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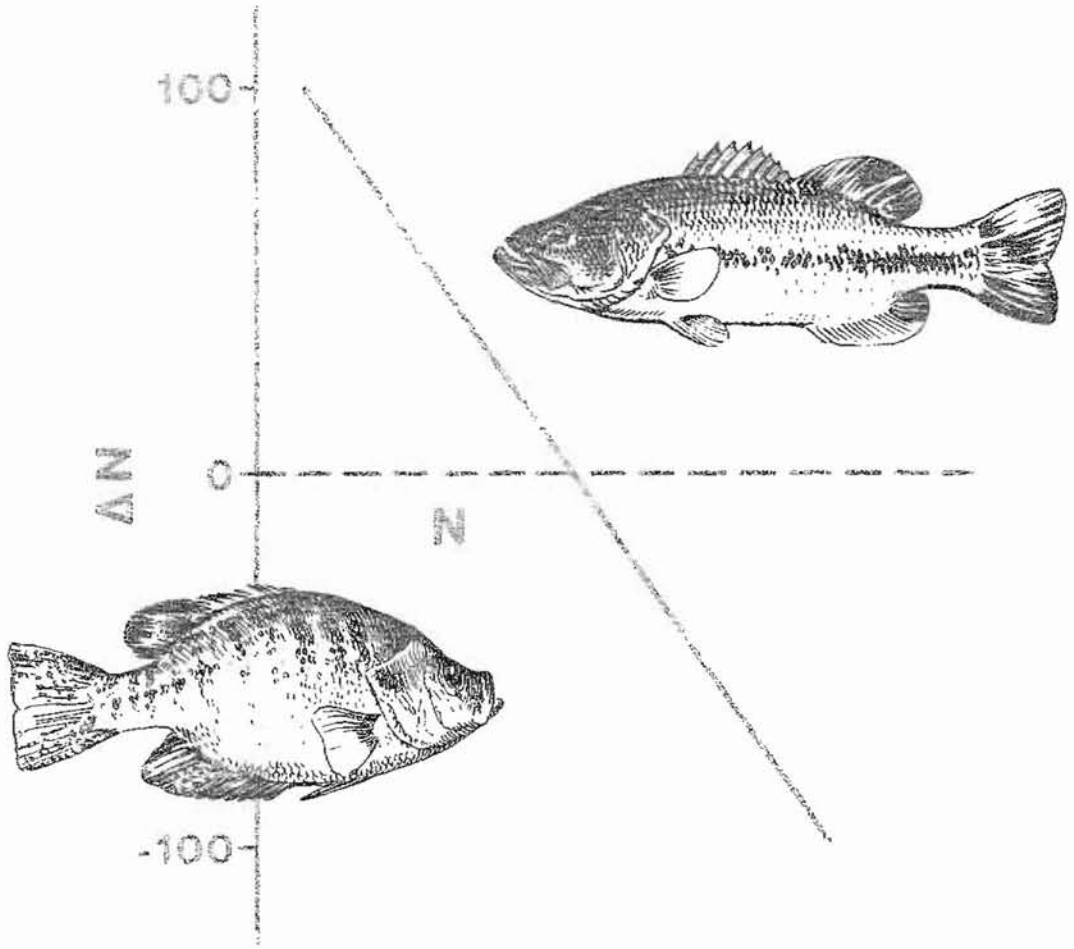
PROCEEDINGS OF A WORKSHOP ON FISH HABITAT SUITABILITY INDEX MODELS



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PROCEEDINGS OF A WORKSHOP ON FISH HABITAT SUITABILITY INDEX MODELS

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PREFACE

One of the habitat-based methodologies for impact assessment currently in use by the U.S. Fish and Wildlife Service is the Habitat Evaluation Procedures (HEP) (U.S. Fish and Wildlife Service 1980).[1] HEP is based on the assumption that the quality of an area as wildlife habitat at a specified target year can be described by a single number, called a Habitat Suitability Index (HSI). An HSI of 1.0 represents optimum habitat; an HSI of 0.0 represents unsuitable habitat. The verbal or mathematical rules by which an HSI is assigned to an area are called an HSI model. A series of Habitat Suitability Index (HSI) models, described by Schamberger et al. (1982),[2] have been published to assist users in applying HEP.

HSI model building approaches are described in U.S. Fish and Wildlife Service (1981).[3] One type of HSI model described in detail requires the development of Suitability Index (SI) graphs for habitat variables believed to be important for the growth, survival, standing crop, or other measure of well-being of a species. Suitability indices range from 0 to 1.0, with 1.0 representing optimum conditions for the variable. When HSI models based on suitability indices are used, habitat variable values are measured, or estimated, and converted to SI's through the use of a Suitability Index graph for each variable. Individual SI's are aggregated into an HSI. Standard methods for testing this type of HSI model did not exist at the time the studies reported in this document were performed.

A workshop was held in Fort Collins, Colorado, February 14-15, 1983, that brought together biologists experienced in the use, development, and testing of aquatic HSI models, in an effort to address the following objectives: (1) review the needs of HSI model users; (2) discuss and document the results of aquatic HSI model tests; and (3) provide recommendations for the future

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[1]U.S. Fish and Wildlife Service. 1980. Habitat Evaluation Procedures (HEP). 102 ESM. U.S. Fish Wildl. Serv., Div. Ecol. Serv. n.p.

[2]Schamberger, M. A., A. H. Farmer, and J. W. Terrell. 1982. Habitat suitability index models: introduction. U.S. Fish Wildl. Serv. FWS/OBS-82/10. 2 pp.

[3]U.S. Fish and Wildlife Service. 1981. Standards for the development of habitat suitability index models. 103 ESM. U.S. Fish Wildl. Serv., Div. Ecol. Serv. n.p.

development, testing, modification, and use of HSI models. Individual presentations, group discussions, and group decision techniques were used to develop and present information at the meeting. A synthesis of the resulting concepts, results, and recommendations follows this preface. Subsequent papers describe individual tests of selected HSI models. Most of the tests involved comparison of values from HSI models or Suitability Index (SI) curves with standing crop, as required contractually. Time and budget constraints generally limited tests to the use of data previously collected for other purposes.

These proceedings are intended to help persons responsible for the development, testing, or use of HSI models by increasing their understanding of potential uses and limitations of testing procedures and models based on aggregated Suitability Indices. Problems encountered when testing HSI models are described, model performance during tests is documented, and recommendations for future model development and testing presented by the participants are listed and interpreted.

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WORKSHOP SYNTHESIS AND RECOMMENDATIONS

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INTRODUCTION

The test results presented in these proceedings focus on Habitat Suitability Index (HSI) models, based on aggregated Suitability Indices (SI's) for selected environmental variables. The Habitat Evaluation Procedures (HEP) (U.S. Fish and Wildlife Service 1980) also can accommodate the use of HSI models based on other types of data analyses (e.g., regression models or discriminant analyses) when appropriate. Some of the papers included in these proceedings describe the development, testing, and performance of models based on these other approaches.

The purposes of this paper are to: (1) summarize and discuss the user needs and constraints identified at the workshop; (2) present the recommendations of the workshop participants concerning the general use, limits to application, and testing of HSI models; (3) provide a discussion of workshop deliberations and recommendations; and (4) present an opinion, as influenced by the workshop discussions, of the potential uses and current status of published HSI models based on aggregated Suitability Indices. This information should help users understand the characteristics of models similar to the tested models, potential model modifications, the information base that is needed for model use, the procedures involved in using and testing selected models, and expected model performance. The recommendations of the workshop participants include individual opinions and were not necessarily endorsed by all participants. The summary of user needs and constraints, the discussion

of workshop deliberations and recommendations, and the opinion on the potential uses and status of published HSI models based on aggregated suitability indices described below represent our views of the selected topics and are not necessarily the view of other workshop participants.

User Needs and Constraints

Assessment of the impacts of a proposed project or a habitat management activity is a complex process that generally requires definite yes or no decisions to proceed to the next level of assessment or to implement management or mitigation strategies. Persons evaluating development impacts may be faced with the necessity of making decisions even though all of the necessary or desirable information is not available. Therefore, a tool is needed that can be used to make the "best" decision possible, consistent with the level of knowledge and time available. If applied properly, HSI models can contribute meaningfully to this decision process.

Responsibility for impact assessment usually rests with biologists in various field offices, such as the Ecological Services (ES) Offices of the U.S. Fish and Wildlife Service. These biologists often have to make decisions within a relatively short time period. There is a need, therefore, for habitat models that have well documented assumptions and references to technical information used in their development. In addition to simplicity and general applicability, models should involve use of standardized terminology so that users do not have to learn a new and specialized jargon for each application. The rationale for including each model variable should be explained, and any assumptions that must be met to use the model should be specifically stated. The most critical model variables should be listed, as well as substitute variables where substitution is possible. Users also need to know the relative importance of each variable and what to do if the sampling necessary to measure the variable cannot be accomplished. The geographical limits of model applicability also need to be stated. Finally, use of the model should not require the collection of extensive data sets, because assessments often have very limited time and money available for data acquisition.

Each user of HSI models must carefully develop and state the specific objectives of the study in which HSI models will be applied. These study objectives help define the acceptable limits of model precision, generality, and realism. A complete description of reality is not the goal of building a model. Rather, a model simplifies reality effectively to apply existing knowledge to the timely solution of a specified problem. The user must decide what type of model is appropriate given the available data base, constraints of time and money, and the importance of the pending decision. HSI models based on aggregated Suitability Index (SI) curves can be an effective method of applying existing knowledge to the timely solution of impact assessment problems. However, other HSI models, based on different building techniques (e.g., statistically derived models), may be more appropriate for some types of data bases and particular situations.

It is difficult, if not impossible, to create a model that both meets all of the requirements listed above and that is accurate enough to differentiate between various management or impact alternatives throughout the range of a species. If an HSI model based on aggregated SI's contains clearly described instructions, assumptions, and limits of applicability, it will, at a minimum, provide an organized system to document and defend the logic used to derive impact estimates.

Workshop Participants' Recommendations

The primary conclusion of the workshop participants was that habitat models are the best choice among the alternative tools currently available for decisionmaking when the aggregate impacts of proposed developments on various habitats must be assessed. The term "habitat models" was not limited to models based on aggregated SI's, but also included traditional statistical models, such as regression models for predicting standing crops, discriminant models for classifying habitat, use of individual SI curves for impact analysis without aggregating the curves into a single HSI, and SI curve useage for analyses other than HEP, such as the Instream Flow Incremental Methodology (IFIM) described by Bovee (1982).

Habitat models often do not provide narrow confidence limits for estimates of a response variable, such as standing crop; however, such limits are generally not needed in impact assessment. Human value judgements during an impact assessment can add an extra dimension of interpretation to simple estimates of changes in habitat. Even in situations where habitat models or SI curves provide only the most general estimate of the trend and magnitude of change of a selected response variable (e.g., survival rates) resulting from a habitat perturbation, they are logical, organized, and subject to improvement. The only alternative, in many cases, is reliance on "expert opinion" of the person making the assessment. There is no justification for assuming that an "expert opinion" is more accurate or valid than a habitat model or SI curve unless the accuracy of the opinion is subjected to the same systematic testing as the model or curves. The validity of poorly documented opinions may be more difficult to test than the validity of a structured model.

Because specific decisions must be made for any proposed project, a single graphical or numerical value that represents the overall impact of changes in the habitat needs to be formulated. That value can be defined or undefined and developed formally or informally, logically or illogically, but one overall value or judgement is needed and will be used as a basis for decisions. The workshop participants agreed that habitat models represent the best method presently available for developing a summary value, even though model accuracy in predicting a selected response variable (e.g., standing crop) is often below that expected in more rigorous scientific research.

The workshop participants developed a number of recommendations concerning the general use, limits to applications, and testing and modification of habitat models. These recommendations are provided below, by category. The numbering system is for organizational convenience and does not indicate or imply relative significance.

General use of models

1. The level for confidence limits for model output used to differentiate alternatives should be left to the discretion of the user; however, 75% usually is adequate in impact assessments. Confidence limits for individual suitability indices should be at the 90% level.

2. Impact assessment does not require the formal development of an HSI model to aggregate the individual suitability indices. A comparison of before and after SI's for individual habitat variables can be a useful impact assessment technique and can be used to discuss and modify project-induced changes in individual habitat variables.

3. Each model should be able to function with a minimal data base (either existing data or data that can be collected within a relatively short time, such as 2 to 4 weeks).

Limits to applications of models

1. The geographic limits to model application should be clearly stated in each published model.

2. Suitability Index curves in publications need to be large enough for accurate interpretation. The 2" x 2" curve format may be too small for appropriate accuracy.

3. Separate models are needed for different types of habitats (e.g., lakes versus rivers).

4. A glossary of terms should be included, as well as instructions for measuring each variable used in the model. These additional instructions are especially important for variables with a high degree of temporal and spatial variability, such as temperature. The rationale for the inclusion of each variable in the model should be explained thoroughly.

5. The effects of various levels of sampling intensity on model accuracy should be predicted and included in models, where possible.

6. The fact that changes in HSI's calculated from models based on aggregated Suitability Indices are not equivalent to changes in standing crop and can, at best, be expected to correlate only with changes in carrying capacity, needs to be emphasized in published models. Additionally, there should be a statement that this type of HSI model cannot be expected to predict specific changes in population numbers resulting from various habitat management strategies.

7. The potential impact of density-dependent variables on standing crop and the possible lack of correlation between HSI's and standing crops should be discussed in published models.

8. The quality of data in the data sets used to develop each SI graph and the complete HSI model should be evaluated. For each graph, data points based on documented data should be indicated to inform users of the degree of professional judgement that was exercised in developing complete graphs.

9. The rationale for assigning mathematical values to life requisite components and the overall HSI expression should be included in models.

Testing and modification of SI curves and HSI models

1. It would be desirable to test Suitability Index curves over the whole range of possible values before including them in HSI models.

2. A new or modified model needs to be tested against new data sets, not the data used in its development.

3. Long term, before and after, studies are needed to test the predictive abilities of models; therefore, additional research and development funds are needed to support further habitat assessment work.

4. All of the hypotheses and aggregating strategies used in developing an HSI model should be tested, not just the final model.

5. Each new model should be tested, at least once, with real data before the model is published. A discussion of the degree to which a model has been tested should be included in all publications that describe the model.

6. A single archive location for data sets used to develop and test HSI models should be established.

Discussion of Workshop Deliberations and Recommendations

Models can be developed and tested in a variety of ways. Simple direct comparisons of HSI's with standing crop estimates have not automatically led to an improved understanding of fish habitat requirements, although the steps required to complete the comparison have documented the feasibility (or infeasibility) of collecting adequate data to estimate the variables required to use the model. It is important to consider alternate model development and testing methods that will document model performance, improve the understanding of species habitat requirements, and, therefore, lead to a better habitat model.

Model tests can be divided into two general categories, verification and validation, following the terminology of Farmer et al. (1982). Verification is the determination of whether or not the model performs the way the model builder or potential user expects it to behave and is not a test of how well the model depicts reality. A model can be verified by checking model output using sample data sets and through sensitivity analysis (Farmer et al. 1982),

as well as by applying the model in the field to determine if the variables are realistically defined and measurable and if the model is logical. Verification testing does not appear to present any major conceptual problems, as long as the verifier recognizes that counterintuitive results with sample (i.e., "made up") data sets do not necessarily indicate a totally incorrect representation of the system being modeled. In other words, if the model is logically structured, counterintuitive answers could indicate that the testers intuition is incorrect.

Validation is a test of whether or not the model output depicts reality. The accuracy of the model over a selected (or the entire) range of possible habitat variation is evaluated for validation. How far the test results should be extrapolated is a matter of personal preference. If the model is intended for use in impact assessments, it should be tested for both existing habitat conditions and habitat conditions that mimic proposed changes.

Testing of models clearly requires both verification and validation. However, an HSI model cannot be validated [or, more correctly, invalidated, by understanding the model's degree of unreliability, as described by Holling (1978)] unless a complete definition of the basis of the model predictions (which are a 0.0 to 1.0 unitless index) is provided. An HSI consists of two parts:

$$\text{HSI} = \frac{\text{Value of interest}}{\text{Standard of comparison}}$$

where the numerator and denominator must have the same units of measure (U.S. Fish and Wildlife Service 1980). These units of measure (e.g., growth rate of individual fish in grams/day) are the basis of model predictions and must be specified before the model can be invalidated. The model is then tested as a predictor of the specified measurable response through the comparison of predicted values to actual values of the response.

The Habitat Evaluation Procedures (HEP) (U.S. Fish and Wildlife Service 1980) require more than a simple prediction of some measurable response. HEP is based on the assumption that the relationship between HSI and carrying capacity is linear or can be converted to a linear relationship. Determining the "reliability" or accuracy of an HSI model in predicting "carrying capacity" requires the formulation of explicit assumptions of how a measurable response (e.g., growth rate of individual fish in grams/day) relates to carrying capacity. The accuracy of the model in predicting a value of interest (the numerator of the HSI assumed to represent carrying capacity) is then evaluated. Such testing does not directly prove (or disprove) the model's ability to predict or measure "carrying capacity" unless one is willing to accept the explicit assumptions on how a measurable response defines carrying capacity. If one is willing to accept these assumptions, model performance in predicting the measurable response is viewed as a test of the model's ability to predict carrying capacity. If one does not accept the assumptions, model performance is viewed simply as a test of the model to predict the measurable response; no conclusions are made concerning model ability to predict carrrying capacity.

The usefulness of a model for an impact assessment depends on user objectives and constraints, in addition to accuracy. Biological systems are complex and the fact that a model adequately predicts or correlates with a selected response variable for one data set may not indicate that the model will work equally well with another data set, especially one from a different geographical area. Models that can predict derived values (e.g., means and maxima) fairly accurately will provide much less accurate predictions of site specific values (e.g., standing crop at a specific stream reach).

When an HSI is based on aggregated SI's for individual environmental variables, it is difficult to determine the point(s) at which the model has failed when it does fail. This problem is even more serious when complicated aggregation techniques are applied to data from SI curves developed from different responses and in a nonrigorous manner. Meaningful testing cannot be directed at critical model hypotheses and assumptions unless they are clearly defined. Simply diagraming a model and identifying assumed links between components, subcomponents, and variables is not sufficient to develop a falsifiable, or testable, hypothesis. The links must be described in such a manner that they result in falsifiable predictions of some measurable response. Even when the final model output is a conceptual value (e.g., carrying capacity) for which predictions cannot be falsified and a test of the accuracy of the complete model is infeasible, the accuracy of the links should be testable.

The test results described in these proceedings indicate that acceptable suitability index curves for individual variables can be developed, especially if the curve development technique is rigorously defined. However, different curves represent different measurable responses (e.g., growth, survival, habitat preferences, and standing crop) for both populations and individuals. Conversion of these responses to unitless suitability index curves results in a net loss of information to users unless the conversion is carefully documented. Biological and ecological processes represented by the original data tend to be obscured. What the individual SI curves represent varies depending on how the curve was developed, the quality and quantity of the data base, and the type of response used in development of the curves. When the curves represent different responses, it is unlikely that a uniform method of aggregating curves to predict a single response exists.

The confidence limits or acceptance levels that should be applied to results from tests of HSI models have not been firmly established. A 5% (or even a 1%) probability level is often required in order to minimize the probability of a Type I error (rejecting the tested hypothesis when it is true) in test results. However, such probability levels are rarely obtainable (or needed) in day-to-day management decisionmaking. When analyzing test statistics, the probability of a Type II error (accepting the hypothesis when it is false) also must be considered. The model selected for a management application simply may be the one that is the best among the possible alternatives in terms of meeting multiple objectives, such as ease of use, accuracy, and cost of model application. The tested HSI models derived from aggregated suitability indices based on a variety of measurable responses were designed to reflect the magnitude and direction of change in the carrying capacity of a habitat for a selected species. Because carrying capacity is a concept

relating to what the habitat could support, an index of carrying capacity (e.g., the HSI) will not necessarily be a predictor of actual population numbers or the value of any other measurable response variable on a site specific basis. Decisions as to which model to use will depend on user experiences and the quantity and quality of models available. We suggest that test statistic values and probability levels be reported by model evaluators to help users make these decisions concerning appropriateness of model use, rather than trying to develop a standard level of acceptance for test statistics that must be met for all model applications.

Improved models and model understanding can be achieved by reviewing the problems associated with HSI models based on aggregated suitability indices and how they were tested. Some of the problems can be solved relatively easily by including additional variables, substitution of new variables for the existing variables, or development and use of a different type of model for particular applications. Other problems seem to be inherent in generalized habitat models. A model that provides the best fit to a particular data set may not be applicable to other data sets. In one test (Layher and Maughan 1984), a model based on discriminant analysis fit a data set for Kansas fishes much better than did a general HSI model based on aggregated SI's. However, the discriminant model based on Kansas data provided predictions of the presence or absence of a species that were less accurate than would be expected by random guessing when applied to an Oklahoma data set.

Particular problems associated with the testing of HSI models and interpretion of results are discussed below. Many of the test interpretation problems are related to difficulties in defining the relationship between the measured response variable (e.g., standing crop) and the concept of carrying capacity. The assumption that the model outputs can be directly correlated with "carrying capacity" remains untested. No universally accepted, measureable, definition of carrying capacity was developed, although Trial et al. (1984) described a useable definition, based on several years of standing crop data.

The impact of short term localized events, such as temperature or dissolved oxygen levels, that are lethal or near lethal at a sampling location but which are avoided by fish because they are able to move to more suitable areas, were not accurately assessed with many of the models tested. This problem appears to be solvable by redefining the model variables to allow more flexibility in when and where the data are collected (Gilbert 1984). In many cases, it is unknown if particular habitat variables in the models actually have any limiting effect on "carrying capacity" or the selected measurable response within the range of values reported in the data set. Questions then arise as to which variables should be included in the model, how values of variables should be estimated, and the relative importance of the variables in specific situations. Investigators found that some model variables seemed to be of little or no importance in predicting measurable responses of a particular species in their area, whereas variables not originally in the model [e.g., a depth variable to account for drying out of borrow pits, as reported by Nelson and Miller (1984)] were of great importance.

For many of the tests reported in these proceedings, it was impossible to determine if the lack of correlation between model output (HSI) and the selected response variable (e.g., standing crop) was due to a correctable error in the model structure, the influence of variables not included in the model, or some other factor. There are two potential extremes of reasoning when model output (HSI) fails to correlate with the selected response variable. The first extreme is to always defend the model and argue that the test was inadequate. This reasoning is based on the fact that variables not in the model (e.g., biological interactions and sport fish harvest) are likely to have an impact on the response variable. Unless model tests are based on carefully screened long term population data sets where the impacts of variables not included in the model are known, the tests are rejected as inadequate. If this line of reasoning is followed, then a model based exclusively on habitat variables seldom, if ever, can be rejected as a totally erroneous model because it can be argued that a test was performed incorrectly. Given enough time and money to meet the data restrictions imposed by the described reasoning, it may be possible to build habitat models that accurately predict a measurable response for at least a short period of time and improve or reject poor models. However, this reasoning would fail to reject a totally, or almost totally, incorrect model tested with imperfect field data sets. Imperfect data sets are all that are commonly available and were used for the tests reported in these proceedings. Very inaccurate models might be subjected to a very expensive testing program if they were not eliminated or improved based on less expensive tests.

The second extreme of reasoning is to always reject models as being unacceptably formulated measures of carrying capacity if they fail to predict the selected response variable with a high degree of accuracy. There is a major problem with this reasoning. A model may, by chance, provide a reasonable representation of how the selected model variables interact to affect the selected response variable for a narrow range of conditions of additional variables not included in the model. If the range of values of these additional variables not in the model is outside of this narrow range, the model will fail the test. Under these conditions, a complete rejection would eliminate model useage under the conditions where the model would have been accurate enough to use. A single test should not be the basis for complete model rejection.

These two extremes of reasoning result from viewing testing as a "pass-fail" situation and from either accepting or rejecting some measurable response (e.g., standing crop) as an independent measure of "carrying capacity". Both extremes view an HSI model as a hypothesis to be accepted or rejected based on test-statistic values. Both views are based on a common concern for the consequences of making the wrong "pass-fail" decision. Those who defend the model do not want to reject a model that might be adequate but was subject to a poor test. Those who tend to quickly reject a model do not want the use of a faulty model to lead to faulty impact assessments. A balanced interpretation of "pass-fail" types of tests is needed, as well as integrated model building and testing approaches that identify the reasons for model failure. When tests are performed, there should be a goal to obtain data to improve model accuracy and not merely to report a "pass" or "fail".

Tests conducted for the purpose of selecting a model for a specific impact assessment should emphasize a comparison of models, rather than simple rejection or acceptance because the resource decisions may be made regardless of the test outcome. Tests also should include measures of variables not in the model that may influence the measured response variable and an estimate of the degree of influence of these variables. With this information, the predictive abilities of the model can be more accurately evaluated relative to the amount of variation in the measured response variable. For example, a tested model based on habitat variables might explain only 20% of the variation in a measured response variable (e.g., standing crop). However, if a model based on variables not in the habitat model accounted for 70% of the variation and the sources of variation were additive, the habitat model would account for two-thirds of the variation (30%) unexplained by the alternate model and might be considered an acceptable model. Conversely, if a tested habitat model accounted for 20% of the variation in a response variable, while an alternative habitat model based on the same environmental variables accounted for 60% of the variation in the response variable, the alternative model would likely be considered a more accurate representation of the species' habitat requirements. The way that physical and chemical variables interact to affect a response variable may vary depending on the value of specific biological variables. Therefore, there is no a priori reason to exclude biological variables from HSI models.

There are several options for the development and testing of SI graphs and HSI models developed from those graphs, based on the test results and the above discussion. One option for developing SI graphs is to use the concept described by Li et al. (1984) as maximum performance and by Persons and Bulkley (1984) as a theoretical regression line. This method defines the SI for a selected value of an environmental variable as the quotient of the maximum value of the response variable observed in conjunction with the selected value of the environmental variable divided by the maximum value of the response variable ever observed. This method of curve construction logically leads to an HSI that is related to the maximum observed (rather than actual) value of a selected response variable.

Another option for building an SI graph is based on the average level of a response variable. Layher and Maughan (1984) developed this type of SI graph using an estimate of the average standing crop as the response variable. This method defines an SI for a specified value of an environmental variable as the quotient of the average value of the response variable observed in conjunction with the specified value of the environmental variable divided by the maximum average value of the response variable ever observed. This method of curve construction logically leads to a model that predicts average values of a selected response variable. SI graphs for a selected environmental variable may look very similar regardless of whether mean or maximum values of the selected response variable were used to develop the graph.

Response variables selected by model testers for SI graph construction tended to be population parameters (e.g., standing crop). However, individual physiological responses (e.g., growth) and behavior-based responses (e.g., selection of specific environmental variable conditions by an individual) were often the basis of the suitability indices furnished to the model testers.

Regardless of how an SI curve is built (maximum or average performance of individuals or populations), it is difficult to develop a testable logic for combining SI's into a single HSI when the individual SI's depict response variables (e.g., growth and survival) based on different units of measure or the response variables are a mixture of individual and population responses. The HSI models provided to the testers were invariably of this mixed type. Different types of responses are not directly comparable just because they have been converted to a unitless suitability index. The transformation of different measurable responses (e.g., growth, survival, standing crop, fish location, or catch per unit effort) to different environmental variables into a unitless, unmeasurable response (the suitability index) and the subsequent aggregation of these indices into an HSI can result in an unmeasurable HSI that is a concept rather than a hypothesis that can be invalidated. Tests consisting of simple HSI/measurable response comparisons provide data that can be used to evaluate model reasonableness for the specific test data. However, general model veracity as a predictor of "HSI" cannot be disproved with such a test (or perhaps any test) because the unit (HSI) predicted by the model does not exist and cannot be measured. It is difficult, if not impossible, to determine if the correlation (or lack of correlation) between model output (HSI) and the response variable is due to model formulation problems or factors not considered in the model.

There are at least two model development and testing approaches that can be used to overcome this logic problem. One approach is to simply evaluate the usefulness (if not the veracity) of the concept represented by the HSI model. The other approach is to develop a model that makes falsifiable predictions and to evaluate model veracity.

The first approach is primarily verification testing. Model outputs (HSI) are compared with some response variable, as was done in the tests reported in these proceedings. Rank correlations (Trial et al. 1984), linear regression analysis (Gilbert 1984), and discriminant function analysis (Nelson and Miller 1984) were used to make this comparison. These tests do not readily demonstrate why a model performs at the level indicated but they do demonstrate whether or not model variables can be estimated and how well a model predicts a specified response variable. Results are open to the two extremes of interpretation described previously. Evaluation of the quality of the test data and documentation of how model variable values were estimated are especially important. The impact of changes in model variable definitions or model structure on the HSI-response variable correlation can be quantified with this type of testing. However, model changes that result in a better correlation do not necessarily indicate that a more realistic causal model structure has been developed. Recommended model modifications resulting from this approach are: (1) define model variables (e.g., percent pools) so they can be more easily measured; (2) refine curves for selected environmental variables with use of additional data for the same (or a different) response variable used to develop the original curves; and (3) develop more logical SI aggregation techniques. This type of testing not only improves model performance, it also provides data on performance of different models to help users decide which, if any, of the tested models are adequate for a particular application.

The key to the second approach, assuming that the model incorporates SI graphs, is to test and rebuild the model so that model output is based directly on a measurable response. One way to do this is to base all SI curves on the same measurable response. If this method is used, it is not necessary to convert the y axis of each curve to a suitability index. The HSI is based on the selected response variable with predicted values of the variable comprising the numerator of the ratio defining HSI. As an alternative, the methods used to transform SI's that are based on different response variables into a prediction of the selected measurable response can be clearly stated so that the transformations can be tested by comparing model predictions with real world values of selected response variables. If the transformations are logically stated and generate testable hypotheses about the accuracy of the transformation, the model will have dimensional consistency in the transformation of the measurable responses depicted by the SI's into the single measurable response depicted by the HSI.

Selecting the response variable that the model will predict is critical and depends on the objectives that the model needs to meet. It is not necessary (or possible) to "prove" or assume that the selected response variable is equal to "carrying capacity". It is only necessary to demonstrate that impact assessment objectives can be met by using the model to evaluate changes in the selected response variable. The goal of this type of model building and testing is to develop a model that meets a very specific applicational objective. A change in the selected response variable must be shown to be an acceptable change on which to base a planning decision prior to testing and building the model. In addition to the modifications described for the first model building/testing approach, the following model modifications result from this approach: (1) collect new data and redraft the SI curves so that all curves are based on a single response variable (e.g., standing crop or oxygen consumption rate) that has been selected as an appropriate response variable on which to base a decision for a specified application; (2) develop new SI curves for additional habitat variables believed appropriate for a specific application; and (3) develop and test hypotheses about how a measurable response variable for which an SI curve has been constructed is related to a different, measurable response variable used as model output.

Linear regression analysis may be an inappropriate test of the output of an HSI model developed from SI graphs based on maximum performance. This type of HSI model assumes the relationship between the HSI and the response variable illustrated in Figure 1, whereas regression analysis is used to evaluate the type of relationship depicted in Figure 2. Attempting to combine SI's derived from graphs developed using the concept of maximum performance into a model that predicts specific (rather than maximum) performance is a frustrating experience, at best. A more logical approach is simply to select the lowest SI as the HSI (see Li et al. 1984). The resulting HSI provides a reasonable estimate of the lowest <u>maximum</u> value of "performance" (i.e., the maximum value of a selected response variable) likely to occur for the specified environmental conditions. This approach assumes that all SI graphs either depict performance in terms of the same response variable (e.g., oxygen consumption rate) or link different response variables to model output in a logical manner subject to evaluation.

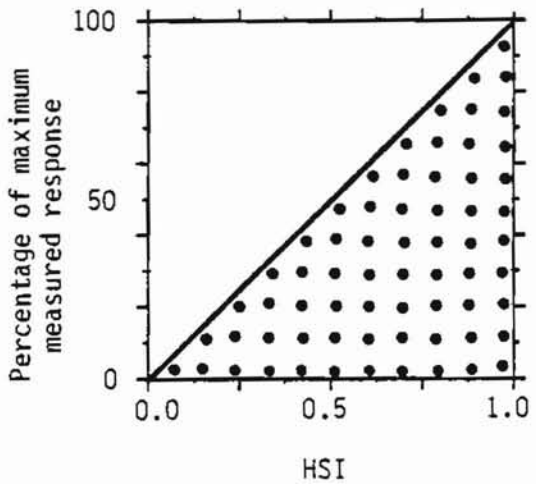

Figure 1. The HSI-response variable relationship that can be expected when SI graphs based on maximum performance are used to develop the HSI. All points should be on or below the 45° line.

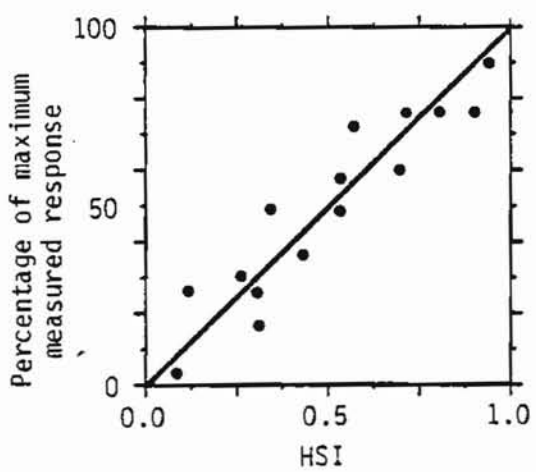

Figure 2. HSI-response variable relationship that is evaluated with linear regression analysis.

Curves based on average values of a response (average performance) logically lead to a model that predicts some average value of a selected response variable. Selecting the lowest SI leads to an HSI that is defined in terms of the lowest average response, assuming that the same, or logically linked, response variables are used. Regression or correlation analyses can be used to test the output of a model based on this type of SI graph. If the individual SI's are based on the mean value of the same response variable, the HSI can logically be expected to predict the mean value of the response variable. However, for any given data set, the environmental variable value with the lowest SI would have been shown, empirically, to be the environmental variable associated with the lowest mean value of the selected response variable.

Opinion on Current Status and Potential Use of HSI Models

The greatest accuracy that can be expected from the types of models based on aggregated suitability indices that were tested for this workshop is a prediction of the trend and general magnitude of changes in some maximum value of a measurable response associated with a specified set of habitat variables. Accuracy is the same or perhaps greater than that obtained with a less structured approach. However, the structured model approach should lead to quicker improvement of predictive techniques because there is a basis for testing and refining specific assumptions. The models identify variables that can serve as the basis for project-specific impact assessment models that utilize fewer variables. In order to make the models more accurate predictors of site specific values of a selected measurable response, restructuring and refinement will be necessary. The degree of model accuracy in predicting carrying capacity is difficult to assess because carrying capacity is a concept, not a measurable variable. Impact assessment should not require "proving" that an HSI model accurately describes carrying capacity.

Effective use of the published models based on aggregated SI's requires considerable judgment and expertise. They are not intended to be, and do not meet the need for, a single, broadly applicable species model that can be used without modification by a person with limited specialization in species requirements and impact assessment. Major problems in using the models include determining how to estimate values for model variables that ideally should be estimated based on long term monitoring data, rather than estimated by one or a few point-in-time estimates, and how to modify a model to solve specific impact assessment problems. The models should be used by experts to help assess the general trend and magnitude of habitat changes resulting from development and management activities. Development of a more specialized model (for example, a discriminant function or regression model) utilizing original HSI model variables may be needed for specific impact assessments. However, the test results reported in this workshop indicated that the area of applicability of specialized models is often limited.

Development of a single model that will meet the needs of all Ecological Services field offices, in terms of adequate predictive capabilities and ease of application for a wide array of habitats, species, environmental perturbations, and input data restrictions, may be impossible. However, specific information is needed concerning the impact of proposed development projects and associated activities on fish and wildlife resources; this information is

used in making the decision to approve or reject a specific project or management alternative. The U.S. Fish and Wildlife Service has produced both broad, generalized HSI models and more specific, statistically-derived models for use in the decisionmaking process.

The HSI models based on aggregated suitability indices for different measurable responses should become more logical and accurate as they are used and tested, new field data are acquired, and the limits of each model and model building approach become better known. Documentation of applications and easy access to the data by potential users should speed up the model improvement process. HSI models based on aggregated suitability indices will, however, probably continue to have lower confidence limits than traditionally expected of research models. They are most useful as aids for formulating judgements and making decisions during the early stages of project planning. This is an appropriate role for these models.

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HSI MODELS FOR NORTHEASTERN FISHES

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INTRODUCTION

Habitat Suitability Index (HSI) models are used in the Habitat Evaluation Procedures (HEP) (U.S. Fish and Wildlife Service 1980) to document habitat quality and its ability to support the life stages of a species. HSI's can be generated using a variety of models (U.S. Fish and Wildlife Service 1981). If HEP is to be an effective tool for recommending project alternatives and mitigation of adverse effects, the reliability of the HSI models must be established. The U.S. Fish and Wildlife Service has supported the development of HSI models for both fish and wildlife species. The models, structured in several ways, are designed to produce an index that is linearly related to the potential carrying capacity of the habitat.

HSI's generated from the aggregation of individual variable Suitability Indices (SI's), based on the data collection and analysis methods described below, were compared to population estimates of native fish in Maine streams. The ability of these HSI's to predict fish populations and, presumably, carrying capacity of several stream sections was tested. The study, therefore, involved model applications similar to those that would be used to document baseline habitat conditions for input to HEP.

Draft habitat suitability index models (Appendix A) were developed from the literature on the biology and life history of four ecologically important fishes in the Northeast. Model variables were linked to the survival, growth, reproductive success, or standing crop of blacknose dace (*Rhinichthys atratulus*), common shiner (*Notropis cornutus*), fallfish (*Semotilus corporalis*), and Atlantic salmon (*Salmo salar*). All of the models were tested and refined by field measurements, including one developed for brook trout (*Salvelinus fontinalis*) (Raleigh 1982). In this paper, the problems and limitations of model development and the results of field testing the models are discussed. The common shiner, blacknose dace, and fallfish draft models were developed with the assistance of other workers and eventually modified and published by Trial et al. (1983a, 1983b, 1983c).

METHODS

Environmental data were gathered during one visit to each of 11 stream sections, distributed among nine streams, in the summer when the water was low and the temperature high. Habitat variables related to stream size, current, and the amount of cover (Table 1) were measured on five transects per section. Table 1 also illustrates the method used to record data in the field during this study. Standard methods for data gathering and compilation in habitat studies of this type have not yet been established. In addition to the transect data described in Table 1, temperature, dissolved oxygen, alkalinity, pH, and turbidity were measured and gradient, percent pools, and percent shade estimated on each stream section. The transect and general stream section data were used to produce values for the variables included in each species model (Table 2). Although averages were most often needed, one variable required the mode. When the data collected could not be used to directly calculate a required value (e.g., annual averages, minimums, or maximums), observations from other streams and information from local biologists were used to estimate the value.

Next, the values for variables were converted to SI's, using SI curves (Appendix A; Raleigh 1982). HSI's were calculated for each species and its life stages, using a published HSI model (brook trout) or the models included in Appendix A. A computer program was written for each species HSI model in order to faciliate the calculations. Each life stage of a species was not evaluated in every stream section. For example, if spawning areas were not present in a section, the reproductive component for a species was not included in the HSI calculation. If a component or variable was not included in a calculation, the formula was adjusted accordingly; i.e., the formula for brook trout HSI without the embryo component was $(T_A \times T_F \times T_J \times T_O)^{1/4}$. Optional variables in the brook trout model (V_{11} and V_{12}) were not included in HSI calculations. The HSI's reported for the Atlantic salmon model do not include pH data because the model was very sensitive to the effects of fluctuating pH (Trial and Stanley 1984).

Finally, the HSI for a stream section was compared to standing crop estimates to test the predictiveness of the index. The standing crop estimates, based on multiple removal or mark-recapture methods, were made by the study team (six sections) or by State biologists (five sections). The sections were between 20 and 100 m long. Fish were captured with D.C. electrofishing units. Nonparametric correlations of standing crop with HSI's were calculated for each species. In streams where nongame species were sparsely distributed, reliable population estimates were impossible and no correlation analyses were performed. Population data from State files on Sunkhaze Stream and two additional brook trout streams (Greenlaw Stream and Hayes Brook) were used to develop Moran diagrams (Williamson 1972) to determine if a better indicator of carrying capacity than a standing crop estimate could be found. In addition, the ability of the models to predict the presence (HSI > 0.4) or absence (HSI ≤ 0.4) of a species was evaluated for the 11 sections using McNamar's test for discordant pairs (Connover 1980). An alpha level of 0.20 was used for all statistical tests.

Table 1. An example of the type of field data gathered for testing HSI models, showing the results of sampling one transect. Streamward extent of selected parameters is indicated by an "I".

Variable value along transect	Distance where measured from left to right bank (cm)					
	100	200	300	400	500	510
Depth (cm)	13.5	26.5	27	23	2	
Velocity (cm/sec)	25	42	36	18	0	
Extent and position of:						
instream cover	---100-I			I----130----------		
overhead cover	none		I---160----------			
gravel-sand	---140---I					
cobble-rubble		I----------370----------				
pools	none					
upwelling	none					
vegetation	none					
weight ratio of sand (< 2mm) to other substrate types	6/94		10/78			

Table 2. Model variables and variable estimation techniques used during tests of Atlantic salmon, brook trout, fallfish, common shiner, and blacknose dace HSI models.

Variable class	Model variable	Estimation technique
Cover	Percent instream cover during the late growing season, low water period at depths > 15 cm and velocities < 15 cm/sec	Calculated from transect data
	Percent cover (e.g., brush, logs, and undercut banks)	Same as above
Depth	Average thalweg depth (cm) during late growing season, low water period	Average of greatest depth on each transect
	Average depth (section)	Calculated from transect data
	Average depth (at head or tail of pool)	Same as above
	Average depth of riffles during spawning and incubation (April-July)	Estimated from average velocity of riffles in section on day sampled
	Mode of water depth measurements taken at 1/4, 1/2, and 3/4 distance across stream	Calculated from transect data
	Stream depth in spawning riffles	Estimated from average depth of riffles in section on day sampled
Dissolved oxygen	Minimum dissolved oxygen	Estimated from one measurement and observed dissolved oxygen trends in Maine streams
	Minimum dissolved oxygen from May to August	Estimated from one measurement and observed dissolved oxygen trends in Maine streams

Table 2. (continued)

Variable class	Model variable	Estimation technique
Dissolved oxygen	Average minimum dissolved oxygen (mg/l) during the late growing season, low water period, and during embryo development	Estimated from one measurement and observed dissolved oxygen trends in Maine streams
Discharge	Average annual base flow regime during the late summer or winter low flow period as a percent of the average annual daily flow	Estimated from typical stream hydrograph data for Maine
Gradient	Stream gradient	Estimated at site and determined using USGS topographic maps
Order	Stream order	Determined using USGS topographic maps
pH	Weekly average pH during year under stable conditions. If frequent (diurnal), large (> 1.0 pH units) changes occur, SI is reduced by 10%	Estimated from one measurement and observed pH trends in Maine streams
	Minimum pH	Estimated from one measurement and observed pH trends in Maine streams
	Minimum pH in fall and winter	Estimated from one measurement and observed pH trends in Maine streams
	Annual maximum or minimal pH. Measurement with the lowest SI is used	Estimated from one measurement and observed pH trends in Maine streams

Table 2. (continued)

Variable class	Model variable	Estimation technique
Pools	Percent pools	Calculated from transect data
	Percent pools during average summer flows	Calculated from transect data
	Percent pools during the late growing season, low water period (August-October)	Calculated from transect data
	Pool class rating during the late growing season, low flow period (August-October)	Calculated from transect data
Shade	Percent of stream area shaded between 1000 and 1400 hr (for streams < 50 m wide). Do not use on cold (< 16° C max. temp.), unproductive streams	Calculated from transect data
Substrate	Predominant substrate in riffles	Calculated from transect data
	Predominant substrate in pools and slow channels (adult)	Calculated from transect data
	Predominant substrate in stream riffles (juvenile)	Calculated from transect data
	Predominant substrate along stream margins (fry)	Calculated from transect data
	Substrate types in streams	Calculated from transect data
	Predominant substrate	Calculated from transect data
	Average size of substrate between 0.3-8.0 cm diameter in spawning areas, preferably during the spawning period	Estimated on site

Table 2. (continued)

Variable class	Model variable	Estimation technique
	Percent substrate in size class (10-40 cm) used for winter and escape cover by fry and small juveniles	Estimated on site
	Predominant (> 50%) substrate type in riffle-run areas; used to estimate food production	Estimated on site
Temperature	Maximum temperature	Estimated from one measurement and observed temperature trends in Maine streams
	Temperature during spawning	Estimated from one measurement and observed temperature trends in Maine streams
	Average temperature during warmest time of year (in lakes-epilimnion; in rivers-main channel)	Estimated from one measurement and observed temperature trends in Maine streams
	Least suitable temperature during the spawning season	Estimated from one measurement and observed temperature trends in Maine streams
	Average of mean weekly water temperatures during July and August (adult and juvenile)	Estimated from one measurement and observed temperature trends in Maine streams
	Average mean weekly water temperatures during July and August (fry)	Estimated from one measurement and observed temperature trends in Maine streams
	Average of mean weekly water temperatures during spawning and incubation (April through July) (embryo)	Estimated from one measurement and observed temperature trends in Maine streams

Table 2. (continued)

Variable class	Model variable	Estimation technique
	Average temperature	Estimated from one measurement and observed temperature trends in Maine streams
	Spawning temperature	Estimated from one measurement and observed temperature trends in Maine streams
	Embryo incubation temperature (winter)	Estimated from one measurement and observed temperature trends in Maine streams
	Average maximum water temperature (°C) during the warmest period of the year (adult, juvenile, and fry). For lacustrine habitats, temperature strata nearest optimum in dissolved oxygen zones of > 3 mg/l is used	Estimated from one measurement and observed temperature trends in Maine streams
	Average maximum water temperature (°C) during embryo development	Estimated from one measurement and observed temperature trends in Maine streams
Turbidity	Turbidity	Estimated from one measurement and observed trends in Maine streams
	Average turbidity	Estimated from one measurement and observed trends in Maine streams
	Maximum monthly average turbidity during the year	Estimated from one measurement and observed trends in Maine streams

Table 2. (concluded)

Variable class	Model variable	Estimation technique
Velocity	Velocity in riffles	Calculated from transect data
	Average velocity in pools and slow channels (adult)	Calculated from transect data
	Velocity in riffles (juvenile)	Calculated from transect data
	Velocity along stream margins (fry)	Calculated from transect data
	Average riffle velocity in channel during spawning and incubation (April through July) (embryo)	Estimated from transect data
	Velocity at/on bottom	Calculated from transect data
	Average velocity (cm/sec) over spawning areas during embryo development	Estimated from transect data
Width	Stream width	Calculated from transect data

RESULTS

Not all stream sections contained all species. Seven sections had brook trout, three had Atlantic salmon, six had blacknose dace, one had common shiners, and none had fallfish. The models for brook trout and common shiner actually predicted presence or absence; the models for blacknose dace and fallfish did not (Table 3). The Atlantic salmon model was tested only in known salmon streams because the species is absent in most streams in Maine (although several streams have potential for restored populations).

Ranks of HSI's produced by the Atlantic salmon and brook trout models were significantly correlated with ranks of standing crops (Tables 4 and 5). However, ranks of blacknose dace HSI's were not significantly correlated with ranks of standing crops (Table 6).

If a population fluctuates around a particular density, that density level usually represents the limit to population growth in that habitat. The slopes of Moran diagrams for brook trout populations were between -1 and -2, classifying the population cycles as damped oscillations about an equilibrium (Fig. 1).

DISCUSSION

The major problems encountered during model development were identifying the variables that limit the species and obtaining data on these variables. The published literature contains data on numerous environmental variables encountered when sampling fish or that affect fish under laboratory conditions. However, in many studies, a variable often does not vary over a range in which it becomes limiting, and critical values are not observed. Observed values for habitat variables may not be linked with survival, growth, reproductive success, or standing crop for a species. The manner in which different variables interact is seldom studied, and it was difficult in this study to determine how the individual SI's should be aggregated to determine an HSI. These problems were especially serious when developing HSI models for nongame species because of the lack of available information for these species.

There were several problems in using the HSI models. How to measure values for variables required as input to the models was not always explained, and some variables could not be measured as described without extensive monitoring data. For the brook trout model (Raleigh 1982), it was difficult to determine where and when to measure dissolved oxygen, and the use of absolute concentration of oxygen, rather than percent saturation, made the SI graph difficult to interpret. There were also vague variable descriptions in the models listed in Appendix A.

As a result of this study, the following changes in the variable descriptions are recommended. Model variables need to be less simplistic, with a more complete description of how the data should be handled; e.g., how to reduce velocity data from several transects. Better definitions of the necessary data for input in the SI curves are needed. Data on annual flow regimes often are unavailable; artificial indices of flow regimes are needed

Table 3. Success of the HSI models in predicting presence of the various species.

Species model	Accurately predicted presence
Brook trout	Yes
Common shiner	Yes
Blacknose dace	No
Fallfish	No
Atlantic salmon	Not tested

Table 4. Rank correlation between brook trout HSI and population densities (± standard error) in nine stream sections.

Stream	No./ha	± S.E.	HSI value	HSI rank
Lord Brook	21330	--	0.67	4
Otter Brook	11778	±1,780	0.79	3
Sunkhaze Stream	5001	± 316	0.65	5
Turner Brook	2907	± 323	0.92	2
Presque Isle Stream 2	859	± 94	0.54	6
Presque Isle Stream 1	232	± 19	0.43	8
Presque Isle Stream 3	46	± 57	0.49	7
E. Branch Piscatiquis	0	--	0.00	9
Pollard Brook	0	--	0.95	1

Probability of correlation = 0.82

Table 5. Rank correlation between Atlantic salmon HSI's, parr component (C_{parr}) SI's, and summer population densities in three streams.

	HSI	fry and parr/100 m²	C_{parr}	parr/100 m²
Old Stream	0.97	117.7	0.89	93.4
Bowles Brook	0.84	66.0	0.88	45.5
Pollard Brook	0.83	32.0	0.84	26.8
Probability of correlation =	0.83		0.83	

Table 6. Rank correlations between blacknose dace HSI's and population densities in five stream sections.

Stream	No./ha	HSI
E. Branch Piscatiquis	4162	0.3
Presque Isle Stream 1	3667	0.1
Presque Isle Stream 2	3206	0.1
Presque Isle Stream 3	2710	0.1
Pollard Brook	18	0.1
Probablity of correlation = 0.60		

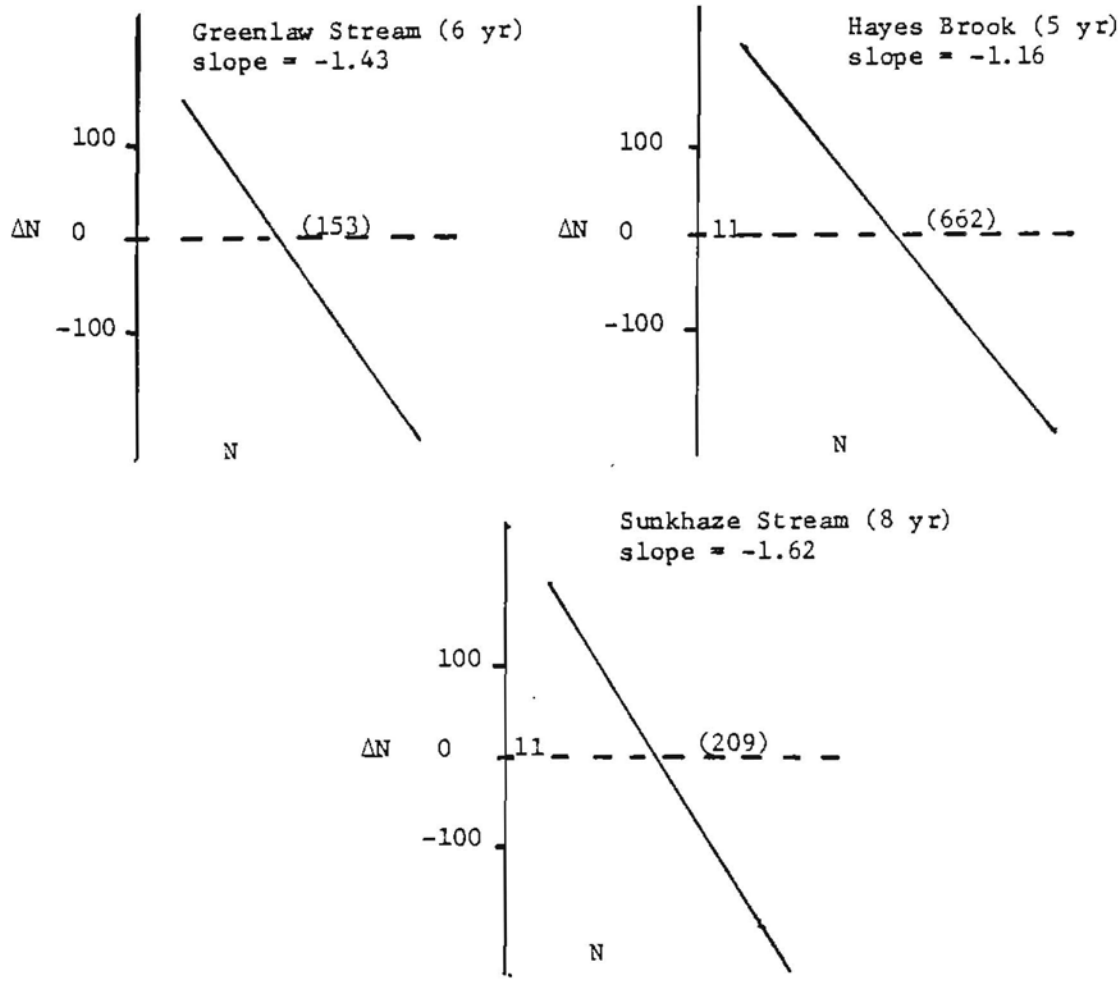

Figure 1. Moran diagrams based on annual brook trout density (number/ha) estimates in three streams. The number of years in the data series follows the stream name. Slopes of the lines relating density fluctuations ($\Delta N = n_t - n_{t+1}$) and density ($N = n_{t+1}$) are between -1 and -2, indicating that annual densities oscillate about an equilibrium. The dotted line is a reference ($\Delta N = 0$), and the density (N) where the solid line crosses the dotted line is noted.

in these cases. All the models tested had some variables that were interrelated; e.g., thalweg depth and average temperature. The extra weighting placed on colinear variables may not be justified.

Results of tests of HSI models may be significantly affected by season because habitat changes, carrying capacity varies (Fretwell 1972), and fish populations move. Test results may depend heavily on where and when variable and fish density measurements are made. In this study, the models were tested using transect data gathered during one visit during the summer to each of several streams. Values for depth, velocity, substrate, and cover varied among the transects sampled, and data interpolation was required before a value needed for a different season could be determined.

Temperature, pH, alkalinity, and dissolved oxygen in the stream sections tested were generally within the optimum range for the fish species involved. However, the data could not be used directly in the models because annual averages, maximums, or minimums were needed for the SI curves. Observations from other streams and information obtained from local State biologists were subjective but sometimes necessary in order to estimate values for the variables flow regime, maximum temperature, minimum dissolved oxygen, and minimum pH. For example, the minimum pH that might have occurred during spring runoff was predicted for low alkalinity streams. Such estimates and data interpretations introduced uncertainty into the SI's assigned to some variables.

Although the brook trout and Atlantic salmon model outputs were significantly correlated with standing crop ranks, the models can be improved. Some of the variables believed important for these species were not included in the models. Upwelling for spawning and alkalinity as a determinant of productivity are important for brook trout. The Atlantic salmon model does not include a component for adult holding areas, even though they are necessary for successful reproduction.

The blacknose dace model did not accurately predict species presence. Problems with three model variables are probably responsible for its failure. The narrow range for spawning temperature considered suitable on the SI curve may have resulted in an underestimate of the reproductive component value in the stream sections tested. The adult velocity curve seems to be unrealistic. The maximum temperature SI curve and the aggregation of the variable in the HSI model does not account for the ability of blacknose dace to find refugia or otherwise avoid unsuitable temperatures for part of the year or within part of the stream. The SI curves were modified before publication (Trial et al. 1983a, 1983b, 1983c).

The fallfish model was not tested against population densities because none of the stream sections studied contained this species. In addition, it is unrealistic to expect a model to predict the presence or absence of a generalist, such as the fallfish, because even habitats where the species is absent are likely to have an unrealized potential for supporting the species. This model should be tested at sites known to contain fallfish. The common shiner model should also be tested in streams with resident populations.

HSI models are used in HEP as if they were a linear index of potential carrying capacity, based on the physical and chemical characteristics of a habitat. Biological interactions were not included in the tested models. Carrying capacity is a characteristic of an environment, not a population. However, population densities at equilibrium are an indication that the limits of growth for that environment have been attained. If the population being measured is fluctuating about equilibrium, average population densities derived from several years of data may present a more accurate estimate of the carrying capacity of a stream than a single density estimate. However, approximations of equilibrium density include the influence of predation, competition, nutrition, and environmental stability and do not represent the potential carrying capacity defined by the physical and chemical environment. A single estimate of standing crop or even an average for several years may not represent the actual carrying capacity.

Acceptable model output in this study was based on an association between the highest HSI's and the highest population estimates when the HSI's and species density estimates were ranked for a stream section. A higher probability of making an incorrect decision (alpha = 0.20) than usual in research was accepted in this study.

A more realistic acceptability level would have been if the rankings of stream sections based on HSI's were comparable to rankings based on equilibrium densities (average density over several years). Moran diagrams demonstrating that population cycles are damped about an equilibrium need to be produced before averages are accepted as estimates of a population equilibrium. This approach will be used to test modified models for brook trout and Atlantic salmon. However, model outputs may need to be redefined, perhaps including measures of growth, condition, and age structure, as well as density. Without the necessity of finding a measure of potential carrying capacity, scientific testing of models would be easier.

The objective of HSI model development is to help predict how changes in the physical and chemical characteristics of a habitat, resulting from development projects, will affect potential carrying capacity and, by inference, populations. Testing the ability of a model to perform this task requires the calculation of HSI's for potentially impacted areas before, during, and after project construction and a comparison of these HSI's with concurrent population data that accurately represent equilibrium densities. This type of testing needs to be done.

CONCLUSIONS

Habitat suitability index models for fish are assumed to be representations of the carrying capacity of the habitat. Therefore, models are valid when they are based on adequate field data that relate standing crop to the relevant environmental measurements. The ability of some of the HSI models tested in this study to rank population data suggests that they may be valid predictors of present and future carrying capacity, during and after water development projects.

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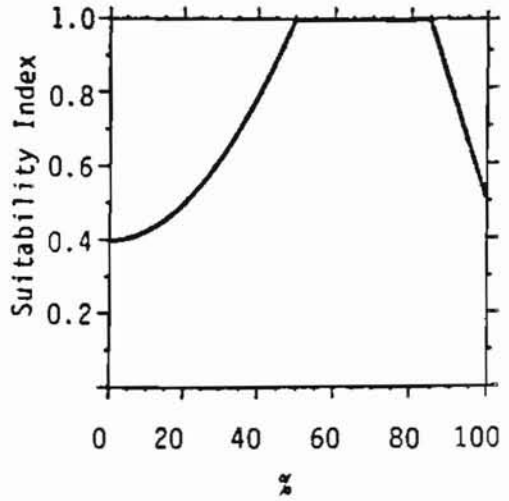
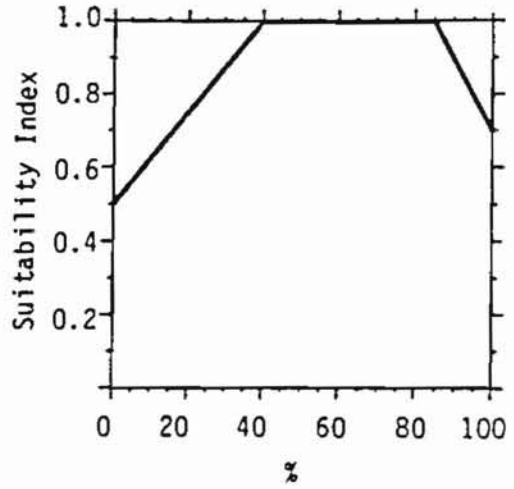
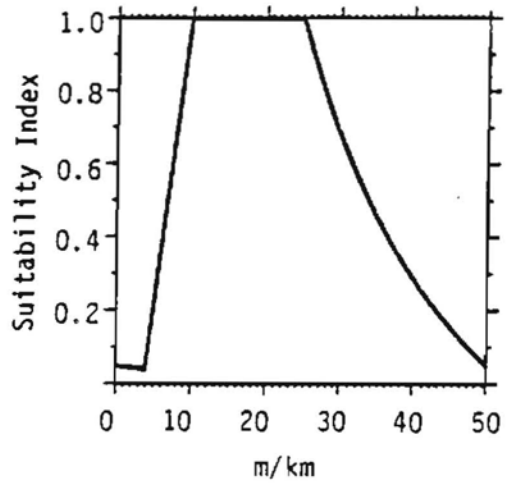
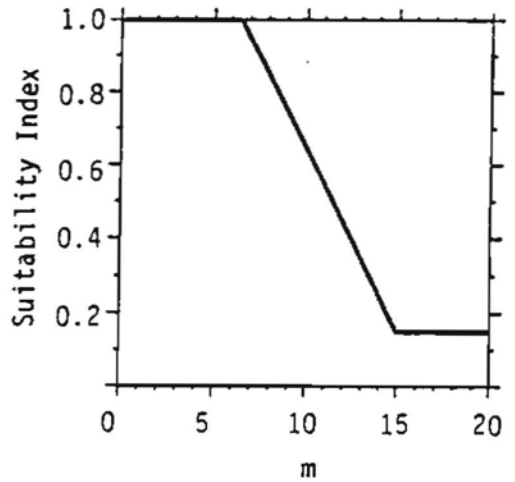
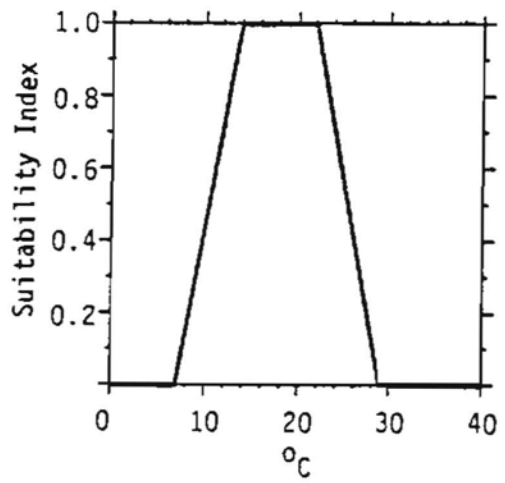
APPENDIX A

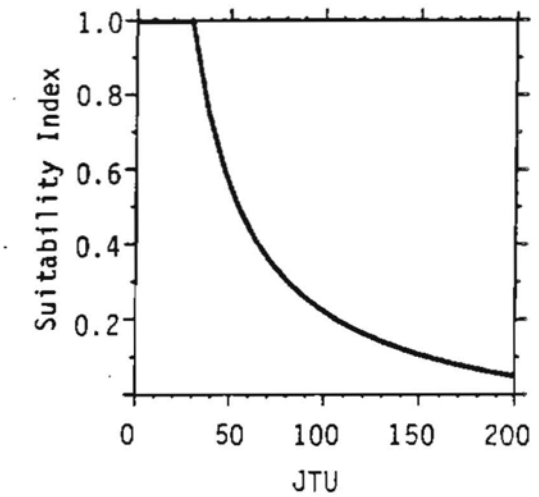
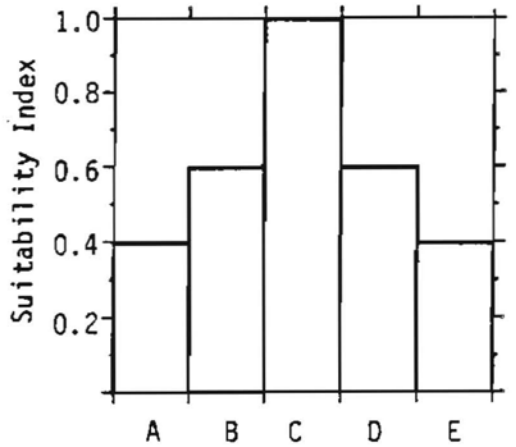
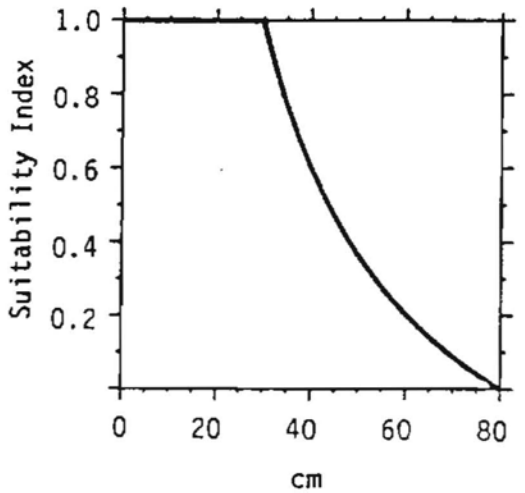
SUITABILITY INDEX GRAPHS AND HABITAT SUITABILITY INDEX MODELS FOR TESTED SPECIES

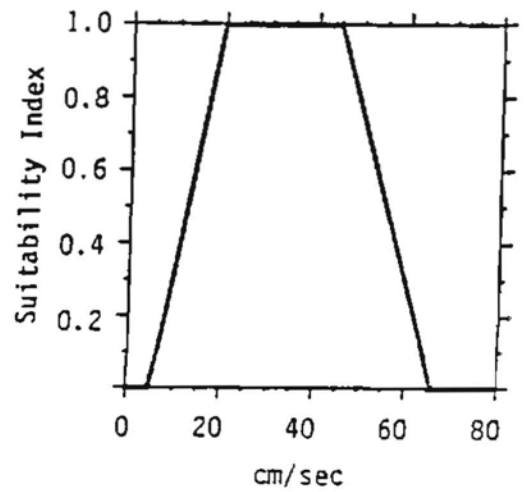
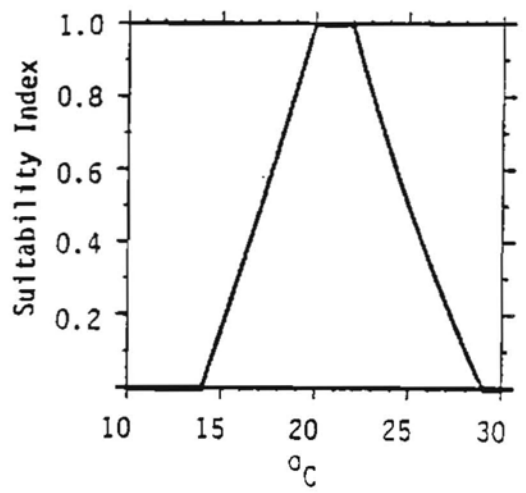
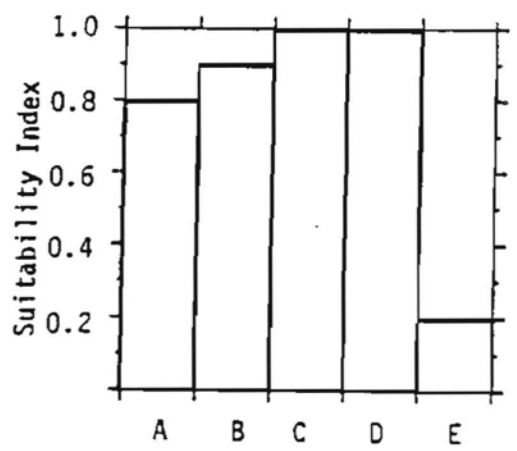
Suitability Index (SI) Graphs for Blacknose Dace Model Variables

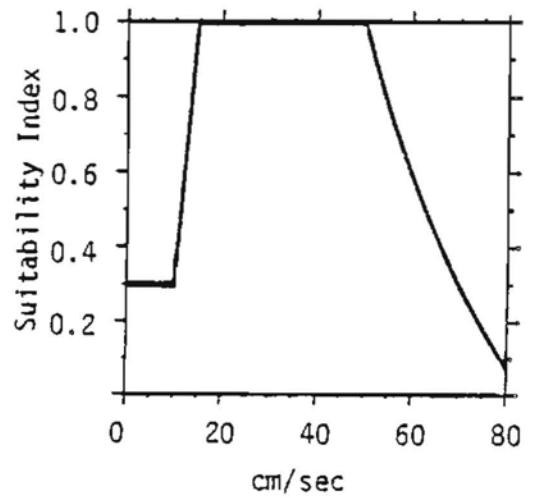
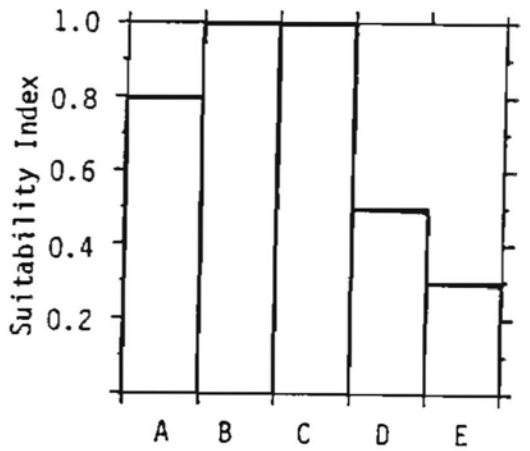
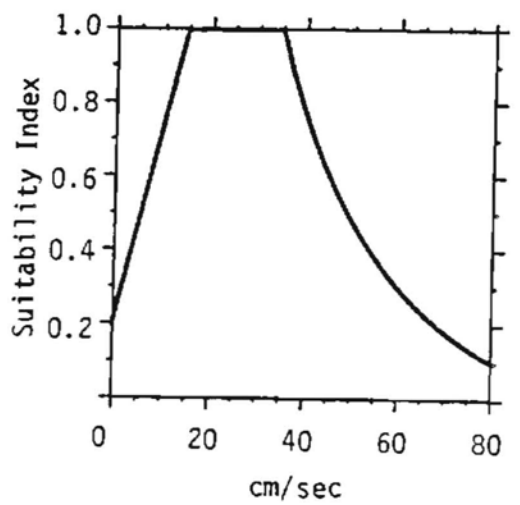
Suitability index graphs for the 16 variables in the model descriptions pertain to riverine (R) or lacustrine (L) habitats, or both.

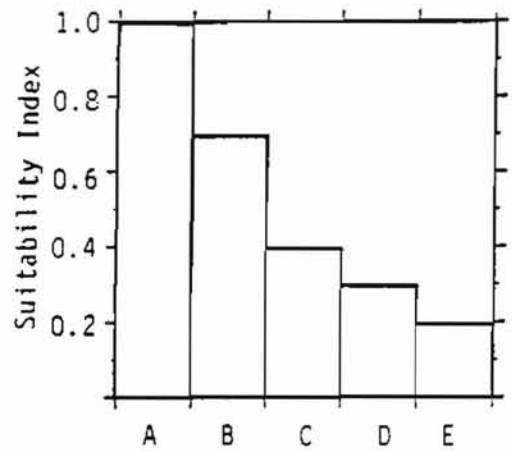
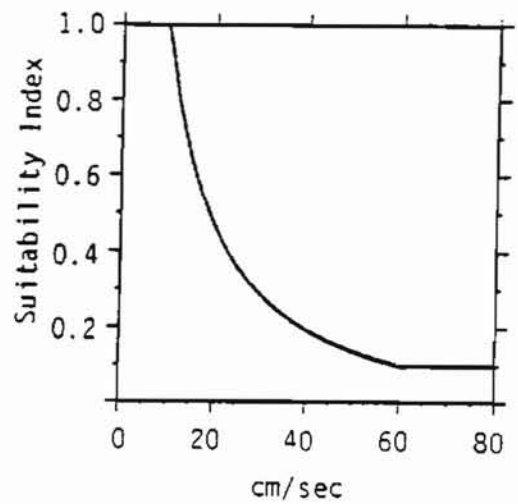
Habitat	Variable		Suitability graph
R	V_1	Percent stream area shaded.	
R	V_2	Percent pools.	

Habitat	Variable		Suitability graph
R	V_3	Stream gradient.	
R	V_4	Stream width.	
R,L	V_5	Maximum temperature.	

Habitat	Variable		Suitability graph
R,L	V_6	Turbidity.	
R	V_7	Dominant substrate in riffles. A. Mud, silt, sand, and debris B. Pebble C. Gravel D. Cobble E. Boulder and bedrock	
R	V_8	Stream depth in spawning riffles.	

Habitat	Variable		Suitability graph
R	V_9	Velocity in riffles.	
R	V_{10}	Temperature during spawning (May-July).	
R	V_{11}	Dominant substrate in pools and slow channels (Adult). A. Mud, silt, sand, and debris B. Pebble C. Gravel D. Cobble E. Boulder and bedrock	

Habitat	Variable		Suitability graph
R	V_{12}	Average velocity in pools and slow channels (Adult).	
R	V_{13}	Dominant substrate in stream riffles (Juvenile). A. Mud, silt, sand, and debris B. Pebble C. Gravel D. Cobble E. Boulder and bedrock	
R	V_{14}	Velocity in riffles (Juvenile).	

Habitat	Variable		Suitability graph
R	V_{15}	Dominant substrate along stream margins (Fry). A. Mud, silt, sand, and debris B. Pebble C. Gravel D. Cobble E. Boulder and bedrock	
R	V_{16}	Velocity along stream margins (Fry).	

Riverine Model

Food-Cover (C_{F-C}).

$$C_{F-C} = \frac{V_1 + V_2 + V_3 + V_4}{4}$$

Or, if any value ≤ 0.4, $C_{F-C} = V_1$, V_2, V_3, or V_4, whichever is lowest.

Water Quality (C_{WQ}).

$$C_{WQ} = (V_5^2 \times V_6)^{1/3}$$

Or, if any value ≤ 0.4, $C_{WQ} = V_5$ or V_6, whichever is lowest.

Reproduction (C_R).

$$C_R = \frac{(V_7 \times V_8 \times V_9^2)^{1/4} + V_{10}}{2}$$

Or, if any value ≤ 0.4, $C_R = V_7$, V_8, V_9, or V_{10}, whichever is lowest.

Adult (C_A).

$$C_A = (V_{11} \times V_{12})^{1/2}$$

Or, if any value ≤ 0.4, $C_A = V_{11}$ or V_{12}, whichever is lowest.

Juvenile (C_J).

$$C_J = (V_{13} \times V_{14})^{1/2}$$

Or, if any value ≤ 0.4, $C_A = V_{13}$ or V_{14}, whichever is lowest.

Fry (C_F).

This is an optional component.

$$C_F = (V_{15} \times V_{16})^{1/2}$$

Or, if any value ≤ 0.4, $C_A = V_{15}$ or V_{16}, whichever is lowest.

HSI determination.

$$\text{Species HSI} = \frac{(C_{F-C} \times C_{WQ})^{1/2} \times (C_A \times C_J \times C_F)^{1/n} + C_R}{2}$$

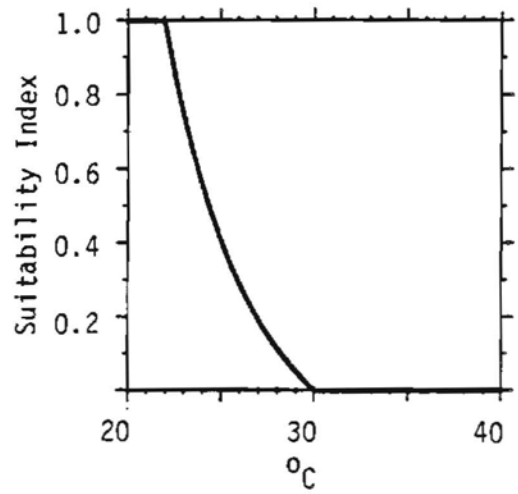
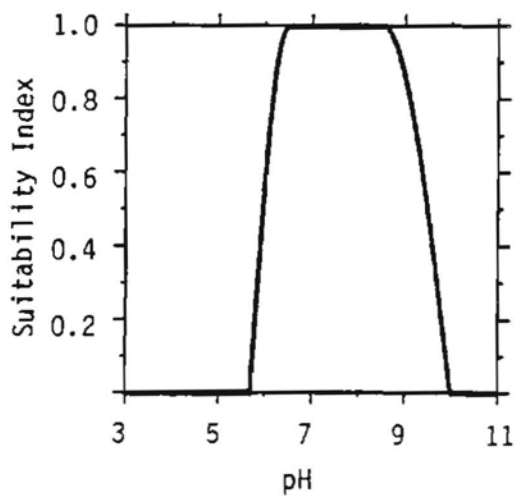
Or, if any component ≤ 0.4, the HSI = C_{F-C}, C_{WQ}, C_R, C_A, C_J, or C_F, whichever is lowest.

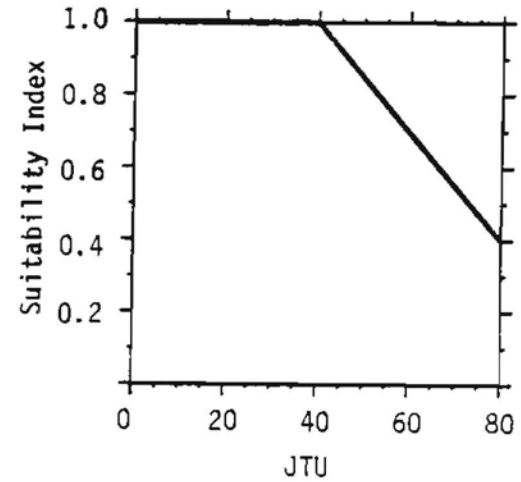
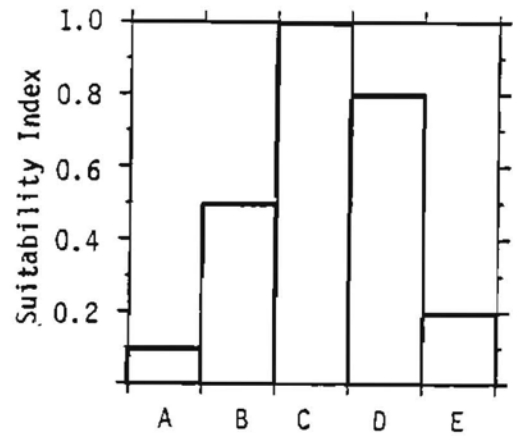
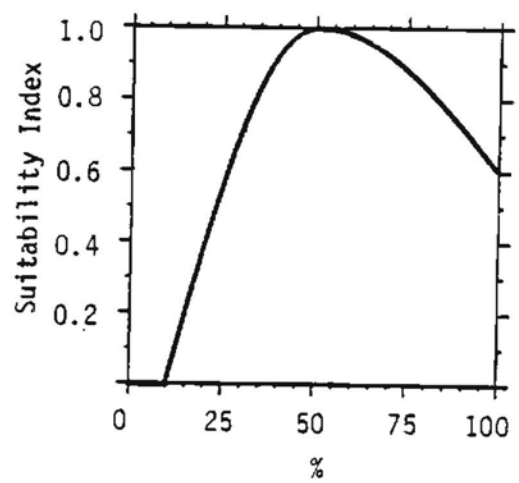
C_A, C_J, and C_F are optional; n = number of components in parentheses.

$$\text{Life stage HSI} = C_{F-C} \times C_{WQ} \times C_{\text{appropriate life stage}}$$

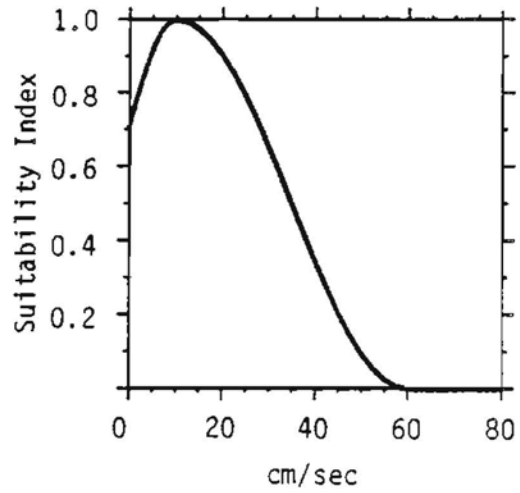
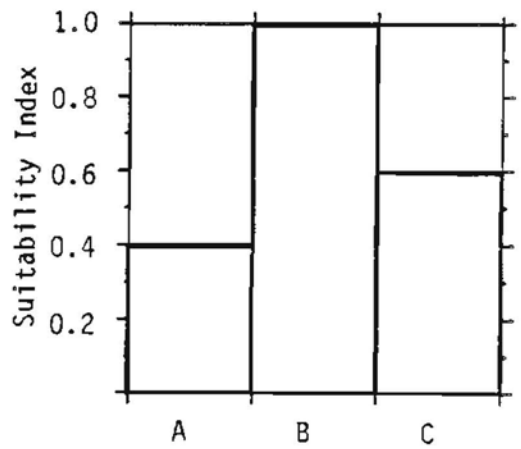
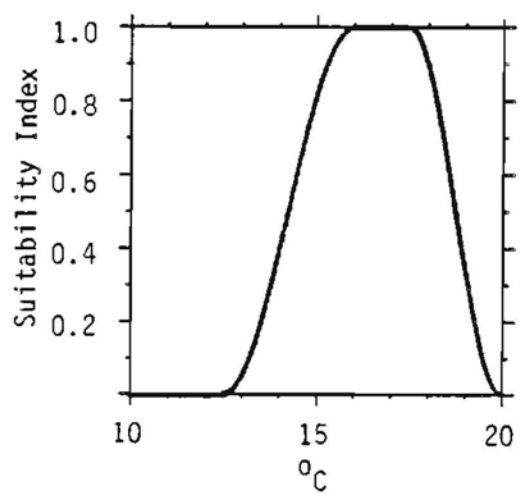
Suitability Index (SI) Graphs for Common Shiner Model Variables

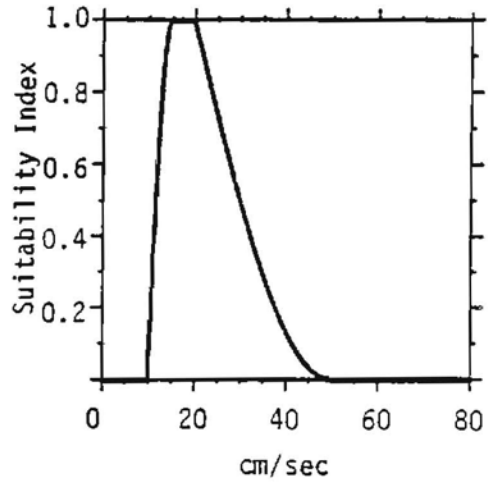
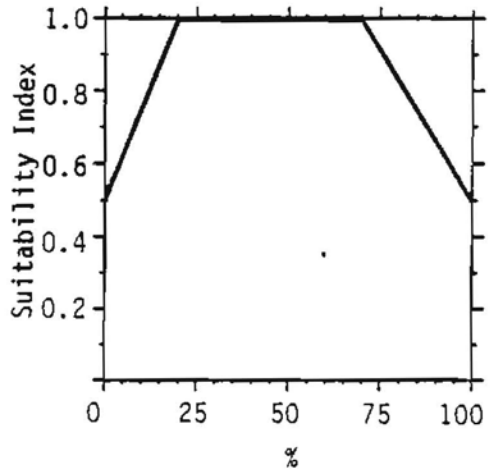
Suitability index graphs for the 10 variables discussed in the model description pertain to riverine (R) or lacustrine (L) habitat, or both.

Habitat	Variable		Suitability graphs
R,L	V_1	Maximum summer temperature persisting for longer than 1 week.	
R,L	V_2	Least suitable pH level occurring during the year.	

Habitat	Variable		Suitability graphs
R,L	V_3	Average turbidity.	
R,L	V_4	Predominant substrate type in riffles or windy shore or shoal. A. Mud, silt, and detritus B. Fine sand C. Sand and gravel D. Rubble E. Large rocks and bedrocks	
R	V_5	Percent pools.	

Note: The area must be on a windy shore or shoal for the lactustrine model.

Habitat	Variable		Suitability graphs
R	V_6	Average current velocity at 60% of depth in pools.	
R	V_7	Predominant pool class. A. Large and deep, "deadwater" pool found at mouths of streams. B. Moderate size and depth, commonly found below falls of riffle-run areas; 5-30% of bottom obscured by depth or turbulence. C. Small or shallow or both, no surface turbulence and little structure.	
R,L	V_8	Average water temperature (°C) in spawning habitat during months of spawning.	

Habitat	Variable		Suitability graphs
R	V_9	Average current velocity just above substrate in riffle areas.	
L	V_{10}	Percent lake area vegetated.	

Riverine Model

The riverine model utilizes the life requisite approach and consists of three components: food-cover; water quality; and reproduction.

Food-Cover (C_{F-C}).

$$C_{F-C} = \frac{V_4 + V_5 + V_6 + V_7}{4}$$

Or, if any variable ≤ 0.4, $C_{F-C} = V_4$, V_5, V_6, or V_7, whichever is lowest.

Water Quality (C_{WQ}).

$$C_{WQ} \ (V_1 \times V_2 \times V_3)^{1/3}$$

Or, if any variables ≤ 0.4, $C_{WQ} = V_1$, V_2, or V_3, whichever is lowest.

Reproduction (C_R).

$$C_R = (V_8^2 \times V_4 \times V_9)^{1/4}$$

Or, if any variable ≤ 0.4, $C_R = V_4$, V_8, V_9, or C_R, whichever is lowest.

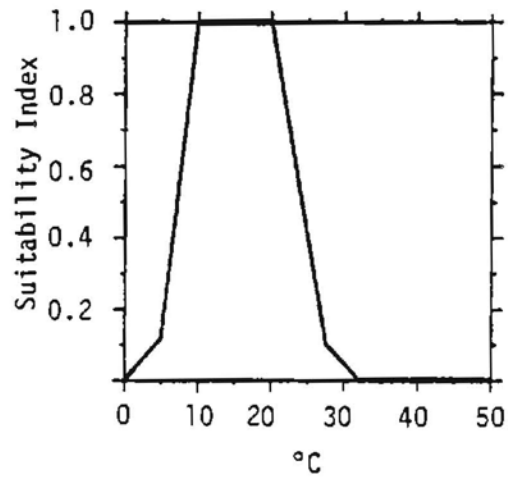
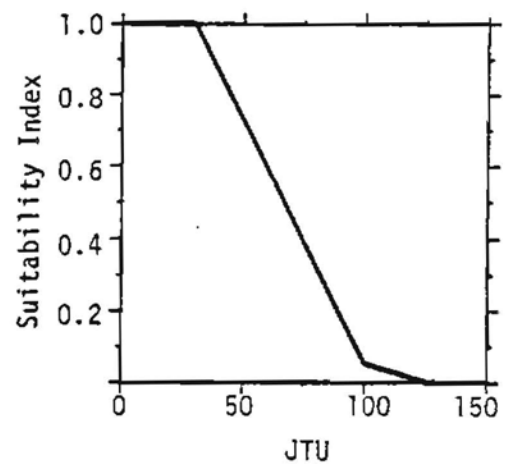
HSI determination.

