of fish harvest ranged from 1-25 years for various reservoirs. We used a mean value for each reservoir as the sampling unit to ensure equal weight for data analysis. These values are summarized in Appendix B, Tables B-1 to B-3.

Data Analysis

The analysis of reservoir harvest data consisted of the following procedures: (1) development of multiple regression equations to predict harvest of selected fishes; (2) conversion of these values to indices of habitat suitability; and (3) exploration of discriminant analysis as an alternate quantitative approach.

[1]An annual cooperative publication of the U.S. Geological Survey and State water resource agencies from 1964 to the present.

Table 1. Fish harvest (dependent) variables and environmental (independent) variables used to develop habitat suitability indices for coolwater and coldwater fishes in reservoirs.

Fish harvest variables	Environmental variables
Coolwater fishes	Surface area
Walleye	Surface elevation
Sauger	Mean depth
Yellow perch	Outlet depth
Northern pike	Water level fluctuation
Muskellunge	Shore development
Esox spp.[a]	Storage ratio
	Growing season
Coldwater fishes	Total dissolved solids
Rainbow trout	
Brook trout	
Brown trout	
Cutthroat trout	
Lake trout	
All trout[b]	
Coho salmon	
Kokanee salmon	

[a]Includes all members of the genus *Esox*.

[b]Includes rainbow, brook, brown, and cutthroat trout.

Multiple regression analysis. Multiple regression analysis was used to quantify relationships between environmental (independent) variables and harvest of selected fishes (dependent variables) in reservoirs with coolwater, coldwater, and seasonal or two story fisheries. In this procedure, variation in environmental factors is used to explain variation in harvest of fish. The predictive value of any environmental factor is determined by how well a unit change in that factor is related to a unit change in harvest of a particular species. It is assumed that the environmental variables that provide the greatest predictive value are biologically important, although high correlation does not necessarily imply a cause and effect relationship.

Multiple regression models relating environmental variables and harvest of selected fishes were developed from the SAS-79 stepwise method of maximum R^2 improvement (Barr et al. 1979). This procedure selects independent variables from all available combinations on the basis of maximum R^2 improvement for each additional variable added in a multiple regression model. We used both arithmetic and log values for each dependent and independent variable, thereby considering possible nonlinear relationships.

Regression equations were limited to a maximum of three environmental (independent) variables. Selection of an equation was based on a combination of the R^2 improvement for each independent variable added and the combined F-values of the regression model. Recommended regression equations for each species or species group in each reservoir type are presented in Appendix C. Equations containing logarithmic expressions of harvest have been adjusted to correct geometric means to arithmetic equivalents using the method of Ricker (1975).

Cumulative frequency plots. The Habitat Evaluation Procedures utilize Habitat Suitability Indices (HSI's) to describe relations between biological and environmental features. In this approach, the habitat measures are scaled from 0-1, with the most suitable habitats having the highest values. To use the harvest predictions developed from multiple regression equations in the Habitat Evaluation Procedures, the predictions must be transformed to the 0-1 scale used for the HSI. Such a transformation does nothing to improve the predictive power of the original regression model and does not aid in interpreting model output.

A predicted harvest can be converted to a 0-1 HSI scale by dividing the prediction by a harvest value that serves as standard of comparison (U.S. Fish and Wildlife 1980). These values can be known maximum estimates like the ones in Tables 2-4. Model outputs derived with this type of model should meet the HEP assumption that the HSI be linearly related to carrying capacity. Unfortunately, conversion of predicted harvest estimates to an HSI by dividing the harvest data by the maximum harvest value results in the majority of the HSI's being below 0.5 because the maximum harvest (that is, the standard of comparison) is usually much higher than most predicted or observed harvests. This phenomenon does not affect the validity of compensation recommendations derived with HEP. However, potential HSI model users may be reluctant to accept a model that rates some of the best available habitat below 0.5 on a scale of 0 to 1.0.

Table 2. Number of observations, means, ranges, and standard deviations for selected environmental and sport fish harvest variables from reservoirs with coolwater fisheries.

Variable	Number of observations	Mean	Range	Standard deviation
Independent				
Surface area (acres)	119	14922	510 - 212000	28502
Surface elevation (ft)	119	1501	14 - 7665	1393
Storage ratio (years)	118	0.94	0.01 - 6.56	1.29
Mean depth (ft)	119	30.7	4.0 - 250.0	29.6
Outlet depth (ft)	119	48.4	0.0 - 220.0	44.3
Fluctuation (ft)	119	15.1	1.0 - 100.0	17.3
Dissolved solids (ppm)	119	316	10 -1000.0	323
Growing season (days)	119	174.9	72 - 330	39.7
Shore development	119	8.98	1.5 - 38.0	7.40
Dependent				
Walleye harvest (kg/ha)	90	1.44	T[a] - 26.00	3.15
Sauger harvest (kg/ha)	12	0.26	T[a] - 1.54	0.40
Yellow perch harvest (kg/ha)	37	3.76	T[a] - 35.09	8.06
Northern pike harvest (kg/ha)	38	3.26	0.01 - 34.86	7.22
Muskellunge harvest (kg/ha)	13	0.39	0.01 - 0.90	0.35
Esox spp. harvest (kg/ha)	52	2.38	0.01 - 34.86	6.00

[a]T = < 0.005

Table 3. Number of observations, means, ranges, and standard deviations for selected environmental and sport fish harvest variables from reservoirs with predominantly coldwater fisheries.

Variable	Number of observations	Mean	Range	Standard deviation
Independent				
Surface area (acres)	57	6023	530 - 29500	7377
Surface elevation (ft)	57	5302	235 - 9869	2707
Storage ratio (years)	57	1.23	0.01 - 15.00	2.13
Mean depth (ft)	57	63.8	4.6 - 228.0	50.0
Outlet depth (ft)	57	90.6	1 - 250	70.7
Fluctuation (ft)	57	34.6	0 - 100	26.8
Dissolved solids (ppm)	57	190	16 - 640	146
Growing season (days)	57	123	6 - 280	51
Shore development	57	3.93	1.1 - 15.2	3.10
Dependent				
All trout harvest (kg/ha)	57	16.72	0.05 - 150.89	25.47
Rainbow trout harvest (kg/ha)	51	17.03	0.22 - 150.89	26.49
Brook trout harvest (kg/ha)	9	0.44	T[a] - 1.69	0.66
Brown trout harvest (kg/ha)	25	1.06	0.01 - 5.38	2.14
Cutthroat trout harvest (kg/ha)	15	1.46	T[a] - 6.39	2.07
Lake trout harvest (kg/ha)	7	0.35	0.01 - 0.90	0.40
Coho salmon harvest (kg/ha)	10	1.78	0.04 - 6.92	2.14
Kokanee salmon harvest (kg/ha)	19	2.57	0.03 - 12.77	3.45

[a]T = < 0.005

Table 4. Number of observations, means, ranges, and standard deviations for selected environmental and sport fish harvest variables from reservoirs with seasonal or two-story coldwater fisheries.

Variable	Number of observations	Mean	Range	Standard deviation
Independent				
Surface area (acres)	39	20137	500 - 115000	27495
Surface elevation (ft)	39	1399	273 - 5550	1295
Storage ratio (years)	39	1.32	0.03 - 6.56	1.59
Mean depth (ft)	39	56.6	40 - 250	51.9
Outlet depth (ft)	39	83.6	1 - 220	57.6
Fluctuation (ft)	39	27.1	0 - 100	27.3
Dissolved solids (mg/l)	39	246	10 - 1140	288
Growing season (days)	39	186	72 - 300	48
Shore development	39	10.31	1.5 - 30.0	9.06
Dependent				
Rainbow trout harvest (kg/ha)	28	2.01	0.01 - 18.32	4.04
All trout harvest (kg/ha)	39	1.61	0.01 - 18.32	3.52

We developed Cumulative Frequency (CF) plots of harvest estimates to more equitably approximate HSI values required in HEP procedures. Harvest estimates for a given species or species group were ranked in increasing order. The cumulative frequency associated with a given harvest value was calculated as the proportion of harvest estimates that were less than or equal to that value. Cumulative frequency values for predicted harvests can, thus, vary between 0 and 1. Initial plotting of data for coolwater and coldwater fishes revealed that frequency distributions of harvest estimates were strongly skewed, with many small values and few large ones. Harvest estimates were, therefore, plotted on a log scale to provide greater resolution for the many small values. An example of the CF plot for walleye is shown in Figure 1. Additional CF plots for species represented in coolwater fisheries, coldwater fisheries, and seasonal two-story fisheries are presented in Appendix D, Figures D-1 to D-17.

The CF plots include all estimates of harvest available to the National Reservoir Research Program. These frequently exceed the number of observations used for multiple regression analysis because environmental variables were not available from all reservoirs where harvest estimates were made. It is assumed that the CF plots represent the true range and frequency of harvest for selected fishes. Obviously, this assumption becomes more valid with a larger and more diverse data source.

Discriminant analysis. The feasibility of classifying reservoirs on the basis of grouped harvest of selected sport fishes, then predicting group membership based on environmental characteristics of a reservoir, was tested with discriminant analysis. In evaluating this technique, we selected the most widely distributed coolwater fish (walleye) and coldwater fish (rainbow trout) and divided the reservoirs where each species occurred into four groups, based on estimated annual harvest of these fishes. Reservoir groups were identified as poor, fair, good, or excellent, based on the ranges of harvest values shown in Table 5.