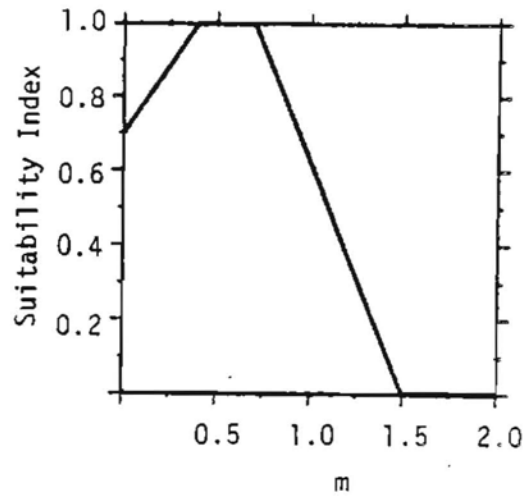
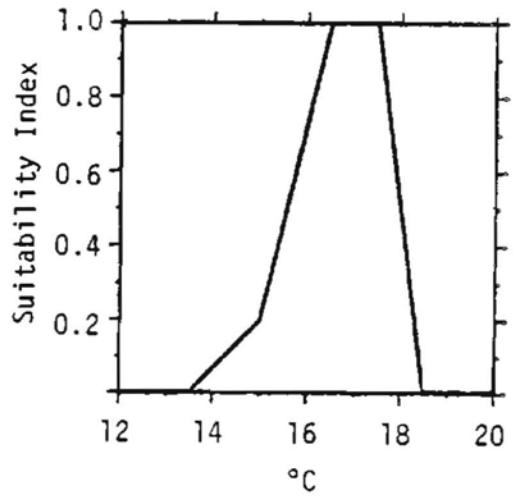
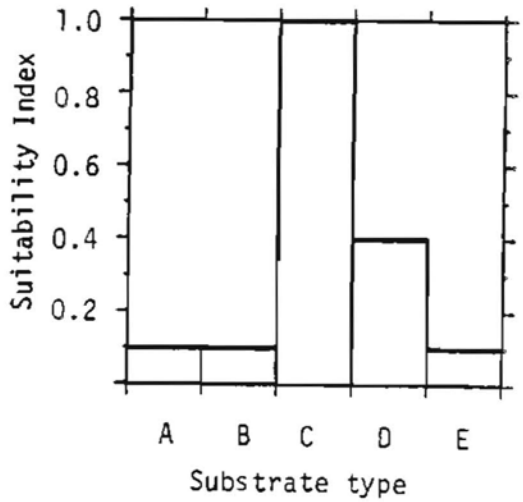
If the value for any component ≤ 0.4, the HSI = the minimum component value. Otherwise,

$$HSI = (C_{F-C} \times C_{WQ} \times C_R)^{1/3}$$

Suitability Index (SI) Graphs for Fallfish Model Variables

Suitability index graphs for the five variables discussed pertain to riverine (R) or lacustrine (L) habitats, or both.

Habitat	Variable		Suitability graphs
R,L	V_1	Average temperature during warmest time of year (in lakes - epilimion, in rivers - main channel).	
R,L	V_2	Average turbidity.	

Habitat	Variable		Suitability graphs
R	V_3	Mode of water depth measurements taken at 1/4, 1/2, and 3/4 distance across stream.	
R	V_4	Least suitable temperature during the spawning season.	
R	V_5	Predominate substrate type in streams. A. Mud, silt, and detritus B. Fine sand C. Sand and gravel D. Rubble E. Large rocks and bedrock.	

Riverine Model

The riverine model has water quality and reproductive components.

Water Quality (C_{WQ}).

$$C_{WQ} = (V_1 \times V_2)^{1/2}$$

or, if any value ≤ 0.4, then C_{WQ} = the lowest of V_1 or V_2.

Reproductive (C_R).

$$C_R = (V_3 \times V_4 \times V_5)^{1/3}$$

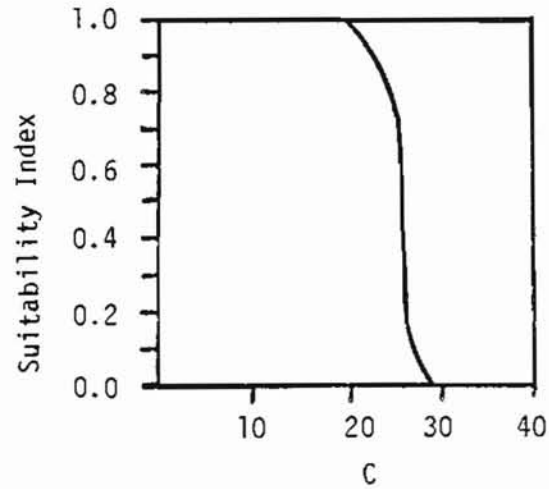
or, if any value ≤ 0.4, then C_R = lowest of V_3, V_4, or V_5

$$HSI = \frac{C_{WQ} + C_R}{2}$$

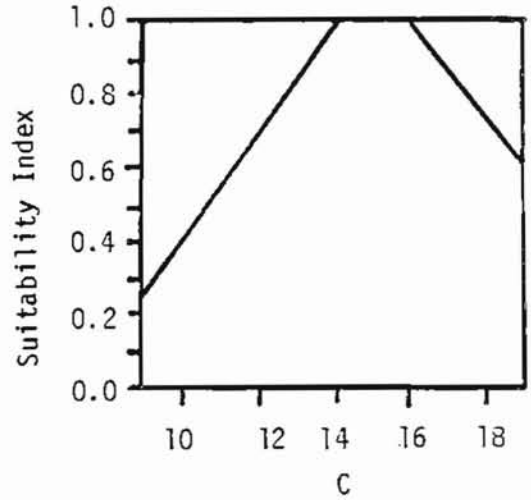
Suitability Index (SI) Graphs for Atlantic Salmon Model Variables

Suitability index graphs for the 18 variables discussed pertain to riverine (R) habitats.

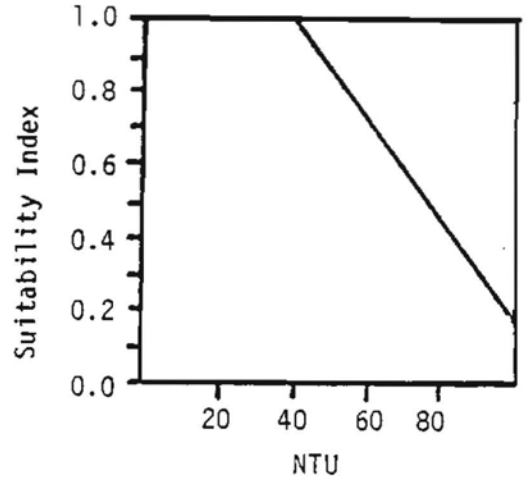
Habitat	Variable		Suitability graphs
R	V_1	Maximum temperature.	



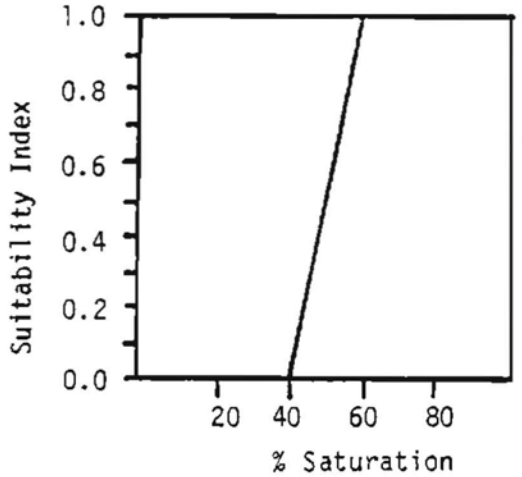
R	V_2	Average temperature.	



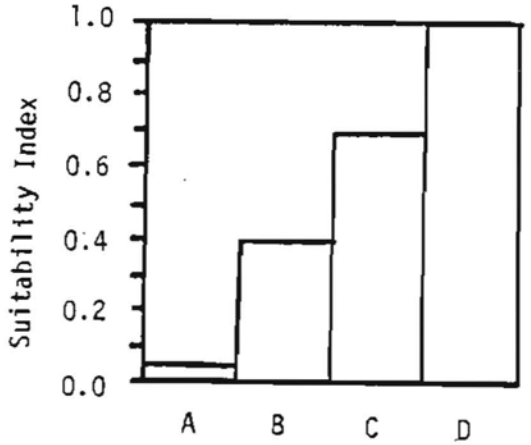
Habitat	Variable		Suitability graphs
R	V_3	Average turbidity.	

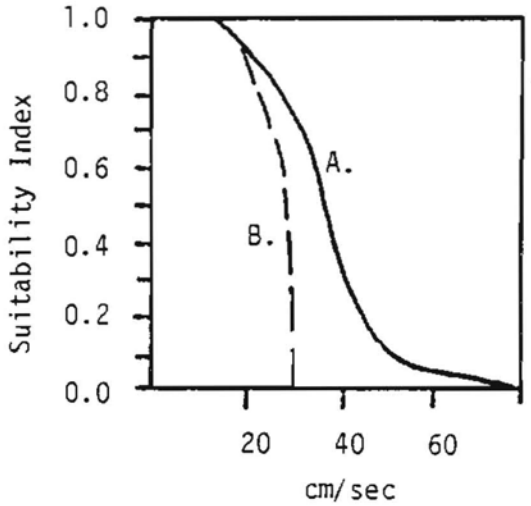
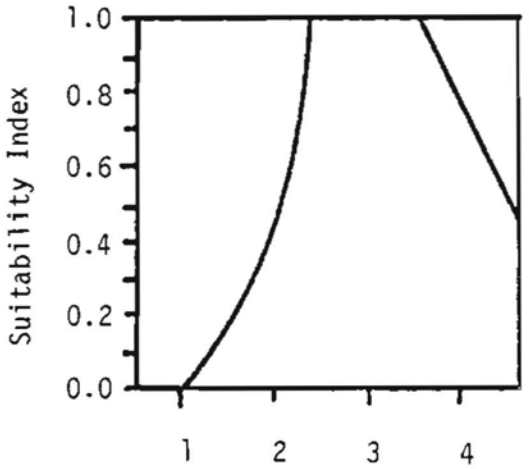
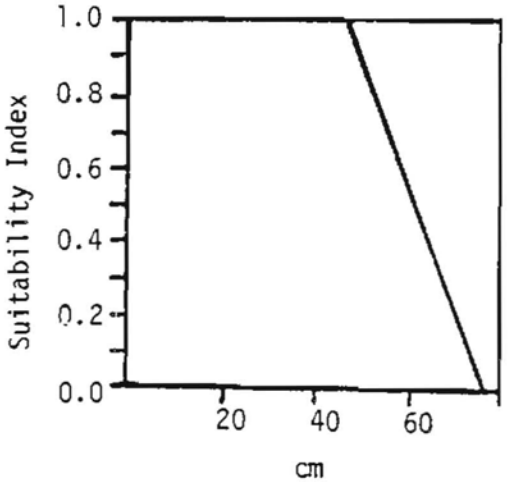


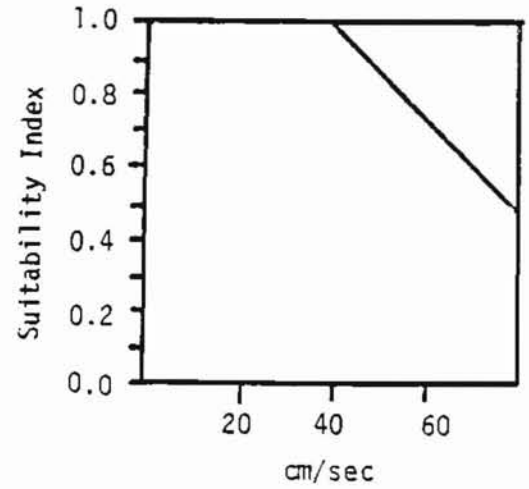
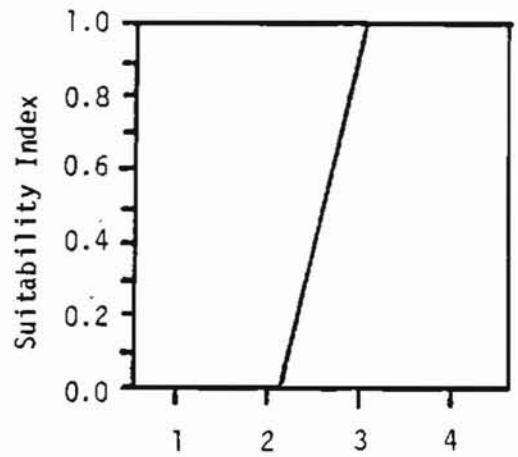
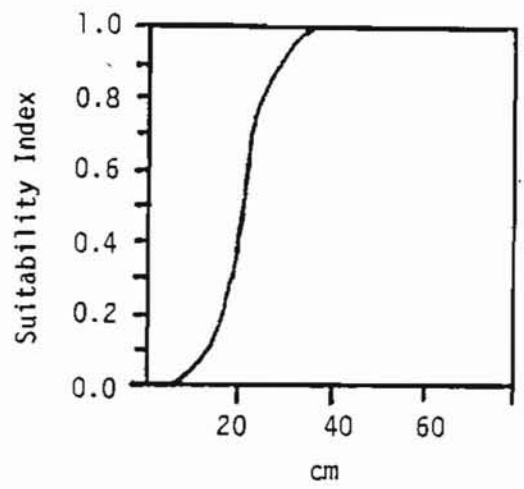
R	R_4	Minimum oxygen.



R	V_5	Minimum pH. A. pH frequently falls below 4.0 B. pH frequently falls below 5.5 but not 4.0 C. pH seldom falls below 5.5 D. Minimum pH fluctuates between 5.5 and 6.8

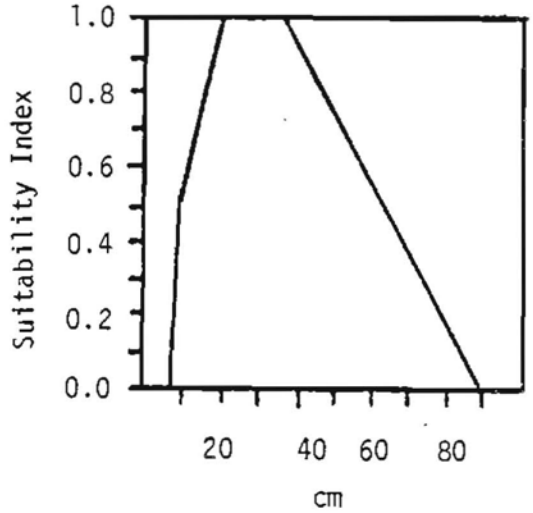


Habitat	Variable		Suitability graphs
R	V_6	Velocity (near bottom). A. Average pH ≥ 4.5 B. Average pH < 4.5	
R	V_7	Predominant substrate. 1. Fines (< 0.5 mm) 2. Sand (0.5-2.2 mm) 3. Pebble/gravel (2.2-22.2 mm) 4. Cobble (22.2-25.6 mm)	
R	V_8	Depth	

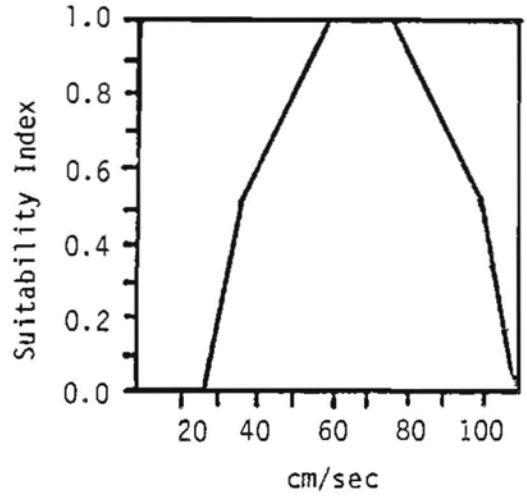
Habitat	Variable		Suitability graphs
R	V_9	Velocity.	
R	V_{10}	Predominant substrate. 1. Fines (< 0.5 mm) 2. Sand (0.5-2.2 mm) 3. Pebble/gravel (2.2-22.2 mm) 4. Cobble (22.2-25.6 mm)	
R	V_{11}	Depth.	

Habitat	Variable		Suitability graphs
R	V_{12}	Depth (reproduction).	

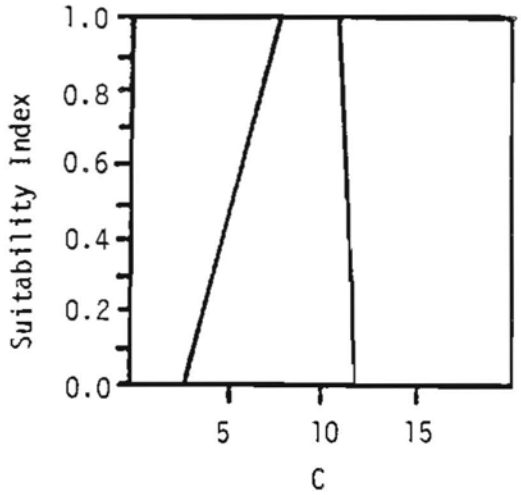
Note: Evaluate only if substrate is 2.2 mm to 256 mm in size and 15 cm deep at the head or tail of pools.

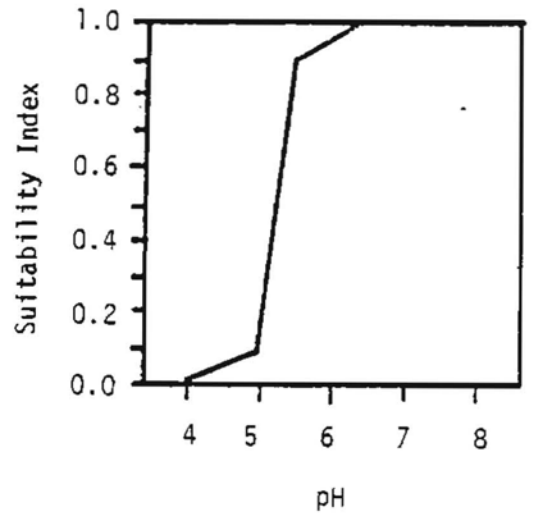
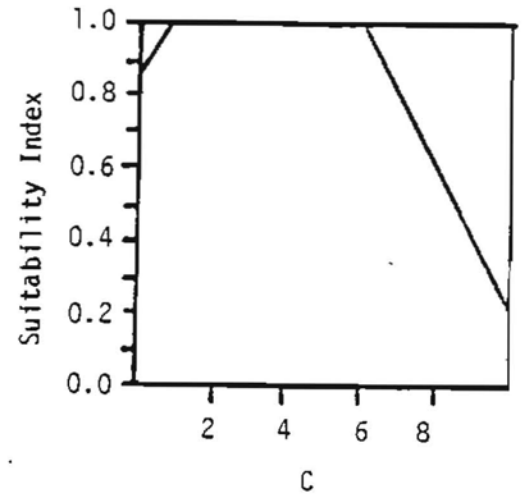
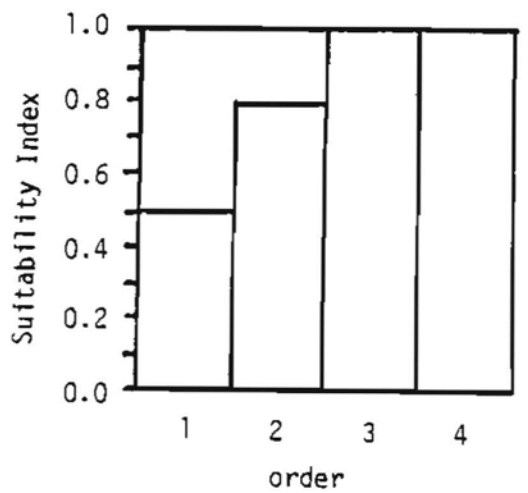


R V_{13} Velocity.

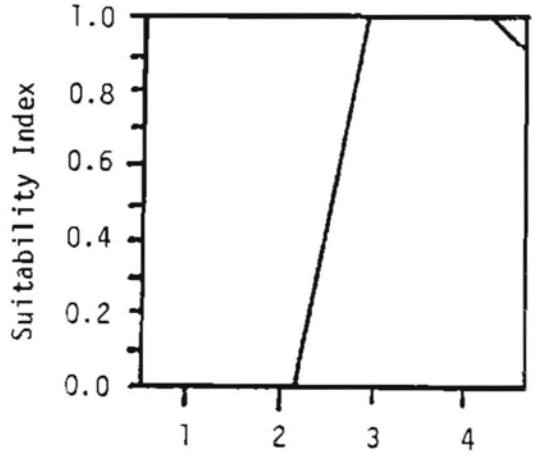


R V_{14} Spawning temperature.



Habitat	Variable		Suitability graphs
R	V_{15}	Minimum pH in fall and winter.	
R	V_{16}	Embryo incubation temperature (winter).	
R	V_{17}	Stream order.	

Habitat	Variable		Suitability graphs
R	V_{18}	Predominant substrate. 1. Fines (< 0.5 mm) 2. Sand (≥ 0.5 mm < 2.2 mm) 3. Pebble/gravel (≥ 2.2 mm < 22.2 mm) 4. Cobble (≥ 22.2 mm ≤ 25.6 mm)	



Water Quality Component

$$C_{WQ} = \text{lowest of } V_1, V_2, V_3, V_4, \text{ or } V_5$$

Fry Component

$$C_{Fry} = (V_6 \times V_7 \times V_8)^{1/3}$$

Parr Component

$$C_{Parr} = (V_9 \times V_{10} \times V_{11})^{1/3}$$

Reproductive Component

$$C_R = \text{Lowest of } (V_{12} \times V_{13} \times V_{18})^{1/3}, V_{14}, V_{15}, V_{16}, \text{ or } V_{17}$$

Species HSI

If any component value is less than 0.4, then:

$$HSI = \text{lowest of } (C_{WQ}, C_{Fry}, C_{Parr}, C_R)$$

Otherwise:

$$HSI = (C_{WQ} \times C_{Fry} \times C_{Parr} \times C_R)^{1/4}$$

ASSESSMENT OF HABITAT QUALITY MODELS FOR CUTTHROAT TROUT (*SALMO CLARKI CLARKI*) AND COHO SALMON (*ONCORHYNCHUS KISUTCH*) FOR OREGON'S COASTAL STREAMS

by

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INTRODUCTION

Habitat Suitability Index (HSI) models, published by the U.S. Fish and Wildlife Service, use quantitative estimates of physical habitat characteristics (e.g., temperature, current, and substrate composition) to determine habitat quality for species of fish. The models do not include biological variables, such as disease, competition, and predation, that may be important in determining fish population levels at a specific point in time. This study was designed to: (1) test the hypothesis that interspecific competition for space from coho salmon and steelhead trout is an unimportant factor in determining the suitability of habitat for cutthroat trout; and (2) test whether or not it is possible to predict empirically-derived HSI's for reaches of streams in different drainages for cutthroat trout and coho salmon from Suitability Indices (SI's) derived from an independent drainage. Coho salmon are known to be competitively dominant over steelhead trout (*Salmo gairdneri*) and cutthroat trout (Hartman 1965; Allee 1974).

OBJECTIVES

The objectives of this study were to:

1. Compare SI curves (profiles) of selected habitat variables thought to be important to coho salmon and cutthroat trout with SI curves derived from an independent data set. These curves were from draft species narratives prepared by the Habitat Evaluation Procedures Group (HEPG, Western Energy and Land Use Team, U.S. Fish and Wildlife Service).

2. Build profiles for important variables not incorporated in the draft narratives of species habitat requirements developed by the HEPG.

3. Compare the HSI's derived from four different experimental approaches (Average Value Method; Most Limiting Factor Method; Interactive Limiting Factor Method; and Discriminant Analysis) with HSI's derived empirically by dividing observed standing crops by maximum standing crops.

METHODS

Drainage Descriptions

SI curves for coho salmon and cutthroat trout were developed independently from survey data from Elk Creek and Bear Creek of the Nestucca Drainage, Tillamook County, Oregon (R. House unpubl. data, Salem District Office, Bureau of Land Management, P.O. Box 3227, Salem, OR 97302). The climate in this area is maritime. Fifty percent of the area has been logged within the past 15 years. The land is unstable and 42% of the banks of Bear Creek have been classified as being in poor condition. Both creeks have barriers to the upstream movement of fishes. Below the barriers, cutthroat trout are sympatric with coho salmon and steelhead trout. Above the waterfall in Elk Creek, cutthroat trout are resident, and a few coho salmon have been experimentally stocked. Steelhead trout are absent. Steelhead trout are sympatric with cutthroat trout, but coho salmon are absent, from above the logjam in Bear Creek.

Different approaches to calculating HSI's were tested on the Smith, South Coos, and Coquille drainages, using data from Duke and Bond (1981). Table 1 displays the range of variable values used to derive the HSI's for these three southcentral coastal Oregon drainages and the Nestucca drainage.

The Smith River drainage has been logged extensively. The river's substrate is characterized by a high percentage of bedrock (Duke and Bond 1981), an outcome of using the stream as a logging chute. The natural retainers of gravel have been eliminated and the substrate blown out during winter spates (J. Sidell, pers. comm., Assoc. Prof., Forest Sciences Laboratory, Oregon State University). The South Fork of the Coos River is a high gradient stream system, characterized by a high percentage of sandstone bedrock (Duke and Bond 1981). The Coquille drainage is a low gradient system that flows over pasture lands. Many streams in this system are characterized by canopies of deciduous hardwoods and conifers that provide dense shade. Fallen timber is present throughout at least one of the streams (Steele Creek), creating pool habitats.

Table 1. Range of variable values for the Smith, South Coos, Coquille, and Nestucca drainages.

Variable	Drainage			
	Smith	South Coos	Coquille	Nestucca
pH	5.4-6.6	6.2-6.5	5.8-6.6	7.1-8.9
Dissolved oxygen (mg/l)	4.0-14.0	9.0-12.0	10.0-12.5	9.2-10.6
Temp. (max.-min. °C)	21.0-8.5	19.0-13.0	20.0-11.0	27.0-10.0
Channel width (m)	1.81-9.97	7.52-15.48	2.69-7.52	5.2-6.5
Discharge (m^3/sec)	0.00-0.11	0.05-0.14	0.01-0.04	0.03-0.20
Species				
Salmo clarki	+[a]	+	+	+
S. gairdneri	+	+	+	+
Onchorhynchus kisutch	+	+	+	+
O. tshawytscha	-[b]	+	+	-
Ptychocheilus umpquae	+	-	-	-
Richardsonius balteatus	+	+	-	-
Rhinichthys evermanni	+	-	-	-
R. cataractae	-	+	-	-
R. osculus nubilis	+	+	+	-
Gasterosteus aculeatus	-	+	+	-
Catostomus macrocheilus	+	+	-	-
Cottus gulosus	+	+	-	?
C. perplexus	+	+	+	?
C. asper	+	-	-	?
C. aleuticus	-	-	+	?

[a] + = species present in drainage.

[b] - = species absent in drainage.

Data Collection

The analysis was designed to test the potential impact of interspecific interactions on the Suitability Indices (SI's). The natural stream barriers (logjams and waterfalls) made it possible to test differences in habitat utilization (as represented by SI curves) by the selected species when sympatric with potential competitors and in allopatric situations. The problem of interspecific competition among these species was considered when predicting HSI's for different drainages of the southcentral Oregon coast based on the regional SI curves developed from the Nestucca system.

One hundred reaches were sampled from two sites in the Nestucca drainage (House unpubl. data), and 29 reaches were sampled from 11 sites on three or four dates from the southcentral Oregon coastal drainages (Duke and Bond 1981). A removal estimate of the population was used in all of the reaches sampled. Technique differences between the two studies occurred in rating instream cover, substrate categories, breakdown of microhabitat types, the number of reaches where all physical data were taken, and the determination of water velocity. For example, House's (unpubl. data) measurements of stream velocity were based on surface drift of a neutrally bouyant object; Duke and Bond's (1981) measurements of velocity were made 0.4 of the total depth from the stream bottom with a Gurley Pygmy flow meter. Empirically derived HSI's for the study sites and a list of variables that were measured are presented in Appendices A and B.

Testing of Suitability Indices

The accuracy of the SI's were tested in two ways: (1) SI's for selected variables were calculated from SI graphs (Appendix C) presented in draft manuscripts prepared by the HEPG and compared to SI's developed from the data collected in the Nestucca drainage; and (2) SI's for selected variables from different streams of the Nestucca drainage were compared as a second test of general model applicability. The highest performance in terms of standing crop (fish/m^2) from either Bear Creek or Elk Creek was used to convert values for individual variables into SI's, as described under method 1 in the U.S. Fish and Wildlife Service's HSI model manual (1981). The data were considered together because the two streams are part of the same drainage. Thus, an SI of 1.0 was used only for the site that had the highest standing crop.

The SI's were developed from the survey data based on the assumption that extremes (maximum population levels), rather than average population levels, represent the ability of a species to perform for a given value of a variable. This assumption is based on the conceptual framework of Performance Capacities (Schreck 1981). The SI for the species was defined by connecting a line through the highest values (standing crops) on the ordinate (y-axis or dependent variable) for corresponding values along the abscissa (x-axis or independent variable). The scatter of points below the line that defines the Suitability Index (performance capacity) presumably represents both individual variation within a population and the multivariate response of a species to a host of factors not accounted for in a bivariate analysis. The consideration of multivariate response is important. SI's presented in a bivariate graph should ideally represent data where all factors are kept constant except for

the specific factor under study. Unfortunately, many data for SI's, including the data in this study, are gathered from the field, and the natural environment is not usually uniform in the distribution of physical elements. Thus, a data point on a bivariate graph may actually be the result of an interaction of variables not measured or included, rather than the result of just the single variable on the x-axis.

RESULTS

Suitability Indices

Suitability Indices did not seem to be generally applicable to streams other than the one from which the original SI curve was derived. This conclusion is based on the lack of correspondence between the SI curves from the HEP Group reports and those for Elk Creek and Bear Creek (Tables 2 through 6). This lack of correspondence suggests that there may be different physical and biological factors in different stream systems that result in changes in species distribution and abundance but are not predictable by a single SI curve.

Figures 1 through 17 illustrate the between-stream variation in habitat utilization patterns by cutthroat trout and coho salmon. Cutthroat trout are more limited below the barriers in both creeks than above them. The only major difference in these two areas is that there are fewer competitors above the barriers. Changes in cutthroat trout densities do not correspond to differences in availability of habitat, as denoted by the SI graphs; SI's are almost always higher above the barrier than below it for the same value of the independent variables. The primary habitat differences between the two streams are that lower Elk Creek has more boulders in its substrate composition and that Elk Creek, in general, has a greater proportion of pools to riffles. The sections of Bear Creek above the logjam are more densely shaded by the tree canopy than are other sections of either creek. These factors resulted in different SI profiles for the two creeks and a different response of the fish populations to environmental factors as a set, perhaps suggesting that different limiting factors govern population density in the two creeks.

Model Tests

Three types of SI aggregation models were tested: (1) the Average Value Method (AVM); (2) the Interactive Limiting Factor approach (ILF); and (3) the Lowest SI approach (LSI). The Average Value Method is described mathematically as follows:

$$HSI = (SI_1 \times SI_2 \times SI_3 \times \ldots \times SI_n)^{1/n}$$

where SI_i = the suitability index of the ith environmental factor

n = the number of environmental factors

Table 2. Comparison between SI's for percent riffles predicted using the HEPG draft curves for cutthroat trout and observed SI's calculated from Elk and Bear Creek standing crop data.

Riffles (%)	Suitability Index (SI)	
	Predicted	Observed
0	0.50	0.45
2	0.51	0.47
10	0.40	0.60
20	0.80	0.75
25	0.90	0.64
55	1.00	0.65
67	0.90	0.78
80	0.80	0.75

Table 3. Comparison between SI's for dominant substrate in riffle sections predicted using the HEPG draft curves for cutthroat trout and observed SI's calculated from Elk and Bear Creek standing crop data.

Substrate[a]	n	Suitability Index (SI)	
		Predicted	Observed (± 0.95 interval)
All reaches			
A	17	1.0	0.32 (0.13)
B	8	0.25-0.60	0.17 (0.26)
C	1	0.25	0.08 (0)
Reaches above barrier			
A	11	1.0	0.45 (0.15)
B	2	0.25-0.60	.057 (-)
C	-	-	- (-)

[a]Substrate type (55% constitutes dominance):
A = Mostly boulders and rubble.
B = Even distribution of bouders, rubble, cobble, and gravel.
C = Bedrock or fines

Table 4. Comparison between SI's for percent fines predicted using the HEPG draft curves for cutthroat trout and observed SI's calculated from Elk and Bear Creek standing crop data.

	Suitability Index (SI)		
		Observed	
Percent fines	Predicted	Elk Creek	Bear Creek
15	0.90	0.55	1.00
30	0.60	0.69	0.97
45	0.39	0.38	0.95
60	0.20	0.08	0.59

Table 5. Comparison between SI's for percent shade predicted using the HEPG draft curves for cutthroat trout and observed SI's calculated from Elk and Bear Creek standing crop data.

	Suitability Index (SI)		
		Observed	
Percent shade	Predicted	Elk Creek	Bear Creek
25	0.65	0.75	0.94
50	1.00	0.52	0.95
75	1.00	0.30	0.99
100	0.40	0.00	0.00

Table 6. Comparison between SI's for pool volume predicted using the HEPG draft curves for coho salmon and observed SI's calculated from Elk Creek standing crop data.

Pool volume (m^3)	Suitability Index (SI)	
	Predicted	Observed
10	0.65	0.25
20	0.78	0.48
30	0.93	0.67
40	0.99	0.83
50	0.95	0.93
60	0.94	1.00

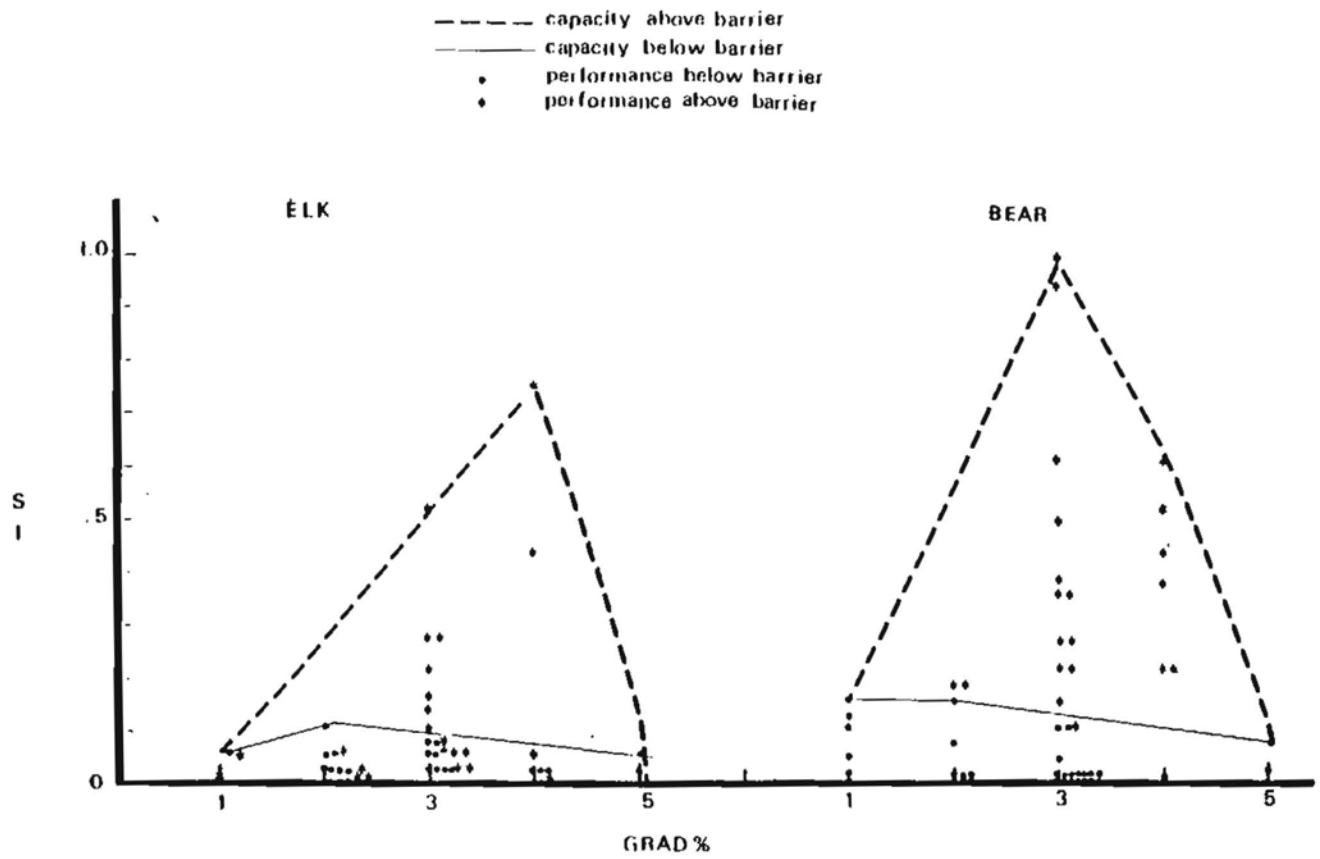

Figure 1. Cutthroat trout SI vs. gradient (%) for Elk and Bear Creeks.

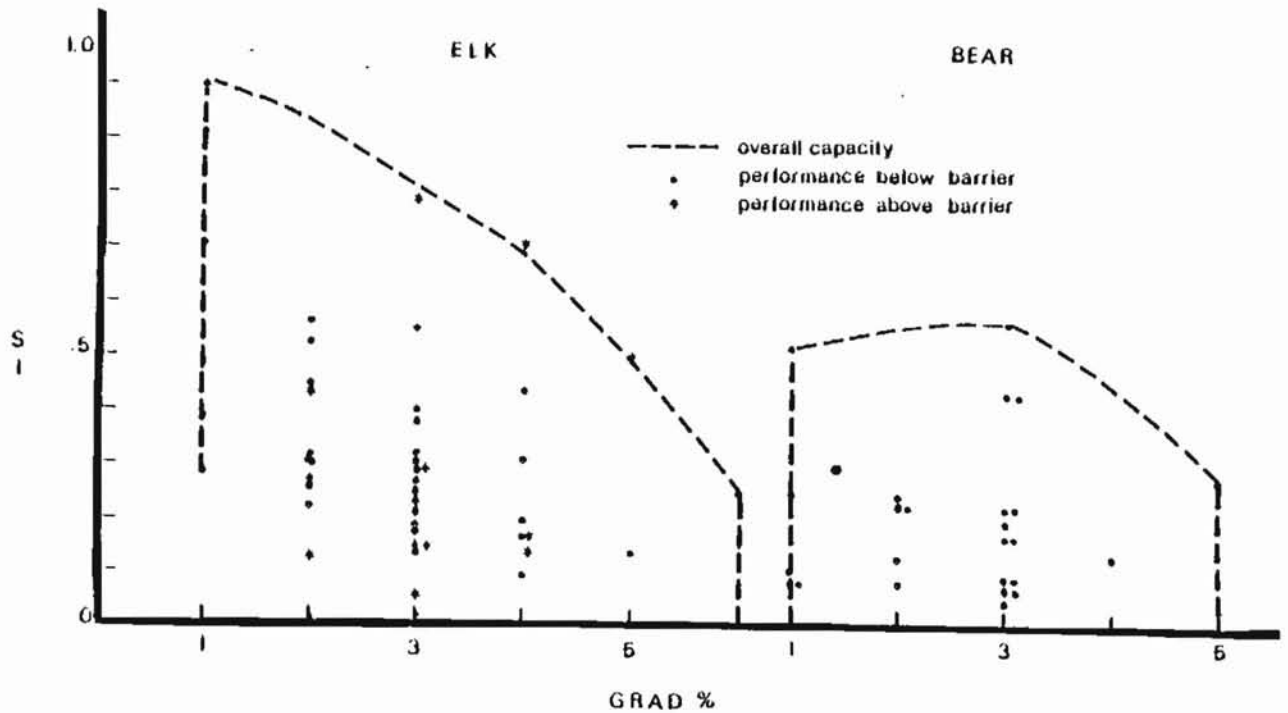

Figure 2. Coho salmon SI vs. gradient (%) for Elk and Bear Creeks.

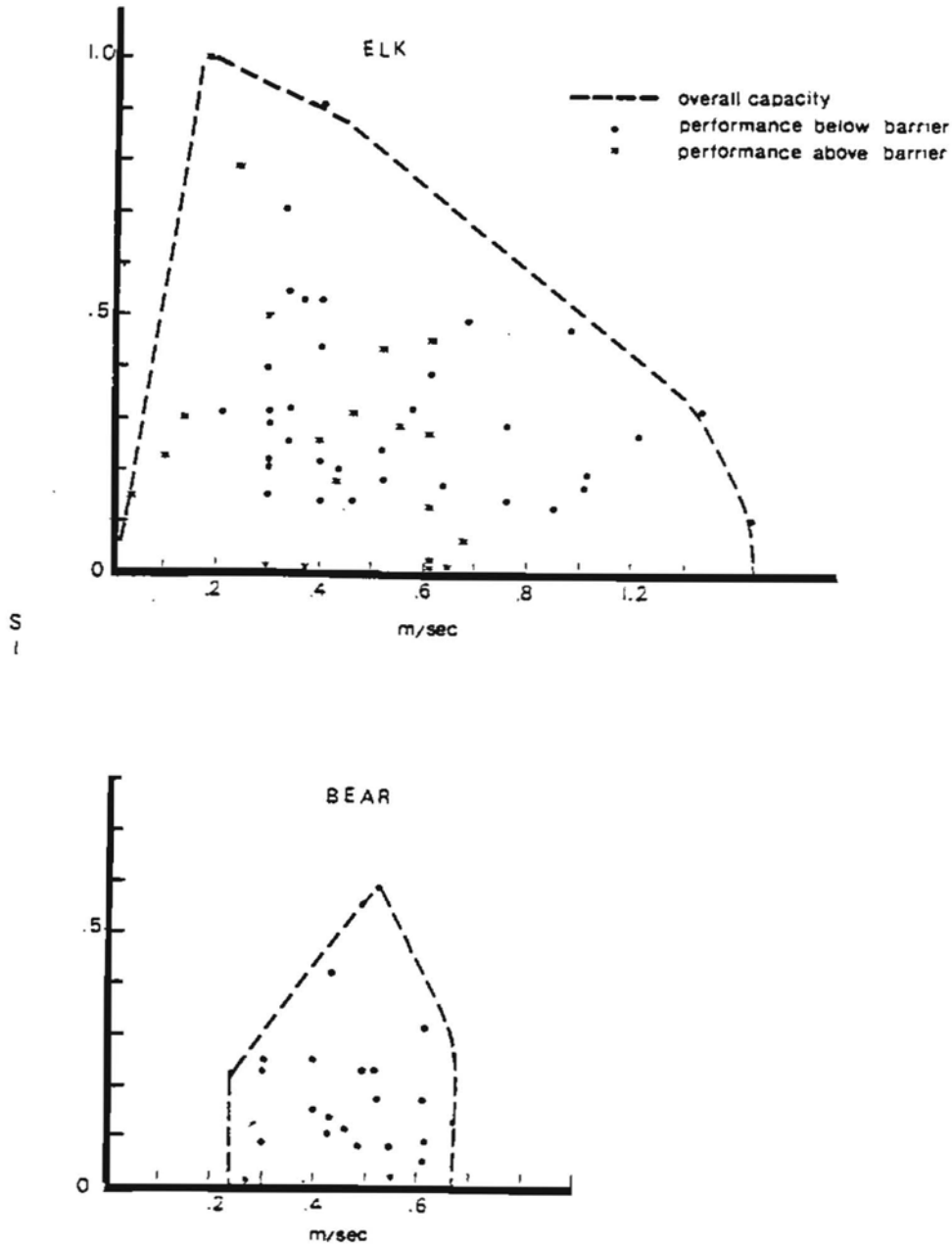

Figure 3. Coho salmon Suitability Index for velocities (m/sec, average for section) for Elk and Bear Creeks.

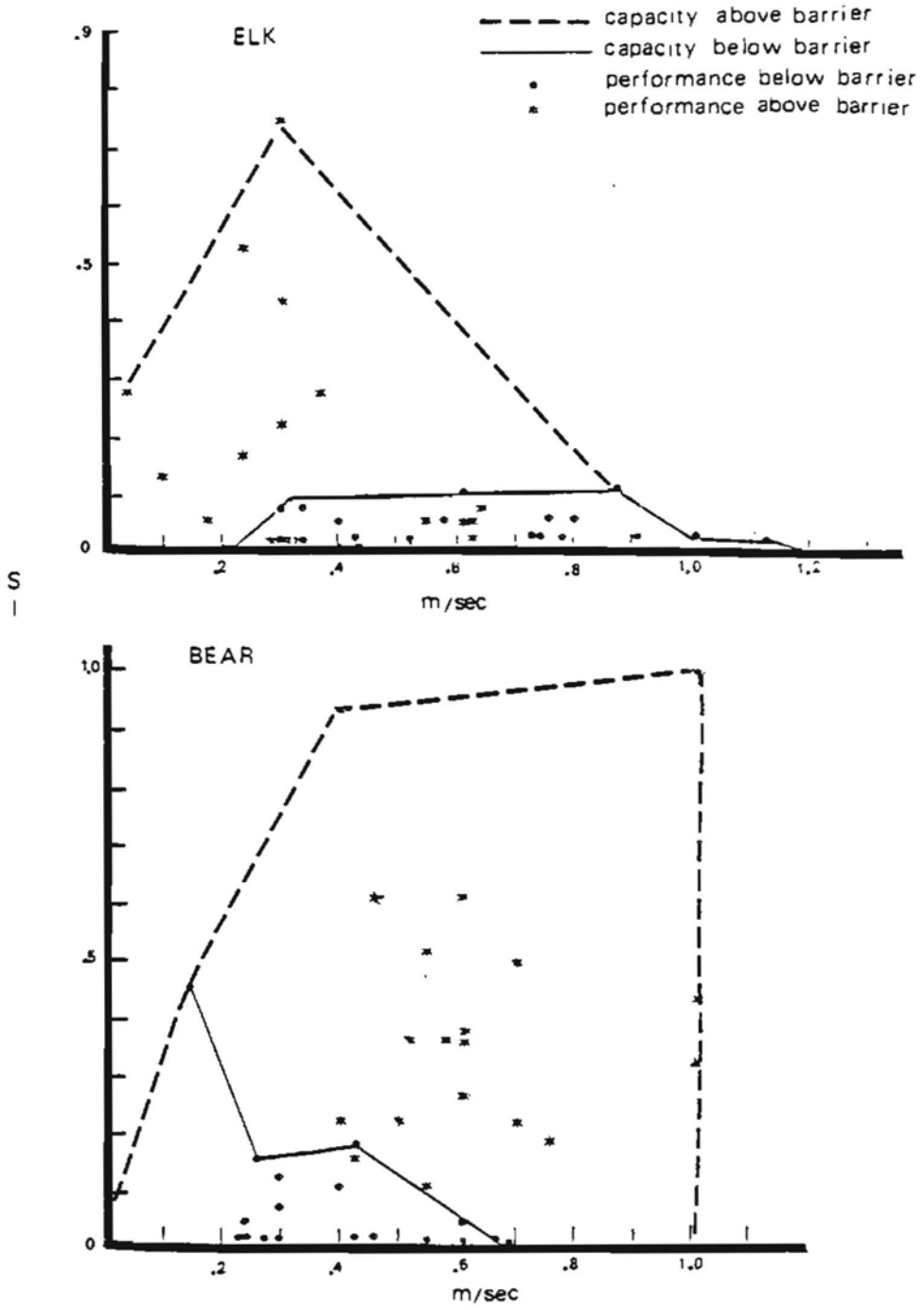

Figure 4. Cutthroat trout Suitability Index for velocities (m/sec, average for section) for Elk and Bear Creeks.

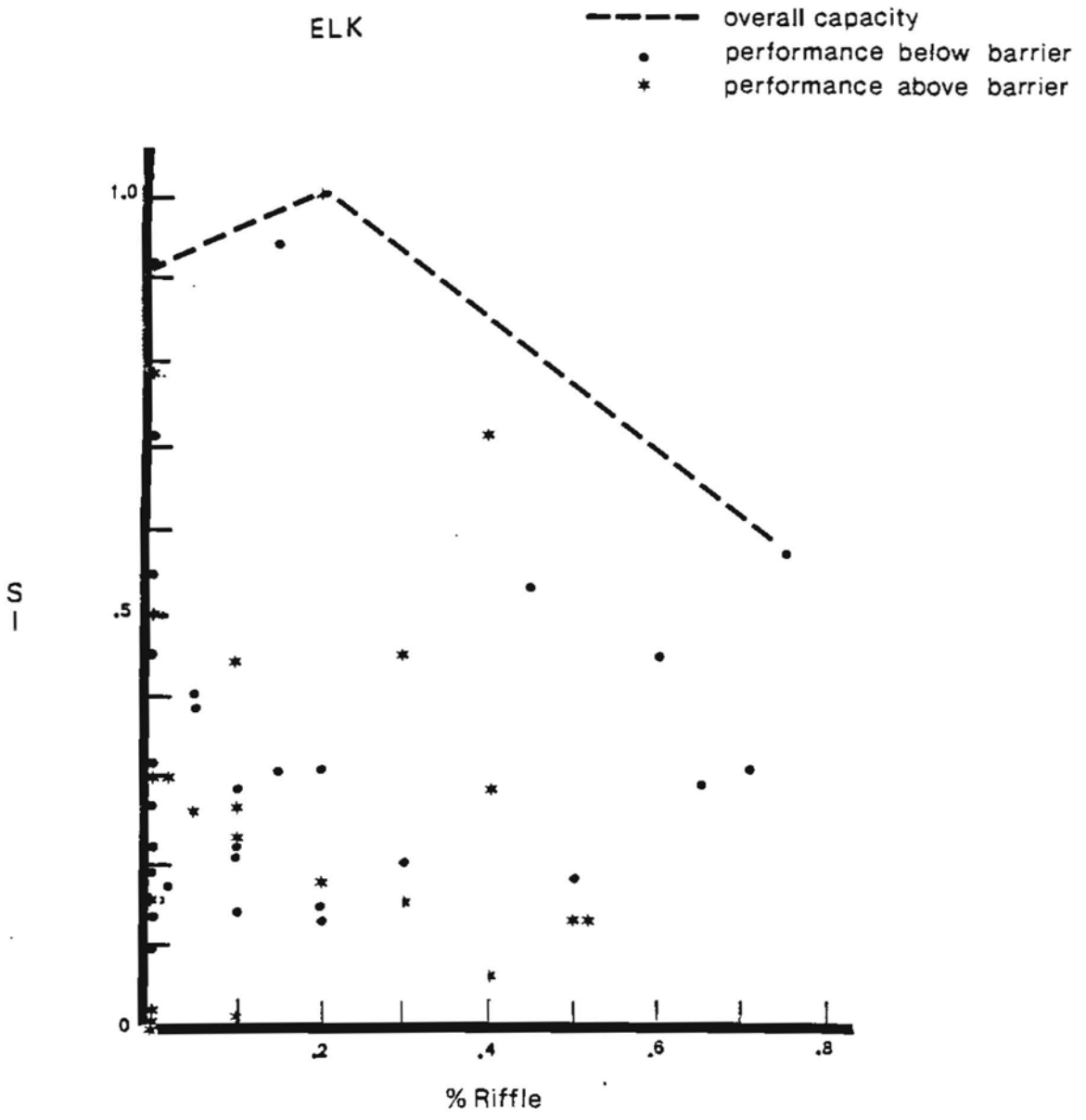

Figure 5. Coho salmon Suitability Index for percent riffles in Elk Creek.

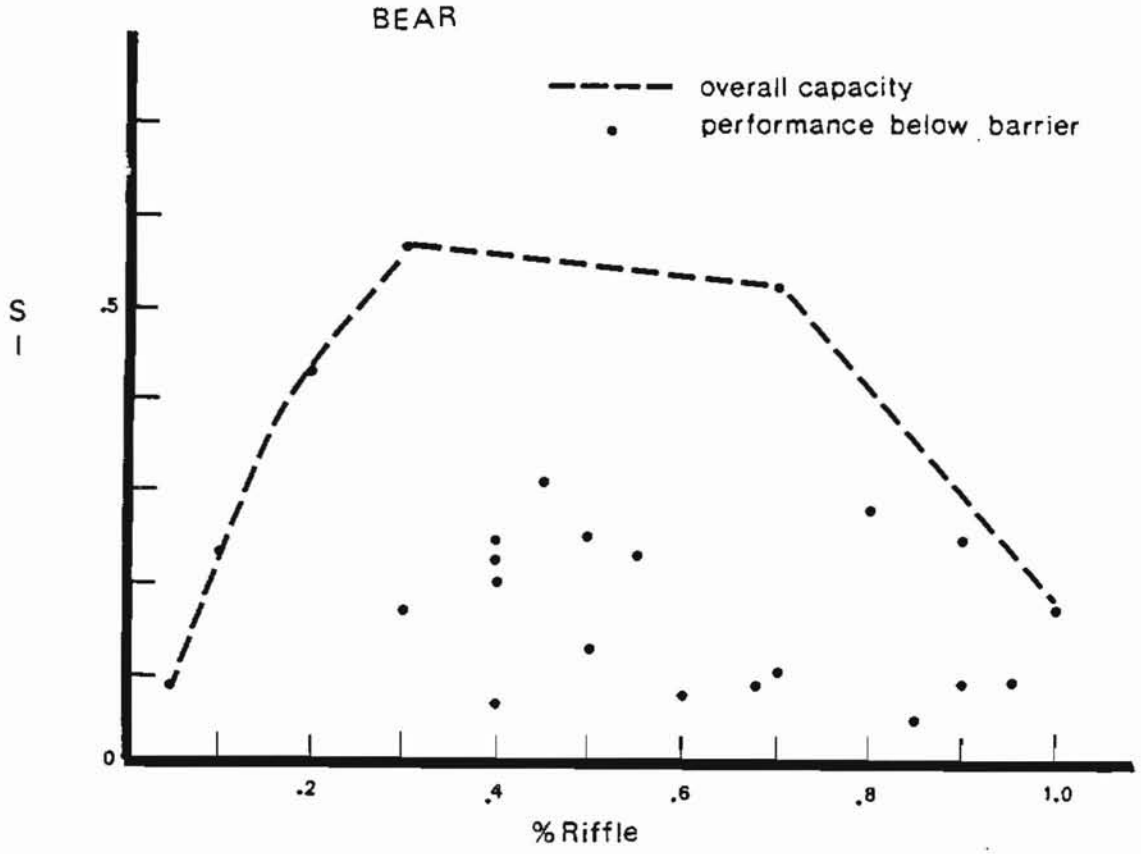

Figure 6. Coho salmon Suitability Index for percent riffles in Bear Creek.

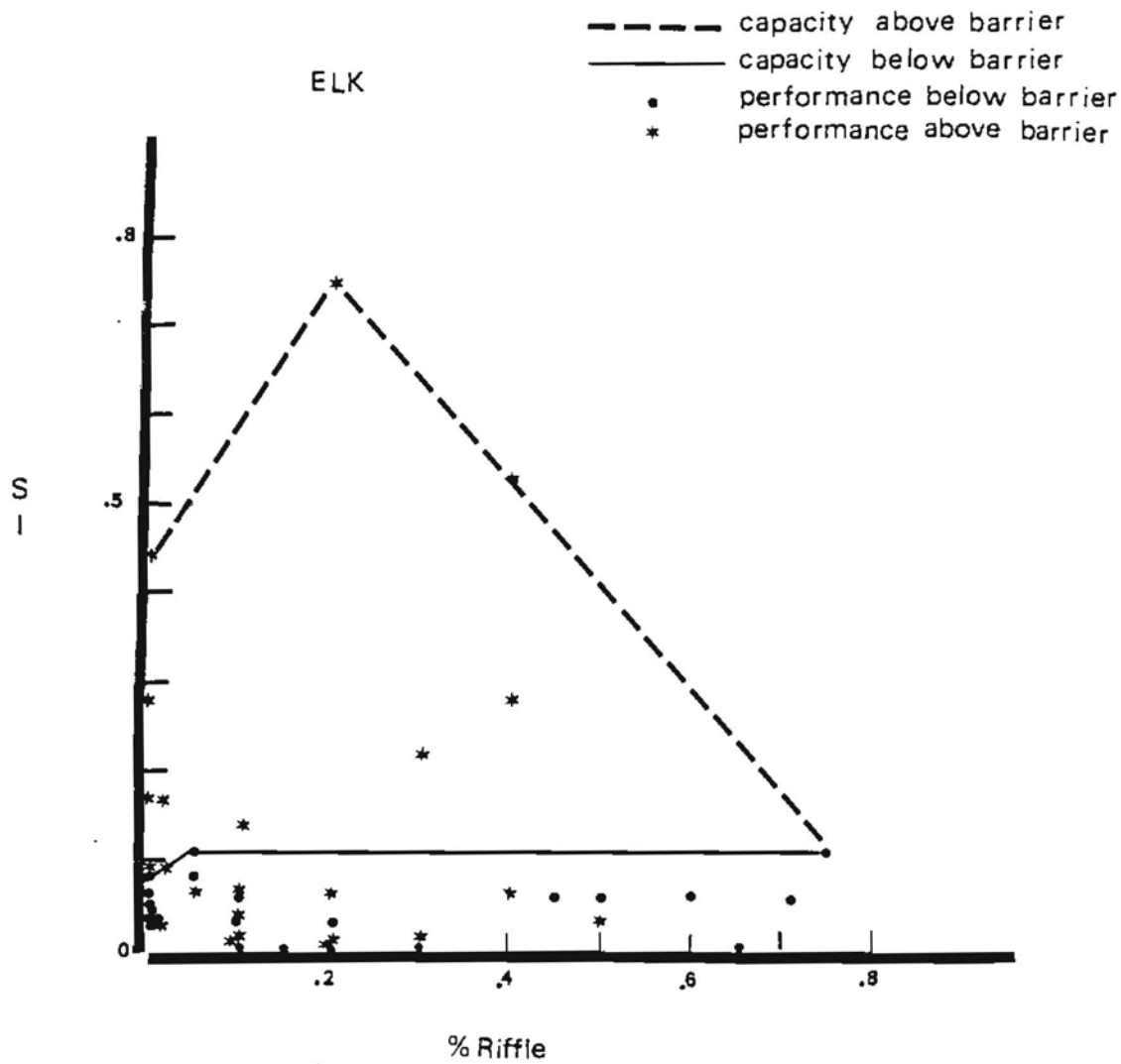

Figure 7. Cutthroat trout Suitability Index for percent riffles in Elk Creek.

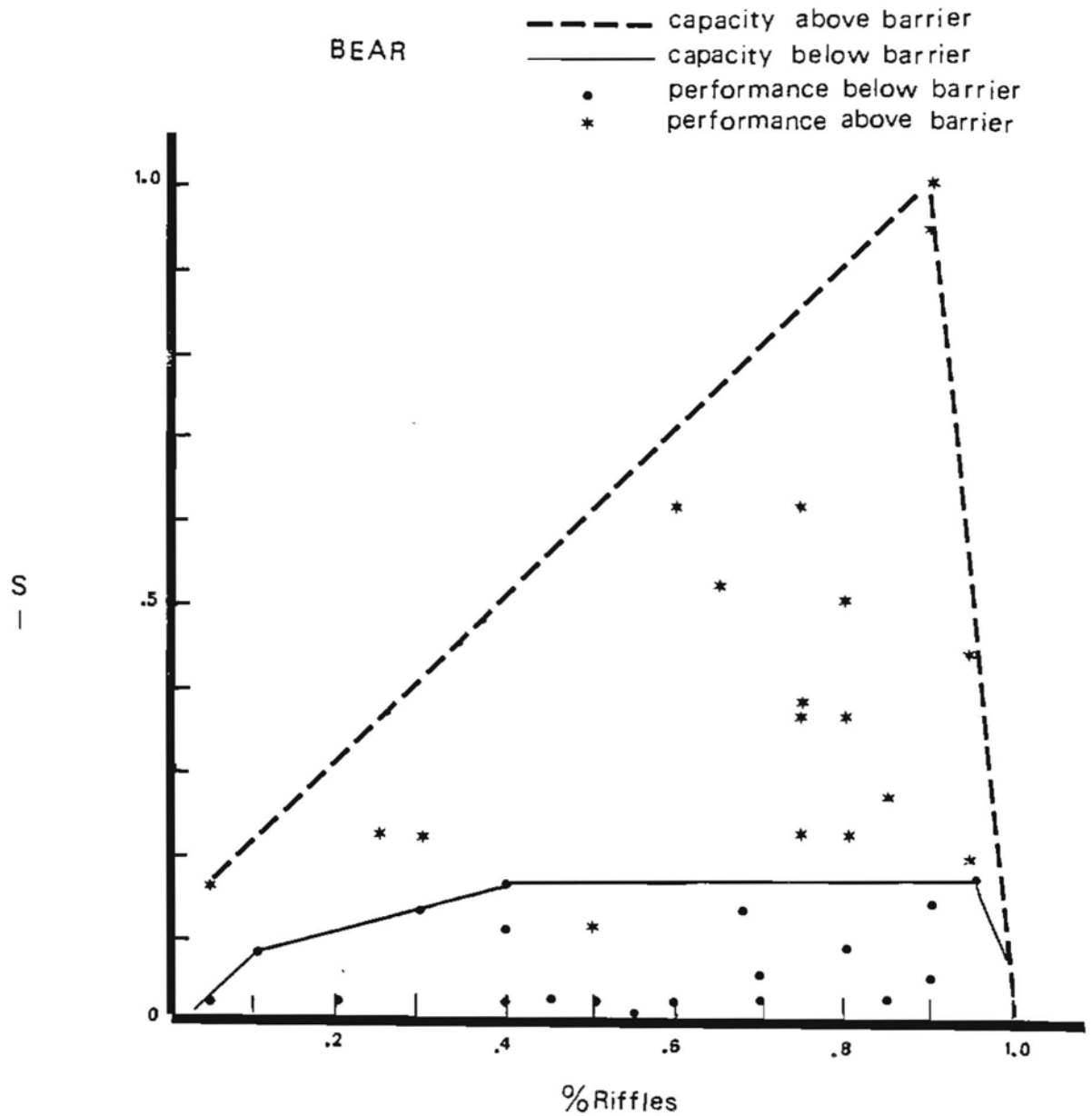

Figure 8. Cutthroat trout Suitability Index for percent riffles in Bear Creek.

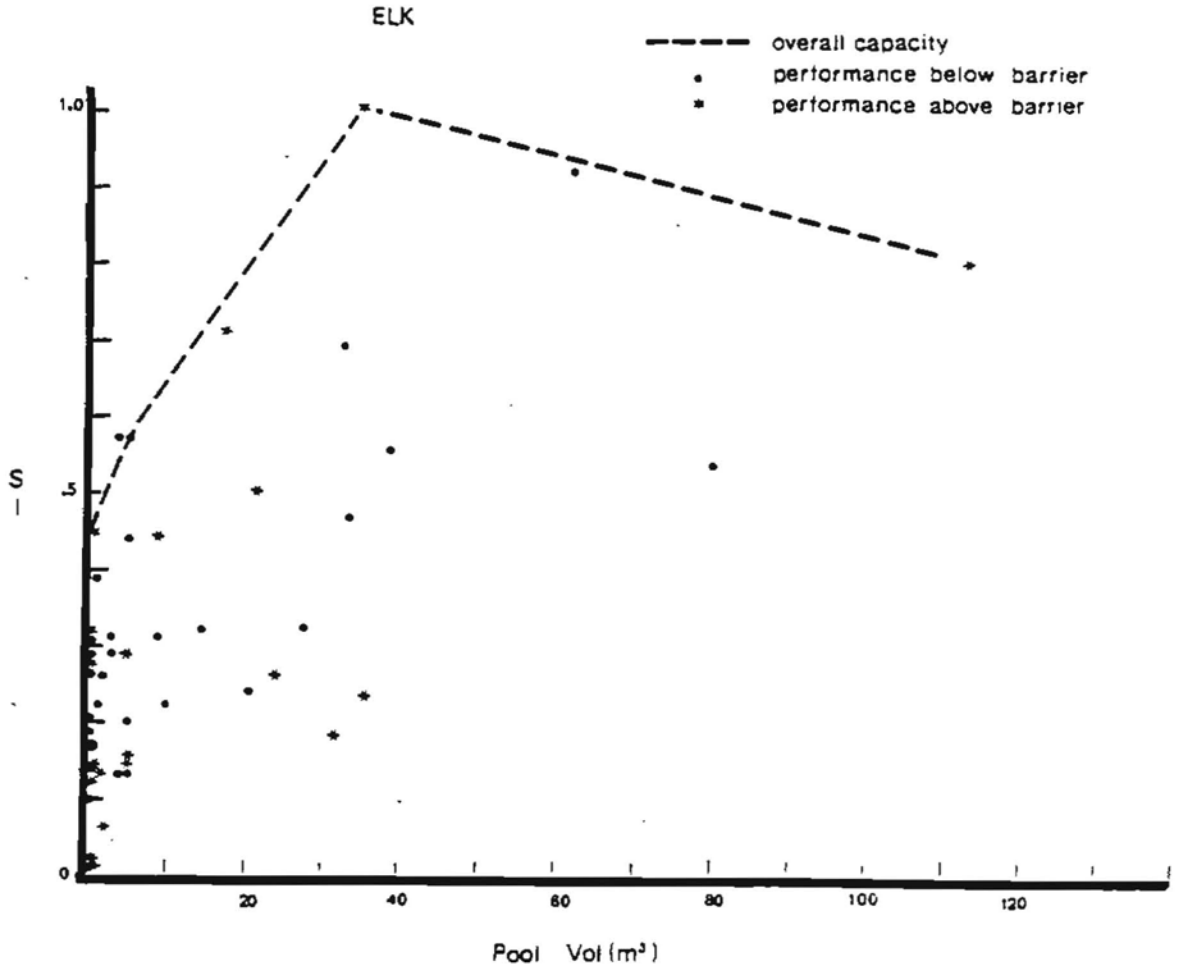

Figure 9. Coho salmon Suitability Index for pool volume (m^3) in Elk Creek.

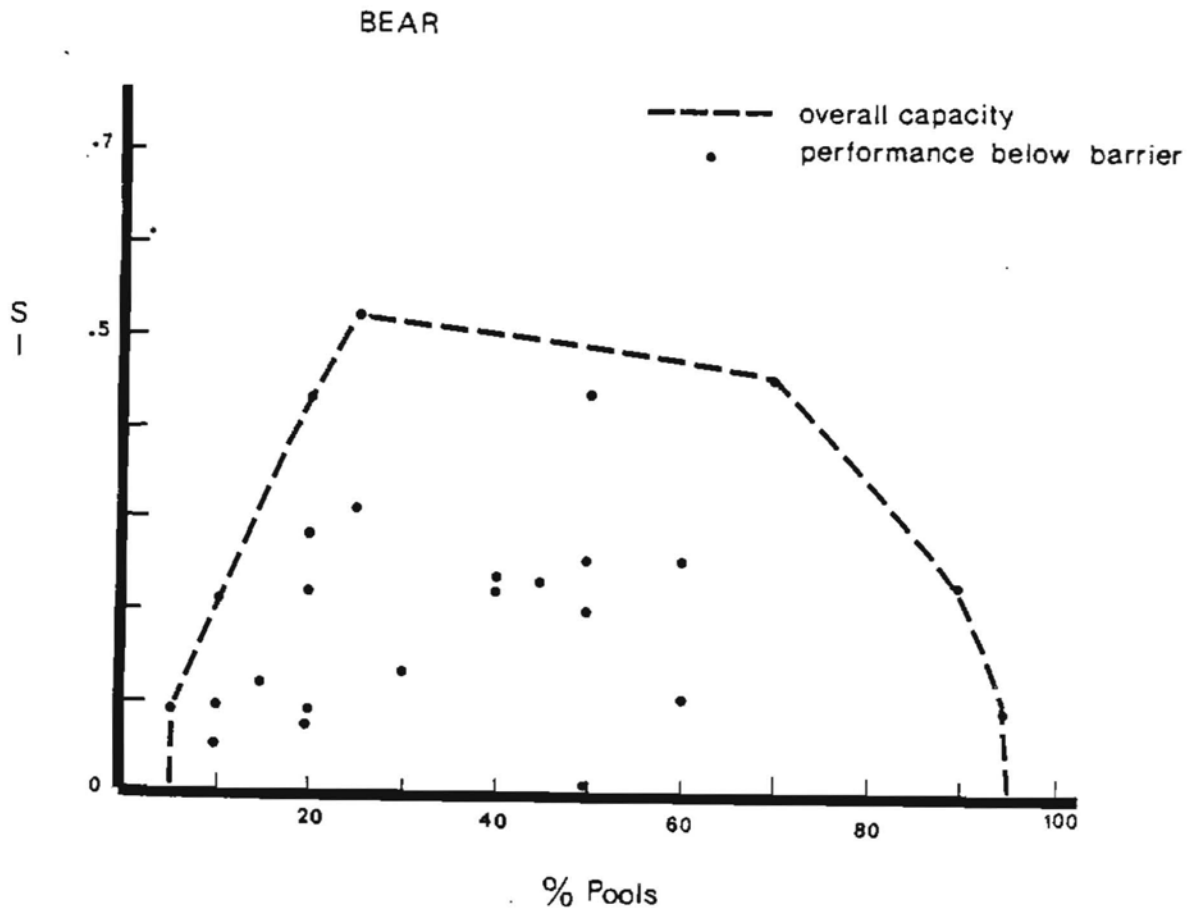

Figure 10. Coho salmon Suitability Index for percent pools in Bear Creek.

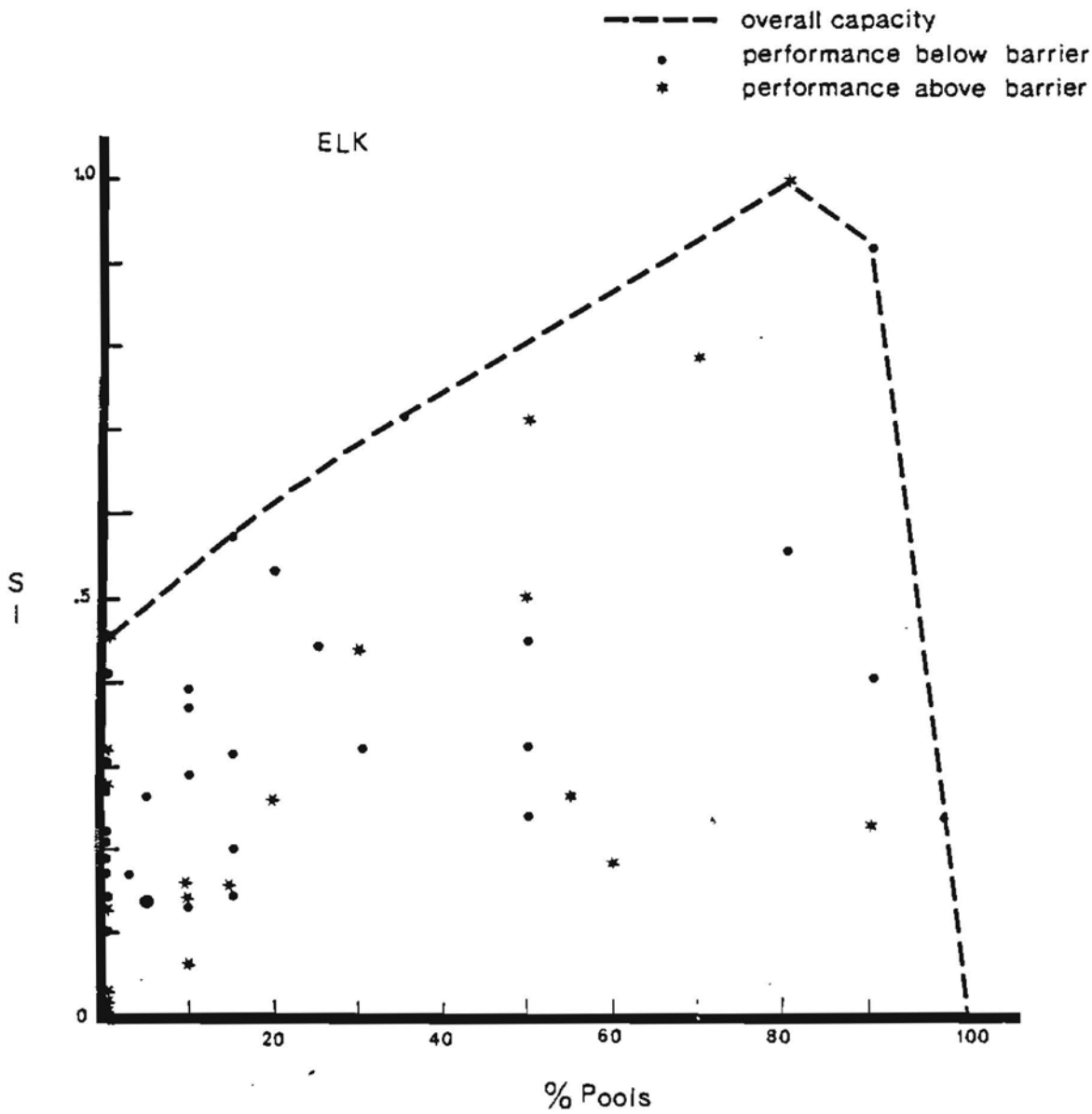

Figure 11. Coho salmon Suitability Index for percent pools in Elk Creek.

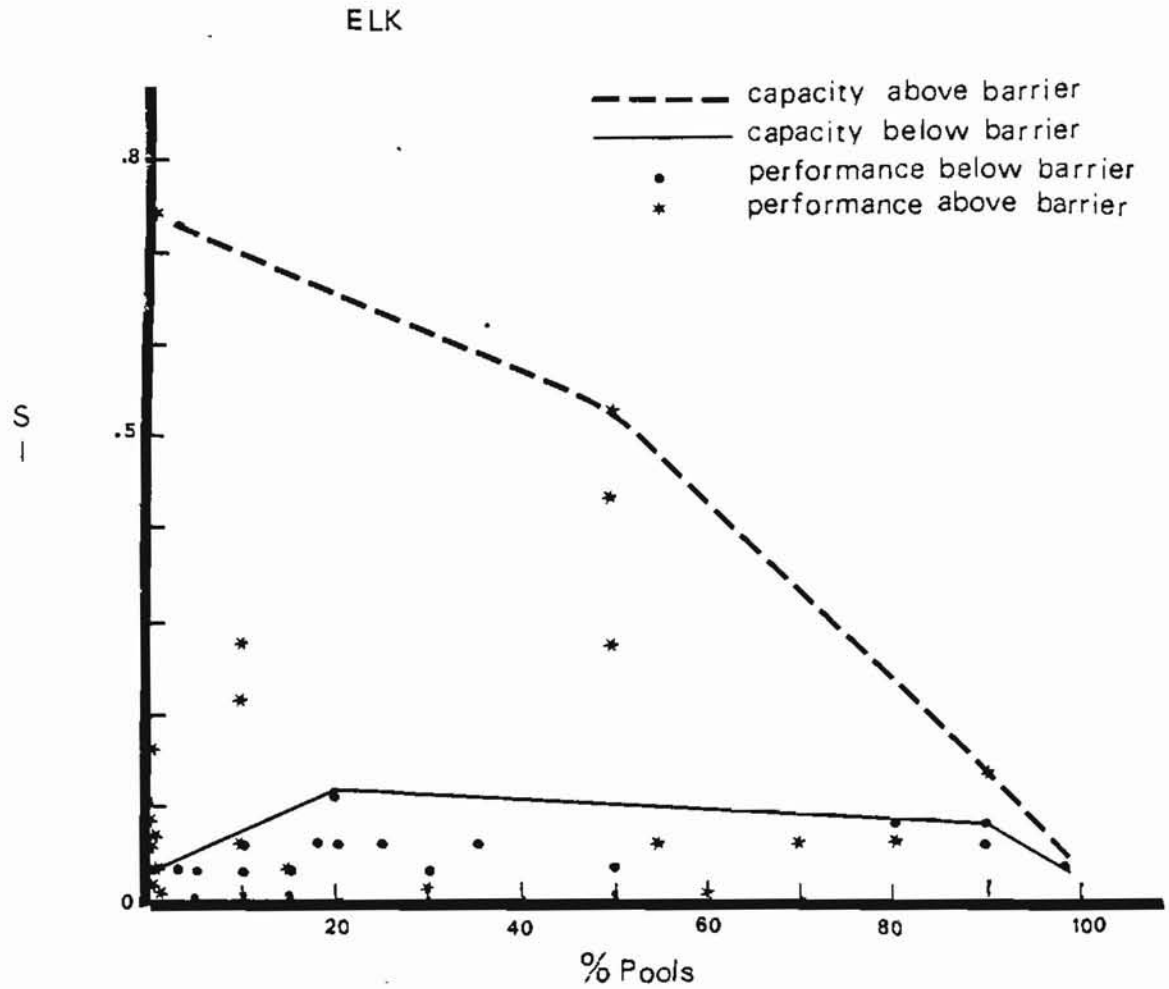

Figure 12. Cutthroat trout Suitability Index for percent pools in Elk Creek.

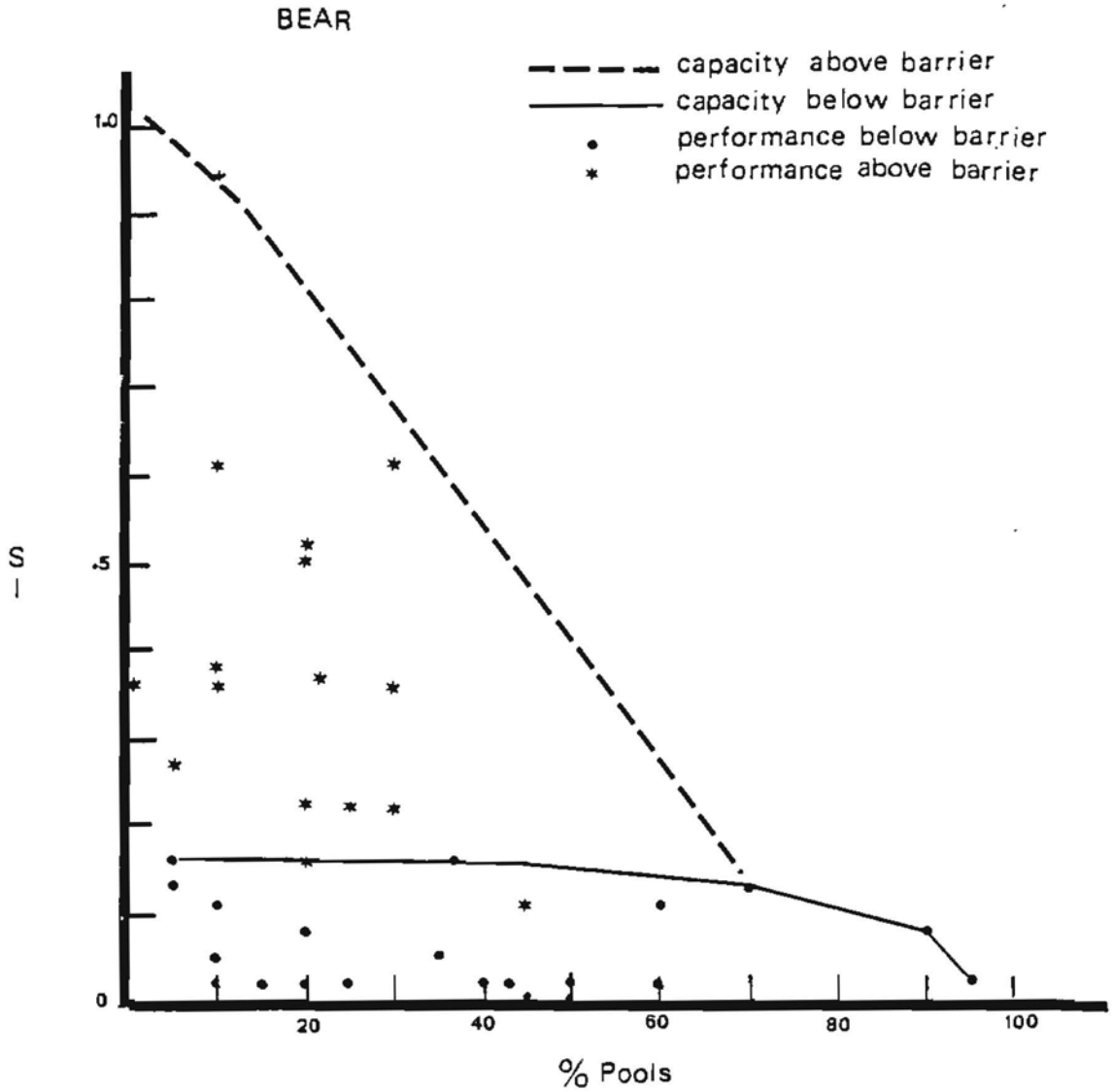

Figure 13. Cutthroat trout Suitability Index for percent pools in Bear Creek.

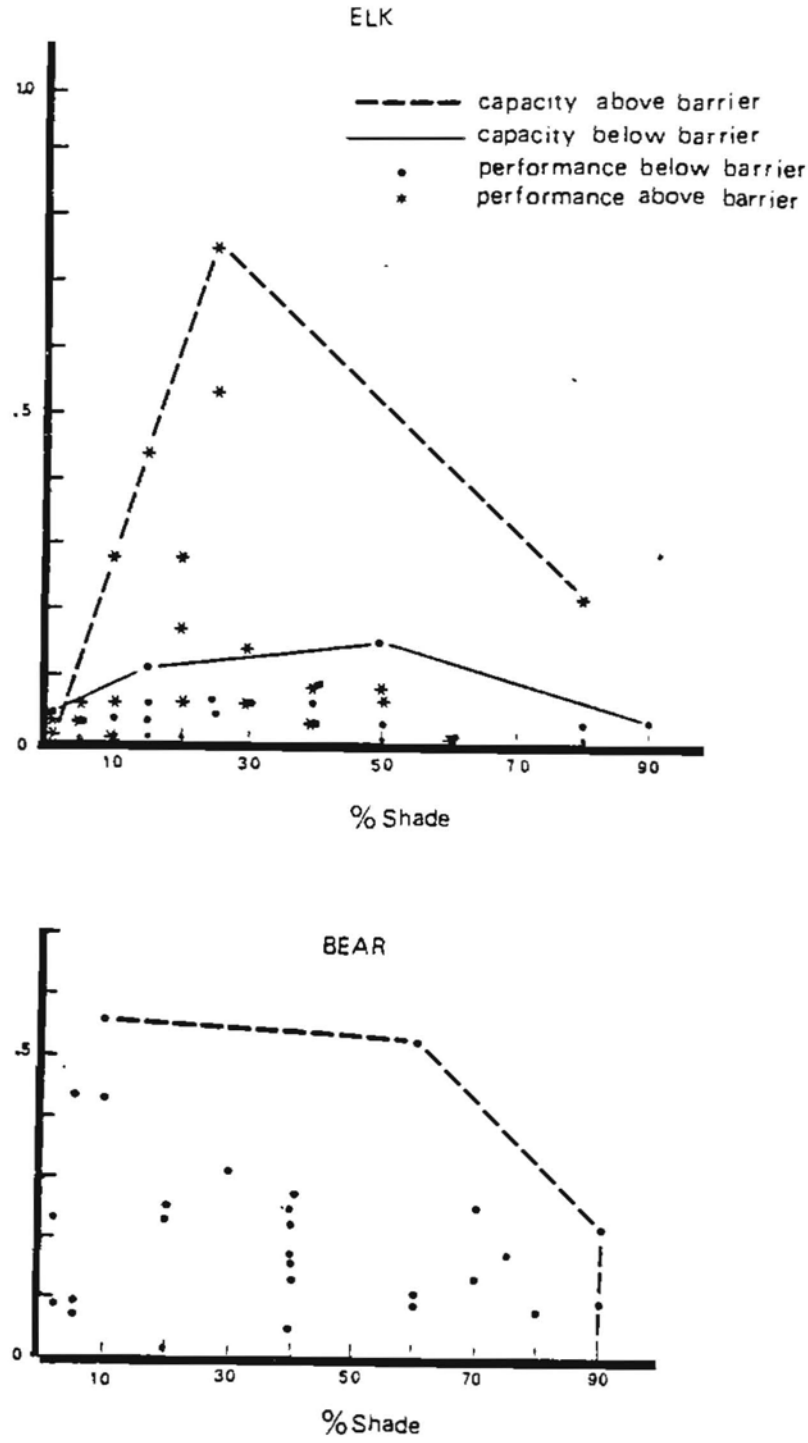

Figure 14. Coho salmon Suitability Index for percent shade in Elk and Bear Creeks.

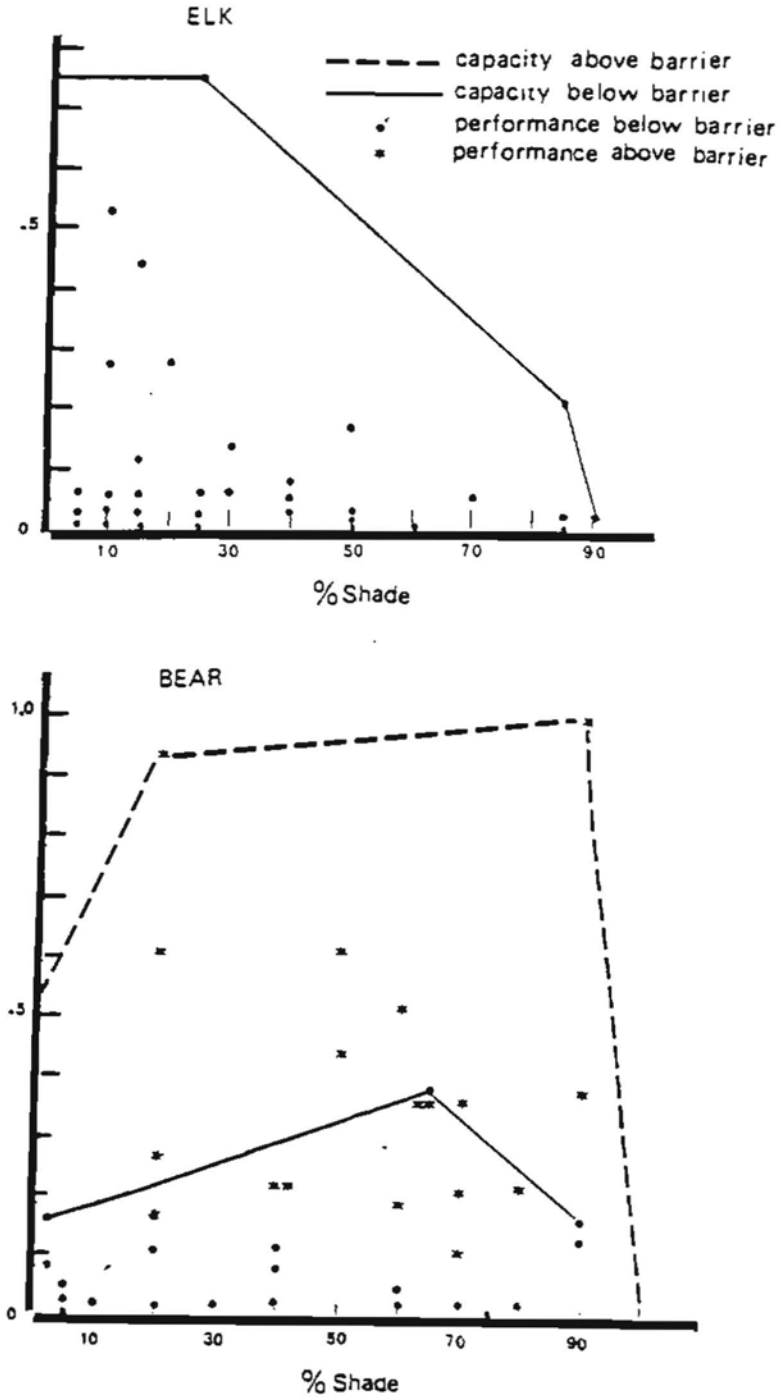

Figure 15. Cutthroat trout Suitability Index for percent shade in Elk and Bear Creeks.

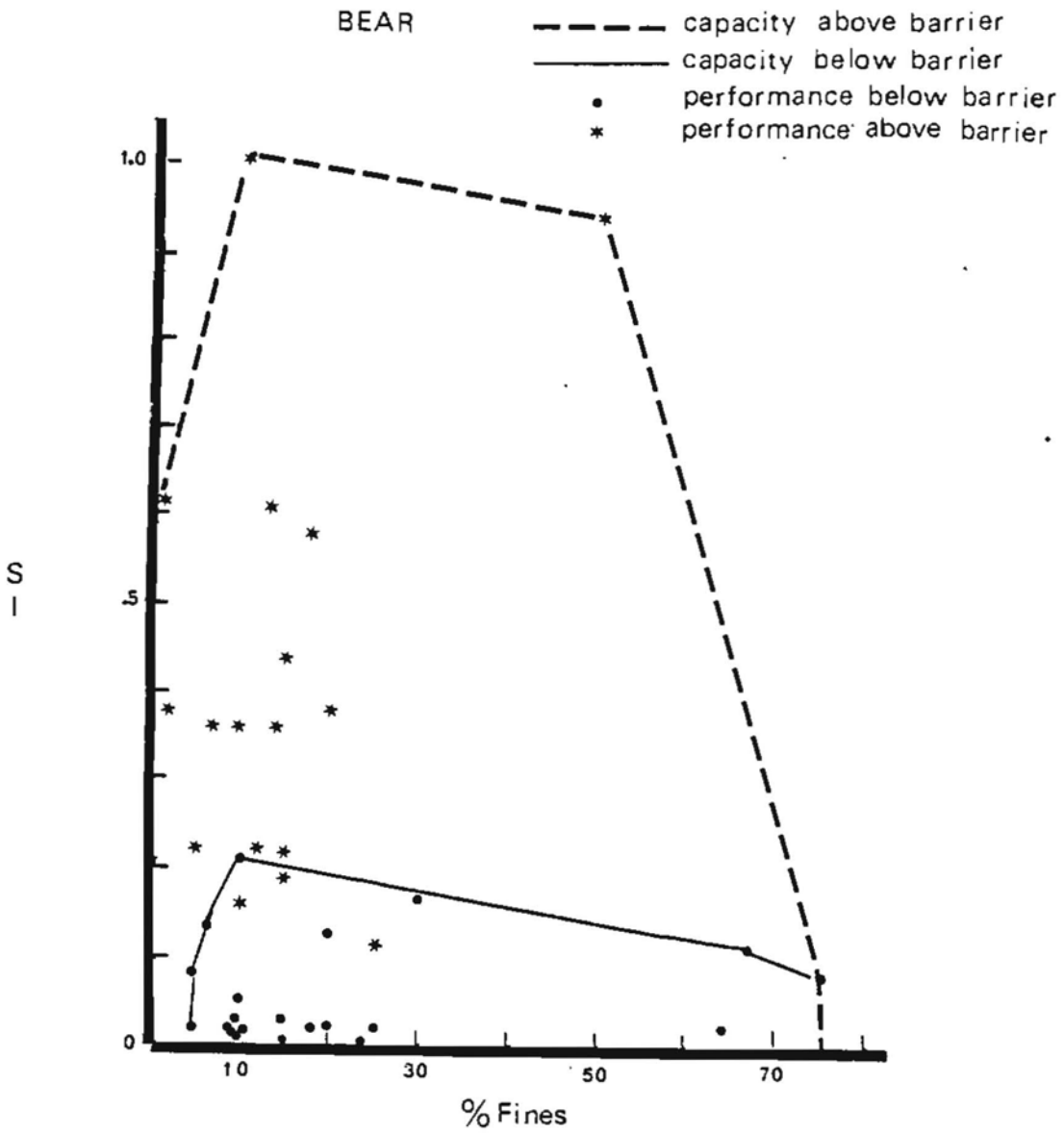

Figure 16. Cutthroat trout Suitability Index for percent fines in Bear Creek.

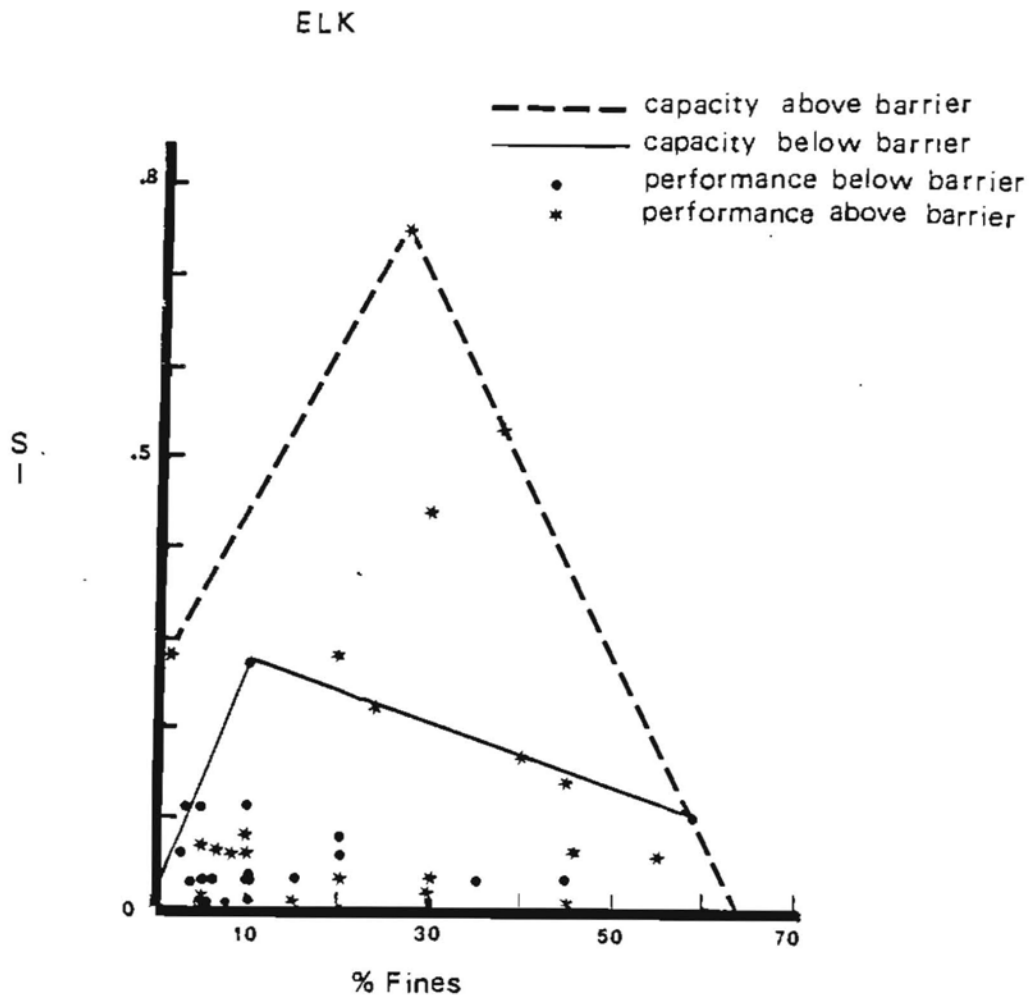

Figure 17. Cutthroat trout Suitability Index for percent fines in Elk Creek.

An average habitat quality value is obtained with this type of model without using an arithmetic mean. This eliminates the problem of obtaining an HSI greater than 0 when one of the components has an SI of 0. This method is based on the assumption that a high SI for one variable can compensate for a low SI for a different variable.

The Interactive Limiting Factor approach is conceptually more conservative than the Average Value Method. This approach is mathematically described as follows:

$$HSI = (SI_1 \times SI_2 \times SI_3 \times \ldots \times SI_n)$$

With this approach, the HSI can be no higher than the lowest SI, but can be lower than the lowest SI. For example, a low dissolved oxygen level may cause a particular habitat to be marginally suitable for trout. However, an additional limitation, such as increased temperature, which may not be totally unsatisfactory by itself, may lower the habitat suitability well below the lowest SI.

Using the Lowest Suitability Index approach to determine habitat suitability is a logical extension of Leibig's Law of the Minimum; that is, the most limiting factor defines the upper limit to population density. The assumption is made that there are no interactions among variables that can compensate for a low suitability index for any one variable or decrease the overall habitat suitability below the level of the lowest suitability index.

The following numerical example will demonstrate the differences between the three approaches:

Five SI's = 1, one SI = 0.9, and one SI = 0.4

$$AVM = (1.0 \times 1.0 \times 1.0 \times 1.0 \times 1.0 \times 0.8 \times 0.4)^{1/7} = 0.86$$

$$ILF = (1.0 \times 1.0 \times 1.0 \times 1.0 \times 1.0 \times 0.9 \times 0.4) = 0.36$$

$$LSI = 0.4$$

Note that the AVM indicates compensation by the high quality elements and that the resulting HSI is more than twice as high as the lowest SI. The HSI for the LSI approach is equal to the most limiting factor, while the HSI for the ILF approach is smaller than the lowest SI.

The validity of the three approaches was tested in the following manner. SI's derived from curves from the HEP group draft manuscripts (Appendix C) and developed from the data for the Nestucca drainage were aggregated to generate HSI's for different sections of the Smith, South Coos, and Coquille Rivers from their physical characteristics. Competition among species was roughly adjusted for by using the appropriate SI curves (Figs. 1 through 17). Table 7 indicates the variables used to generate the HSI's.

Table 7. Variables used in the calculation of Habitat Suitability Indices by the Lowest Suitability Index and Average Value Methods.

Species	Temperature (°C)	Velocity (cm/sec)	% riffles	% pools	d.o.	pH	Depth
Cutthroat trout	X	X	X		X	X	
Coho salmon	X	X		X	X		X

Overall, none of the three approaches performed well in terms of matching the HSI's derived empirically by dividing the observed standing crop by the maximum standing crop (Tables 8 through 10). There were no strong positive correlations between the observed and predicted values. The Average Value Method always had the highest residual error (cumulative absolute difference between the observed and predicted values). The residual error generated by the Lowest Suitability Index approach was intermediate, and the Interactive Limiting Factor approach had the lowest residual error.

Better predictions of habitat suitability for cutthroat trout were obtained when the limitations in performance that were imposed by competitors were accounted for (Table 10). Residual errors were reduced from 5.52 to 3.81, from 7.71 to 4.75, and from 14.04 to 8.16 for the Interactive Limiting Factor approach, the Lowest Suitability Index approach, and the Average Value Method, respectively. However, correlations were still negative except for the Average Value Method (Tables 9 and 10).

None of the three types of aggregation models were precise in terms of predicting empirically derived HSI's to the nearest 0.1. The percentages of correct classifications for coho salmon were 14% (LSI), 11% (ILF), and 0% (AVM). The percentage of correct classifications were 52% (ILF), 7% (LSI), and 0% (AVM) when both biotic and physical variables were entered into the analysis. When the biotic variables were left out, the percentages of correct classifications dropped for the ILF (7%) and LSI (0%) approaches, but increased for the AVM (7%) method. In general, the AVM method predicted high HSI's, the LSI predicted intermediate HSI's, and the ILF predicted low HSI's.

There are several possible reasons for the low correlations between the predicted and observed HSI's in the southcentral coastal Oregon drainages. However, the densities of cutthroat trout and coho salmon were 2.63 to 1.25 greater, respectively, in these drainages than in the Nestucca. These results suggest that populations in the coastal drainages may be limited by the availability of habitat resources not described in the tested models. The two studies reported on here did not measure the exact same set of variables; e.g., gradient and percent canopy were measured by House (unpubl. data) in the Nestucca drainage, but not by Duke and Bond (1981) in the southcentral coastal

Table 8. Validation tests of HSI's from coho salmon habitat models.

Stream section	Number of variables	Predicted HSI			Observed HSI
		ILF[a]	LSI[b]	AVM[c]	
Smith	5	0.05	0.20	0.53	0.00
	4	0.03	0.20	0.43	0.00
	5	0.02	0.20	0.47	0.00
	5	0.04	0.20	0.52	0.57
	4	0.05	0.20	0.47	0.02
	5	0.04	0.20	0.53	1.00
	4	0.04	0.20	0.45	0.08
	4	0.16	0.35	0.63	0.05
	4	0.07	0.20	0.52	0.00
	4	0.06	0.20	0.49	0.00
	5	0.07	0.20	0.58	0.23
	4	0.04	0.20	0.44	0.03
	5	0.06	0.20	0.57	0.03
South Coos	4	0.24	0.35	0.70	0.38
	5	0.25	0.35	0.76	0.43
	4	0.24	0.35	0.70	0.31
	5	0.21	0.35	0.73	0.60
	4	0.07	0.20	0.51	0.90
	4	0.06	0.20	0.57	0.81
	4	0.06	0.20	0.49	0.77
	5	0.05	0.20	0.56	0.53
	4	0.23	0.35	0.69	0.11
	4	0.31	0.35	0.79	0.38
	4	0.27	0.35	0.77	0.14
	5	0.28	0.35	0.78	0.03
	4	0.06	0.20	0.57	0.78
	4	0.06	0.20	0.57	0.93
	4	0.06	0.20	0.56	0.74
	5	0.05	0.20	0.55	0.76
Coquille	4	0.28	0.35	0.77	0.04
	5	0.27	0.35	0.77	0.03
	4	0.07	0.20	0.59	0.24
	5	0.06	0.20	0.58	0.29
	4	0.06	0.20	0.58	0.24
	4	0.06	0.20	0.58	0.06
	$\Sigma\|(O-P)\|$ =	9.33	9.88	14.09	
	r =	-0.19	-0.21	-0.07	

[a]Interactive Limiting Factor approach.

[b]Lowest Suitability Index approach.

[c]Average Value Method.

Table 9. Validation tests of HSI's for cutthroat trout habitat models with no compensation for competitive effects.

Stream section	Number of variables	Predicted HSI			Observed HSI
		ILF[a]	LSI[b]	AVM[c]	
Smith	5	0.00	0.00	0.00	0.51
	3	0.12	0.25	0.50	1.00
	5	0.04	0.29	0.53	0.49
	5	0.09	0.29	0.62	0.01
	3	0.13	0.28	0.51	0.00
	5	0.08	0.29	0.60	0.00
	5	0.34	0.42	0.81	0.01
	3	0.34	0.38	0.69	0.02
	5	0.10	0.29	0.63	0.00
	3	0.16	0.27	0.55	0.00
	5	0.15	0.27	0.68	0.02
South Coos	3	0.27	0.38	0.65	0.00
	5	0.09	0.30	0.53	0.10
	3	0.16	0.29	0.55	0.08
	5	0.10	0.29	0.63	0.03
	3	0.17	0.31	0.56	0.18
	5	0.11	0.29	0.64	0.15
	3	0.15	0.28	0.53	0.10
	5	0.13	0.28	0.51	0.51
	3	0.25	0.41	0.63	0.00
	5	0.22	0.38	0.74	0.51
	3	0.18	0.30	0.57	0.00
	5	0.19	0.31	0.72	0.00
	3	0.16	0.27	0.55	0.00
	5	0.13	0.26	0.66	0.02
	3	0.14	0.26	0.52	0.01
	5	0.13	0.26	0.66	0.00
	$\Sigma\lvert (O-P)\rvert =$	5.52	7.71	14.04	
	$r =$	-0.30	-0.33	-0.28	

[a]Interactive Limiting Factor approach.

[b]Lowest Suitability Index approach.

[c]Average Value Method.

Table 10. Validation tests of HSI's for cutthroat trout habitat models with compensation for competitive effects.

Stream section	Number of variables	Predicted HSI ILF[a]	Predicted HSI LSI[b]	Predicted HSI AVM[c]	Observed HSI
Smith	5	0.00	0.00	0.00	0.51
	3	0.02	0.09	0.62	1.00
	5	0.01	0.09	0.62	0.49
	5	0.02	0.10	0.46	0.01
	3	0.02	0.10	0.28	0.00
	5	0.05	0.10	0.55	0.00
	5	0.05	0.15	0.55	0.01
	3	0.04	0.15	0.35	0.02
	5	0.03	0.09	0.50	0.00
	3	0.02	0.09	0.28	0.00
	5	0.03	0.09	0.50	0.02
South Coos	3	0.02	0.09	0.28	0.00
	5	0.01	0.15	0.33	0.10
	3	0.02	0.15	0.27	0.08
	5	0.01	0.15	0.40	0.03
	3	0.03	0.15	0.31	0.18
	5	0.01	0.15	0.40	0.15
	3	0.01	0.15	0.22	0.10
	5	0.02	0.15	0.46	0.51
	3	0.05	0.15	0.37	0.00
	5	0.03	0.12	0.50	0.51
	3	0.01	0.08	0.22	0.00
	5	0.01	0.15	0.40	0.00
	3	0.01	0.15	0.22	0.00
	5	0.00	0.15	0.33	0.02
	3	0.00	0.15	0.25	0.01
	5	0.00	0.15	0.33	0.00
	$\Sigma \lvert(O-P)\rvert =$	3.81	4.75	8.16	
	$r =$	-0.11	-0.32	0.09	

[a]Interactive Limiting Factor approach.

[b]Lowest Suitability Index approach.

[c]Average Value Method.

drainages. It may be that House (unpubl. data) and Duke and Bond (1981) also defined some variables differently; for instance, riffle, run, glide, and pool are rarely rigorously defined, and their identification is subjective. Key variables, as yet unknown, may not have been measured at all. Biotic variables, such as prey density, endemic diseases, stock differences, and interspecific competition, are not included in the models. Suitability indices (performance capacities) may not have been adequately defined if the best drainage in the region was not inventoried. In fact, the idea of regionalization may be advantageously expanded to a system where streams are regionally classified by climate, geology, available species pool, and geography. This system may resolve differences in the distribution of species resulting from differences in limiting factors. There may have been differences in the precision with which fish densities were measured in the Nestucca (fish/m^2) and the southcentral coastal (gm/m^2) drainages, although HSI standardization removes much of this problem.

Discriminant Analysis

A fourth approach also was taken to describe habitat suitability. A stepwise discriminant analysis was conducted to determine which variables contributed the most to habitat quality for cutthroat trout and coho salmon. The strength of this analysis is that interactions among variables are incorporated into the model. The assumptions of this approach are that: (1) the distribution of the population is multivariate normal; (2) the components have linear relationships; (3) the samples are representative of the total population; and (4) all expected variance-covariance matrices of the population sampled are equal (Pimentel and Frey 1978). This is a very robust approach; violations of the assumptions do not appear to change the outcome of the analysis. Differences in classifications for each species between drainages were compared, as well as differences between classifications for each species within a drainage when only physical parameters were entered into the analysis and when both physical and biotic parameters were entered.

The stepwise discriminant analysis technique selected used the criterion of minimizing Wilks Lambda (Klecka 1975). Habitats were classified into the following habitat quality groups:

1. Unsuitable habitat (HSI = 0);

2. Marginal habitat ($0 < HSI \leq 0.5$); and

3. Acceptable to optimal habitat ($HSI > 0.5$).

The significance level necessary to proceed to the next step in the stepwise progression was extremely stringent ($P < 0.001$). The output from the analysis was as follows: (1) the results of a test of the consistency of the classification scheme; (2) a listing of the discriminating variables included in the classification scheme in order of importance; (3) the functions that discriminate between groups; and (4) the amount each function contributes to the separation of the groups.

Dependable classification of coho salmon habitat into the above three groups were developed for Elk and Bear Creeks (Tables 11 and 12). The discriminant functions were consistent in assigning stream reaches to the correct group. Classifications developed for cutthroat trout habitats in these two creeks were not as strong as those for coho salmon, with only 56 to 79% of the stream reaches correctly categorized (Tables 13 and 14). Variables used in the habitat quality classification for each species were different for each creek. The importance of each variable is listed in stepwise fashion in Tables 15 through 18, with the most important variable listed first. Physical variables were more influential in classifying habitat quality than were biological factors when both types of information were entered into the analysis.

A habitat is assigned a group classification by utilizing the classification function coefficients (Fisher's Linear Discriminant Functions) for each of the three groups (Tables 15 through 18) in the following equation:

$$C_i = c_{i1}V_i + c_{i2}V_2 + \ldots + c_{ip}V_p + c_{i0}$$

where C_i = the classification score of the $i^{\underline{th}}$ group

c_{ij} = classification function coefficient for the $i^{\underline{th}}$ group for the $j^{\underline{th}}$ variable

V_j = the raw scores for the discriminating variables (in this case a variable value, rather than an SI).

The habitat is assigned to the group with the highest C_i score. In this study, three equations were used, one for each group of HSI's. The data for the discriminating variables in each reach (e.g., percent riffles) were entered into each of the three equations. The reach was classified as belonging to the group for which the equation generated the highest classification score. The classification function coefficients from the stepwise discriminant analysis are listed in Tables 15 through 18.

The relative contribution of the different physical factors to the habitat classification can be determined from the standardized cannonical discriminant function coefficients, presented in Tables 19 through 22. The greater the coefficient, irrespective of sign, the greater the relative contribution of that variable to the discriminant function. The discriminant function is a linear array of the variables that separate the classification groups. Therefore, there are, at a maximum, n - 1 functions, where n = the number of groups. The discriminant function takes the following form:

Table 11. Discriminant classification of coho salmon habitat in Elk Creek, Oregon.

		Predicted group membership					
		Physical factors only[b]			Physical and biotic factors[c]		
Actual group[a]	n	1	2	3	1	2	3
1	1	1	0	0	1	0	0
2	45	5	37	3	3	41	1
3	8	0	1	7	0	1	7

[a]Group 1: HSI = 0.
Group 2: 0 < HSI ≤ 0.5.
Group 3: HSI > 0.5.

[b]Percent of grouped classes correctly classified = 83.

[c]Percent of grouped classes correctly classified = 91.

Table 12. Discriminant classification of coho salmon habitat in Bear Creek, Oregon.

		Predicted group membership					
		Physical factors only[b]			Physical and biotic factors[c]		
Actual group[a]	n	1	2	3	1	2	3
1	19	18	1	0	18	1	0
2	25	1	20	4	1	20	4
3	2	0	0	2	0	0	2

[a]Group 1: HSI = 0.
Group 2: 0 < HSI ≤ 0.5.
Group 3: HSI > 0.5.

[b]Percent of group memberships correctly classified = 87.

[c]Percent of group memberships correctly classified = 87.

Table 13. Discriminant classification of cutthroat trout habitat in Bear Creek, Oregon.

		Predicted group membership					
		Physical factors only[b]			Physical and biotic factors[c]		
Actual group[a]	n	1	2	3	1	2	3
1	4	4	0	0	4	0	0
2	36	3	26	7	3	26	7
3	6	0	1	5	0	1	5

[a]Group 1: HSI = 0.
Group 2: 0 < HSI ≤ 0.5.
Group 3: HSI > 0.5.

[b]Percent of group memberships correctly classified = 79.

[c]Percent of group memberships correctly classified = 79.

Table 14. Discriminant classification of cutthroat trout habitat in Elk Creek, Oregon.

		Predicted group membership					
		Physical factors only[b]			Physical and biotic factors[c]		
Actual group[a]	n	1	2	3	1	2	3
1	12	9	2	1	8	4	0
2	40	15	19	6	15	21	4
3	2	0	0	2	0	0	2

[a]Group 1: HSI = 0.
Group 2: 0 < HSI ≤ 0.5.
Group 3: HSI > 0.5.

[b]Percent of group memberships correctly classified = 56.

[c]Percent of group memberships correctly classified = 57.

Table 15. Discriminating variables (in order of importance) and classification function coefficients for coho salmon habitats in Elk Creek, Oregon.

	Classification function coefficient (Fisher's linear discriminant functions)		
	Group[a]		
Discriminating variable	1	2	3
Physical variables only			
Pool area (m^2)	-0.1764271E-01	-0.8873049E-02	0.4097494E-01
% gravel (0.25-7.5 cm)	0.9536458E-01	-0.5001172E-02	0.7867174E-01
% riffles	0.1798793	0.1652062	0.8976250E-01
% sand (< 0.25 cm)	0.4193116	0.2989292	0.1691138
% shade	0.3017159E-01	0.9107727E-01	0.4182216E-01
(constant)	-16.24723	-10.07474	-8.327023
Physical and biotic variables			
Pool area (m^2)	-0.6475417E-01	-0.3857303E-01	0.2490734E-01
% gravel (0.25-7.5 cm)	0.2032602	0.6197721E-01	0.1689894
% riffles	0.1797688	0.1498189	0.7635389E-01
% sand	0.6265413	0.4271926	0.2644377
% shade	-0.2120051E-01	0.3831872E-01	-0.3699811E-01
Cutthroat trout density ($fish/m^2$)	-411.1193	63.29815	359.4763
Velocity (cm/sec)	-0.1341412	-0.2888435E-01	-0.4948371E-04
Gradient (%)	4.788535	2.483439	0.7726576
Wetted width (m)	1.593760	1.358135	2.651411
Reach area (m^2)	-0.3165023	0.1744737E-01	-0.7267815
Adult steelhead trout density ($fish/m^2$)	-10.88195	5.554163	-9.280271
(constant)	-31.39102	-22.12381	-24.46999

[a]Group 1: HSI = 0.
Group 2: 0 < HSI ≤ 0.5.
Group 3: HSI > 0.5.

Table 16. Discriminating variables (in order of importance) and classification function coefficients for coho salmon habitats in Bear Creek, Oregon.

	Classification function coefficient (Fisher's linear discriminant functions)		
	Group[a]		
Discriminating variable	1	2	3
Physical variables only			
Stream station	2.896550	2.038389	2.300972
% cobble (15-30 cm)	0.5977562E-01	0.1378231	0.1027025
Discharge (m^3/sec)	8.796847	7.672117	7.970734
% gravel (0.25-7.5 cm)	0.4459966	0.4198163	0.4938864
(constant)	-77.53604	-51.65622	-60.23201
Physical and biotic variables			
Stream station	3.236951	2.399255	2.734085
Cobble (15-30 cm)	-0.6001767E-02	0.6809110E-01	0.1900992E-01
Discharge (m^3/sec)	10.37424	9.344346	9.977749
% gravel (0.25-7.5 cm)	0.4772158	0.4529125	0.5336085
Steelhead trout density, all ages (fish/m^2)	90.37711	95.61073	114.9923
(constant)	-89.39975	-64.98935	-79.43821

[a]Group 1: HSI = 0.
Group 2: 0 < HSI ≤ 0.5.
Group 3: HSI > 0.5.

Table 17. Discriminating variables (in order of importance) and classification function coefficients for cutthroat trout habitats in Bear Creek, Oregon.

	Classification function coefficient (Fisher's linear discriminant functions)		
	Group[a]		
Discriminating variable	1	2	3
Physical variables only			
Stream station	1.252200	1.242652	1.441748
% pools	0.2467299	0.2949621	0.3316566
Channel width (m)	1.047911	1.367296	1.094882
Velocity (cm/sec)	-0.2047139	-0.2169512E-01	-0.1101369
Discharge (m^3/sec)	4.926466	3.671335	4.360979
% large boulders (> 91 cm)	-0.4831673	-0.2058869	-0.5058722
% riffles	0.3103531	0.2558434	0.3059169
Gradient (%)	4.413873	2.997646	3.827703
(constant)	-54.45631	-54.47107	-60.28322
Physical and biotic variables			
Stream station	1.252200	1.242652	1.441748
% pools	0.2467299	0.2949621	0.3316566
Channel width (m)	1.047911	1.367296	1.094882
Velocity (cm/sec)	-0.2047139	-0.2169512E-01	-0.1101369
Discharge (m^3/sec)	4.926466	3.671335	4.360979
% large boulders (> 91 cm)	-0.4831673	-0.2058869	-0.5058722
% riffles	0.3103531	0.2558434	0.3059169
Gradient (%)	4.413873	2.997646	3.827703
(constant)	-54.45631	-54.47107	-60.28322

[a]Group 1: HSI = 0.
Group 2: 0 < HSI ≤ 0.5.
Group 3: HSI > 0.5.

Table 18. Discriminating variables (in order of importance) and classification function coefficients for cutthroat trout habitats in Elk Creek, Oregon.

	Classification function coefficient (Fisher's linear discriminant functions)		
	Group[a]		
Discriminating variable	1	2	3
Physical variables only			
% sand (< 0.25 cm)	0.3064194	0.3363853	0.6222125
% boulders (> 30-91 cm)	0.3198240	0.3319991	0.6821692
% pools	-0.3545563E-01	-0.1489970E-01	-0.1031930
% cobble (15-30 cm)	0.1900890	0.2276116	0.2642542
(constant)	-6.362928	-8.471548	-17.07285
Physical and biotic variables			
% sand (< 0.25 cm)	0.5349138	0.5928597	1.089571
% boulders (> 30-91 cm)	0.3431303	0.3750123	0.8106874
% pools	-0.6764382E-01	-0.4876971E-01	-0.1852134
% cobble (15-30 cm)	0.1834991	0.2254930	0.2793199
Coho density (fish/m^2)	119.7667	131.1373	224.1337
Pool area (m^2)	-0.6193856E-01	-0.7052875E-01	-0.1397105
Gradient (%)	4.166316	4.315616	6.904890
Velocity (cm/sec)	0.5028090E-01	0.5381426E-01	-0.3304682E-01
(constant)	-16.96520	-20.67998	-43.92655

[a]Group 1: HSI = 0.
Group 2: 0 < HSI ≤ 0.5.
Group 3: HSI > 0.5.

Table 19. Standardized cannonical discriminant function coefficients for cutthroat trout in Elk Creek, Oregon.

Discriminating variable	Function 1	Function 2
Physical variables entered		
% pools	-0.80175	-1.07370
% boulders (> 30-91 cm)	0.85505	0.19983
% cobble (15-30 cm)	0.46436	-0.78645
% sand (< 0.25 cm)	1.60703	0.01799
Physical and biotic variables entered		
Gradient (%)	-0.64726	0.12114
Velocity (cm/sec)	0.49330	-0.34773
Pool area (m^2)	1.10950	0.14048
% pools	0.83786	-1.08514
% boulders (> 30-91 cm)	-0.67364	0.07512
% cobble (15-30 cm)	-0.36845	-0.81955
% sand (< 0.25 cm)	-1.73115	-0.16015
Coho density (fish/m^2)	-1.15427	-0.13623

Table 20. Standardized cannonical discriminant function coefficients for cutthroat trout in Bear Creek, Oregon.

Discriminating variable	Function 1	Function 2
Physical variables entered		
Reach number	0.06886	-1.21032
Gradient (%)	-0.48928	-0.42181
Velocity (cm/s)	1.09707	0.76573
Discharge (m^3/sec)	-1.07956	-0.86700
Channel width (m)	0.57471	0.75300
% pools	0.46071	-0.45037
% riffles	-0.49869	-0.71105
% large boulders (> 91 cm)	0.35201	0.60644
Physical and biotic variables entered		
Reach number	0.06886	-1.21032
Gradient (%)	-0.48928	-0.42181
Velocity (cm/s)	1.09707	0.76573
Discharge (m^3/sec)	-1.07956	-0.86700
Channel width (m)	0.57471	0.75300
% pools	0.46071	-0.45037
% riffles	-0.49869	-0.71105
% large boulders (> 91 cm)	0.35201	0.60644

Table 21. Standardized cannonical discriminant function coefficients for coho salmon in Elk Creek, Oregon.

Discriminating variable	Function 1	Function 2
Physical variables entered		
Pool area	0.99287	0.32698
% riffles	-0.85156	-0.29667
% gravel (0.25-7.5 cm)	0.59945	-0.65021
% sand (< 0.25 cm)	-0.65492	-0.72063
% shade	-0.42275	0.47466
Physical and biotic variables entered		
Gradient (%)	0.48973	-0.53597
Velocity (cm/sec)	-0.22810	0.66529
Pool area (m^2)	-0.96638	0.24749
Reach area (m^2)	0.81616	0.46944
% riffles	0.63365	-0.15947
% gravel (0.25-7.5 cm)	-0.54488	-0.80699
% sand (< 0.25 cm)	0.64810	-0.64039
% shade	0.47023	0.43357
Wetted width (m)	-1.13101	-0.35225
Cutthroat trout density (fish/m^2)	-0.43733	0.57373
Adult steelhead trout density (fish/m^2)	0.29840	0.37420

Table 22. Standardized cannonical discriminant function coefficients for coho salmon in Bear Creek, Oregon.

Discriminating variable	Function 1	Function 2
Physical variables entered		
Reach number	1.55346	-0.20914
Discharge (m^3/sec)	0.63891	-0.01465
% cobble (15-30 cm)	-0.40665	0.21725
% gravel (0.25-7.5 cm)	0.12437	-0.95682
Physical and biotic variables entered		
Reach number	1.50567	0.55071
Discharge (m^3/sec)	0.57577	0.48567
% cobble (15-30 cm)	-0.38145	-0.36226
% gravel (0.25-7.5 cm)	0.11151	0.84024
Steelhead trout density - all ages (fish/m^2)	-0.09628	0.69654

$$D_i = d_{i1} Z_1 + d_{i2} Z_2 + \ldots + d_{ip} Z_p$$

where D_i = the discriminant score for the $i^{\underline{th}}$ group

d_{ij} = weighting coefficients

Z_j = standardized values of p number of discriminating variables.

Stream station number, which reflects the distance of the sampling station upstream from the first transect, is the most important variable for coho salmon habitat classification in Bear Creek (Table 22). The combination of pool area and wetted width of the section are the most important factors for classification of coho salmon habitat in Elk Creek when both physical and biotic factors are considered (Table 21).

The relative importance of these variables was associated with the first discriminant function only, which accounted for 88 to 98% of the variability in classification of habitat for coho salmon, irrespective of the creek classified. The first discriminant function accounted for 70 to 84% of the variability in separating habitat groups for cutthroat trout in Elk Creek (Table 19). The first discriminant function accounted for only 58% of the variability separating habitat groups for cutthroat trout in Bear Creek (Table 20); therefore, the second discriminant function was also considered. The most important variables were those with high values in both discriminant functions, velocity and flow. Entering biotic variables, as well as physical factors, into the classification scheme did not increase the amount of variability that could be accounted for in classifications of habitat for coho salmon or cutthroat trout in Bear Creek. It only increased the discriminating ability of habitat classification 7.41% for coho salmon and 1.85% for cutthroat trout in Elk Creek. This does not necessarily mean that biotic factors are unimportant in these two creeks. However, data on food availability, diseases, and terrestrial predators were unavailable. In addition, Elk Creek and Bear Creek are relatively depauperate in ichthyofauna, and biotic variables may be more important in systems with great species richness. The classification is of the overall stream system; reach-specific predictions will be affected by biotic variables, as shown in Figures 2 through 4, 7, 8, 12, 13, and 15 through 17.

CONCLUSIONS

The discriminant analysis approach was more accurate than HSI's based on aggregated Suitability Indices in predicting groups of standing crop values standardized to a 0-1.0 HSI scale. The percentage of correct classification with the discriminant analysis approach for coho habitats ranged from 87% in Bear Creek to 91% in Elk Creek; for cutthroat trout, it ranged from 57% in Elk Creek to 76% in Bear Creek. Using the same three HSI group classifications as in the discriminant analysis, the percentage of correct classifications of coho habitat with model-produced HSI predictions were 40%, 40%, and 34% for the ILF, LSI, and AVM approaches, respectively. The percentage of correct classifications for cutthroat trout were 70%, 19%, and 26% for the ILF, LSI, and AVM approaches, respectively.

One advantage of the discriminant analysis approach is that it classifies groups in a way that considers various interactions between habitat factors and, indeed, many habitat variables in aquatic systems are partially correlated. The stepwise procedure also helps in the determination of the most important factor limiting species abundance within an individual system. For example, pool area and gravel substrate were the most important physical factors determining habitat quality for coho salmon in Elk Creek. Reach number, discharge, and cobble substrate were the most important factors for coho in Bear Creek. Cutthroat trout also responded to different physical factors in different creeks. Therefore, it appears that different limiting factors can, and do, operate in different systems.

The relationships between physical factors and habitat quality may vary from reach to reach, especially when modified by biotic variables, such as competition. This assumption is supported by the differences in utilization patterns for cutthroat trout between areas above stream barriers that limit competition by other species and areas below barriers where both coho salmon and steelhead trout are found. When an entire stream is considered, biological interactions may not seem to be as important as physical factors in affecting fish distribution. However, biological interactions can be extremely important on a smaller scale, such as a stream reach. As shown in this study, interspecific competition can greatly affect empirically-derived SI's for cutthroat trout. SI's derived from population data were higher for areas where there was no competition.

Another factor to consider at the reach-specific level is the availability of microhabitats and associated resources. This refers both to food and cover and to the presence of predators and competitors that limit access to these resources. These types of interactions have been discussed by Werner and Hall (1976) and Werner (1977).

The feasibility of a hierarchical classification of stream habitats based on HSI's needs to be investigated. Warren (1979), Warren and Liss (1983), and Tonn et al. (1983) strongly advocate hierarchical classification as a practical means of habitat management at the community level. Many tools are available to analyze the influence of habitat variables on the distribution of a particular plant species, such as ordination, gradient analysis, and discriminant analysis. There is a potential problem with the use of some of the multivariate tools because of the likelihood of violating model assumptions despite careful sampling (Green 1980). The consequences of violating the assumptions are not well understood. However, Pimentel and Frey (1978) stated that the results of simulations based on data from known probability distributions indicate that departures from the assumptions do not affect the results of the analysis. For greater detail, consult Pimentel and Frey (1978), Green (1980), and Gauch (1982).

It is important to recognize that the models discussed in this report, including the discriminant model, do not demonstrate cause and effect relationships. However, these models are descriptive tools that can be used to identify possible habitat relationships to test in studies designed to determine the mechanisms that affect the distribution of a species.

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APPENDIX A. EMPIRICALLY-DERIVED HSI'S FOR SURVEY SITES IN THE NESTUCCA DRAINAGE (ELK CREEK AND BEAR CREEK) AND SOUTHCENTRAL OREGON COASTAL DRAINAGES (SMITH, SOUTH COOS, AND COQUILLE).

Table A-1. Empirically derived HSI's for Bear Creek, Oregon.

Station number	Fish species			Station number	Fish species		
	Coho salmon[a]	Steelhead trout[b]	Cutthroat trout[c]		Coho salmon[a]	Steelhead trout[b]	Cutthroat trout[c]
1	0.25	0.06	0	24	0.52	0.35	0.05
2	0.17	0.06	0	25	0.09	0.21	0.13
3	0.09	0.04	0.02	26	0.22	0.37	0.16
4	0.17	0.13	0.02	27	0.28	0.45	0.08
5	0.25	0.14	0.11	28[d]	0	0.42	0.22
6	0.22	0.18	0.02	29	0	0.32	0.22
7	0.07	0.22	0.02	30	0	0.34	0.22
8	0.01	0.11	0.02	31	0	0.21	0.11
9	0.13	0.43	0.02	32	0	0.30	0.19
10	0.10	0.35	0.02	33	0	0.39	0.61
11	0.20	0.21	0.02	34	0	0.31	0.61
12	0.13	0.38	0.02	35	0	0.37	0.36
13	0.05	0.21	0.02	36	0	0.18	0.36
14	0.56	0.47	0.13	37	0	0.22	0.52
15	0.43	0.25	0.02	38	0	0.09	0.50
16	0.23	0.16	0.08	39	0	0.04	0.16
17	0.09	0.31	0.05	40	0	0.03	0.94
18	0.43	0.36	0.02	41	0	0.05	0.38
19	0.09	0.49	0.16	42	0	0.06	1.00
20	0.23	0.71	0	43	0	0.05	0.36
21	0.25	0.50	0.11	44	0	0.17	0.27
22	0.31	0.54	0.02	45	0	0.05	0.44
23	0.08	0.16	0.02	46	0	0.07	0.38

[a]HSI = Estimated standing crop/0.222 fish/m^2.

[b]HSI = Estimated standing crop/0.391 fish/m^2.

[c]HSI = Estimated standing crop/0.036 fish/m^2.

[d]Stations numbered 28 and higher were above a logjam; coho salmon were absent from these stations.

Table A-2. Empirically derived HSI's for Elk Creek, Oregon.

Station number	Fish species			Station number	Fish species		
	Coho salmon[a]	Steelhead trout[b]	Cutthroat trout[c]		Coho salmon[a]	Steelhead trout[b]	Cutthroat trout[c]
47	0.55	0.21	0.08	74	0.19	0.39	0.03
48	0.14	0.28	0.06	75	0.18	0.31	0
49	0.32	0.24	0.03	76	0.14	0.42	0
50	0.32	0.16	0.06	77	0.21	0.36	0
51	0.17	0.31	0.03	78	0.22	0.64	0.03
52	0.29	0.39	0.06	79[d]	0.44	0	0.01
53	0.40	0.10	0.08	80	0.27	0	0.06
54	0.20	0.13	0.0	81	0.31	0	0.03
55	0.13	0.14	0.0	82	0.26	0	0.06
56	0.24	0.09	0.03	83	0.45	0	0
57	0.31	0.29	0.03	84	0.18	0	0
58	0.57	0.20	0.11	85	0.23	0	0.14
59	0.44	0.18	0.06	86	0.29	0	0.06
60	0.27	0.32	0.03	87	0.79	0	0.17
61	0.31	0.09	0.06	88	0.02	0	0.06
62	0.26	0.11	0.03	89	1.00	0	0.06
63	0.91	0.03	0.06	90	0.005	0	0.06
64	0.10	0.26	0	91	0.14	0	0.75
65	0.39	0.20	0.11	92	0	0	0.03
66	0.14	0.19	0.03	93	0.15	0	0.28
67	0.14	0.18	0.03	94	0.71	0	0.53
68	0.53	0.27	0.06	95	0.06	0	0.28
69	0.71	0.14	0.06	96	0.01	0	0
70	0.29	0.18	0	97	0.13	0	0.03
71	0.45	0.14	0	98	0.50	0	0.44
72	0.31	0.49	0	99	0.15	0	0.22
73	0.22	1.00	0.03	100	0.01	0	0.08

[a]HSI = Estimated standing crop/0.222 fish/m².

[b]HSI = Estimated standing crop/0.391 fish/m².

[c]HSI = Estimated standing crop/0.036 fish/m².

[d]Stations numbered 79 and higher were above a waterfall; steelhead trout were absent from these stations.

Table A-3. Empirically derived HSI's for southcentral Oregon coastal drainages.

Drainage	Fish species	
	Coho[a] salmon	Cutthroat[b] trout
Smith	0	0.51
	0	1.00
	0	0.49
	0.57	0.01
	0.02	0
	1.00	0
	0.08	0.01
	0.05	0.02
	0	--
	0	--
	0.23	0
	0.03	0
	0.03	0.02
South Coos	0.38	0
	0.43	0.10
	0.31	0.08
	0.60	0.03
	0.90	0.18
	0.81	0.15
	0.77	0.10
	0.53	0.51
	0.11	0
	0.38	0.51
	0.14	0
	0.03	0
	0.78	0
	0.93	0.02
	0.74	0.01
	0.76	0
Coquille	0.04	Absent
	0.03	Absent
	0.24	Absent
	0.29	Absent
	0.24	Absent
	0.06	Absent

[a]HSI = Estimated standing crop/2.91 gm/m².

[b]HSI = Estimated standing crop/7.81 gm/m².

APPENDIX B. PHYSICAL FACTORS MEASURED AT SURVEY SITES IN THE NESTUCCA DRAINAGE AND IN THE SOUTHCENTRAL OREGON COASTAL DRAINAGES.

Nestucca drainage	Southcentral coastal drainages
Gradient (%)	Elevation (m)
Velocity (m/sec)	Site length (m)
Flow (cfs)	Average width (m)
Channel width (m)	Maximum width (m)
Wetted width (m)	Average depth (m)
Pool width (m)	Maximum depth (m)
Maximum pool depth(m)	Station volume (m^3)
% pools/riffles/glides/rapids/cascades	Station surface area (m^2)
% bedrock	Flow (cfs)
% boulders	Average velocity (m/sec)
% cobble	Maximum temperature (°C)
% rubble	Minimum temperature (°C)
% coarse gravel	Pool/riffle ratio
% fine gravel	% canopy
% sand	% shade
% silt	% bedrock
% large organic material	% mixed substrate
% fine organic material	% boulders (> 30 cm)
Landform type	% cobble (15-30 cm)
Landform gradient	% rubble (7.6-14.9 cm)
Riparian width (m)	% coarse gravel (2.6-7.5 cm)
% cover	% small gravel (0.25-2.5 cm)
Channel stability	% sand (< 0.25)
Bank stability	% wood
Air temperature	% instream cover
Water temperature	
Average depth	

APPENDIX C

DRAFT SUITABILITY INDEX (SI) GRAPHS PRODUCED BY THE HABITAT EVALUATION PROCEDURES GROUP

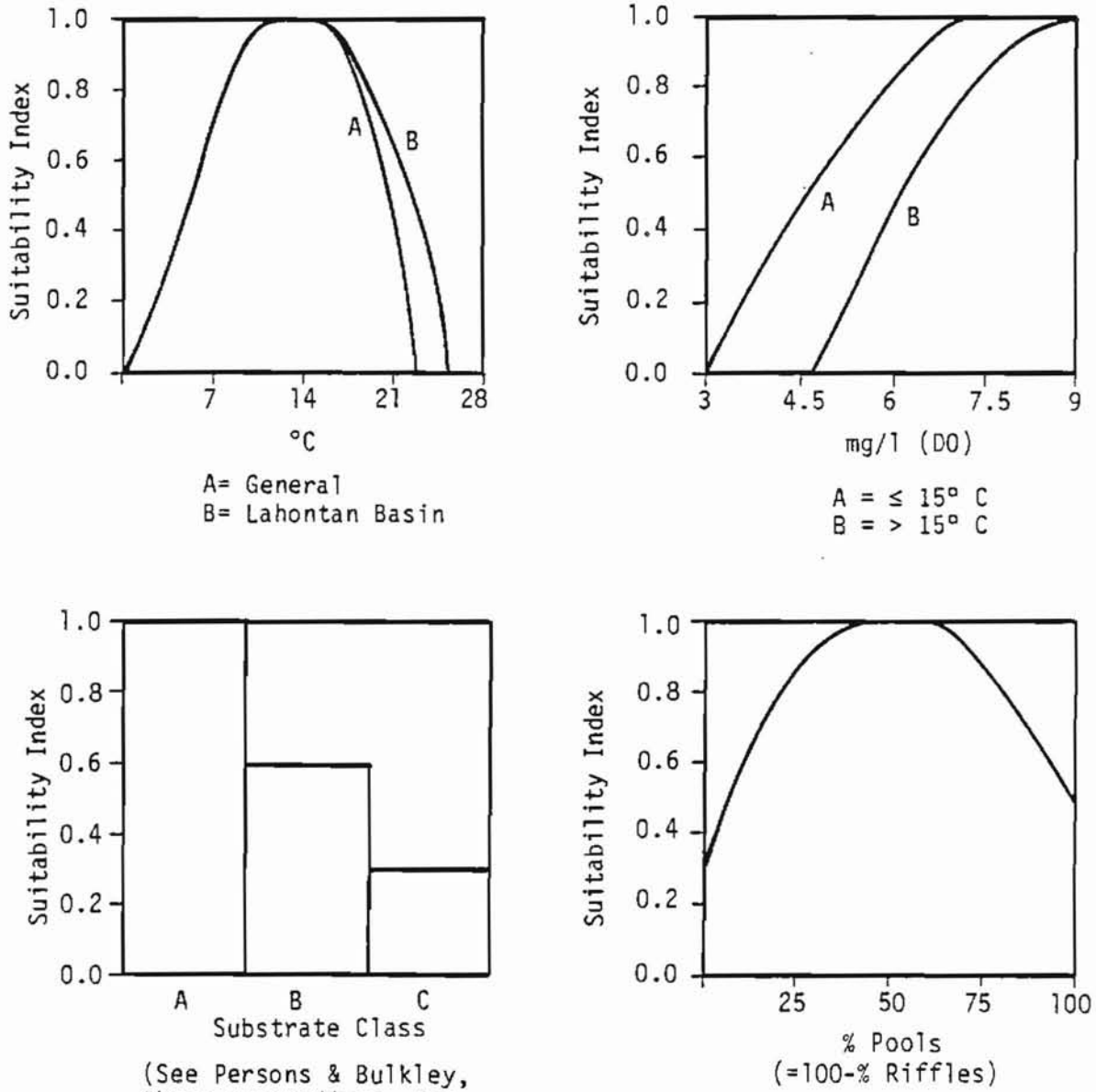
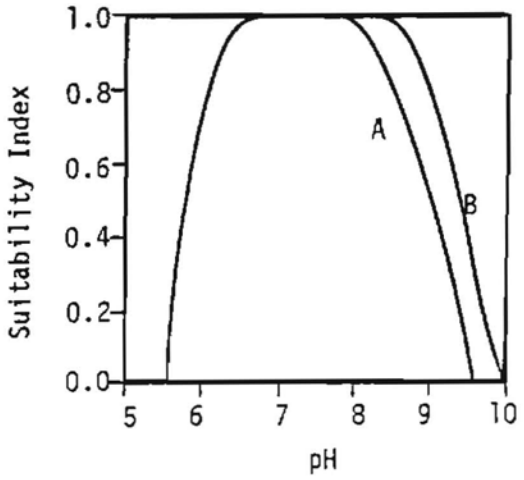
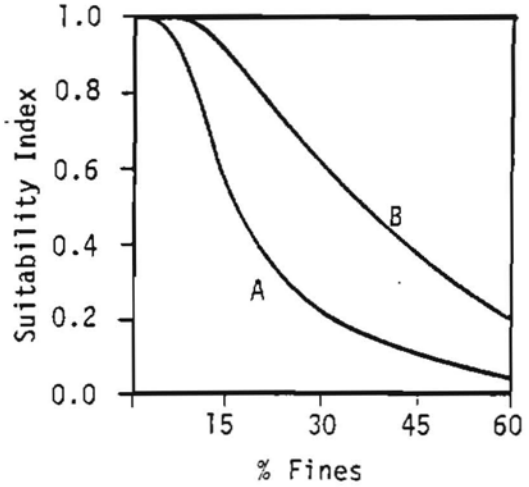


Figure C-1. Cutthroat trout draft SI graphs.



A= General
B= Lahontan Basin



A= Spawning
B= Riffle-run

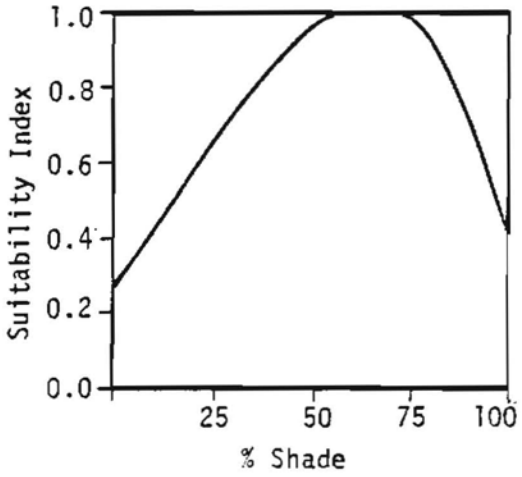


Figure C-1. (concluded)

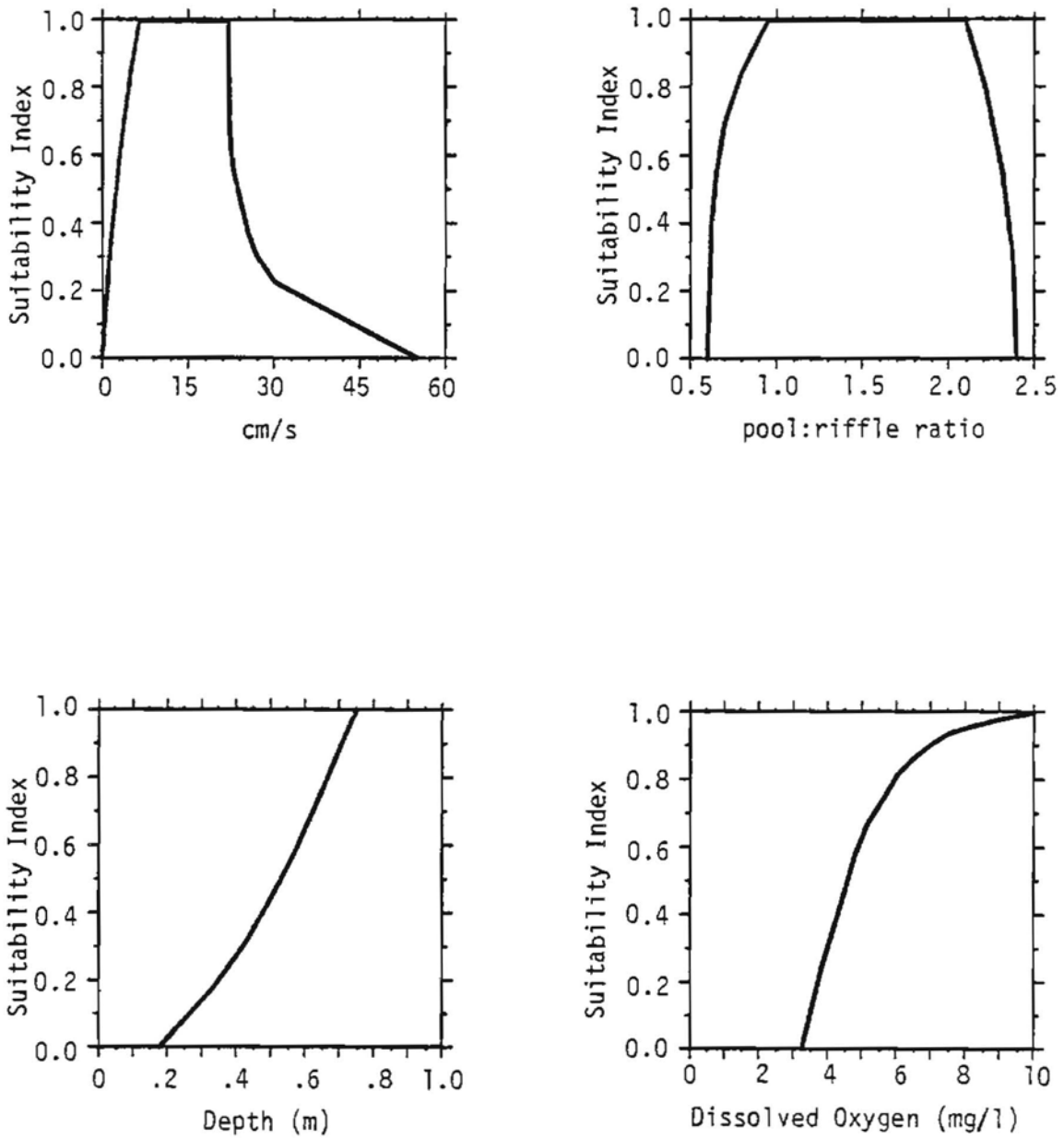
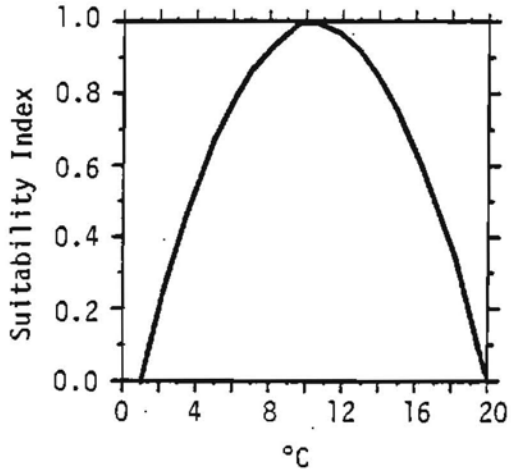


Figure C-2. Coho salmon draft SI graphs.



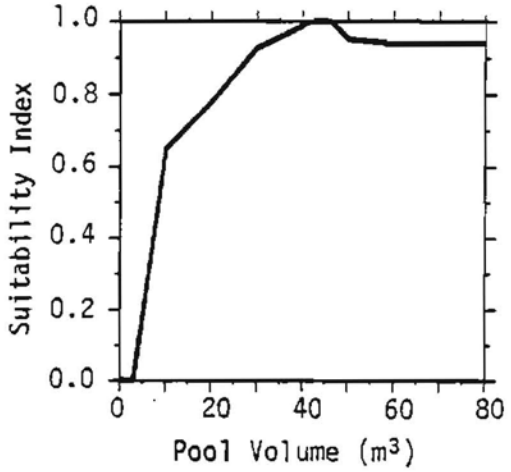


Figure C-2. (concluded)

EVALUATION OF THE RIVERINE CUTTHROAT TROUT HABITAT SUITABILITY INDEX MODEL

by

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Logan, UT

INTRODUCTION

The Western Energy and Land Use Team of the U.S. Fish and Wildlife Service has developed a cutthroat trout (Salmo clarki) riverine Habitat Suitability Index (HSI) model (Hickman and Raleigh 1982) for use with the Habitat Evaluation Procedures (HEP) (U.S. Fish and Wildlife Service 1980). The HSI is a numerical index that represents the ability of a given habitat to support riverine cutthroat trout. The HSI has a minimum value of 0.0, which represents a lack of suitable habitat, and a maximum value of 1.0, which represents optimum habitat.

The objective of this project was to evaluate a draft version (Appendix A) of the cutthroat trout riverine HSI model with field data.

MATERIALS AND METHODS

Habitat Model

The cutthroat trout HSI model that was tested was a draft of the model later published by Hickman and Raleigh (1982). The model (Appendix A) defines habitat variables (V_i) and, through the use of Suitability Index curves, assigns the data for each variable a Suitability Index (SI) from 0.0 to 1.0. An SI of 1.0 represents optimal conditions for a variable; an index of 0.0 represents unsuitable conditions. Suitability indices for individual variables are combined, or aggregated, by various techniques to produce a life stage component (C) suitability index (SI) for the different life stages (embryo, fry, juvenile, and adult). Life stage component SI's are then aggregated to produce a species Habitat Suitability Index (HSI).

In order to properly use an HSI model with the Habitat Evaluation Procedures (HEP), the user must assume a direct linear relationship between the HSI and carrying capacity (U.S. Fish and Wildlife Service 1980). Specifically, HEP is based on the assumption that a unit change in the HSI always has the same significance for an evaluation species (i.e., always corresponds to the same change of carrying capacity units) (Fig. 1).

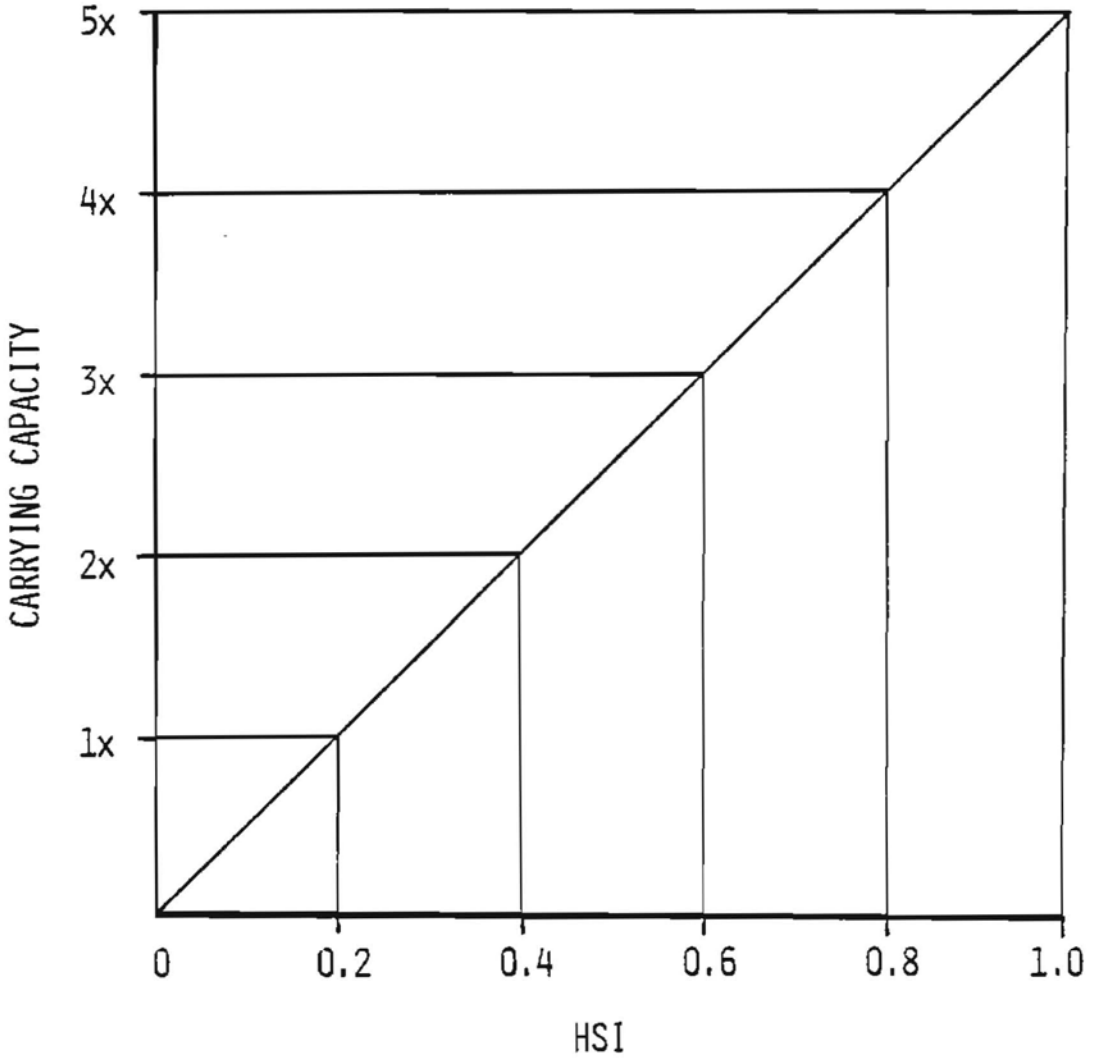

Figure 1. Assumed relationship between the HSI and habitat carrying capacity.

Data Set

The data set used to evaluate the model was taken from information collected for several years at 24 sample sites in seven Idaho, Nevada, and Utah streams (Appendix B) (Platts and Partridge 1980; Platts et al. 1980; Platts and Nelson 1981a, 1981b, 1981c, 1981d). Physical habitat data were collected from two to six sites in each stream on transects at 3 m intervals and perpendicular to the stream flow. Each site usually contained 60 transects. Yearly mean values of physical habitat data at each site were used to test the HSI model. Data were not always available exactly as described for each variable in the model; estimates or data for similar variables were used in these instances (Table 1).

Fish populations were sampled by electrofishing with the two-step removal depletion method (Serber and LeCren 1967). Each study site was fished twice within each transect interval; first from the lower to the upper transect and then from the upper to the lower. Body length, weight, and species were recorded for each fish collected. Total fish populations and total weights were estimated from the sample with a 95% confidence interval (Platts and Nelson 1981a). Mean biomass (g/m^2) was used as a standing crop estimate at each site for each year sampled. Twenty-seven standing crop estimates for cutthroat trout were available from four streams. Eighteen rainbow trout standing crop estimates were available for three streams. Because the draft rainbow and cutthroat trout HSI models were similar, the cutthroat trout model was also tested with rainbow trout data.

Standing crop estimates were based on data for adult and juvenile life stages. Ideally, life stage component SI's are tested with their respective biomass estimates. It is necessary to assume constant recruitment in order to estimate embryo and fry life stage biomass from adult and juvenile biomass estimates.

STREAM DESCRIPTIONS

Cutthroat Trout Streams

Angus Creek, Caribou County, Idaho, is a small, spring-fed, low gradient stream, flowing primarily through valley bottomlands. Streamside vegetation consists of grasses (*Gramineae*), willow (*Salix* spp.), and sagebrush (*Artemisia* spp.). Angus Creek contains cutthroat trout, one or two species of suckers (*Catostomus catostomus*, *C. platyrhynchus*), dace (*Rhinichthys* spp.), redside shiner (*Richardsonius balteatus*), and sculpin (*Cottus* spp.) (Platts and Partridge 1980; Platts et al. 1980).

Diamond Creek, Idaho, similar to Angus Creek in most respects, joins Lane's Creek to form the Blackfoot River in Caribou County. It is the primary tributary used by cutthroat trout for spawning and rearing in the drainage. It also contains brook trout (*Salvelinus fontinalis*), sculpin, dace, redside shiner, and suckers. During low stream flows in the summer and fall, portions of Diamond Creek dry up because of irrigation diversions and stream channel splitting (Platts and Partridge 1980; Platts et al. 1980).

Table 1. Variables used to test the riverine cutthroat trout HSI model.

	Model variable[a]	Variable used to test model
V_1	Maximum temperature	Estimated when data were not available.[b]
V_2	Maximum temperature (reproduction stage)	Estimated during embryo development.[b]
V_3	Dissolved oxygen	Estimated when data were not available.[b]
V_4	Depth	Average depth during the sampling period.
V_5	Velocity	Estimated effects of velocity on embryo development.[b]
V_{6A}	Percent cover (Adult)	Calculated as percent vegetative overhang + percent undercut banks + percent boulders.
V_{6J}	Percent cover (Juvenile)	Calculated as percent vegetative overhang + percent undercut banks + percent boulders.
V_7	Substrate (Embryo)	Estimated suitability of substrate for spawning and embryo development.[b]
V_8	Substrate (Cover)	Calculated as percent rubble + percent boulder.
V_9	Substrate (Food production)	Substrate for food production rating (Appendix B, Table B-1).
V_{10}	Percent pools	Calculated from (pool width)/(stream width).
V_{11}	Streambank vegetation	Streamside cover rating (Appendix B, Table B-2).
V_{12}	Bank stability	Streamside stability rating (Appendix B, Table B-3).
V_{13}	pH	Estimated when data were not available.[b]
V_{14}	Flow regime	Data or estimate not available.
V_{15}	Pool class rating	Pool quality rating (Appendix B, Table B-4).
V_{16}	Percent fines	Embeddedness rating (Appendix B, Table B-5).

[a]Model variables are described in Appendix A.

[b]Variable values estimated by W. S. Platts (personal communication, U.S. Forest Service, Boise, Idaho).

The Blackfoot River and reservoir produce trophy-size cutthroat trout that migrate up the river to spawn in tributary streams. The Blackfoot River above the reservoir contains cutthroat trout, rainbow trout (Salmo gairdneri), suckers, carp (Cyprinus carpio), dace, redside shiner, sculpin, brook trout, and chub (Gila spp.) (Platts and Partridge 1980; Platts et al., 1980).

Gance Creek, Elko County, Nevada, is a highly unstable system, as reflected by the dramatic fluctuations over time of its hydrologic, aquatic habitat, and fish population characteristics (Platts and Nelson 1981a). The Gance Creek watershed is primarily sagebrush grazing land. Nonnative species of trout have been introduced in the past, but, at the time of the data collection, the salmonid population appeared to be Lahontan cutthroat trout (Salmo clarki henshawi) or, possibly, Humboldt River cutthroat (Salmo clarki subsp.). Sculpin and dace also occur in Gance Creek, although primarily below the area of highest concentration of cutthroat trout (Platts and Nelson 1981d).

Rainbow Trout Streams

Tabor Creek, Elko County, Nevada, is surrounded by semiarid shrubsteppe, with an almost uniform stand of sagebrush, used primarily for grazing. Tabor Creek contains rainbow trout, sculpin, dace, and suckers. Hatchery rainbow trout have been stocked in part of the study area (Platts and Nelson 1981a).

Otter Creek, Utah, is a meandering, low gradient stream in grazing land located in Piute County. The creek receives considerable recreational fishing pressure and supports only limited natural reproduction. It is managed as a put-and-take fishery to provide more recreation than the stream is capable of producing naturally. Brown trout (Salmo trutta) and rainbow trout were collected from the stream. Biomass estimates may be biased due to stocking and angler harvesting (Platts and Nelson 1981b).

Big Creek, Rich County, Utah, is similar to Otter Creek. The land surrounding Big Creek is a semiarid shrubsteppe. Big sagebrush (Artemisia tridentata) is the dominant plant on the grazed hills surrounding the stream. Nongame species dominate the fish community; sculpins are the most abundant species present. Suckers, rainbow trout, and cutthroat trout are also present (Platts and Nelson 1981c).

RESULTS

Evaluation of Cutthroat Trout Suitability Index Curves

Correlation coefficients. Suitability indices (SI's) for 16 habitat variables were compared with 27 cutthroat trout standing crop estimates. Correlation coefficients could be calculated for 14 of the 16 variables; coefficients for 10 of these variables had a negative value. The low values for most of the correlation coefficients (< 0.5) indicated a poor relationship between estimates of standing crop and suitability indices for individual variables (Table 2). The Suitability Index for average depth (V_4) had a significant negative correlation with cutthroat trout biomass ($r = -0.46$, $p \leq 0.01$); however, the relationship was the opposite of that expected.

Table 2. Mean, standard deviation, and correlation of suitability indices and biomass for 27 cutthroat trout and 18 rainbow trout samples.

Variable	Cutthroat (n = 27)			Rainbow (n = 18)			Total (n = 45)		
	Mean	SD	r	Mean	SD	r	Mean	SD	r
V_1	0.75	0.19	-0.12	0.80	0.15	0.53	0.77	0.17	0.13
V_2	0.61	0.24	-0.07	0.53	0.38	0.47	0.58	0.30	0.22
V_3	1.00	0	-	0.83	0.24	0.28	0.93	0.17	0.26
V_4	0.51	0.35	-0.46**	0.65	0.26	-0.49	0.56	0.33	-0.49**
V_5	0.82	0.24	-0.49**	0.93	0.10	0.28	0.86	0.20	-0.35**
V_{6A}	0.79	0.18	-0.18	0.83	0.24	-0.42	0.81	0.21	-0.30
V_{6J}	0.93	0.12	0.02	0.93	0.12	-0.20	0.93	0.12	-0.06
V_7	0.96	0.13	0.34	1.0	0	-	0.98	0.10	0.21
V_8	0.68	0.39	0.09	0.74	0.39	0.28	0.70	0.39	0.14
V_9	0.57	0.14	-0.01	0.60	0	-	0.58	0.11	-0.03
V_{10}	0.78	0.20	0.37	0.81	0.17	0.01	0.79	0.19	0.22
V_{11}	0.72	0.17	-0.21	0.49	0.08	0.11	0.63	0.18	0.05
V_{12}	0.77	0.24	-0.39	0.68	0.20	-0.07	0.73	0.23	-0.22
V_{13}	1.00	0	-	0.90	0.15	0.25	0.96	0.10.	0.24
V_{15}	0.57	0.23	-0.18	0.62	0.25	-0.36	0.59	0.24	-0.28
V_{16}	0.28	0.13	-0.03	0.27	0.11	0.38	0.27	0.12	0.13

**$P \leq 0.01$

Streams with relatively shallow mean depths (< 10 cm) had high standing crops of trout, whereas relatively deep streams (> 40 cm) had low standing crops. The Suitability Index for average velocity (V_5) was also significantly negatively correlated with cutthrot trout biomass ($r = -0.49$, $P \leq 0.01$). These two negative correlations indicated a need to revise the suitability curves for depth (V_4) and velocity (V_5) for cutthroat trout in the streams sampled.

Suitability Index - biomass plots. If field data exactly fit the suitability curves, all data points fall on a theoretical (45°) regression line, as illustrated in Figure 1. However, if all the data points for a particular variable did fall on the theoretical 45° line, it would indicate that the variable independently determined standing crop. This condition does not occur because many habitat variables interact to determine standing crop. Therefore, a Suitability Index curve can be accurate if most data points are on or below the theoretical regression line. Data points far above the 45° line may indicate poor data, inaccurate suitability index curves, or a combination of these two factors.

For the data tested, the theoretical regression line was drawn to reflect an "optimum" carrying capacity (maximum standing crop) of 14.6 g/m², measured for rainbow trout. Suitability indices for each variable were plotted against standing crop estimates (Figs. 2 to 17) so that the fit of the field data to the suitability index curves and verbal ratings of the model could be examined.

Water temperature for adults, juveniles, and fry (V_1) was not significantly correlated with biomass, but most data points were in the acceptable range under the theoretical regression line (Fig. 2). Most values for embryo temperature (V_2) also were under the theoretical regression line (Fig. 3). The three data points (SI = 0.5, biomass = 9 to 12 g/m²) above the theoretical regression line in Figure 3 represent Lahontan, or possibly Humboldt River, cutthroat strains from Gance Creek, Nevada. Both of these strains are very adaptable to warm temperatures. Based on the location of most of the data points in relation to the theoretical regression lines, the assumed relationship between habitat suitability and temperature is probably accurately described by the model suitability index curves V_1 and V_2. However, evaluating an embryo SI curve (V_2) with adult and juvenile biomass estimates is questionable because it is based on an assumption of constant year class strength and recruitment.

Dissolved oxygen in all cutthroat trout streams was rated as optimal, and all of the data points were under the theoretical regression line (Fig. 4). Because all of the data points equated to the same SI rating, an evaluation of the model's suitability index curve for oxygen was not possible.

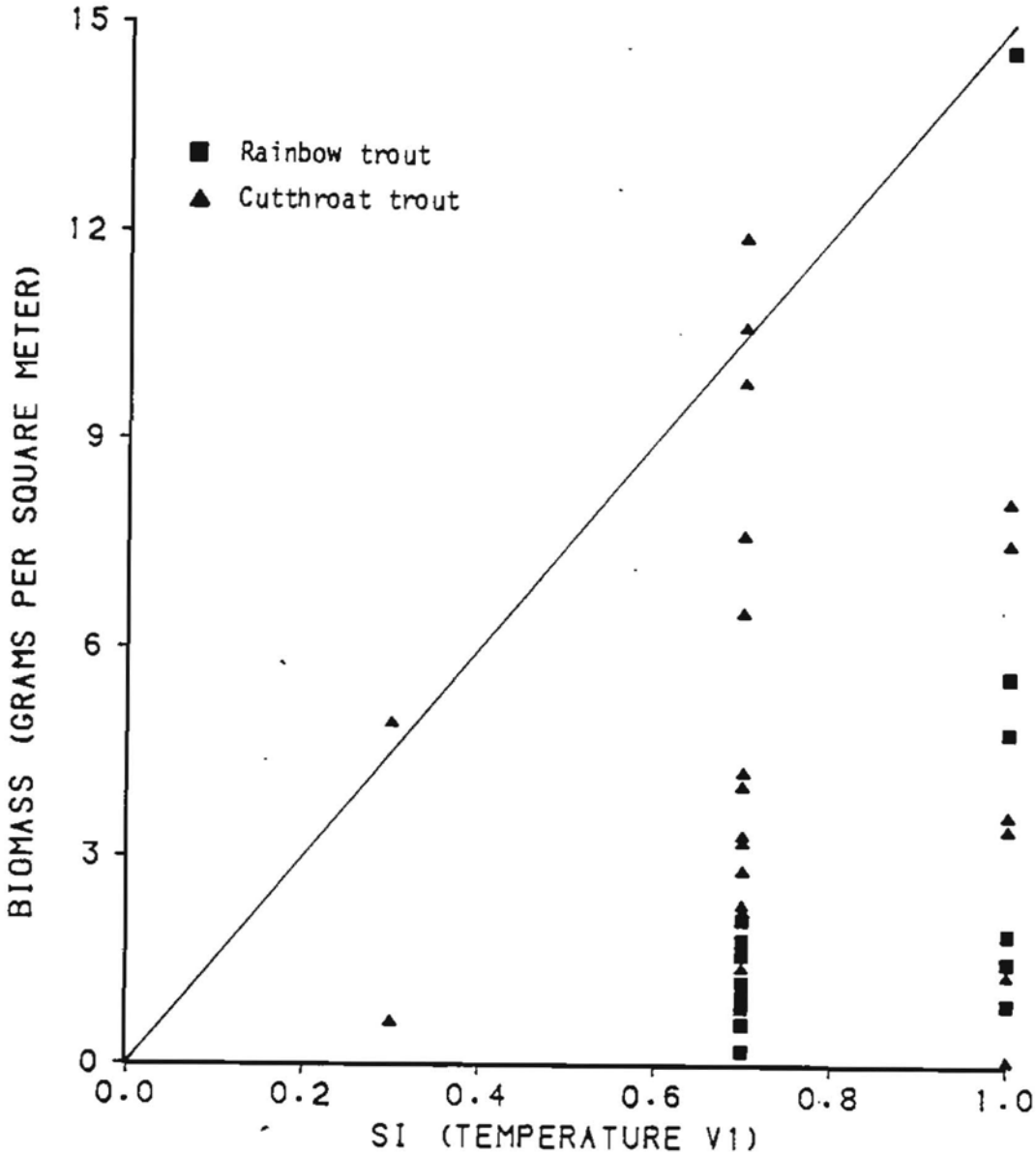

Figure 2. Relationship between temperature for adults, juveniles, and fry (V_1) and biomass.

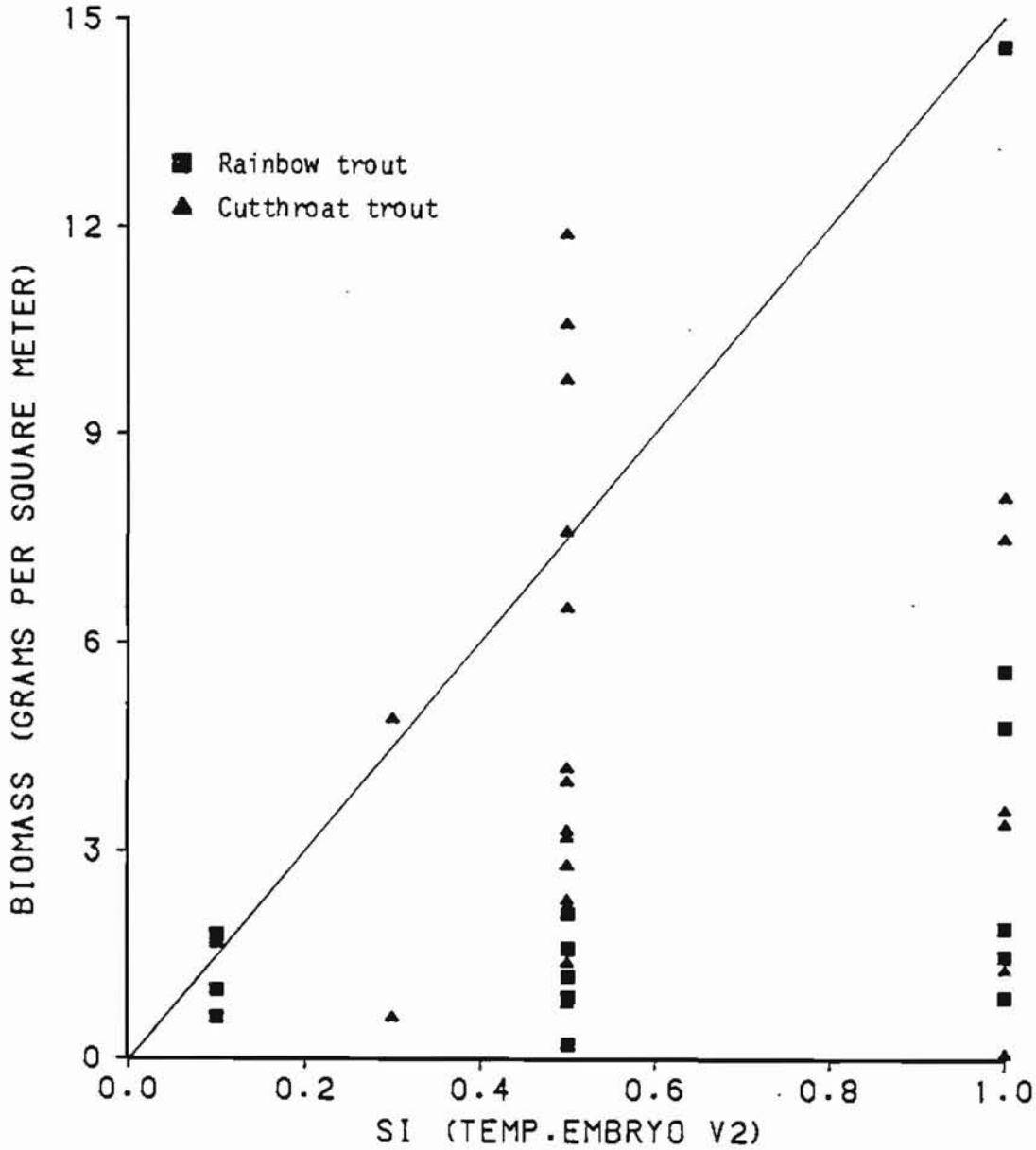

Figure 3. Relationship between temperature for embryos (V_2) and biomass.

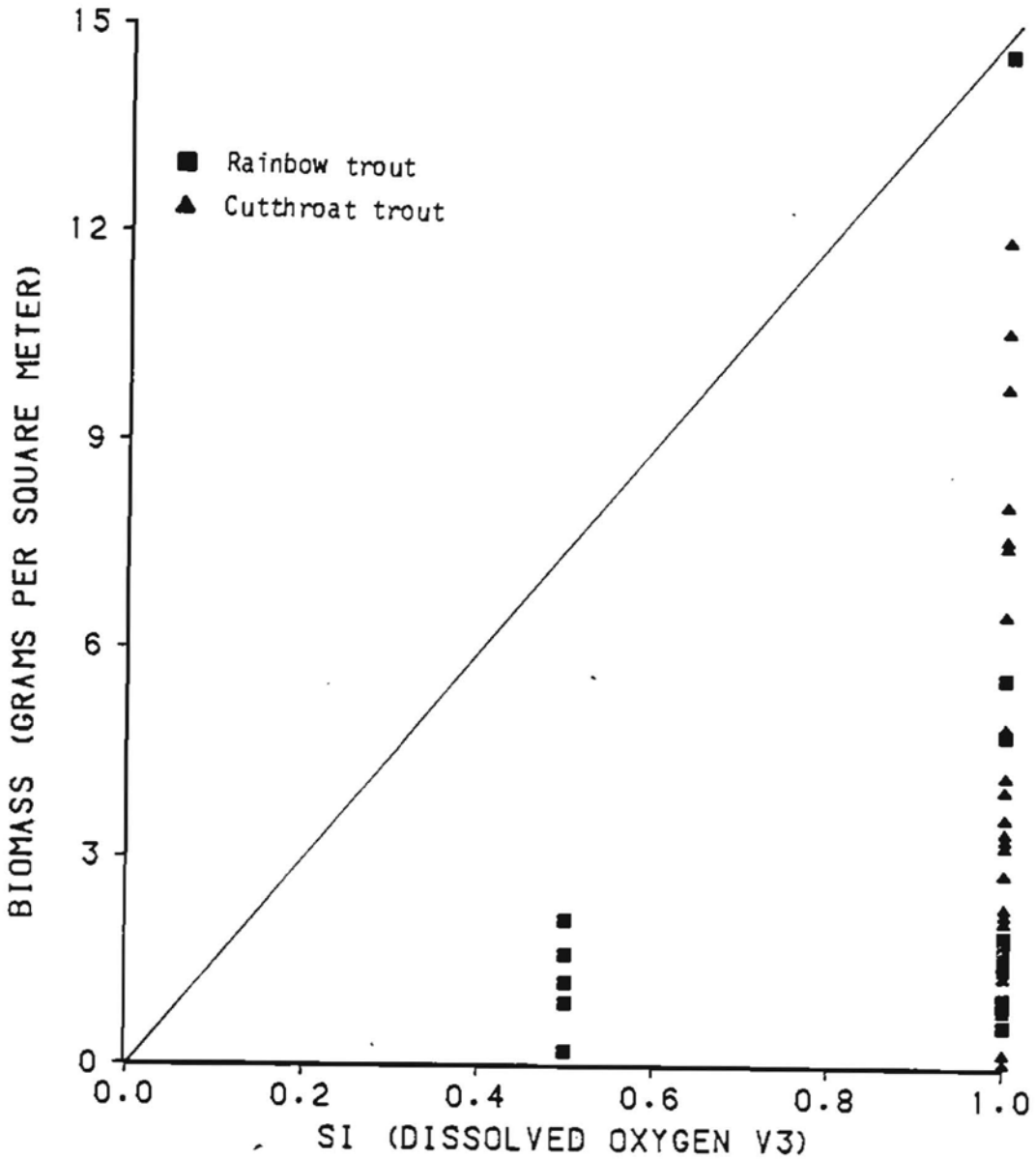

Figure 4. Relationship between dissolved oxygen (V_3) and biomass.

One-fourth of the data points were located above the theoretical regression line when depth SI ratings versus biomass were plotted (Fig. 5). Therefore, the actual biomass was greater than the biomass predicted by the suitability index curve. All of the SI's of 0.1 were from Gance Creek, which contains the Lahontan or Humboldt River subspecies of trout. The adaptability and hardiness of this strain may explain the relatively high standing crops present when the SI's predicted a low carrying capacity. It appears that alternate SI curves for depth may be needed for different populations of cutthroat.

With the exception of three data points for Gance Creek, most of the data points for water velocity in embryo habitat (V_5) were below the theoretical regression line (Fig. 6). Although the SI's for this variable had a significant negative correlation with biomass (Table 2), most data points were within the acceptable range of values. However, the validity of testing this embryo curve with adult and juvenile biomass data is questionable because it is based on an assumption of constant recruitment.

Data points for percent cover suitability indices for adults and juveniles (V_{6A}, V_{6J}) were below the theoretical regression lines (Figs. 7 and 8). Data from the Gance Creek population were again above the theoretical regression line, suggesting that different suitability curves may be needed for some cutthroat populations.

With the exception of two sample sites on the Blackfoot River, spawning substrate (V_7) at cutthroat streams was rated as optimal (Fig. 9); therefore, the model suitability index curve could not be evaluated. Most juvenile substrate ratings (V_8) were near or below the theoretical regression line (Fig. 10), indicating that the suitability index curve was probably valid. Substrate for food production (V_9) was most often rated as 0.6 (Fig. 11). Three of the data points above the theoretical regression line were for the Gance Creek population.

Data points for percent pools (V_{10}) ratings were on or below the theoretical regression line (Fig. 12). With the exception of three data points from Gance Creek, data points for streamside cover (V_{11}) and bank stability (V_{12}) ratings also were below the theoretical regression line (Figs. 13 and 14). Therefore, suitability index curves for V_{10}, V_{11}, and V_{12} were assumed to be relatively valid, although changes in the curves may be necessary for certain populations or subspecies.

All pH (V_{13}) values for cutthroat were rated at 1.0; therefore, the suitability curve could not be evaluated (Fig. 15). Pool rating (V_{15}) had several data points above the theoretical regression line (Fig. 16); most of these points were from the Gance Creek population. The standing crops of cutthroat at Gance Creek were higher than predicted by the suitability index

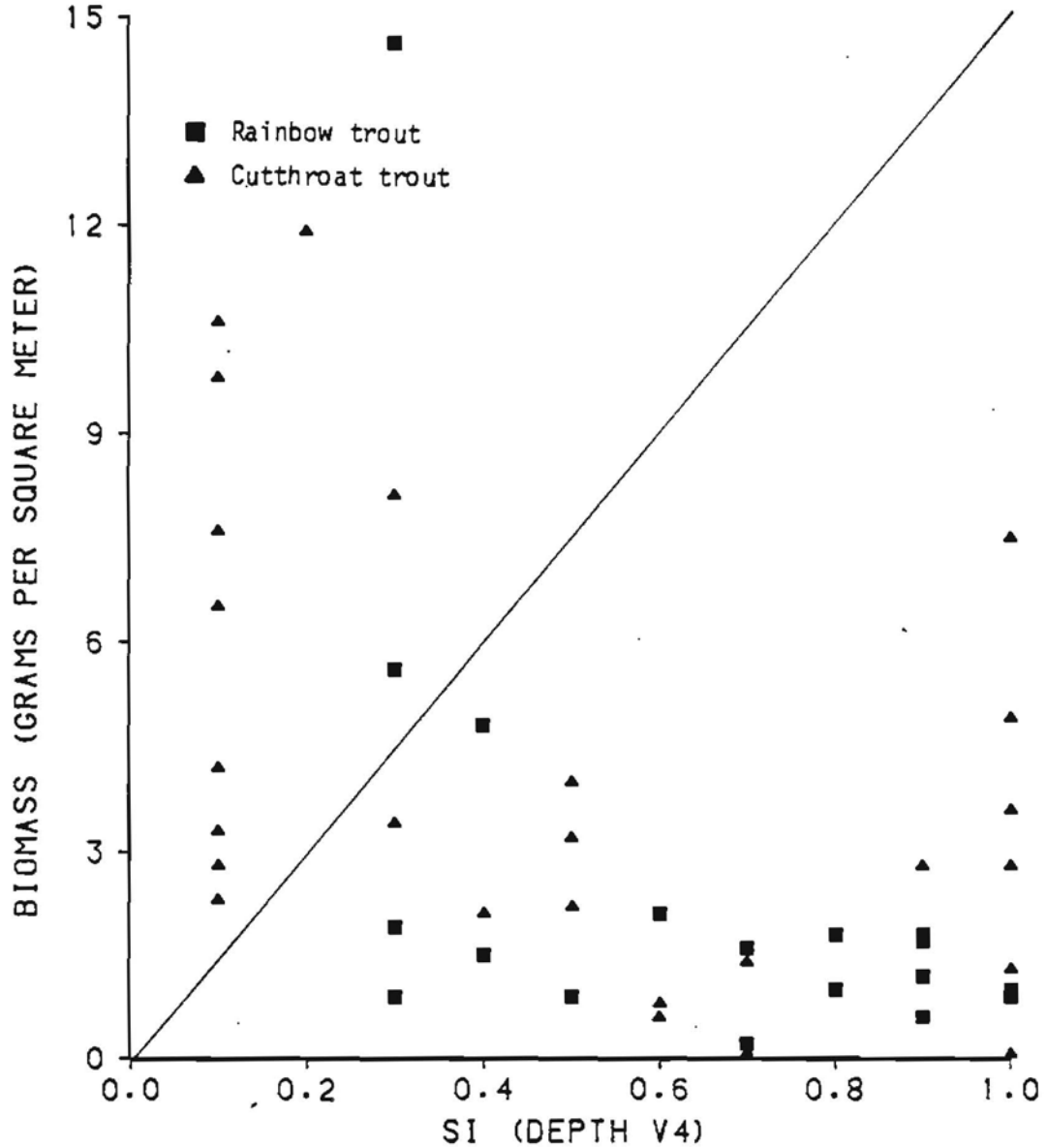

Figure 5. Relationship between depth (V_4) and biomass.