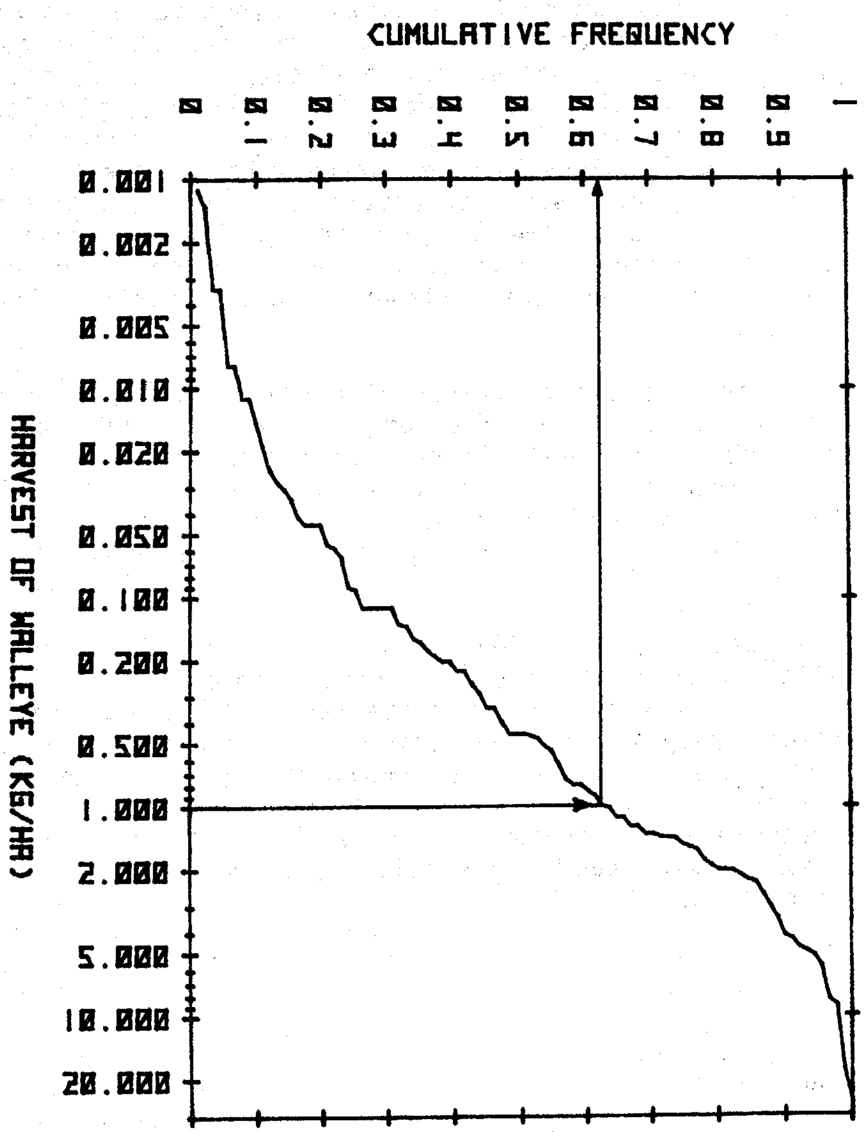

Figure 1. Cumulative frequency plot of walleye harvest, showing a procedure for obtaining CF values.

Table 5. Classification of walleye and rainbow trout reservoirs, based on observed groupings of estimated annual harvest.

Class	Walleye harvest Minimum (kg/ha)	Walleye harvest Maximum (kg/ha)	Sample size	Rainbow trout harvest Minimum (kg/ha)	Rainbow trout harvest Maximum (kg/ha)	Sample size
Poor	0.0	0.1	28	0.0	2.2	35
Fair	> 0.1	1.1	30	> 2.2	11.2	21
Good	> 1.1	2.2	18	> 11.2	22.4	9
Excellent	> 2.2		14	> 22.4		12

Discriminant analysis was performed on each data set, using the program of Barr et al. (1979). Covariance matrices were unequal in both instances, and a multivariate normalization procedure was used to equalize the variances within matrices. Each data set was then reanalyzed, using the transformed values and the BMDP discriminant function procedure (Brown 1977). The classes developed for harvest were poorly defined by the environmental characteristics in both tests. Testing of additional species was discontinued pending development of alternative classification schemes for harvest.

Interpreting Model Outputs

Computing habitat suitability by the procedure described in this report involves two steps: (1) obtaining an estimate of harvest from observed data or the appropriate regression formula; and (2) converting the harvest estimate to a Habitat Suitabilty Index (HSI) using the appropriate maximum harvest or CF plot. Ideally, the user should estimate annual harvest from published sources, or from the appropriate State fishery management agency, and then compute the HSI value from the appropriate CF plot or maximum harvest value.

To use the CF plots, first select the appropriate CF plot for a species or group of species and reservoir type (coolwater, coldwater, seasonal, or two-story coldwater). The calculated or observed value for harvest should be located on the X-axis, and a perpendicular line extended to the point of intersection on the CF line. By extending a line parallel to the X-axis from this point of intersection to the Y-axis, a 0-1.0 value is obtained (Fig. 1). This value represents the proportion of available harvest estimates that were less than, or equal to, the observed or predicted harvest and can be used as an HSI.

In planned reservoirs or impoundments where harvest data are not available, a predicted harvest can be obtained from the appropriate multiple regression equation in Appendix C. Use of these equations requires estimates of the environmental parameters defined in Appendix A. Reservoir planning or operating agencies can usually supply needed data. Water Resources Data, published for each State by the U.S. Geological Survey, is also a good data source. The regression equations can be solved easily with a desktop or pocket calculator and standard log tables. Harvest estimates in logarithmic form require that the antilog be obtained before proceeding with the evaluation. Predicted harvest values can then be converted to an HSI by dividing by the appropriate maximum value for harvest provided in Tables 2-4.

A regression model will not reflect a real world situation, but insights into the strengths of the relations can be gained by examining the following relationships: (1) the number of observations used to develop each equation; (2) the coefficient of multiple determination (R^2) (printed below each regression equation), which defines the percentage of variability in harvest explained by the equation; and (3) the probability (P), which is the chance of obtaining an equal or larger F-value when the hypothesis of no correlation is true. Ranges and standard deviations of harvest and environmental variables for reservoirs included in each sample are provided in Tables 2-4. These statistics provide information that aids in determining whether or not the model should be applied. Environmental parameters should fall within the range of values used to develop the regression model or the model should not be used.

Where computing facilities are available, the multiple regression equations and CF plots can be programmed to permit users to input environmental data and receive harvest and cumulative frequency values as output. The multiple regression equations presented herein are easily programmed for this purpose. However, CF plots present a more complicated programming problem in that cumulative frequency distributions of harvest are variable, but tend to be skewed with few relatively high values and with means well above the median. A cumulative Weibull distribution provides reliable approximation of the CF distribution. Characteristics of the Weibull distribution and computational procedures are described in Johnson and Kotz (1970).

RECOMMENDATIONS

The value of the Habitat Evaluation Procedures rests largely on how well HSI models used in the Procedures predict environmental impacts for specific habitats and the degree of acceptance by persons charged with using the Procedures. The NRRP's multiple regression procedures for predicting fish standing crop and harvest have been widely used within the fisheries community. However, harvest data are an incomplete method of population assessment. Conceptually, harvest should be a satisfactory index of habitat suitability, because it represents the desired end product for resource managers and is ultimately influenced by carrying capacity. In most instances, the environmental factors tested accounted for less than 50% of the variation in harvest of selected fishes. However, it should be recognized that the use of environmental factors to predict harvest in coolwater and coldwater reservoirs may remain relatively imprecise. Some coolwater fishes and a large percentage of coldwater fishes are maintained in reservoirs through put-and-take or put-grow-and-take fisheries. Factors, such as stocking rate or access by fishermen, may be equally as important as environmental variables in predicting harvest of coolwater and coldwater fishes. In addition, harvest estimates are not exact and may be influenced by differences in creel census designs.

Discriminant analysis did not produce precise classification schemes in reservoirs, based on harvest of walleye and rainbow trout. However, evaluation of the technique should continue. Harvest data in this study were grouped by arranging observations in ascending order and arbitrarily separating these into levels of harvest, based on pulses in the distribution of values. Quantitative methods for identifying appropriate levels of harvest should be sought and tested before the procedure is abandoned.

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APPENDIX A. DEFINITIONS OF ENVIRONMENTAL VARIABLES USED IN EQUATIONS FOR PREDICTING HARVEST OF COOLWATER AND COLDWATER FISHES IN RESERVOIRS

surface area - In acres at average annual pool level or use conservation pool, operating pool, summer pool, or power pool area, as listed by operating agency.

surface elevation - In feet above mean sea level at listed surface area.

volume - In acre feet at the elevation listed for surface area.

mean depth - Average depth in feet (volume divided by surface area).

outlet depth - Midline depth of principal outlet, in feet below listed elevation.

water level fluctuation - Mean annual vertical fluctuation of reservoir surface level, in feet.

shoreline length - In miles at listed surface area.

shore development - The ratio of shoreline length to the circumference of a circle equal in area to that of the reservoir.

storage ratio - Reservoir water volume in acre-feet (at listed surface elevation) divided by the average annual water release (discharge) in acre feet.

growing season - Average number of days between last and first frost annually.

total dissolved solids - Residue after evaporation at 180° C in ppm.

APPENDIX B. LIST OF RESERVOIRS AND YEARS OF RECORD USED TO DEVELOP PREDICTORS OF HARVEST IN RESERVOIRS WITH COOLWATER, COLDWATER, AND SEASONAL OR TWO-STORY COLDWATER FISHERIES

Table B-1. Reservoir names and numbers of years of harvest records used to develop suitability indices for coolwater fishes in reservoirs.

Reservoir and State	Years of records	Reservoir and State	Years of records
Altus, OK	1	Douglas, TN	1
Anderson Ranch, ID	10	East Lynn, WV	3
Angostura, SD	2	Fall River, KS	3
Arbuckle, OK	1	Fletcher Pond, MI	1
AuTrain, MI	1	Fort Cobb, OK	2
Banks, WA	1	Fort Peck, MT	2
Belleville, MI	1	Fort Supply, OK	1
Big Creek, IA	4	Foss, OK	1
Blue Ridge, GA	2	Francis Case, SD	3
Boyd, CO	9	Glen Elder, KS	3
Boysen, WY	2	Greenwood, SC	4
Buckhorn, KY	6	Hamlin, MI	1
Cagles Mill, IN	2	Hartwell, SC	4
Canton, OK	5	Hefner, OK	1
Canyon, AZ	8	Hodenpyle and Tippy, MI	1
Carry Falls, NY	1	Holloway, MI	1
Cascade, ID	8	Hubbard, MI	1
Cave Run, KY	2	Hugh Butler, NE	1
Cedar Bluff, KS	3	Hugo, OK	1
Center Hill, TN	7	Jackson, GA	4
Cheney, KS	3	Jocassee, SC	3
Cherry Creek, CO	1	John Redmond, KS	3
Chickamauga, TN	2	Kanopolis, KS	9
Chickasha, OK	1	Kent, MI	1
Chippewa Flowage, WI	1	Kentucky, KY	6
Clark Hill, GA	8	Keowee, SC	5
Claytor, VA	1	Keyhole, WY	5
Cohoon, VA	6	Keystone, OK	3
Conchas, NM	1	Kirwin, KS	3
Coralville, IA	1	Lake of the Ozarks, MO	16
Council Grove, KS	3	Lovewell, KS	3
Dale Hollow, TN	10	Macbride, IA	2
Deep Creek, MD	5	Marion, KS	3

Table B-1. (concluded).