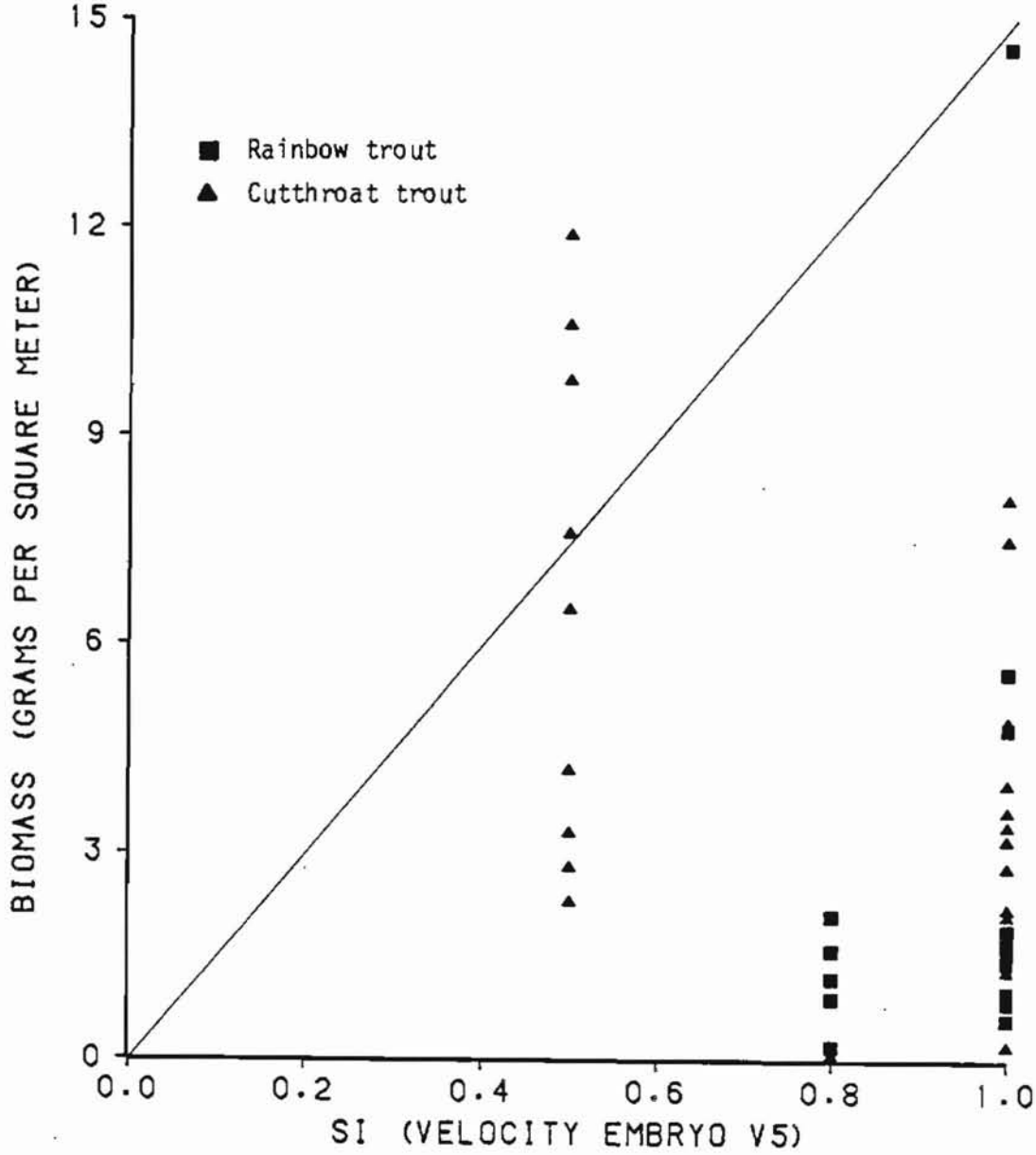

Figure 6. Relationship between velocity for embryos (V_s) and biomass.

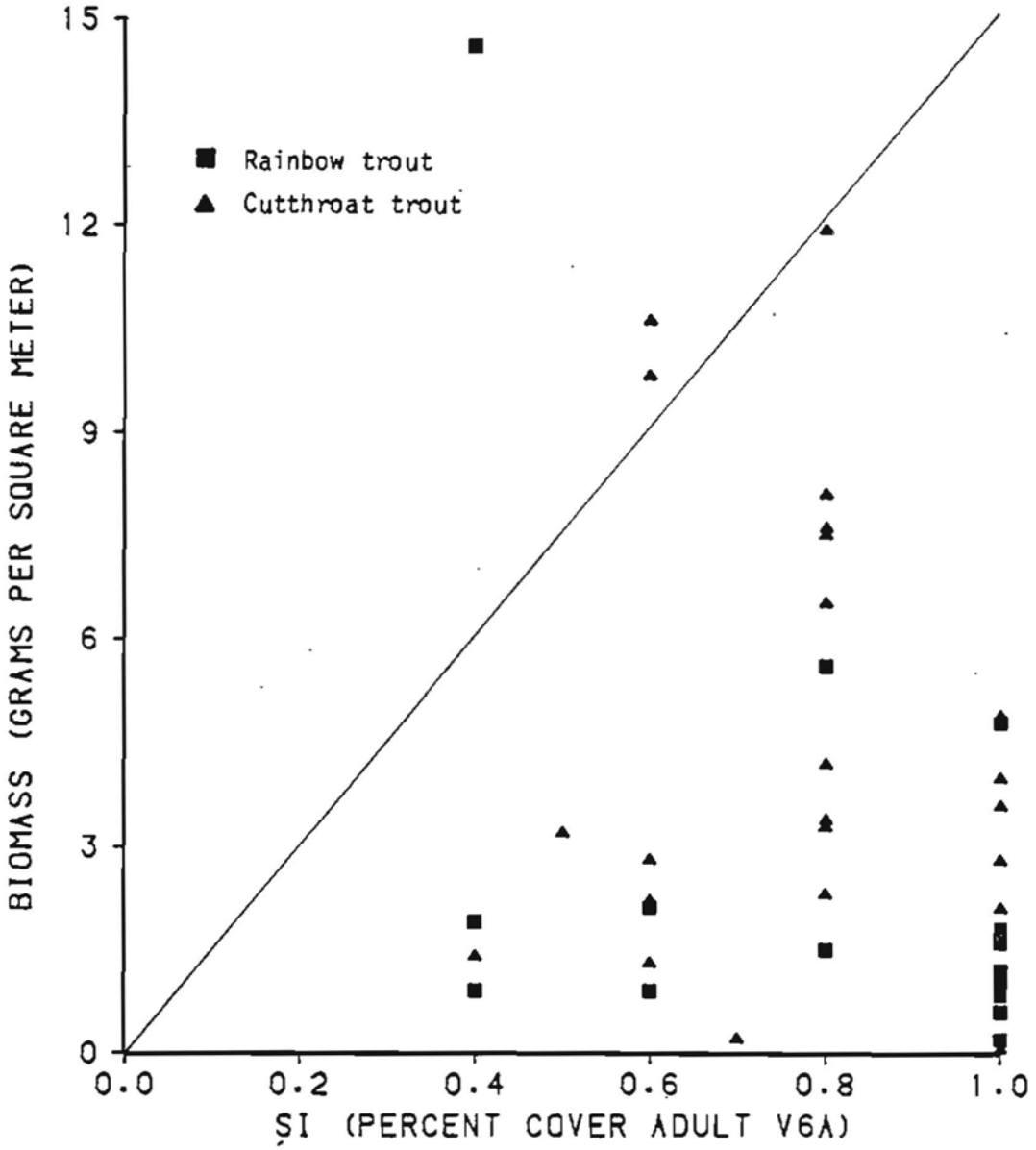

Figure 7. Relationship between percent cover for adults (V_{6A}) and biomass.

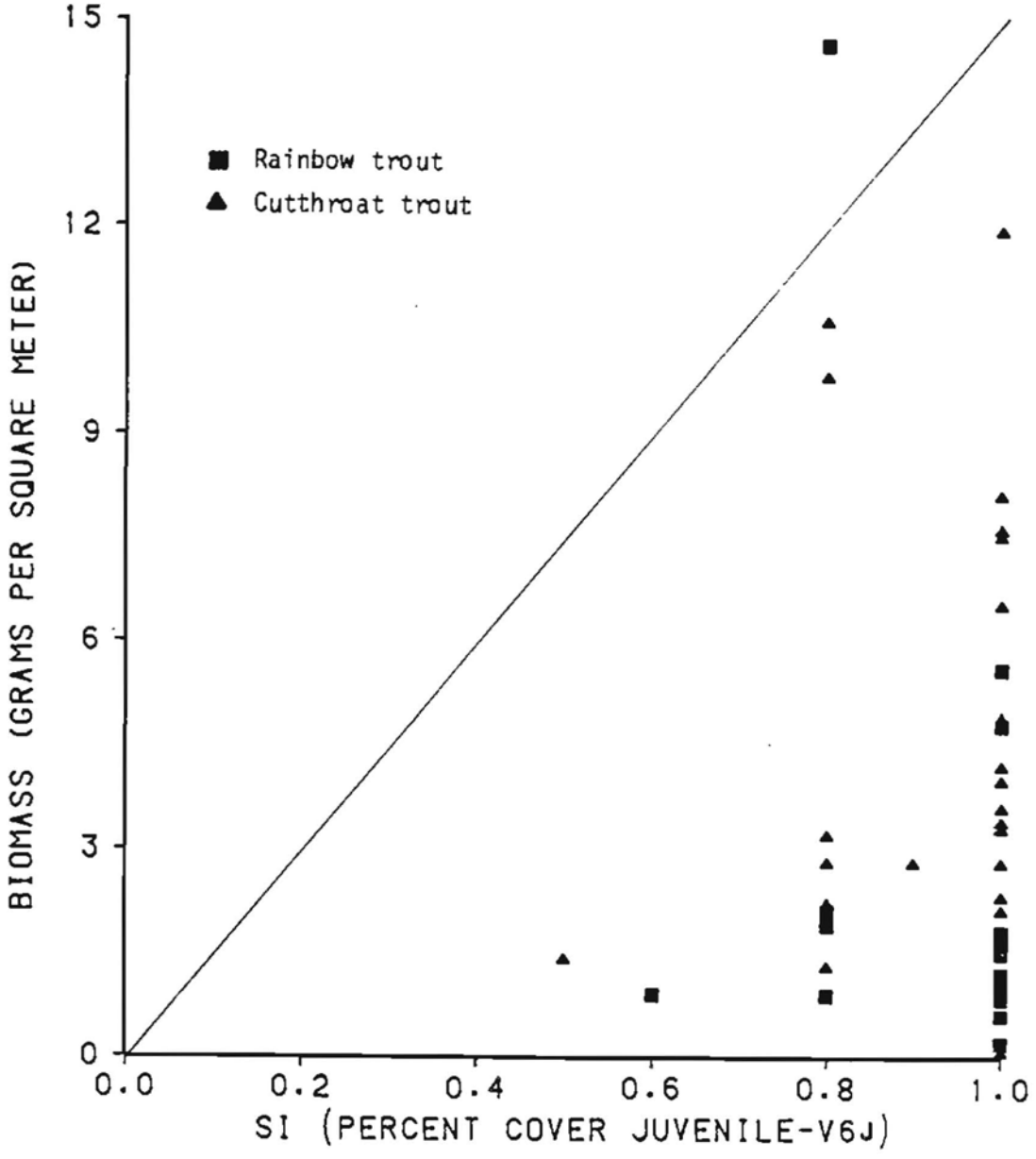

Figure 8. Relationship between percent cover for juveniles (V_{6J}) and biomass.

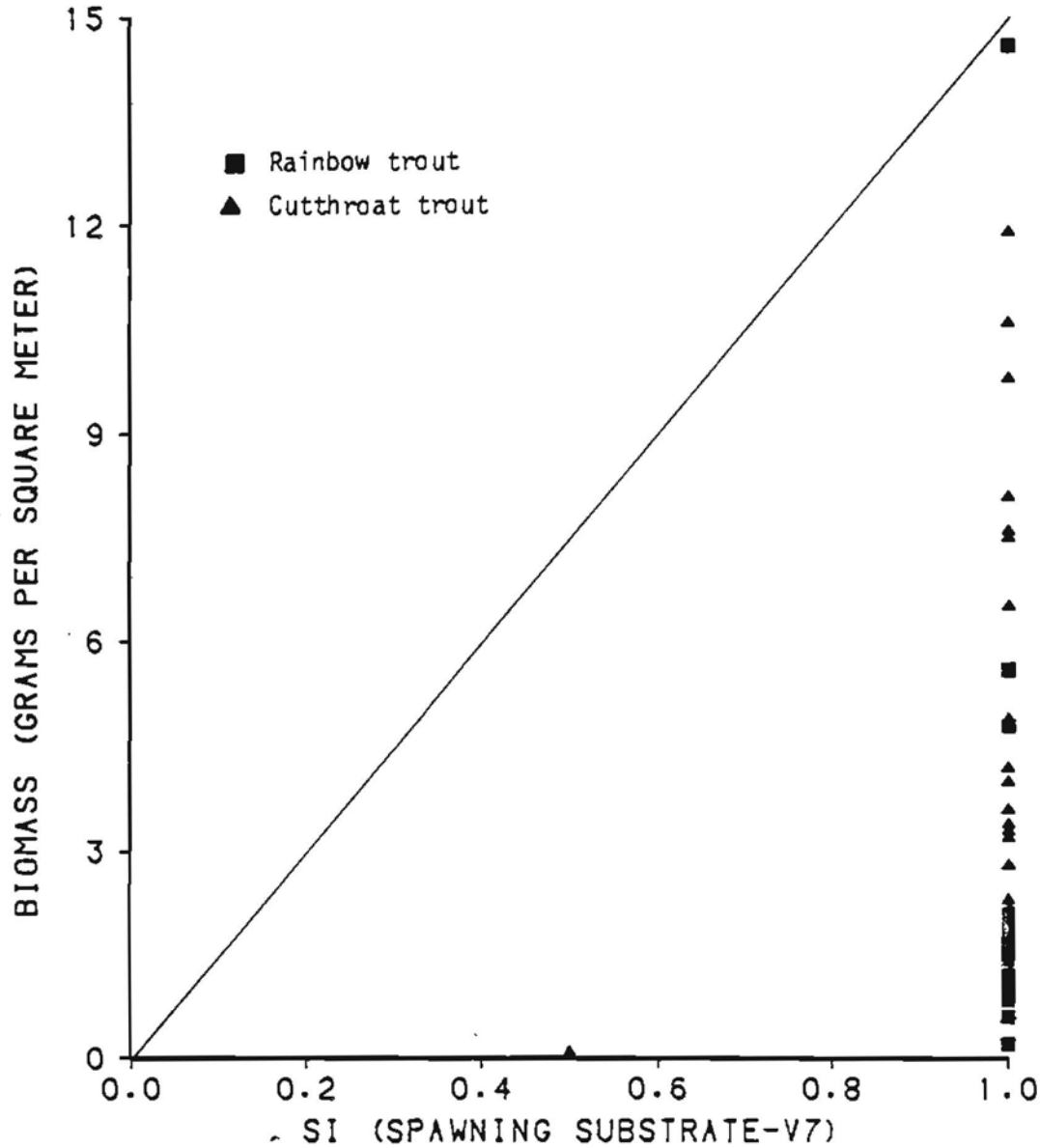

Figure 9. Relationship between spawning substrate (V_7) and biomass.

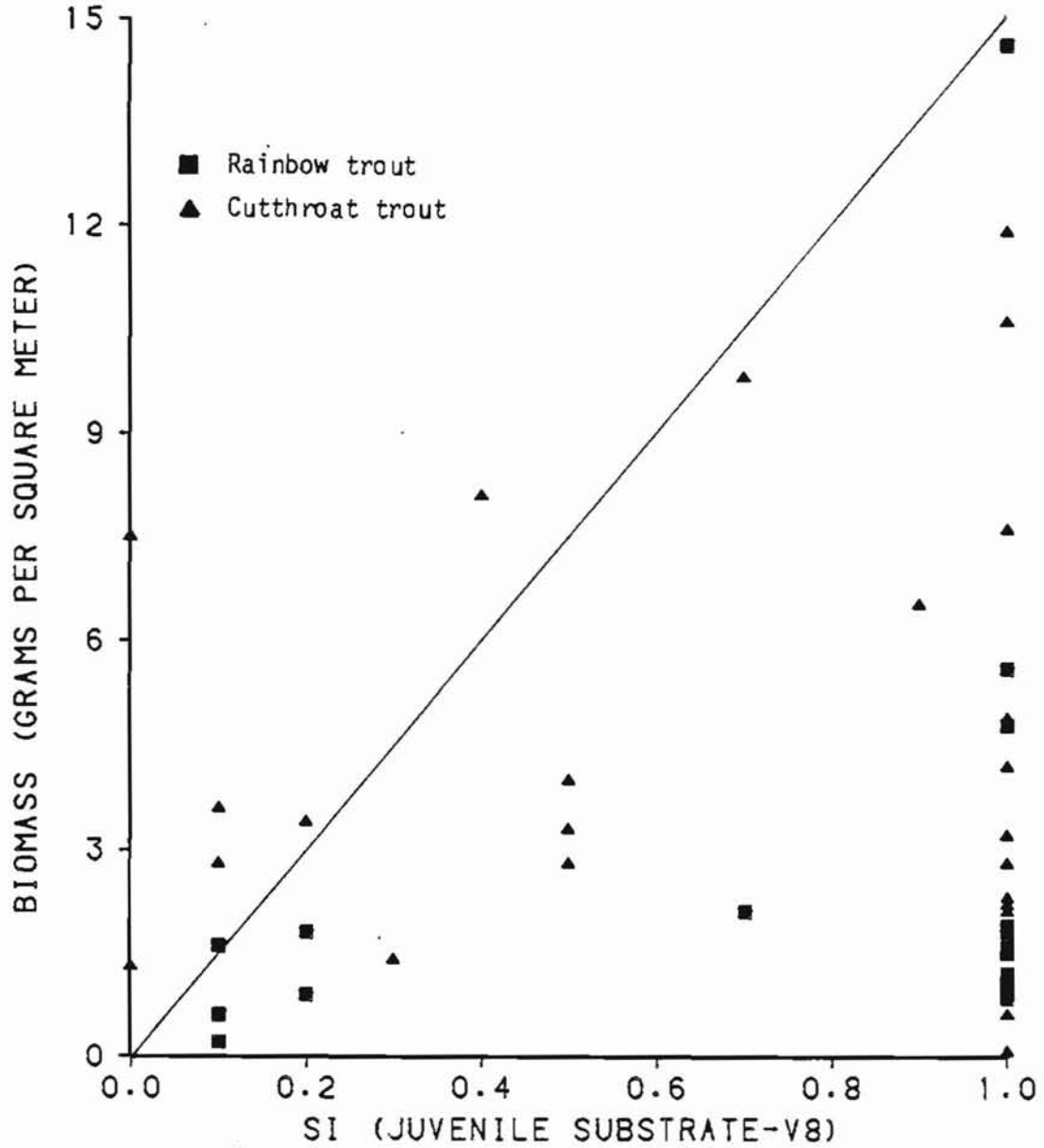

Figure 10. Relationship between substrate for juveniles (V_8) and biomass.

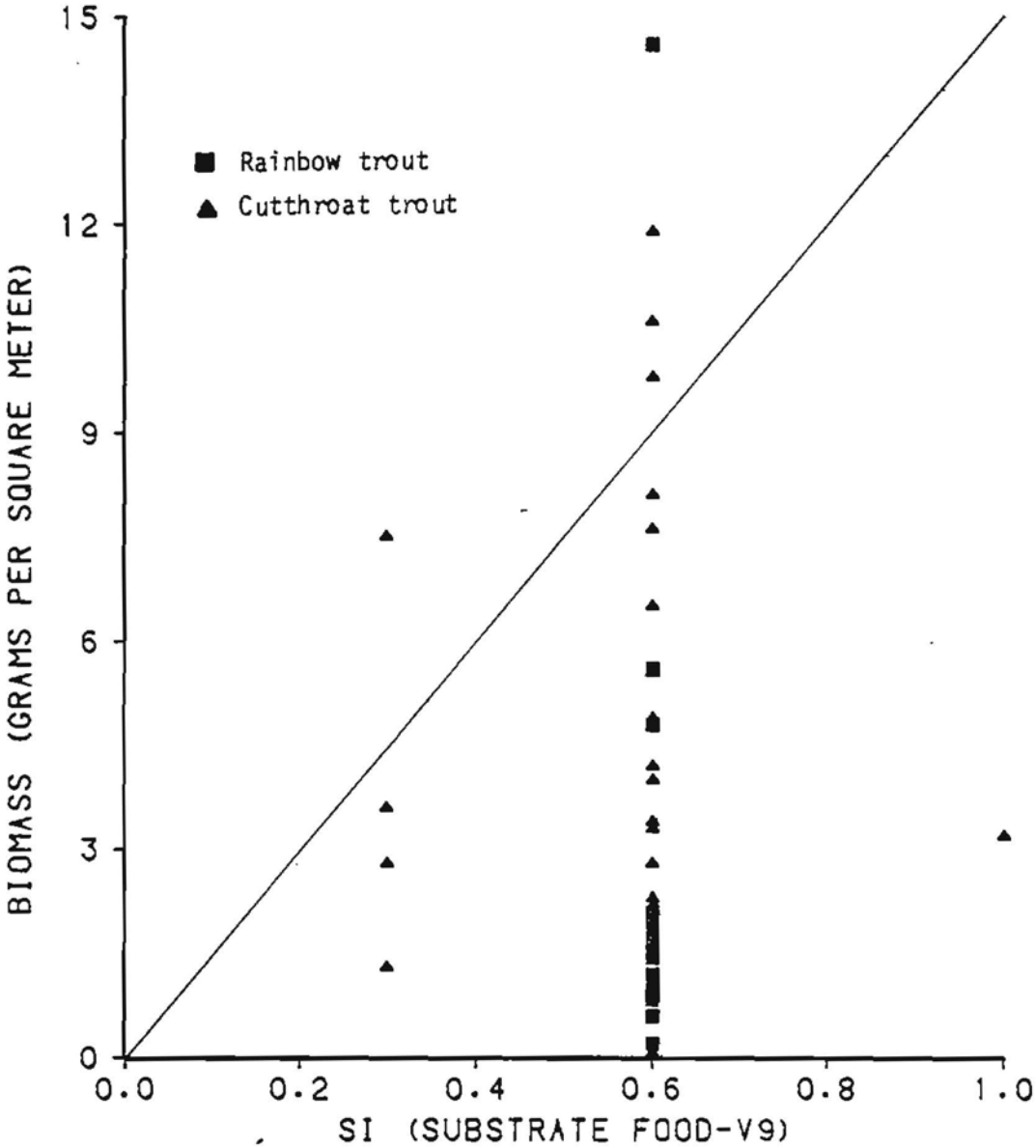

Figure 11. Relationship between substrate for food production (V_9) and biomass.

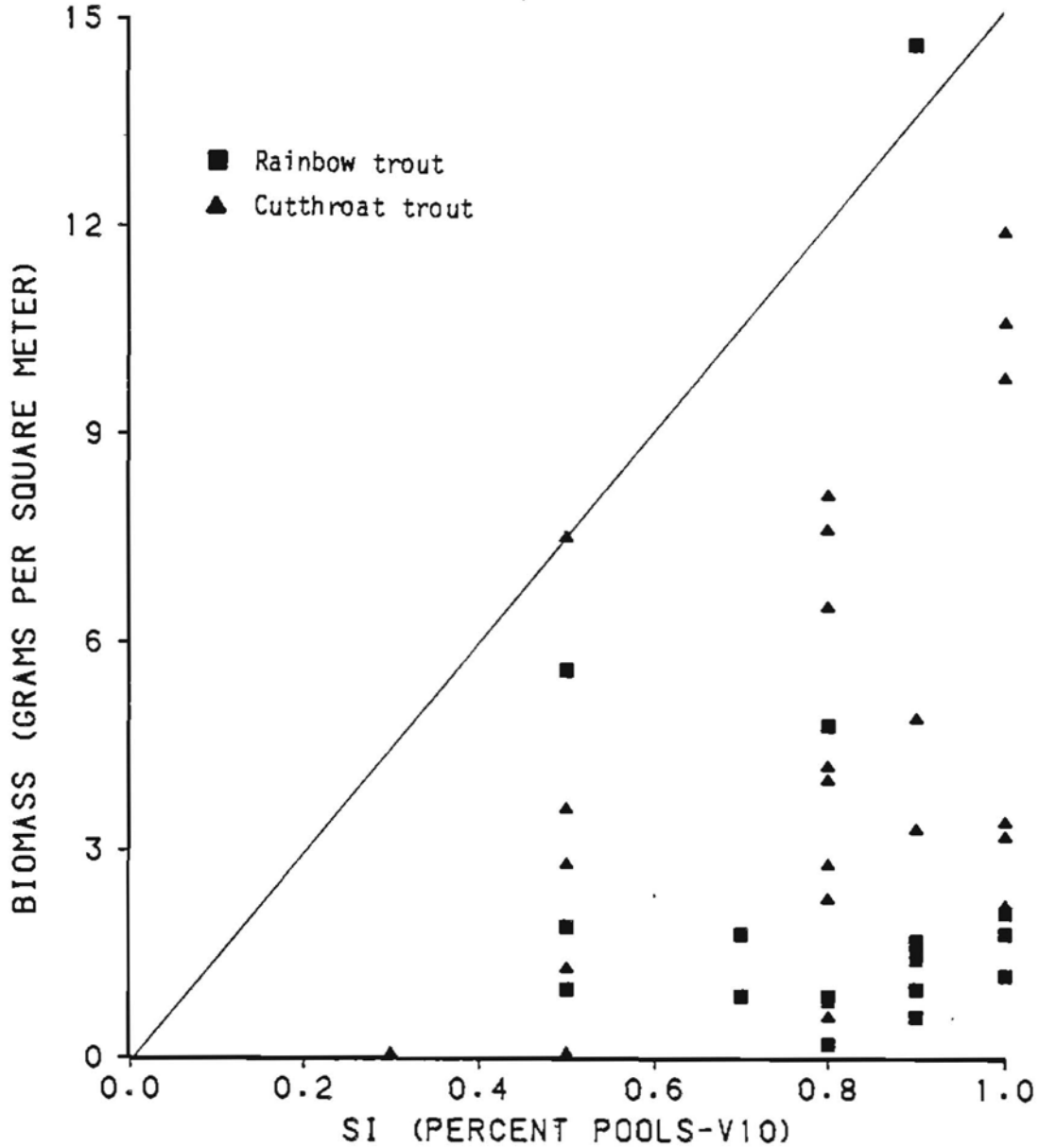

Figure 12. Relationship between percent pools (V_{10}) and biomass.

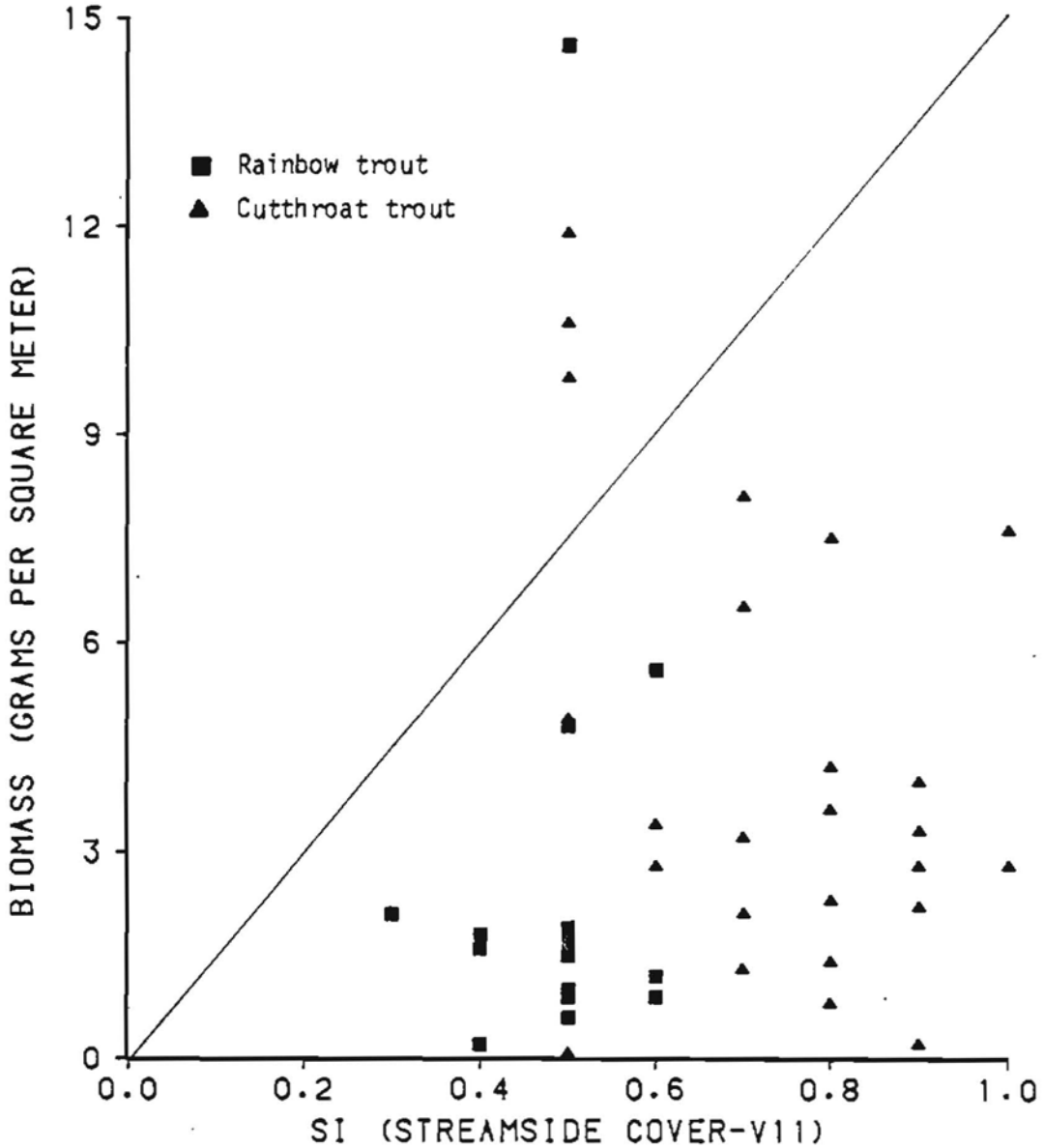

Figure 13. Relationship between streamside cover (V_{11}) and biomass.

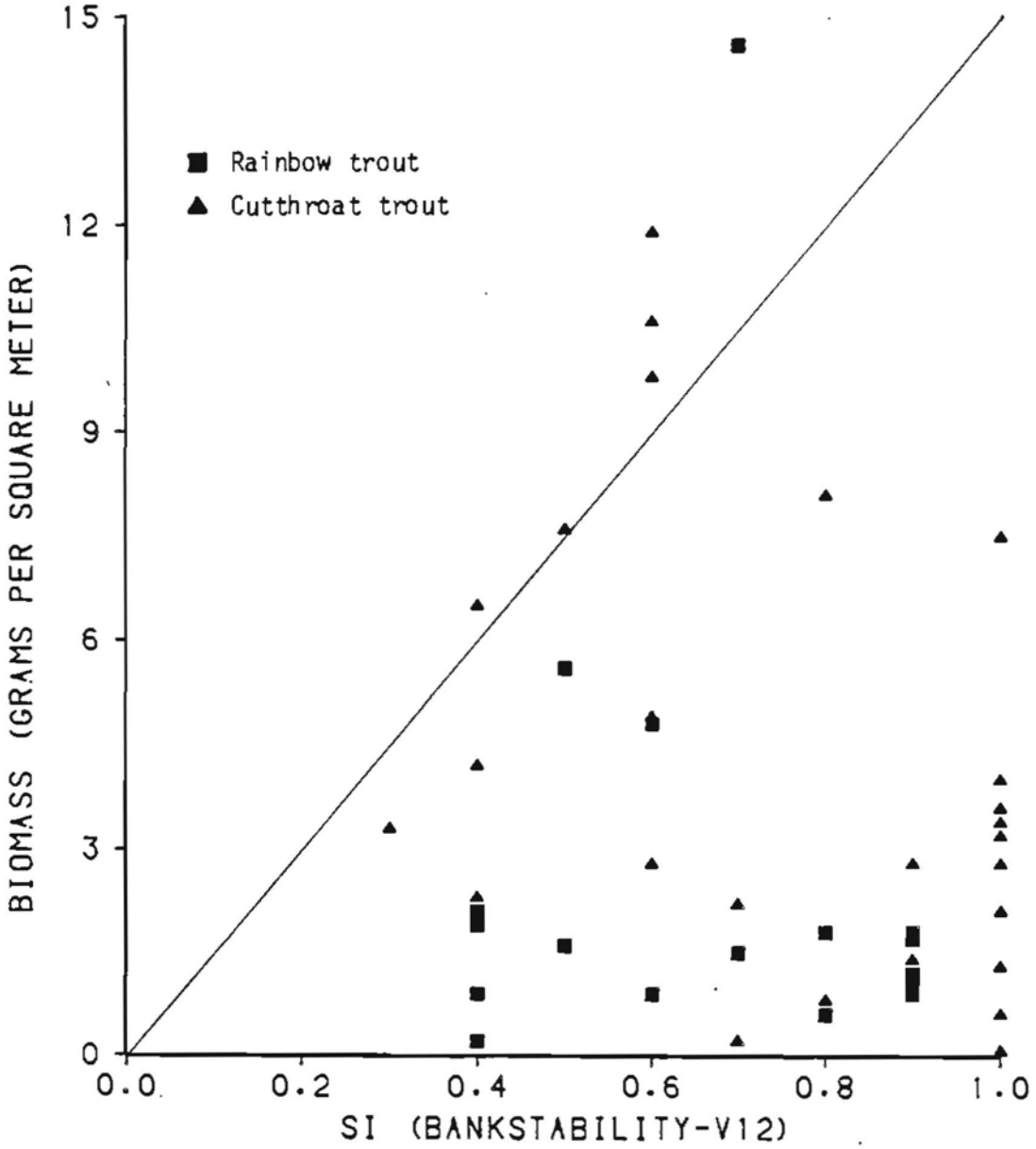

Figure 14. Relationship between bank stability (V_{12}) and biomass.

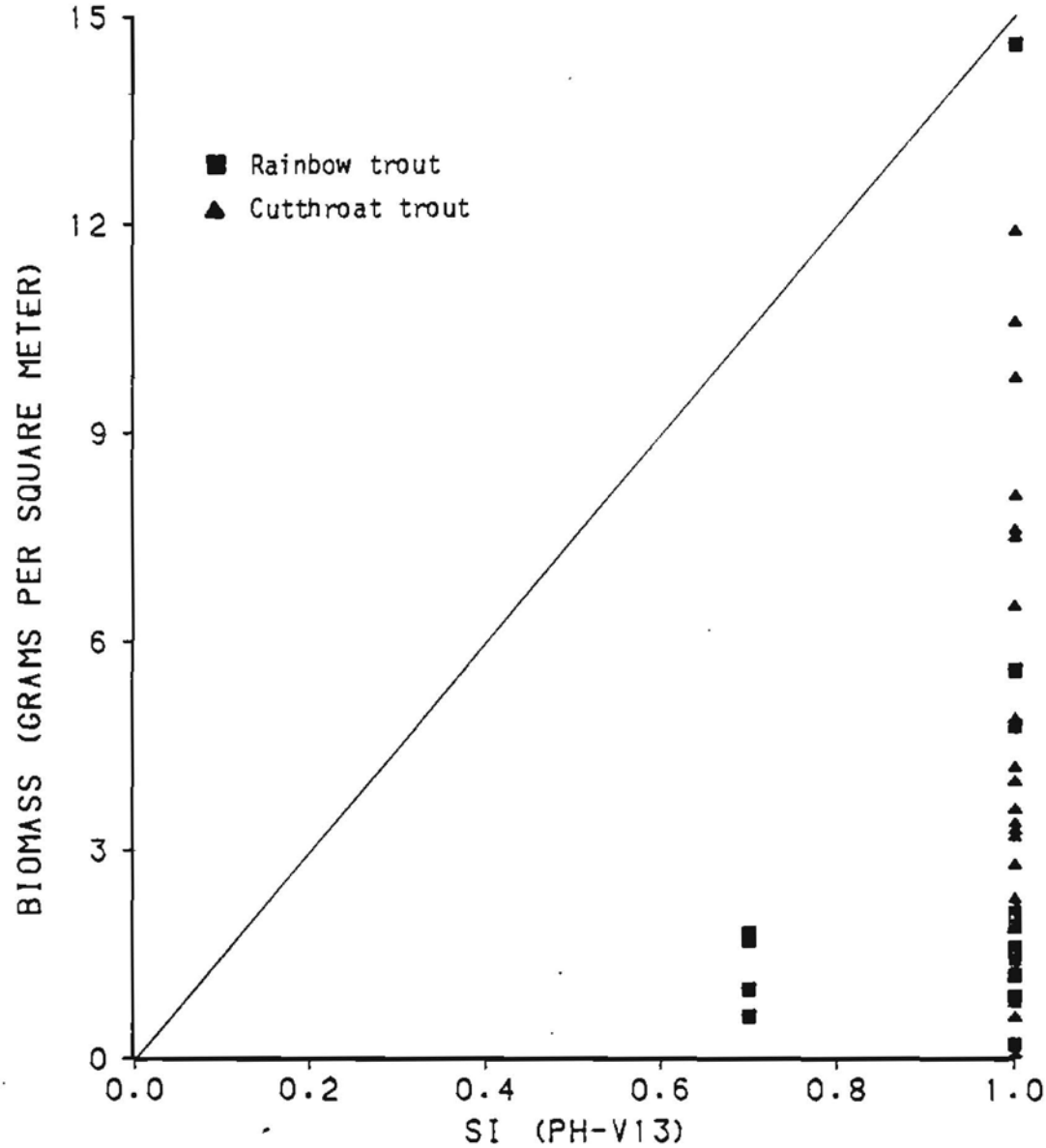

Figure 15. Relationship between pH (V_{13}) and biomass.

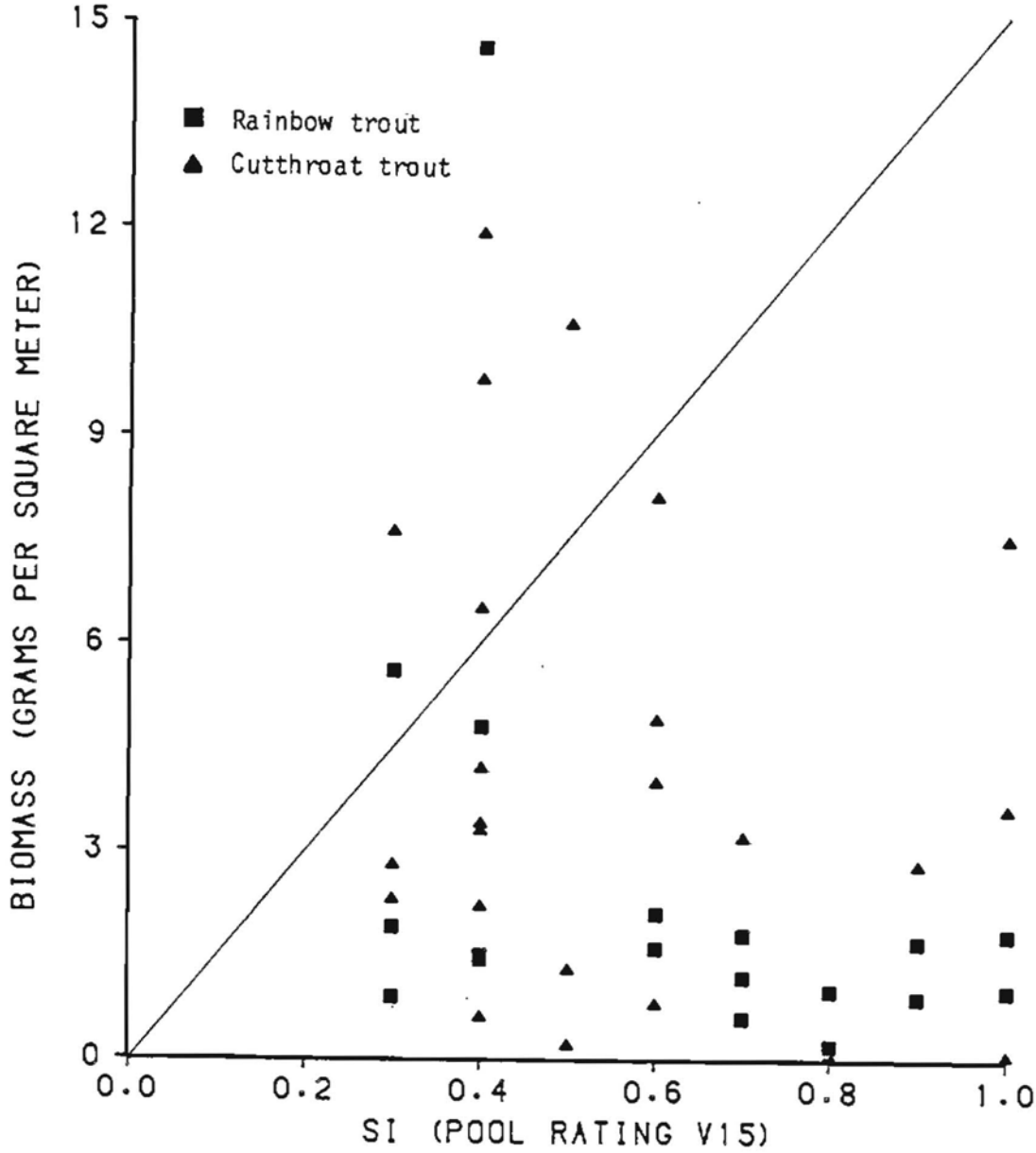

Figure 16. Relationship between pool rating (V_{15}) and biomass.

rating for pool quality. Because the Lahontan or Humboldt subspecies of trout found in Gance Creek may have different habitat requirements than other subspecies, different habitat suitability curves may be needed for this population.

Percent embeddedness ratings (V_{16}) did not have a significant relationship to standing crops of cutthroat (Fig. 17); many of the data points are above the theoretical regression line. Because no ratings were higher than 0.5, the rating system for percent embeddedness used in testing the model may have been inaccurate.

Evaluation of Life Stage Components

Life stage component ratings are calculated by aggregating SI's for individual variables in various ways. The aggregation technique attempts to reflect the interactions of habitat variables in determining habitat suitability. For example, the aggregation of SI's for the juvenile component (CJ) (Appendix A) is an arithmetic mean for three variables (V_6, V_{10}, and V_{15}):

$$CJ = \frac{V_6 + V_{10} + V_{15}}{3}$$

If any of these three variables ≤ 0.4, then CJ = the lowest variable score. Additional life stage components for the cutthroat trout used geometric means and/or arithmetic means of from three to seven variables. For example, the "other" component (CO) combines seven variables:

$$CO = \left[\frac{(V_9 \times V_{16})^{1/2} + V_{11}}{2} \times (V_1 \times V_3 \times V_{12} \times V_{13})^{1/4} \right]^{1/2}$$

The habitat suitability index (HSI) is assumed to have a direct linear relationship with carrying capacity when used in HEP. We used estimated standing crop as a measure of carrying capacity and evaluated life stage component suitability indices (SI's) by comparing their fit to the theoretical regression line (Fig. 1), as was done for single variables. If aggregation techniques are valid, the plots of life stage component ratings versus biomass data points will be on (not below) the theoretical regression line and correlations between life stage component SI's and biomass will be positive.

There were no significant positive correlations between life stage component ratings and biomass; the only significant correlation was negative [Adult component (CA), $r = -0.45$, $P \leq 0.01$] (Table 3). The model only has predictive ability for our data set when life stage component ratings have a linear relationship with biomass. Therefore, none of the life stage aggregation techniques were valid because none of the life stage components had a linear relationship with biomass (Figs. 18 to 22).

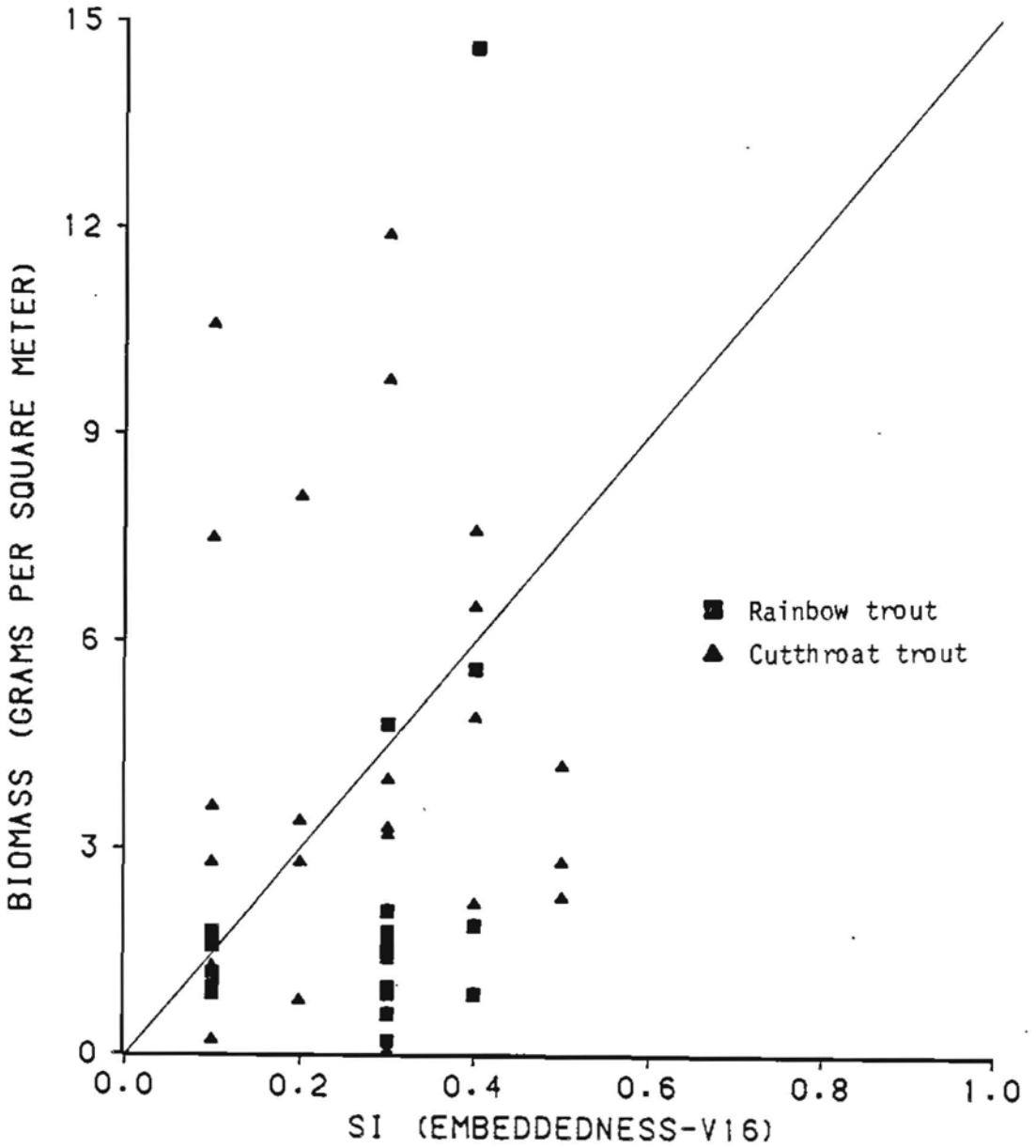

Figure 17. Relationship between percent embeddedness (V_{16}) and biomass.

Table 3. Mean, standard deviation, and correlation coefficient of life stage component suitability indices and species HSI's for 27 cutthroat trout and 18 rainbow trout samples.

Variable[a]	Cutthroat (n = 27)			Rainbow (n = 18)			Total (n = 45)		
	Mean	SD	r	Mean	SD	r	Mean	SD	r
CA	0.60	0.19	-0.45**	0.66	0.25	-0.52	0.62	0.22	-0.49**
CJ	0.74	0.10	0.08	0.78	0.12	-0.30	0.76	0.11	-0.13
CF	0.46	0.25	0.13	0.46	0.23	-0.45	0.46	0.24	0.24
CE	0.56	0.08	-0.41	0.42	0.26	0.44	0.50	0.19	0.21
CO	0.69	0.04	-0.20	0.59	0.07	0.41	0.65	0.07	0.24
HSI-1	0.40	0.22	-0.12	0.24	0.15	0.23	0.34	0.21	0.07
HSI-2	0.36	0.17	-0.11	0.23	0.12	0.30	0.31	0.16	0.10
HSI-3	0.39	0.21	-0.11	0.23	0.12	0.30	0.32	0.19	0.10

**$P \leq 0.01$

[a]CA = Adult component

CJ = Juvenile component

CF = Fry component

CE = Embryo component

CO = Other component

HSI-1 = Equal component method

HSI-2 = Noncompensatory method

HSI-3 = Compensatory method

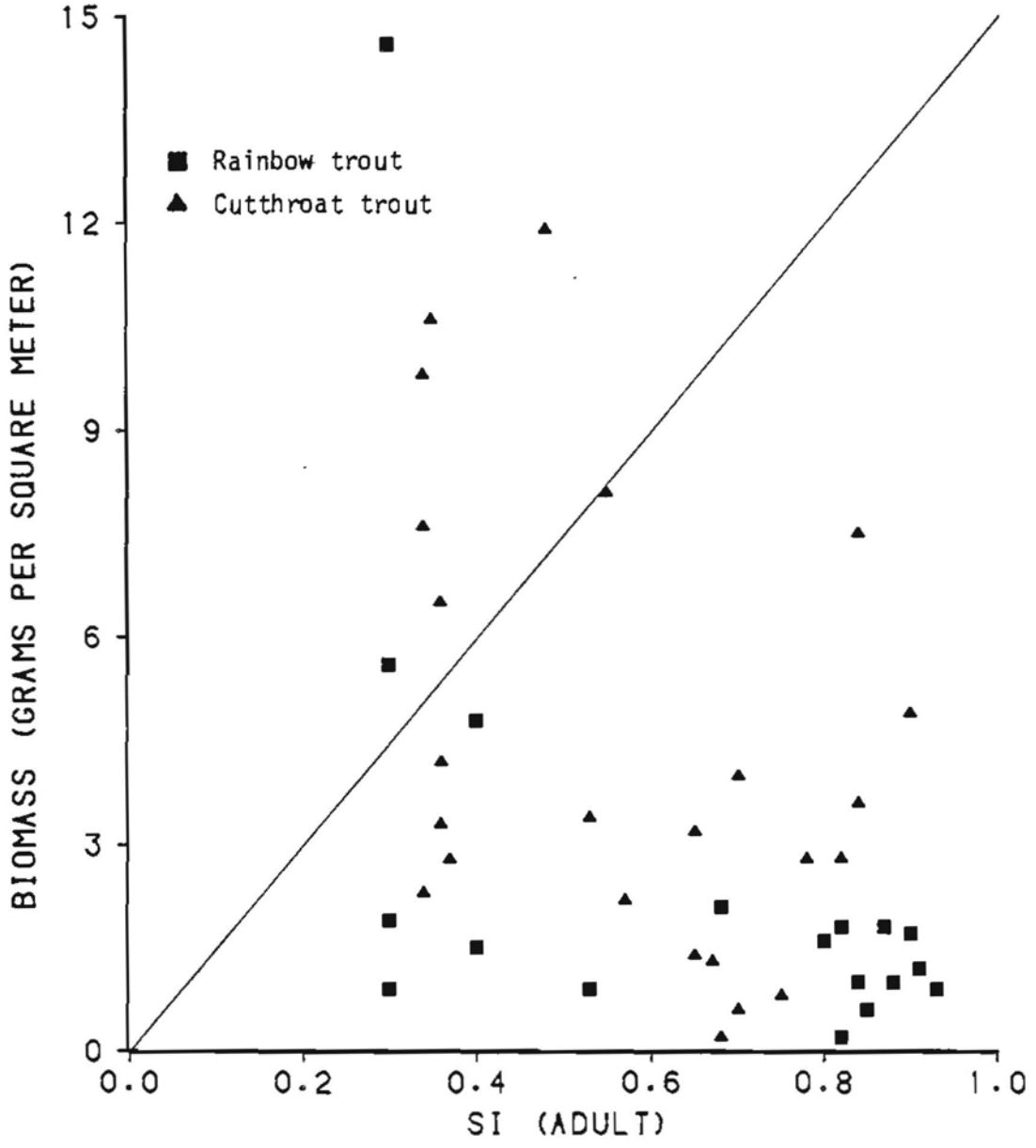

Figure 18. Relationship between adult component SI and biomass.

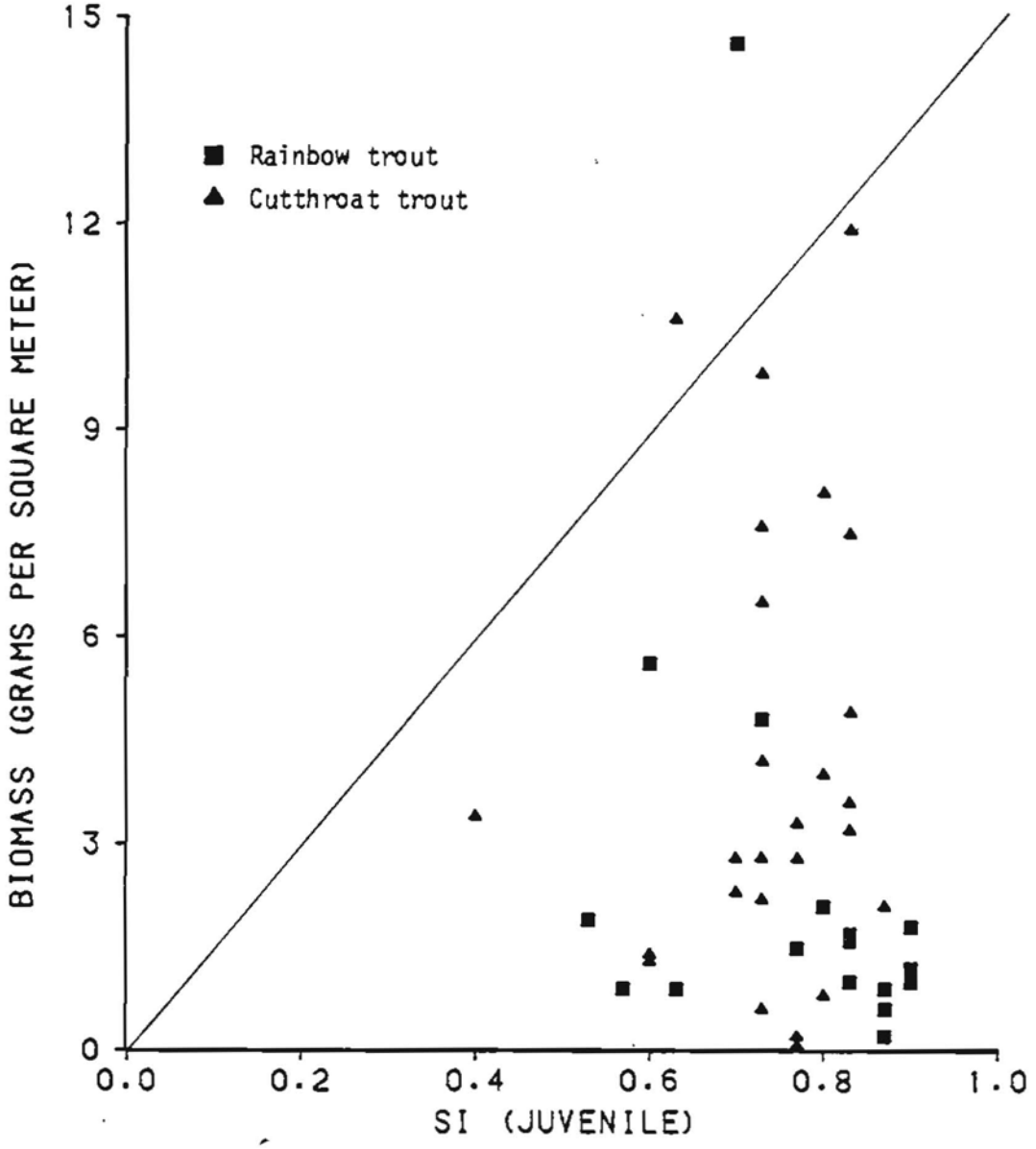

Figure 19. Relationship between juvenile component SI and biomass.

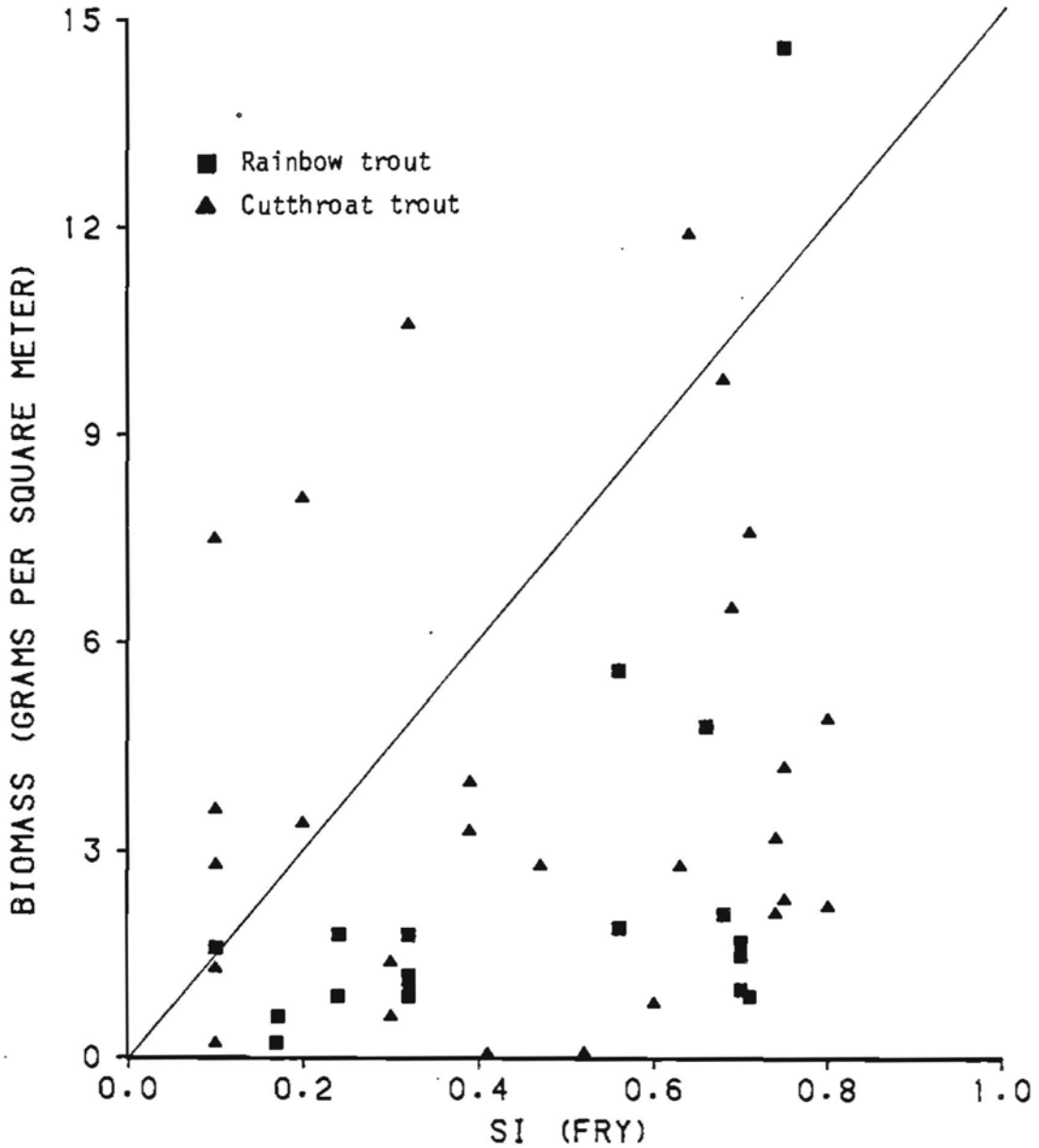

Figure 20. Relationship between fry component SI and biomass.

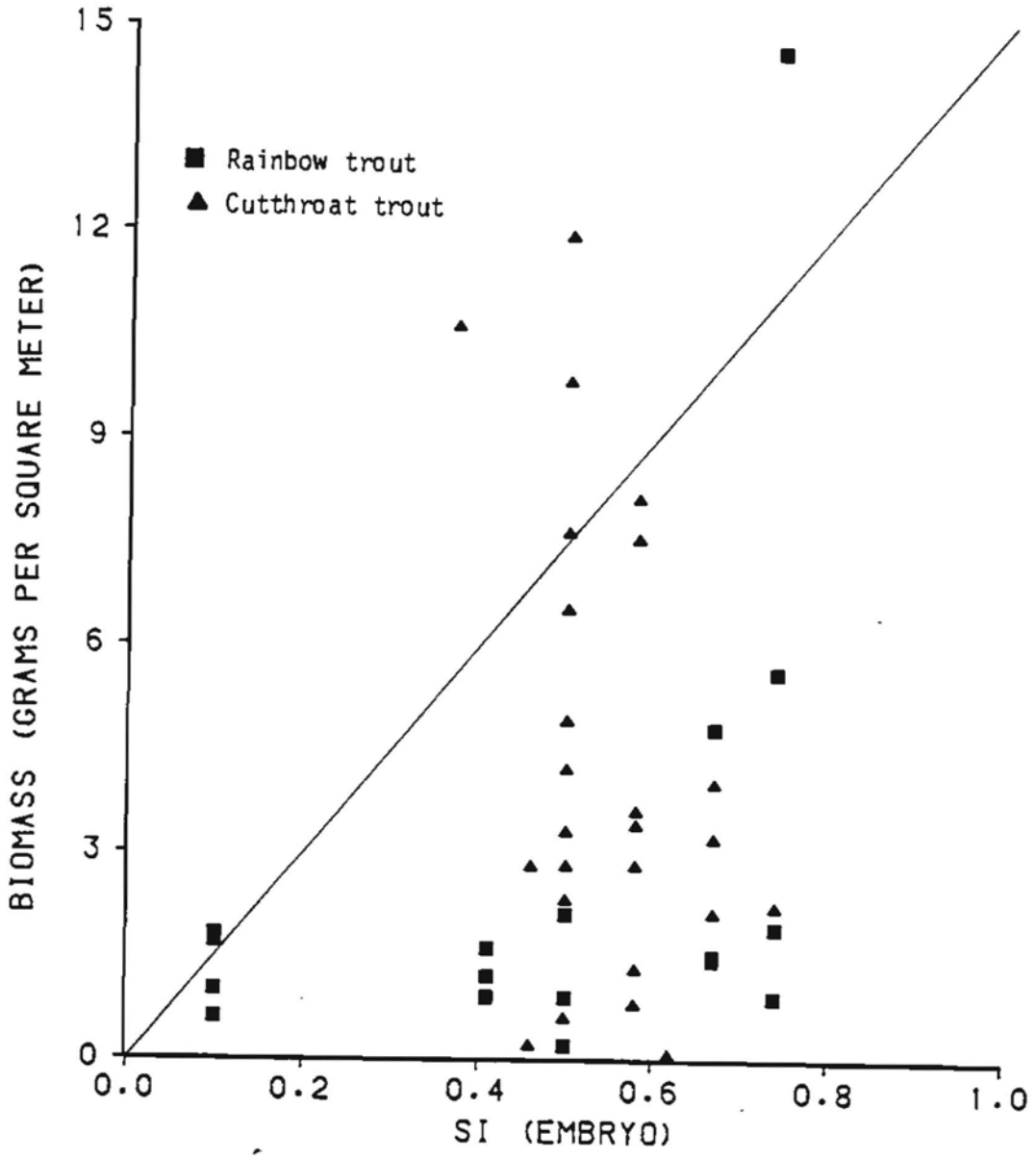

Figure 21. Relationship between embryo component SI and biomass.

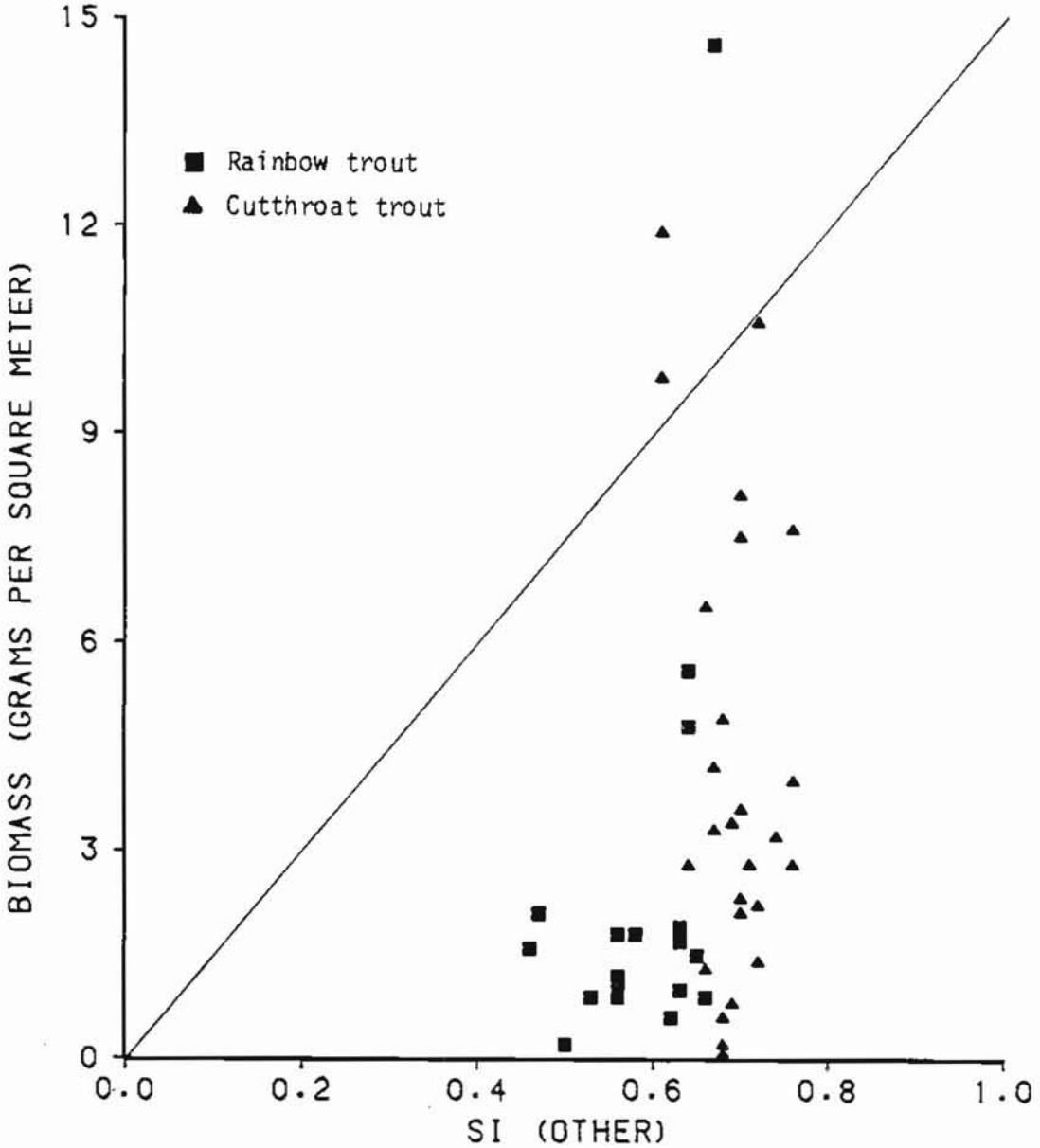

Figure 22. Relationship between other component SI and biomass.

Evaluation of species HSI's. Species HSI's were calculated by aggregating the five life stage component SI's. Three potential aggregations of the life stage component SI's were provided in the model (Appendix A). The species HSI's cannot be expected to be accurate because the life stage component SI's were shown to be invalid. All correlations between biomass and cutthroat species HSI's were negative (Table 3). A direct linear relationship between species HSI's and biomass was not evident (Figs. 23 to 25); therefore, the aggregation techniques proposed in the model are not valid.

Evaluation of Rainbow Trout Suitability Index Curves

Correlation coefficients. There were no significant correlations between rainbow trout biomass and suitability indices of individual variables (Table 2). The low values of most correlation coefficients (< 0.6) indicated the lack of a significant relationship between standing crop estimates and suitability indices of individual variables.

Suitability index - biomass plots. Most data points in Figures 2 to 18 for rainbow trout were below the theoretical regression line relating an individual SI to biomass. The theoretical regression line was based on the maximum biomass observed for rainbow trout (14.6 g/m^2). Therefore, every time the calculated SI for a habitat variable value associated with this biomass estimate was less than optimum (1.0), the data point was above the theoretical regression line for that variable (Figs. 5, 10, 12, 13, 16, and 17). The maximum biomass observed was associated with suboptimum SI's for depth (V_4), substrate for food production (V_9), streamside cover (V_{11}), bank stability (V_{12}), pool quality (V_{15}), and percent fines (V_{16}). Based on the data used in this study, many of these SI curves may need revision. Nevertheless, most of the suitability index curves and rating criteria seemed to adequately describe the relationship between individual habitat variables and habitat suitability, as estimated by standing crop measurements.

Evaluation of Life Stage Component Ratings

There was no direct linear relationship between life stage component SI's and biomass; therefore, the life stage component aggregation techniques for this species were not valid (Table 3, Figs. 19 to 22).

Evaluation of Species HSI's

Rainbow trout species HSI's were not significantly correlated with biomass estimates, and there was no direct linear relationship between species HSI's and rainbow trout biomass (Table 3, Figs. 23 to 25). Because the life stage component SI's were not valid, the species HSI's could not be expected to be valid. Unless the life stage component SI's used as input for species HSI's are valid, any aggregation of life stage components to produce a species HSI cannot be accurately tested.

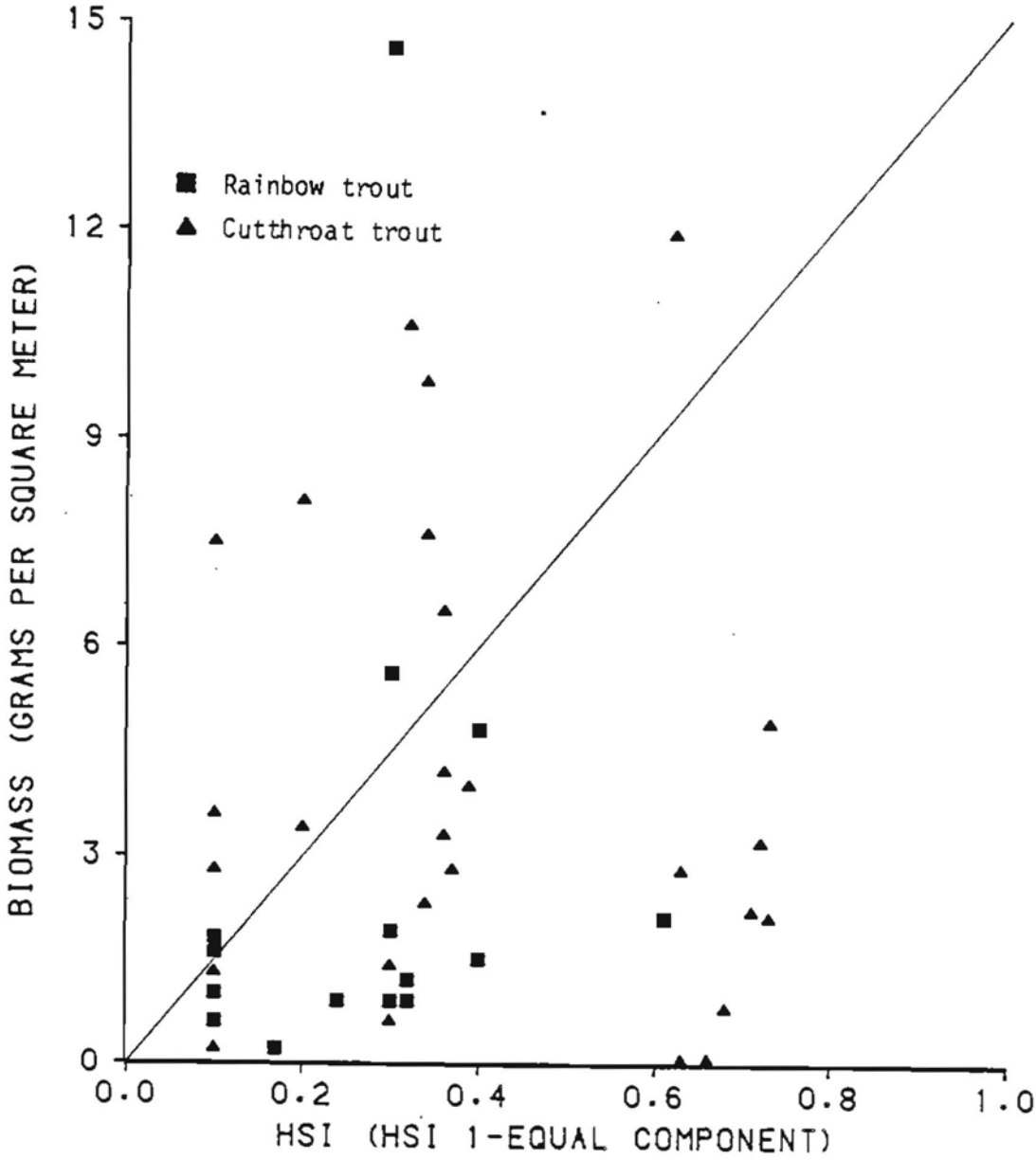

Figure 23. Relationship between the equal component HSI and biomass.

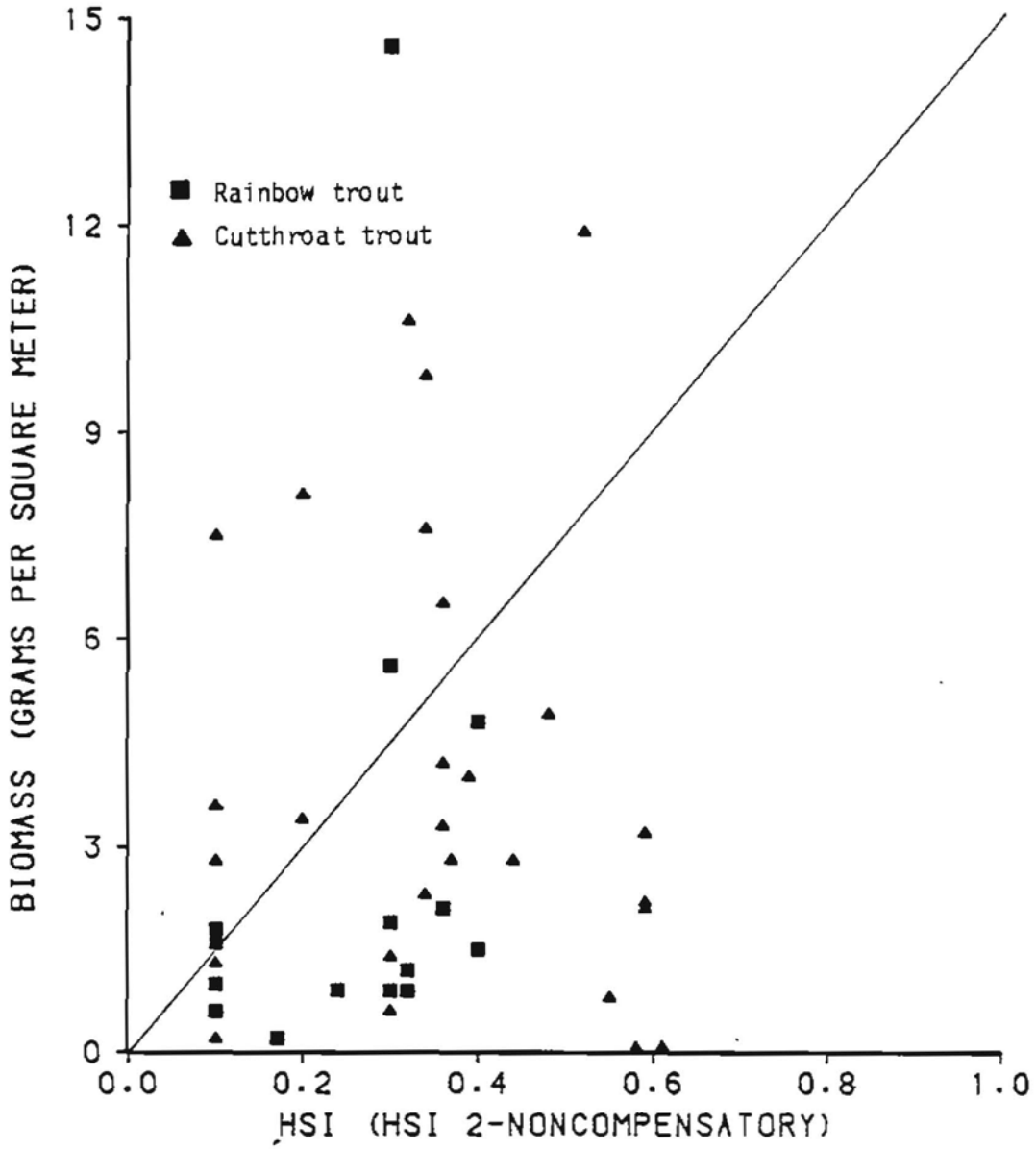

Figure 24. Relationship between the noncompensatory HSI and biomass.

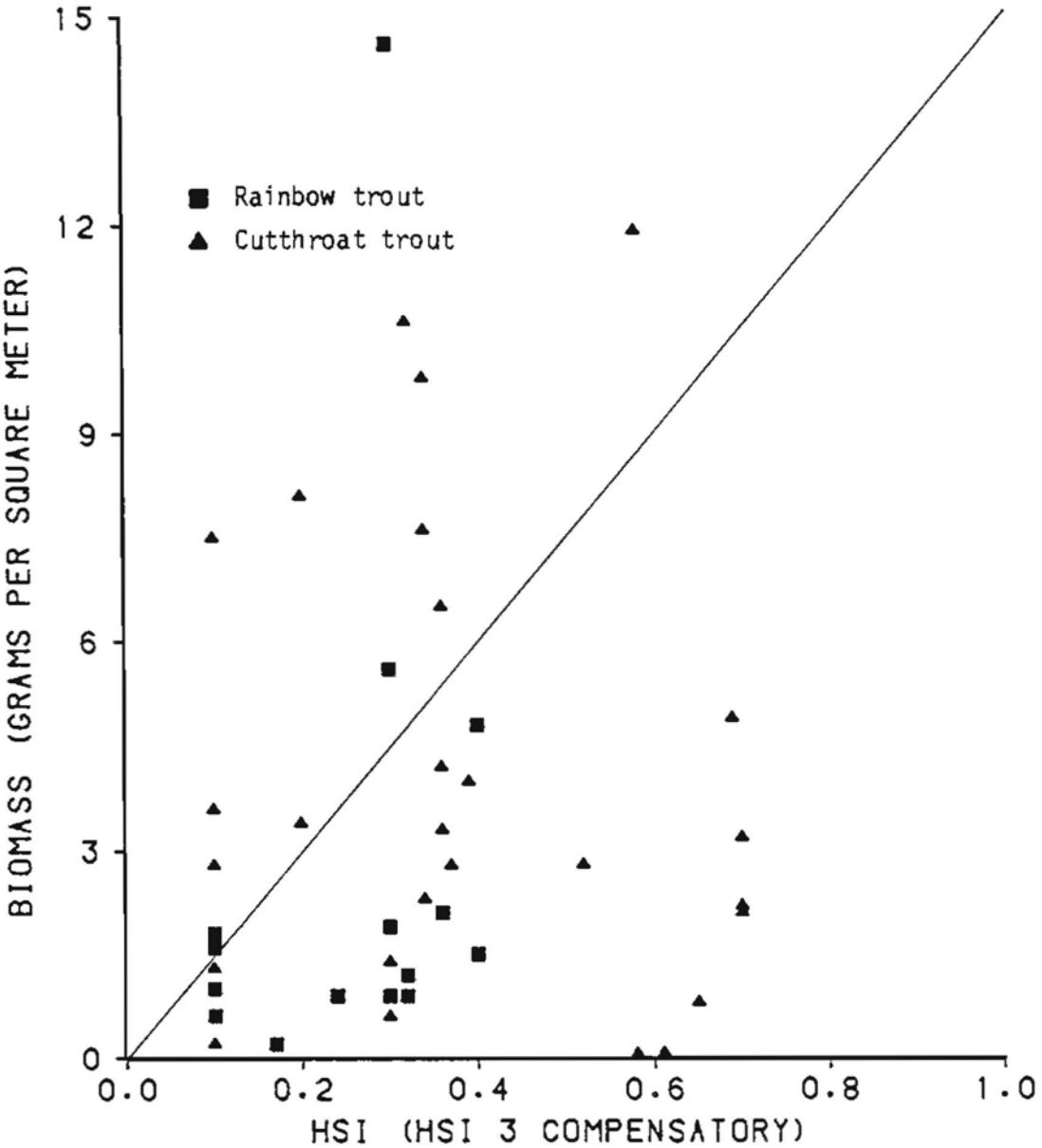

Figure 25. Relationship between the compensatory HSI and biomass.

DISCUSSION

The tested riverine cutthroat trout HSI model (Appendix A) did not accurately predict standing crops of cutthroat trout in the four streams examined. The model also failed to reflect standing crops of rainbow trout in three streams. Although there were some inadequacies in the data set, data for most habitat variables required in the model were tested. The reliance on estimates for some variables may have had an affect on model output; however, the estimates were considered accurate, and most of the estimates were for optimal (SI = 1.0) conditions. The omission of the variable for stream flow regime (V_{14}) affected output of the "other" component (CO) and the species HSI's. However, V_{14} was not included as input for the adult (CA), juvenile (CJ), fry (CF), or embryo (CE) life stage components and, therefore, did not affect their output.

The lack of biomass estimates for each life stage was a major flaw in the data base. Adult and juvenile biomass estimates can be used to test embryo and fry life stage components only with the assumption of constant recruitment. An assumption of constant recruitment necessitates an assumption of constant habitat suitability. However, habitat conditions vary considerably over time; therefore, the assumption of constant recruitment is probably not valid. Evaluation of early life stage component SI's using adult and juvenile biomass estimates does not appear to be meaningful.

The suitability index curves may provide valuable insight for biologists. In general, the relationship between a single habitat variable and habitat suitability is fairly accurately described by most habitat suitability curves and the rating criteria (e.g., pool class rating) in the model. However, Lahontan or Humboldt River cutthroat trout subspecies appear to have tolerances and adaptabilities for many habitat parameters that are different from those for other subspecies. Alternative suitability index curves and ratings may be needed for these populations.

The inability of the model to quantitatively describe trout habitat quality as measured by standing crop may be due in part to the omission of important habitat parameters in the present model. Barriers to upstream migration, winter ice scouring, and species interactions are factors that probably affect trout standing crops in the streams examined (Dr. W. S. Platts, personal communication, U.S. Forest Service, Boise, ID). The omission of this type of parameter from the model is certainly expected to affect the ability of the model to predict carrying capacity as measured by standing crops.

Many factors affect the carrying capacity of trout habitat, including the parameters presently included in the tested model. The lack of correlation between single habitat variables and standing crop substantiates the fact that habitat variables interact with each other in a dynamic manner to affect overall habitat suitability. The exact nature of these interactions is unknown, but the reality of variable interaction and interdependency cannot be overlooked. Aggregation of variables into life stage components attempts, in a very crude manner, to address and quantify these interactions. Because variable interactions are unknown, the model structure is based on the intuition and biological knowledge of the model authors, rather than on rigorous

data analysis. Therefore, it is not surprising that variable aggregations do not represent real life conditions, as illustrated by data tested in this study.

Although SI curves may adequately describe habitat suitability for individual variables, the major weakness of the tested model is in attempting to combine SI's for individual variables into a suitability index for a life stage. That weakness is magnified when life stage suitability indices are combined into a single HSI for the species.

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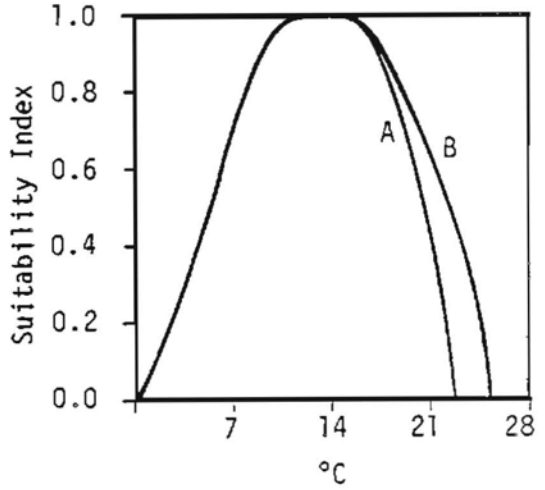
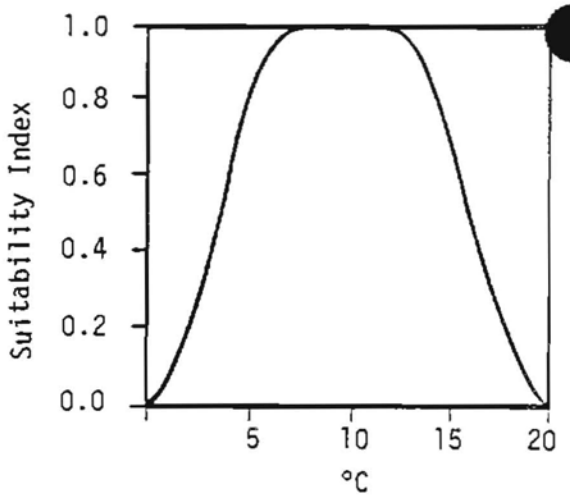
APPENDIX A

DRAFT HSI MODEL (JULY 1981) FOR CUTTHROAT TROUT USED FOR MODEL TESTS

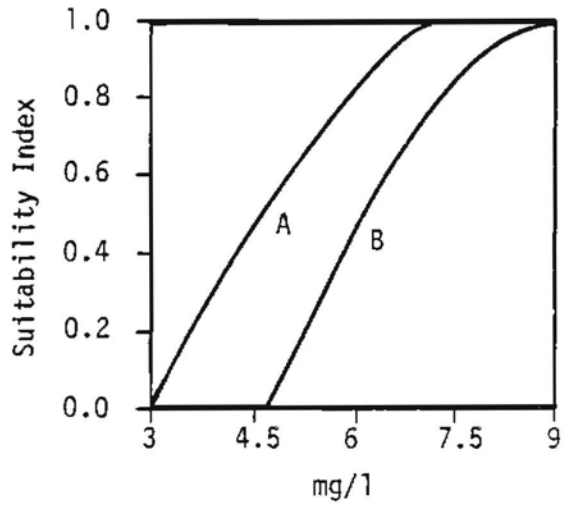
The letters R and L in the habitat column identify variables used to evaluate riverine (R) or lacustrine (L) habitats.

Habitat	Variable		Suitability graph
R,L	(V_1)	Average maximum water temperature (°C) during the warmest period of the year (adult, juvenile, and fry). For lacustrine habitats, use temperature strata nearest optimal in dissolved oxygen zones of > 3 mg/l. A = General B = Lahontan Basin	
R	(V_2)	Average maximum water temperature (°C) during embryo development.	

R,L (V_3) Average minimum dissolved oxygen (mg/l) during the late growing season low water period and during embryo development (adult, juvenile, fry, and embryo).