Reservoir and State	Years of records	Reservoir and State	Years of records
McConaughy, NE	1	Saguaro, AZ	6
Meade, VA	6	Seminoe, WY	4
Melton Hill, TN	3	Sharpe, SD	1
Melvern, KS	3	Shelbyville, IL	1
Michigamme, MI	1	Smith Mountain, VA	5
Milford, KS	3	South Holston, TN	4
Mina, SD	1	Spring, IL	3
Monroe, IN	1	Stockton, MO	5
Nickajack, TN	1	Stonecoal, WV	3
Nolin, KY	8	Stony, MI	1
Norris, TN	6	Strunk, NE	1
Norton, KS	3	Sutton, WV	2
Nottely, GA	3	Taneycomo, MO	11
Old Hickory, TN	3	Tenkiller Ferry, OK	4
Perry, KS	3	Thomas Hill, MO	5
Pomme De Terre, MO	8	Tuttle Creek, KS	3
Pomona, KS	3	Upper Lake Mary, AZ	4
Pontiac, MI	1	Ute, NM	1
Potholes, WA	1	Vallecito, CO	1
Powell, UT	3	Watauga, TN	9
Prince, VA	6	Watts Bar, TN	1
Quabbin, MA	25	Webster, KS	3
Rabun, GA	2	Western Branch, VA	4
Rathbun, IA	4	Whitney Point, NY	1
Reedsburg, MI	1	Wilson, KS	3
Robert S. Kerr, OK	1	Woods, TN	6
Rough River, KY	8	TOTAL	421

Table B-2. Reservoir names and numbers of years of harvest records used to develop suitability indices for coldwater fishes in reservoirs with predominantly coldwater fisheries.

Reservoir and State	Years of records	Reservoir and State	Years of records
Alcova, WY	4	Mohave, AZ	3
Anderson Ranch, ID	10	Navajo, NM	1
Banks, WA	1	Oroville, CA	2
Beardsley, CA	6	Palisades, ID	5
Big Lake, AZ	2	Pathfinder, WY	3
Big Sandy, WY	1	Pishkun, MT	1
Blue Mesa, CO	7	Riffle, CO	1
Bluewater, NM	3	Ruedi, CO	1
Buffalo Bill, WY	3	Scofield, UT	1
Cottage Grove, OR	1	Seminoe, WY	4
Crowley, CA	1	Shadow Mountain, CO	2
Deer Creek, UT	5	Shasta, CA	2
Dillon, CO	1	Spaulding, CA	1
Dworshak, ID	1	Starvation, UT	5
Ennis, MT	1	Steinaker, UT	2
Flaming Gorge, UT	13	Storrie, NM	3
Fontenelle, WY	4	Strawberry, UT	9
Georgetown, MT	3	Swift, WA	2
Gibson, MT	1	Taneycomo, MO	10
Glendo, WY	2	Taylor Park, CO	1
Granby, CO	4	Turquoise, CO	2
Green Mountain, CO	1	Twin Lakes, CO	2
Hebgen, MT	1	Upper Lake Mary, AZ	4
Henrys Lake, ID	5	Vallecito, CO	1
Ice House, CA	1	Wild Horse, NV	8
John, CO	6	Willow Creek, (Harrison)[a] MT	1
Mackay, ID	1	Willow Creek, (Sun River)[a] MT	1
Mayfield, WA	1	Yale, WA	2
Merwin (Ariel)[a], WA	2		
		TOTAL	172

[a]Synonym for reservoir name.

Table B-3. Reservoir names and numbers of years of harvest records used to develop suitability indices for coldwater fishes in reservoirs with seasonal or two-story coldwater fisheries.

Reservoir and State	Years of records	Reservoir and State	Years of records
Angostura, SD	1	McConaughy, NE	1
AuTrain, MT	2	Mead, AZ	1
Belleville, MD	1	Melton Hill, TN	2
Blue Ridge, GA	1	Merle Collins, CA	7
Broken Bow, OK	1	Old Hickory, TN	1
Bull Shoals, AR	4	Pine Flat, CA	4
Cachuma, CA	1	Piru, CA	1
Cascade, ID	8	Potholes, WA	1
Cherry Creek, CO	1	Powell, UT	3
Clark Hill, GA	2	Quabbin, MA	25
Dale Hollow, TN	5	Robert S. Kerr, OK	1
Fish Trap, KY	1	Round Valley, NJ	1
Folsom, CA	1	Smith Mountain, VA	1
Hartwell, SC	4	South Helson, TN	4
Holloway, MI	1	Spruce Run, NJ	2
Hubbard, MI	1	Stony, MI	1
Isabella, CA	2	Sutton, WV	1
Jocassee, SC	3	Table Rock, MO	1
Key Hole, WY	1	Watauga, TN	9
Laurel, KY	2		
		TOTAL	110

APPENDIX C. MULTIPLE REGRESSION FORMULAS FOR ESTIMATING HARVEST (KG/HA) OF COOLWATER AND COLDWATER FISHES FROM RESERVOIRS.

The coefficient of multiple determination (R^2) provides an approximation of the percentage of variation in harvest explained by the equation. The probability (P) indicates the chance of obtaining an "F" value as large, or larger, when the hypothesis of no correlation is true.

Reservoirs which had incomplete or missing environmental variables were not used in the final regression equations. Therefore, the number of observations in the equations below do not necessarily correspond to the number of observations listed in Tables B-1 to B-3 or in cumulative frequency plots (Figs. D-1 to D-16).

Regression equations were omitted for sauger and brown trout, because statistically significant correlations were not found between environmental variables and their respective harvests.

COOLWATER FISHERIES

Walleye

Log (harvest of walleye) = 2.1299 + 0.3563 log (storage ratio) - 0.8364 log (shore development) - 0.00622 (growing season).

Number of observations = 89 $R^2 = 0.315$ $P = 0.0001$

Yellow Perch

Log (harvest of yellow perch) = 3.7117 - 0.0142 (growing season) - 0.7530 log (outlet depth).

Number of observations = 37 $R^2 = 0.378$ $P = 0.0004$

Northern Pike

Log (harvest of northern pike) = 3.7882 - 0.0177 (growing season) - 0.8447 log (outlet depth).

Number of observations = 37 $R^2 = 0.665$ $P = 0.0001$

Muskellunge

Log (harvest of muskellunge) = 2.8421 - 0.0117 (growing season) - 0.9585 log (water level fluctuation).

Number of observations = 12 $R^2 = 0.518$ $P = 0.0370$

Esox spp.

Log (harvest of *Esox* spp.) = 3.4687 - 0.0142 (growing season) - 0.00108 (total dissolved solids) - 0.7573 log (outlet depth).

Number of observations = 52 $R^2 = 0.634$ $P = 0.0001$

COLDWATER FISHERIES

All Trout

Harvest of all trout = 137.55 - 26.94 log (surface area) - 30.68 log (mean depth) + 50.13 log (shore development).

Number of observations = 56 $R^2 = 0.359$ $P = 0.0001$

Rainbow Trout

Harvest of rainbow trout = 148.79 - 31.53 log (surface area) - 28.16 log (mean depth) + 51.38 log (shore development).

Number of observations = 50 $R^2 = 0.372$ $P = 0.0001$

Brook Trout

Harvest of brook trout = 2.449 + 0.0354 (water level fluctuation) - 2.337 log (water level fluctuation).

Number of observations = 9 $R^2 = 0.794$ $P = 0.0087$

Cutthroat Trout

Log (harvest of cutthroat trout) = 4.8065 - 3.0508 log (mean depth) + 0.0103 (outlet depth).

Number of observations = 15 $R^2 = 0.487$ $P = 0.0255$

Coho Salmon

Log (harvest of coho salmon) = 1.0102 log - 2.4191 log (shore development) + 0.0149 (water level fluctuation).

Number of observations = 9 $R^2 = 0.755$ $P = 0.0147$

Kokanee Salmon

Harvest of kokanee salmon = 8.771 + 2.682 (storage ratio) - 4.682 log (growing season).

Number of observations = 19 $R^2 = 0.640$ $P = 0.0003$

Lake Trout

Harvest of lake trout = 1.826 - 0.8714 log (outlet depth)

Number of observations = 6 $R^2 = 0.950$ $P = 0.0012$

SEASONAL AND TWO-STORY COLDWATER FISHERIES

All Trout

Harvest of all trout = -7.765 + 0.00194 (surface elevation) - 0.03534 (mean depth) + 0.0465 (growing season).

Number of observations = 39 $R^2 = 0.452$ $P = 0.0001$

Rainbow Trout

Log (harvest of rainbow trout) = 1.4068 - 0.5862 log (surface area) + 0.3122 log (storage ratio) + 0.7855 log (water level fluctuation).

Number of observations = 28 $R^2 = 0.551$ $P = 0.0003$

APPENDIX D. CUMULATIVE FREQUENCY PLOTS OF HARVEST OF SELECTED SPORT FISHES IN RESERVOIRS WITH COOLWATER, COLDWATER, AND SEASONAL OR TWO-STORY COLDWATER FISHERIES