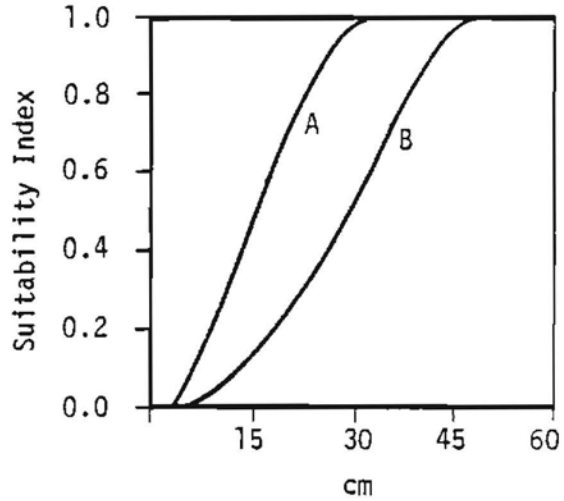
For lacustrine habitats, use the dissolved oxygen readings in temperature zones nearest to optimal where dissolved oxygen is > 3 mg/l.

A = ≤ 15° C
B = > 15° C

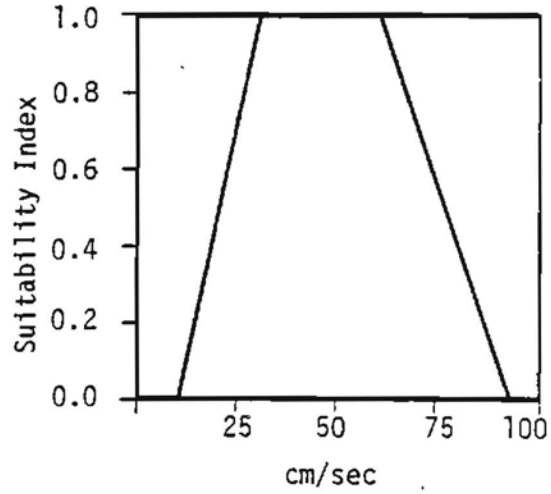


R (V_4) Average thalweg depth (cm) during the late growing season low water period.

A = ≤ 5 m stream width
B = > 5 m stream width



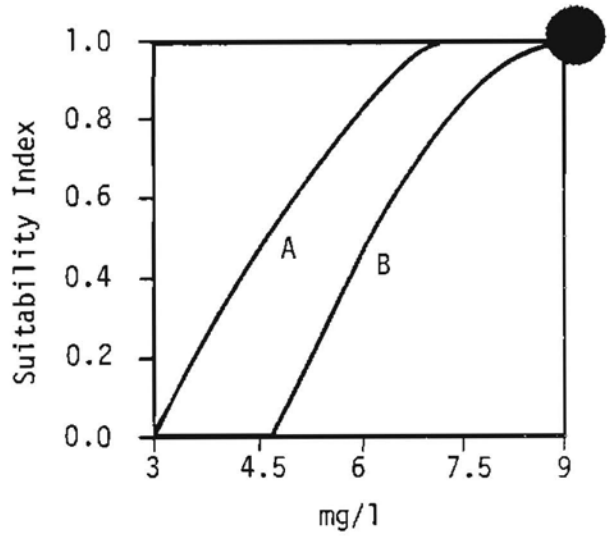
R (V_5) Average velocity (cm/sec) over spawning areas during embryo development.



R,L (V_3) Average minimum dissolved oxygen (mg/l) during the late growing season low water period and during embryo development (adult, juvenile, fry, and embryo).

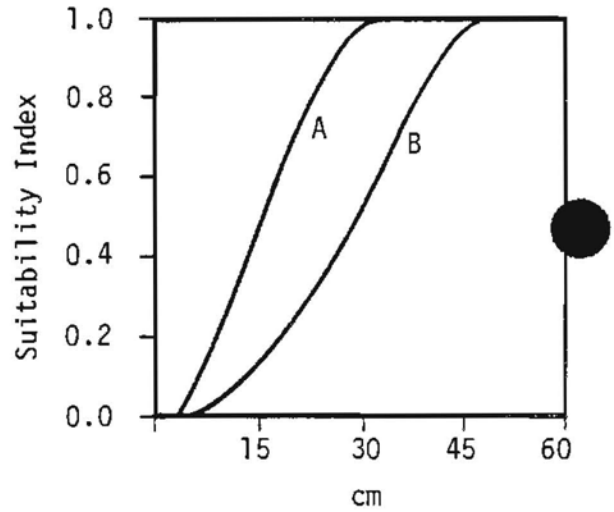
For lacustrine habitats, use the dissolved oxygen readings in temperature zones nearest to optimal where dissolved oxygen is > 3 mg/l.

A = ≤ 15° C
B = > 15° C

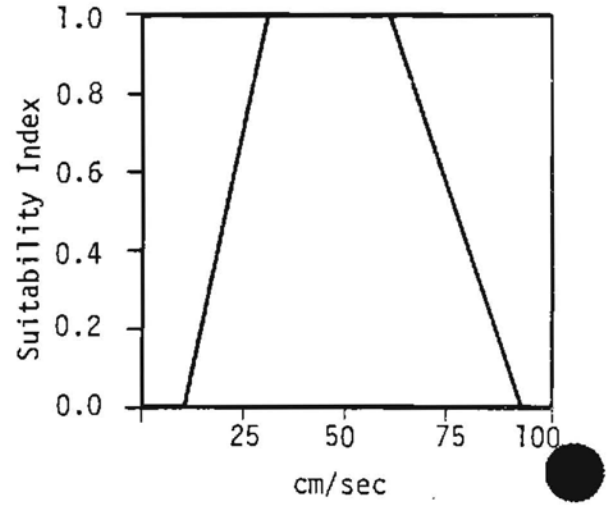


R (V_4) Average thalweg depth (cm) during the late growing season low water period.

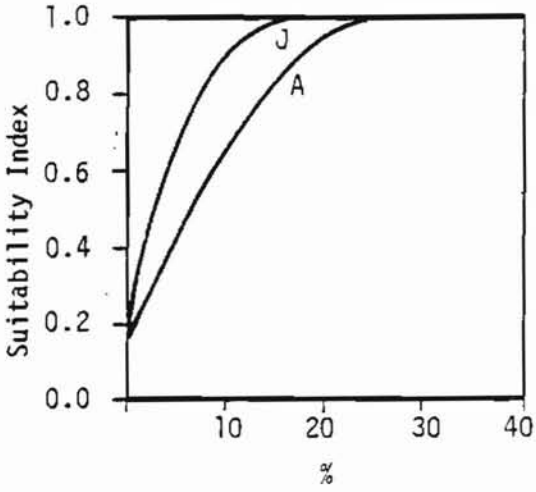
A = ≤ 5 m stream width
B = > 5 m stream width



R (V_5) Average velocity (cm/sec) over spawning areas during embryo development.

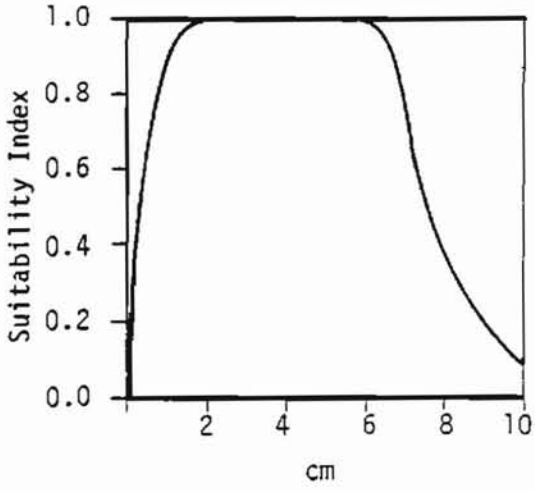


R (V_6) Percent cover during the late growing season, low water period at depths ≥ 15 cm and velocities < 15 cm/sec.
J = Juveniles
A = Adults

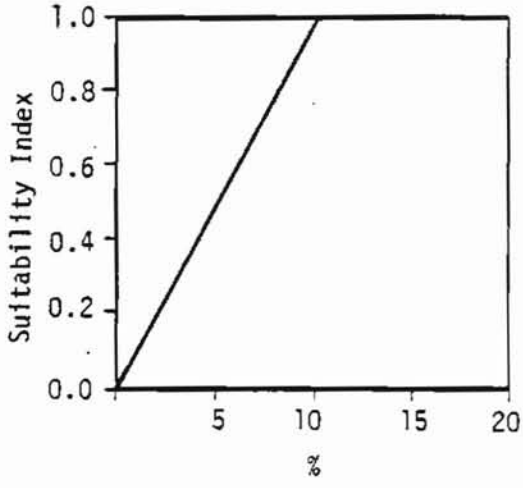


R (V_7) Average size of substrate between 0.3-8 cm diameter in spawning areas, preferably during the spawning period.

To derive an average value for use with graph V_7, include areas containing the best spawning substrate sampled until all potential spawning sites are included or until the sample contains an area equal to 5% of the total cutthroat habitat being evaluated.

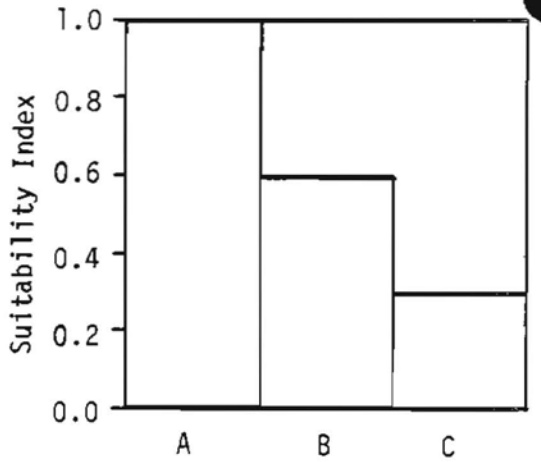


R (V_8) Percent substrate size class (10-40 cm) used for winter and escape cover by fry and small juveniles.

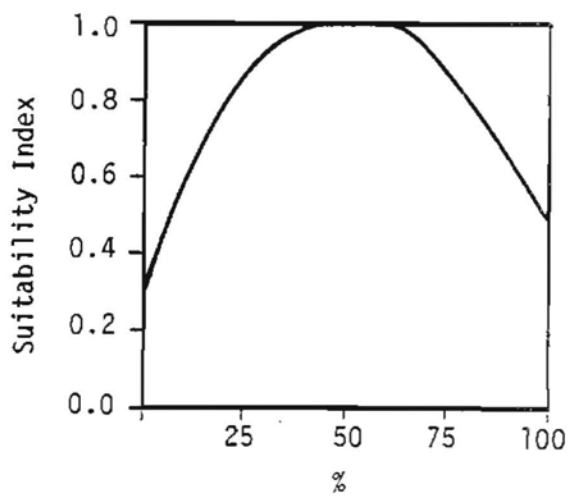


R (V_9) Dominant (≥ 50%) substrate type in riffle-run areas for food production.

A) Rubble or small boulders or aquatic vegetation in spring areas dominant with limited amounts of gravel, large boulders, or bedrock.
B) Rubble, gravel, boulders, and fines occur in approximately equal amounts or gravel is dominant. Aquatic vegetation may or may not be present.
C) Fines, bedrock, or large boulders are dominant. Rubble and gravel are insignificant (≤ 25%).

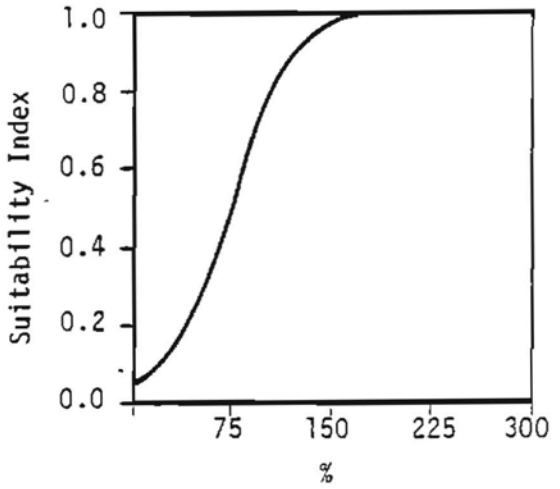


R (V_{10}) Percent pools during the late growing season, low water period.

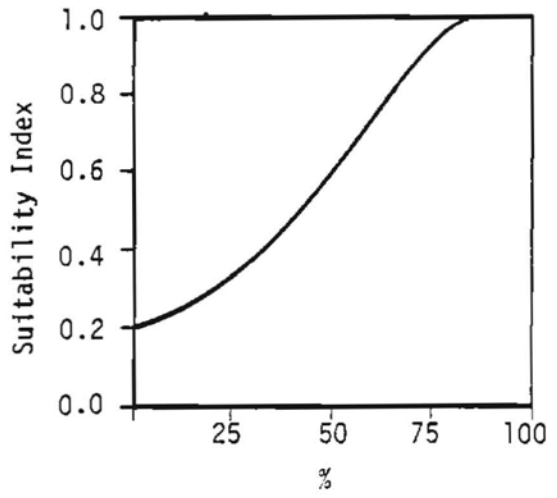


R (V_{11}) Average percent vegetation (trees, shrubs, and grasses-forbs) along the streambank during the summer for allochthonous input. Vegetation Index = 2 (% shrubs) + 1.5 (% grasses) + (% trees) + 0 (% bareground).

(For streams ≤ 50 m wide)



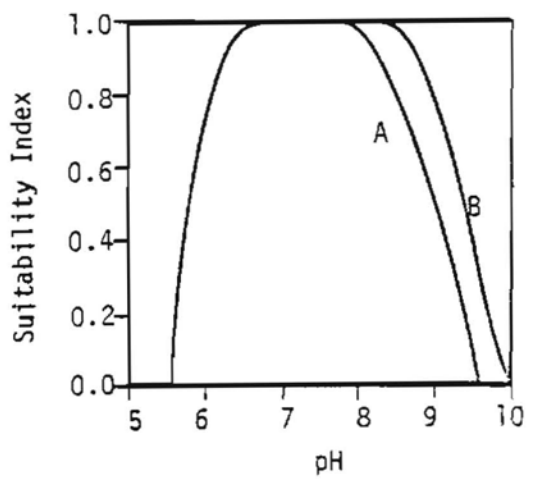
R (V_{12}) (Optional) Average percent rooted vegetation and stable rocky ground cover along the streambank during the summer (erosion control).



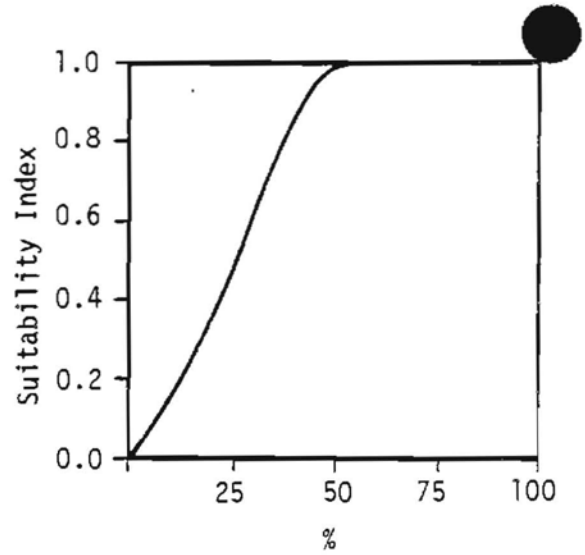
R,L (V_{13}) Annual maximal or minimal pH. Use the measurement with the lowest SI.

For lacustrine habitats, measure pH in the zone of the best combination of dissolved oxygen and temperature.

A = General
B = Lahontan Basin



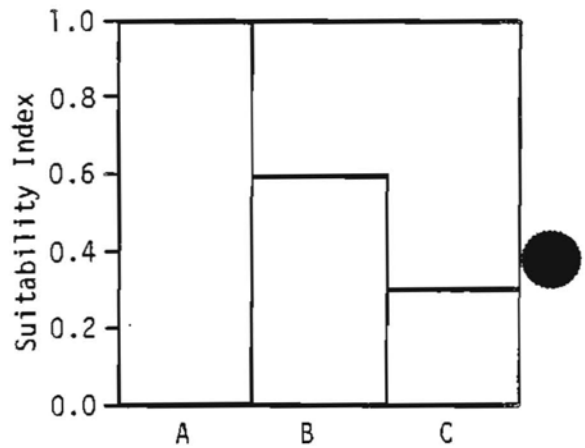
R (V_{14}) Average annual base flow regime during the late summer or winter low flow period as a percentage of the average annual daily flow.



R (V_{15}) Pool class rating during the late growing season low flow period. The rating is based on the % of the area containing pools of 3 classes as described below.

A) ≥ 30% of the area is comprised of 1st-class pools.
B) ≥ 10%-< 30% 1st-class pools or ≥ 50% 2nd-class pools.
C) < 10% 1st-class pools and < 50% 2nd-class pools.

(See pool class descriptions below)



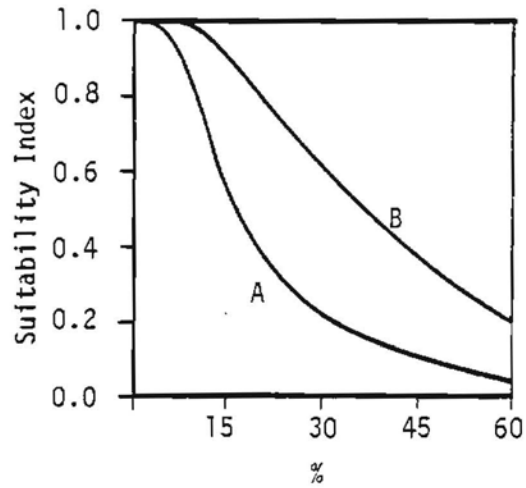
A) First-class pool: Large and deep. Pool depth and size are sufficient to provide a low velocity resting area for several adult trout. More than 30% of the pool bottom is obscure due to depth, surface turbulence, or the presence of structures; e.g., logs, debris piles, boulders, or overhanging banks and vegetation. Or, the greatest pool depth is ≥ 1.5 m in streams ≤ 5 m wide or ≥ 2 m deep in streams > 5 m wide.

B) Second-class pool: Moderate size and depth. Pool depth and size are sufficient to provide a low velocity resting area for a few adult trout. From 5 to 30% of the bottom is obscure due to surface turbulence, depth, or the presence of structures. Typical second class pools are large eddies behind boulders and low velocity, moderately deep areas beneath overhanging banks and vegetation.

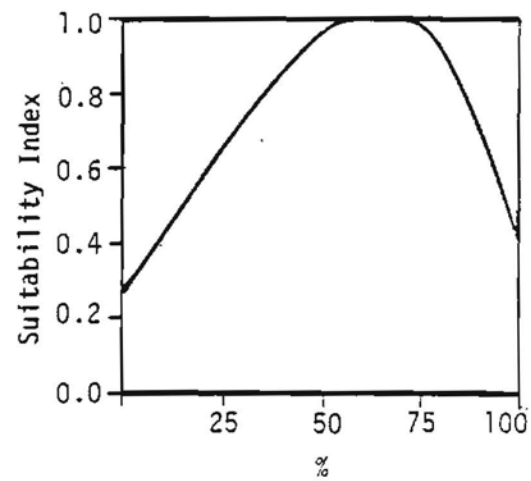
C) Third-class pool: Small or shallow or both. Pool depth and size are sufficient to provide a low velocity resting area for one to very few adult trout. Cover, if present, is in the form of shade, surface turbulence, or very limited structure. Typical third-class pools are wide, shallow pool areas of streams or small eddies behind boulders. Virtually the entire bottom area is discernable.

R (V_{16}) Percent fines (< 3 mm) in riffle-run and in spawning areas during average summer flows.

A = Spawning
B = Riffle-run



R (V_{17}) (Optional) Percent of stream area shaded between 1000 and 1400 hrs (for streams ≤ 50 m wide). Do not use on cold (<18°C), unproductive streams.



B) Second-class pool: Moderate size and depth. Pool depth and size are sufficient to provide a low velocity resting area for a few adult trout. From 5 to 30% of the bottom is obscure due to surface turbulence, depth, or the presence of structures. Typical second class pools are large eddies behind boulders and low velocity, moderately deep areas beneath overhanging banks and vegetation.

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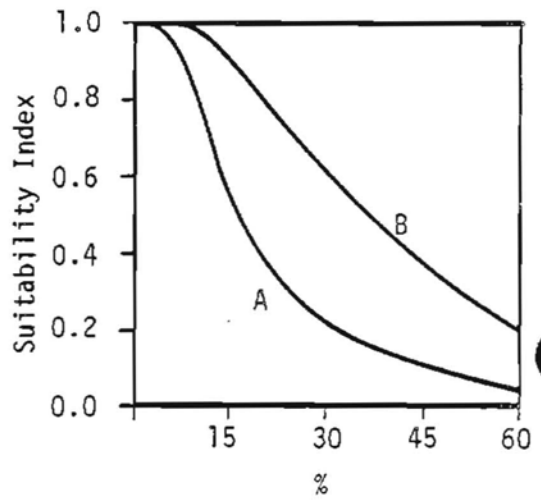
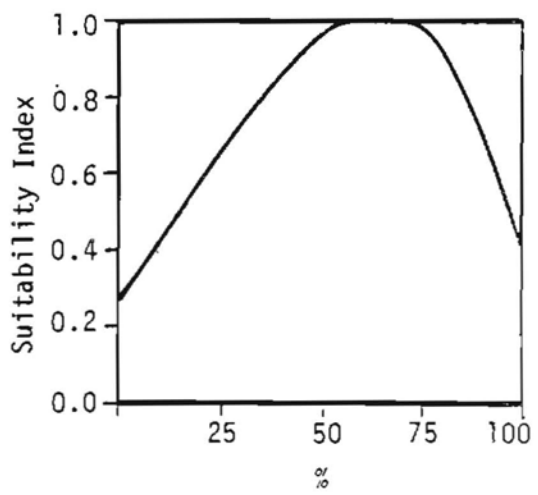
B = Riffle-run



R (V_{17}) (Optional) Percent of stream area shaded between 1000 and 1400 hrs (for streams ≤ 50 m wide). Do not use on cold (<18°C), unproductive streams.



Riverine Model

This model uses a life stage approach with five components: adult; juvenile; fry; embryo; and other.

Adult (C_A). C_A variables: V_4; V_6; V_{10}; and V_{15}

Case 1: where V_6 is > $(V_{10} \times V_{15})^{1/2}$

$$C_A = [V_4 \times V_6 (V_{10} \times V_{15})^{1/2}]^{1/3}$$

Case 2: where V_6 is ≤ $(V_{10} \times V_{15})^{1/2}$

$$C_A = [V_4 (V_{10} \times V_{15})^{1/2}]^{1/2}$$

If V_4 or $(V_{10} \times V_{15})^{1/2}$ is ≤ 0.4 in either equation, then C_A = the lowest variable score.

Juvenile (C_J). C_J variables: V_6; V_{10}; and V_{15}

$$C_J = \frac{V_6 + V_{10} + V_{15}}{3}$$

or, if any variable is ≤ 0.4, then C_J = the lowest variable score.

Fry (C_F). C_F variables: V_8; V_{10}; and V_{16}

$$C_F = [V_{10} (V_8 \times V_{16})^{1/2}]^{1/2}$$

or, if V_{10} or $(V_8 \times V_{16})^{1/2}$ is ≤ 0.4, then C_F = the lowest variable score.

Embryo (C_E). C_E variables: V_2; V_3; V_5; V_7; and V_{16}

Steps:

A. A potential spawning site is an ≥ 0.5 m² area of gravel, 0.3-8.0 cm in size, covered by flowing water ≥ 15 cm deep. At each spawning site sampled, record:

1. The average water velocity over the site;
2. The average size of all gravel 0.3-8.0 cm;
3. The percentage of fines < 0.3 cm in the gravel; and
4. The total area in m² of each site.

B. Derive a spawning site suitability index (V_s) for each site by combining V_5, V_7, and V_{16} values for each site.

$$V_s = (V_5 \times V_7 \times V_{16})^{1/3}$$

C. Derive a weighted average ($\overline{V}_s$) for all sites included in the sample.

Select the best V_s scores until all sites are included, or until a total spawning area equal to, but not exceeding, 5% of the total cutthroat trout habitat has been included, whichever comes first.

$$\overline{V}_s = \frac{\sum_{i=1}^{n} A_i \, V_{si}}{\text{total habitat area}} \; /0.05 \text{ (output cannot > 1.0)}$$

where A_i = the area of each spawning site in m², but ΣA_i cannot exceed 5% of the total cutthroat habitat.

V_{si} = the individual SI's from the best spawning areas until all spawning sites have been included or until SI's from an area equal to 5% of the total cutthroat habitat being evaluated has been included, whichever occurs first.

D. Derive C_E

C_E = the lowest score of V_2, V_3, or $\overline{V}_s$

Other (C_O). C_O variables: V_1; V_3; V_9; V_{11}; V_{12}; V_{13}; V_{14}; V_{16}; and V_{17}

$$C_O = \left[\frac{(V_9 \times V_{16})^{1/2} + V_{11}}{2} \times (V_1 \times V_3 \times V_{12} \times V_{13} \times V_{14} \times V_{17})^{1/N} \right]^{1/2}$$

where N = the number of variables within the parentheses. Note that variables V_{12} and V_{17} are optional and, therefore, can be omitted.

HSI determination. HSI's can be derived for a single life stage, a combination of two or more life stages, or all life stages combined. In all cases, except for the embryo component (C_E), an HSI is obtained by combining one or more life stage component scores with the other component (C_O) score.

1. Average Value Method. Components: C_A, C_J, C_F, C_E, and C_O

$$HSI = (C_A \times C_J \times C_F \times C_E \times C_O)^{1/N}$$

or, if C_A is ≤ 0.4, then $HSI = C_A$.

where N = the number of components in the equation.

Solve the equation for the number of components to be included in the evaluation. There will be a minimum of two, one or more life stage components and the component (C_O), unless only the embryo life stage (C_E) is being evaluated; then $HSI = C_E$.

2. Average Value Probability Method. This method also uses a life stage approach with five components: adult (C_A); juvenile (C_J); fry (C_F); embryo (C_E); and other (C_O). However, the C_O component is divided into two subcomponents, food (C_{OF}) and water quality (C_{OQ}). It is assumed that the C_{OF} subcomponent can either increase or decrease the suitability of the habitat by its effect on growth at each life stage except embryo, but the C_{OQ} subcomponent is either neutral or can decrease the habitat suitability.

Components and subcomponents: C_A; C_J; C_F; C_E; C_{OF}; and C_{OQ}

Steps:

A. Calculate the subcomponents C_{OF} and C_{OQ} of C_O

$$C_{OF} = \frac{(V_9 \times V_{16})^{1/2} + V_{11}}{2}$$

$$C_{OQ} = (V_1 \times V_3 \times V_{13} \times V_{14})^{1/4}$$

or, if any variable is ≤ 0.4, then C_{OQ} = the value of the lowest variable.

B. Calculate the HSI by either the noncompensatory or the compensatory method.

Noncompensatory method

$$HSI = (C_A \times C_J \times C_F \times C_E \times C_{OF})^{1/N} \times C_{OQ}$$

or, if C_A is ≤ 0.4, then $HSI = C_A \times C_{OQ}$.

where N = the number of components and subcomponents inside the brackets.

If only the embryo component is being evaluated, then $HSI = C_E \times C_{OQ}$.

Compensatory method.

1) $HSI' = (C_A \times C_J \times C_F \times C_E \times C_{OF})^{1/N}$

or, if C_A is ≤ 0.4, then $HSI' = C_A$

where N = the number of components and subcomponents in the equation.

2) If C_{OQ} is < HSI', then HSI = HSI' x [1 - (HSI' - C_{OQ})]; if not, HSI = HSI'.

3) If only the embryo component is being evaluated, then HSI = C_E x (step 2 applied to C_E instead of HSI').

APPENDIX B

ALTERNATIVE RATING SYSTEMS USED FOR DETERMINING SUITABILITY INDICES VALUES FOR SELECTED VARIABLES IN TESTING THE DRAFT HSI MODEL FOR CUTTHROAT TROUT

Table B-1. Substrate for food (V_s) ratings.

		Direction	Rating
1A.	If the percentage of rubble and boulders is greater than or equal to 50% of the total bottom materials	Go to 2	
1B.	If the percentage of rubble and boulders is less than 50% of the total bottom materials	Go to 3	
2A.	If the percentage of gravel and boulders is greater than or equal to 25% of the total bottom materials		0.6
2B.	If the percentage of gravel and boulders is less than 25% of the total bottom materials		1.0
3A.	If the percentage of gravel is greater than or equal to 50% of the total bottom materials		0.6
3B.	If the percentage of gravel is less than 50% of the total bottom materials	Go to 4	
4A.	If the percentage of fines and boulders is greater than or equal to 50% of the total bottom materials	Go to 5	
4B.	If the percentage of fines and boulders is less than 50% of the total bottom materials		0.6
5A.	If the percentage of gravel and rubble is greater than or equal to 25% of the total bottom materials		0.6
5B.	If the percentage of gravel and rubble is less than 25% of the total bottom materials		0.3

Table B-2. Streamside cover rating.

Rating		
Platts	SI	Streamside cover
4	0.75 (tree)	The dominating vegetation influencing the streamside and/or water environment is of tree form.
3	1.00 (brush)	The dominating vegetation influencing the streamside and/or water environment is brush.
2	0.50 (grass)	The dominating vegetation influencing the streamside and/or water environment is grass.
1	0.25 (exposed)	Over 50% of the streambanks have no vegetation and the dominant material is soil, rock, bridge materials, culverts, mine tailings, or similar materials.

Table B-3. Streamside stability condition analysis rating.

Rating		Environmental condition
Platts	SI	
4	1.0	Over 80% of the streambank is covered by vegetation in vigorous condition. If the streambanks are not dominated by vegetation, then the streambanks are formed by bedrock or large boulders. The streambank, in combination with the stream, provides (within the evaluation area) all of the following environmental needs of fish: (1) escape cover, under or near the banks; (2) favorable protection from predators and good feeding conditions; and (3) fish resting areas. The streambanks control the waterflow, assisting in maintaining a favorable width/depth ratio. (The stream has not widened by eroding its present banks to the point that the stream is starting to meander again within the meander banks). The stream and its bank function as a unit with the streambank buffering high water flows without significant streambank erosion.
3	0.8	Fifty to 80% of the streambanks are covered by vegetation, bedrock, boulder, or rubble. The streambank, in combination with the stream (within the reach), provides at least two of the following environmental needs of fish: (1) escape cover, under or near the banks; (2) favorable protection from predators and good feeding conditions; or (3) fish resting areas. The streambanks have some control over water flows, assisting in keeping a good width/depth ratio. The stream and its banks function over most of the transect reach as a unit. The streambanks handle high water flows with little damage to the streambank.
2	0.5	Twenty-five to 50% of the streambanks are covered by vegetation, rubble, or boulder, or the streambank is dominated by gravel. The streambanks (within the reach), in combination with the stream, provide at least one of the following environmental needs for fish: (1) escape cover; (2) favorable protection from predators and good feeding conditions; or (3) resting areas. The streambanks have some control over water flow, assisting in maintaining a fair width/depth ratio. The stream and its banks function as a unit over some of the reach at low flows. The streambank has some buffer ability to lessen damage from high water flows.

Table B-3. (concluded)

Rating		Environmental condition
Platts	SI	
1	0.3	Less than 25% of the streambank is covered by vegetation, bedrock, boulder, or rubble. The streambank is composed mainly of soil and, in combination with the stream, provides no significant amount of the following environmental needs of fish: (1) escape cover; (2) favorable protection from predators and good conditions for feeding; or (3) resting areas. The streambank has little or no control over water flows. The stream and its bank do not function as a unit over much of the transect reach during low flow conditions. The streambank is usually damaged by high water flows.

Table B-4. Key to pool quality rating.

		Direction	Rating Platts	Rating SI
1A	If the maximum pool diameter exceeds the average stream width	Go to 2		
1B	If the maximum pool diameter is less than the average stream width	Go to 3		
1C	If the maximum pool diameter is about equal to the average stream width	Go to 4		
2A	If the pool is over 3 ft deep or the pool is over 2 ft deep and has abundant fish cover		Rate 5	(1.0)
2B	If the pool is less than 2 ft deep or if the pool is between 2 and 3 ft deep and lacks fish cover		Rate 4	(0.8)
3A	If the pool is less than 2 ft deep and pool cover is classified as exposed		Rate 1	(0.2)
	If the pool is over 2 ft deep with intermediate or better cover		Rate 3	(0.6)
3B	If the pool is less than 2 ft deep but pool cover for fish is intermediate or better		Rate 2	(0.4)
4A	If the pool is less than 2 ft deep	Go to 5		
4B	If the pool is more than 2 ft deep	Go to 2		
5A	If the pool has intermediate to abundant cover		Rate 3	(0.6)
5B	If the pool has exposed cover conditions		Rate 2	(0.4)

(1) If cover is rated abundant, more than half of the pool perimeter has fish cover.

(2) If cover is rated intermediate, between one-fourth and one-half of the pool perimeter has fish cover.

(3) If there is no cover and pool is exposed, less than one-fourth of the pool perimeter has fish cover.

Table B-5. Embeddedness rating for channel substrate materials (gravel, rubble, and boulder).

Rating		
Platts	SI	Environmental description
5	1.0	The gravel, rubble, and boulder particles have less than 5% of their perimeter (surface) covered by fine sediment, and fine sediment makes up less than 10% of the channel substrate.
4	0.5	The gravel, rubble, and boulder particles have between 5 and 25% of their perimeter (surface) covered by fine sediment, and fine sediment makes up less than 25% of the channel substrate.
3	0.3	The gravel, rubble, and boulder particles have between 25 and 50% of their perimeter (surface) covered by fine sediment or fine sediment makes up 25 to 50% of the channel materials.
2	0.1	The gravel, rubble, and boulder particles have between 50 and 75% of their perimeter (surface) covered by fine sediment or fine sediment makes up 50 to 75% of the channel materials.
1	0.0	The gravel, rubble, and boulder particles have over 75% of their perimeter (surface) covered by fine sediment or the fine sediment makes up over 75% of the channel materials.

APPENDIX C

DATA SETS USED IN TESTING THE RIVERINE CUTTHROAT TROUT HSI MODEL

Table C-1. Big Creek data sets.

Variable	Units	V	Site 1				Site 2				Site 3			
			1979		1980		1979		1980		1979		1980	
			Data	SI	Data	SI	Data	SI	Data	SI	Data	SI	Data	SI
Temperature	°C	1	20	0.7	20	0.7	20	0.7	20	0.7	20	0.7	20	0.7
Temperature	°C	2	16	0.5	16	0.5	16	0.5	16	0.5	16	0.5	16	0.5
Dissolved O	mg/l	3	5.4	0.5	5.4	0.5	5.4	0.5	5.4	0.5	5.4	0.5	5.4	0.5
Depth	cm	4	16	0.5	18	0.6	27	0.9	30	1.0	20	0.7	21	0.7
Velocity	cm/s	5	-	0.8	-	0.8	-	0.8	-	0.8	-	0.8	-	0.8
Cover	%	6A	11	0.6	11	0.6	35	1.0	43	1.0	41	1.0	26	1.0
Cover	%	6J	11	0.8	11	0.8	35	1.0	43	1.0	41	1.0	26	1.0
Substrate		7	-	1.0	-	1.0	-	1.0	-	1.0	-	1.0	-	1.0
Substrate	%	8	2.0	0.2	6.9	0.7	24.5	1.0	39.7	1.0	0.1	0.1	0	0.1
Substrate	Class	9	B	0.6	B	0.6	B	0.6	B	0.6	B	0.6	B	0.6
Pools	%	10	22	0.8	56	1.0	58	1.0	85	0.7	38	0.9	71	0.8
Vegetative cover	Class	11	1.9	0.5	1.4	0.3	2.1	0.6	2.1	0.6	1.8	0.4	1.5	0.4
Bank stability	Class	12	1.7	0.4	1.6	0.4	3.4	0.9	3.2	0.9	2.0	0.5	1.7	0.4
pH		13	8	1.0	8	1.0	8	1.0	8	1.0	8	1.0	8	1.0
Pool class	Class	15	1.6	0.3	3.1	0.6	3.7	0.7	4.5	0.9	3.1	0.6	3.9	0.8
Embeddedness	Class	16	2.9	0.3	3.3	0.3	2.2	0.1	2.3	0.1	2.2	0.1	3.0	0.3
Biomass (g/m)			0.9		2.1		1.2		0.9		1.6		0.2	

Table C-2. Angus Creek data sets.

Variable	Units	V	Site 1				Site 2				Site 3				Site 5			
			1976		1978		1976		1978		1976		1978		1976		1978	
			Data	SI	Data	SI	Data	SI	Data	SI	Data	SI	Data	SI	Data	SI	Data	SI
Temperature	°C	1	-	1.0	-	1.0	-	1.0	-	1.0	-	1.0	-	1.0	-	0.3	-	0.3
Temperature	°C	2	-	1.0	-	1.0	-	1.0	-	1.0	-	1.0	-	1.0	-	0.3	-	0.3
Dissolved O	mg/l	3	12	1.0	12	1.0	12	1.0	12	1.0	12	1.0	12	1.0	12	1.0	12	1.0
Depth	cm	4	10	0.3	10	0.3	42	1.0	39	0.8	47	1.0	39	1.0	32	1.0	18	0.6
Velocity	cm/s	5	-	1.0	-	1.0	-	1.0	-	1.0	-	1.0	-	1.0	-	1.0	-	1.0
Percent cover	%	6A	21	0.8	24	0.8	32	1.0	18	0.8	20	0.8	11	0.6	61	1.0	31	1.0
Percent cover	%	6J	21	1.0	24	1.0	32	1.0	18	1.0	20	1.0	11	0.8	61	1.0	31	1.0
Substrate		7	-	1.0	-	1.0	-	1.0	-	1.0	-	1.0	-	1.0	-	1.0	-	1.0
Substrate	%	8	3.5	0.4	2.2	0.2	1.0	0.1	0	0	0	0	0	0	59	1.0	45	1.0
Substrate	Class	9	B	0.6	B	0.6	C	0.3	C	0.3	C	0.3	C	0.3	B	0.6	B	0.6
Percent pools	%	10	76	0.8	45	1.0	96	0.5	98	0.5	100	0.5	100	0.5	63	0.9	77	0.8
Vegetative cover	Class	11	2.3	0.7	2.2	0.6	2.6	0.8	2.6	0.8	2.6	0.8	2.3	0.7	2.0	0.5	2.0	0.5
Bank stability	Class	12	3.0	0.8	4.0	1.0	3.9	1.0	4.0	1.0	3.7	1.0	4.0	1.0	2.3	0.6	3.7	1.0
pH		13	7.5	1.0	7.5	1.0	7.5	1.0	7.5	1.0	7.5	1.0	7.5	1.0	7.5	1.0	7.5	1.0
Pool class	Class	15	3.3	0.6	2.4	0.4	5.0	1.0	3.4	0.7	4.9	1.0	2.5	0.5	3.2	0.6	2.1	0.4
Embeddedness	Class	16	2.5	0.2	2.6	0.2	1.2	0.1	1.0	0.1	1.0	0.1	1.1	0.1	4.2	0.5	2.8	0.3
Biomass (g/m)			8.1		3.4		3.6		--		7.5		1.3		4.9		0.6	

Table C-3. Otter Creek data sets.

Variable	Units	V	Site 1				Site 2				Site 3			
			1979		1980		1979		1980		1979		1980	
			Data	SI	Data	SI	Data	SI	Data	SI	Data	SI	Data	SI
Temperature	°C	1	19	0.7	19	0.7	19	0.7	19	0.7	19	0.7	19	0.7
Temperature	°C	2	19	0.1	19	0.1	19	0.1	19	0.1	19	0.1	19	0.1
Dissolved O	mg/l	3	-	1.0	-	1.0	-	1.0	-	1.0	-	1.0	-	1.0
Depth	cm	4	22	0.8	27	0.9	24	0.8	43	0.9	28	0.9	46	1.0
Velocity	cm/s	5	-	1.0	-	1.0	-	1.0	-	1.0	-	1.0	-	1.0
Cover	%	6A	71	1.0	24	1.0	70	1.0	63	1.0	87	1.0	81	1.0
Cover	%	6J	71	1.0	24	1.0	70	1.0	63	1.0	87	1.0	81	1.0
Substrate		7	-	1.0	-	1.0	-	1.0	-	1.0	-	1.0	-	1.0
Substrate	%	8	1.8	0.2	0.3	0.1	24.3	1.0	30.2	1.0	9.6	1.0	13.1	1.0
Substrate	Class	9	B	0.6	B	0.6	B	0.6	B	0.6	B	0.6	B	0.6
Percent pools	%	10	53	1.0	66	1.0	62	0.9	70	0.9	90	0.7	98	0.5
Vegetative cover	Class	11	1.6	0.4	2.0	0.5	1.9	0.5	2.0	0.5	1.9	0.5	2.0	0.5
Bank stability	Class	12	2.9	0.8	2.9	0.8	3.4	0.9	3.4	0.9	3.3	0.9	3.5	0.9
pH		13	8.7	0.7	8.7	0.7	8.7	0.7	8.7	0.7	8.7	0.7	8.7	0.7
Pool class	Class	15	3.7	0.7	3.8	0.7	4.2	0.8	4.6	0.9	4.9	1.0	5.0	1.0
Embeddedness	Class	16	2.9	0.3	3.1	0.3	2.9	0.3	3.2	0.3	1.8	0.1	1.5	0.1
Biomass (g/m)			1.8		0.6		1.0		1.7		1.8		1.0	

Table C-4. Blackfoot River data sets.

Variable	Units	V	Site 6				Site 7			
			1976		1978		1976		1978	
			Data	SI	Data	SI	Data	SI	Data	SI
Temperature	°C	1	-	1.0	-	1.0	-	1.0	-	1.0
Temperature	°C	2	-	1.0	-	1.0	-	1.0	-	1.0
Dissolved O	mg/l	3	12	1.0	12	1.0	12	1.0	12	1.0
Depth	cm	4	34	0.7	37	0.8	49	1.0	54	1.0
Velocity	cm/s	5	-	0.8	-	0.8	-	0.8	-	0.8
Percent cover	%	6A	25	1.0	25	1.0	25	1.0	25	1.0
Percent cover	%	6J	25	1.0	25	1.0	25	1.0	25	1.0
Substrate		7	-	0.5	-	0.5	-	0.5	-	0.5
Substrate	%	8	71	1.0	15	1.0	22	1.0	6	0.6
Substrate	Class	9	B	0.6	B	0.6	B	0.6	B	0.6
Percent pools	%	10	15	0.5	20	0.8	8	0.3	27	0.8
Vegetative cover	Class	11	1.9	0.5	2.0	0.5	2.0	0.5	2.0	0.5
Bank stability	Class	12	3.8	1.0	3.4	0.9	3.9	1.0	3.1	0.9
pH		13	7.5	1.0	7.5	1.0	7.5	1.0	7.5	1.0
Pool class	Class	15	4.3	0.8	1.3	0.2	4.9	1.0	2.0	0.4
Embeddedness	Class	16	3.0	0.3	2.4	0.2	3.1	0.3	2.8	0.3
Biomass (g/m)			0.07				0.06			

Table C-5. Diamond Creek data sets.

			Site 8				Site 9				Site 10				Site 11		Site 12				Site 13			
			1976		1978		1976		1978		1976		1978		1976		1976		1978		1976		1978	
Variable	Units	V	Data	SI	Data	SI	Data	SI	Data	SI	Data	SI	Data	SI	Data	SI	Data	SI	Data	SI	Data	SI	Data	SI
Temperature	°C	1	21	0.7	21	0.7	21	0.7	21	0.7	21	0.7	21	0.7	21	0.7	21	0.7	21	0.7	21	0.7	21	0.7
Temperature	°C	2	-	0.5	-	0.5	-	0.5	-	0.5	-	0.5	-	0.5	-	0.5	-	0.5	-	0.5	-	0.5	-	0.5
Dissolved O_2	mg/l	3	12	1.0	12	1.0	12	1.0	12	1.0	12	1.0	12	1.0	12	1.0	12	1.0	12	1.0	12	1.0	12	1.0
Depth	cm	4	13	0.4	16	0.5	14	0.5	16	0.5	17	0.6	20	0.7	42	1.0	30	0.5	30	0.5	43	0.8	35	0.7
Velocity	cm/s	5	-	1.0	-	1.0	-	1.0	-	1.0	-	1.0	-	1.0	-	1.0	-	1.0	-	1.0	-	1.0	-	1.0
Percent cover	%	6A	27	1.0	10	0.6	30	1.0	20	0.9	26	1.0	15	0.7	12	0.6	9	0.5	8	0.5	10	0.6	5	0.4
Percent cover	%	6J	27	1.0	10	0.8	30	1.0	20	1.0	26	1.0	15	1.0	12	0.9	9	0.8	8	0.7	10	0.8	5	0.5
Substrate		7	-	1.0	-	1.0	-	1.0	-	1.0	-	1.0	-	1.0	-	1.0	-	1.0	-	1.0	-	1.0	-	1.0
Substrate	%	8	36	1.0	10	1.0	5	0.5	4	0.4	12	1.0	0.2	0.1	1.0	0.1	50	1.0	4	0.4	18	1.0	3	0.3
Substrate	Class	9	B	0.6	B	0.6	B	0.6	B	0.6	8	0.6	B	0.6	C	0.3	A	1.0	B	0.6	B	0.6	B	0.6
Percent pools	%	10	57	1.0	56	1.0	77	0.8	82	0.7	75	0.7	72	0.8	94	0.5	58	1.0	56	1.0	96	0.5	64	0.9
Vegetative cover	Class	11	2.3	0.7	2.7	0.9	2.7	0.8	3.0	1.0	2.6	0.8	2.8	0.9	2.9	1.0	2.3	0.7	2.8	0.9	2.2	0.6	2.6	0.8
Bank stability	Class	12	3.7	1.0	2.7	0.7	3.6	1.0	2.8	0.8	3.0	0.8	2.6	0.7	3.4	0.9	3.6	1.0	2.8	0.8	3.7	1.0	3.3	0.9
pH		13	7.5	1.0	7.5	1.0	7.5	1.0	7.5	1.0	7.5	1.0	7.5	1.0	7.5	1.0	7.5	1.0	7.5	1.0	7.5	1.0	7.5	1.0
Pool class	Class	15	2.9	0.6	2.2	0.4	3.0	0.6	2.8	0.6	3.1	0.6	2.3	0.5	4.5	0.9	3.4	0.7	2.4	0.5	4.4	0.9	2.2	0.4
Embeddedness	Class	16	3.0	0.3	3.6	0.4	3.2	0.3	2.7	0.2	2.7	0.2	2.3	0.1	1.6	0.1	3.2	0.3	3.0	0.3	2.3	0.2	3.0	0.3
Biomass (g/m^2)			2.1		2.2		4.0				0.8		0.2		2.8		3.2		-		2.8		1.4	

Table C-6. Gance Creek data sets.

Variable	Units	V	Site 1						Site 2						Site 3					
			1978		1979		1980		1978		1979		1980		1978		1979		1980	
			Data	SI	Data	SI	Data	SI	Data	SI	Data	SI	Data	SI	Data	SI	Data	SI	Data	SI
Temperature	°C	1	21	0.7	21	0.7	21	0.7	21	0.7	21	0.7	21	0.7	21	0.7	21	0.7	21	0.7
Temperature	°C	2	16	0.5	16	0.5	16	0.5	16	0.5	16	0.5	16	0.5	16	0.5	16	0.5	16	0.5
Dissolved O	mg/l	3	-	1.0	-	1.0	-	1.0	-	1.0	-	1.0	-	1.0	-	1.0	-	1.0	-	1.0
Depth	cm	4	6	0.1	7	0.1	7	0.1	7	0.1	7	0.1	8	0.2	5	0.1	6	0.1	6	0.1
Velocity	cm/s	5	-	0.5	-	0.5	-	0.5	-	0.5	-	0.5	-	0.5	-	0.5	-	0.5	-	0.5
Percent cover	%	6A	19	0.8	16	0.8	10	0.6	19	0.8	20	0.8	17	0.8	25	1.0	19	0.8	13	0.6
Percent cover	%	6J	19	1.0	16	1.0	10	0.8	19	1.0	20	1.0	17	1.0	25	1.0	19	1.0	13	0.8
Substrate		7	-	1.0	-	1.0	-	1.0	-	1.0	-	1.0	-	1.0	-	1.0	-	1.0	-	1.0
Substrate	%	8	5	0.5	16	1.0	12	1.0	9	0.9	30	1.0	22	1.0	5	0.5	11	1.0	7	0.7
Substrate	Class	9	B	0.6	B	0.6	B	0.6	B	0.6	B	0.6	B	0.6	B	0.6	B	0.6	B	0.6
Percent pools	%	10	31	0.9	26	0.8	57	1.0	22	0.8	21	0.8	52	1.0	29	0.8	25	0.8	47	1.0
Vegetative cover	Class	11	2.7	0.9	3.0	1.0	1.9	0.5	2.4	0.7	2.5	0.8	1.9	0.5	2.7	0.9	2.5	0.8	1.8	0.5
Bank stability	Class	12	1.3	0.3	1.9	0.5	2.2	0.6	1.4	0.4	1.6	0.4	2.3	0.6	2.2	0.6	1.6	0.4	2.2	0.6
pH		13	-	1.0	-	1.0	-	1.0	-	1.0	-	1.0	-	1.0	-	1.0	-	1.0	-	1.0
Pool class	Class	15	1.9	0.4	1.6	0.3	2.5	0.5	1.9	0.4	1.8	0.4	2.6	0.5	1.6	0.3	1.7	0.3	2.2	0.4
Embeddedness	Class	16	3.1	0.3	3.5	0.4	2.1	0.1	3.6	0.4	4.0	0.5	2.7	3.0	3.8	0.5	4.2	0.5	3.1	0.3
Biomass (g/m)			3.3		7.6		10.6		6.5		4.2		11.9		2.8		2.3		9.8	

Table C-7. Tabor Creek data sets.

Variable	Units	V	Site 1				Site 2				Site 3			
			1979		1980		1979		1980		1979		1980	
			Data	SI	Data	SI	Data	SI	Data	SI	Data	SI	Data	SI
Temperature	°C	1	14	1.0	14	1.0	14	1.0	14	1.0	14	1.0	14	1.0
Temperatue	°C	2	14	1.0	14	1.0	14	1.0	14	1.0	14	1.0	14	1.0
Dissolved O	mg/l	3	-	1.0	-	1.0	-	1.0	-	1.0	-	1.0	-	1.0
Depth	cm	4	10	0.3	10	0.3	13	0.4	13	0.4	11	0.3	11	0.3
Velocity	cm/s	5	-	1.0	-	1.0	-	1.0	-	1.0	-	1.0	-	1.0
Percent cover	%	6A	8	0.4	6	0.4	25	1.0	21	0.8	15	0.8	9	0.4
Percent cover	%	6J	8	0.8	6	0.6	25	1.0	21	1.0	15	1.0	9	0.8
Substrate		7	-	1.0	-	1.0	-	1.0	-	1.0	-	1.0	-	1.0
Substrate	%	8	36	1.0	50	1.0	32	1.0	36	1.0	30	1.0	33	1.0
Substrate	Class	9	B	0.6	B	0.6	B	0.6	B	0.6	B	0.6	B	0.6
Percent pools	%	10	19	0.5	24	0.8	21	0.8	37	0.9	15	0.5	37	0.9
Vegetative cover	Class	11	2.0	0.5	1.9	0.5	2.0	0.5	2.0	0.5	2.1	0.6	1.9	0.5
Bank stability	Class	12	1.7	0.4	2.2	0.6	2.3	0.6	2.5	0.7	1.9	0.5	2.5	0.7
pH		13	8.1	1.0	8.1	1.0	8.1	1.0	8.1	1.0	8.1	1.0	8.1	1.0
Pool class	Class	15	1.3	0.3	1.5	0.3	1.8	0.4	2.0	0.4	1.4	0.3	2.0	0.4
Embeddedness	Class	16	3.3	0.4	3.5	0.4	2.8	0.3	3.2	0.3	3.7	0.4	3.5	0.4
Biomass (g/m)			1.9		0.9		4.8		1.5		5.6		14.6	

APPENDIX D

LIFE STAGE COMPONENT SI'S AND SPECIES HSI'S CALCULATED WITH THE CUTTHROAT TROUT MODEL

Table D-1. Life stage component SI's and species HSI's calculated with the cutthroat trout model.

Angus Creek

	Site 1		Site 2		Site 3		Site 5	
	1976	1978	1976	1978	1976	1978	1976	1978
Adult SI	0.55	0.53	0.84	0.72	0.84	0.67	0.90	0.70
Juvenile SI	0.80	0.40	0.83	0.73	0.83	0.60	0.83	0.73
Fry SI	0.20	0.20	0.10	0.10	0.10	0.10	0.80	0.30
Embryo SI	0.58	0.58	0.58	0.58	0.58	0.58	0.50	0.50
Other SI	0.70	0.69	0.70	0.70	0.70	0.66	0.68	0.68
HSI-1	0.20	0.20	0.10	0.10	0.10	0.10	0.73	0.30
HSI-2	0.20	0.20	0.10	0.10	0.10	0.10	0.48	0.30
HSI-3	0.20	0.20	0.10	0.10	0.10	0.10	0.69	0.30

Blackfoot River

	Site 6		Site 7	
	1976	1978	1976	1978
Adult SI	0.76	0.68	0.74	0.83
Juvenile SI	0.77	0.67	0.77	0.73
Fry SI	0.52	0.60	0.41	0.58
Embryo SI	0.62	0.54	0.62	0.62
Other SI	0.68	0.41	0.68	0.68
HSI-1	0.66	0.57	0.63	0.68
HSI-2	0.61	0.57	0.58	0.63
HSI-3	0.61	0.57	0.58	0.63

Table D-1. (continued)

Diamond Creek

	Site 8		Site 9		Site 10		Site 11	Site 12		Site 13	
	1976	1978	1976	1978	1976	1978	1976	1976	1978	1976	1978
Adult SI	0.68	0.57	0.70	0.66	0.75	0.68	0.82	0.65	0.59	0.78	0.65
Juvenile SI	0.87	0.73	0.80	0.73	0.80	0.77	0.77	0.83	0.73	0.73	0.60
Fry SI	0.74	0.80	0.39	0.28	0.60	0.10	0.10	0.74	0.35	0.47	0.30
Embryo SI	0.67	0.74	0.67	0.58	0.58	0.46	0.46	0.67	0.67	0.58	0.67
Other SI	0.70	0.72	0.76	0.75	0.69	0.68	0.71	0.74	0.74	0.64	0.72
HSI-1	0.73	0.71	0.39	0.28	0.68	0.10	0.10	0.72	0.35	0.63	0.30
HSI-2	0.59	0.59	0.39	0.28	0.55	0.10	0.10	0.59	0.35	0.44	0.30
HSI-3	0.70	0.70	0.39	0.28	0.65	0.10	0.10	0.70	0.35	0.52	0.30

Tabor Creek

	Site 1		Site 2		Site 3	
	1979	1980	1979	1980	1979	1980
Adult SI	0.30	0.30	0.40	0.40	0.30	0.30
Juvenile SI	0.53	0.57	0.73	0.77	0.60	0.70
Fry SI	0.56	0.71	0.66	0.70	0.56	0.75
Embryo SI	0.74	0.74	0.67	0.67	0.74	0.74
Other SI	0.63	0.66	0.64	0.65	0.64	0.67
HSI-1	0.30	0.30	0.40	0.40	0.30	0.30
HSI-2	0.30	0.30	0.40	0.40	0.30	0.30
HSI-3	0.30	0.30	0.40	0.40	0.30	0.30

Table D-1. (continued)

Gance Creek

	Site 1			Site 2			Site 3		
	1978	1979	1980	1978	1979	1980	1978	1979	1980
Adult SI	0.36	0.34	0.35	0.36	0.36	0.48	0.37	0.34	0.34
Juvenile SI	0.77	0.73	0.63	0.73	0.73	0.83	0.70	0.70	0.73
Fry SI	0.39	0.71	0.32	0.69	0.75	0.74	0.63	0.75	0.68
Embryo SI	0.50	0.50	0.37	0.50	0.50	0.50	0.50	0.50	0.50
Other SI	0.67	0.76	0.72	0.66	0.67	0.61	0.76	0.70	0.61
HSI-1	0.36	0.34	0.32	0.36	0.36	0.62	0.37	0.34	0.34
HSI-2	0.36	0.34	0.32	0.36	0.36	0.52	0.37	0.34	0.34
HSI-3	0.36	0.34	0.32	0.36	0.36	0.58	0.37	0.34	0.34

Otter Creek

	Site 1		Site 2		Site 3	
	1979	1980	1979	1980	1979	1980
Adult SI	0.87	0.85	0.88	0.90	0.82	0.84
Juvenile SI	0.90	0.87	0.90	0.83	0.90	0.83
Fry SI	0.24	0.17	0.70	0.70	0.32	0.32
Embryo SI	0.10	0.10	0.10	0.10	0.10	0.10
Other SI	0.58	0.62	0.63	0.63	0.56	0.56
HSI-1	0.10	0.10	0.10	0.10	0.10	0.10
HSI-2	0.10	0.10	0.10	0.10	0.10	0.10
HSI-3	0.10	0.10	0.10	0.10	0.10	0.10

Table D-1. (concluded)

Big Creek

	Site 1		Site 2		Site 3	
	1979	1980	1979	1980	1979	1980
Adult SI	0.53	0.68	0.91	0.93	0.90	0.82
Juvenile SI	0.63	0.80	0.90	0.87	0.83	0.87
Fry SI	0.24	0.68	0.32	0.32	0.10	0.17
Embryo SI	0.50	0.50	0.41	0.41	0.41	0.50
Other SI	0.53	0.47	0.56	0.56	0.46	0.50
HSI-1	0.24	0.61	0.32	0.32	0.10	0.17
HSI-2	0.24	0.36	0.32	0.32	0.10	0.17
HSI-3	0.24	0.36	0.32	0.32	0.10	0.17

ANALYSIS AND REFINEMENT OF HABITAT SUITABILITY INDEX MODELS FOR EIGHT WARM WATER FISH SPECIES

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INTRODUCTION

Water scarcities often result in conflicts between resource development and habitat protection (U.S. Fish and Wildlife Service 1979). Public concern over this conflict resulted in a legislative mandate for the development of a quantitative method of determining the habitat requirements of important fish and wildlife species. In response to this charge, habitat suitability index (HSI) models, based on the assumption that a relationship exists between various physical and chemical parameters of streams and carrying capacity, are currently being developed by the U.S. Fish and Wildlife Service for use with the Habitat Evaluation Procedures (HEP) (U.S. Fish and Wildlife Service 1980). If these models prove accurate, a biologist will be able to sample physical factors and predict the changes in carrying capacity that would occur with any proposed environmental alteration.

The HSI models tested in this study were based on aggregated suitability indices (SI's) derived from draft suitability index curves that were provided by the U.S. Fish and Wildlife Service's Western Energy and Land Use Team. These draft SI curves were based on information from the literature. Most recently, some authors have measured biomass-habitat relationships in the field and developed curves based on these data (Jones and Maughan 1980; Orth and Maughan 1980). However, many of the HSI models published by the U.S. Fish and Wildlife Service (Schamberger et al. 1982) are based on literature-developed SI curves and have not been field tested. The assumptions made in the tested HSI models seem reasonable and are supported in the ecological

literature. However, the fact remains that the model assumptions require testing and verification. Testing these assumptions was the goal of this study.

Specific objectives of the study were to: (1) evaluate relationships between standing crops of selected fish species and selected physical and chemical variables in prairie streams; (2) evaluate the relationship between species Habitat Suitability Indices (as calculated by selected models) and fish standing crops in prairie streams; (3) attempt to improve the predictive capabilities of the models for estimating standing crops of various fish species, based on physical and chemical variables; and (4) determine the general applicability of the models.

MATERIALS AND METHODS

The data set used in this evaluation contained information from 420 Kansas stream sites. The data were collected primarily during the summers of 1974 through 1977 by the Kansas Fish and Game Commission. Each site was sampled once. These data were originally used in the development of a technical report, entitled Assessment of the Aquatic Environment in Kansas (Layher et al. 1978), and delivered to the Kansas Department of Health and Environment pursuant to section 208 of Public Law 92-500.

Standing crop information was calculated for each fish species that occurred at each site sampled. The sites were classified according to percent pool, percent riffle, and percent run combinations. The climate at each site was classified by estimating the growing season as delineated on agricultural maps. Physical factors were measured at each site, including total length of the site, maximum stream width, minimum stream width, mean stream width, mean water depth, surface area of water, volume of flow, velocity, substrate type, gradient (from topographic maps), and water temperature. Chemical factors were also measured, primarily through the use of Hach DR-EL units, and included total dissolved solids, turbidity, total alkalinity, calcium hardness, magnesium hardness, sulfates, phosphates, nitrates, dissolved oxygen, pH, conductivity, and chlorides. Statistical analyses were done utilizing the Statistical Analyses System (SAS) (Blair et al. 1979). Not all of the variables listed were measured at all sites. However, only those variables that were measured at all sites where the species was found were used in analysis of individual species data.

Data for adults of eight fish species were used in the study: largemouth bass (*Micropterus salmoides*); spotted bass (*Micropterus punctulatus*); white crappie (*Pomoxis annularis*); channel catfish (*Ictalurus punctatus*); green sunfish (*Lepomis cyanellus*); slenderhead darter (*Percina phoxocephala*); orangethroat darter (*Etheostoma spectabile*); and central stoneroller (*Campostoma anomalum*). Literature-based SI curves had previously been developed in draft species completion reports for variables thought to be limiting to fish populations for five of the eight species (largemouth bass, spotted bass, green sunfish, channel catfish, and white crappie). Using these SI curves (Appendix A), presented in the individual draft species completion reports,

Habitat Suitability Indices were calculated for adults using the following formula, with each variable given equal weight ($n = 1$ for all variables, $N = \sum_{i=1}^{x} n$).

$$HSI = [(SI_1)^n (SI_2)^n \ldots\ldots\ldots (SI_x)^n]^{1/N}$$

Suitability Indices were assigned for each species for each stream section sampled, based on SI curves in the draft species completion reports. A stepwise multiple regression analysis was used for individual species to determine the relationship of adult life stage HSI, calculated with the above equation, to standing crop.

ALTERNATE MODELS

Presence-Absence Models

Alternate HSI models for the adult life stage were developed by using a presence-absence test. This test originally was developed to eliminate zero standing crop values from the data set for individual species. This approach was assumed to eliminate those sites where a species cannot exist from further analysis. Following this procedure, data were analyzed for the remaining sites in order to determine relationships of habitat variables to species standing crop. In other words, zero standing crop values were not used in regression analyses to determine variables important in explaining the variation in standing crop. This does not mean that zero values cannot be used in the development of suitability index curves. For a selected species and variable very little difference existed between curves that utilized zero standing crop values and curves that were developed without using zero values.

We conducted t-tests to identify variables that had statistically different mean values where a species occurred and where it was absent. It was important to make the proper assumption as to whether or not the variances of the two groups were equal, because variables can appear to be significantly different under one assumption and not significantly different under the other assumption. SAS computes an F value to test the null hypothesis that variances are equal among the groups tested. The SAS system computes t-tests both ways. The F value and its significance are used to select the proper t-test. Variables that had statistically significant differences between means for the presence and absence groups for a given species were used in a discriminant function analysis. The purpose of this analysis was to determine how accurately presence and absence groups could be separated on the basis of the physical and chemical characteristics of stream sample sites. If accurate, a presence-absence model could be used to predict fish occurrence. An HSI of 1.0 would be assigned to areas where fish presence was predicted; an HSI of 0.0 would be assigned where fish were predicted to be absent.

Suitability Index Curves and Standing Crop Models

New suitability index curves were drawn for each fish species for each variable measured and compared with the draft curves. The procedures for drawing these curves were the same, regardless of the species. Values for each variable were divided into increments, and mean standing crop values associated with each increment were calculated. The curves were drawn through as many means as possible. The number of observations within each increment allowed an estimate of the validity of the mean standing crop estimate for that increment. If the observed standing crop estimate was high at a point where the major portion of the data indicated a low standing crop and the standing crop value was based on only one or a few samples, the curve was drawn to reflect the majority of the data.

The increment of a variable associated with the highest mean standing crop estimate was usually assigned the highest suitability index, a value of 1.0. Suitability indices were assigned proportionately to the segments of the curve that passed through any given increment of a physical or chemical variable. This procedure linearized the f(x) = standing crop equation, where x was one of the physical or chemical variables.

Variable values from each observation (sample site) were assigned an index from the SI curves for each variable for which a curve could be drawn. This procedure was repeated for each of the eight species. Stepwise multiple regression analysis was used to identify limiting variables and to develop predictive equations. Results of the regression analysis were used to explain the variation in a species standing crop, based on suitability indices, rather than empirical values, for each variable.

RESULTS

Fish Population Sampling Techniques

No significant r^2 values were obtained for the overall HSI models or for stepwise regression equations using SI's derived from the draft curves (Appendix A). The r^2 values all were less than 0.14 and significance was always greater than 0.10.

These results led to several possible conclusions: (1) the model tested for calculating adult life stage habitat suitability indices was invalid; (2) the variables selected as being important to individual species were incorrect; (3) variables other than those measured were limiting; or (4) the suitability index curves were invalid. The suitability curves were redrawn with the Kansas field data, using the procedure described in the alternate models section, in order to test these possible conclusions. In most instances, the new curves closely approximated the original draft curves (see individual species discussions). Therefore, conclusion (4) did not seem related to the problem. In reference to the other three possible conclusions, no way was found to systematically develop weighting values that could be used in the geometric mean model to improve the correlation between habitat suitability indices for adult life stages and standing crop. (Note: The

individual suitability index for each variable should serve the function of defining the limiting factors; therefore, computing weighting factors, n in the model, can be considered redundant.) Because the other two possible conclusions were related to the first, and because it was not possible to verify the life stage models and to compute life stage habitat suitability indices, an alternate methodology was developed. This limitation does not invalidate the approach used in the tested models; it emphasizes our lack of understanding of the controlling factors of standing crop. For example, the suitability index curves for individual variables were not affected by the failure of the HSI equation to predict standing crop.

Descriptive statistics for the data set are provided in Table 1. When regression analyses were performed on the entire data set by species, no significant relationships between standing crop and habitat variables were obtained. Mean values of individual species standing crops varied considerably with the type of capture method used. The Kansas stream survey data utilized eight different techniques to sample the fish populations: (1) seining was used on some sites, and the fish biomass collected was extrapolated directly to a kg/ha unit; (2) shocking or electrofishing was utilized on some sites; (3) some sites were sampled by both shocking and seining and the data were directly extrapolated; (4) some sites were sampled via the application of a fish toxicant, such as rotenone, with the direct extrapolation of fish biomass to a standard unit; in other instances, the fish populations were sampled with a mark and recapture technique; (5) a mark and recapture technique was used with seining done to capture and recapture the fish; (6) electrofishing was performed at some sites; (7) on some sites, seining was used to initially capture fish, the fish were marked, and electrofishing was used to recapture the fish; and (8) a fish toxicant was used to recapture marked fish after an unspecified initial collection method. In the following discussion, the techniques listed above are referred to, respectively, as follows: (1) seining; (2) shocking; (3) seining and shocking; (4) kill; (5) mark and recapture seining; (6) mark and recapture shocking; (7) mark and recapture seining and shocking; and (8) mark and recapture kill. The data set was split according to the sampling method and stepwise regression analyses relating environmental variables to standing crop performed. Significant results were obtained when the data were separated in this manner; therefore, the data and analysis performed for each species is presented by sample method.

Analysis of the effect of substrate on standing crop was not included in any of the models because only the predominant substrate was recorded during sampling. This averaging effect might have resulted in substrates that were not utilized appearing to be important to fish in the model.

Table 1. Descriptive statistics for chemical and physical variables utilized from the Kansas Fish and Game Commission stream survey data set.

Variable	N	Mean	Standard deviation	Minimum value	Maximum value	Standard error of the mean	Sum	Variance	C.V.
Calcium hardness (ppm)	373	252.64	158.52	0.0	1,350.0	8.2079	94,237.0	25,129.3206	62.745
Chlorides (ppm)	395	99.66	184.40	0.1	1,870.0	9.2735	39,367.3	33,969.1486	184.928
Conductivity (µmhos/cm)	218	1,073.51	1,047.93	85.0	9,100.0	70.9750	234,027.0	1,908,164.9144	97.617
Dissolved oxygen (ppm)	380	9.99	3.31	1.0	19.0	0.1700	3,798.9	10.9822	33.149
Gradient (m/km)	369	1.46	1.11	0.1	7.9	0.0578	539.7	1.2340	75.957
Growing season (days)	420	178.62	11.69	82.0	194.0	0.5708	75,021.0	136.8563	6.549
Maximum width (m)	405	11.99	12.21	0.9	125.5	0.6069	4,856.9	149.2012	101.853
Mean depth (m)	420	0.49	0.39	0.1	4.5	0.0193	209.6	0.1547	79.493
Mean width (m)	420	9.51	10.72	0.9	110.0	0.5235	3,996.5	115.1208	112.752
Magnesium hardness (ppm)	371	92.71	164.18	0.0	2,530.0	8.5240	34,396.0	26,956.3949	177.091
Minimum width (m)	406	6.39	8.59	0.3	101.1	0.4263	2,594.7	73.8064	134.424
Nitrates (ppm)	384	7.47	7.40	0.0	92.4	0.3778	2,869.6	54.8227	99.081
pH	401	8.01	0.60	3.5	9.3	0.0300	3,214.2	0.3631	7.518
Phosphates (ppm) (Ortho)	396	0.60	0.92	0.0	9.0	0.0466	240.5	0.8608	152.740
Pool (%)	409	42.66	40.24	0.0	100.0	1.9898	17,488.0	1,619.4160	94.332
Riffle (%)	408	9.41	16.19	0.0	100.0	0.8015	3,843.0	262.1654	171.901
Runoff (inches/yr)	420	2.02	1.99	0.1	10.0	0.0972	849.1	3.9682	98.535
Run (%)	408	48.41	42.40	0.0	100.0	2.0991	19,755.0	1,797.8804	87.572
Sulfates (ppm)	380	146.12	159.95	0.0	1,250.0	8.2055	55,527.0	25,586.0136	109.466
Total alkalinity (ppm)	403	217.28	73.55	0.0	590.0	3.6642	87,567.0	5,411.0711	33.854

Table 1. (concluded)

Variable	N	Mean	Standard deviation	Minimum value	Maximum value	Standard error of the mean	Sum	Variance	C.V.
Total dissolved solids (ppm)	210	498.88	527.30	22.0	4,200.0	36.3872	104,765.0	278,016.1149	105.697
Total length (m)	416	74.13	173.37	6.0	2,414.0	8.5004	30,838.7	30,059.0561	233.875
Turbidity (JTU)	253	41.54	75.72	0.0	560.0	4.7608	10,512.0	5,734.3596	182.254
Velocity (m/sec)	377	0.19	0.41	0.0	5.7	0.0215	71.9	0.1755	220.126
Volume of flow (m^3)	377	0.90	3.21	0.0	28.3	0.1656	341.9	10.3411	354.537
Water temperature (°C)	405	20.86	7.07	1.0	36.0	0.3514	8,451.0	50.0168	33.893

Spotted Bass

Presence-absence model. Not all of the variables used in the discriminant function analysis (Table 2) were measured at each sample site. However, the 109 sites where complete sampling was done represented 11 of the 16 major river basins in Kansas (Table 3). Sixty-six of the sites did not contain spotted bass. Forty-one of the 43 sites containing spotted bass were correctly classified using discriminant analysis, but only 47 of the sites that did not contain spotted bass were correctly classified. Nine of the 19 sites incorrectly predicted to contain spotted bass were outside of the natural range of the species. Eight of these nine locations were in the Kansas River Basin, which historically has not contained a population of spotted bass (Cross 1967).

Recently naturalized populations of spotted bass have been reported at some stream locations within the Kansas River Basin (Layher et al. 1978). These recent successful introductions indicate that the basin does provide the necessary habitat requirements for spotted bass. The remaining site where the model predicted bass but they were absent appears to represent an isolated pocket of suitable habitat in the western reaches of the lower Arkansas River Basin (Fig. 1). This pocket may not be available naturally to spotted bass because of its distance from areas where spotted bass currently occur.

The remaining 10 sites where the presence of spotted bass was incorrectly predicted are within the natural range of the species but fish were collected only with seines at these locations. If the comparative standing crops of fishes obtained by different sampling techniques are reliable estimators of collecting efficiency, seining appears to be a poor method of collecting spotted bass (Fig. 2). Therefore, the data from these 10 mispredicted sites may not accurately reflect the actual standing crop of spotted bass.

The model accurately described the presence or absence of spotted bass for 88 stream sites. Of the 21 misclassified sites, 19 appear to be related to the zoogeographical distribution of the species or the capture method utilized for sampling.

Suitability index curves. Suitability index (SI) curves were developed from spotted bass standing crop data for the following variables: mean width; minimum width; percent riffle; pH; turbidity; water temperature; and nitrates and are presented in Layher (1983). Data for other variables related to spotted bass mean standing crops that were not applicable for the development of curves are also presented in Layher (1983).

Standing crop models. Literature based SI curves were available for the following four variables: stream gradient; substrate; water temperature; and average velocity (Appendix A). Suitability indices were assigned for each stream site for each of these variables. A habitat suitability index (HSI) was computed for each site using the unweighted geometric mean of the SI's.

Table 2. Results of significant T-tests between presence and absence of spotted bass for physical and chemical variables.

Variable	Group[a]	N	Mean	Standard deviation	Minimum value	Maximum value	Variance	T	DF	PROB > |T|
Pool (%)	A	342	40.66	40.24	0.0	100.0				
	P	67	52.88	38.94	0.0	100.0	Equal	-2.2851	417.0	0.0228
Run (%)	A	341	50.37	47.38	0.0	100.0				
	P	67	35.55	40.40	0.0	100.0	Equal	2.7386	406.0	0.0064
Maximum width (m)	A	342	11.13	12.59	0.9	125.5				
	P	63	16.63	8.59	6.0	45.4	Unequal	-4.2929	117.5	0.0001
Minimum width (m)	A	342	6.11	9.11	0.3	101.2				
	P	64	7.90	4.79	0.6	19.8	Unequal	-2.3057	163.3	0.0224
Mean depth (m)	A	351	0.47	0.37	0.1	4.5				
	P	69	0.65	0.46	0.1	3.1	Unequal	-3.0543	86.2	0.0030
Total dissolved solids (mg/l)	A	154	564.84	573.32	22.0	4,200.0				
	P	56	317.48	310.64	125.0	1,750.0	Unequal	3.9826	177.7	0.0001
Turbidity (JTU's)	A	200	45.62	84.07	0.0	560.0				
	P	53	26.18	20.99	2.0	115.0	Unequal	2.9413	250.6	0.0036
Sulfates (mg/l)	A	322	153.12	154.43	0.0	1,250.0				
	P	58	107.26	184.41	1.0	95.0	Equal	2.1083	378.0	0.0445
Phosphates (mg/l)	A	337	0.64	0.96	0.0	9.0				
	P	59	0.37	0.61	0.0	3.4	Unequal	2.8319	116.1	0.0055
Conductivity (µmhos/cm)	A	161	1,193.09	1,123.26	85.0	9,100.0				
	P	57	735.79	702.39	200.0	4,000.0	Unequal	3.5610	158.0	0.0005
Chlorides (mg/l)	A	335	107.85	194.98	0.1	1,870.0				
	P	60	53.98	95.58	0.5	700.0	Unequal	3.3048	163.7	0.0012
Mean width (m)	A	351	8.70	11.00	0.9	110.0				
	P	69	13.68	8.08	3.0	45.7	Unequal	-4.3854	123.4	0.0001
Dissolved oxygen (mg/l)	A	316	10.22	3.30	1.0	19.0				
	P	64	8.91	3.21	4.0	19.0	Unequal	2.9427	91.9	0.0041

[a] A = Absent
P = Present

Table 3. Classification of stream sites in various river basins in Kansas utilizing a discriminant analysis model to predict presence or absence of spotted bass.

River basin	Number	Correct classifications		Misclassification	
		Presence	Absence	Presence to absence	Absence to presence
Big Blue	1	-	2	-	-
Cimarron	2	-	-	-	-
Kansas	3	-	7	0	2
Little Arkansas	4	-	-	-	-
Lower Arkansas	5	5	3	0	3
Lower Republican	6	-	21	0	0
Marias des Cygnes	7	-	1	0	0
Missouri	8	-	-	-	-
Neosho	9	14	-	2	2
Saline	10	-	4	0	1
Smoky Hill	11	-	2	0	4
Solomon	12	-	4	0	1
Upper Arkansas	13	-	-	-	-
Upper Republican	14	-	-	-	-
Verdigris	15	7	-	0	1
Walnut	16	15	3	0	5
Totals		41	47	2	19
Grand Totals		88		21	

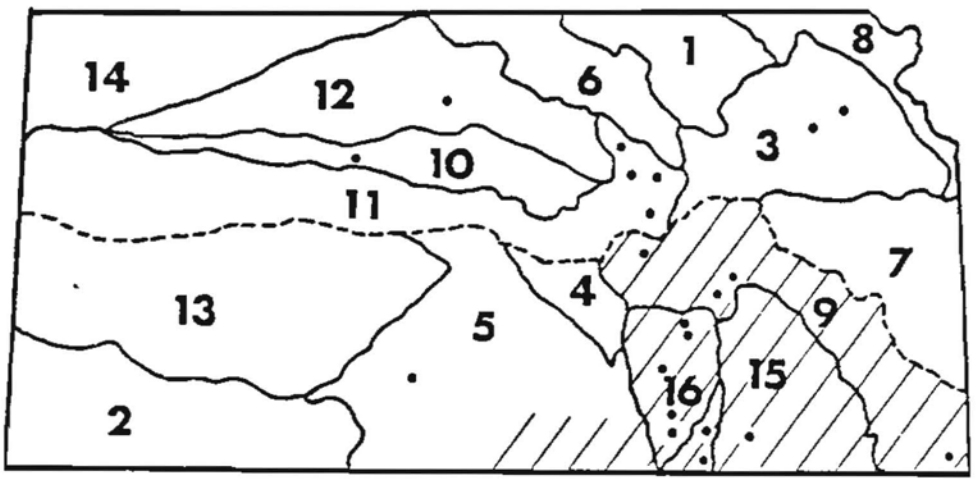


Figure 1. Misclassified Kansas stream sites for presence-absence groups of spotted bass. Numbers identify river basins (see Table 3). Misclassified sites from presence to absence are designated by a •. Sites misclassified from absence to presence are represented by a o. Oblique lines designate the native range of spotted bass. The dotted line separates the Kansas River Basin (above the line) from the Arkansas River Basin (below the line).

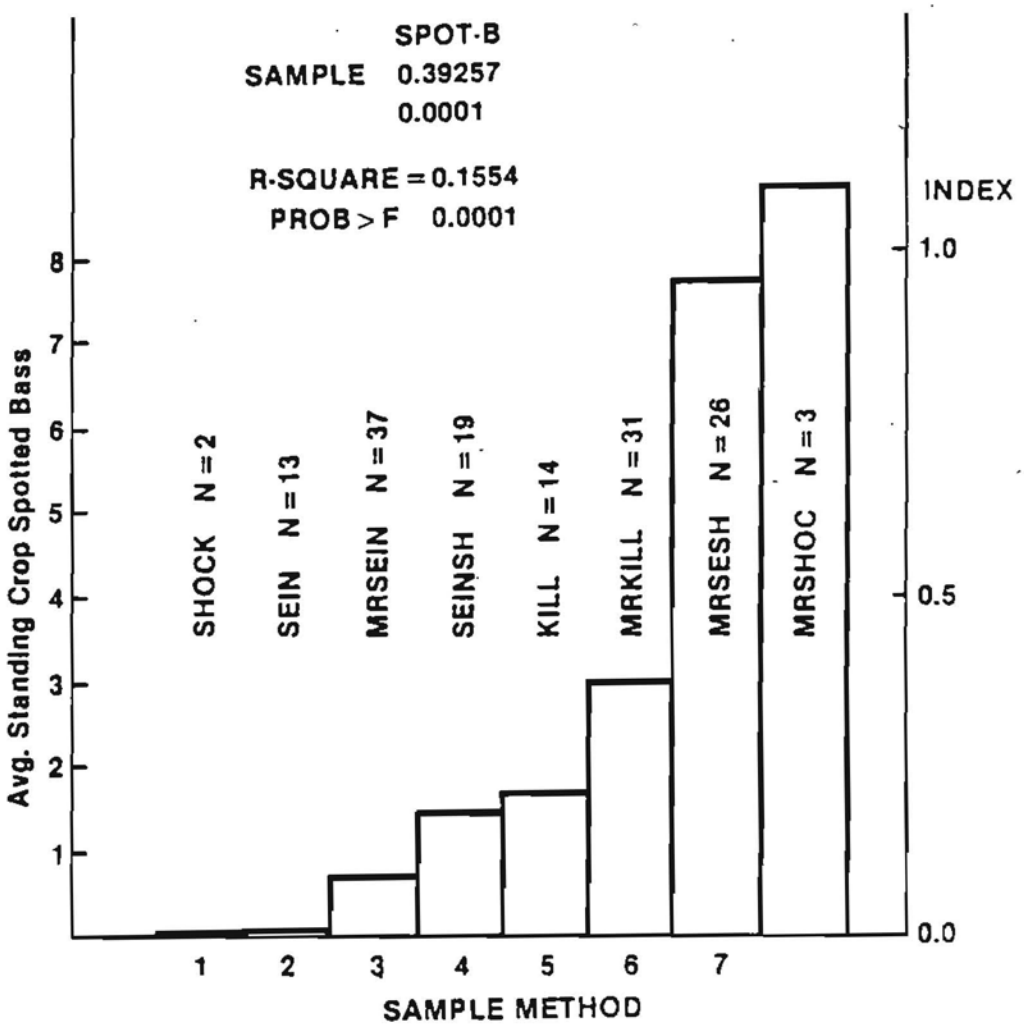


Figure 2. Average standing crops (kg/ha) for spotted bass collected by various sampling techniques. All sites represented by this figure were located within the native range of spotted bass. Sample method codes are: shock = shocking; sein = seining; mrsein = mark and recapture using seining; seinsh = seining and shocking; kill = rotenone; mrkill = rotenone with mark and recapture; mrsesh = seining and shocking with mark and recapture; and mrshoc = shocking with mark and recapture.

Correlations between HSI's and spotted bass standing crops were less than 0.10 and not significant. However, a trend toward larger standing crops of spotted bass when higher HSI's occur may be evident (Fig. 3).

A stepwise regression analysis was performed to explain the variability in the standing crop of spotted bass using SI's derived from the curves presented in Layher (1983) as the independent variables. These curves were developed from the Kansas stream survey data. No significant r^2 values were obtained when the entire data set was used. However, significant r^2 values were obtained when the data set was categorized by the sampling technique used (Table 4).

When data were analyzed that were obtained by the mark and recapture method with either seining or shocking used as the capture technique, a low r^2 value resulted and the relationship was not significant. Conversely, r^2 values were high and significant when the final sample in a mark and recapture series was obtained by a complete kill method or was based on electroshocking or when only kill methods were used. The relative importance of the variables in terms of explaining the variation in standing crop also changed with sampling method. It appears, from these data, that methods that utilized kill techniques resulted in the most reliable data.

Substrate composition. Ninety-eight point six percent of the sites that contained spotted bass also contained sand or silt; however, 91.9% of all sites sampled in Kansas contained sand or silt. Seventy-three point nine percent of the sites where spotted bass were collected also contained gravel, while only 39.8% of the total sample sites contained gravel. Cobble occurred at 63.8% of the sites containing spotted bass, but only 30.2% of all sites sampled. Bedrock occurred at 27.5% of the sites where spotted bass were collected, but occurred in only 12.4% of all sample sites. These data are summarized in Figure 4 and suggest that substrate type, such as gravel and bedrock, may be important to spotted bass.

Slenderhead Darter

Presence-absence model. The variables that show significant differences between where slenderhead darters were present and where they were absent are summarized in Table 5. When these variables were used to predict the occurrence of slenderhead darters, all of the 17 sites where slenderhead darters were collected were classified correctly. One hundred and sixty-four of the 195 sites where slenderhead darters were absent were predicted correctly. Twelve of the misclassified sites were outside of the natural range of the species (Fig. 5).

Suitability curves. Suitability index curves were drawn for the slenderhead darter for the following variables: calcium hardness; chlorides; conductivity; dissolved oxygen; gradient; growing season; maximum width; mean depth; mean width; minimum width; nitrates; pH; phosphates; percent pools; percent

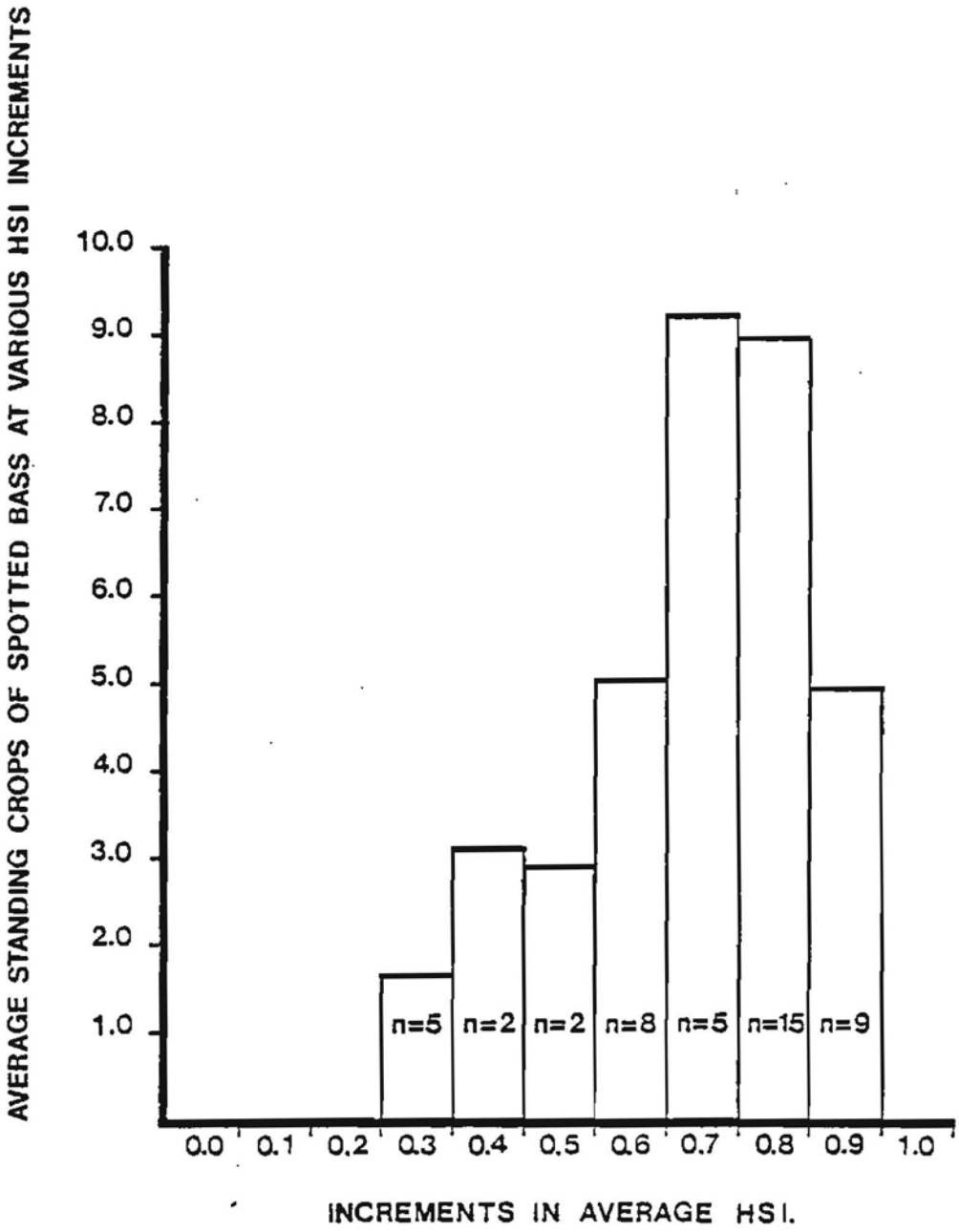
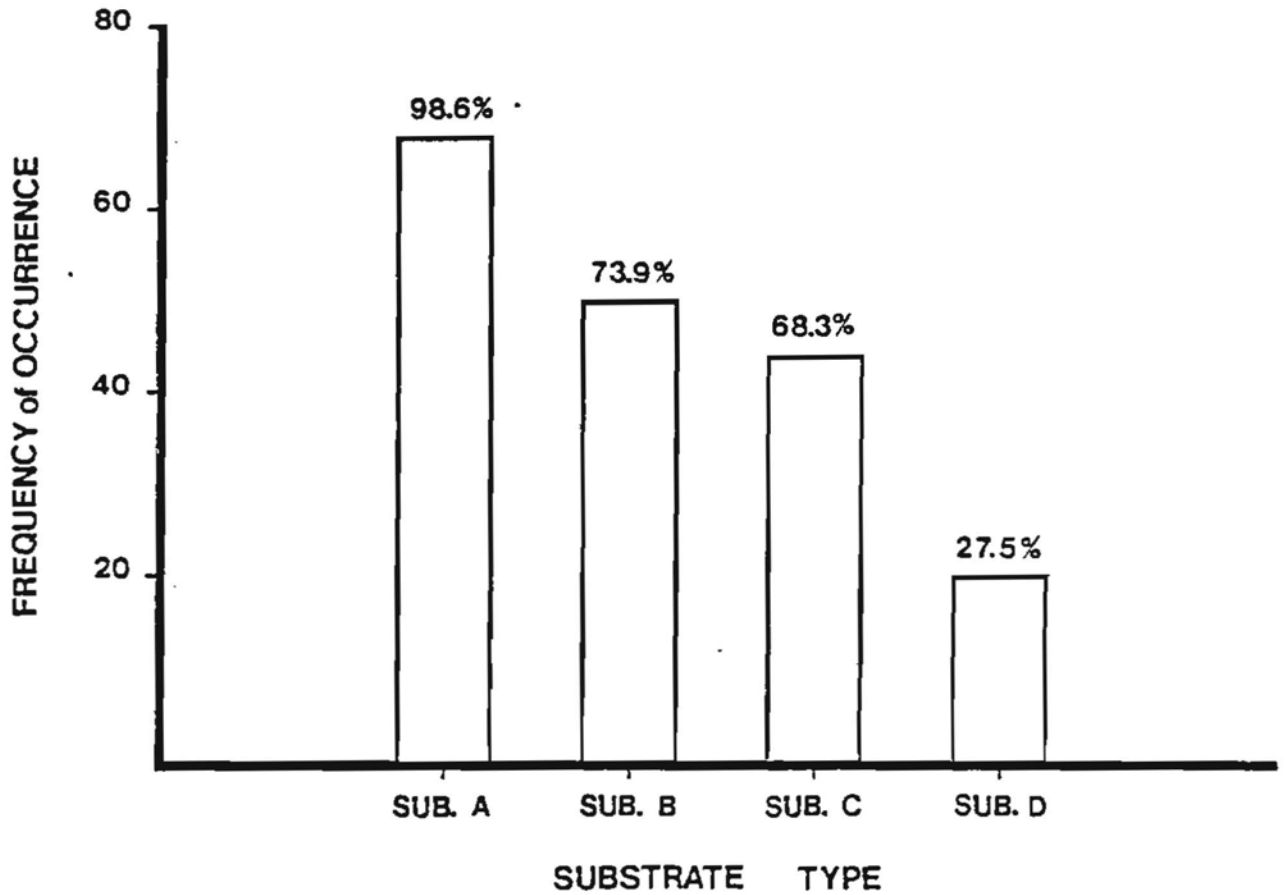


Figure 3. Average standing crops of spotted bass vs. HSI.