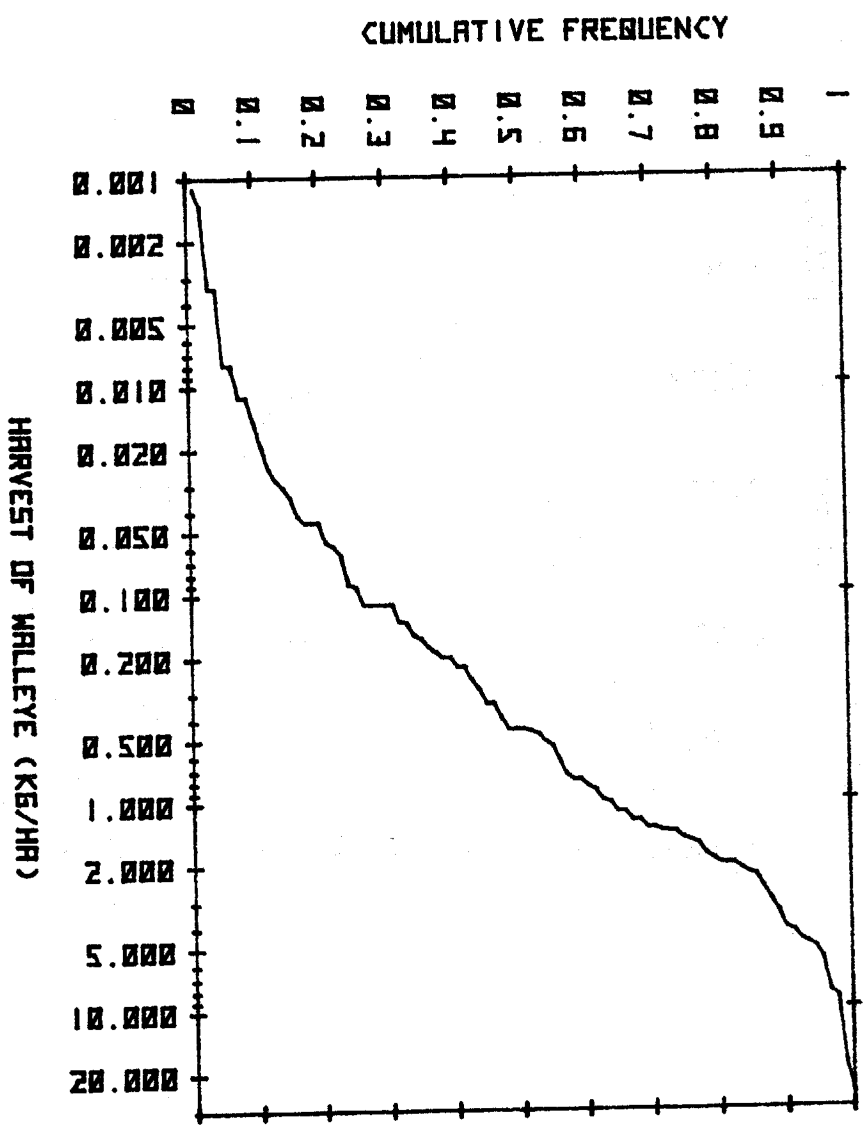

Figure D-1. Cumulative frequency plot of walleye harvest in reservoirs with coolwater fisheries.

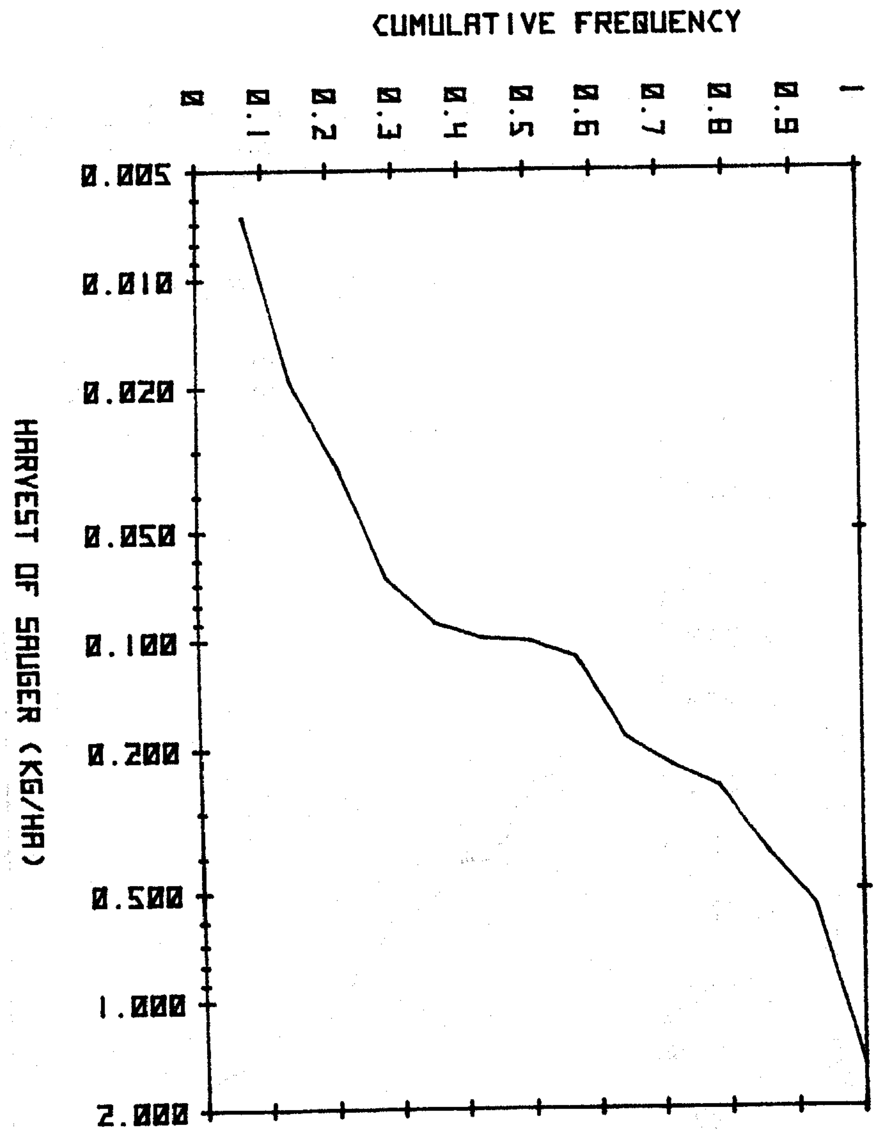

Figure D-2. Cumulative frequency plot of sauger harvest in reservoirs with coolwater fisheries.

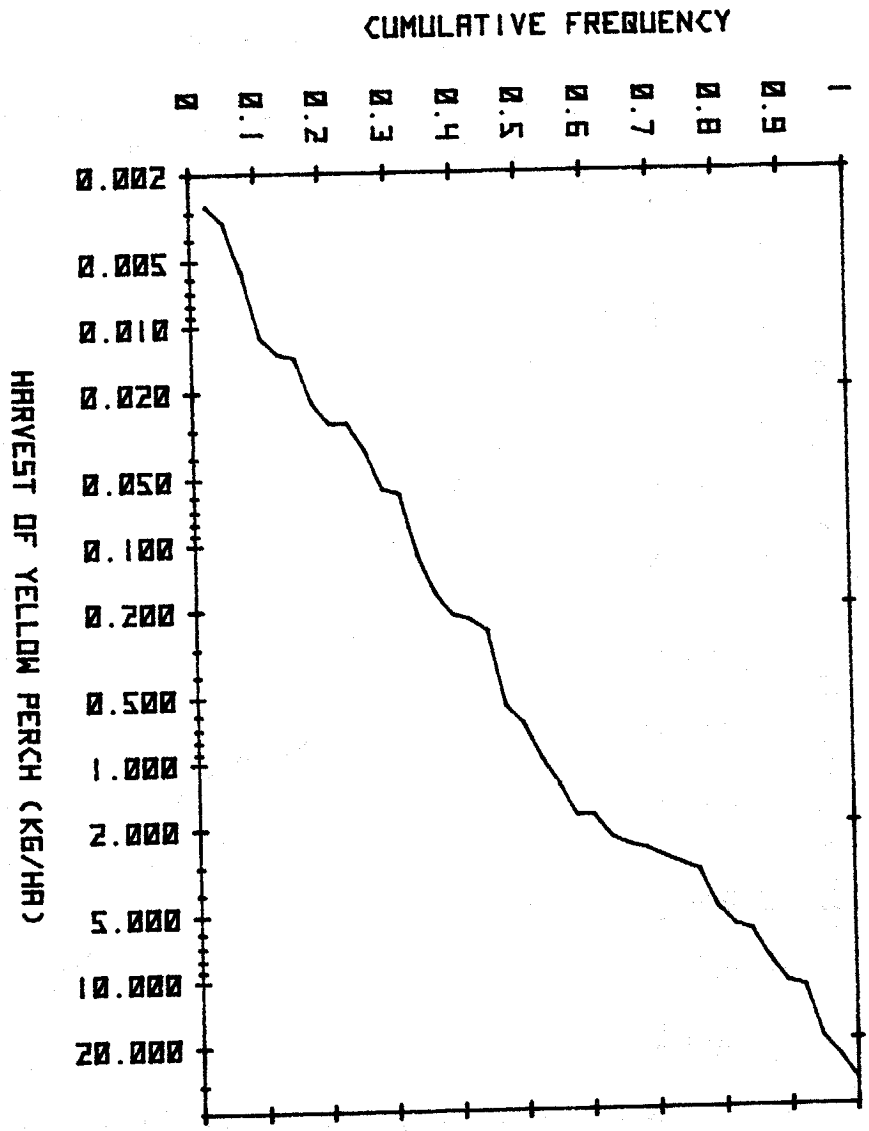

Figure D-3. Cumulative frequency plot of yellow perch harvest in reservoirs with coolwater fisheres.

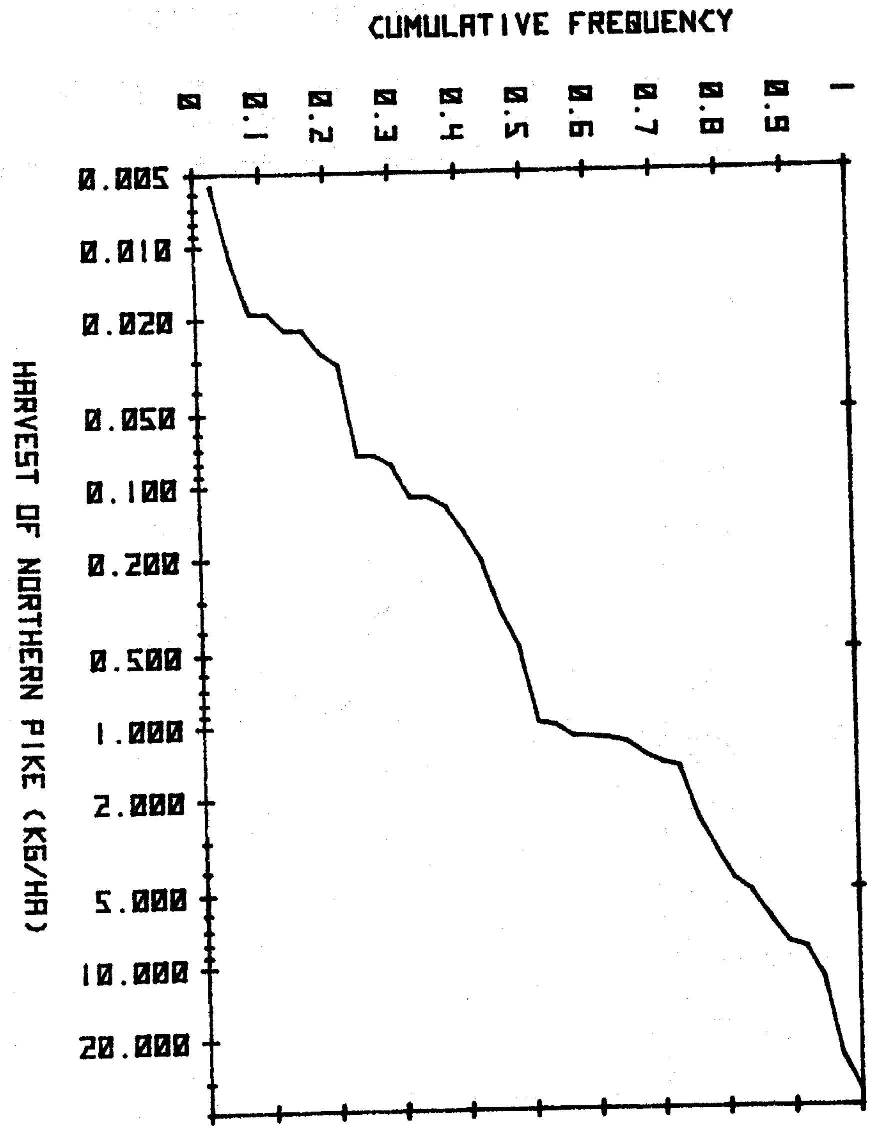

Figure D-4. Cumulative frequency plot of northern pike harvest in reservoirs with coolwater fisheries.

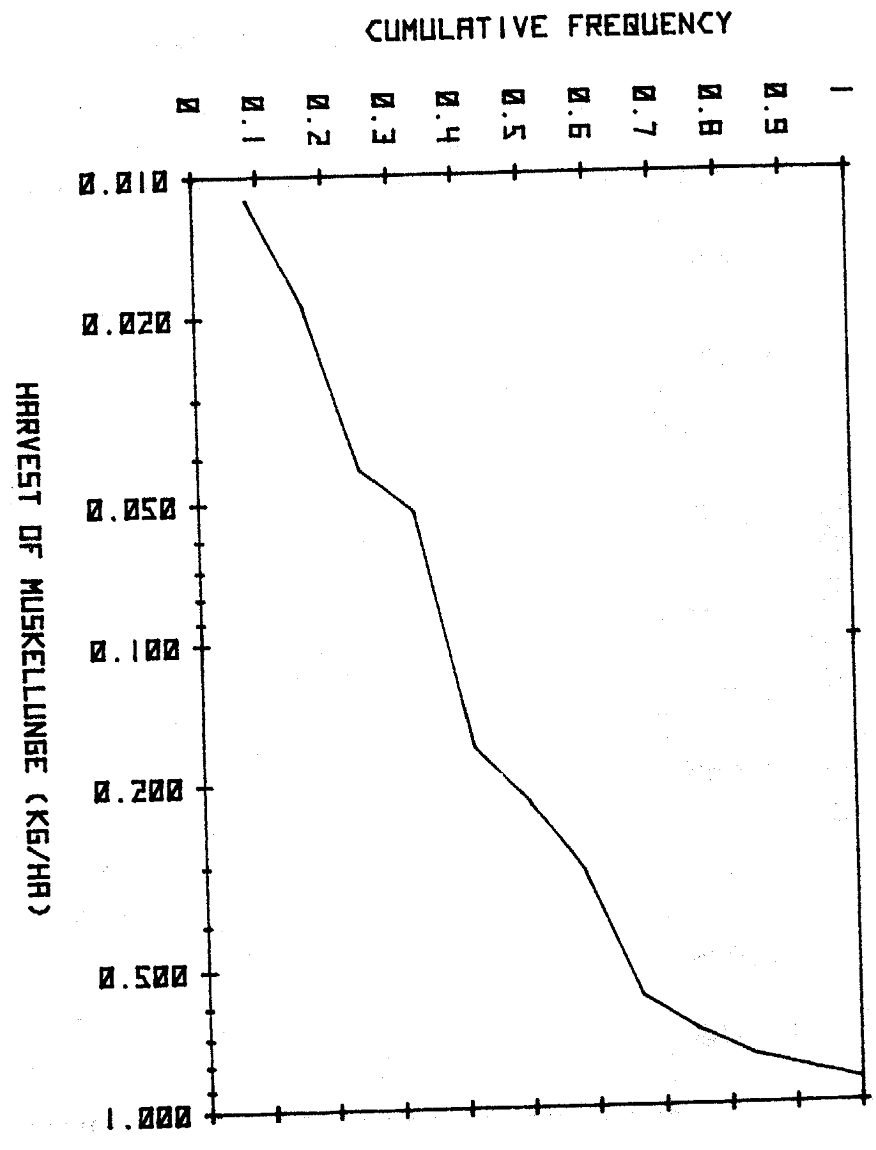

Figure D-5. Cumulative frequency plot of muskellunge harvest in reservoirs with coolwater fisheries.

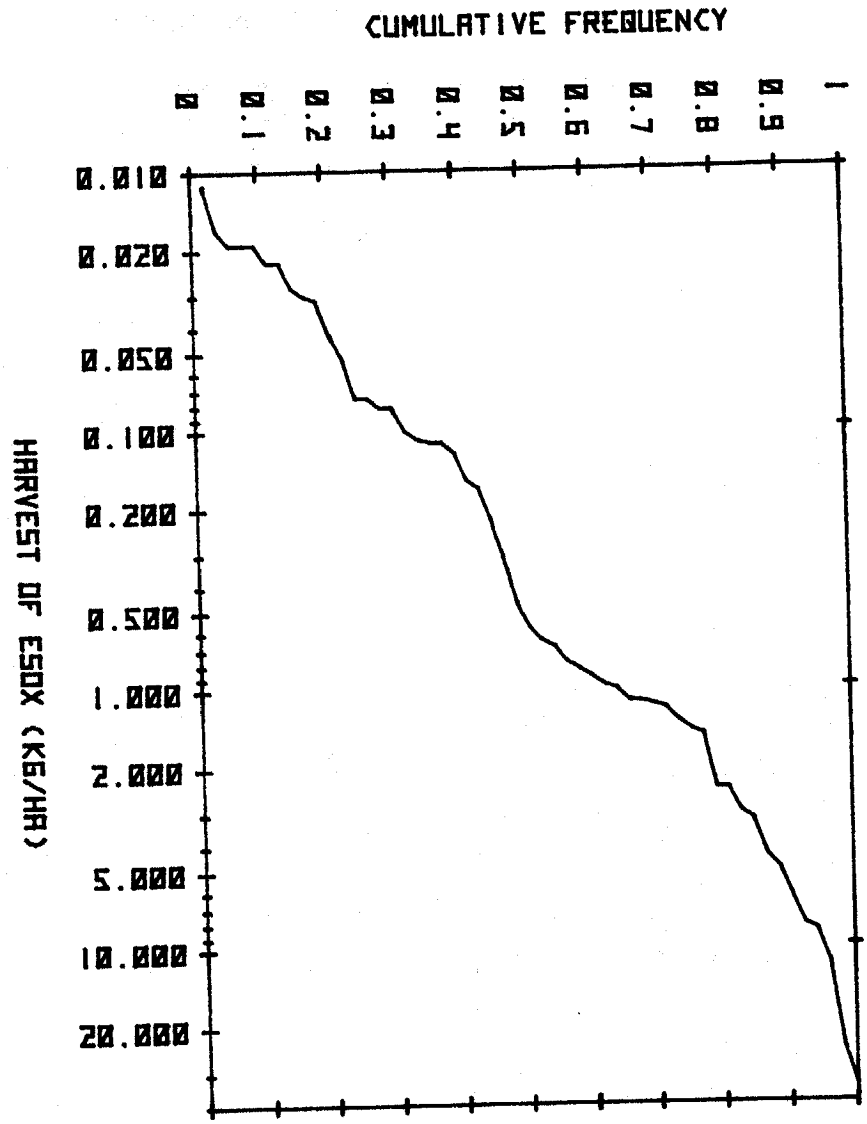

Figure D-6. Cumulative frequency plot of Esox spp. harvest in reservoirs with coolwater fisheries.

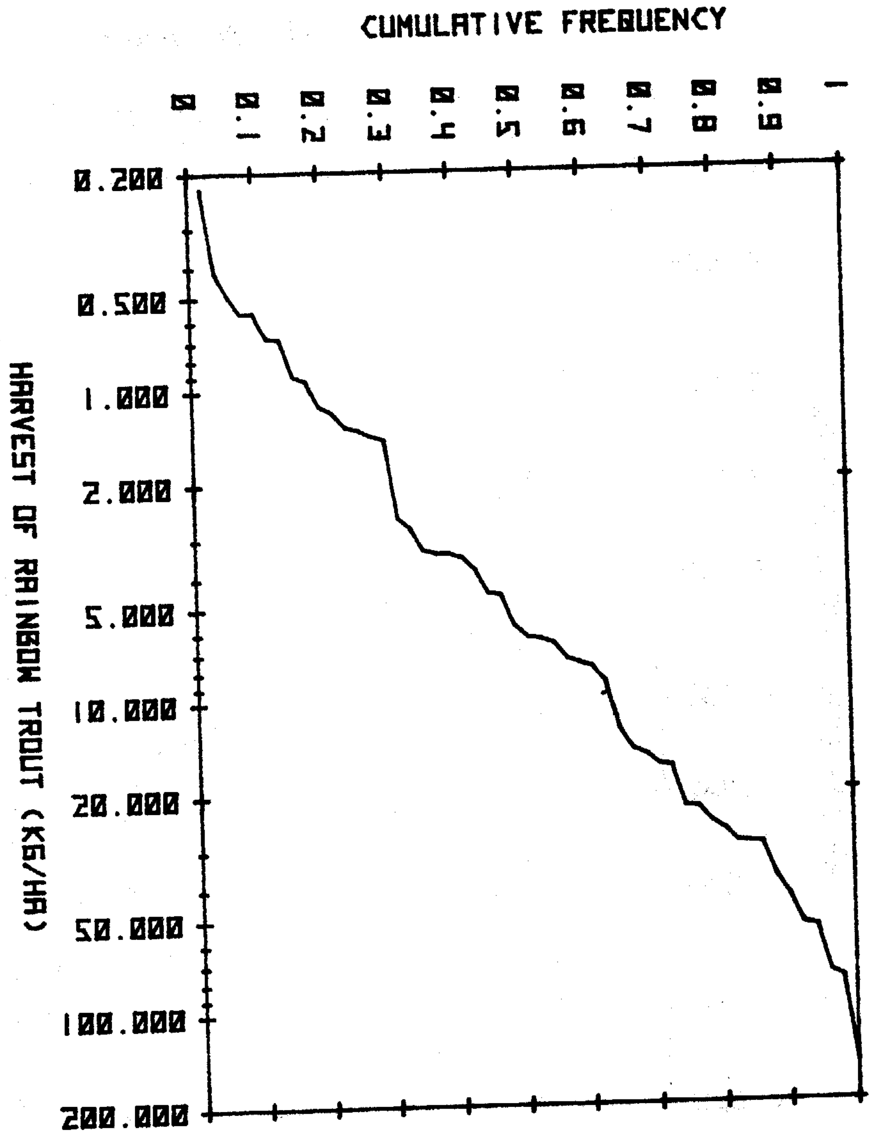

Figure D-7. Cumulative frequency plot of rainbow trout harvest in reservoirs with coldwater fisheries.