Table 4. Stepwise multiple regression analyses of variation in spotted bass standing crop by collection method.

Method of collection	N	r^2	F	PROB > F	Variables	F	PROB > F
Mark and recapture with kill technique	16	.86	9.78	.0016	Water temperature	12.20	.0082
					Mean width	2.61	.1451
					pH	6.26	.0368
					Minimum width	30.54	.0006
					Nitrates	5.39	.0488
					Percent riffles	3.90	.0839
					Mean depth	2.61	.1451
Mark and recapture with kill technique combined with kill technique used alone	19	.71	5.05	.0084	Water temperature	10.32	.0075
					Mean depth	7.94	.0155
					Mean width	6.96	.0216
					Minimum width	11.46	.0054
					Nitrates	3.45	.0081
					Percent riffles	1.37	.2654
Mark and recapture seining with electroshocking	21	.09	0.31	.8987	Water temperature	0.34	.5688
					Turbidity	0.42	.5298
					Mean width	0.41	.5332
					Minimum width	0.53	.4766
					Nitrates	0.20	.6577
Mark and recapture with electroshocking	14	.75	6.38	.0012	Water temperature	3.42	.1018
					Turbidity	2.56	.1482
					Mean depth	15.67	.0042
					Minimum width	1.77	.2205
					Percent riffles	3.08	.1172
Mark and recapture with seining	12	.92	6.85	.0410	Turbidity	7.66	.0495
					Mean depth	27.45	.0063
					Mean width	23.25	.0085
					pH	1.51	.2869
					Minimum width	17.25	.0142
					Nitrates	2.42	.1949



A = Sand
B = Gravel
C = Cobble
D = Bedrock

Figure 4. The relationship between the presence of various substrates and spotted bass occurrence.

Table 5. Results of significant T-tests between the presence and absence of slenderhead darters for physical and chemical variables.

Variable	Group[a]	N	Mean	Standard deviation	Minimum value	Maximum value	Variance	T	DF	PROB > |T|
Chlorides (mg/l)	A	370	102.64	189.42	0.1	1,870.0				
	P	25	55.50	61.48	0.0	245.0	Unequal	-2.9928	63.0	0.0039
Gradient (m/km)	A	340	1.51	1.12	0.1	7.9				
	P	29	0.81	0.66	0.1	3.4	Unequal	5.0906	43.3	0.0001
Growing season (days)	A	388	177.91	11.78	82.0	194.0				
	P	32	187.15	5.86	179.0	193.0	Unequal	-7.7183	54.6	0.0001
Maximum width (m)	A	377	11.50	12.28	0.9	125.5				
	P	28	18.61	9.16	7.6	45.4	Unequal	-3.8595	34.6	0.0005
Mean width (m)	A	388	9.07	10.87	0.9	110.3				
	P	32	14.91	6.88	3.6	32.3	Unequal	-4.3743	44.9	0.0001
Minimum width (m)	A	378	6.14	8.75	0.3	101.1				
	P	28	9.69	5.05	0.6	19.8	Unequal	-3.3647	40.2	0.0017
Pool (%)	A	379	41.50	40.23	0.0	100.0				
	P	30	57.30	37.97	0.0	100.0	Equal	-2.0784	407.0	0.0383
Riffle (%)	A	377	8.98	16.27	0.0	100.0				
	P	31	14.74	14.41	0.0	49.0	Unequal	-2.1172	36.6	0.0411
Runoff (inches/yr)	A	388	1.84	1.76	0.1	10.0				
	P	32	4.18	3.11	1.0	10.0	Unequal	-4.2020	32.7	0.0002
Run (%)	A	378	50.06	42.21	0.0	100.0				
	P	30	27.73	39.90	0.0	100.0	Equal	2.7993	406.0	0.0054
Water temperature (°C)	A	374	20.60	7.22	1.0	36.0				
	P	31	24.03	3.76	14.0	30.0	Unequal	-4.4390	50.7	0.0001

[a] A = Absent
P = Present

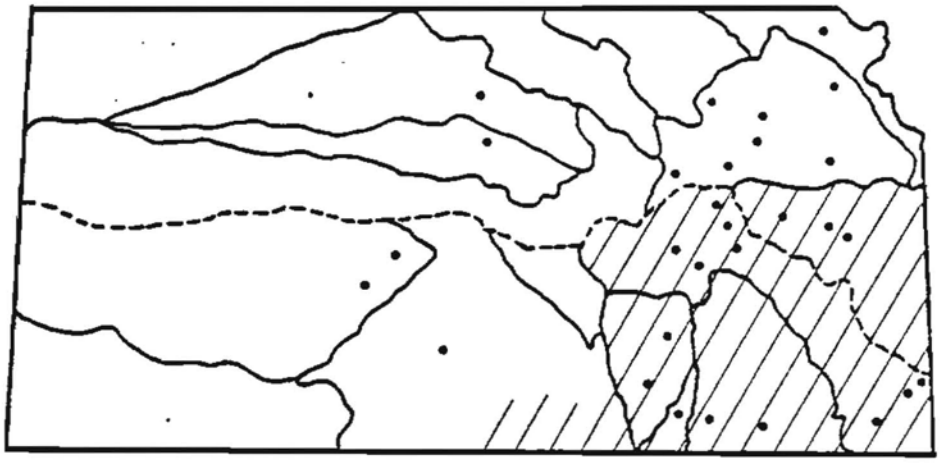


Figure 5. Misclassified Kansas stream sites from absence to presence for slenderhead darters. Oblique lines designate the native range of the species. Misclassified sites from presence to absence are designated by a •. The dotted line separates the Kansas River Basin (above the line) from the Arkansas River Basin (below the line).

riffles; percent runs; runoff; sulfates; total alkalinity; total dissolved solids; turbidity; volume of flow; and water temperature (see Layher 1983). Data for additional variables are also presented in Layher (1983).

Standing crop models. There were no significant relationships between average standing crops of slenderhead darters and sampling technique. However, a majority of the sites (13) where slenderhead darters were collected were sampled with a mark and recapture technique. The recapture was accomplished by a kill method. Occurrence data obtained with other sampling techniques always involved five or fewer sites; therefore, only mark and recapture data with kill as the recapture technique were used in regression model development. A single variable, calcium hardness, was responsible for 87.9% of the variation in standing crop. The model was significant at the $p \leq 0.0001$ level. The addition of the percent riffles variable increased the r^2 value to 0.915; the significance of the entire model remained the same. With the addition of the maximum stream width variable, the r^2 increased to 0.942, but the significance of the model remained at $p \leq 0.0001$. Equations for the one, two, and three variable standing crop models (kg/ha) were:

(1) -0.651 + 8.198 (calcium hardness SI) = slenderhead darter standing crop

$R^2 = 0.88$ PROB > F = 0.0001

(2) -1.069 + 7.398 (calcium hardness SI) + 1.244 (% riffles SI) = slenderhead darter standing crop

$R^2 = 0.92$	PROB > F = 0.0001
Calcium hardness	PROB > F = 0.0001
Percent riffles	PROB > F = 0.0519

(3) -1.442 + 6.877 (calcium hardness SI) + 0.832 (maximum width SI) + 1.342 (% riffles SI) = slenderhead darter standing crop

$R^2 = 0.94$	PROB > F = 0.0001
Calcium hardness	PROB > F = 0.0001
Maximum width	PROB > F = 0.0519
Percent riffles	PROB > F = 0.0215

Addition of other variables to the equation increased the r^2 of the model, but resulted in a minor decrease in significance. However, the additional variables did not individually meet the 0.05 level of significance needed to be worthwhile additions to the model. Calcium hardness also appeared to be the most important variable in models developed from sites sampled with other methods. All SI's were derived from the curves presented in Layher (1983).

Orangethroat Darter

Presence-absence models. The variables with significant differences between where orangethroat darters were present and where they were absent are summarized in Table 6. Ninety percent of the sites (45 of 50) were correctly predicted to contain orangethroat darters. Only 30 of the 46 (65.2%) sites where orangethroat darters did not occur were correctly predicted not to contain orangethroats. The misclassification of these 16 sites is difficult to explain. The small size of the darter may restrict movement to some isolated yet suitable areas. However, the orangethroat darter occurs throughout much of the eastern two-thirds of Kansas, and zoogeographical isolationism does not appear to be a satisfactory explanation for the misclassifications. Eradication due to fish kills resulting from exogenous factors may have occurred at some sites. Another possibility for the misclassification is that the streams may have been sampled at times when the variables measured were not representative of the usual stream conditions at the individual sites.

Suitability index curves. Suitability index curves were drawn for the orangethroat darter for the following variables: water temperature; volume of flow; velocity; turbidity; total alkalinity; sulfates; percent runs; runoff; percent riffles; percent pools; phosphates; pH; nitrates; magnesium hardness; minimum width; mean width; mean depth; maximum width; growing season; gradient; dissolved oxygen; conductivity; and calcium hardness (see Layher 1983). Data for additional variables are also in Layher (1983).

Standing crop models. Sixteen sets of data from mark and recapture stations that utilized a combination of seining and electrofishing were available for use in model development. An r^2 of 0.64 was obtained, utilizing five independent variables. Variables included in the model were mean width, minimum width, percent pools, percent runs, and total alkalinity. All of the variables were significant below the 0.0095 level. The entire model was significant at the 0.0269 level ($F = 3.95$). Four additional model variables (conductivity, magnesium hardness, percent riffles, and sulfates) increased the r^2 value to 0.9490 ($F = 14.49$; $P > F = 0.001$). Each of the nine variables was significant below the 0.0078 level. F values for individual variables ranged from 13.57 for total alkalinity (the lowest F value) to 73.32 (the highest F value) for percent runs. The addition of two more variables, dissolved oxygen and turbidity, increased the model r^2 to 0.98 ($F = 36.53$; $P > F = 0.0005$). Both variables were significant below the 0.05 level.

Sixty-three sets of data were available for model development using kill as the recapture method in a mark and recapture technique. Five independent variables produced an r^2 of 0.3906 ($F = 7.44$; $P > F = 0.0001$). Only three of the variables in the model were significant below the 0.05 level: magnesium hardness; nitrates; and phosphates. However, only phosphates and magnesium hardness of these additional variables were significant at the 0.05 level. Dissolved oxygen and maximum width were the other two variables included in the model. Significance levels were 0.1394 and 0.1996, respectively, for these other two variables. Adding more variables to the model resulted in an r^2 of 0.4993 ($F = 2.00$; $P > F = 0.0282$).

Table 6. Results of significant T-tests between the presence and absence of orangethroat darters for physical and chemical variables.

Variable	Group[a]	N	Mean	Standard deviation	Minimum value	Maximum value	Variance	T	DF	PROB > |T|
Chlorides (mg/l)	A	255	125.80	216.00	0.5	1,870.0				
	P	140	52.00	86.10	0.1	665.0	Unequal	-4.8065	366.2	0.0001
Conductivity (µmhos/cm)	A	139	1,225.00	172.20	200.0					
	P	79	807.10	715.00	85.0	4,000.D	Unequal	3.2675	214.9	0.0013
Gradient (m/km)	A	233	1.28	1.03	0.1	7.9				
	P	136	1.76	1.17	0.0	5.0	Unequal	-3.9282	255.8	0.0001
Minimum width (m)	A	260	7.10	10.20	0.3	101.1				
	P	146	5.12	4.10	0.6	22.8	Unequal	2.7547	374.7	0.0062
Nitrates (mg/l)	A	246	6.72	4.71	0.0	35.2				
	P	138	8.82	10.52	0.0	92.4	Unequal	-2.2261	168.3	0.0273
Phosphates (mg/l)	A	256	0.69	1.03	0.0	9.0				
	P	140	0.45	0.68	0.0	4.5	Unequal	2.7364	379.3	0.0065
Pools (%)	A	258	38.97	41.28	0.0	100.0				
	P	151	48.95	37.70	0.0	100.0	Equal	-2.4342	407.0	0.0154
Riffles (%)	A	257	7.97	16.02	0.0	100.0				
	P	151	11.88	16.13	0.0	88.0	Equal	-2.3672	406.0	0.0184
Runoff (inches/yr)	A	268	1.49	1.62	0.1	10.0				
	P	152	2.95	2.23	0.1	10.0	Unequal	-7.1082	242.9	0.0001
Runs (%)	A	257	54.06	43.44	0.0	100.0				
	P	151	38.81	38.84	0.0	100.0	Unequal	3.6617	343.0	0.0003
Sulfates (mg/l)	A	248	161.44	161.95	0.0	1,250.0				
	P	132	117.33	152.59	1.0	900.0	Equal	2.5788	378.0	0.0103
Total dissolved solids (mg/l)	A	137	571.26	595.51	22.0	4,200.0				
	P	73	363.04	329.49	34.0	1,750.0	Unequal	3.2615	207.7	0.0013
Turbidity (JTU's)	A	140	51.65	87.14	0.0	560.0				
	P	113	29.03	56.50	0.0	510.0	Unequal	2.4899	240.5	0.0135

[a] A = Absent
P = Present

Twenty-three complete data sets were available from sites where kill methods were used. Four variables produced an r^2 of 0.6259 ($F = 7.95$; $P > F = 0.0006$): conductivity; growing season; nitrates; and turbidity. These variables were all significant below the 0.05 level. F values for the individual variables in the model ranged from 3.52 for turbidity to 28.40 for nitrates. The addition of three variables, mean width, mean depth, and total alkalinity, increased the r^2 of the model to 0.7230 ($F = 5.97$; $P > F = 0.0015$). F values for these three variables were 0.0736, 0.1981, and 0.1025, respectively. The significance level of all of these three variables was below 0.0303. By adding data for additional variables, an r^2 of 0.8830 was obtained; however, the model was no longer significant. The model was significant at the 0.0356 level with 15 independent variables; the F value was 3.63 and $r^2 = 0.8719$.

Complete data sets were available for 11 sites where fish were sampled by seining and shocking. Mean depth was the only variable that was significant at the 0.05 level ($F = 4.78$; $r^2 = 0.3236$).

Twenty data sets were available for mark and recapture stations where only seining had been used. Nine variables, all significant below the 0.0019 level, produced an $r^2 = 0.9254$ ($F = 18.63$; $P > F = 0.0001$). Addition of these variables to the model produced the following results (r^2 in parentheses): phosphates (0.3065); percent pools (0.5381); minimum width (0.6394); conductivity (0.7202); growing season (0.7699); nitrates (0.8129); percent riffles (0.8556); magnesium hardness (0.8860); nitrates removed and replaced by turbidity (0.9158); and maximum width removed and replaced by mean width (0.9254).

Ten data sets were available from sites where seining was the only method of collection. Five variables produced a model with an r^2 of 0.9721 ($P > F = 0.0007$). All of these variables were significant below the 0.04 level. The five variables produced the following model (r^2 in parentheses): water temperature (0.2234); sulfates (0.5941); percent pools (0.8790); total alkalinity (0.9323); and calcium hardness (0.9721).

All of the sites where a combination of seining and shocking were used to collect fish without mark and recapture activities had at least one variable missing from the data set. In addition, no data were available for sites where the recapture technique was electroshocking. Consequently, no model was developed for data from these capture techniques. Regression models are summarized in Table 7.

Central Stoneroller

Presence-absence model. The variables that had significant differences between areas where central stonerollers were present and where they were absent are summarized in Table 8. Ninety point five percent of the 42 sites where stonerollers were absent were classified correctly. Sixty-nine percent of the 52 sites where stonerollers were found were classified correctly. Seventy-four of the 94 sites with complete data sets were classified correctly.

Table 7. Results of stepwise multiple regression analyses of variation in orangethroat darter standing crop by collection method.

Method of collection	N	r^2	F	PROB > F	Variables	F	PROB > F
Mark and recapture with shocking	16	.64	3.95	.0269	Mean width	12.68	.0045
					Minimum width	10.63	.0076
					Percent pools	9.81	.0075
					Percent runs	14.61	.0028
					Total alkalinity	1.49	.2484
Mark and recapture with kill	63	.39	7.44	.0001	Magnesium hardness	3.82	.0555
					Nitrates	6.72	.0120
					Phosphates	30.90	.0001
					Dissolved oxygen	2.25	.1394
					Mean width	1.68	.1996
Kill without mark and recapture	23	.62	7.95	.0006	Conductivity	5.90	.0252
					Growing season	9.02	.0073
					Nitrates	28.40	.0001
					Turbidity	3.52	.0761
Seining and shocking	11	.32	4.78	.0536	Mean depth		
Mark and recapture with seining	20	.92	18.63	.0001	Phosphates	62.92	.0001
					Percent pools	71.29	.0001
					Conductivity	23.12	.0004
					Growing season	18.19	.0011
					Percent riffles	21.60	.0006
					Magnesium hardness	29.92	.0001
					Turbidity	23.37	.0004
					Mean width	15.60	.0019
Seining	10	.97	?	.0007	Water temperature	138.26	.0001
					Sulfates	113.50	.0001
					Percent pools	40.58	.0014
					Total alkalinity	10.97	.0212
					Calcium hardness	7.15	.0441

Table 8. Results of significant T-tests between presence and absence of central stoneroller for physical and chemical variables.

Variable	Group[a]	N	Mean	Standard deviation	Minimum value	Maximum value	Variance	T	DF	PROB > |T|
Calcium hardness (mg/l)	A	193	235.82	125.53	10.0	850.0				
	P	180	270.67	186.24	0.0	1,350.0	Unequal	-2.1039	310.8	0.0362
Gradient (m/km)	A	183	1.24	0.97	0.1	5.0				
	P	186	1.67	1.19	0.1	7.9	Unequal	-3.7415	354.8	0.0002
Maximum width (m)	A	206	13.48	15.48	1.2	125.5				
	P	199	10.44	7.17	0.9	42.6	Unequal	2.5169	291.3	0.0114
Mean depth (m)	A	212	0.55	0.43	0.1	4.5				
	P	208	0.44	0.34	0.1	3.1	Unequal	2.9928	403.2	0.0029
Mean width (m)	A	212	10.68	13.54	0.9	110.0				
	P	208	8.32	6.56	0.9	45.7	Unequal	2.2829	306.3	0.0231
Minimum width (m)	A	206	7.65	11.25	0.6	101.1				
	P	200	5.09	4.05	0.3	27.4	Unequal	3.0678	259.9	0.0024
Nitrates (mg/l)	A	197	6.41	3.95	0.0	34.3				
	P	187	8.59	9.69	0.0	92.4	Unequal	-2.8564	243.6	0.0047
Phosphates (mg/l)	A	206	0.70	1.09	0.0	9.0				
	P	190	0.50	0.68	0.0	4.5	Unequal	2.2168	348.1	0.0273
Runoff (inches/yr)	A	212	1.56	1.66	0.1	10.0				
	P	208	2.48	2.18	0.1	10.0	Unequal	-4.8621	387.7	0.0001
Total dissolved solids (mg/l)	A	104	596.51	567.95	22.0	3,590.0				
	P	106	403.08	467.23	34.0	4,200.0	Unequal	2.6925	199.1	0.0077
Turbidity (JTU's)	A	116	55.35	95.63	0.0	560.0				
	P	137	29.86	50.90	0.0	510.0	Unequal	2.5782	168.6	0.0108
Volume of flow (m^3/sec)	A	187	1.24	4.05	0.0	28.3				
	P	190	0.57	2.03	0.0	25.1	Unequal	2.0370	272.9	0.0426

[a]A = Absent
P = Present

Suitability index curves. Suitability index curves were drawn for the central stoneroller for the following variables: gradient; dissolved oxygen; conductivity; chlorides; velocity; turbidity; water temperature; volume of flow; total dissolved solids; total alkalinity; sulfates; percent run; percent riffles; percent pools; phosphates; pH; nitrates; magnesium hardness; minimum width; mean width; maximum width; and mean depth (see Layher 1983). Data for additional variables are summarized in Layher (1983).

Standing crop models. Complete data sets were available for 18 sites that were sampled by a mark and recapture method, utilizing seining followed by shocking. A standing crop model based on five variables resulted in an r^2 of 0.9029 ($F = 24.18$; $P > F = 0.0001$). Variables were entered into the model in the following order (r^2 in parentheses): mean width (0.5670); percent run (0.6988); magnesium hardness (0.7644); sulfates (0.8744); and pH (0.9029). All model variables were significant below the 0.006 level, with the exception of pH, which was significant at the 0.0730 level.

Data sets were available from 85 sample sites where mark and recapture involved a final kill technique. A model based on eight variables resulted in an r^2 of 0.5012 ($F = 9.67$; $P > F = 0.0001$). The following variables were entered into the model in the order given (r^2 values in parentheses): mean width (0.1996); gradient (0.2870); pH (0.2924); water temperature (0.3602); maximum width (0.4138); mean depth (0.4356); total dissolved solids (0.4609); phosphates (0.4835); and total alkalinity (0.5012). All variables in the model were significant below the 0.03 level, with the exception of phosphates (0.1238) and alkalinity (0.0609). The addition of 13 more independent variables produced at r^2 of only 0.5665, although the entire model remained significant at the 0.0001 level.

Data sets were available for 35 stations where sampling was done by kill techniques. Variables were added in a stepwise manner in the following order (r^2 values in parentheses): magnesium hardness (0.1761); maximum width (0.3019); nitrates (0.4178); maximum width replaced by mean width (0.4281); percent pools (0.4723); dissolved oxygen (0.5203); and mean width replaced by maximum width (0.5397). The five-variable model had an $F = 7.04$; $P > F = 0.0002$. All variables in the model were significant below the 0.05 level. Additional variables improved the r^2 of the model but lowered its significance level.

Complete data sets were available for 13 sample sites where a combination of seining and shocking techniques were used. A model based on three variables resulted in an r^2 of 0.8821 ($F = 24.95$; $P > F = 0.001$). The three variables were added in a stepwise manner (r^2 values in parentheses): percent riffle (0.5656); sulfates (0.7868); and pH (0.8821). All three variables were significant below the 0.01 level. A model based on six variables resulted in an r^2 of 0.9980 ($F = 0.0001$; $P > F = 125.89$). The variables in this model were chlorides, gradient, mean width, phosphates, sulfates, and velocity. All of the individual variables were significant below the 0.007 level, except chlorides, which had a significance level of 0.1137.

Complete data sets were available for 23 sample sites that were sampled by mark and recapture methods, using only seining. The three variables produced an r^2 of 0.7406 ($F = 19.04$; $P > F = 0.0001$) and were all significant below the 0.0203 level. They were entered into the model in a stepwise manner as follows (r^2 values in parentheses): percent runs (0.5282); water temperature (0.6582); and gradient (0.7406). Additional variables increased the r^2 value of the model but their importance was questionable because of the lowered number of degrees of freedom.

Data sets were available for 21 sample sites where only seining was used as a capture technique. Three variables produced an r^2 of 0.7815 ($F = 21.46$; $P > F = 0.0001$). The three variables were entered into the model in a stepwise manner as follows: mean width; maximum width; and phosphates.

No complete data sets were available for sites sampled by shocking or shocking as part of a mark and recapture method. The models developed from data for the various sampling techniques are summarized in Table 9.

Channel Catfish

Presence-absence model. The variables that showed significant differences between areas where channel catfish were present and where they were absent are summarized in Table 10. One hundred and thirty-five (88%) of the 153 samples sites where channel catfish were absent were predicted not to contain this species. However, only 61 (40%) of the 152 sample sites where channel catfish were collected were correctly predicted to contain the species. Overall, 64% of all sites were classified correctly.

Suitability index curves. Suitability index curves were drawn for the channel catfish for the following variables: conductivity; dissolved oxygen; gradient; maximum width; mean depth; mean width; minimum width; nitrates; pH; percent pools; percent riffles; runoff; percent runs; sulfates; total alkalinity; total dissolved solids; turbidity; volume of flow; and water temperature (see Layher 1983). Data for additional variables are also in Layher (1983).

Standing crop models. Complete data sets were available for only 10 sample sites where kill methods were utilized. A model based on three variables had an r^2 of 0.6617, with an F of 4.56 and a probability of a greater F of 0.0450. The variables used in the model were (r^2 and significance in parentheses): percent pools (0.2376, 0.0136); minimum width (0.5035, 0.230); and conductivity (0.6617, 0.1133).

Complete data sets were available for 42 sites where channel catfish were collected by a mark and recapture technique with a final kill. The model, based on the independent variables percent runs, runoff, water temperature, and maximum width, had an r^2 of 0.4985 ($F = 9.20$; $P > F = 0.0001$). All of the variables in the model were significant below the 0.05 level, with the exception of maximum width (alpha = 0.1199). When maximum width was removed, the r^2 was reduced to 0.4641 ($F = 10.97$; $P > F = 0.0001$).

Table 9. Results of stepwise multiple regression analyses of the variation in central stoneroller standing crop by collection method.

Method of collection	N	r^2	F	PROB > F	Variables	F	PROB > F
Mark and recapture with seining and shocking	18	.90	24.18	.0001	Mean width	90.43	.0001
					Percent run	10.71	.0061
					Magnesium hardness	17.85	.0010
					Sulfates	15.15	.0019
					pH	3.81	.0730
Mark and recapture with a final kill	85	.50	9.67	.0010	Mean width	9.73	.0025
					Gradient	14.42	.0003
					pH	6.22	.0148
					Water temperature	4.89	.0301
					Mean depth	7.49	.0077
					Total dissolved solids	7.00	.0099
					Phosphates	2.42	.1238
					Total alkalinity	3.62	.0609
Kill technique without mark and recapture	35	.53	7.04	.0002	Magnesium hardness	12.72	.0012
					Maximum width	9.07	.0052
					Nitrates	7.62	.0078
					Percent pools	4.14	.0507
					Dissolved oxygen	4.79	.0366
Seining and shocking	13	.88	24.95	.0010	Percent riffles	52.53	.0001
					Sulfates	21.78	.0009
					pH	8.09	.0174
Mark and recapture with seining	23	.74	19.04	.0001	Percent runs	18.30	.0004
					Water temperature	15.48	.0008
					Gradient	6.35	.0203
Seining	21	.78	21.46	.0001	Mean width	51.75	.0001
					Maximum width	12.78	.0022
					Phosphates	9.91	.0056

Table 10. Results of significant T-tests between presence and absence of channel catfish for physical and chemical variables.

Variable	Group[a]	N	Mean	Standard deviation	Minimum value	Maximum value	Variance	T	DF	PROB > |T|
Maximum width (m)	A	209	8.65	8.71	0.9	91.4				
	P	196	15.55	14.26	2.4	125.5	Unequal	-5.8249	318.7	0.0001
Minimum width (m)	A	210	4.56	4.87	0.3	54.8				
	P	196	8.35	10.96	0.6	101.1	Unequal	-4.4433	265.2	0.0001
Mean depth (m)	A	211	0.45	0.44	0.1	4.5				
	P	209	0.54	0.33	0.1	2.1	Unequal	-2.2236	389.9	0.0267
Volume of flow (m^3/sec)	A	196	0.39	1.94	0.0	25.1				
	P	181	1.45	4.11	0.0	28.3	Unequal	-3.1519	251.7	0.0018
Gradient (m/km)	A	171	1.77	1.18	0.1	7.9				
	P	198	1.19	0.96	0.1	5.0	Unequal	5.0630	327.7	0.0001
Water temperature (°C)	A	207	18.80	6.83	1.0	30.0				
	P	198	22.77	5.77	1.0	36.0	Unequal	-6.3172	396.9	0.0001
Mean width (m)	A	211	6.70	7.42	0.9	76.2				
	P	209	12.35	12.65	1.8	110.0	Unequal	-5.5738	335.4	0.0001
Riffles (%)	A	210	6.48	13.59	0.0	81.0				
	P	198	12.53	18.07	0.0	100.0	Unequal	-3.8003	365.2	0.0002

[a]A = Absent
P = Present

Complete data sets were available for 12 sites where mark and recapture methods were used with the first capture by seining and the second by shocking, at six sites where collecting was done by a combination of seining and shocking but no mark and recapture occurred, and at 11 sites where mark and recapture methods with shocking only were used. Percent pools was the most important variable in terms of channel catfish standing crop for the first sampling method, while gradient was the most important variable for the last two sampling methods. Standing crop models for these sampling methods are not included because of the small number of sites sampled with each method.

Complete data sets were available from only seven sites sampled by mark and recapture using only seining. Conductivity was the most important variable in terms of standing crop. A standing crop model is not included because of the small number of available data points. Shocking and seining used separately only provided two and four data points, respectively, and, consequently, an analysis was not performed. Regression models are summarized in Table 11.

Largemouth Bass

Presence-absence model. The variables that had significant differences between areas where largemouth bass were present and where they were absent are included in Table 12. There were 171 complete data sets relating information about physical factors to standing crop. Classification was correct for 108 sites or 63% of the observations. The model correctly predicted the occurrence of largemouth bass for 55 (90%) of the 61 sites that contained the species. However, the model correctly predicted their absence at only 48% of the 110 sites where largemouth bass were not found. When the velocity variable was added to the model, model predictions were more accurate. There were complete data sets for 161 sites available for use in the model based on this addition. With this model, 45 of 55 sites containing largemouth bass were classified correctly; a reduction of about 8% in correct predictions. However, 77 (73%) of 106 sites where largemouth bass were absent were classified correctly; an improvement of about 13%.

Suitability index curves. Suitability index curves were drawn for the largemouth bass for the following variables: chlorides; conductivity; dissolved oxygen; gradient; growing season; maximum width; mean depth; mean width; minimum width; nitrates; pH; phosphates; percent pools; percent riffles; percent runs; water temperature; total alkalinity; total dissolved solids; turbidity; and velocity (see Layher 1983). Data for additional variables are also in Layher (1983).

Standing crop models. Complete data sets were available for 53 sites where a mark and recapture method incorporating kill as the recapture method was used. Mean width and mean depth were the most important variables in terms of largemouth bass standing crop with this capture technique. Both variables were significant at the 0.01 level, but together resulted in only an r^2 of 0.1951 ($F = 6.18$; $P > F = 0.0039$).

Table 11. Results of stepwise multiple regression analyses of the variation in channel catfish standing crop by collection method.

Method of collection	N	r^2	F	PROB > F	Variables	F	PROB > F
Mark and recapture with a final kill	42	.49	9.20	.0001	Maximum width	2.53	.1199
					Runoff	10.65	.0024
					Percent run	13.82	.0007
					Water temperature	3.89	.0560
Kill technique used without mark and recapture	11	.66	9.56	.0450	Conductivity	3.27	.1133
					Minimum width	8.41	.0230
					Percent pools	10.72	.0136
Mark and recapture with kill (combined with kill stations)	53	.38	4.88	.0006	Maximum width	3.02	.0892
					Nitrates	3.00	.0901
					Percent pools	4.38	.0419
					Runoff	2.29	.1366
					Percent run	4.10	.0487
					Total alkalinity	3.86	.0556
Mark and recapture with seining and shocking	13	.72	7.94	.0067	Percent pools	16.83	.0074
					Runoff	2.75	.1315
Mark and recapture with shocking	12	.68	5.83	.0206	Dissolved oxygen	5.11	.0536
					pH	2.88	.1284
					Gradient	7.25	.0274
Seining and shocking	6	.99	129.31	.0011	pH	5.68	.0974
					Percent pools	5.27	.1054
					Gradient	318.97	.0004
Mark and recapture with seining	7	.49	2.48	.1787	Conductivity	4.95	.0766
					Dissolved oxygen	1.00	.3638

Table 12. Results of significant T-tests between presence and absence of largemouth bass for physical and chemical variables.

Variable	Group[a]	N	Mean	Standard deviation	Minimum value	Maximum value	Variance	T	DF	PROB > |T|
Maximum width (m)	A	248	10.94	11.54	0.9	91.4				
	P	157	13.65	13.06	3.0	125.5	Unequal	-2.1281	301.8	0.0341
Mean depth (m)	A	257	0.45	0.42	0.1	4.5				
	P	163	0.57	0.33	0.1	2.1	Unequal	-3.3202	400.8	0.0010
Gradient (m/km)	A	221	1.32	0.96	0.1	5.0				
	P	148	1.67	1.27	0.1	7.9	Unequal	-2.8731	257.3	0.0044
Calcium hardness (mg/l)	A	228	265.36	149.24	5.0	930.0				
	P	145	232.64	170.71	0.0	1,350.0	Unequal	1.8936	276.6	0.0593
Water temperature (°C)	A	248	19.08	7.01	1.0	32.0				
	P	157	23.36	4.98	1.0	36.0	Unequal	-7.1752	397.6	0.0001
Conductivity (µmhos/cm)	A	137	1,183.63	1,066.25	85.0	910.0				
	P	81	887.27	955.07	200.0	6,400.0	Unequal	2.0687	177.4	0.0400
Chlorides (mg/l)	A	240	117.23	179.66	0.5	1,250.0				
	P	155	72.45	188.63	0.1	1,870.0	Equal	2.3717	393.0	0.0182
Pools (%)	A	246	35.50	39.70	0.0	100.0				
	P	163	53.46	38.72	0.0	100.0	Equal	-4.5221	407.0	0.0001
Riffles (%)	A	247	8.14	15.89	0.0	100.0				
	P	161	11.37	16.49	0.0	88.0	Equal	-1.9809	406.0	0.0483
Runs (%)	A	248	56.42	39.30	0.0	100.0	Equal	4.8783	406.0	0.0001

[a]A = Absent
P = Present

Kill methods with no mark and recapture were used at only 16 sites. Only total alkalinity and secchi disc reading met the 0.05 significance level set for inclusion in the model; they produced an overall model with an r^2 of 0.3246 ($P > F = 0.0629$).

No data were available to develop a model for shocking as a capture technique without mark and recapture, and complete data sets were available for only two sites where mark and recapture, including shocking as one of the sampling techniques, was used.

Fourteen data sets were available for sites where a combination of seining and shocking, not utilizing a mark and recapture procedure, was used. In the model representing this sampling technique, pH alone produced an r^2 of 0.9091 ($F = 130.08$; $P > F = 0.0001$). Mean depth and total alkalinity increased the r^2 value to 0.9478, without affecting the significance level. Significance levels for the three variables pH, mean depth, and total alkalinity were 0.0001, 0.0284, and 0.0977, respectively.

Sixteen data sets were used in the stepwise regression analysis described in the preceding paragraph, except that the sampling method for these sites also involved mark and recapture. Percent runs and water temperature were the two most important variables in this model, but together only resulted in an r^2 of 0.35.

Thirteen data sets where seining alone was used as a method of capture resulted in a model with an r^2 of 0.9008 and a significance level of 0.0001. Turbidity, conductivity, and phosphates were the three most important variables in this model. These variables were added in a stepwise procedure in the order listed above and resulted in the following r^2 values, respectively: 0.4611; 0.8533; and 0.9008. Individual significance levels for the three variables were 0.0001, except for phosphates, which was 0.0580. The regression models are summarized in Table 13.

White Crappie

Presence-absence model. The variables that were significantly different between where white crappie were present and where they were absent are summarized in Table 14. Presence or absence of the species was correctly predicted in 58% of the 180 sites. Thirty-three (89%) of the 37 sites where crappie were found were correctly classified. However, only 50% of the sites where crappie were absent were correctly classified.

Suitability index curves. Suitability index curves were drawn for the white crappie for the following variables: conductivity; dissolved oxygen; gradient; growing season; mean depth; maximum width; mean width; magnesium hardness; nitrates; pH; phosphates; percent riffles; turbidity; velocity; volume of flow; and water temperature (see Layher 1983). Data for additional variables are also presented in Layher (1983).

Table 13. Results of stepwise multiple regression analyses of the variation in largemouth bass standing crop by collection method.

Method of collection	N	r^2	F	PROB > F	Variables	F	PROB > F
Mark and recapture with a final kill	53	.19	6.18	.0039	Mean width	5.89	.0188
					Mean depth	5.83	.0194
Kill technique without mark and recapture	16	.32	3.39	.0629	Total alkalinity	4.64	.0492
					Secchi disc	5.77	.0307
Seining and shocking	14	.90	130.08	.0001	pH	-	-
Mark and recapture with seining and shocking	16	.35	3.90	.0450	Percent runs	4.93	.0433
					Water temperature	2.15	.1645
Seining	13	.90	30.27	.0001	Turbidity	64.55	.0001
					Conductivity	41.86	.0001
					Phosphates	4.58	.0580
Mark and recapture with seining	21	.71	10.49	.0001	Gradient	16.43	.0008
					pH	12.39	.0026
					Nitrates	13.70	.0018
					Turbidity	2.14	.1613

Table 14. Results of significant T-tests between the presence and absence of white crappie for physical and chemical variables.

Variable	Group[a]	N	Mean	Standard deviation	Minimum value	Maximum value	Variance	T	DF	PROB > |T|
Maximum width (m)	A	326	10.10	10.46	0.9	125.5				
	P	79	19.77	15.49	3.0	91.4	Unequal	-5.2607	95.9	0.0001
Minimum width (m)	A	327	5.52	7.91	0.3	101.1				
	P	79	9.96	10.24	0.6	54.8	Unequal	-3.5980	101.6	0.0005
Mean depth (m)	A	338	0.44	0.32	0.1	3.1				
	P	82	0.70	0.56	0.2	4.5	Unequal	-3.9515	94.7	0.0001
Gradient (m/km)	A	289	1.53	1.12	0.1	7.9				
	P	80	1.18	1.01	0.1	5.0	Equal	2.5619	367.0	0.0108
Total dissolved solids (mg/l)	A	167	550.16	569.49	22.0	4,200.0				
	P	43	299.72	255.18	34.0	1,200.0	Unequal	4.4827	174.5	0.0001
Water temperature (°C)	A	327	19.99	6.96	1.0	36.0				
	P	78	23.89	3.62	11.0	30.0	Unequal	-6.9361	230.3	0.0001
Conductivity (μmhos/cm)	A	173	1,179.46	1,127.55	145.0	9,100.0				
	P	45	666.22	481.92	85.0	2,700.0	Unequal	4.5887	170.2	0.0001
Mean width (m)	A	338	8.08	9.60	0.9	110.0				
	P	82	15.39	12.96	2.1	76.2	Unequal	-4.7899	103.5	0.0001

[a]A = Absent
P = Present

Standing crop models. There were only three complete data sets available where kill techniques were employed without mark and recapture. Twenty-six sites were sampled where mark and recapture involved kill as the final capture technique. Three variables met the 0.5 significance level for inclusion in the stepwise regression model (r^2 and individual significance levels are in parentheses): magnesium hardness (0.1551, 0.0225); gradient (0.2611, 0.0827); and growing season (0.3351, 0.1231).

Complete data sets were available for 14 sites where mark and recapture methods, with a combination of seining and shocking, were used. Only one variable, pH, was significant at the 0.0001 level; it resulted in an r^2 of 0.9709 ($F = 435.14$). Other variables that met the 0.5 significance level for inclusion in the model were phosphates, nitrates, and turbidity. The addition of these three variables increased the r^2 to 0.9930, but did not change the significance level of the model. All of the variables were significant at least to the 0.05 level, with the exception of turbidity ($\alpha = 0.2313$).

Only eight sites were sampled with a combination of seining and shocking but without mark and recapture. Growing season, turbidity, percent runs, and phosphates were all significant variables in the standing crop model for this sampling method. There were no data sets available for sites sampled by shocking or mark and recapture with shocking.

Thirteen sites were sampled by seining, with population estimates based on mark and recapture methods. None of the variables for which curves were drawn produced significant r^2 values with these techniques. Only five sites that were sampled by seining alone contained white crappie; therefore, no models were developed for these data. The available regression models are summarized in Table 15.

Green Sunfish

Presence-absence model. The variables that had significant differences between areas where green sunfish were present and where they were absent are summarized in Table 16. Two hundred and fifty (77%) of 323 sites used in the analysis were classified correctly. Eighty-nine percent of the 240 sites where green sunfish occurred were classified correctly. However, only 44% of the 83 sites where green sunfish were absent were correctly classified.

Suitability index curves. Suitability index curves were drawn for the green sunfish for the following variables: pH; phosphates; turbidity; velocity; magnesium hardness; maximum width; minimum width; and mean depth (see Layher 1983). Data for additional variables are also in Layher (1983).

Table 15. Results of stepwise multiple regression analyses of variation in white crappie standing crop by collection method.

Method of collection	N	r^2	F	PROB > F	Variables	F	PROB > F
Mark and recapture with a final kill	27	.33	3.87	.0225	Gradient	3.29	.0827
					Growing season	2.56	.1231
					Magnesium hardness	5.99	.0225
Kill without mark and recapture	3	.97	84.33	.0117	Mean width		
Mark and recapture with a final kill technique (combined with kill)	31	.45	4.16	.0069	Dissolved oxygen	3.47	.0742
					Gradient	4.35	.0475
					Growing season	5.97	.0220
					Mean width	2.13	.1567
					Magnesium hardness	4.79	.0382
Mark and recapture with seining and shocking	14	.99	414.62	.0001	Nitrates	4.97	.0500
					Phosphates	12.28	.0057
					pH	1,557.85	.0001
					Turbidity	1.82	.2313
Seining and shocking	8	.90	15.45	.0058	Growing season	37.58	.0017
					Turbidity	12.33	.0173
					Percent runs	6.99	.0458
Mark and recapture with seining	14	.20	1.46	.2741	Secchi disc	1.99	.1855
					Percent runs	1.30	.2791
Seining	5	.98	141.78	.0011	Mean width	235.27	.0006
					Turbidity	21.85	.0185

Table 16. Results of significant T-tests between the presence and absence of green sunfish for physical and chemical variables.

Variable	Group[a]	N	Mean	Standard deviation	Minimum value	Maximum value	Variance	T	DF	PROB > |T|
Maximum width (m)	A	104	15.43	20.09	0.9	125.5				
	P	301	10.80	7.53	1.8	45.7	Unequal	-2.2923	113.1	0.0237
Minimum width (m)	A	104	9.52	14.94	0.6	101.1				
	P	302	5.31	4.28	0.3	30.4	Unequal	2.8329	108.9	0.0055
Volume of flow (m^3/sec)	A	91	1.96	5.56	0.0	28.3				
	P	286	0.57	1.84	0.0	25.1	Unequal	2.3400	96.3	0.0213
Magnesium hardness (mg/l)	A	94	73.80	65.71	0.0	440.0				
	P	277	99.1	185.79	0.0	2,530.0	Unequal	-1.9386	368.4	0.0533
Water temperature (°C)	A	103	18.66	7.17	3.0	32.0				
	P	302	21.45	6.29	1.0	36.0	Unequal	-3.5045	159.0	0.0006
Mean width (m)	A	104	12.24	17.28	0.9	110.0				
	P	316	8.61	7.22	1.2	73.1	Unequal	2.0793	115.1	0.0398
Pools (%)	A	100	29.41	37.24	0.0	100.0				
	P	302	46.94	40.29	0.0	100.0	Equal	-3.8578	407.0	0.0001
Runs (%)	A	101	61.00	40.48	0.0	100.0				
	P	307	44.27	42.26	0.0	100.0	Equal	3.4871	406.0	0.0005
Velocity (m/sec)	A	91	0.27	0.36	0.0	2.21				
	P	286	0.16	0.43	0.0	5.7	Unequal	2.5602	175.6	0.0113

[a]A = Absent
P = Present

Standing crop models. Complete data sets were available for 106 sites that contained green sunfish where sampling was by mark and recapture with a final kill as the recapture method. Maximum width, velocity, and Secchi disk reading were the most important variables in terms of green sunfish standing crop ($r^2 = 0.1457$; $F = 5.86$; $P > F = 0.0011$). These were the only three variables significant at the 0.5 level set for inclusion in the model.

Kill only was used at 48 sites. Maximum width and pH resulted in an r^2 of 0.1407 ($P > F = 0.0329$) for the model containing these two variables. No significant models were developed for mark and recapture sites where both seining and shocking were used or where mark and recapture was used with shocking alone. Only two complete data sets were available for stations that were sampled by shocking without mark and recapture.

Fourteen sites were sampled with a combination of seining and shocking but no mark and recapture. An r^2 of 0.5063 ($F = 5.64$; $P > F = 0.0206$) resulted when the variables phosphate ($\alpha = 0.0075$) and pH ($\alpha = 0.0962$) were included in the model.

Thirty-seven sites were sampled by seining and mark and recapture. An r^2 of 0.1649 ($F = 3.36$; $P > F = 0.0467$) resulted from the inclusion of the variables Secchi disk reading and maximum width. Maximum width was the only significant variable in terms of green sunfish standing crop for the 29 sites sampled by seining only. This one variable produced an r^2 of 0.2695 ($F = 9.96$; $P > F = 0.0039$). The regression models developed are summarized in Table 17.

Discussion

One of the justifications for the development of HSI models is to standardize the method used to predict impacts. Standardization can have both positive and negative effects. A loss of credibility can occur when individual biologists make conflicting recommendations (Lockard 1979),while standardization of impact predictions can increase credibility. However, if specific models are widely used and later proven invalid, the credibility of the predictions becomes even lower. Therefore, HSI models should be developed slowly and frequently tested. The individual suitability index curves developed from the Kansas data were generally similar to those developed from literature surveys. This similarity seems to support the approach used in suitability index curve development.

Presence-absence models. Presence-absence models developed through the use of discriminant analysis appear to be useful in predicting whether or not a species can occur in a specific area. These models may be of value in predicting situations where the loss of a species from a habitat will result from man-induced alterations. Similar models, based on data for life stages other than the adult, would probably reduce the number of model misclassifications.

Discriminant analysis models contained in this report compute the probability of a species belonging to one group or the other (absent or present). A probability of 0.5 or greater places a site in the presence group, while sites with probabilities of less than 0.5 are placed in the absence group. If habitat variables are assumed to be "pulsing", the closer a value gets to 0.5,

Table 17. Results of stepwise multiple regression analyses of the variation in green sunfish standing crop by collection method.

Method of collection	N	r^2	F	PROB > F	Variables	F	PROB > F
Mark and recapture with a final kill	107	.14	5.86	.0011	Secchi disc Maximum width Velocity	5.59 12.05 2.26	.0199 .0088 .1355
Kill without mark and recapture	48	.14	3.69	.0329	Maximum width pH	3.81 3.23	.0572 .0782
Mark and recapture with a final kill technique (combined with kill stations)	154	.07	6.48	.0020	Maximum width pH	10.15 1.65	.0017 .2014
Mark and recapture with seining and shocking	21	.15	1.79	.1942	Secchi disc Mean depth	1.16 2.57	.2955 .1252
Seining and shocking	14	.50	5.64	.0206	Phosphates pH	10.66 3.31	.0075 .0962
Mark and recapture with shocking	7	.54	2.37	.2096	Secchi disc Maximum width	4.71 2.17	.0958 .2151
Mark and recapture with seining	37	.16	3.36	.0467	Secchi disc Maximum width	3.03	.0910
Seining	29	.26	9.96	.0039	Maximum width		

moving from 1.0, the greater the probability that the environmental variables frequently fluctuate out of the range suitable for the species concerned. In other words, habitats classified as marginal or close to marginal, but greater than 0.5, may, in reality, be uninhabitable by the species.

The use of statistically-derived presence-absence and suitability models to determine habitat value may be useful in evaluating overall habitat suitability for a species. The results of tests of these models are provided in the last section of this report.

Suitability index curves. It appears that most suitability index curves derived from the literature closely approximate curves developed from large scale field surveys, such as the Kansas data set. Therefore, it may be possible to develop relationships between a parameter for which field data are lacking and habitat suitability for a particular species of fish. The development of suitability index curves for various habitat parameters is possible, but the synthesis of the individual suitability indices, as attempted in the tested model, is currently impossible. At the present time, SI curves based on quantitative data can be a significant tool for use in determining impacts, even though valid numerical models do not exist. Because limiting factors vary from one location to the next (as noted for species with broad niches), the best approach to impact assessment may be determining suitability indices for as many variables as possible and subjectively arriving at a prediction about the impact on a species based on knowledge of species-habitat relationships.

Standing crop models. Sampling technique had a significant effect on data analysis. No significant correlations resulted when data from all sites where a species occurred were grouped in stepwise regression analyses. Significant correlations were obtained when the data set was separated according to sample method.

No consistent guidelines were followed in determining the appropriate sampling method for each site; however, it is likely that seining was not used in areas with uneven substrates. Consequently, while some variation in the sampling technique used probably was related to equipment availability, the use of some sampling techniques may have been limited to a particular habitat type. These sampling constraints explain, at least partially, why different variables assume importance with the different sampling techniques. However, it is also possible that different variables are limiting in different habitat types. When the data were categorized on the basis of sampling technique, the potential number of variables affecting the equation for a given species standing crop was reduced and significant regressions were obtained. It may be necessary to restrict modeling attempts to limited geographical areas to increase the probability of a few factors being limiting for species that utilize several dissimilar habitat types over a wide geographic area.

The probability of accurately modeling habitat suitability is greatly enhanced for species with a restricted set of environmental conditions under which they can exist. Even though a species occurs over a wide geographic area, modeling is more likely to be successful if the habitats it occupies are similar in terms of the variables that influence suitability, expressed as

standing crop. Spotted bass and slenderhead darters may represent two species for which valid quantitative models can be constructed because of the rather homogeneous habitat occupied by each species.

Channel catfish, white crappie, largemouth bass, and green sunfish represent species that occupy habitats with more variability in terms of physical and chemical characteristics. Consequently, the number of limiting factors over all of the occupied range is much greater than the number for species with narrower niches. Consequently, the approach of quantitatively modeling habitat suitability will probably produce good results for some species and poor results for others, depending on the overall niche breadth of the species. This hypothesis needs further testing, and a way to determine overall niche breadths of species on a comparative basis is needed.

Test results for habitat suitability index models. Large, significant r^2 values between an HSI based on adult life stage requirements and standing crop estimates did not result for the HSI defined as the geometric mean of suitability indices derived from the graphs presented in Appendix A. This observation was also tested by multiple regression analysis for all geographical areas to increase the probability of only a few factors actually being limiting.

If a species has a more restricted set of environmental conditions under which it can exist, the possibility of accurately modeling habitat suitability would be greater. Models developed through regression analyses must be used as a habitat quality predictor in their complete form.

Based on the results of this study, it is recommended that the formula $HSI = [(I_1)n\ (I_2)n\ \ldots\ldots\ (I_x)n]^{1/N}$ be used only as a rough approximation of habitat suitability. The data do indicate that the tested curves have utility and appear to adequately describe habitat suitability for individual variables.

Species Suitability Index Curves for Individual Species

The U.S. Fish and Wildlife Service has developed habitat suitability index models for individual species that contain suitability index curves for parameters believed to be important in describing habitat suitability. The following discussion compares draft and published suitability index curves to the curves Layher (1983) developed from field data from the Kansas stream surveys.

Spotted bass suitability index curves. Test results from this study suggest that the draft suitability index curve for substrate (Appendix A) is correct if the percent of sites where a major substrate type occurs is used as a qualifier for habitat suitability. However, the greater occurrence of gravel, rubble, and bedrock in sites where spotted bass were sampled, compared to percent of occurrence by substrate type at all sites sampled, indicate that these substrate types should receive higher suitability values than indicated. Because several types of substrate can occur together, it may be more appropriate to develop suitability indices for each substrate type based on its percent composition.

The water temperature curve was almost exactly the same as the curve developed from the Kansas field data.

Green sunfish suitability index curves. A substrate curve was not developed in this study for the green sunfish because quantitative data were lacking. Substrates were divided into five categories in the Kansas stream surveys: silt; sand; gravel; cobble; and bedrock. No distinction was made between silt and mud substrates, and no data were available on the amount of rooted vegetation present. However, the substrate SI curve for green sunfish (Stuber et al. 1982a) was similar in shape to the plotted data for frequency of occurrence vs. substrates present for green sunfish from the Kansas survey. No modifications are recommended for this curve.

Water temperature data from the Kansas stream survey for green sunfish were not suitable for curve development. Several streams were sampled during cold weather months, and these nonsummer measurements (increments 0° C to < 5° C and 5° C to < 10° C) can be disregarded. The optimal temperature conditions appear to be between 20 and 30° C. Consequently, the adult and juvenile green sunfish temperature curve (V_7) may need to be shifted approximately 5° C toward the origin on the graph.

The velocity curve for green sunfish indicates an optimum velocity of approximately 0 to 5 cm/sec. The data from the Kansas stream survey indicates a much greater range, extending to average velocities of 50 cm/sec. Three hundred sixty-seven observations were made at average velocities of less than 100 cm/sec. Only ten observations were above 100 cm/sec. These high velocities, however, probably represent areas with some protected habitat. Green sunfish apparently can occur at fairly high average velocities. If this interpretation of the data is correct, the suitability index curve (V_{11}) for average current velocity within pools may need to be redefined as average stream velocity and extended to the right, with the optimal velocity range at approximately 40 cm/sec and the upper limit at approximately 100 cm/sec. It is important to remember that these data relate only to average stream velocity and not the velocity in the microhabitat occupied by the fish. Therefore, the curve is expected to indicate suitability over a greater range of velocities than would curves based on more localized measurements.

Largemouth bass suitability index curves. No modifications are recommended in the dissolved oxygen suitability index curve (V_6) for the largemouth bass (Stuber et al. 1982b). The dissolved oxygen curve derived from the Kansas data indicates that high standing crops of this species can occur at dissolved oxygen levels as low as approximately 6 ppm. However, extreme variation in standing crop values for largemouth bass occurred above 6 ppm, indicating that factors other than dissolved oxygen may be limiting this species in many Kansas streams. No data were available to evaluate the salinity curve. However, variables possibly related to salinity, such as conductivity and chlorides, had an inverse relationship with average standing crop.

Quantitative data for substrate were lacking in the Kansas data set utilized in this analysis (see Discussion - Green Sunfish Curves). However, plots of substrate occurrence vs. largemouth bass occurrence supported the curve (V_{15}) presented by Stuber et al. (1982b).

The temperature curve (V_8) in the published largemouth bass model agreed with the curve derived from the Kansas data. Optimal range, as well as the entire range, for the graph coincided well with the field data, and no modifications are recommended in this curve.

The suitability index graph for turbidity (V_{11}) indicates an optimal turbidity range up to approximately 25 ppm, with a gradual decline in suitability up to 100 ppm, and the habitat given a constant rating for turbidities greater than 100 ppm. Field data analyzed in this report indicate an optimal range to 30 JTU's, with a sharp decline in habitat suitability after that point. However, largemouth bass were found where the turbidity was as high as 555 JTU's. In general, the field data suggest very low habitat suitabilities at turbidities above 140 JTU's (see Results - Largemouth Bass).

The velocity curve for adult and juvenile largemouth bass (V_{19}) indicates that velocities ≤ 6 cm/sec are optimum. Field data from the Kansas stream surveys suggest that this optimum range could be extended to almost 25 cm/sec. The data for V_{19} may include some microhabitat measurements and, therefore, not accurately reflect average velocities recorded at stream sites. The general shape of the curve is supported, but the curve probably should be shifted to the right.

White crappie suitability index curves. When the frequency of occurrence of white crappie vs. substrate data from the Kansas stream survey were plotted (Layher 1983), there was little difference in substrate preference, although species occurrence over sand and bedrock were approximately one-half of the occurrence over silt (mud), gravel, and rubble.

The water temperature suitability index curve (V_6) in Edwards et al. (1982) was almost precisely the same as the curve developed from the Kansas field data. Consequently, no modifications are recommended in the water temperature SI curve.

Channel catfish suitability index curve. The ascending limb of the water temperature SI curve (V_5) in the channel catfish model (McMahon and Terrell 1982) is similar to the curve developed from the Kansas field data. However, the temperature range of 35 to 40° C reflects a single observation in the Kansas stream survey. The standing crop for the temperature interval immediately preceding the 35 to 40° C interval is lower than the standing crop in the intervals on either side. Therefore, it appears that the curve for V_5 should turn downward near 30° C, instead of continuing upward as shown in Layher (1983). No modifications are recommended for V_5. The turbidity SI

curve (V_7) indicates an optimal turbidity range that extends to approximately 120 ppm. The curve developed from the Kansas field data indicates an optimal range of 0 to 30 JTU's, followed by a rather sharp drop in suitability. The curves cannot be directly compared because they were developed from different types of turbidity analyses. The field data does, however, seem to indicate a more abrupt change in habitat suitability for this species with increases in turbidity than indicated by the published curve. However, there is a wide range of turbidity tolerance.

The dissolved oxygen SI curve (V_8) appears to match the Kansas field data quite well, and no curve modifications are recommended.

Salinity measurements were not recorded during the Kansas stream surveys; therefore, it is not possible to evaluate this curve (V_9). An SI curve for conductivity was developed from the Kansas field data, however, and an inverse relationship was evident between channel catfish mean standing crop and conductivity values over 1500 µmhos/sec.

FIELD TEST OF STATISTICAL MODELS

In order to further test the ability of the regression models to predict standing crop, the discriminant models to predict presence and absence, and the relationship between abiotic factors and fish populations over a wide geographical area, data were collected at 50 stream sites in Oklahoma (Table 18). Initially, we attempted to use complete kill techniques because the Kansas data indicated that complete kill techniques (cyanide) gave more reliable results than nonkill techniques. However, cyanide was not cleared for use in Oklahoma and in preliminary tests rotenone (Marking and Bills 1976) and primacord (Layher 1981) were found to be inefficient. Consequently, population estimates at each site were made using the depletion method (Carle and Maughan 1980) and the maximum likelihood estimator (Carle and Strubb 1978). We followed the procedures outlined by Raleigh and Short (1981) to allow us to meet the assumptions of this sampling technique.

The field procedures for use of this technique were as follows: a 30-meter section of stream was blocked upstream and downstream with 1/4-inch mesh net. In soft substrates, metal fence posts were driven through loops in the lead line to ensure blockage. In sites with hard substrates, large rocks were placed on the lead line. Fish were collected from each site using a boat mounted DC electrofishing unit composed of a generator, variable voltage pulsator (Coffelt Model VVP-2C), and two hand held, remote electrodes. The cathode was imbedded in the boat bottom. One complete pass through the site constituted a sampling effort. The procedure was repeated until depletions of all species were made. The number of passes made through a site varied from a minimum of three to a maximum of seven. If a species was extremely abundant, each 25 mm length group was treated as a separate unit for analysis of numbers but recombined to obtain biomass estimates. Average weights were then determined for each species or group in the collection. To obtain the biomass estimate for the site, the number of fish estimated to be in the sample area

Table 18. Locations, dates, and names of stream sites sampled in Oklahoma. Site numbers depict order of sampling and are used for reference.

Site	Location	Date sampled	Stream name and county
1	SE1/4,S10,T19N,R1E	6-01-1981	Stillwater Creek, Payne
2	SW1/4,S23,T19N,R4E	6-08-1981	Council Creek, Payne
3	SW1/4,S32,T18N,R2E	6-09-1981	Wildhorse Creek, Payne
4	NE1/4,S16,T22N,R19W	6-10-1981	North Canadian River, Woodward
5	NE1/4,S16,T24N,R22W	6-10-1981	Wolf Creek, Woodward
6	NW1/4,S30,T25N,R25W	6-11-1981	Clear Creek, Harper
7	NE1/4,S9,T26N,R25W	6-11-1981	Beaver River, Harper
8	NE1/4,S15,T26N,R26W	6-11-1981	Kiowa Creek, Harper
9	SW1/4,S10,T18N,R2W	6-16-1981	Beaver Creek, Logan
10	SE1/4,S8,T18N,R3W	6-17-1981	Skeleton Creek, Logan
11	NW1/4,S28,T16N,R1W	6-18-1981	Bear Creek, Logan
12	NE1/4,S17,T15N,R3W	6-19-1981	Cottonwood Creek, Logan
13	SW1/4,S26,T22N,R1E	6-22-1981	Black Bear Creek, Noble
14	NE1/4,S13,T27N,R22W	6-24-1981	Buffalo Creek, Harper
15	SE1/4,S14,T26N,R14W	6-25-1981	Little Eagle Chief Creek, Woods
16	SE1/4,S26,T26N,R14W	6-25-1981	Eagle Chief Creek, Woods
17	NW1/4,S14,T23N,R1E	6-26-1981	Red Rock Creek, Noble
18	SW1/4,S18,T28N,R9W	7-02-1981	Sandy Creek, Alfalfa
19	NW1/4,S14,T27N,R11W	7-02-1981	Salt Fork of the Arkansas, Alfalfa
20	NE1/4,S5,T20N,R5W	7-06-1981	Skeleton Creek, Garfield
21	NE1/4,S27,T28N,R1W	7-07-1981	Bitter Creek, Kay
22	SE1/4,S27,T27N,R6W	7-08-1981	Pond Creek, Grant
23	NW1/4,S31,T28N,R5E	7-09-1981	Little Beaver Creek, Kay
24	SE1/4,S24,T28N,R6E	7-09-1981	Elm Creek, Osage
25	NW1/4,S2,T26N,R6E	7-13-1981	Salt Creek, Osage
26	SW1/4,S19,T23N,R7E	7-14-1981	Salt Creek, Osage
27	SE1/4,S7,T25N,R6E	7-16-1981	Little Chief Creek, Osage
28	SW1/4,S36,T25N,R4E	7-16-1981	Doga Creek, Osage
29	NW1/4,S5,T23N,R6E	7-17-1981	Gray Horse Creek, Osage
30	NE1/4,S29,T22N,R4E	7-21-1981	Black Bear Creek, Pawnee
31	SW1/4,S33,T22N,R5E	7-22-1981	Black Bear Creek, Pawnee
32	NE1/4,S12,T21N,R5E	7-22-1981	Camp Creek, Pawnee
33	SE1/4,S1,T21N,R6E	7-23-1981	Hell Roaring Creek, Pawnee
34	NE1/4,S25,T23N,R6E	7-23-1981	Sycamore Creek, Osage
35	SE1/4,S27,T23N,R7E	7-24-1981	Bug Creek, Osage
36	SE1/4,S26,T27N,R17E	7-28-1981	Big Creek, Nowata
37	SW1/4,S8,T26N,R16E	7-29-1981	California Creek, Nowata
38	NE1/4,S6,T27N,R13E	7-29-1981	Little Caney River, Washington
39	NE1/4,S4,T23N,R12E	8-04-1981	Candy Creek, Osage
40	SE1/4,S12,T23N,R11E	8-04-1981	Bird Creek, Osage

Table 18. (concluded)

Site	Location	Date sampled	Stream name and county
41	NW1/4,S21,T24N,R10E	8-05-1981	Birch Creek, Osage
42	SE1/4,S29,T23N,R9E	8-06-1981	Hominy Creek, Osage
43	SE1/4,S29,T23N,R9E	8-06-1981	Hominy Creek, Osage
44	SE1/4,S32,T22N,R10E	8-10-1981	Wildhorse Creek, Osage
45	SW1/4,S34,T22N,R11E	8-10-1981	Tall Chief Creek, Osage
46	SW1/4,S16,T25N,R13E	8-11-1981	Caney River, Washington
47	NE1/4,S35,T24N,R20E	8-12-1981	Big Cabin Creek, Craig
48	SW1/4,S35,T24N,R20E	8-12-1981	Big Cabin Creek, Craig
49	NE1/4,S23,T23N,R19E	8-13-1981	Rock Creek, Mayes
50	SW1/4,S13,T26N,R5E	8-18-1981	Salt Creek, Osage

minus the number collected was multiplied by the average weight of the fish in the group that had been collected. This biomass was then added to the biomass of the collected group and converted to kg/ha.

Larger fish were measured and weighed to the nearest gram with an accuracy of ±2 grams. Smaller fish, such as sunfishes, were batch weighed as a group (25 mm length groups). Cyprinids and darters were batch weighed, transferred to the lab, correctly identified to species, and weighed to the nearest 0.1 gram. The weights recorded in the lab were then converted to a percent of the weight of the total group and the biomass of each species determined from its percentage of the group weight. All fish whose weight could be determined in the field were released after depletion sampling was completed. After fish populations were sampled, the block nets were removed.

Stream width measurements (m) were made near the end of each site and midway between the location of the block nets. Depth (cm) was measured with a metric wading rod at one meter intervals across the stream. Current velocity (cm/s) was also measured with a pygmy current meter at one meter intervals at 0.6 of the depth from the water surface. Finally, substrate was classified and coded at each meter interval according to a modified Wentworth scale (Bovee and Cochnauer 1977). Depth was converted to meters and velocity to meters per second. An average depth was determined for the site by finding the mean of all three transect measurements. A mean velocity was computed in a similar manner. Substrate was recorded by percentage and the stream segment divided into a percent pools, riffles, and runs combination. The percent pools was determined by computing the percent of current readings which yielded a 0 cm/s reading. Riffle percents were determined by estimating the percent of the site with projecting substrate above the water surface or with turbulent flow. The percent runs was that portion of the site with currents greater than 0 cm/s but no apparent turbulence. Maximum and minimum stream widths (m) within the sampling area were also determined.

EPA-approved Hach meters were used to determine water temperature (C °), conductivity (µmhos/cm), total dissolved solids (mg/l), dissolved oxygen (mg/l), and pH in the field. Water samples for in-lab analyses were taken in acid washed polypropylene bottles and acidified to a pH of 2. Bottles were transported on ice and the pH increased to about 7 before analysis. Analyses of soluble reactive phosphorus (SRP) and nitrate (NO3-N) were done using methods outlined by Strickland and Parsons (1968). EPA standard reference solutions were used to validate the methods each time samples were processed. Chlorides, sulfates, total hardness, calcium hardness, magnesium hardness, total alkalinity, and turbidity were all determined with a Hach DR-EL/2 Direct Reading Engineers Laboratory Kit. Boyd (1976, 1977, 1980) has determined that the reliability of such units are adequate for general surveys of water quality, fisheries management decisions, and research requiring only approximate data on water quality.

Gradients (m/km) for each site were determined from U.S. Geological Survey (1969) topographic maps. Growing season (frost-free days) was determined from maps in Hambridge and Drown (1941). Runoff (in/yr) values were obtained from climatological maps (Oklahoma State University 1979).

Species Occurrence

The model developed from the Kansas stream survey data using the SAS PROC DISCRIM procedures was used to classify each stream site in Oklahoma to determine if species presence or absence could be predicted using the discriminate analysis model based on data for Kansas physical and chemical stream attributes and species occurrence. A discriminate analysis was also performed for each species using Oklahoma data for the same physical and chemical variables measured for the Kansas data set.

Species Biomass Predictions

The suitability index curves developed from the Kansas stream survey data (Layher 1983) were used to assign indices for each variable measured at each site in Oklahoma. Regression equations developed from Kansas data (Appendix B) were used to predict biomass for each species at the Oklahoma sample sites. Pearson and Spearman correlation coefficients were then calculated between observed and predicted biomass for each species to evaluate the accuracy of these predictions. New regression equations were then developed for the Oklahoma data to determine whether or not the curves developed from Kansas data generated SI's that could be used to develop a regression equation to explain variation in standing crops in Oklahoma streams. This approach allowed a determination of whether or not there was any indication that the same variables limited fish populations in Oklahoma and Kansas streams.

Results

Spotted bass. When the discriminant model developed from the Kansas data was used, 14 sites were misclassified from absence into presence. Twenty-two sites where the species was not found were correctly classified. Only five of 14 sites where the species was found were correctly classified. A discriminant analysis was also performed on the Oklahoma data using the same variables that were used in the Kansas analysis. Only one site of the 50 was misclassified.

A significant correlation between predicted and observed standing crops was not found in the Oklahoma data when the regression model developed from Kansas data was applied. However, assigning suitability indices from the curves developed with the Kansas data and performing a stepwise regression analysis resulted in a significant model. The following variables, when added to the model in the order given, produced the r^2 value and significance level given in parentheses: turbidity (0.29; 0.0465); mean depth (0.49; 0.0235); minimum width (0.53; 0.0456); mean width (0.69; 0.0198); pH (0.84; 0.0054); percent riffles (0.87; 0.0076); and water temperature (0.87; 0.0236).

Slenderhead darter. When the discriminant model developed from the Kansas data was used, a total of 37 sites where slenderhead darters were not found were properly classified. Two sites were misclassified from absence into the presence group. However, 81.9% of the sites where slenderhead darters occurred were misclassified into the absence group. When a discriminant analysis was performed on the Oklahoma data using the same physical and chemical variables that were used in the Kansas analysis, only one of the 50 sites was misclassified. This site (number 36; Big Creek, Nowata County) is within the range of the species in Oklahoma but no slenderhead darters were captured at this location.

A significant correlation was not obtained between predicted and observed standing crops of slenderhead darters when the regression model based on the Kansas data was applied. However, when suitability indices were assigned for each variable using the curves developed from the Kansas data, stepwise regression analysis resulted in a significant model. The model was based on 11 sites where the species occurred. Three variables produced a r^2 of 0.79 with a significance level of 0.0197. Variables included in the model were maximum width, mean depth, and phosphates. The addition of total alkalinity increased the r^2 to 0.86, but the significance of the model changed to 0.0249. The further addition of water temperature to the model increased the r^2 to 0.996 with a significance level of 0.0001.

Orangethroat darter. The discriminant model developed from the Kansas data incorrectly placed 25 of 38 sites into the presence group. Of the 12 remaining sites, seven were properly placed in the presence group.

When a discriminant analysis was performed on the Oklahoma data using the same physical and chemical variables that were used in the Kansas analysis, all but one site was correctly classified. This site (number 34, Sycamore Creek in Osage County) was misclassified into the presence group.

No significant correlations were found between predicted and observed standing crops using regression equations and SI graphs developed from Kansas data. However, when a new stepwise regression analysis was performed, using the same SI's derived from the original Kansas data base SI graphs, significant regression models were obtained. Three variables explained 75% of the variation in standing crop. The significance level of the regression model was 0.0090. Variables, in order of importance in explaining variation, were percent runs, gradient, and runoff. The addition of mean depth increased the r^2 to 0.84; the addition of conductivity increased the r^2 to 0.88. In both cases, the significance level was less than 0.01. Additional variables increased the r^2 value without a reduction in model significance.

Central stoneroller. Poor results were obtained using the discriminant model derived from the Kansas data. Thirty-four sites were misclassified into the presence group. Three sites were misclassified into the absence group. Ten sites where the central stoneroller did not occur were classified correctly while three sites where the species did occur were classified correctly.

The discriminant model developed from the Oklahoma data for the same physical and chemical variables used in the Kansas analysis misclassified five sites from the absence into the presence group. All six sites where the species actually occurred were properly classified.

No significant correlations were obtained between predicted and observed standing crops of central stonerollers using the regression model developed from the Kansas data. However, assigning suitability values for stream characteristics using the SI graphs developed from the Kansas data and performing a stepwise regression analysis resulted in a regression equation with an r^2 of 0.60 with a significance level of 0.06. The most important variable in explaining standing crop was mean depth. Maximum width and water temperature increased the r^2 to 0.99 with a significance level of 0.007.

Channel catfish. The discriminant model based on the Kansas data misclassified nine of 27 sites where the species was not found. Eighteen of 23 sites where the species was found were also misclassified.

The discriminant model based on the Oklahoma data misclassified seven of 27 sites where the species was not found. Four of 19 sites where the species did occur were also misclassified.

The regression equation developed from the Kansas survey sites, based on samples taken with a mark and recapture technique with a total kill for recapture, showed a significant correlation between predicted and observed biomass values for the Oklahoma sites. The Pearson correlation coefficient was 0.52 with a significance level of 0.0107. The N value was 23.

Assigning suitability indices for each physical and chemical stream attribute for each Oklahoma site and performing a stepwise regression analysis also produced a significant biomass model. The r^2 obtained with 10 variables was 0.74 with a significance level of 0.0386. The variable, percent riffle, produced an r^2 of 0.48 with a level of significance of 0.0003. Other variables, in order of importance, were conductivity, turbidity, gradient, pH, total dissolved solids, dissolved oxygen, sulfates, percent pools, and runoff.

Largemouth bass. The discriminant model based on the Kansas data correctly classified 13 of 19 sites where the species was not found. Twenty of 31 sites where the species occurred were also correctly classified.

The discriminant model based on the Oklahoma data misclassified only two of 19 sites where the species was not found. Six of 31 sites were misclassified into the absence group. Approximately 84% of the sites were correctly classified.

Two significant Spearman correlation coefficients occurred between predicted and observed standing crops of largemouth bass using the regression equation developed from the Kansas data. A correlation of 0.4237, significant at the 0.0175 level, occurred for predictions generated by the equation based on mark and recapture utilizing a final kill technique. The regression equation developed from mark and recapture data utilizing seining followed by shocking also predicted standing crops that were significantly correlated to observed standing crops in Oklahoma streams. The correlation coefficient for this relationship was 0.4828 with a significance level of 0.0059. The N value in both cases was 31.

Utilizing suitability curves developed from the Kansas data to assign suitability index values to Oklahoma sites and performing a new stepwise regression analysis produced an r^2 of 0.60 with a significance level of 0.005. Variables entered into the model were mean depth, total alkalinity, water temperature, dissolved oxygen, total dissolved solids, turbidity, percent runs, velocity, and gradient.

White crappie. The discriminant model based on the Kansas data misclassified 26 of 34 sample sites where the species was not found. Seven of nine sites where the species was found were also misclassified.

The discriminant model based on the Oklahoma data resulted in 17 misclassifications. Sixteen sites were incorrectly placed in the presence group. One of 16 sites where the species did occur was placed in the absence group.

A significant Pearson correlation coefficient (0.5191, significance level of 0.0393) occurred between predicted and observed standing crops of white crappie where the predicted value was computed by a regression equation derived from total kill stations in Kansas ($N = 16$).

Four variables produced an r^2 of 0.31 when a stepwise regression analysis was performed to explain standing crop of white crappie based on suitability indices at Oklahoma sites. The model, however, was not significant below the 0.05 level. Mean width alone produced an r^2 of 0.27 and was significant at the 0.0393 level. Addition of other variables also produced nonsignificant ($p > 0.05$) models.

Green sunfish. The discriminant model based on the Kansas data misclassified two of three sites where green sunfish were not found. Seven of 47 sites where green sunfish were found were incorrectly classified as belonging to the absence group.

The discriminant model based on the Oklahoma data correctly classified all three of the sites where green sunfish were not found. However, eight of 47 sites where the species did occur were misclassified.

When regression equations developed for this species from the Kansas stream survey data were used to predict standing crop, no significant Pearson or Spearman correlation coefficients were obtained. No significant standing crop models could be developed from a stepwise regression analysis of the Oklahoma data set.

Discussion

Discriminant analysis results. The ability to use discriminant analysis to confidently predict the probability of presence (or absence) of a species has several potential applications. One possible use is to predict effects on fish when alterations in physical and chemical habitats have occurred or are anticipated. Another potential use is in the determination of whether or not a particular stream can support the introduction of a species. For example, the decision between managing for put-and-take fisheries or self-sustaining populations can be aided with such models.

The discriminant model for predicting presence or absence of spotted bass developed from the Kansas data set showed high reliability when applied to the original data set; 19 of 21 misclassifications were readily explainable. However, when the same model was used to predict presence or absence in an Oklahoma data set, many misclassifications resulted. Consequently, it seems

that these models are reliable only over a limited geographical area. However, even though the model based on the Kansas data showed low reliability when applied to Oklahoma streams, a discriminant analysis on the Oklahoma data set based on the same variables that were important in Kansas streams resulted in a model that classified all but one of the stream sites correctly. Identical results occurred for slenderhead darters, and similar results were obtained for orangethroat darters.

These results lead to several conclusions: (1) building reliable models may be a possibility only over small, relatively homogeneous geographical areas; (2) as application of the model is expanded to larger geographical areas, the possibility of encountering additional limiting variables is increased. Consequently, tolerance limits for a species for a given variable may not be exceeded at one location but may be at another. Such a situation would result in the need for more or different variables to develop a model in each area. The addition of more variables, in turn, would necessitate that the synergistic effects of variables be addressed. Therefore, the limits of the geographical area to be included in the development of a discriminant analysis model should be a function of the homogeneity of the area considered. It remains to be tested whether or not the Kansas data set and the Oklahoma data set can accurately predict presence or absence of the selected species at new stream sites in the geographical areas where the original data were collected.

Accuracy of discriminant models in predicting presence of a species in the Kansas data set was low for central stoneroller, channel catfish, largemouth bass, green sunfish, and white crappie. When the models derived from the Kansas data were applied to an Oklahoma data set, an even greater percentage of misclassifications occurred. These results might indicate that the occurrence of some species is governed by the abiotic environment and others by the biotic environment. The analyses performed in this study disregarded the possibility of biological controls.

In general, discriminant models developed solely from the Oklahoma data set produced better predictions when applied to Oklahoma data than did similar models developed from the Kansas data set when applied to the Kansas data. This improved reliability may have resulted from greater consistency in how the Oklahoma data were collected. Data from Kansas were based on a variety of sampling techniques and field crews, whereas the Oklahoma data was collected with only one technique by a single field crew.

Suitability index curves. Originally, suitability index curves for five of the species were based on information in the literature relating physical and chemical variables to habitat quality (Gebhart et al. 1980). Most curves developed from the Kansas data set closely approximated these original curves for spotted bass (water temperature); green sunfish (water temperature); largemouth bass (dissolved oxygen, water temperature, turbidity, and velocity); and white crappie (water temperature). Draft curves developed by other authors from information contained in the literature for channel catfish also closely matched curves developed from the Kansas data (water temperature, turbidity, and dissolved oxygen).

The repeatability of these curves intuitively suggests that they may accurately describe habitat suitability along a single axis. Theoretically, if a single habitat dimension is modified, the effect on the fish population can be predicted from the suitability curve. However, such a relationship may seldom occur because changes in one parameter often results in changes in other parameters (Orth 1980).

Biomass models. Low biomass predictability was obtained when regression equations to aggregate SI's derived from graphs developed from the Kansas data were used to predict biomass in Oklahoma. However, when the same suitability indices were assigned to Oklahoma stream parameters at each site, a new regression analysis produced highly significant equations (also high r^2 values) for predicting standing crop for spotted bass, slenderhead darters, orange-throat darters, and central stonerollers. Results were also significant for largemouth bass and white crappie but the r^2 values were lower, 0.60 and 0.31, respectively. Data on green sunfish produced no significant relationships.

The variables that produced the significant regression models for species biomass differed between the Kansas and Oklahoma data sets. These differences suggest that limiting factors may vary from one stream to another and even within locations on the same stream. However, the statistical analyses suggest that, in plains streams, much of the biomass is controlled by abiotic factors and that the SI curves developed actually reflect habitat suitability. Application of the curves to delineate limiting conditions to fish populations in individual streams may provide a useful tool to aquatic resource managers.

The Oklahoma data confirms the previous conclusion that it is easier to model habitat suitability for those species with restricted habitat requirements. Spotted bass and slenderhead darters are two examples of species with restricted habitat requirements for which the models showed relatively high reliability. Some of the other species investigated (channel catfish, white crappie, largemouth bass, and green sunfish) have broader physical and chemical tolerances, and the models had reduced reliability. We believe that the difference in the predictive power of the models is related to the number of aggregate factors that can limit a species. This hypothesis needs further testing and a comparative way to determine overall species niche breadth along multiple dimensions.

The data demonstrate a standard approach to developing SI curves but no way to develop actual numerical models for aggregating SI's into an HSI. We believe that, even without aggregation models, SI curves based on quantitative data may be a strong aid in determining impacts. However, because limiting factors can vary from one location to the next (as noted for species with broad niches), the best approach may be one of determining SI's for as many variables as possible and intuitively predicting the impact due to changes in all of the variables.

Another approach to predicting postproject impacts is to collect stream characteristic and fish population data at a number of sites on the potentially impacted stream. This restriction of area should reduce the number of limiting factors affecting the populations and allow high predictability of biomass. Factors most limiting, or at least factors closely associated with those that

are limiting, would also be identified. By using values for variables that are expected after project completion, the effect on the fish population can be assessed. This approach requires intensive data collection for each project; however, the use of previously developed suitability index curves to assign indices greatly reduces the number of sample sites needed to develop predictive models based on empirical formulas. The identification of these limiting factors may make species management and habitat enhancement possible. In addition, identification of limiting factors may aid in planning development projects to enhance the potential for supporting desirable fish populations.

SUMMARY AND CONCLUSIONS

Variables useful in predicting presence and absence of individual species differed between Kansas streams and Oklahoma streams. Consequently, it appears that these predictive models are applicable over only relatively homogeneous geographic areas. However, the SI curves developed from the literature were often very similar to empirically derived curves and generally defined optimal ranges correctly. Based on these data, we conclude that SI curves may be useful in identifying limiting factors or those factors correlated with limiting factors.

Variables useful for predicting biomass or standing crop were also different between Kansas and Oklahoma streams. However, the data from Kansas and Oklahoma indicated that, by sampling a number of stream segments within a project area and assigning SI's for each variable from a standard set of curves for a given species, a stepwise regression analysis of suitability index and standing crop values can be used to develop models that explain much of the variation in a species standing crop. Based on these data, we suggest that care be exercised in using models developed for one area to predict changes in populations in other areas because different variables may be limiting to an individual species in different streams.

In evaluating project impacts, a resource manager must determine which species are the most important. Changes in physical or chemical attributes of streams may cause a decrease in one population but an increase in another. Addressing changes in habitat quality is meaningless unless unacceptable levels of changes to the environment are defined.

It is quite possible that the curves or models developed herein can be misused if the limitations are not understood. Only a relatively few variables were used to assess presence or absence and biomass. Failure of these models will sometimes occur because factors limiting at one site or region may be different from the limiting factors at another location. In addition, a habitat change can result in a factor that was not included in model development becoming a limiting factor. This sequence of events would lead to model failure.

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APPENDIX A

DRAFT SUITABILITY INDEX CURVES USED IN TESTS

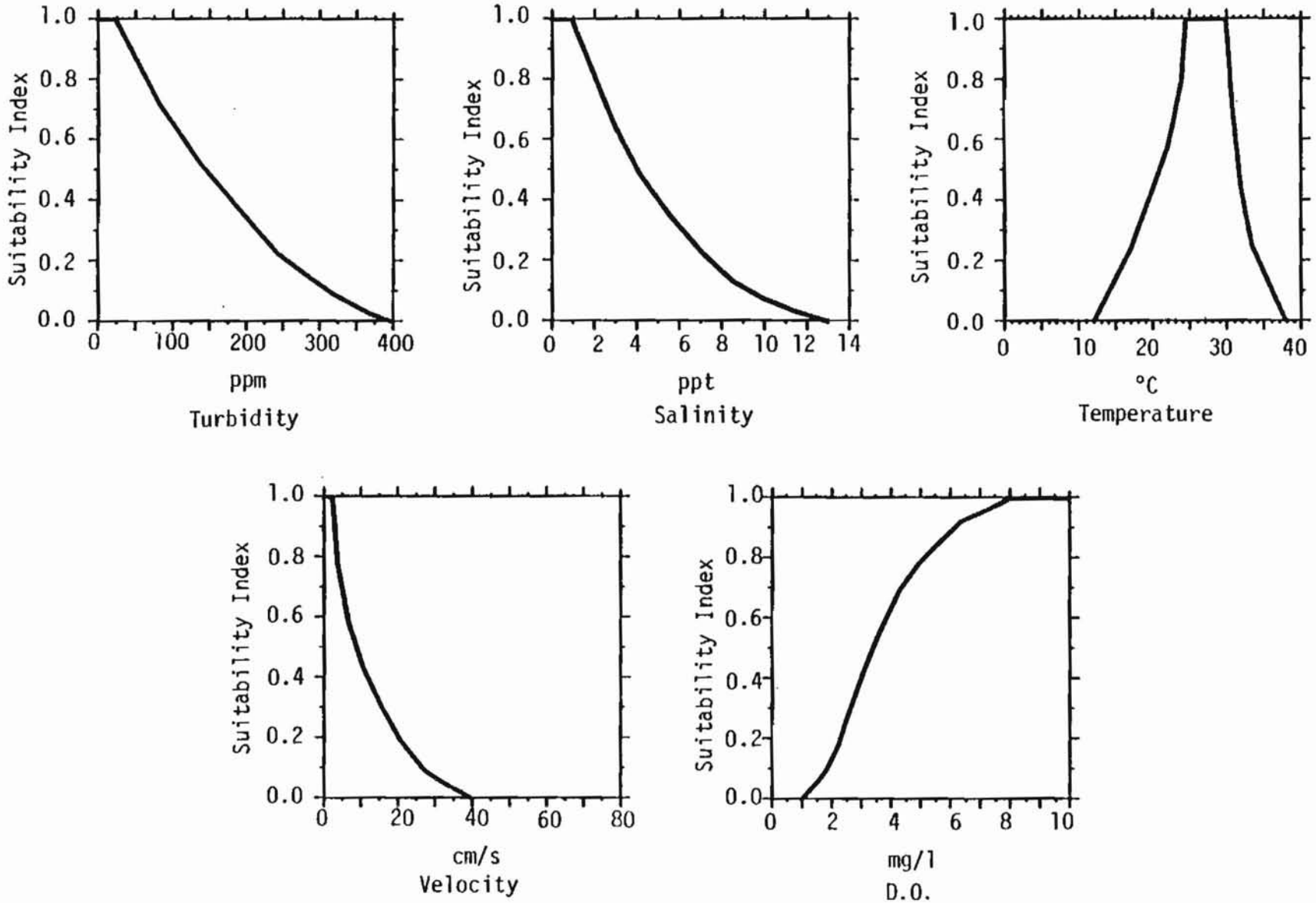
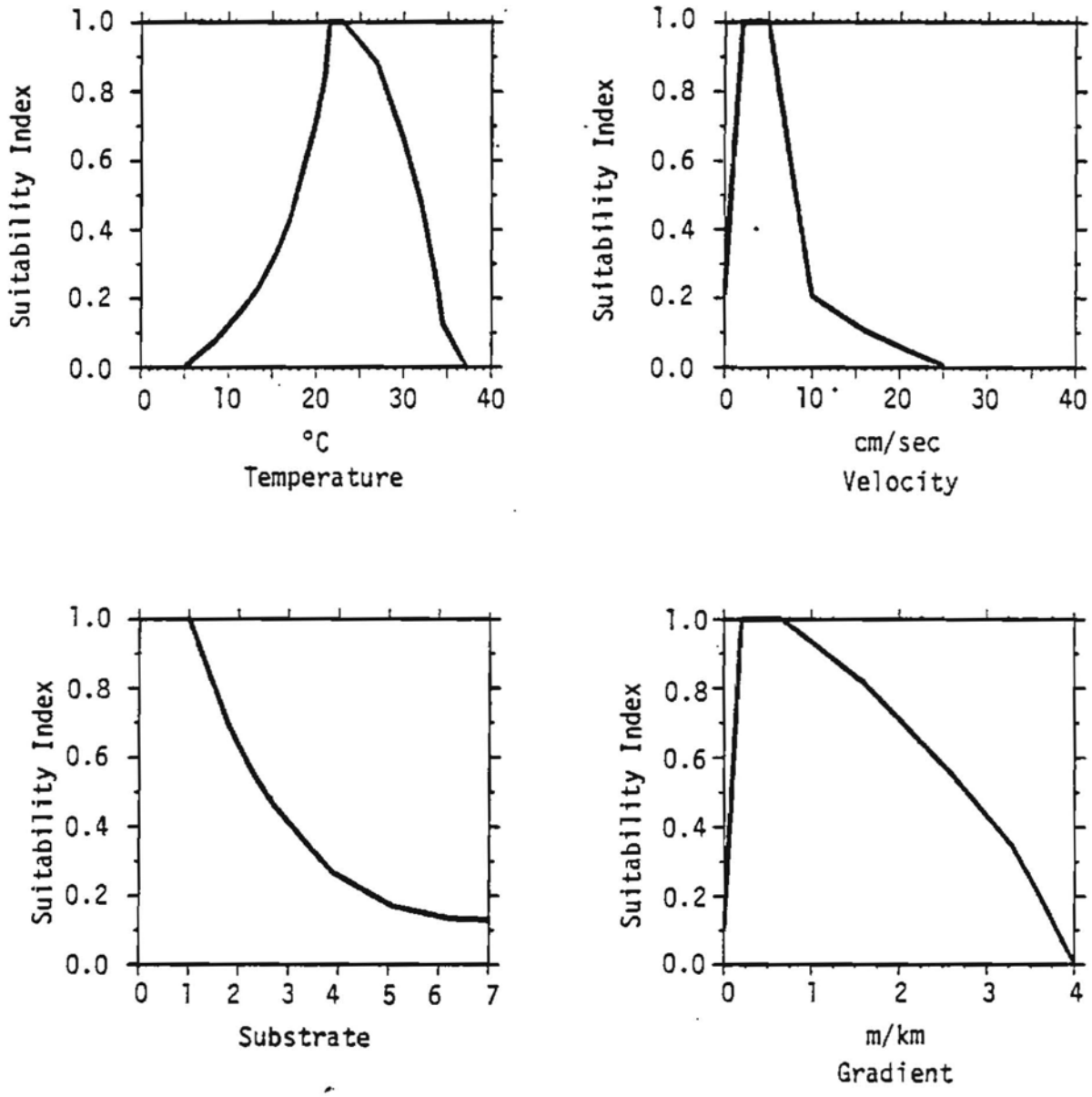
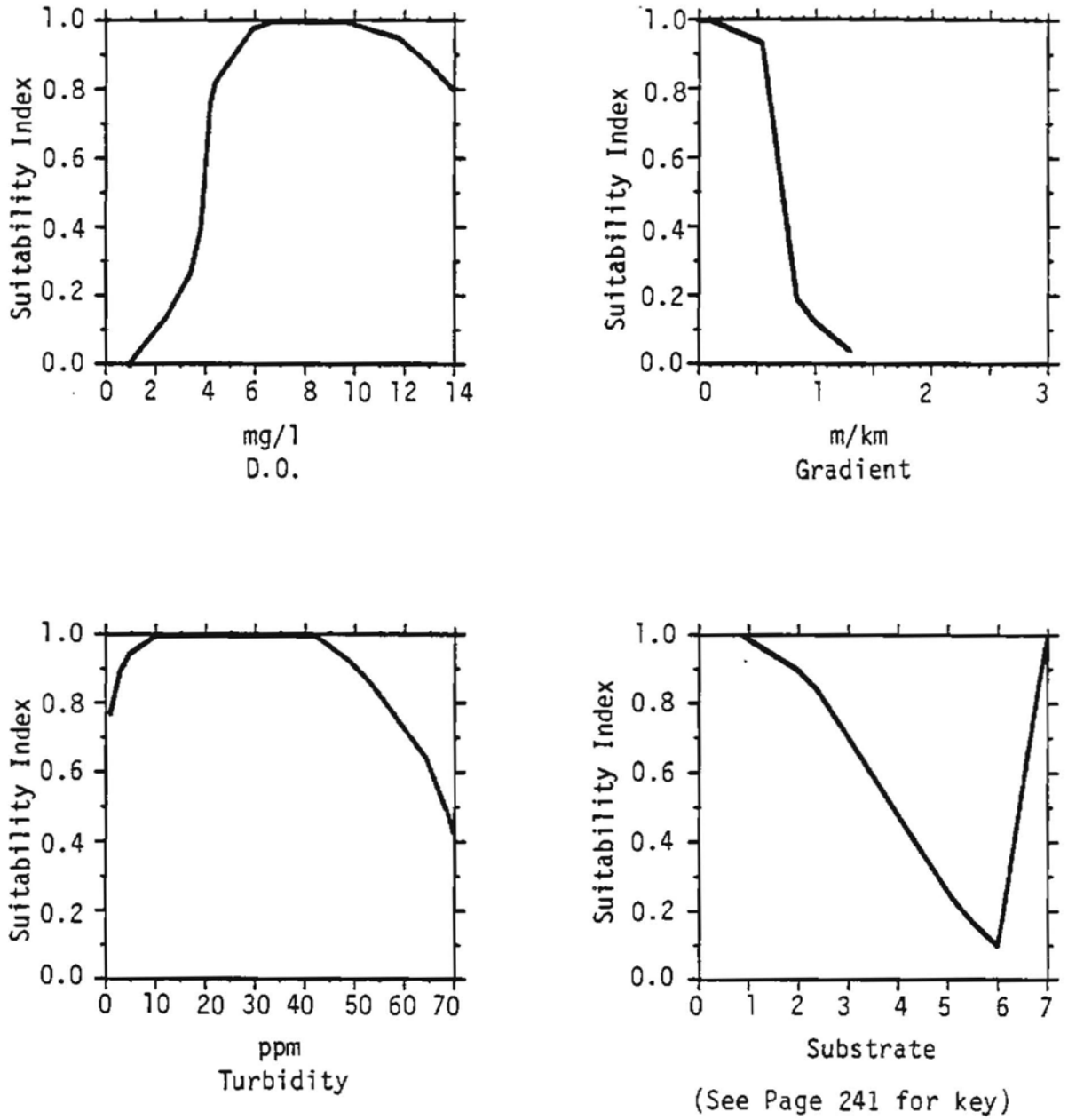


Figure A-1. Draft Suitability Index curves, adult largemouth bass.



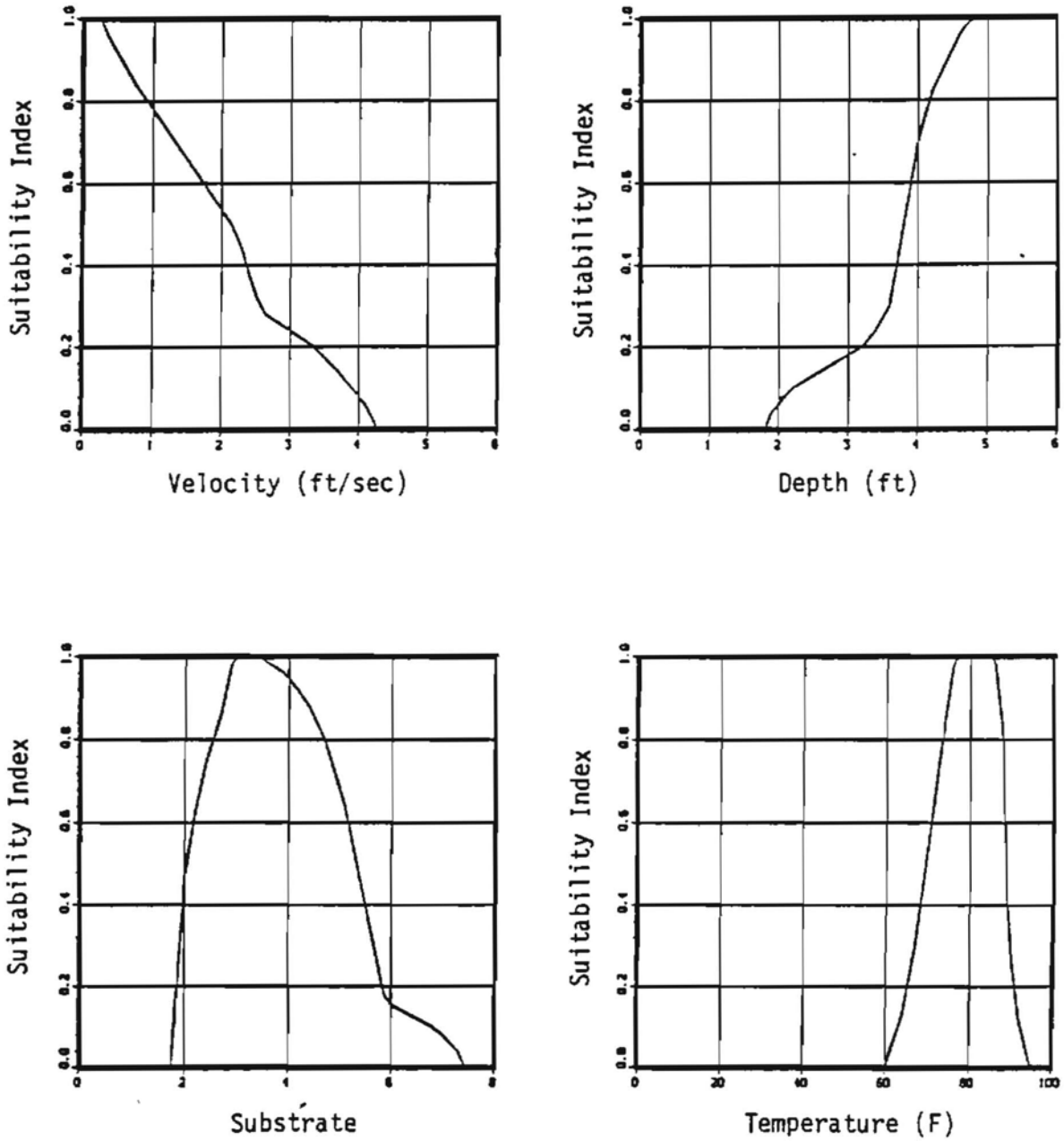
1 = Silt and sand (≤ 0.2 cm)
2 = Pebble (> 0.2 to 1.5 cm)
3 = Gravel (> 1.5 to 5.0 cm)
4 = Cobble (> 5.0 to 20.0 cm)
5 = Boulder (> 20.0 cm)
6 = Bedrock
7 = Rooted vegetation

Figure A-2. Draft Suitability Index curves, adult spotted bass.



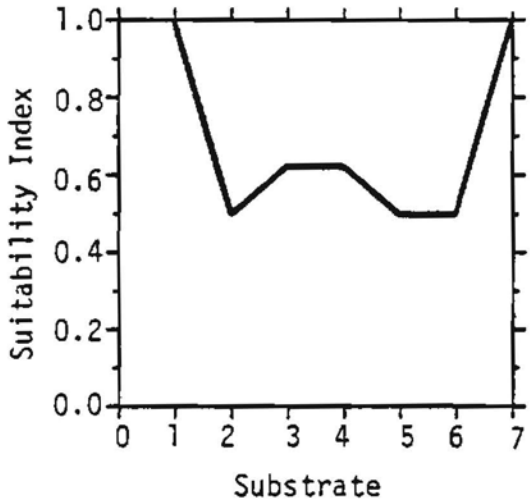
(See Page 241 for key)

Figure A-3. Draft Suitability Index curves, adult white crappie.

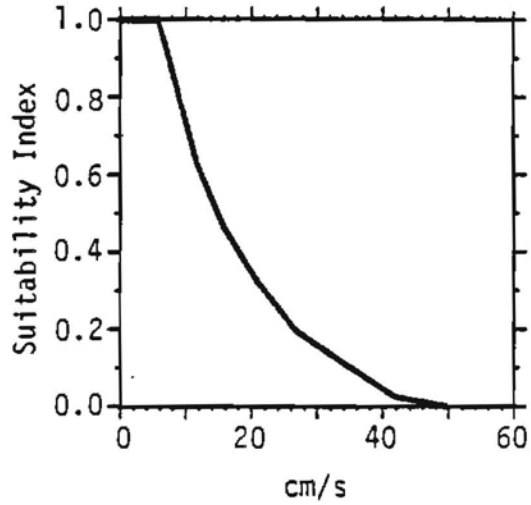


(See Page 241 for key)

Figure A-4. Draft Suitability Index curves, adult channel catfish.



(See Page 241 for key)



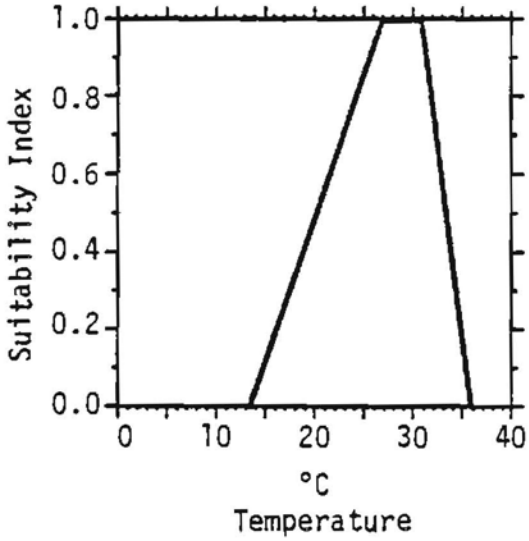


Figure A-5. Draft Suitability Index curves, adult green sunfish.

APPENDIX B

REGRESSION MODELS EXPLAINING VARIATION IN STANDING CROP (kg/ha) BY SPECIES

Table B-1. Regression models explaining standing crop (kg/ha) by species. All models were significant at the 0.05 level. Refer to text for a description of sample methods and for model discussions.

Species	Sample method[a]	Regression equation explaining standing crop based on suitability index (SI) values
Spotted bass	6	4.30 + (-21.24 x water temperature SI) + (20.95 x mean width SI) + (13.60 x pH SI) + (-25.65 x minimum width SI) + (9.78 x nitrate SI) + (6.95 x riffle SI)
	D	-5.81 + (-22.6308 x turbidity SI) + (34.47 x mean depth SI) + (-25.82 x minimum width SI) + (31.10 x mean width SI) + (19.40 x pH SI) + (10.38 x riffle SI)
Slenderhead darter	6	-1.44 + (6.88 x calcium hardness SI) + (0.83 x maximum width SI) + (1.34 x riffle SI)
	D	-1.12 + (2.25 x maximum width SI) + (1.67 x mean depth SI) + (-50.84 x phosphate SI) + (0.84 x total alkalinity SI) + (-5.42 x water temperature SI)
Orangethroat darter	8	-0.06 + (1.83 x mean width SI) + (0.86 x maximum width SI) + (3.20 x pool SI) + (3.86 x run SI) + (-0.38 x total alkalinity SI)
	6	-11.18 + (-6.49 x dissolved oxygen SI) + (4.46 x maximum width SI) + (8.22 x magnesium hardness SI) + (28.19 x nitrates SI) + (33.02 x phosphate SI)
	5	-14.72 + (-25.06 x conductivity SI) + (13.16 x growing season SI) + (16.41 x nitrate SI) + (4.75 x turbidity SI)

Table B-1. (continued)

Species	Sample method[a]	Regression equation explaining standing crop based on suitability index (SI) values
Orangethroat darter (cont.)	4	0.8 + (0.15 x mean depth SI)
	3	-18.36 + (3.09 x conductivity SI) + (-12.45 x growing season SI) + (-2.67 x mean width SI) + (4.04 x magnesium hardness SI) + (165.31 x phosphate SI) + (11.50 x pool SI) + (-9.14 x riffle SI) + (4.66 x turbidity SI)
	2	-13.40 + (-2.75 x calcium hardness SI) + (-7.04 x pool SI) + (10.37 x sulfate SI) + (-4.47 x total alkalinity SI) + (20.64 x water temperature SI)
	D	-0.15 + (1.63 x run SI) + (-0.40 x gradient SI) + (-2.03 x runoff SI) + (-0.47 x pool SI) + (0.26 x conductivity SI)
Central stoneroller	7	-73.91 + (158.27 x mean width SI) + (72.01 x magnesium hardness SI) + (7.44 x pH SI) + (18.59 x run SI) + (-24.33 x sulfate SI)
	6	-32.79 + (26.90 x growing season SI) + (-26.62 x mean depth SI) + (39.23 x mean width SI) + (18.01 x pH SI) + (15.13 x phosphate SI) + (19.08 x total alkalinity SI) + (20.47 x total dissolved solids SI) + (19.33 x water temperature SI)
	5	19.71 + (20.23 x dissolved oxygen SI) + (34.81 x maximum width SI) + (-15.63 x minimum width SI) + (-54.64 x magnesium hardness SI) + (59.74 x nitrate SI) + (-28.60 x pool SI)
	4	4.20 + (1.59 x pH SI) + (-13.88 x riffle SI) + (5.26 x sulfate SI)
	3	-25.07 + (-17.77 x growing season SI) + (63.54 x run SI) + (48.52 x water temperature SI)

Table B-1. (continued)

Species	Sample method[a]	Regression equation explaining standing crop based on suitability index (SI) values
Central stoneroller (cont.)	2	-35.29 + (-55.94 x maximum width SI) + (180.73 x mean width SI) + (41.71 x phosphate SI)
	D	-1.45 + (2.66 x mean depth SI) + (-9.19 x maximum width SI) + (4.00 x water temperature SI)
Channel catfish	6	-275.13 + (126.6 x maximum width SI) + (178.76 x runoff SI) + (179.90 x run SI) + (223.58 x water temperature SI)
	5	-167.90 + (-177.45 x conductivity SI) + (340.90 x minimum width SI) + 360.61 x pool SI)
	8	-54.51 + (325.51 x dissolved oxygen SI) + -50.77 x pH SI) + (-227.72 x growing season SI)
	4	47.46 + (-2.06 x pH SI) + (-7.65 x pool SI) + (-42.07 x gradient SI)
	3	1.40 + (51.07 x conductivity SI) + (-18.65 x dissolved oxygen SI)
	D	-4220.43 + (6268.78 x riffle SI) + (284.96 x conductivity SI) + (-178.3870 x turbidity SI) + (-455.25 x gradient SI) + (188.11 x pH SI) + (-158.52 x total dissolved solids) + (95.13 x dissolved oxygen SI) + (-186.27 x sulfate SI) + (94.41 x pool SI) + (108.94 x runoff SI)
Largemouth bass	6	-26.46 + (39.85 x mean width SI) + (46.62 x mean depth SI)
	4	-11.62 + (36.31 x pH SI)
	7	8.70 + (15.69 x run SI) + (-10.74 x water temperature SI)

Table B-1. (continued)

Species	Sample method[a]	Regression equation explaining standing crop based on suitability index (SI) values
Largemouth bass (cont.)	2	-27.29 + (164.44 x conductivity SI) + (25.83 x phosphate SI) + (-148.05 x turbidity SI)
	3	0.94 + (22.10 x growing season SI) + (-20.90 x nitrate SI) + (24.43 x pH SI) + (6.0 x turbidity SI)
	D	72.12 + (73.97 x mean depth SI) + (22.57 x total alkalinity SI) +(-37.83 x water temperature SI) + (-34.58 x dissolved oxygen SI) + (-25.86 total dissolved solids SI) + (-15.15 x turbidity SI) + (20.80 x run SI) + (-33.80 x velocity SI) + (-16.97 x gradient SI)
White crappie	6	-12.34 + (9.36 x gradient SI) + (17.46 x growing season SI) + (26.40 x magnesium hardness SI)
	5	-5.60 + (34.97 x maximum width SI)
	7	250.91 + (15.34 x nitrate SI) + (32.69 x phosphate SI) + (-265.02 x pH SI) + (7.76 x turbidity SI)
	4	5.51 + (-20.62 x growing season SI) + (9.65 x turbidity SI) + (8.49 x run SI)
	2	-11.77 + (31.21 x mean width SI) + (5.98 x turbidity SI)
	D	0.23 + (4.27 x mean width SI)
Green sunfish	5	66.86 + (94.55 x maximum width SI) + (82.78 x pH SI)
	4	189.77 + (13.97 x pH SI) + (-196.63 x phosphate SI)

Table B-1. (concluded)

Species	Sample method[a]	Regression equation explaining standing crop based on suitability index (SI) values
Green sunfish (cont.)	2	-9.35 + (67.87 x maximum width SI)
	D	none

[a]All numbered sample methods refer to Kansas data set analysis; D represents the depletion estimate method and all models so described are based on the Oklahoma data set.

1 = shocking
2 = seining
3 = mark and recapture using seining
4 = seining and shocking
5 = kill technique using rotenone
6 = mark and recapture using rotenone as the final capture technique
7 = mark and recapture using seining as the first collection method followed by a final capture using shocking
8 = mark and recapture using only shocking

APPLICATION OF HABITAT SUITABILITY INDEX MODELS FOR WHITE CRAPPIE, BLUEGILL, AND LARGEMOUTH BASS

by

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INTRODUCTION

Background

The Habitat Evaluation Procedures (HEP) of the U.S. Fish and Wildlife Service are designed to document the quality and quantity of available habitat for selected fish and wildlife species. Information from HEP can be used for two types of comparisons: (1) the relative value of wildlife habitats at one point in time; and (2) the relative value of these habitats at future points in time. By combining the two types of comparisons, the impact of a proposed water resource project can be estimated (U.S. Fish and Wildlife Service 1980). HEP is based on the assumption that habitat for a selected fish and wildlife species can be described by a Habitat Suitability Index (HSI). The method used to assign an HSI to habitat is left to the discretion of the HEP user.

Three general types of HSI models had been published by late 1982: (1) regression equations that predicted a measurable response, such as standing crop, from selected environmental variables; (2) descriptive or word models that assigned a numerical value based on the presence or absence of a specified level of pertinent environmental variables; and (3) mechanistic species models that aggregated Suitability Indices (SI's) based on concentrations (or levels, presence, or similar measures) of selected environmental variables (e.g., cover or substrate) (Terrell et al. 1982). With HEP, the calculated HSI, which ranges from 0.0 (no value) to 1.0 (optimal value), is multiplied by the quantity (area) of available habitat to obtain habitat units. Habitat units are used to calculate habitat gains and losses through time. The usefulness of the habitat unit data displayed with HEP is directly dependent on the ability of the user to assign well-defined, meaningful HSI's to the habitats selected for evaluation. Reproducibility is greatly increased when documented criteria (i.e., HSI models) for obtaining HSI's are used (Farmer et al. 1982).

Purpose

This paper describes methods used to test and modify mechanistic species models for the bluegill (*Lepomis macrochirus*), largemouth bass (*Micropterus salmoides*), and white crappie (*Pomoxis annularis*), utilizing data collected at 25 borrow pits along the Mississippi River in Mississippi, Missouri, Arkansas, and Louisiana. The objective was not to simply verify the models, but to determine the steps required to apply the models in a specific type of lentic habitat in the Southcentral United States. The approach was that models are never perfect but do provide a vehicle for understanding biotic systems (see Green 1979). If the modified models developed in this study are used in other parts of the country, a similar modification procedure, using the original tested models, may be needed. Layher and Maughan (1984) observed that models developed with Kansas data failed to make reliable predictions for sites in Oklahoma. The modified models could require additional alteration even if the same borrow pits were evaluated at a future time.

STUDY AREA

When the mainline levee along the lower Mississippi River was constructed, fill material was taken from areas adjacent to the river. This resulted in a series of depressions or borrow pits of variable size (e.g., 0.4 to 20.0 ha). Depths of the borrow pits range from 1 to 5 m, with some pits becoming dry by midsummer. The pits on the riverside of the levee typically are inundated for several months of each year, depending on Mississippi River stages. The periodic flooding brings in nutrients, suspended sediments, fish, and other aquatic organisms, which influence the ecological characteristics of the pits. The land around the borrow pits is usually pastured, prepared for row crops, or left in bottomland woods. Borrow pits provide excellent habitat for aquatic invertebrates, wading and shore birds, migrant birds, fish, and certain mammals (Svedarsky and Crawford 1982). Additional information on these pits can be found in Landin (1982) and Sanders et al. (1982).

METHODS

During the spring and summer of 1981, the U.S. Army Corps of Engineers District, Vicksburg, MS, contracted with the Aquatic Habitat Group at the Corps of Engineers Waterways Experiment Station, Vicksburg, to collect biological, physical, and chemical data from 25 borrow pits on the river side of the mainline levee (Fig. 1). The borrow pit study was designed by personnel of the Corps of Engineers Vicksburg District and Lower Mississippi Valley Division/Mississippi River Commission environmental staff. Model variable values were estimated from specific conductance, water temperature, dissolved oxygen, and pH measured *in situ*, near the middle of the borrow pits, using a Hydrolab model 8000. A Hach turbidimeter was used to obtain turbidity values; clarity was measured using a Secchi disc. Fish were collected by applying rotenone to two separate 0.4 ha areas enclosed by block nets. All fish were identified, weighed, and measured in the field. Additional physical data on each pit (i.e., water depth, surface area, elevation, and other similar

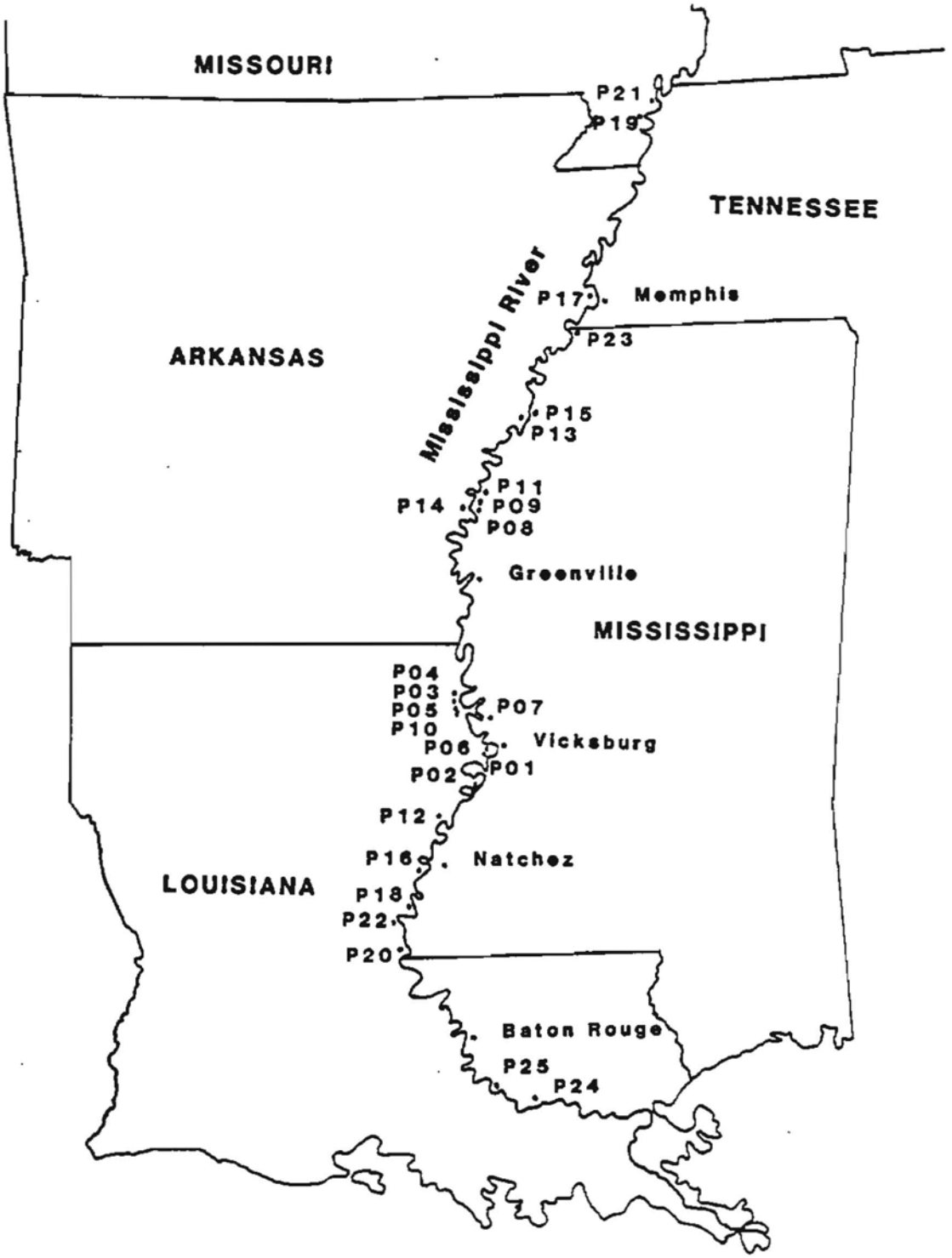

Figure 1. Locations of borrow pits along the Mississippi River in Louisiana, Mississippi, Arkansas, Tennessee, and Missouri.

measurements) were obtained from the Lower Mississippi Valley Division/ Mississippi River Commission. Information on percent coverage of vegetation and standing timber was obtained from black and white aerial photographs (1:12,000) or color prints made at the time of the field sampling.

All HSI calculations and statistical tests were done at the Waterways Experiment Station using a TI-59 programmable calculator and the Statistical Analytical System (SAS) (SAS Institute 1982) package on an IBM 4330 computer. Data analysis consisted of alternately testing hypotheses, making modifications, and testing results.

RESULTS

Using lacustrine HSI models for bluegill (Stuber et al. 1982a) and white crappie (Edwards et al. 1982), HSI's were calculated for all borrow pits. A total of 13 variables were used for the bluegill model (Table 1); calculated HSI's ranged from 0.08 to 0.34 ($\bar{X} = 0.25$), with a correlation coefficient between standing crop and the HSI of 0.09 (Fig. 2; Table 2). Eleven variables were used for the white crappie model, the "optional" salinity variable was not evaluated. Correlations with standing crop were also low for the white crappie model ($r = 0.08$; $P < 0.40$) (Fig. 3). Because of the low accuracy of the unmodified bluegill and white crappie models and their similarity to the largemouth bass model (Stuber et al. 1982b), the unmodified largemouth bass model was not evaluated.

Schamberger et al. (1982) noted that the accuracy level of the type of HSI models tested in this study was expected to be low. Inter- and intraspecific competition, fishing pressure, and, in the present study, the influence of farming and grazing practices, as well as a possible 2 to 3 month flooding period during the spring, were major confounding factors that affected fish populations. However, the HSI's were believed to be acceptable predictors of standing crop and habitat quality if the models were subjected to fairly detailed analysis and modification. A major concern was the maximum midsummer littoral zone temperature, which ranged from 28° to 34° C for the period of the study. For bluegill, these values resulted in SI's equal to 0.0.[1] Nevertheless, viable fish populations were present in most pits, which demonstrated that water temperatures along shore were not limiting, probably because of fish movement to deeper water during periods of high temperatures. Gilbert (1984) reported a similar problem with SI's for water temperatures in littoral areas of Georgia reservoirs. However, before altering or deleting variables, the similarities and differences among pits based on collected biological, chemical, and physical data were analyzed. The information from this analysis allowed meaningful and useful modifications to the models.

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[1]For purposes of calculation, SI's of 0.0 were adjusted to 0.05; see Table 1.

Table 1. Variables and range in suitability indices for bluegill in borrow pits along the Mississippi River, 1981.

Variable	Variable number	Range in SI's	Comments
Percent logs, brush, and debris	V_2	0.25-1.00	Important variable
Percent aquatic vegetation	V_3	0.10-0.75	Important variable
Percent littoral area	V_4	0.05[a]	Important variable
Average total dissolved solids	V_5	0.95-1.00	Dropped because all pits were within optimum range
Maximum monthly average turbidity	V_6	1.00	Pits had clear water
pH range during growing season	V_7	0.20-1.00	Variable not useful
Maximum dissolved oxygen during summer	V_8	0.10-0.70	Variable not useful
Maximum midsummer temperature in littoral area	V_{10}	0.05	Not applicable
Average of mean weekly water temperatures during spawning	V_{11}	0.30-1.00	Variable not useful
Maximum early summer temperature	V_{12}	0.05-1.00	Variable not useful
Maximum midsummer temperature	V_{13}	0.22-0.80	Excluded because not applicable for shallow, borrow pit water
Drawdown during spawning	V_{19}	1.00	None
Substrate composition	V_{20}	0.70	Deleted because all pits were the same (0.7)

[a]0.05 SI's were used in place of the 0.0 values indicated by the SI graphs.

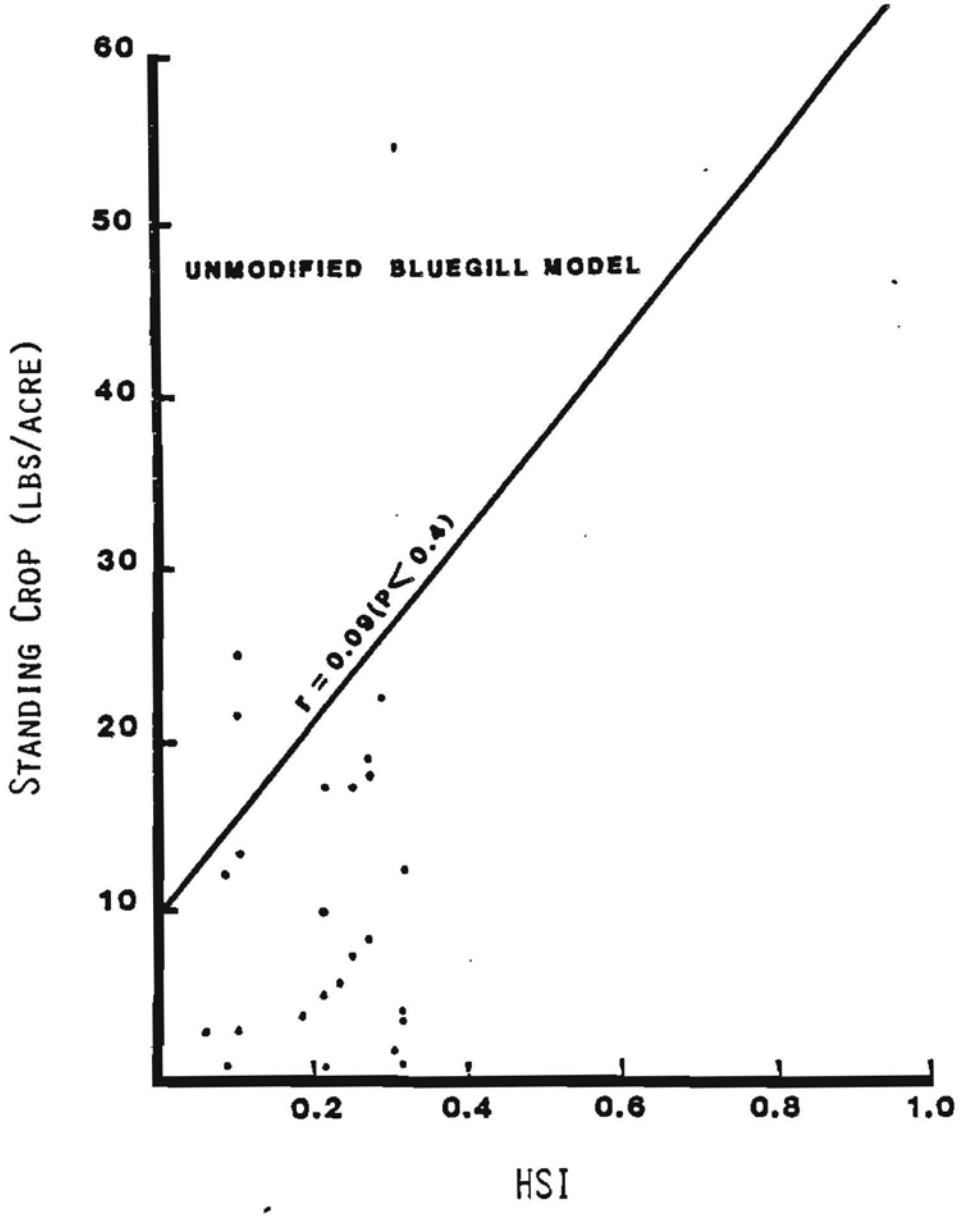

Figure 2. Bluegill standing crop as a function of the habitat suitability index (HSI) (unmodified model).

Table 2. Range, mean, standard deviation, and correlation coefficients for HSI's calculated for bluegill, white crappie, and largemouth bass.

Species	Model	HSI range[a]						Range	$\overline{X}$	S.D.	r	P <
		0.05-0.20	0.21-0.40	0.41-0.60	0.61-0.80	0.81-0.99	1.00					
Bluegill	Unmodified	8	17	-	-	-	-	0.08-0.34	0.25	0.15	0.09	0.40
	Modification I	-	7	10	4	4	-	0.31-0.95	0.56	0.19	0.46	0.025
	Modification II	7	10	4	-	4	-	0.10-0.93	0.40	0.27	0.48	0.01
	Descriptive	-	2	7	6	8	2	0.33-1.00	0.67	0.19	0.11	0.20
Crappie	Unmodified	24	-	1	-	-	-	0.05-0.52	0.08	0.09	0.08[b]	0.40[b]
	Modification I	-	7	5	6	5	2	0.25-1.00	0.60	0.26	0.25	0.20
	Modification II	7	5	5	3	1	4	0.13-1.00	0.48	0.32	0.23	0.20
	Descriptive	-	1	7	6	7	4	0.33-1.00	0.71	0.19	0.16	0.20
Largemouth bass	Modification I	4	5	4	5	7	-	0.18-0.94	0.54	0.29	0.42	0.025
	Modification II	7	5	7	3	2	1	0.12-1.00	0.44	0.28	0.54	0.005
	Descriptive	-	8	7	8	-	2	0.40-1.00	0.63	0.20	0.16	0.20

[a]All 0.0 SI's set equal to 0.05 for HSI calculation.

[b]Pit 10 omitted.

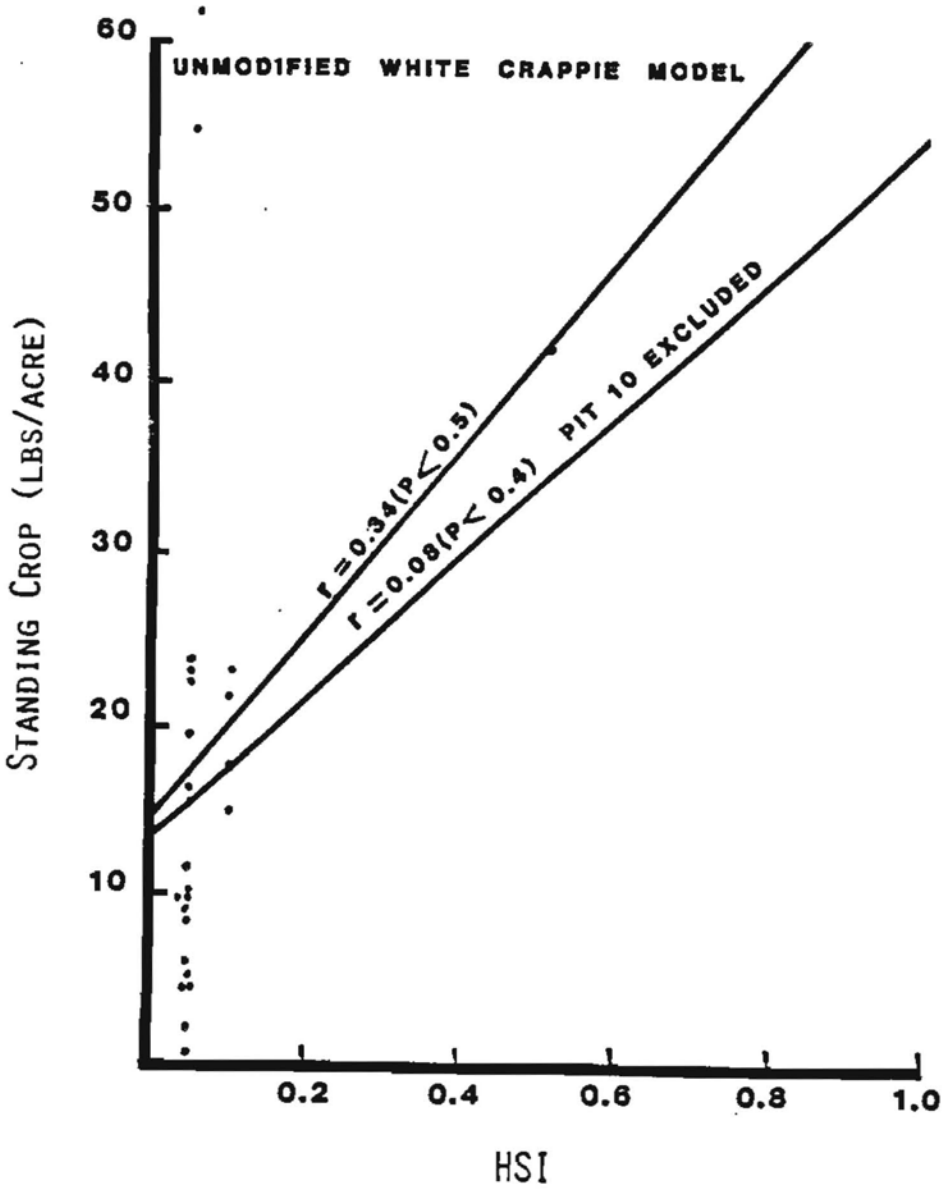

Figure 3. White crappie standing crop as a function of the Habitat Suitability Index (HSI) (unmodified model).

A principal components analysis was performed to identify underlying patterns among sources of covariation, individual species, standing crops, and the relative contribution of each pit to a factor (Table 3). This analysis allowed the grouping of fish according to habitat variables. Bottom feeding fish (Ictaluridae and Catostomidae) and rough fish (Lepisosteidae, Cyprinidae, and Sciaenidae) exhibited high loading for Factor I, while the sportfish (white crappie, largemouth bass, bluegill, and Percichthyidae) loaded high on Factor II. Although not considered a sportfish, the Clupeidae also loaded high on Factor II. Factor II was hypothesized to be an indication of conditions suitable for the maintenance of sportfish populations. Attention was directed to variables that influenced the sport fishery in pits with high standing crops rather than variables in pits that provided suboptimal habitat.

Using criteria outlined in Terrell et al. (1982), each variable in the bluegill model was examined for possible exclusion. Variables for total dissolved solids, substrate conditions, dissolved oxygen, and water temperature were deleted from the HSI model (see Table 1 for reasons for exclusion). A new variable, the percentage of water greater than 1.5 m deep, was added to the model. Percentages and corresponding SI's[2] were assigned based on the analysis of depth profiles and the observation that most pits less than 1.0 m deep dried out by fall.

With only seven of the original 13 variables remaining, plus the addition of the depth variable, a second set of HSI's (model modification I) was calculated (Table 2). These data yielded an r value of 0.46 ($P < 0.025$) (Fig. 4), which was significantly higher than the r value for the unmodified bluegill model ($r = 0.09$, $P < 0.40$). Bluegill standing crop and SI's for model modification I were compared using a principal component factor analysis. The variables with the highest loadings (percent vegetation, percent snags, percent littoral area, and percent deep water) all related to a measure of cover (Table 4). Model modification II was developed using only these four variables (Table 5), and a third set of HSI's was calculated (Table 2). The resulting correlation coefficient was 0.48 ($P < 0.01$) (Fig. 5), which was a slight increase over the correlation coefficient calculated after the first modification of the bluegill model.

Following the same modification techniques used with the bluegill model, the white crappie and largemouth bass models were modified. The correlations for white crappie were 0.25 for modification I and 0.23 for modification II (Figs. 6 and 7). Correlation coefficients for largemouth bass were 0.42 for modification I and 0.54 for modification II (Figs. 8 and 9).

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[2]When the percentage of water deeper than 1.5 m ranged from 0 to 5%, the SI = 0.1; from 6 to 20%, the SI = 0.7; 21 to 60%, the SI = 1.0; 61 to 90%, the SI = 0.5; and from 91 to 100%, the SI = 0.1.

Table 3. Factor loadings for standing crops. Loadings greater than ± 0.50 are in parentheses.

Variable	Factor I	Factor II
White crappie	0.42	0.43
Largemouth bass	0.37	(0.62)
Bluegill	0.12	(0.66)
Catfishes (Ictaluridae)	(0.82)	-0.18
Gars (Lepisosteidae)	(0.80)	-0.27
Herrings (Clupeidae)	0.02	(0.71)
Suckers (Catostomidae)	(0.88)	-0.28
Minnows (Cyprinidae)	(0.93)	-0.05
Sea basses (Percichthyidae)	-0.06	(0.65)
Drums (Sciaenidae)	(0.51)	0.45
Total	(0.95)	-0.05
Factor	Eigenvalue	Relative %
I	4.44	40.4
II	2.32	21.1

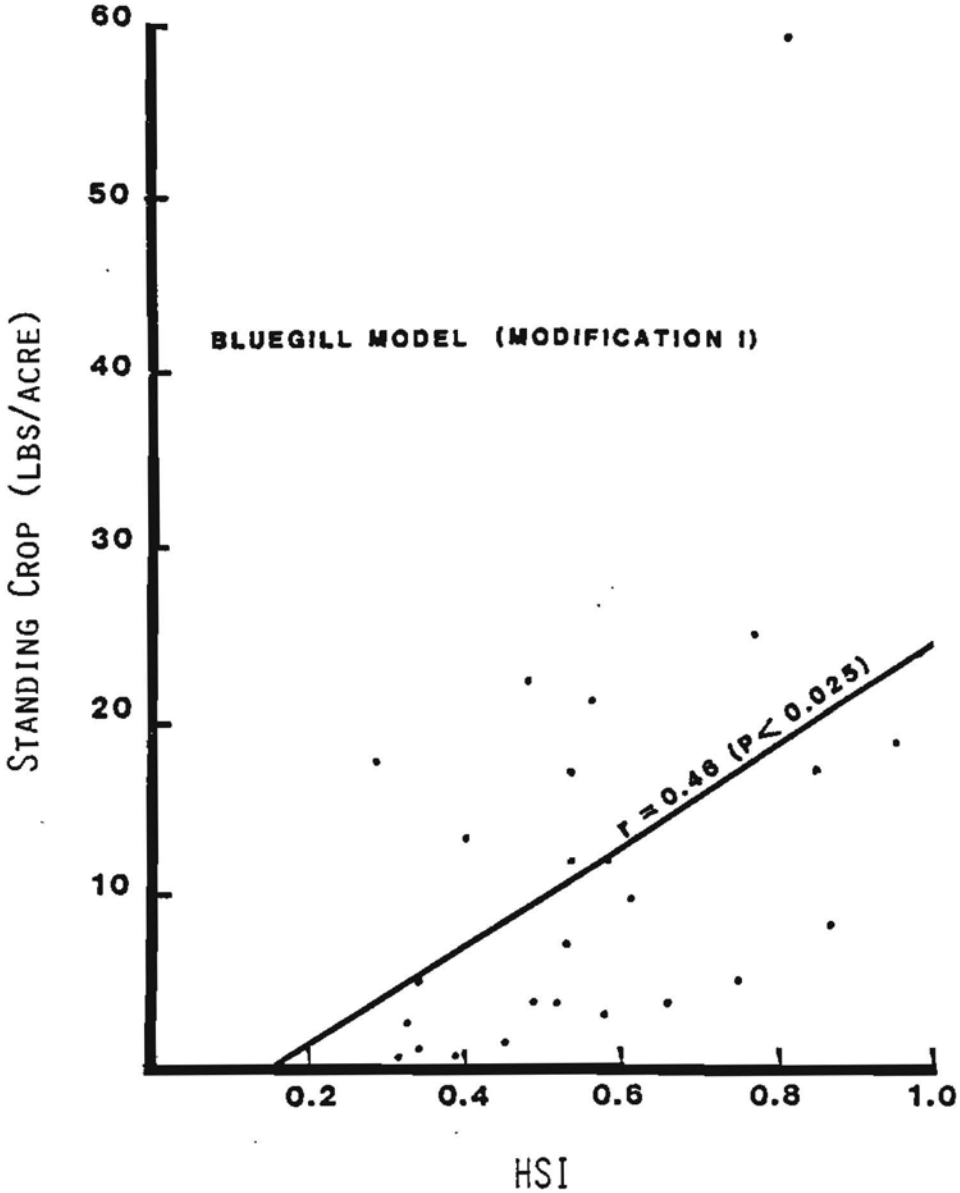

Figure 4. Bluegill standing crop as a function of the Habitat suitability index (HSI) (Model Modification I).

Table 4. Factor loadings for bluegill standing crops and suitability indices. Loadings with an absolute value greater than 0.50 are in parentheses.

Variable	Factor I	Factor II
Bluegill	(0.71)	0.39
Percent aquatic plants	0.44	(0.66)
Percent snags	-0.25	(0.70)
Percent littoral area	(0.83)	-0.28
Percent deep water	(0.76)	-0.17
pH	0.48	-0.14
DO	-0.41	-0.42
Turbidity	0.46	-0.29
Factor	Eigenvalue	Relative %
I	2.62	32.8
II	1.46	18.2

Table 5. Final HSI models (Model Modification II) for bluegill, white crappie, and largemouth bass.

Bluegill	$(V_2 \times V_3 \times V_4^2 \times V_D)^{1/5}$
White crappie	$(V_2 \times V_4 \times V_D)^{1/3}$
Largemouth bass	$\left[V_2 \times \left(\frac{V_3 + V_4}{2}\right) \times V_D\right]^{1/3}$

Bluegill

V_2 = suitability index for % snags

V_3 = suitability index for % aquatic vegetation

V_4 = suitability index for % littoral area

V_D = suitability index for % deep water

White crappie

V_2 = suitability index for % cover

V_4 = suitability index for % littoral area

V_D = suitability index for % deep water

Largemouth bass

V_2 = suitability index for % lacustrine (≤ 6 m deep)

V_3 = suitability index for % cover (for adult and juvenile)

V_4 = suitability index for % cover (fry)

V_D = suitability index for % deep water

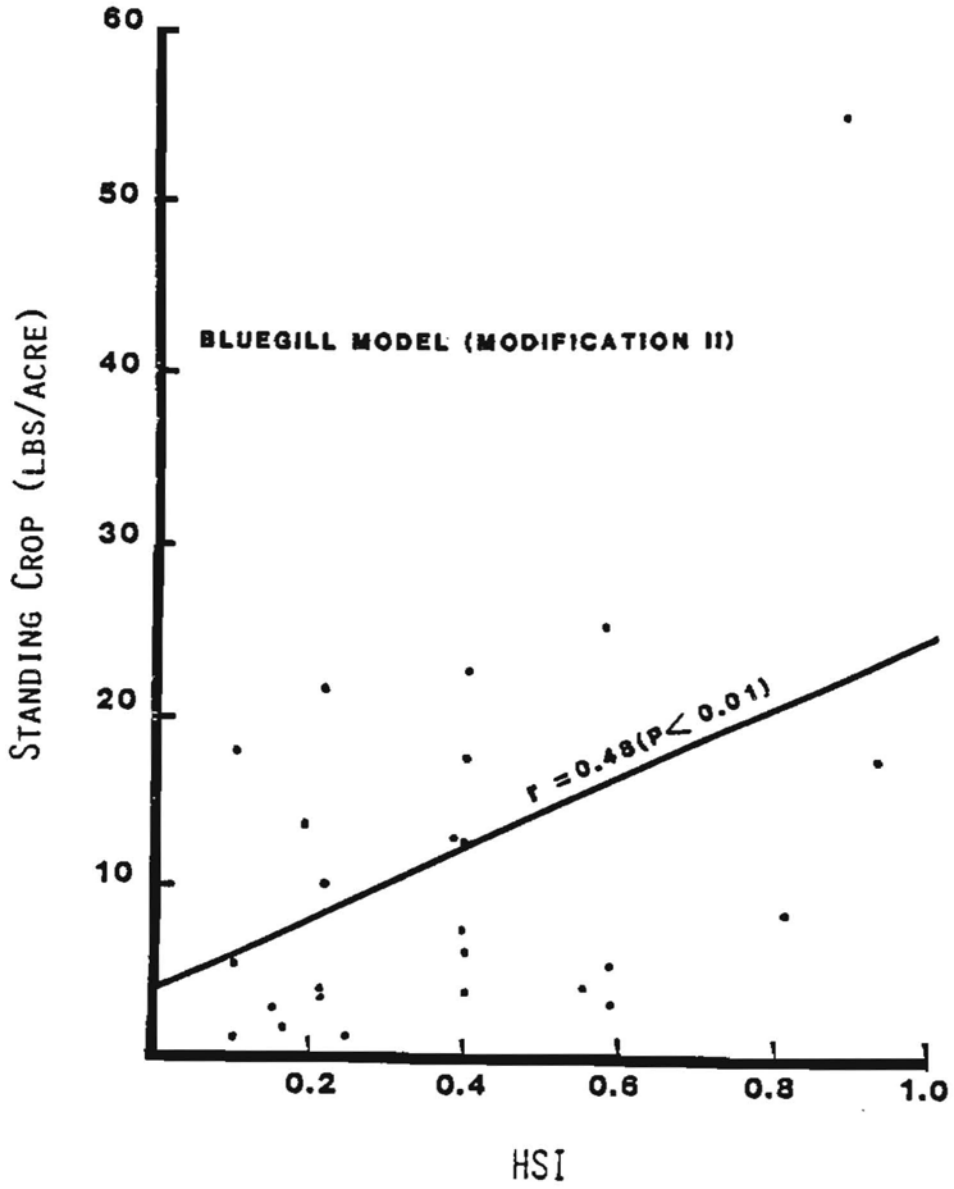

Figure 5. Bluegill standing crop as a function of the habitat suitability index (HSI) (Model Modification II).

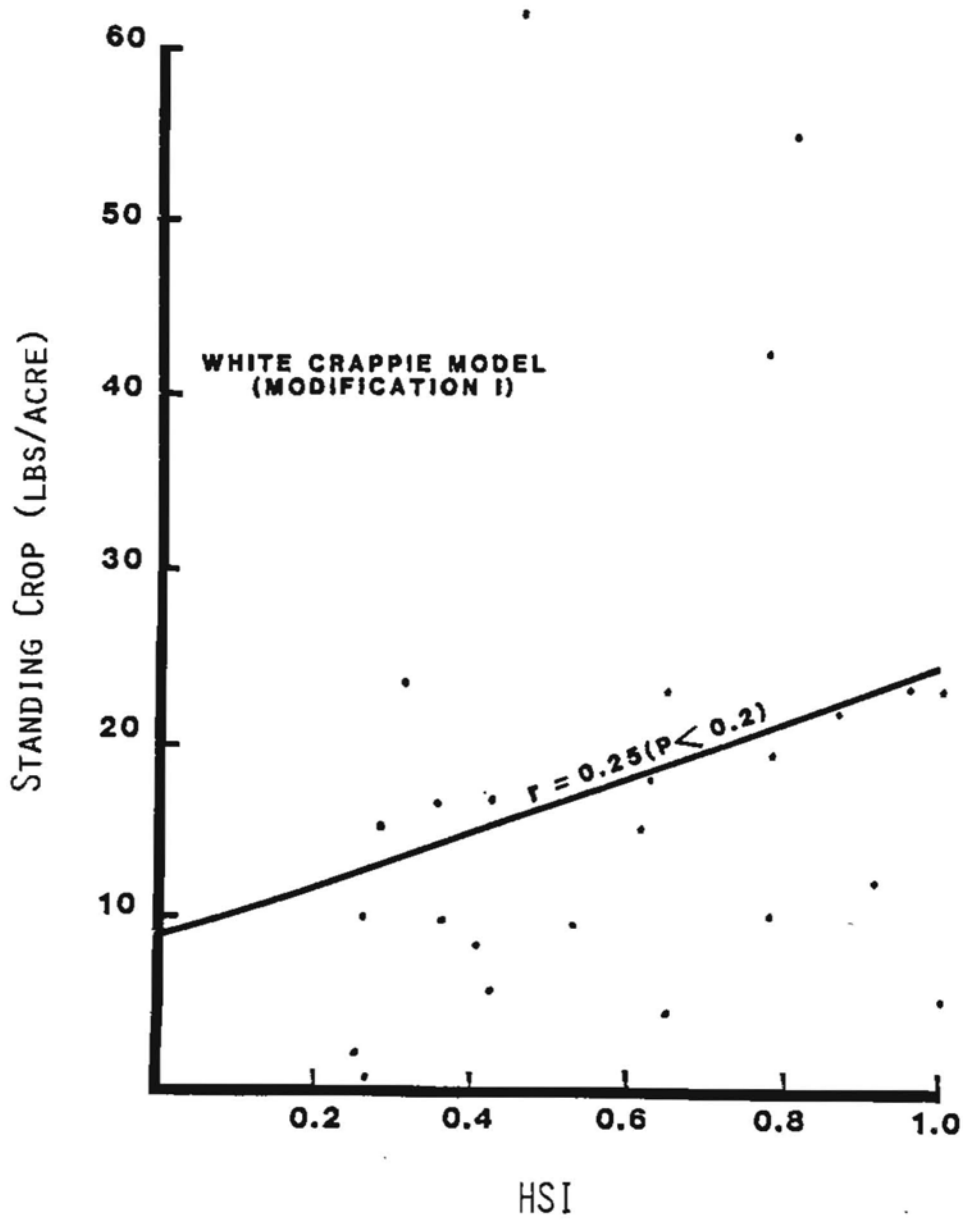

Figure 6. White crappie standing crop as a function of the habitat suitability index (HSI) (Model Modification I).

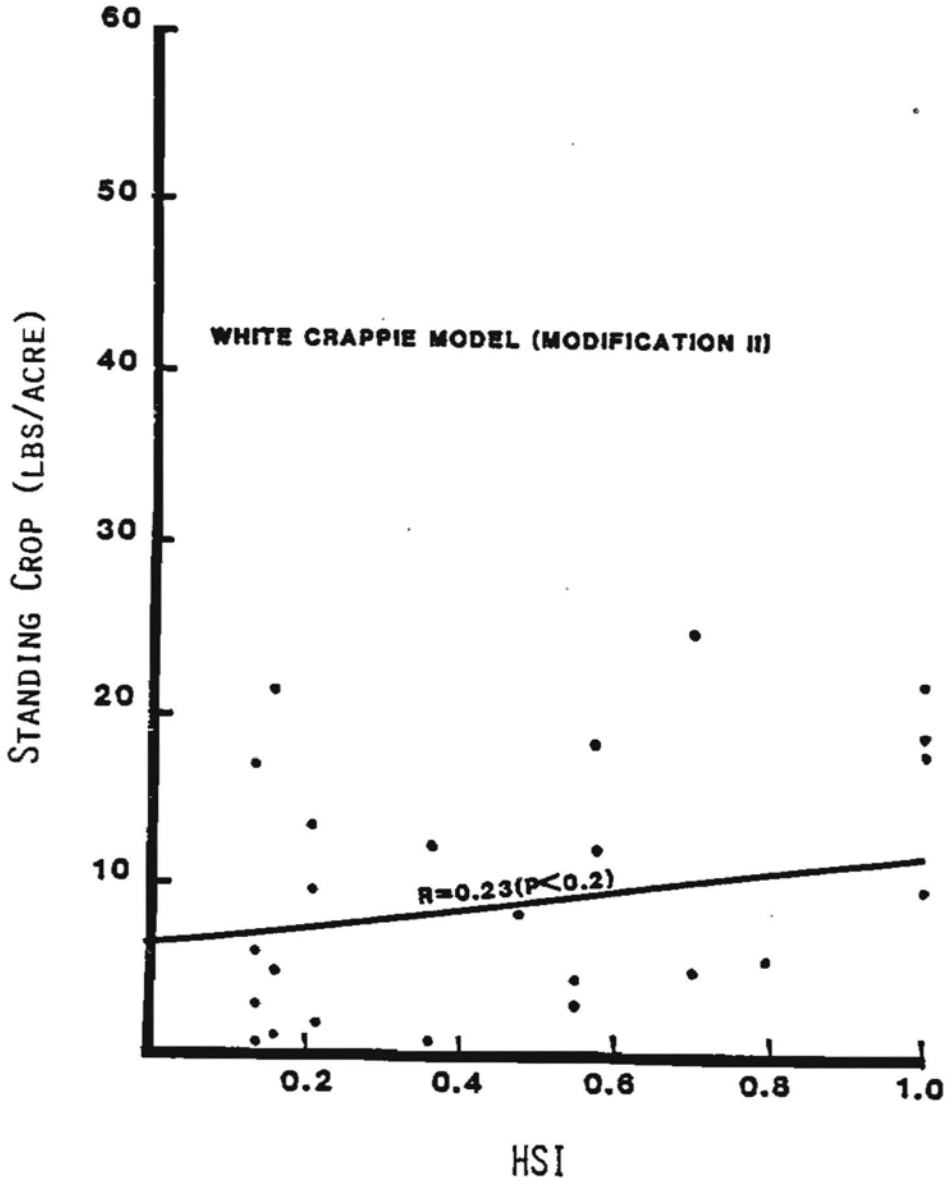

Figure 7. White crappie standing crop as a function of the habitat suitability index (HSI) (Model Modification II).

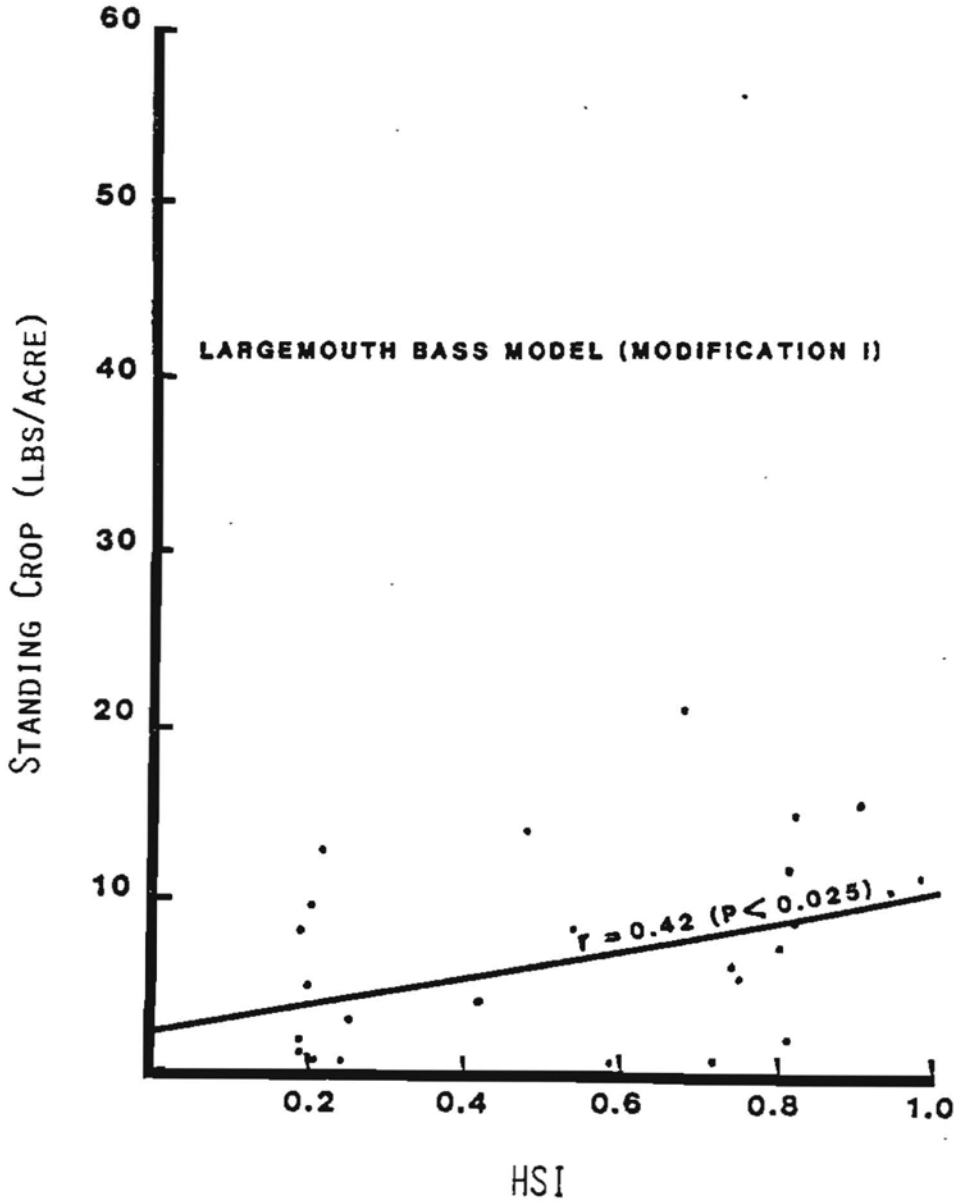

Figure 8. Largemouth bass standing crop as a function of the habitat suitability index (HSI) (Model Modification I).

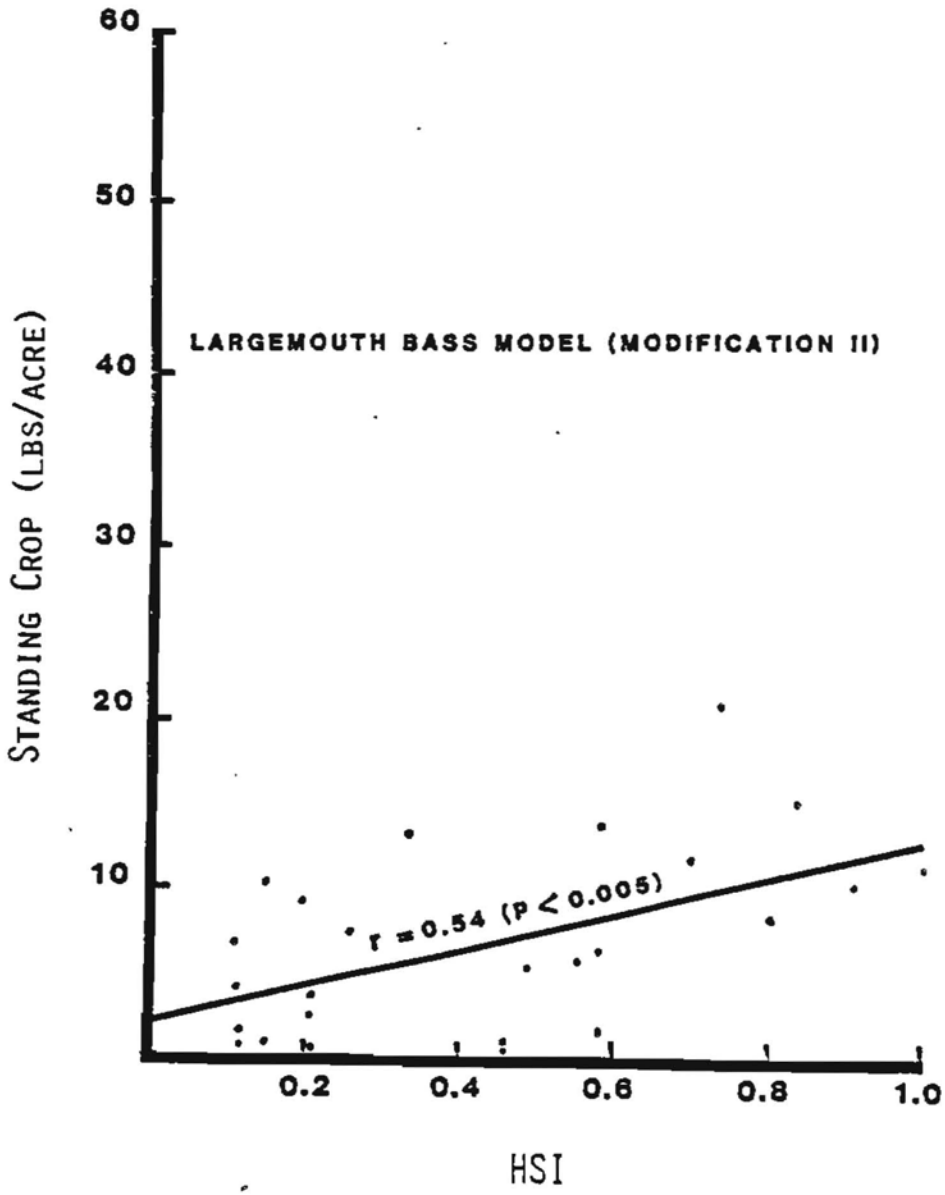

Figure 9. Largemouth bass standing crop as a function of the habitat suitability index (HSI) (Model Modification II).

In a study of the habitat requirements of trout in Wyoming streams, Binns (1979) reported correlations between standing crop and habitat quality scores that exceeded 0.95. None of the correlations for the three species in this study were higher than 0.54 ($P < 0.005$). Layher and Maughan (1984) concluded that HSI models work best for species with narrow, as opposed to broad, niches. For the second modification of the species models, the white crappie model resulted in r values approximately one half of those calculated for the bluegill and largemouth bass models. All three of these fish are generalists, and a convincing argument for white crappie having substantially broader habitat requirements than bluegill or largemouth bass probably could not be made. The low r values for the white crappie model are probably a reflection of the relative distribution of this species during the survey; it was almost always present in the pits and averaged two or three times the biomass of the other two species.

The simple, descriptive or word models for bluegill, largemouth bass, and white crappie, described as "additional model 2" by Stuber et al. (1982a, 1982b) and Edwards et al. (1982), were also tested. All three of these models were similar. The descriptive bluegill model assumes that, if water quality is adequate, the following criteria must be met to provide optimal habitat: (1) total dissolved solids ranging from 100 to 350 mg/l; (2) littoral areas greater than 20%; (3) maximum water temperatures greater than 20° C; and (4) clear water with less than 50 mg/l of suspended solids (Stuber et al. 1982a). The HSI is calculated by dividing the number of criteria present for the evaluation area by the total number of criteria for consideration (in this case, four). Using this technique for bluegill, the HSI ranged from 0.33 to 1.00 ($\bar{X} = 0.67$); the correlation coefficient with standing crop was low ($r = 0.11$) (Fig. 10). Correlation coefficients were also low for the white crappie and largemouth bass descriptive models ($r = 0.16$) (Figs. 11 and 12). Thus, while easy to use, the models were not good predictors of standing crop.

For the bluegill and white crappie models, the first and second modifications resulted in a larger range of HSI's than did the unmodified versions. Elimination of the temperature variable, which skewed the SI's to the low side, enabled other variables to influence the final scores. For all three species, the descriptive models produced the highest HSI's, although the range in values and correlation coefficients were usually greatest for the second model modification. The second modification, which resulted in only slightly higher r values than the first modification, provided a much simpler representation of the important environmental features of the habitat. The descriptive models provided HSI's rapidly and with fairly general data; however, the HSI's did not relate well to standing crop. In this regard, the major benefit of using the mechanistic models (i.e., a more detailed knowledge of relationships in an aquatic system) is probably lost with the simple descriptive models.

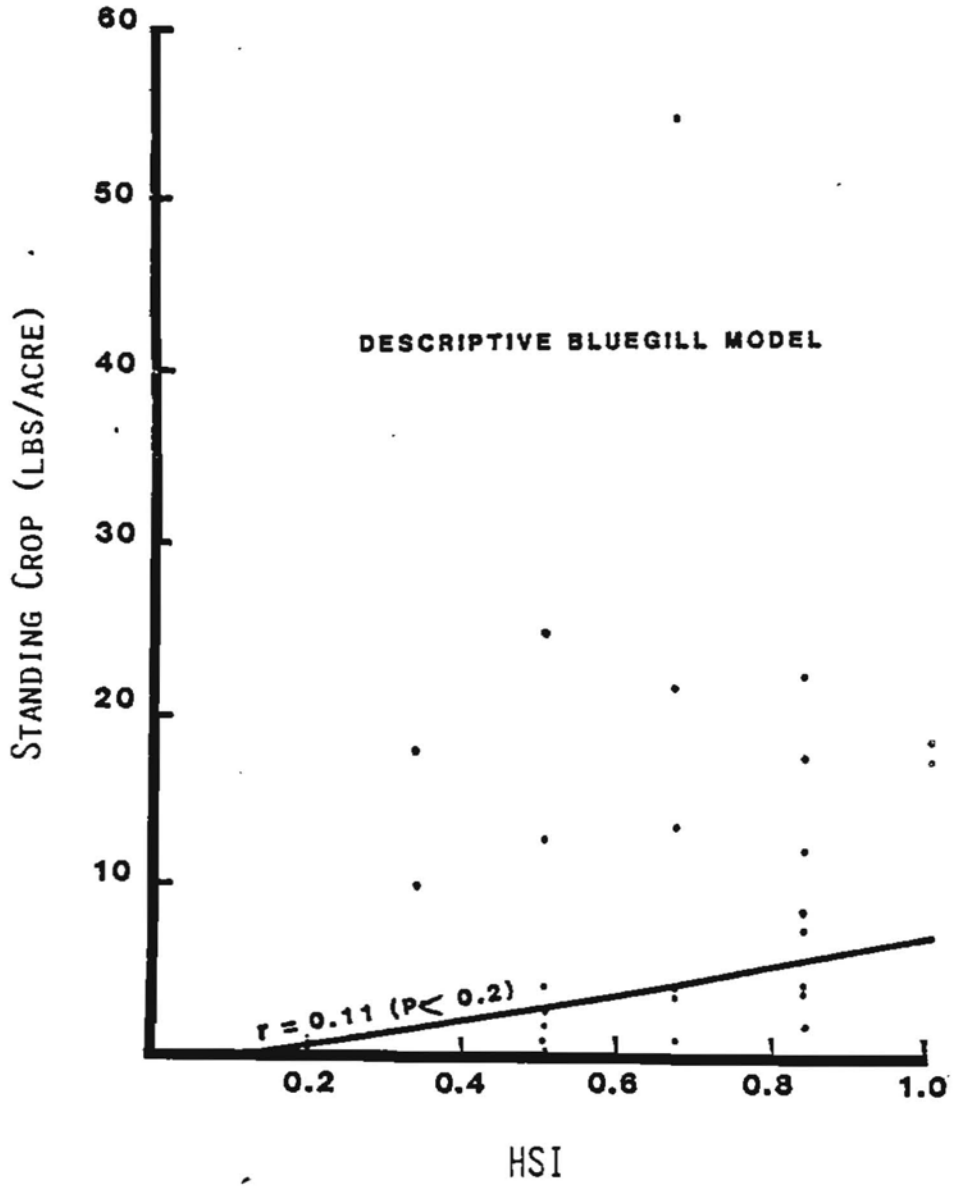

Figure 10. Bluegill standing crop as a function of the descriptive habitat suitability index (HSI) model.

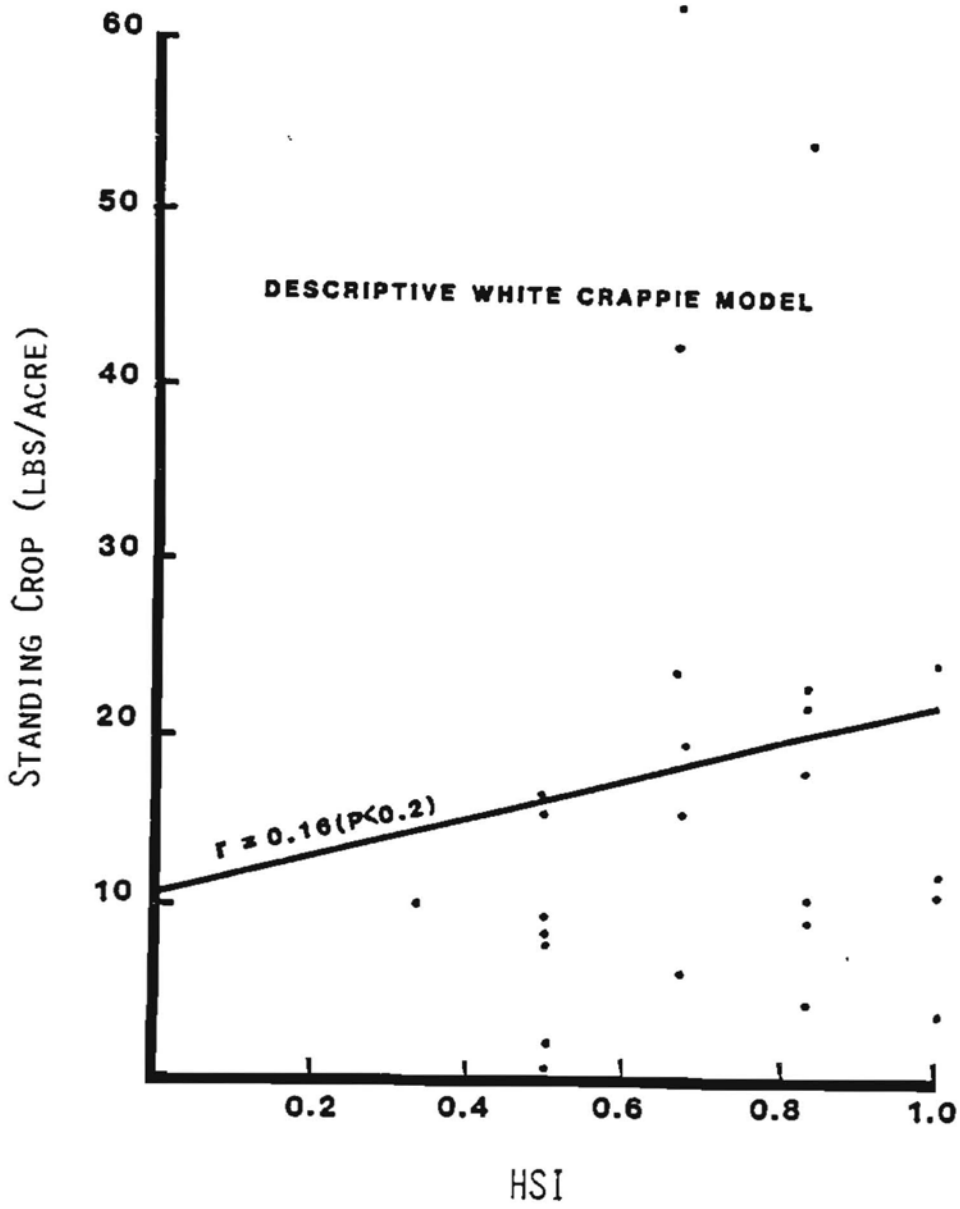

Figure 11. White crappie standing crop as a function of the descriptive habitat suitability index (HSI) model.

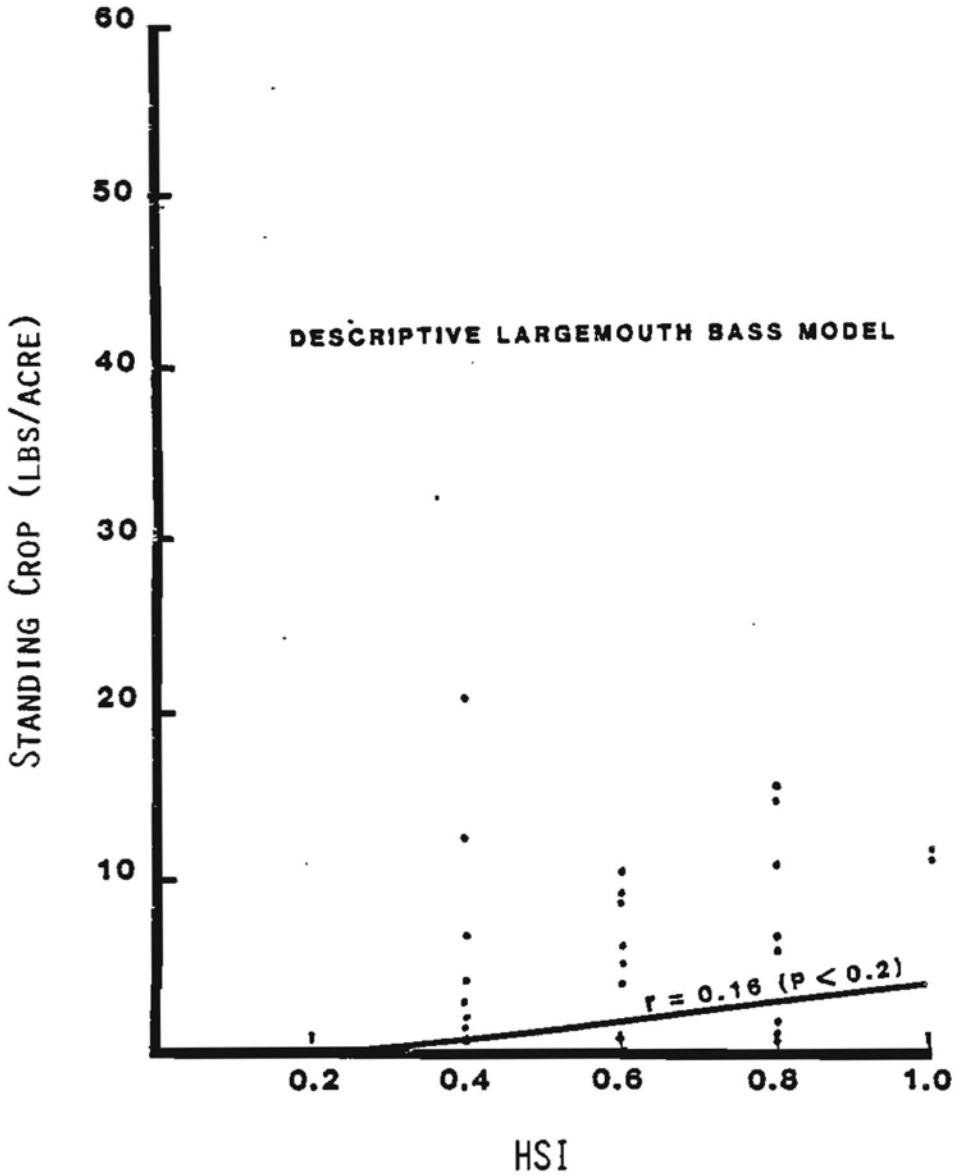

Figure 12. Largemouth bass standing crop as a function of the descriptive habitat suitability index (HSI) model.

SUMMARY

Mechanistic species models provided a vehicle for analyzing habitat variables and relating them to standing crop of fishes in borrow pits. The unmodified models were poor predictors of observed fish standing crop; however, correlations between biomass and HSI's were improved when the models were modified within the original HSI/SI framework. Factor analysis was used to identify the variables that supported sport and rough fish, respectively. Attention was paid to those pits that were similar and loaded highly on variables identified by factor analysis as enhancing sport fish populations. Two modifications were used; first, some variables were deleted based on ease of measurement and variability of the variable. Next, Suitability Indices for selected variables, including a variable not a part of the original modified model, were identified by principal component analysis as having loading values for explaining standing crop. The HSI's developed from these variables (e.g., percent vegetation, percent snags, percent littoral area, and percent deep water) had the highest correlation coefficients with standing crop, even though the models had the fewest number of variables.

The general procedure used in this study to utilize multivariate statistics to better relate HSI's to standing crop can be easily implemented. For the habitat under study, HSI model variables should be retained that are significant to the organisms of interest. The prospective user should develop an understanding of the system and use only key variables in the final HSI model. The published HSI models that were tested in this study provided a framework for the identification of key habitat variables.

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ASSESSMENTS OF SELECTED HABITAT SUITABILITY INDEX (HSI) MODELS

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INTRODUCTION

The U.S. Fish and Wildlife Service is developing Habitat Suitability Index (HSI) models for use with their Habitat Evaluation Procedures (HEP) (U.S. Fish and Wildlife Service 1980) to assess the potential effects of habitat alterations on fish and wildlife species. The HSI models used in this study were developed from literature surveys and had not been previously tested against field data. The objectives of this study were to: (1) compare the Habitat Suitability Indices (HSI's) calculated from models developed by the U.S. Fish and Wildlife Service with estimated standing crops of selected species of fishes from Eastern United States reservoirs and rivers; and (2) modify existing models as needed to improve performance. The intent and general use of HSI models was discussed by Schamberger et al. 1982.

MATERIALS AND METHODS

Habitat Suitability Indices were calculated and evaluated from draft models provided by the U.S. Fish and Wildlife Service, Western Energy and Land Use Team, for the following species: green sunfish (*Lepomis cyanellus*); warmouth (*L. gulosus*); bluegill (*L. macrochirus*); black crappie (*Pomoxis nigromaculatus*); largemouth bass (*Micropterus salmoides*); black bullhead (*Ictalurus nebulosus*); channel catfish (*I. punctatus*); and common carp (*Cyprinus carpio*). In most cases, models available at the time of these assessments were not the models published by the U.S. Fish and Wildlife Service; therefore, detailed descriptions of models, variables, and suitability index graphs are presented in Appendix A. Reservoirs selected for the evaluations were West Point (Georgia-Alabama), Oconee (Georgia), Lanier (Georgia), Clarks Hill (Georgia-South Carolina), Center Hill (Tennessee), Shelbyville (Illinois), and Sangchris (Illinois). River stations selected included three from the Altamaha River (Altamaha drainage, Georgia), two from the Ocmulgee River (Altamaha drainage, Georgia), and one from the Flint River (Apalachicola drainage, Georgia). These reservoirs and riverine areas encompass a variety

of habitats and were considered sufficiently physically, chemically, and geographically diverse to adequately evaluate the species models. Specific habitat variable values for each species model are presented with the discussion of model performance. Some habitat and standing crop estimates represent a single sample while other values are the mean of several samples. Standing crop data (kg/ha) determined from river and reservoir cove rotenone surveys were compared to calculated HSI's at the selected sites.

River rotenone survey data were collected using the standardized method described by Holder (1975) and were provided by D. Johnson, D. Holder, and R. Weaver of the Georgia Department of Natural Resources. Reservoir cove rotenone samples were collected during the summer months (June through September) by blocking off a cove with a net and treating the enclosed area with rotenone. Data for the reservoirs were obtained from the following sources: West Point (Davies et al. 1980); Center Hill (Mathews 1975); Shelbyville (Tranquilli et al. 1979); Sanchris (Larimore and Tranquilli 1981); all reservoirs (Aggus pers. comm.).

Major physical habitat parameters for streams (width and depth) were measured on site at the time of the rotenone survey. Velocity estimates were derived from velocity measurements used to calculate discharge at the time of the rotenone survey. Gradient was estimated from USGS 7.5-minute maps. Growing season (number of days between last frost of spring and first frost of fall) was assumed to be the same as that recorded by the climatological station nearest the survey site. Physical habitat parameters for reservoirs, based on depth and shoreline development, were estimated from construction agency records and maps, and information from the USFWS National Reservoir Research Program.

Estimates of water chemistry (temperature, pH, dissolved oxygen, total dissolved solids, and turbidity) related model variables were derived from the Water Resources Data for Georgia series published by the U.S. Geological Survey. Total dissolved solids was estimated by multiplying the specific conductance by 0.66. This conversion factor is commonly used in Southeastern reservoirs (Aggus pers. comm.) and is within the range of conversion values reported by Lennon (1959). Measurements from the downstream gaging station nearest the rotenone survey site were used. Measurements were not always available for the year of the survey. In these cases, data from the year closest to the rotenone survey were used. When standing stock data were available for more than 1 year, physical and chemical data for the collection years were averaged to derive the model variable values.