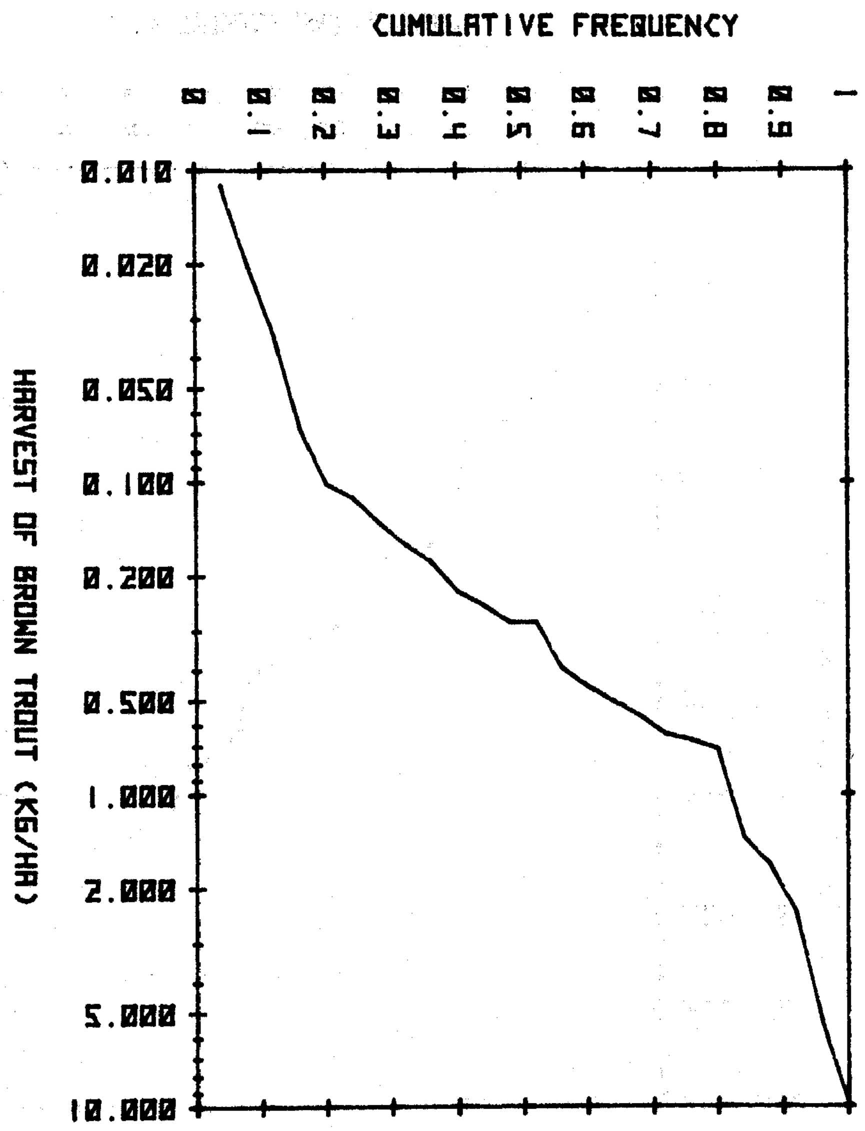

Figure D-8. Cumulative frequency plot of brown trout harvest in reservoirs with coldwater fisheries.

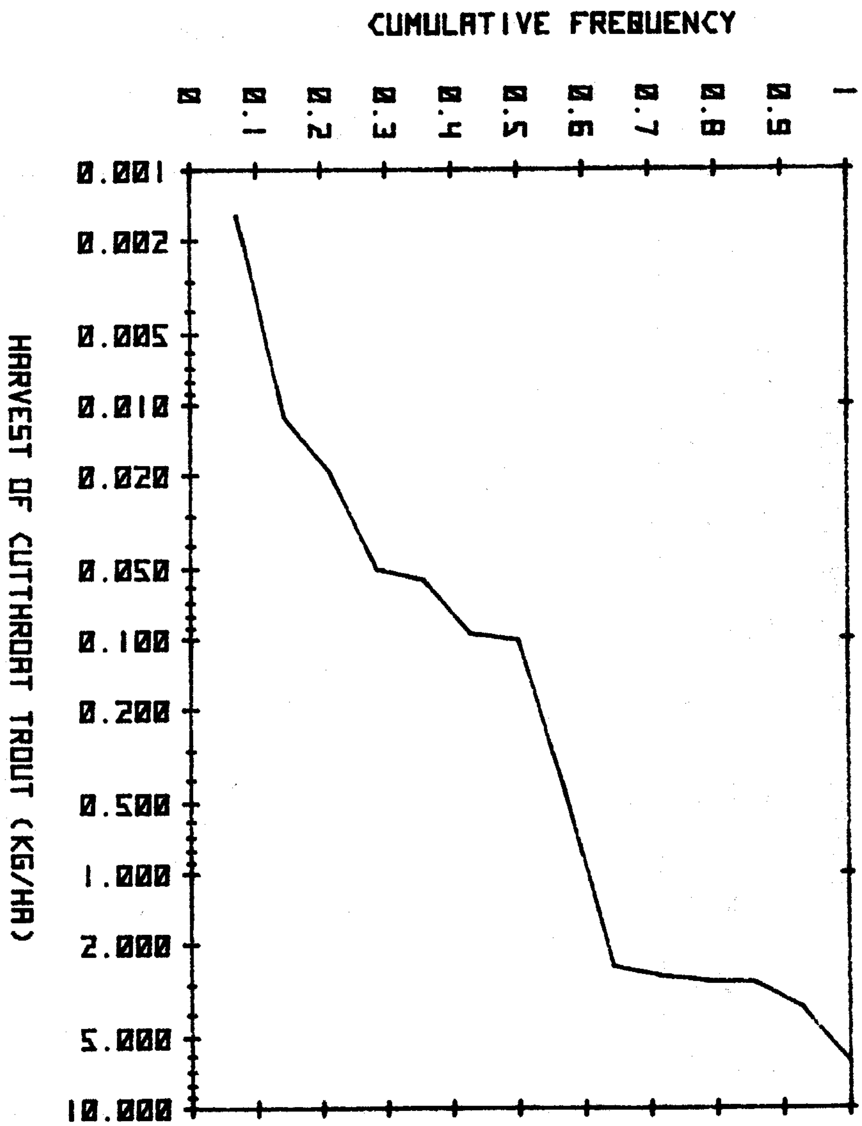

Figure D-9. Cumulative frequency plot of cutthroat trout harvest in reservoirs with coldwater fisheries.

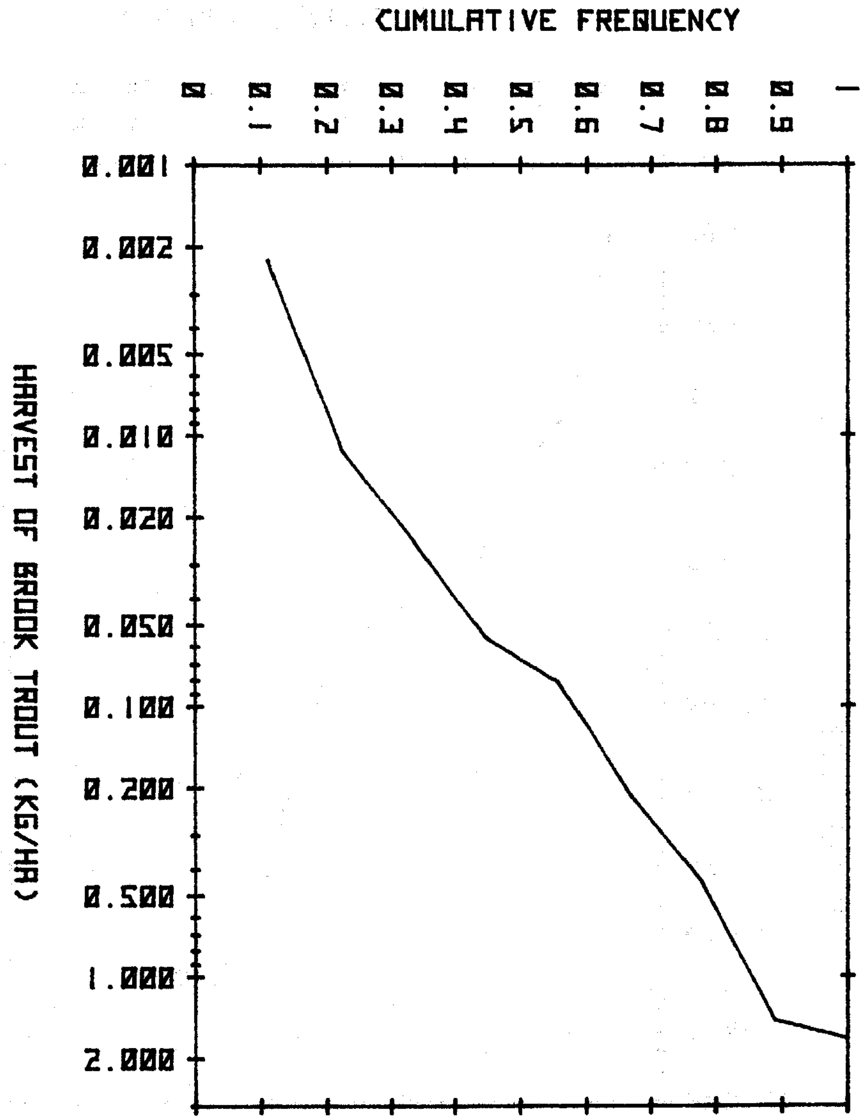

Figure D-10. Cumulative frequency plot of brook trout harvest in reservoirs with coldwater fisheries.

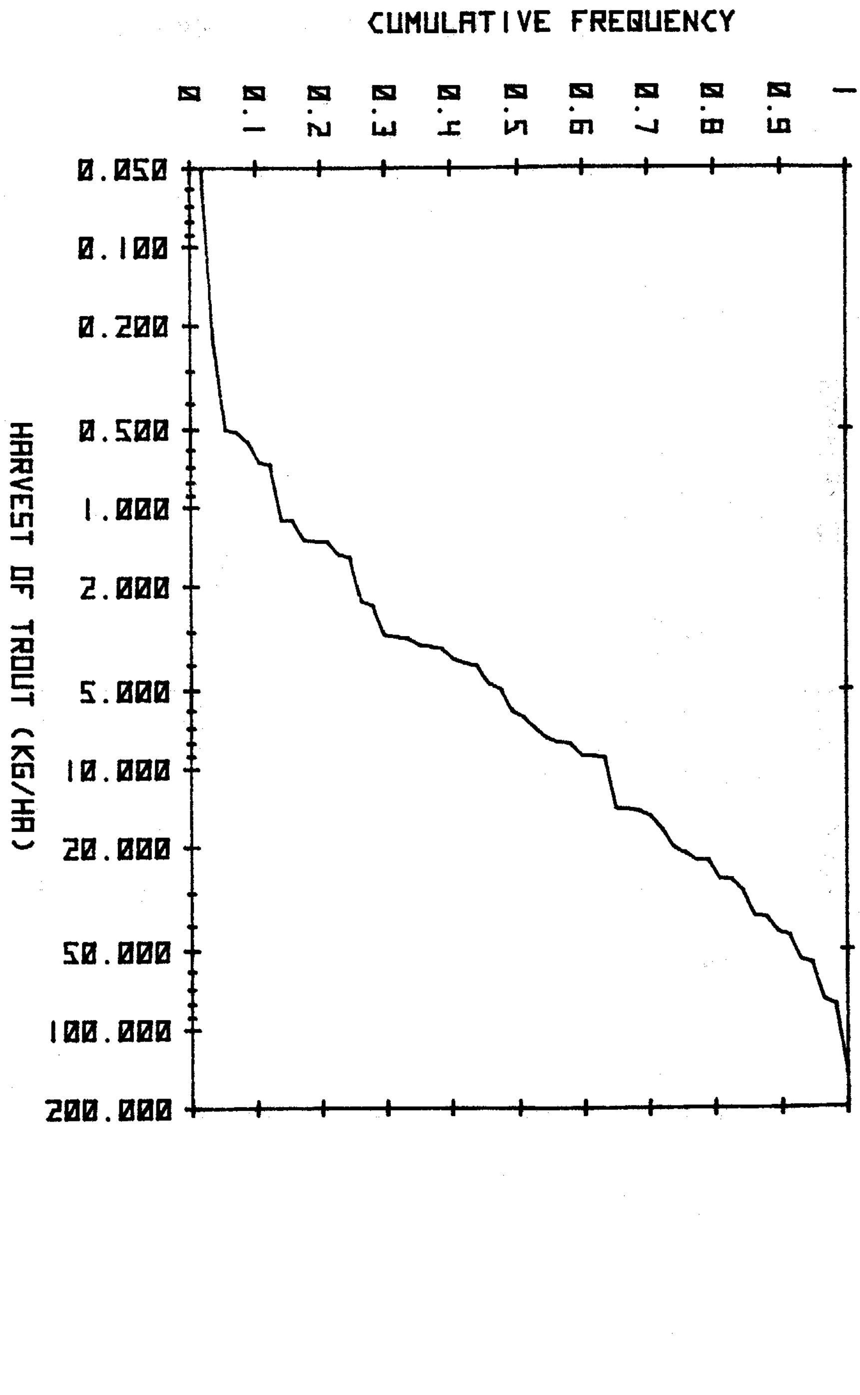

Figure D-11. Cumulative frequency plot of total trout harvest in reservoirs with coldwater fisheries.

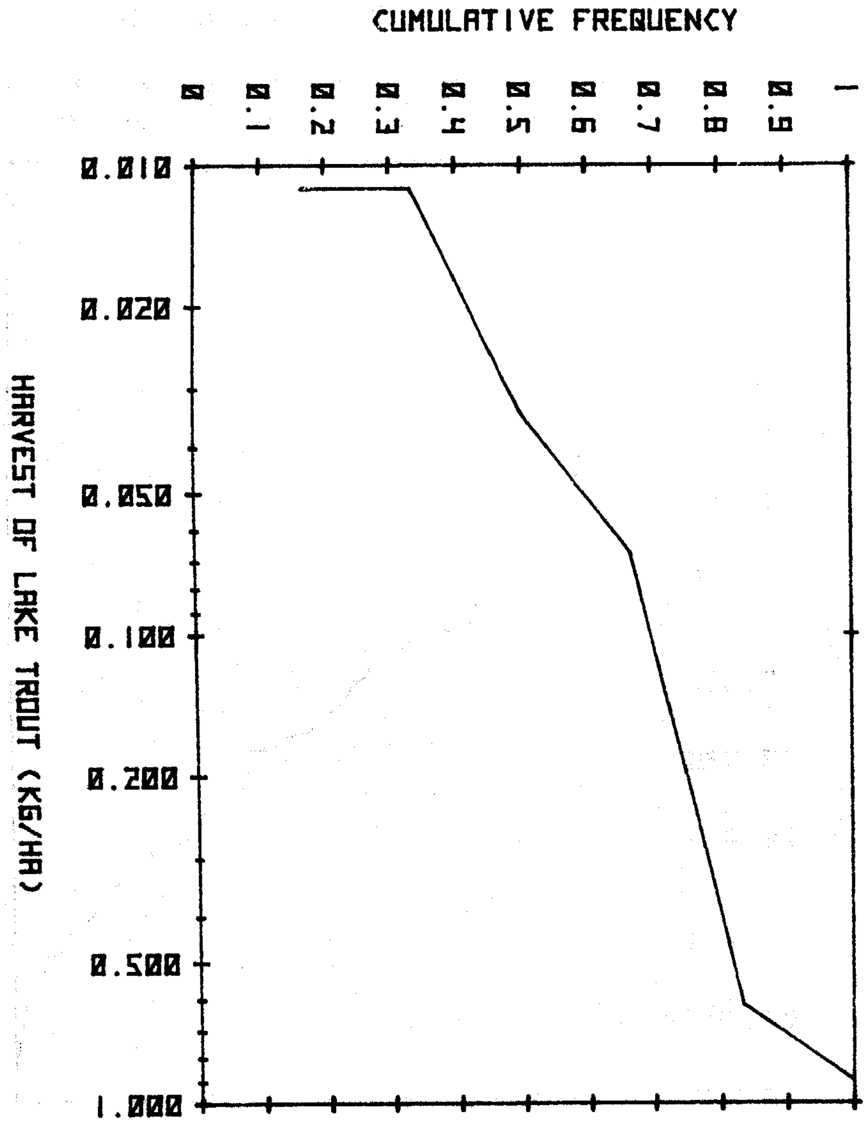

Figure D-12. Cumulative frequency plot of lake trout harvest in reservoirs with coldwater fisheries.

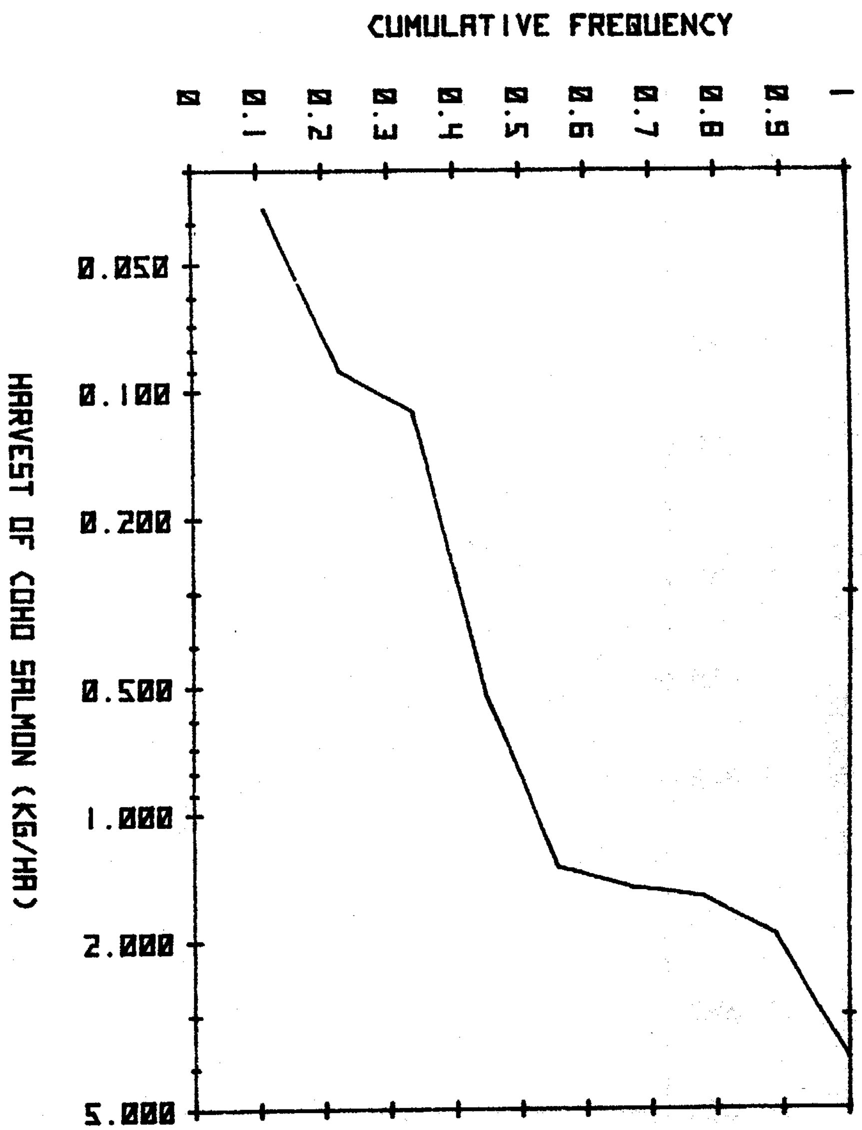

Figure D-13. Cumulative frequency plot of coho salmon harvest in reservoirs with coldwater fisheries.

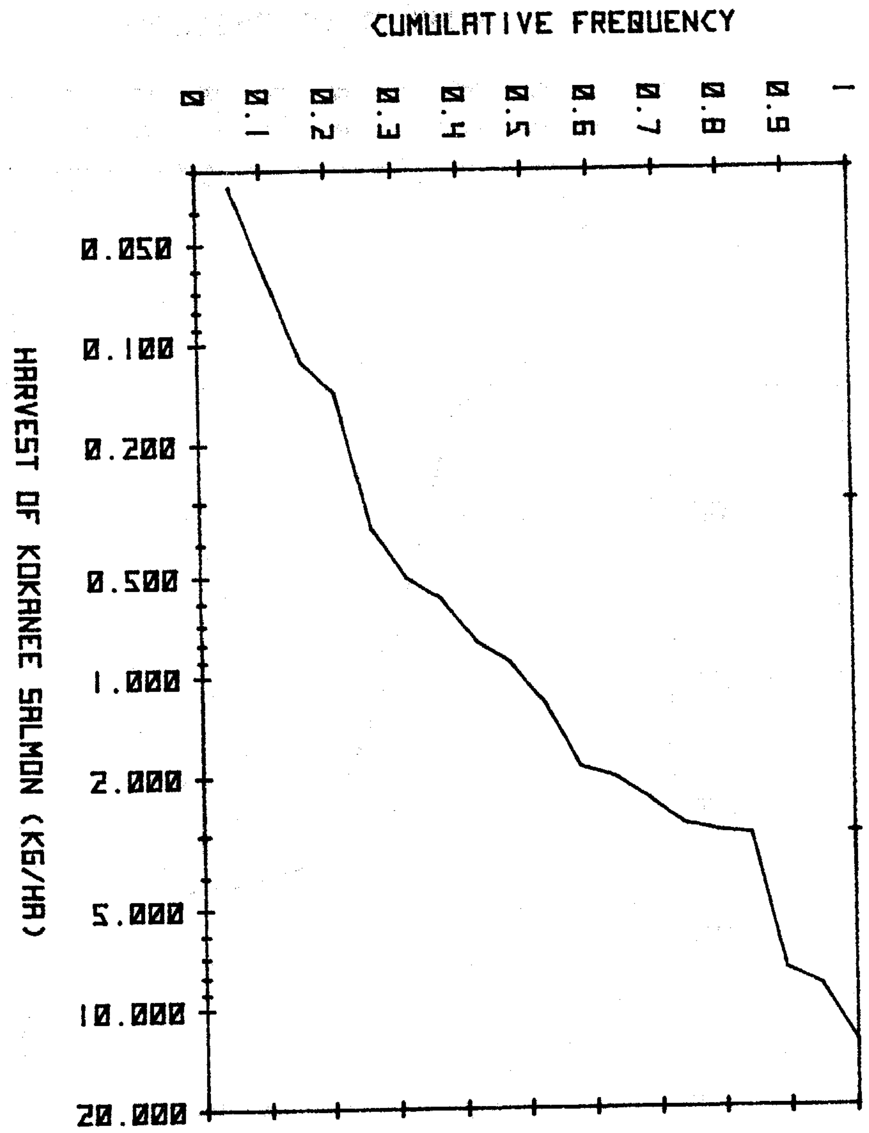

Figure D-14. Cumulative frequency plot of kokanee salmon harvest in reservoirs with coldwater fisheries.

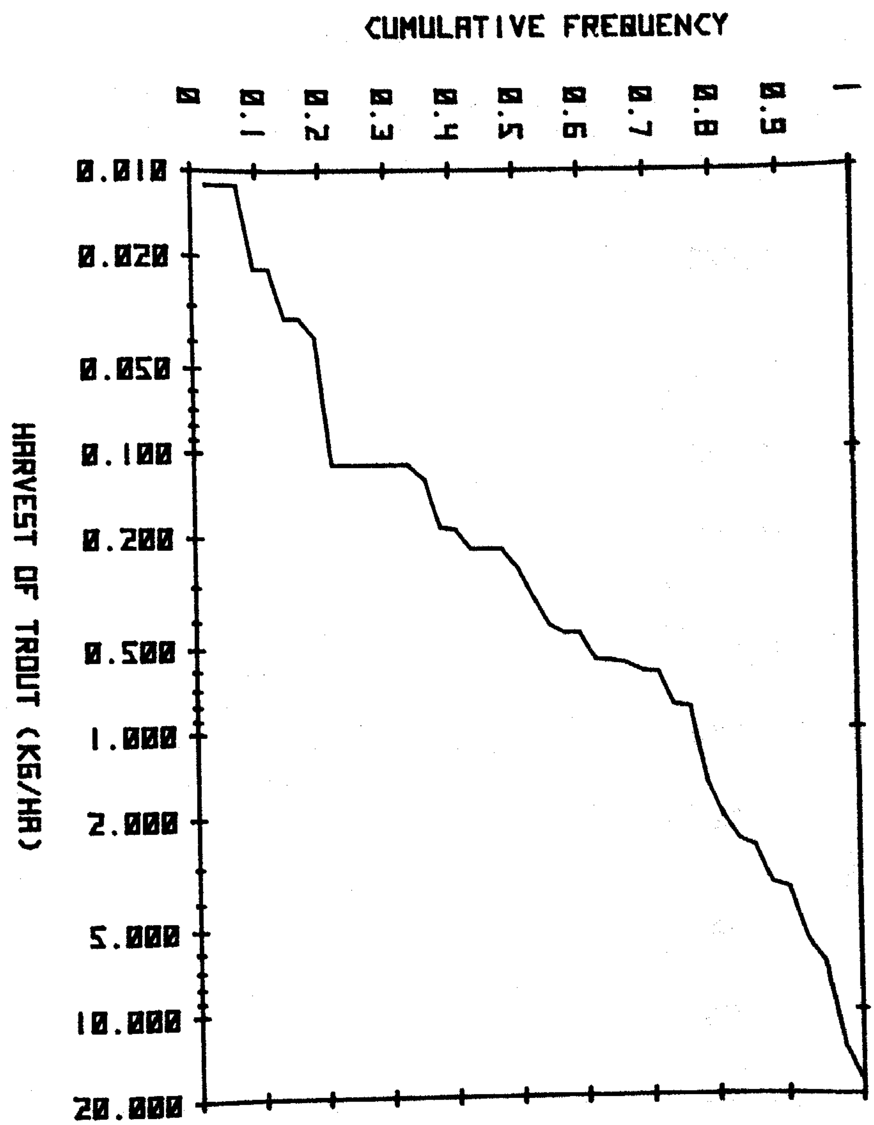

Figure D-15. Cumulative frequency plot of total trout harvest in reservoirs with seasonal or two-story fisheries.

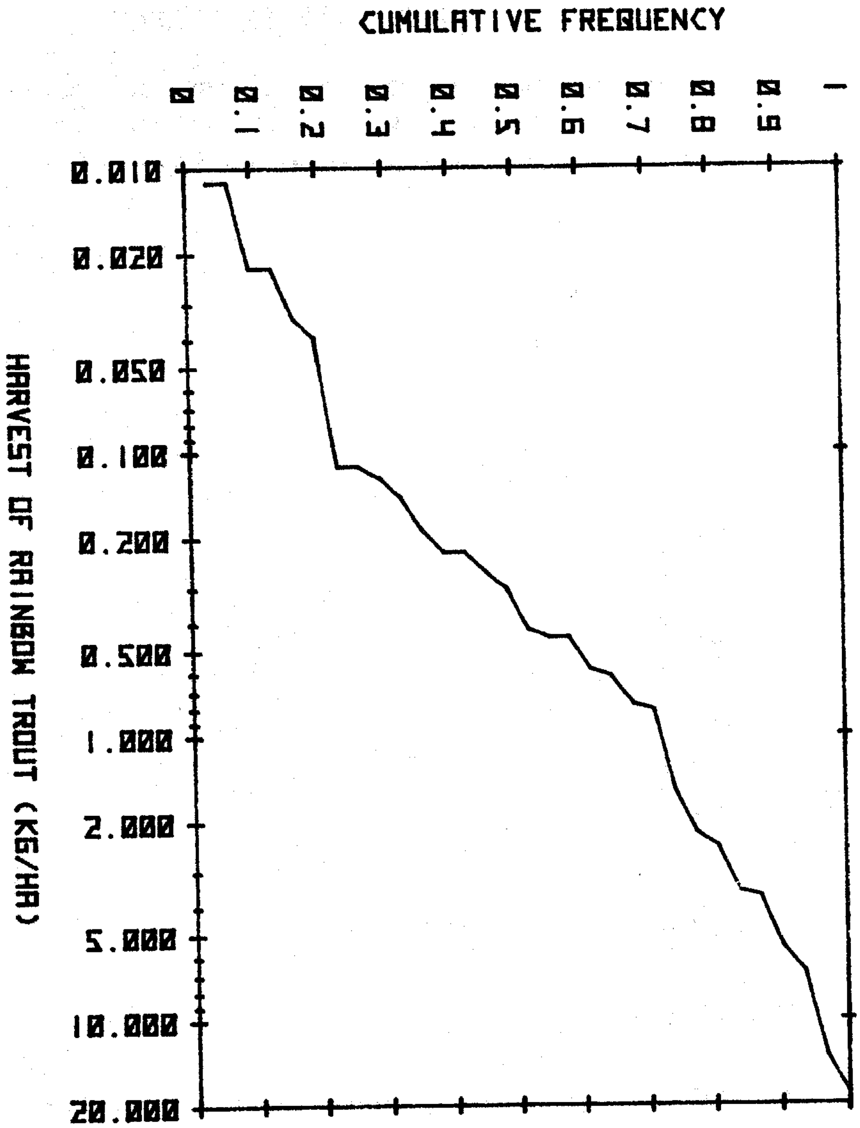

Figure D-16. Cumulative frequency plot of rainbow trout harvest in reservoirs with seasonal or two-story fisheries.

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16. Abstract (Limit: 200 words)

This report presents methods designed to permit habitat classification of reservoirs that contain coolwater, coldwater, and seasonal two-story fisheries. Multiple regression equations describing relations between reservoir environmental characteristics and biomass harvest of selected sport fish species or groups are presented. Cumulative frequency plots of known harvest estimates from the various classes of reservoirs are presented to facilitate conversion of harvest predictions to Habitat Suitability Indices (HSI's). Detailed descriptions and limitations of the procedures are discussed.

17. Document Analysis a. Descriptors

Reservoirs
Habitability
Water
Aquatic biology
Fisheries
Fishes
Biomass
Fresh water

b. Identifiers/Open-Ended Terms

Habitat classification
Coolwater fishes
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Environmental characteristics
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Habitat Suitability Index

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