Precise data were not available for variables describing percent bottom cover, substrate, percent pools, water level fluctuation, and vegetative cover. Biologists familiar with the study sites provided estimates of these variables based on their personal experience working at the study sites.

Results of the evaluations and recommended modifications are presented and discussed individually by species model. Common problems with obtaining the needed variable values or applications of the models are presented in the Discussions.

RESERVOIR MODEL TEST RESULTS

For all models tested, suitability indices (SI's) for each model variable were derived for the SI graphs presented in Appendix A. Individual variable SI's were aggregated into component SI's and species HSI's utilizing the equations presented in Appendix A. The actual SI's calculated for each model variable are presented in Appendix B.

Green Sunfish

The green sunfish originally occurred only in East-central North America; however, it has been introduced widely in Eastern North America (Lee 1980a). Of the six reservoirs for which HSI's were calculated, Center Hill, Shelbyville, and Sangchris are within the natural range of the species, while populations in West Point, Oconee, and Lanier are introduced and represent the southeastern distribution limits of the species (Lee 1980a).

The food component (C_F) of the tested HSI model is directly related to average total dissolved solids (TDS) (V_{15}), which is assumed to directly reflect the food component suitability because of the positive correlation between centrarchid standing crops and TDS levels. The cover component (C_C) is calculated from percent bottom cover (V_1) and is included because species abundance has been correlated positively with percent cover. Percent littoral area (V_{16}) is intended to represent quantitatively the amount of habitat available as cover. The water quality component (C_{WQ}) is limited to dissolved oxygen (V_4), turbidity (V_5), pH (V_6), temperature (V_7 and V_8), and salinity (V_{18}) measurements because these parameters have been shown to affect growth or survival. Variables related to temperature and dissolved oxygen are assumed to be limiting if they reach near-lethal levels. The reproduction component (C_R) includes the parameters of temperature (V_9), substrate (V_{10}), and reservoir drawdown (V_{17}).

Four of the six reservoirs that supported green sunfish populations had HSI's of 0 for the species (Table B-1). In Lake Lanier, 0 values were due to a maximum temperature within the littoral area that exceeded 31° C during spawning [June-July (V_9)]. The suitability curve for V_9 indicates that the optimum temperature during June-July is 20 to 27° C (Appendix A). June and July water temperatures in the littoral zone normally exceed 27° C in many southeastern reservoirs. Cooler water temperatures are available in deeper water in most of these reservoirs. According to Hunter (1963), green sunfish can successfully reproduce and embryos survive at temperatures from 19 to 31° C. During most years, many centrachids in southeastern reservoirs already have spawned by June-July and the fact that water temperatures in shallow areas exceed 31° C does not limit reproduction or embryo survival.

The other two reservoirs with HSI's of zero and green sunfish populations were Shelbyville and Sangchris (Table B-1). In these reservoirs, drawdowns during spawning (V_{17}) were responsible for the 0 HSI's. These drawdowns apparently do not exclude reproduction or embryo survival of green sunfish. This is not surprising because green sunfish apparently spawn over an extended period of time and range of temperatures (19 to 31° C), and conditions likely will be favorable at some point in time. For example, even though temperatures exceeded 31° C in shallow areas in June and July, the water temperature was within the optimum range earlier in the year. If the species reproduced during the more favorable period and the embryos moved to cooler water when shallow water temperatures exceeded 31° C, then maximum shallow water temperature in June-July would have little effect on C_R. Therefore, the model appears too stringent in setting limits on values that may occur for a short time sometime during the spawning period.

The green sunfish model was modified by excluding V_9 and V_{17}, the two parameters that resulted in the 0 HSI's for Lanier, Center Hill, Shelbyville, and Sangchris Reservoirs. Although this modification eliminated the 0 HSI's, the performance of the model was not improved significantly. There was little correlation between calculated HSI's and estimated standing crop of green sunfish in the tested reservoirs ($r = 0.370$). Specific model problem areas apparently were maximum summer temperatures in littoral areas, drawdowns, and possibly lower population levels at the edge of the species' range. Most fishes are very adaptable in terms of avoiding adverse conditions and some related flexibility in the model appears warranted.

Warmouth

All of the reservoirs tested were within the natural range of the warmouth (Lee 1980b), and warmouth were expected to occur in all of them. Suitability indices (Table B-2) were based on the SI curves in Appendix A.

The food component (C_F) of the warmouth model is determined from mean TDS during summer (V_{13}), percent cover in shoreline areas < 3 m depth during average summer conditions (V_{14}), and average mean depth/shoreline development during average summer conditions (V_{15}). The cover component (C_C) value is based on water level stability during spawning and incubation from mid-May to mid-July (V_{12}) and V_{14} and V_{15} as used in the food component. The water quality component (C_{WQ}) is based on length of the growing season (V_1), dissolved oxygen concentrations during the summer (V_3), pH range (V_6), maximum salinity (V_7), average mean weekly shoreline water temperature from mid-June to mid-September (V_8), and maximum monthly average turbidity (V_{10}), with V_3 and V_8 weighted most heavily. The reproductive component value (C_R) is based on average mean weekly water temperature during mid-May to mid-June (V_9) and water level stability during spawning and incubation (V_{12}).

Model developers considered vegetation, cover, and parameters associated with shallow water important determinants of warmouth habitat suitability. Four of the six reservoirs tested supported warmouth populations, with Oconee having a relatively high HSI (0.85) and warmouth standing crop (5.26 kg/ha) (Table B-2). However, Shelbyville and Sangchris Reservoirs had high HSI's and insignificant warmouth populations. A major weakness of the model appears to be the lack of consideration of interspecific competition. Warmouth are piscivores and, even though increased TDS may indicate increased biomass of centrarchids, other centrarchids may increase more than warmouth, which seem to do better in harsher environments. The tested model did not accurately reflect standing crops of warmouth in selected reservoirs ($r = 0.196$).

Bluegill

All reservoirs studied were within the natural range of the bluegill (Lee 1980c), and all were expected to support bluegill populations. The food component (C_F) of the model (Appendix A) is calculated from percent bottom cover within littoral areas during summer (V_2) and average TDS (V_4), because TDS levels and centrarchid standing crops are positively correlated. The cover component (C_C) is based on V_2 and percent littoral area during summer stratification (V_3). The water quality component (C_{WQ}) is determined from summer dissolved oxygen concentrations (V_7), with some flexibility added in terms of "seldom", "usually", and "often". Use of these terms allows the user to ignore short term or one time events that otherwise might result in SI's of 0. Other influential water quality components are maximum monthly average turbidity (suspended solids) during summer stratification (V_5), pH range during growing season (V_6), and maximum midsummer temperature in littoral areas (V_{11} for fry; V_{12} for juveniles). The reproductive component (C_R) is based on the average of mean weekly water temperatures in littoral areas during spawning (V_{10}) and substrate composition in littoral areas (V_{19}).

Of the six reservoirs tested, only Oconee had a calculated HSI of 0 (Table B-3). As with other southeastern reservoirs, maximum summer temperatures in the littoral zone exceeded 31° C, although cooler water was usually available close by. As previously discussed, midsummer littoral water temperatures probably should be ignored for southeastern reservoirs and a deeper water temperature used instead.

Of the models tested, the bluegill HSI had one of the higher correlations with estimated standing crop ($r = 0.498$). A possible explanation for the greater correlation is the greater flexibility in determining some of the variable values (e.g., dissolved oxygen concentrations).

Black Crappie

All reservoirs studied were within the natural range of the black crappie (Lee 1980d), and black crappie were expected to occur in all of the reservoirs. The developers of the model assumed that the food component (C_F) is directly related to TDS during the growing season (V_{15}) (Appendix A). The cover component (C_C) is based on percent cover (e.g., vegetation, brush, debris, and standing timber) during midsummer in the littoral zone (V_2) and percent littoral area during spring and summer (V_6). The water quality component (C_{WQ}) is based on the most suitable water temperature within the epilimnion during midsummer for adults (V_8) and juveniles (V_9); average water temperature in littoral areas during midsummer (V_{10}) for fry; minimum dissolved oxygen levels in the temperature strata selected in V_8, V_9, and V_{10} during summer (V_{12}); pH levels during the year (V_7); and maximum monthly average turbidity during summer (V_1). The reproductive component (C_R) is based on V_2, V_6, average water temperature within littoral areas during spawning (V_{11}), and minimum dissolved oxygen levels within littoral areas during spawning (V_{13}).

The black crappie HSI's had the highest correlations with estimated standing crops in selected reservoirs ($r = -0.740$) of all species models evaluated. Unfortunately, it was a negative correlation, and those reservoirs with the lowest HSI's supported the highest black crappie standing crops (Table B-4). Lake Oconee (HSI = 0.20) supports 32.5 kg/ha of black crappie, an exceptionally high standing crop. Lake Oconee has several large stands of timber that are extensively used by crappie. However, the importance of these areas was not accounted for by the model variables because the stands are in deeper water, not in the littoral zone. Model modifications that account for the attributes of deeper water cover should be considered.

Largemouth Bass

All reservoirs evaluated were within the presumed natural range of the largemouth bass (Lee 1980e), and largemouth bass were expected to occur in all of the reservoirs. The food component (C_F) of the model (Appendix A) is assumed to be directly related to average total dissolved solids (TDS) concentration during the growing season, when the carbonate-bicarbonate ionic concentration > the sulfate-chloride ionic concentration (V_5). When the sulfate-chloride ionic concentration > the carbonate-chloride ionic concentration, the suitability index for variable V_5 is reduced by 0.2. However, there are interspecific interactions among various sunfishes (Swingle 1950) and, although TDS may relate directly to the standing crop of sunfishes, it is doubtful that it relates directly to the standing crop of one particular species of sunfish under all conditions. It might be more realistic to weight C_F to compensate for the variety of sunfishes that occur in different reservoirs.

The cover component (C_C) of the largemouth bass model consists of variables representing the percent bottom cover weighted for adults and juveniles (V_3) and fry (V_4); average water temperature within pools, backwaters, or littoral areas during the growing season (V_8); and average water level fluctuations during the growing season (V_{16}). Water quality component (C_{WQ}) parameters include minimum dissolved oxygen levels during midsummer in pool or littoral areas (V_6); pH range during the growing season (V_7); average water temperature within pools, backwaters, or littoral areas during the growing season for adults and juveniles (V_8); average water temperature within pools, backwaters, or littoral areas during the growing season for fry (V_{10}); and maximum monthly average turbidity (suspended solids) during the growing season (V_{11}).

Salinity can influence the reproductive success of largemouth bass, and maximum salinity during summer is considered for adults (V_{12}), fry (V_{13}), and embryos (V_{14}). The reproductive component (C_R) is influenced by maximum salinity during spawning and incubation (V_{14}). If $V_{14} = 1.0$, then the variables considered include percent lacustrine area ≤ 6 m depth (V_2), average weekly mean temperature within pools or littoral areas during spawning and incubation for embryos (V_9), substrate composition within lacustrine littoral areas for embryos (V_{15}), and maximum water level fluctuation during spawning for embryos (V_{17}). If $V_{14} < 1.0$, then the variable value for V_{14} is included in the calculation of C_R. If C_{WQ} or $C_R \leq 0.4$, the HSI equals the lowest value of C_{WQ}, C_R, or $(C_F \times C_C \times C_{WQ} \times C_R)^{1/4}$.

All of the variables listed under the various components of the model are undoubtedly important in determining habitat suitability for largemouth bass. However, exceptionally high standing crops of largemouth bass occur in unexploited populations (Gilbert and Hightower 1981) and sport harvest is probably a much more influential variable than habitat in determining the existing standing crop in most reservoirs. It is doubtful that largemouth bass standing crops in reservoirs can be evaluated solely on the basis of physical and chemical variables, with no consideration of harvest factors. There was a low negative correlation ($r = -0.112$) between the calculated HSI and the largemouth bass standing crop (Table B-5) in tested reservoirs.

Black Bullhead

The natural range of the black bullhead does not include Lake Oconee, and West Point is near the eastern range limits of the species (Glodeck 1980a). Therefore, black bullheads were not expected to occur in all of the reservoirs evaluated. Many of the model suitability index curves were based on data from other bullheads and catfishes. Where bullheads were not separated by species in standing crop data, a total bullhead estimated standing crop (Table B-6) was used in evaluating the model.

The food component of the model (C_F) (Appendix A) is assumed to be directly related to food production, which, in turn, is assumed to be directly related to TDS, because of the positive correlation between catfish standing crop and TDS. However, this assumption fails to recognize interactions among various fishes. Obviously, the same food supply cannot be unlimited for all species that utilize it.

The cover component of the model (C_C) is comprised of percent cover (e.g., vegetation, brush, and debris) in littoral areas during summer (V_2), percent littoral area during summer (V_{14}), and lake or reservoir size (V_{15}). The water quality component (C_{WQ}) is determined first by maximum salinity during summer for adults and juveniles (V_7) and maximum salinity during May to July for embryos and fry (V_8). If the salinity is less than 2 ppt, the variables used to determine C_{WQ} include maximum midsummer water temperature in pools, backwaters, or littoral areas (V_4); dissolved oxygen range within pools, backwaters, or littoral areas during summer (V_5); pH range during the year (V_6); and maximum monthly average turbidity (suspended solids) during the growing season (V_9). Variables V_4 and V_5 are weighted more heavily. If V_4 or V_5 is ≤ 0.4, C_{WQ} = lowest of V_4, V_5, or C_{WQ} equation. If the salinity suitability index for V_7 or V_8 is 1.0, consideration is given to maximum salinity during the summer for adults and juveniles (V_7) and the maximum salinity during May-July for embryos and fry (V_8). The determination of the reproductive component value (C_R) initially depends on the salinity suitability index (V_8). If V_8 = 1.0, C_R is dependent on average water temperature in pools, backwaters, or littoral areas during spawning and embryonic development for embryos (V_{10}); dominant substrate type in pools, backwaters, or littoral areas during spawning for embryos (V_{11}); percent cover objects (e.g., vegetation, brush, and debris) in pools, backwaters, or littoral areas during spawning for embryos (V_{12}); percent littoral area during summer (V_{14}); and reservoir drawdown during spawning and embryonic development for embryos (V_{16}). If $V_8 \leq 1.0$, V_8 is included in the C_R calculations.

Habitat suitability indices were not well correlated with estimated standing crops of bullheads from tested reservoirs ($r = 0.336$).

One possible problem with the bullhead model is that many of the suitability index curves are based on preferences of other species, which are assumed to be appropriate for black bullheads. The following examples illustrate the numerous assumptions provided with the draft model:

1. Because the species seems to prefer a diversity of velocities and structural features, it is assumed that 50 to 80% pool/backwater areas with ≤ 20% cover (e.g., vegetation, brush, and debris) are optimum.

2. It is assumed that smaller bodies of water provide more food and cover habitat. It is also assumed that optimal lacustrine habitat includes extensive littoral areas (≥ 25% of surface area) with moderate to abundant (≥ 20%) cover within this area.

3. It is assumed that optimal ratings for black bullheads correspond to a TDS range of 100 to 600 ppm.

4. Based on quantitative data from other catfishes, it is assumed that optimal dissolved oxygen levels are ≥ 7 mg/l.

5. No quantitative information is available on the optimal turbidity range. It is assumed that the black bullhead exhibits a response similar to channel catfish and that optimal suitability index ratings correspond to an intermediate turbidity range of 25 to 100 ppm.

6. Information is not available on optimal pH ranges or tolerance limits for black bullheads. Stroud (1967) believed that a pH range of 6.5 to 8.5 allowed full production and growth for all life stages of freshwater fish. Hence, this range corresponds to an optimal SI rating.

7. Data about thermal optima for black bullheads are somewhat conflicting.

8. No specific information was found in the literature concerning the salinity tolerance of the black bullhead. However, optimal levels for adults are assumed to be ≤ 2 ppt, with lethal levels near 15 ppt, based on data for other catfishes.

It appears that there are insufficient data for model development and that is impossible to determine habitat requirements of black bullheads from currently available literature. It might be appropriate to postpone further development of an HSI model for black bullhead until additional information is available or, perhaps, to develop a general "bullhead model" instead.

Channel Catfish

Although originally absent from central Atlantic drainages, the channel catfish has been widely introduced and now occurs throughout the United States and much of northern Mexico (Glodek 1980b). Channel catfish were expected to occur in all of the reservoirs investigated. In the channel catfish model used (Appendix A), the food component (C_F) is dependent on percent cover (logs, boulders, cavities, brush, debris, or standing timber) during summer within pools, backwater areas, and littoral areas (V_2); percent littoral area during summer (V_3); and monthly average TDS during summer (V_{16}). The cover component (C_C) is calculated from variables V_2 and V_3. The water quality component (C_{WQ}) is determined from the average midsummer water temperature within pools, backwaters, or littoral areas for adults (V_5), fry (V_{13}), and juveniles (V_{14}); maximum monthly average turbidity during summer (V_7); average minimum dissolved oxygen levels in pools, backwaters, or littoral areas during midsummer (V_8); and maximum salinity during summer for adults (V_9) and fry and juveniles (V_{12}). If any of these variables ≤ 0.4, C_{WQ} = the lowest of the variable values or the C_{WQ} equation. Twice the value from the suitability index curve for the length of the agricultural growing season ($2V_6$) can be used instead of:

$$2\left(\frac{V_5 + V_{12} + V_{14}}{3}\right)$$

to determine C_{WQ}. Agricultural growing season was used for Lanier, West Point, Shelbyville, and Sangchris Reservoirs. The reproductive component (C_R) is determined from percent cover (logs, boulders, cavities, brush, debris, or standing timber) during summer in pools, backwater, and littoral areas (V_2); percent littoral area during summer (V_3); average minimum dissolved oxygen levels in pools, backwaters, or littoral areas during midsummer (V_8); average water temperatures in pools, backwaters, and littoral areas during spawning and embryo development for embryos (V_{10}); and maximum salinity during spawning and embryo development for embryos (V_{11}). If V_8, V_{10}, or $V_{11} \leq 0.4$, C_R = the lowest of V_8, V_{10}, V_{11}, or C_R equation.

There was a relatively low correlation between the HSI and estimated standing crop (Table B-7) of channel catfish from the reservoirs tested ($r = 0.461$). Fishing pressure may influence standing crop to the degree that habitat is not the limiting factor in these reservoirs. As with the other HSI models evaluated, the failure of the model to account for biological interactions may limit the applicability of the model for predicting standing crops.

Common Carp

Although the common carp is native to temperate portions of Eurasia, it has become established throughout the United States (Allen 1980). The common carp was expected to occur in all of the reservoirs investigated. The food/cover component ($C_{C/F}$) of the model (Appendix A) is determined from the percent vegetative cover in shallow areas during spring and summer (V_1) and percent littoral area during spring and summer (V_5). The water quality component (C_{WQ}) is calculated from maximum monthly average turbidity during average summer flow or summer stratification (V_7); maximum midsummer water temperature during average summer flow for adults (V_8); maximum water temperature during average summer flow for juveniles and fry (V_{10}); average dissolved oxygen levels during summer for fry, juveniles, and adults (V_{13}); and pH range during the year (V_{15}). If $(V_8 \times V_{10})^{1/2}$ or $V_{14} \leq 0.4$, C_{WQ} = the lowest of $(V_8 \times V_{10})^{1/2}$, V_{14}, or the C_{WQ} equation. An optional salinity variable (V_{12}) can be used if salinity is considered a potential problem in the study area. The reproductive component (C_R) is determined from V_1, percent littoral area during spring and summer (V_5), average water temperatures during spawning for embryos (V_9), and average dissolved oxgyen levels during spawning (March-June) for embryos (V_{14}). An additional component (C_{OT}) is directly related to the reservoir storage ratio (V_6).

The carp model had one of the highest correlations (r = 0.55) of HSI's and standing crops of the models tested. Reservoirs with the lowest standing crops also had the lowest HSI's. However, the four reservoirs with 0 or extremely low HSI's still supported relatively high standing crops of common carp (Table B-8).

Discussion

Cove rotenone samples can be expected to be biased in terms of describing an entire fish population. Cove samples would underestimate the reservoir-wide abundance of fish that prefer open water and overestimate abundance of fish that prefer cove areas. Factors to adjust species cove sample data to represent open water areas are summarized by Davies and Shelton (1983). These factors were not applied to the data described in this report. The HSI models were actually tested as predictors of standing crops in coves rather than an entire reservoir.

Predicting the biological consequences of habitat alterations is an appealing idea. The HSI models tested in this study failed to predict standing crops in reservoirs (Table 1) and, thus, may not be capable of predicting consequences of alterations. Based on these preliminary tests, the assumption that fish species abundance is directly regulated by certain physical and chemical habitat characteristics has not been demonstrated. Some obvious problems with the tested models and designing a test for the models included: (1) difficulty in obtaining or predicting the precise information concerning variables required by the models; (2) dependence on relatively simple and easily measured physical-chemical parameters; (3) determination of appropriate variable weighting values and the interactions among variables; (4) failure of individual model variables to compensate for the ability of fish to overcome short term or localized adverse physical-chemical conditions; (5) failure to include interspecific interactions among fish species; (6) failure to include the influences of exploitation on sport and commercial species; (7) the assumption that standing crop is a direct reflection of carrying capacity did not appear to be valid for the test data utilized; and (8) physical-chemical factors were apparently not limiting elements for the fish populations evaluated.

Table 1. Regression equations, probability values, correlation coefficients of HSI's, and standing crops of selected reservoir fishes.

Species	Regression equation	P	Correlation coefficient
Green sunfish	$Y = 0.01890X + 0.0588$	0.470	0.370
Warmouth	$Y = 0.02336X + 0.6467$	0.674	0.196
Bluegill	$Y = 0.00887X + 0.3652$	0.315	0.498
Black crappie	$Y = -0.02027X + 0.7608$	0.093	-0.740
Largemouth bass	$Y = -0.00071X + 0.7635$	0.833	-0.112
Black bullhead	$Y = 0.01970X + 0.4029$	0.515	0.336
Channel catfish	$Y = 0.02074X + 0.5799$	0.366	0.461
Carp	$Y = 0.01016X + 0.0369$	0.256	0.552

Even the relatively easily measured parameters used the in tested models are not routinely recorded for most reservoirs. The following examples illustrate some problem areas in model variable determination. The models were evaluated for reservoirs where intensive limnological and fisheries studies recently had been completed. Information concerning percent cover usually was obtained from State or Federal biologists familiar with the reservoir. Where there was considerable variation in estimates provided by various individuals, the estimate of percent cover was considered very impercise. "Littoral area" was used in determination of several components. However, the term was not defined in the model, and each model user was forced to define this variable based on the limnological literature or their own experience. These two commonly used parameters were the most difficult to estimate and probably the least precise. Total dissolved solids is seldom measured, but, in southeastern reservoirs, it usually is directly obtainable from specific conductivity measurements (TDS = specific conductance x 0.66).

Only physical-chemical parameters that can be predicted or measured easily are used in the models. This necessary limitation of variables forces the assumption that these are the parameters that limit fish populations when testing the models against population data.

Many of the models included variables such as maximum temperature, flow, and drawdown. Stringent definitions concerning possible one time or short term events fail to recognize the ability of fish to avoid or overcome such adverse conditions by seeking temporary refuge in a less harsh environment. Therefore, 0 SI's or HSI's may occur in some situations where fish obviously survive or even thrive.

A major shortcoming of the tested models appears to be a lack of consideration of the biological interactions of different species of fish. The population dynamics of predators (e.g., largemouth bass) affect the population dynamics of prey species (e.g., bluegills), and the inclusion of variables that recognize such interactions or even potential diversity (e.g., number of species reported from drainage) might improve model performance.

Limiting the models to physical-chemical parameters precludes consideration of the influence of exploitation. Unfortunately, the species that often are most important to man are those that have recreational or commercial value. Regulation of catch rates and size limits of fishes to increase catch and standing crop of a particular species confirms the importance of the effect of exploitation on fish populations.

In order to evaluate the models as predictors of carrying capacity, it is necessary to assume that standing crop is a direct reflection of carrying capacity. However, exploitation, biological interactions, and numerous other factors can limit fish abundance short of carrying capacity. In addition, it was assumed that estimates of standing crop based on rotenone samples accurately reflected actual fish abundance. However, rotenone samples are subject to interpretation and sampling errors (Davies and Shelton 1983).

Model performance for the species models tested (green sunfish, warmouth, bluegill, black crappie, largemouth bass, black bullhead, channel catfish, and common carp) generally was very poor (Table 1). Positive correlation coefficients of HSI's and estimated standing crops ranged from 0.196 for the warmouth model to 0.552 for the common carp model. Minor modifications of the models to preclude 0 HSI's in reservoirs where the species occurred did not significantly improve model performance. The highest correlation coefficient was for the black crappie model, but it was a negative value, as was the correlation coefficient for the largemouth bass model.

Based on these results, it is unlikely that the tested models could be modified enough to significantly improve performance in predicting actual standing crops as long as the models are limited to physical and chemical factors.

RIVERINE MODEL TEST RESULTS

Green Sunfish

The green sunfish is not native to Atlantic coastal drainages (Lee 1980a) and was not expected to occur in the Altamaha or lower Apalachicola drainages. However, green sunfish are relatively common in some areas of the Apalachicola drainage (e.g., Chattahoochee River at Buford Dam tailwaters). The food/cover component ($C_{F/C}$) of the model (Appendix A) is determined from percent bottom cover (e.g., vegetation, rocks, and debris) within pools or littoral areas during summer (V_1) and percent pool area during average summer flow (V_2). The water quality component (C_{WQ}) is based on minimum dissolved oxygen levels during summer (V_4), maximum monthly average turbidity in pools or littoral areas during summer (V_5), pH range during summer growing season (V_6), maximum midsummer temperature within pools and littoral areas for adults and juveniles (V_7), maximum midsummer temperature in pools or littoral areas for fry (V_8), and an optional variable concerning maximum monthly average salinity during the growing season (V_{10}). The reproductive component (C_R) is determined from the maximum temperature within pools or littoral areas during spawning (June-July) for embryos (V_9), substrate composition within pools or littoral areas during spawning for embryos (V_{10}), and average current velocity within pools during spawning (June-July) for embryos (V_{12}).

Green sunfish were not expected to occur in the tested riverine habitats because they were not in its distribution range. It is difficult to assess the significance of the consistent 0 HSI's for the unmodified models (Table B-9). Zero HSI's were due primarily to high average current velocities in pools during spawning. Elimination of velocity variables resulted in positive HSI's. Mainstream sampling stations were selected to sample flowing water; these large southeastern coastal plain rivers have very few "pools". Even though "pools" may be absent from sample areas, microhabitats among obstructions probably could provide sufficient shelter for green sunfish

reproduction. Green sunfish abundance in the tailwaters of Buford Dam (Chattahoochee River, Georgia) indicate that this species can do very well in areas with virtually no pools and high velocities.

Because of the distribution of the species, attempts to evaluate the performance of the green sunfish model in Georgia rivers were inappropriate. The addition of a model variable concerning species distribution might be appropriate. For example, a value of 1.0 might be assigned to the variable if the sample area was in the center of the species distribution range with correspondingly lower values as sample areas occur toward the edge of the species' distribution range.

Warmouth

All of the sample areas were within the natural range of the warmouth (Lee 1980b), and the species was expected to occur in all of them. The food component (C_F) of the model (Appendix A) is determined from percent instream rooted aquatic vegetation, logs, rocks, roots, and brush in pools during average summer flow (V_2) and percent pool area during average summer flow (V_5). The cover component is based on V_2, V_5, and water level stability during spawning and incubation (mid-May to mid-July) for embryos (V_{12}). The water quality component (C_{WQ}) is determined from the length of the agricultural growing season (average number of days from last to first frost) (V_1), dissolved oxygen range during summer (V_3), pH range during the year (V_6), maximum salinity during average summer flow (V_7), average mean weekly water temperature during mid-June to mid-September (V_8), and maximum monthly average turbidity during average summer flow (V_{10}), with V_3 and V_8 weighted most heavily. If any subcomponent of the C_{WQ} equation equals zero, C_{WQ} equals zero. The reproductive component (C_R) of the model is based on V_{12}, average mean weekly water temperature during spawning (mid-May to mid-June) for embryos (V_9) and V_2. The "other" component (C_{OT}) is determined from average stream velocity at 0.6 depth during average summer flow (V_{11}) and stream gradient in reach (V_4).

All sample areas had HSI's of 0. However, estimates of warmouth standing crop varied from 15.3 kg/ha in Altamaha (Oxbow) River to 0.05 kg/ha in the Flint River (Table B-10). Zero HSI's were due to the fact that the average stream velocity at 0.6 depth during average summer flow (V_{11}) exceeded 16 cm/s.

When V_{11} was eliminated from C_{OT} determination, performance of the model improved. It appears that the average velocity variable (V_{11}) does not account for the numerous microhabitats available in the diverse environment of a large southeastern coastal plain river. Warmouths and other riverine fishes apparently utilize these available microhabitats to avoid the harsh conditions associated with high velocities.

Bluegill

All of the sample areas were within the natural range of the bluegill (Lee 1980c), and the species was expected to occur in all of them. The food component (C_F) of the bluegill model (Appendix A) is based on percent pool area during average summer flow (V_1) and percent bottom cover (aquatic vegetation, logs, and debris) in pools or littoral areas during summer (V_2). The cover component (C_C) of the model is dependent only on V_2. The water quality component (C_{WQ}) is determined from maximum monthly average turbidity (suspended solids) during average summer flow (V_5), pH range during growing season (V_6), dissolved oxygen range during summer (V_7), maximum monthly average salinity during the growing season (V_8), maximum midsummer temperature within pools or littoral areas for adults (V_9), and maximum early summer temperature within pools or littoral areas for fry (V_{11}) and for juveniles (V_{12}). The reproductive component (C_R) is determined from the average of mean weekly water temperatures in pools or littoral areas during spawning (February-August; water temperature 19 to 34° C) (V_{10}), average current velocity during spawning for embryos (V_{14}), and substrate composition in pools or littoral areas during spawning for embryos (V_{19}). The "other" component (C_{OT}) of the model is based on average current velocity during growing season for adults (V_{13}) and for fry (V_{15}) and stream gradient within a representative reach (V_{17}).

Bluegill HSI's and estimated standing crops (Table B-11) were strongly correlated (r = 0.79). The bluegill model performed better than any other model tested, and no model modifications were attempted.

Black Crappie

All of the sample areas were within the natural range of the black crappie (Lee 1980d), and the species was expected to occur in all of them. The food/cover component ($C_{F/C}$) of the black crappie model (Appendix A) is based on percent cover (e.g., vegetation, brush, debris, and standing timber) during midsummer in pools, overflow areas, and back waters (V_2) and percent pools and backwater areas during average spring and summer flow (V_5). The water quality component (C_{WQ}) is determined from the most suitable water temperature in pools and backwaters during midsummer for adults (V_8), juveniles (V_9), and fry (V_{10}); minimum dissolved oxygen levels within the temperature strata selected above (V_8, V_9, and V_{10}) during midsummer (V_{12}), pH levels during the year (V_7), and maximum monthly average turbidity during summer (V_1). An optional variable concerning maximum salinity during growing season (V_{14}) can be added to the C_{WQ} equation. The reproductive component (C_R) is based on V_2, V_5,

average water temperature in backwaters during spawning for embryos (V_{11}), and minimum dissolved oxygen levels in backwaters during spawning for embryos and fry (V_{13}). The "other" component (C_{OT}) of the model is determined from stream gradient within the study area (V_3) and average current velocity in pools and backwater areas during average summer flow (V_4).

The HSI's did not correlate well with estimated standing crops ($r = -0.096$). Only the Altamaha (Mainstream B) sample area had an HSI = 0 (Table B-12), which was due to the high water temperatures in pools and backwaters during midsummer that might adversely effect black crappie juvenile and fry. Variables, such as this one, fail to consider the ability of fishes to avoid an excessively high "average" temperature by temporarily seeking refuge in adjacent areas with lower temperatures.

Largemouth Bass

All of the sample areas were within the natural range of the largemouth bass (Lee 1980e), and the species was expected to occur in all of them. The food component (C_F) of the largemouth bass model (Appendix A) is determined from percent pool and backwater area during average summer flow (V_1) and percent bottom (e.g., aquatic vegetation, logs, and debris) cover within pools or backwaters during summer for adults and juveniles (V_3) and for fry (V_4). The cover component (C_C) of the model is based on V_3, V_4, average water level fluctuation during the growing season for adults and juveniles (V_{16}) and for fry (V_{18}). The water quality component C_{WQ} of the model is based initially on maximum salinity during summer for adults and juveniles (V_{12}) and for fry (V_{13}). Minimum dissolved oxygen levels during midsummer in pools (V_6), pH range during growing season (V_7), average water temperature in pools or backwaters during the growing season for adults and juveniles (V_8) or for fry (V_{10}), and maximum monthly average turbidity (suspended solids) during the growing season (V_{11}) are also considered in C_{WQ}. The reproductive component of the model is determined from V_1, average weekly mean temperature within pools during spawning and incubation for embryos (V_9), maximum salinity during spawning and incubation for embryos (V_{14}), substrate composition in riverine pools and backwaters for embryos (V_{15}), maximum water level fluctuation during spawning for embryos (V_{17}), and maximum current velocity at 0.2 depth within pools or backwaters during spawning (May to June) for embryos (V_{20}). The user has two options for the "other" component (C_{OT}). One option considers average current velocity at 0.6 depth during summer for adults and juveniles (V_{19}) and for fry (V_{21}). The other option for the C_{OT} determination considers only the stream gradient within the representative reach (V_{22}).

The original model performed very poorly, with all sample areas having an HSI of 0. Zero HSI's were due to 0 C_R values resulting from high velocities in pools and backwaters. In many of the sample areas, actual "pools" or "backwaters" were absent, and the maximum velocities during the designated time period exceeded 10 cm/s. Elimination of this variable (V_{20}) resulted in considerable improvement in model performance (r = 0.785). Large segments of many southeastern coastal plain rivers have virtually no "pools" or "backwaters", and the definition of variable V_{20} probably should be modified for this area. The new definition should take into consideration the fact that largemouth bass can thrive in these situations by staying in small protected areas along the shore. The relatively high standing crops in mainstream samples confirm the ability of largemouth bass to thrive in large, fast flowing rivers.

Black Bullhead

The black bullhead is not native to any of the sample areas (Glodek 1980a) and was not expected to occur in the tested rivers. The food component (C_F) of the model (Appendix A) is determined from percent pools and backwaters during average summer flow (V_1) and percent cover objects (e.g., vegetation, brush, and debris) within pools or backwaters during summer (V_2). The cover component (C_C) is based on V_1, V_2, and average current velocity at 0.6 depth during average summer flow (V_3). The water quality component (C_{WQ}) is determined from maximum midsummer water temperature within pools or backwaters (V_4), dissolved oxygen range within pools or backwaters during summer (V_5), pH range during the year (V_6), and maximum monthly average turbidity (suspended solids) during the growing season (V_9). The reproductive component (C_R) is determined from maximum salinity during early summer (May-June) for embryos and fry (V_8), V_1, average water temperature within pools or backwaters during spawning and embryonic development for embryos (V_{10}), dominant substrate type in pools and backwaters for spawning (V_{11}), and percent cover objects (e.g., vegetation, brush, and debris) in pools or backwaters during spawning for embryos (V_{12}).

As expected, black bullheads did not occur in any of the sample areas. HSI's were 0 for all sample areas (Table B-14).

Many of the Suitability Index curves used to determine variable values were based on assumed similarities of habitat requirements between black bullheads and other bullheads or catfishes in general because of the lack of information specific to the black bullhead. Therefore, it was assumed that the model also could be used to assess habitat suitability for other bullheads. Models were modified by eliminating variables that resulted in 0 HSI's and comparing the resulting HSI's with estimated standing crops of brown bullheads

(Table B-14). HSI's for the original and the modified model did not correlate well with estimated standing crops of "bullheads"; correlation coefficients were 0.200 and 0.263, respectively.

Zero HSI's in tested habitats were due to high average current velocities; however, standing crops of brown bullheads were relatively high (> 40 kg/ha) at three of the sample areas. Lack of specific information concerning the habitat requirements of the black bullhead obviously limits the use of the model.

Channel Catfish

The channel catfish is native to central drainages of the United States; however, it also has been widely introduced in Atlantic coastal drainages (Glodek 1980b). The channel catfish was expected to occur in all of the sample areas. The food component (C_F) of the channel catfish model (Appendix A) is based on percent cover (logs, boulders, cavities, brush, debris, or standing timber) during summer in pools or backwater areas (V_2) and food production potential in the river by substrate type present during average summer flow (V_4). The cover component (C_C) is determined from percent pools during average summer flow (V_1), V_2, and average current velocity in cover areas during average summer flow (V_{18}). The water quality component (C_{WQ}) is based on average midsummer water temperature within pools or backwaters for adults (V_5), fry (V_{12}), and juveniles (V_{14}); maximum monthly average turbidity during summer (V_7); average minimum dissolved oxygen levels within pools or backwaters during midsummer (V_8); and maximum salinity during summer for adults (V_9) and for fry and juveniles (V_{13}). The reproductive component (C_R) is based on V_1, V_2, V_8, average water temperatures within pools and backwaters during spawning and embryo development for embryos (V_{10}), and maximum salinity during spawning and embryo development for embryos (V_{11}). In HSI determinations, C_{WQ} and C_R were weighted more heavily than C_F and C_C.

HSI's and estimated standing crops were not well correlated (0.049). There was little variation in HSI's (0.55 to 0.69), and two sample areas having HSI's of 0.69 had standing crops of 1.7 and 33.6 kg/ha, respectively (Table B-15).

There were no obvious problem areas in the channel catfish model. However, factors other than habitat may be limiting channel catfish abundance. All of the sample areas support a commercial catfish fishery, and channel catfish is the preferred species.

Common Carp

The common carp has been widely introduced throughout the United States (Allen 1980) and was expected to occur in all of the sample areas. The food component (C_F) of the model (Appendix A) is based on percent vegetative cover in shallow areas during spring and summer (V_1) and percent pools, backwaters, and marsh areas during average summer flow (V_4). The cover component (C_C) is determined from V_1, V_4, and percent cover in deeper pools (V_3). The water quality component (C_{WQ}) is based on maximum monthly average turbidity during average summer flow (V_7), maximum midsummer water temperature during average summer flow for adults (V_8) and for juveniles and fry (V_{10}); average dissolved oxygen levels during summer for fry, juveniles, and adults (V_{13}); and pH range during the year (V_{15}), with the option of adding a maximum salinity variable (V_{12}). The reproductive component (C_R) is determined from V_1, V_4, average water temperatures during spawning for embryos (V_9); maximum depth of pools, marshes, and backwaters during spawning (V_{11}); and average dissolved oxygen levels during spawning (March-June) for embryos (V_{14}). The "other" component (C_{OT}) is determined from average velocity during average summer flow (V_2).

All sample areas had HSI's within the rather narrow range of 0.49 to 0.62 (Table B-16); however, estimated standing crops ranged from 0 to over 136 kg/ha. The HSI's had a weak positive correlation with estimated standing crops. No variables were obviously dissimilar for the habitats tested, and it is impossible to determine the specific variables that need to be modified to improve model performance.

Discussion

Tested riverine HSI models performed poorly, and HSI's generally did not correlate well with estimated standing crops (Table 2). The bluegill model was a notable exception, with a correlation coefficient of 0.79. An obvious problem with the application of the tested riverine HSI models in large southeastern coastal plain rivers was associated with the current velocity variables. Model performance in some other cases (e.g., largemouth bass) was improved considerably by modifying current velocity variables. Elimination of the velocity variables that resulted in 0 HSI's in the largemouth bass model resulted in a correlation coefficient of 0.79 when slough and oxbow velocities were assumed to be 0. It should be noted that these modifications eliminated an obviously important habitat characteristic (current velocity), and such model modification probably would not be appropriate for smaller, less diverse habitats.

Table 2. Regression equations, probability levels, and correlation coefficients between HSI's and standing crops of selected species of riverine fishes.

Species	Model	Regression equation	P	Correlation coefficient
Green sunfish	Orig.	not calc.; only 1 data set		
	Mod.	Y = 0.20.4X + 0.632	-	-0.602
Warmouth	Mod.	Y = 0.0064X + 0.6967	0.375	0.446
Bluegill	Orig.	Y = 0.0046X + 0.5364	0.059	0.791
	Mod.	No data set		
Black crappie	Orig.	Y = -0.0014X + 0.4895	0.857	-0.096
	Mod.	not calc.; only 1 data set		
Largemouth bass	Orig.			
	Mod.	Y = 0.0095X + 0.6031	0.157	0.785
Black bullhead	Orig.	Y = -0.092X + 0.092	-	0.200
	Mod.	Y = 0.0022X + 0.5487	0.582	0.263
Channel catfish	Orig.	Y = 0.0002X + 0.5923	0.927	0.049
	Mod.	not calc.; only 1 data set		
Carp	Orig.	Y = -0.0001X + 0.5559	0.825	0.117

Many riverine fishes utilize the protected areas along the bank. Although these areas may be small, they provide sufficient protected habitat for the fish to thrive. Also, many of the models rely heavily on "pool" and "backwater" characteristics. In the sample areas tested, and in a considerable portion of large southeastern rivers that support these species, "pools" and "backwaters" are virtually nonexistent.

Riverine models apparently were based to a large degree on assumptions that apply better to small streams with alternating pools and riffles. The sample areas tested were large rivers that consist of flowing waters with few, if any, "pools" or "backwaters". Different suitability curves based on geographic or physiographic characteristics and flow might need to be developed for these situations.

The models tested did not result in HSI's that accurately reflected estimated standing crops. It appears that major modifications of some variable definitions (e.g., velocity standards, percent pools and backwaters, and associated cover components) would be required to make the models appropriate for all flowing water environments. As discussed for the reservoir models, stringent variable definitions fail to recognize the adaptability of fishes in terms of avoiding short term adverse conditions.

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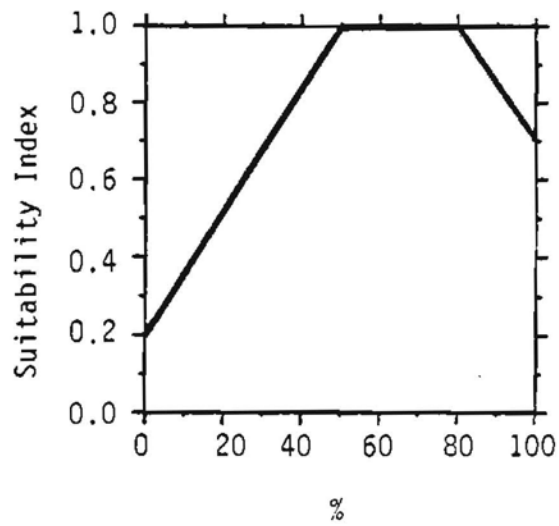
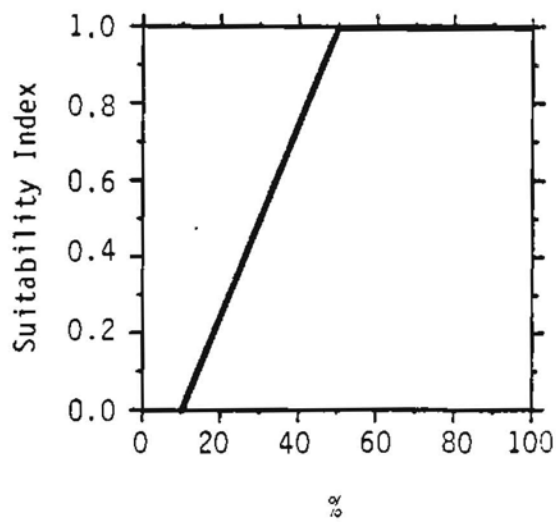
APPENDIX A

SUITABILITY INDEX (SI) GRAPHS AND HABITAT SUITABILITY INDEX (HSI) MODELS TESTED

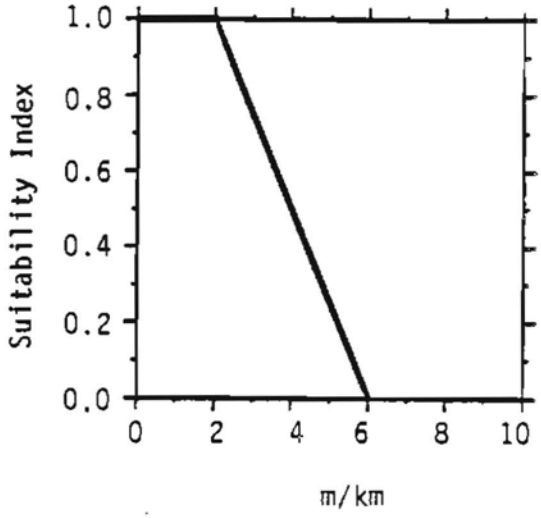
GREEN SUNFISH

Suitability Index (SI) Graphs for Green Sunfish Model Variables

The "R" for riverine and "L" for lacustrine under the heading "habitat" describe where the variable should be measured.

Habitat	Variable		Suitability graph
R,L	V_1	Percent bottom cover (e.g., vegetation, rocks, debris, etc.) within pools or littoral areas during summer.	
R	V_2	Percent pool area during average summer flow.	

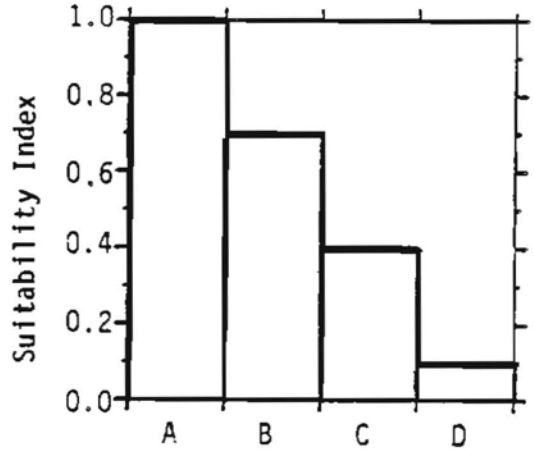
R V_3 Stream gradient within representative reach.



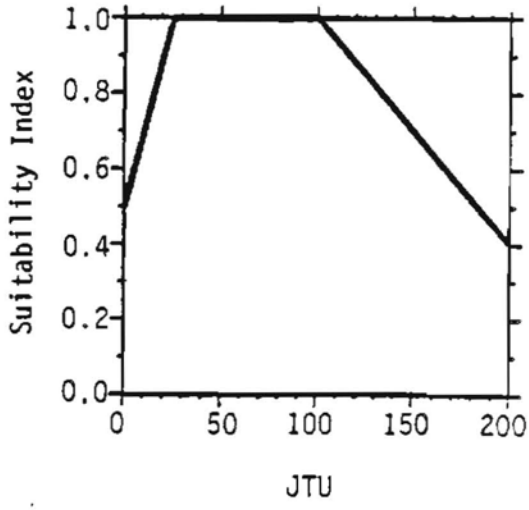
R,L V_4 Minimum dissolved oxygen levels during summer.

A) Usually > 5 mg/l
B) Usually 4-5 mg/l
C) Usually 2-4 mg/l
D) Frequently ≤ 2 mg/l

Note: Lacustrine DO levels refer to littoral areas.

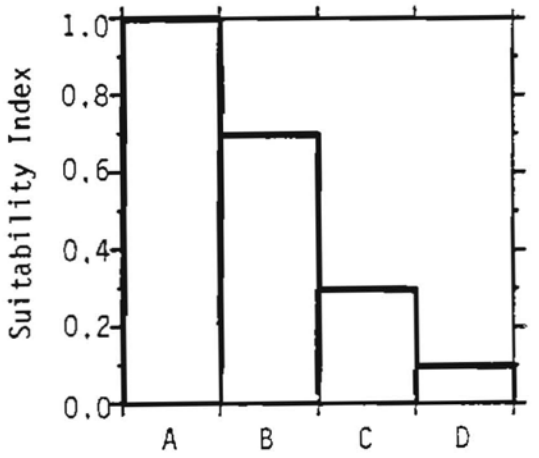


R,L V_5 Maximum monthly average turbidity within pools or littoral areas during the summer.

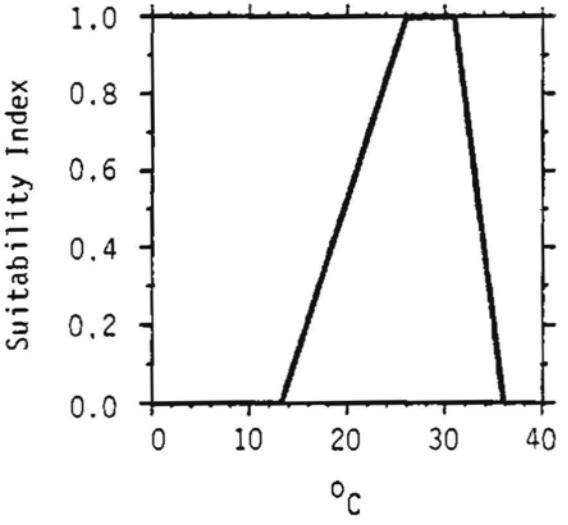


R,L V_6 pH range during summer growing season.

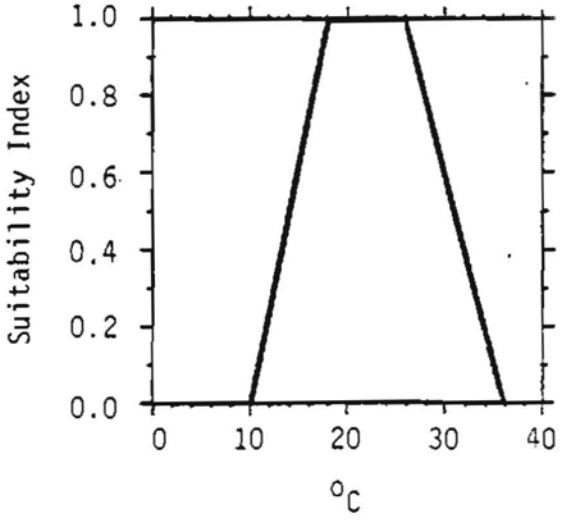
A) 6.5-8.5
B) 5.0-6.5 or 8.5-9.0
C) 4.0-5.0 or 9.0-10.0
D) < 4.0 or > 10.0

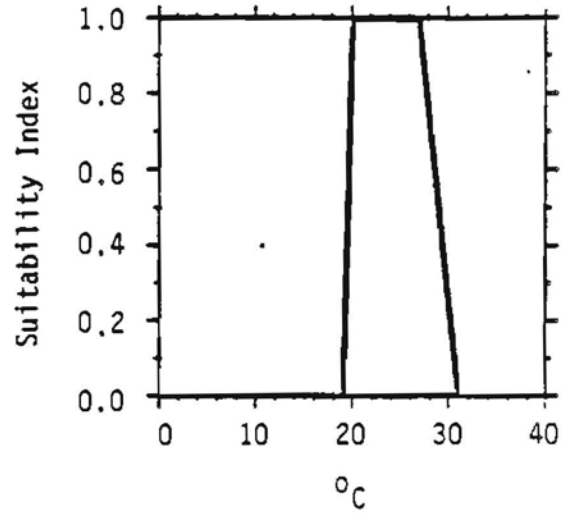
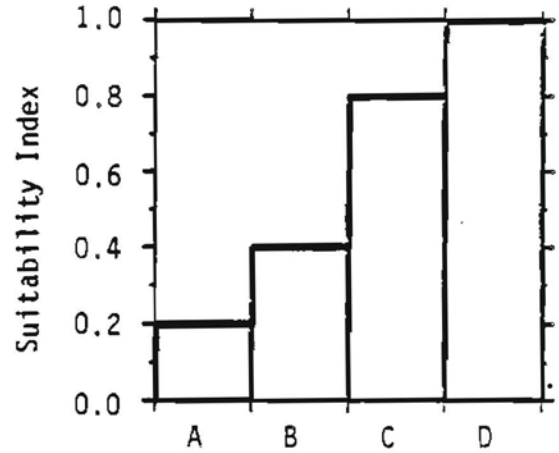
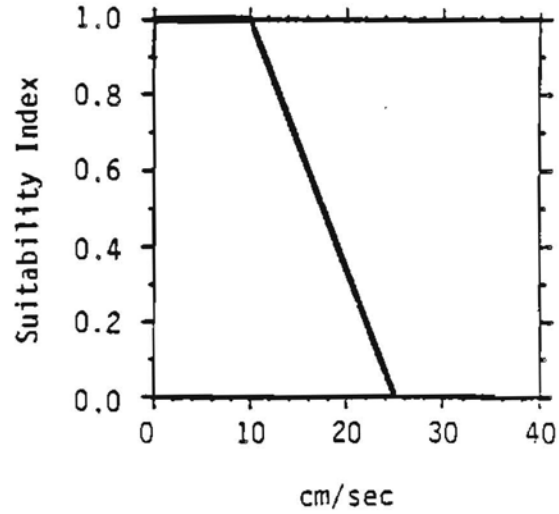


R,L V_7 Maximum midsummer temperature within pools or littoral areas (Adult, Juvenile).

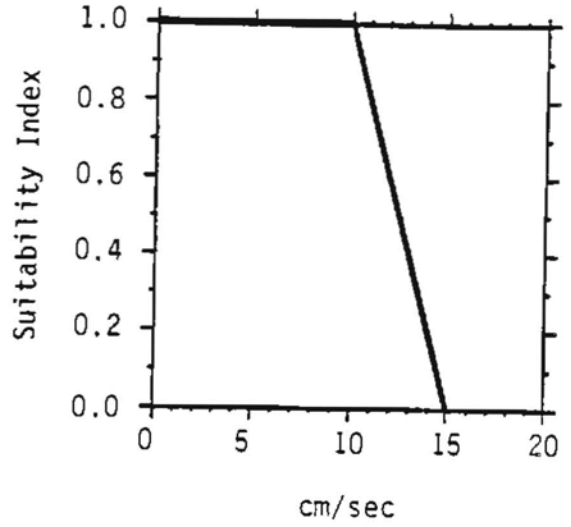


R,L V_8 Maximum midsummer temperature within pools or littoral areas (Fry).

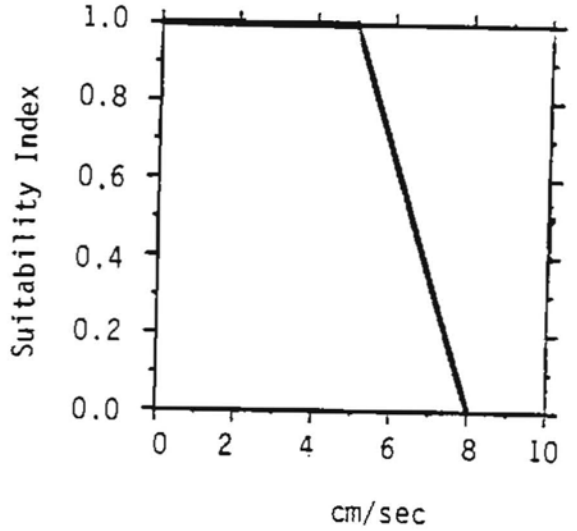


R,L	V_9	Maximum temperature within pools or littoral areas during spawning (June-July) (Embryo).	
R,L	V_{10}	Substrate composition within pools or littoral areas for spawning (Embryo). A) Boulder (> 20.0 cm) and bedrock predominate (≥ 50%). B) Cobble (5.0-20.0 cm) predominate. C) Silt and sand (≤ 0.2 cm) predominate. D) Pebbles and gravel (0.2-5.0 cm) predominate.	
R	V_{11}	Average current velocity within pools during average summer flow (Adult, Juvenile).	

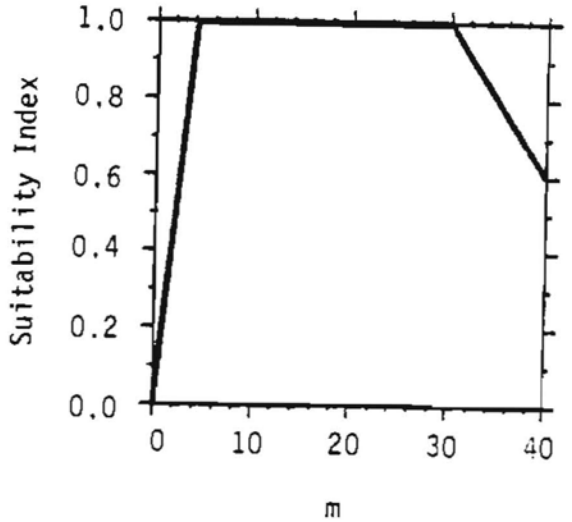
R V_{12} Average current velocity within pools during spawning (June-July) (Embryo).



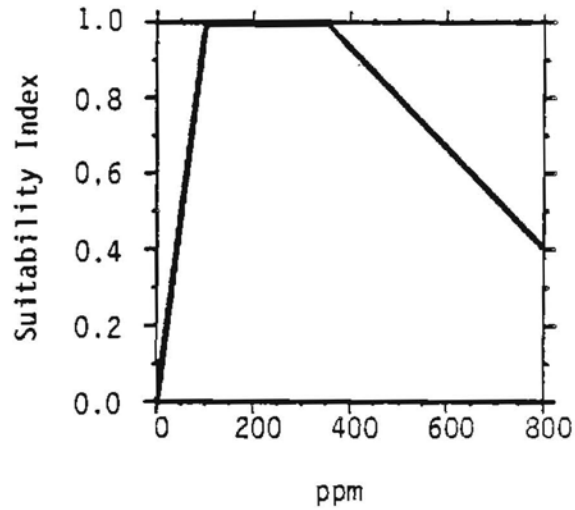
R V_{13} Average current velocity within pools during average summer flow (Fry).



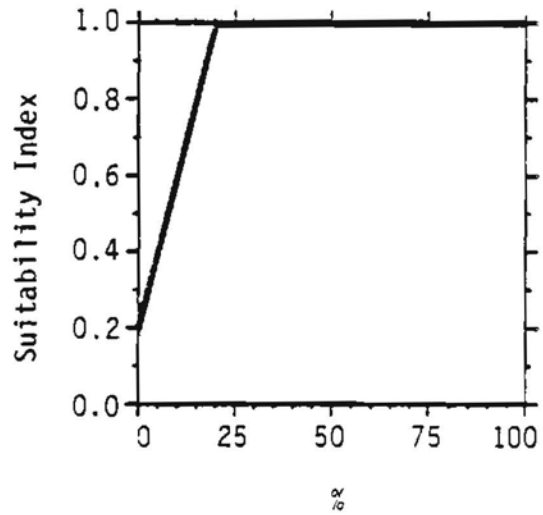
R V_{14} Average stream width within representative reach.



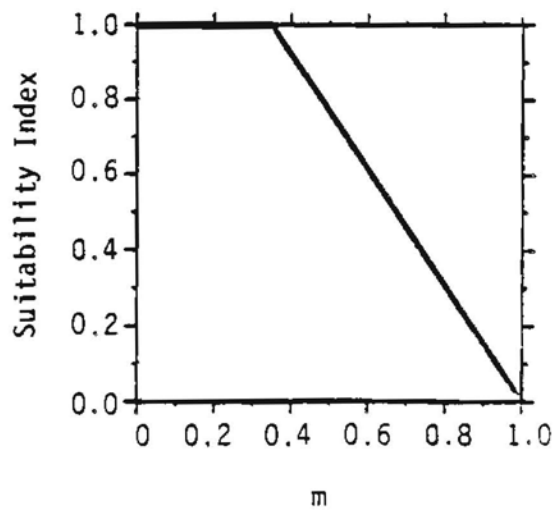
L V_{15} Average TDS level during growing season when the carbonate-bicarbonate > sulfate-chloride ionic concentration. If the sulfate-chloride ionic concentration > the carbonate-bicarbonate ionic concentration, the SI should be lowered by 0.2.



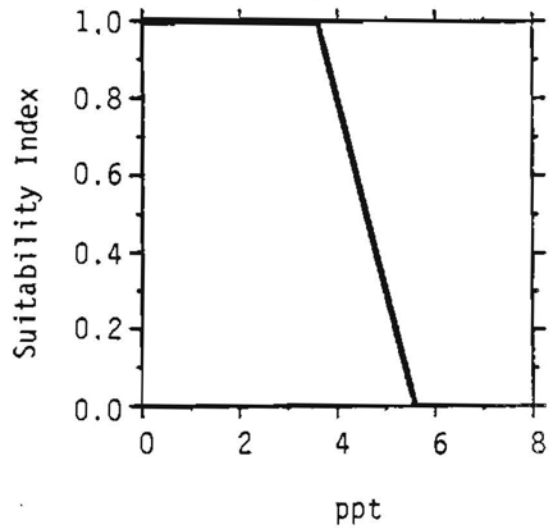
L V_{16} Percent littoral area during summer stratification.



L V_{17} Reservoir drawdown during spawning (Embryo).



R,L	V_{18}	Maximum monthly average salinity during growing season (Optional). Note: V_{18} can be omitted if salinity is not considered to be a potential problem within the study area.



Reservoir Habitat Suitability Index Model

Food Component (C_F) = V_{15}

Cover Component (C_C) = $(V_1 \times V_{16})^{1/2}$

Water Quality Component (C_{WQ}) = $\frac{2V_4 + V_5 + V_6 + V_7 + V_8}{6}$ if V_{18}, optional variable, is omitted.

If V_4, V_7, or $V_8 \leq 0.4$, C_{WQ} = the lowest of V_4, V_7, V_8, or above equation.

Reproduction Component (C_R) = $(V_9 \times V_{10} \times V_{17})^{1/3}$

If habitat being evaluated is a natural pond or lake, omit V_{17}:

$C_R = (V_9 \times V_{10})^{1/2}$

$HSI = (C_F \times C_C \times C_{WQ} \times C_R)^{1/4}$

If C_{WQ} or $C_R \leq 0.4$, the HSI = lowest of C_{WQ}, C_R, or above equation.

Riverine Habitat Suitability Index Model

$$C_{F/C} = (V_1 \times V_2)^{1/2}$$

$$C_{WQ} = \frac{2V_4 + V_5 + V_6 + V_7 + V_8 + V_{18}}{7}$$

If V_4, V_7, or $V_8 \leq 0.4$, C_{WQ} = lowest of V_4, V_7, V_8, or above equation.

$$C_{WQ} = \frac{2V_4 + V_5 + V_6 + V_7 + V_8}{6}$$ if V_{18} (optional salinity variable) is omitted

$$C_R = (V_9 \times V_{10} \times V_{12})^{1/3}$$

$$C_{OT} = \frac{V_3 + \frac{V_{11} + V_{13}}{2} + 0.5\ V_{14}}{2.5}$$

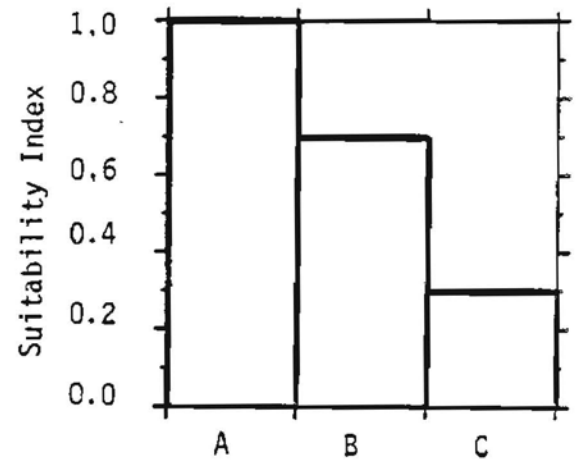
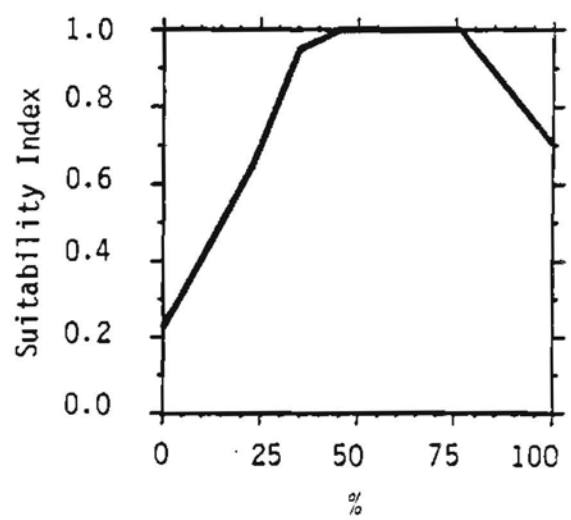
$$HSI = (C_{F/C} \times C_{WQ} \times C_R \times C_{OT})^{1/4}$$ if $C_{WQ} > 0.4$.

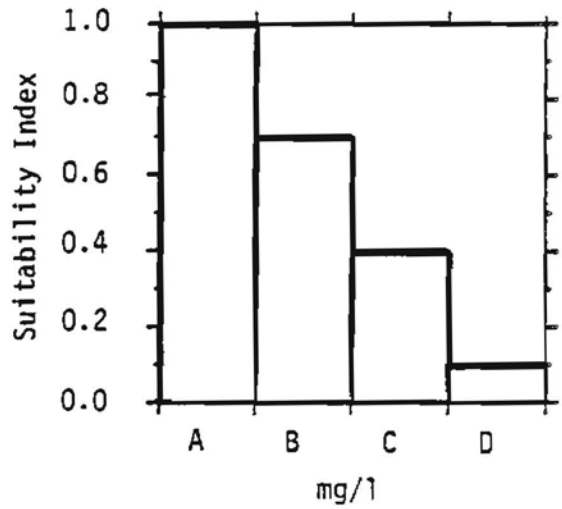
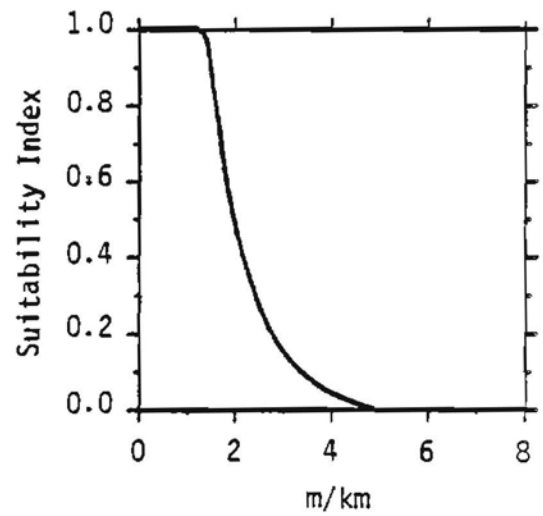
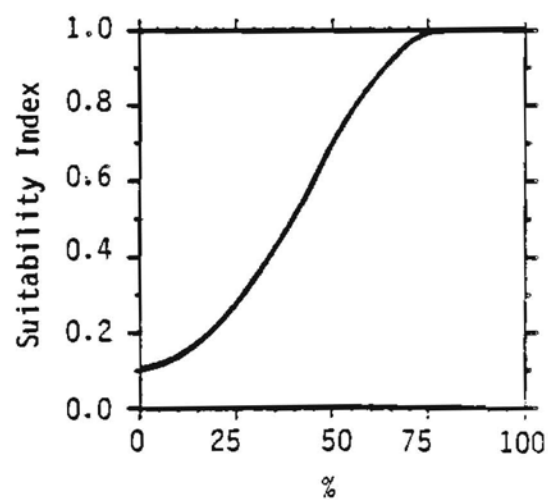
If $C_{WQ} \leq 0.4$, HSI = C_{WQ} or above equation, whichever is lower.

WARMOUTH

Suitability Index (SI) Graphs for Warmouth Model Variables

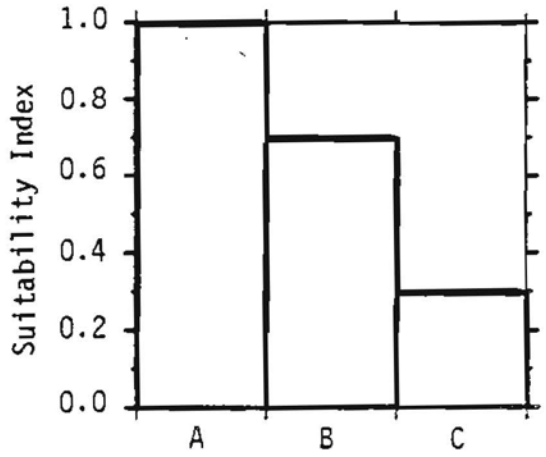
The "R" for riverine and "L" for lacustrine entered under the heading "habitat" describe where the variable should be measured.

Habitat	Variable		Suitability graph
R,L	V_1	Length of agricultural growing season (average number of days from last to first frost). This rating criteria would not be applicable to areas where exogenous factors significantly affect water temperature. A) > 200 days B) 160-200 days C) < 160 days	
R	V_2	Percent instream structure of rooted aquatic vegetation, logs, rocks, roots, and brush in pools during average summer flow. Note: This variable provides a measure of cover availability to all life stages and a measure of habitat for food production.	

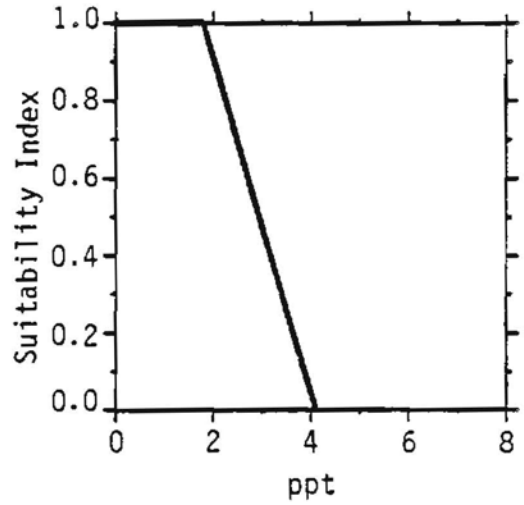
R,L	V_3	Dissolved oxygen range during summer (temperature ≥ 20° C). A) DO usually > 6 mg/l; never < 5 mg/l. B) DO usually > 3.6 mg/l; never < 2.0 mg/l. C) DO often < 3.6 mg/l, but > 1 mg/l. D) DO drops to levels ≤ 1 mg/l. Measure in pools or shallow shoreline areas in lakes or reservoirs.	
R	V_4	Stream gradient in reach.	
R	V_5	Percent pool area during average summer flow.	

R,L V_6 pH range during the year:

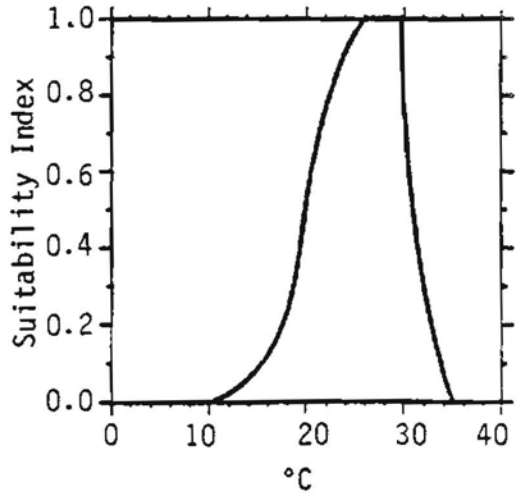
A) pH between 6.0 and 9.0.
B) pH between 5.0-6.0 or 9.0-11.0.
C) pH < 5.0 or > 11.0.

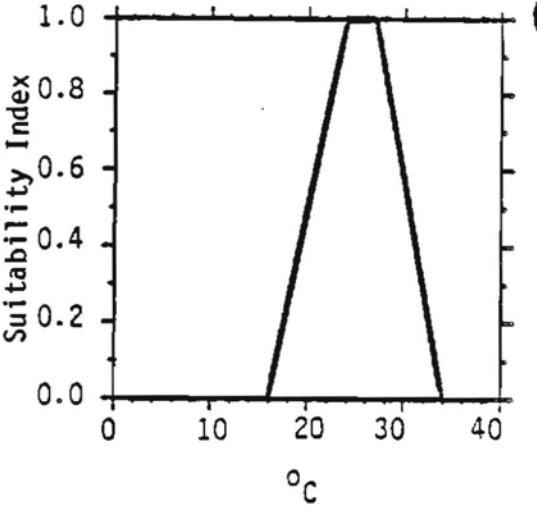
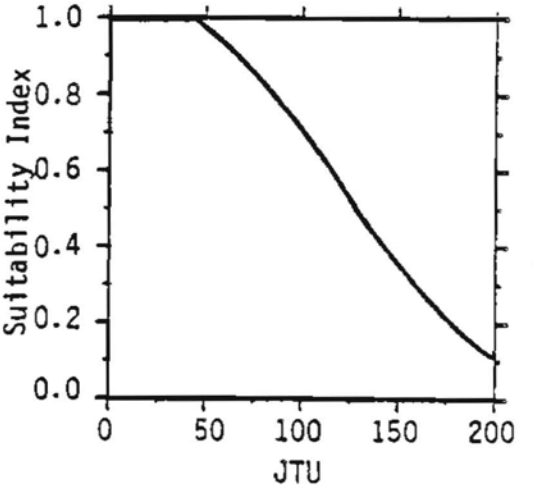
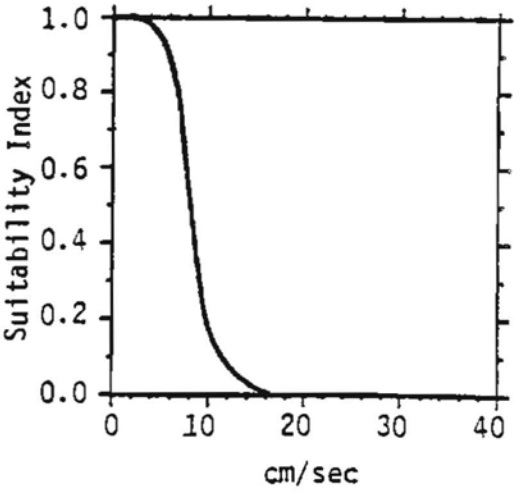


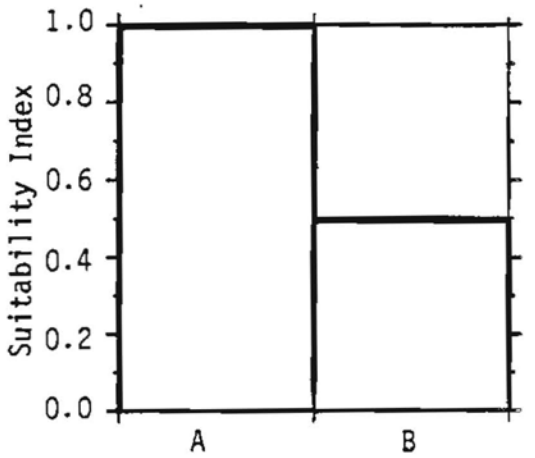
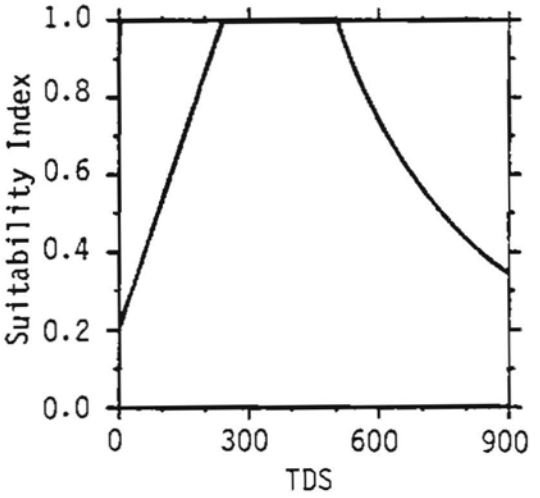
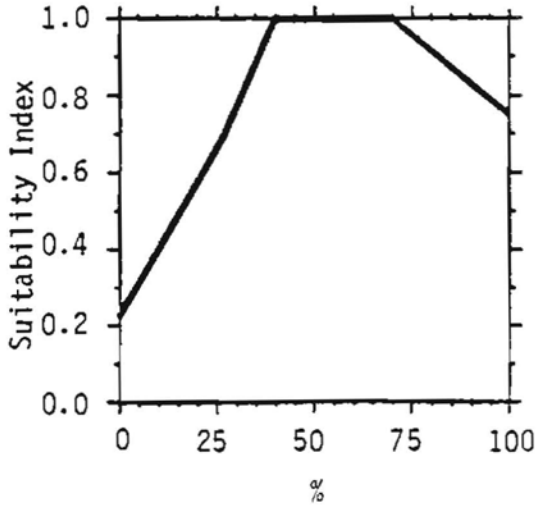
R,L V_7 Maximum salinity during average summer water level.



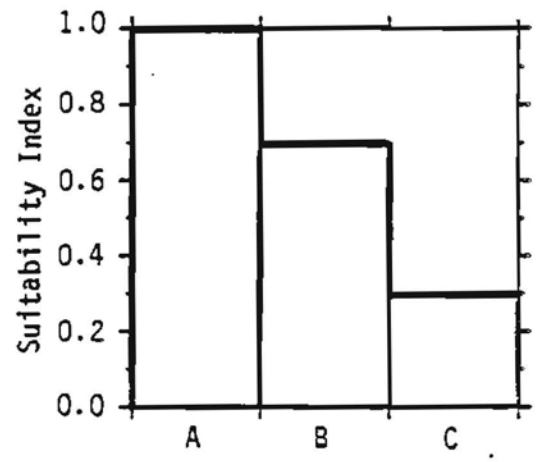
R,L V_8 Average mean weekly water temperature during mid-June to mid-September (Fry, Juvenile, and Adult). Measure in pools or shallow shoreline areas in lakes or reservoirs.



R,L	V_9	Average mean weekly water temperature during spawning (mid-May to mid-June) (Embryo). <u>Note</u>: If daily temperature fluctuations are > 5° C, SI = 0.	
R,L	V_{10}	Maximum monthly average turbidity during average summer flow.	
R	V_{11}	Average stream velocity at 0.6 depth during average summer flow.	

R,L	V_{12}	Water level stability during spawning and incubation (mid-May to mid-July) (Embryo). A) Water level fluctuations < ±1 m. B) Water level fluctuations > ±1 m.	
L	V_{13}	Mean total dissolved solids (TDS) during the summer.	
L	V_{14}	Percent cover along the shoreline at < 3 m depth during average summer conditions.	

L	V_{15}	Average mean depth/ shoreline development during average summer conditions. A) Characterized by low mean depths (< 3 m) and/or high shoreline development of extensive areas (≥ 20%) of shallow, gently sloping shoreline. B) Characterized by moderate mean depths (3-8 m) and/or moderate shoreline development of some (< 20%) shallow, gently sloping shoreline areas present. C) Characterized by high mean depths (> 8 m) and/or low shoreline development (steep, rocky shoreline).



Reservoir Habitat Suitability Index Model

$$C_F = \frac{V_{13} + V_{14} + V_{15}}{3}$$

$$C_C = (V_{12} \times V_{14}^2 \times V_{15})^{1/4}$$

$$C_{WQ} = \frac{V_1 + 2\,V_3 + V_6 + V_7 + 2\,V_8 + V_{10}}{8} \quad \text{if } V_3 \text{ and } V_8 > 0.4$$

If V_3 or $V_8 \leq 0.4$, C_{WQ} = the lowest of V_3, V_8, or above equation.

If any variable equals 0, $C_{WQ} = 0$

$$C_R = (V_9 \times V_{12})^{1/2}$$

$$HSI = (C_F \times C_C \times C_{WQ}^2 \times C_R^2)^{1/6}$$

If C_C, C_R, or $C_{WQ} \leq 0.4$, HSI = the lowest component rating.

Riverine Habitat Suitability Index Model

$$C_F = \frac{V_2 + V_5}{2}$$

$$C_C = (V_2^2 \times V_5^2 \times V_{12})^{1/5}$$

$$C_{WQ} = \frac{V_1 + 2(V_3) + V_6 + V_7 + 2(V_8) + V_{10}}{8} \text{ if } V_3 \text{ and } V_8 \text{ both} > 0.4$$

If V_3 or $V_8 \leq 0.4$, C_{WQ} = lowest of V_3, V_8, or above equation.

If any variable = 0, $C_{WQ} = 0$.

$$C_R = (V_{12} \times V_9^2 \times V_2)^{1/4}$$

$$C_{OT} = \frac{2(V_{11}) + V_4}{3}$$

If V_{11} or V_4 equals 0, $C_{OT} = 0$

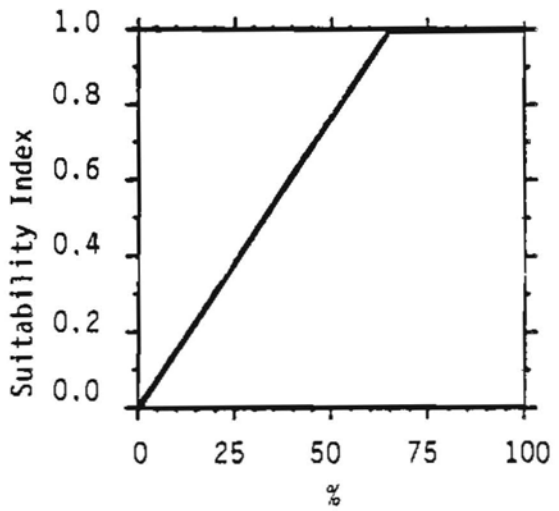
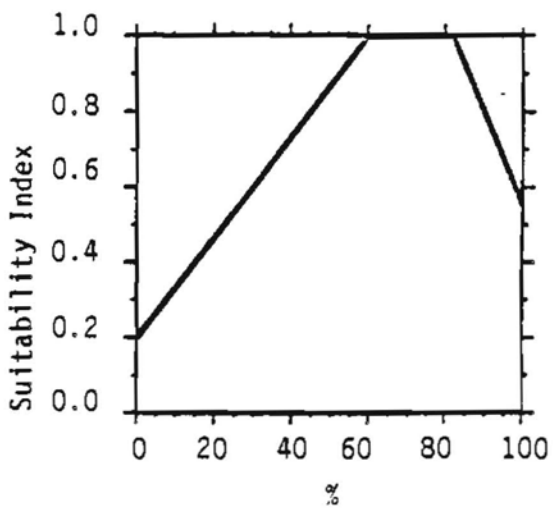
$$HSI = (C_F \times C_C \times C_{WQ}^2 \times C_R^2 \times C_{OT})^{1/7} \text{ if all component ratings are} > 0.4$$

If C_C, C_{WQ}, C_R, or $C_{OT} \leq 0.4$, the HSI = the lowest component.

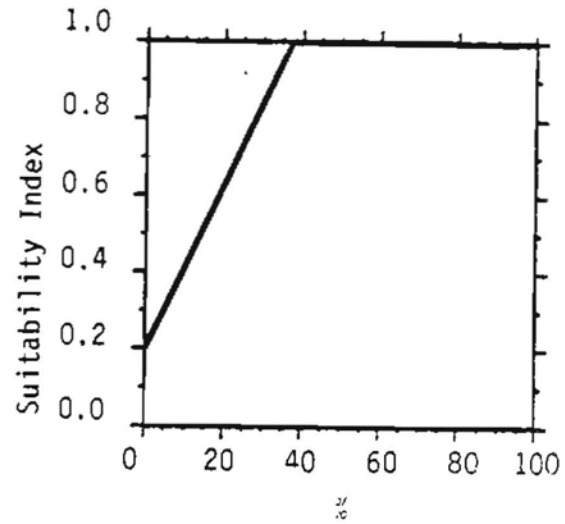
BLUEGILL

Suitability Index (SI) Graphs for Bluegill Model Variables

The "R" for riverine and "L" for lacustrine entered under the heading "habitat" describe where the variable should be measured.

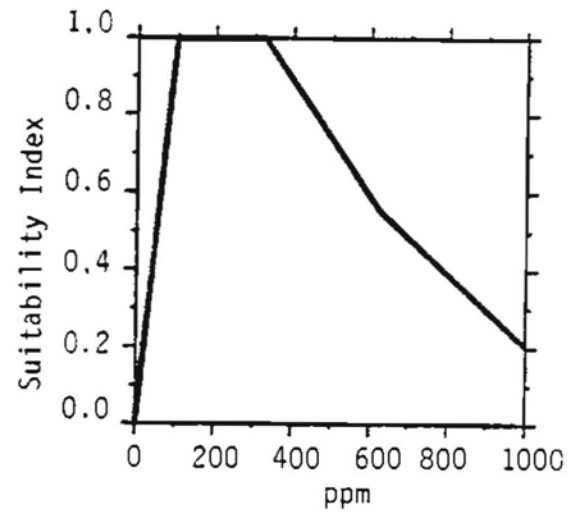
Habitat	Variable		Suitability graph
R	V_1	Percent pool area during average summer flow.	
R,L	V_2	Percent bottom cover (aquatic vegetation, logs, debris, etc.) within pools or littoral areas during summer.	

L V_3 Percent littoral area during summer stratification.

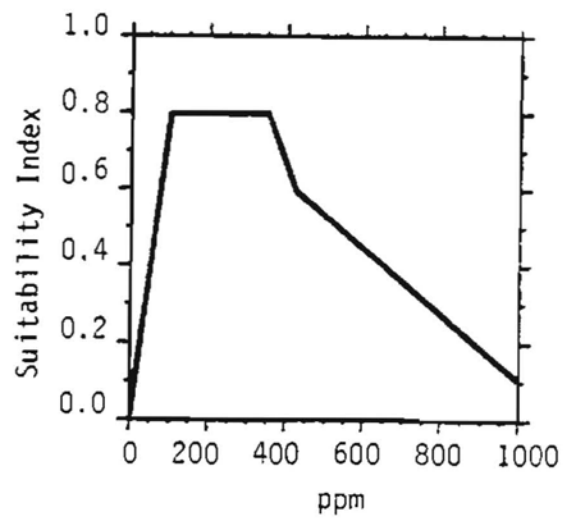


L V_4 Average TDS level during growing season.

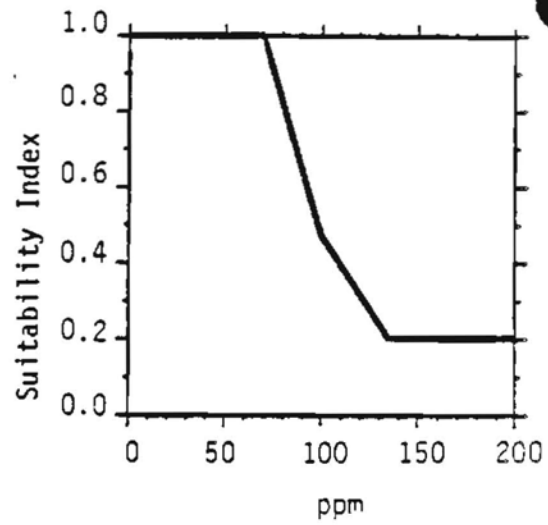
A) Carbonate-bicarbonate > sulfate-chloride ionic concentration.



B) Sulfide-chloride > carbonate-bicarbonate ionic concentration.

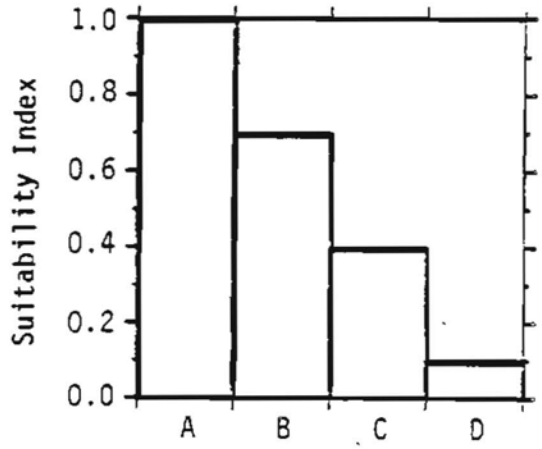


R,L V_5 Maximum monthly average turbidity (suspended solids) during average summer flow or summer stratification.



R,L V_6 pH range during growing season.

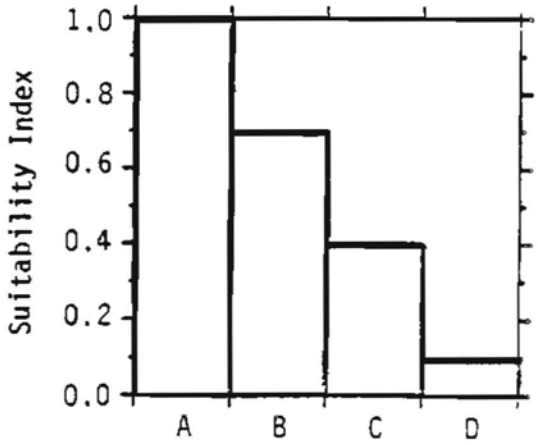
A) 6.5-8.5
B) 5.0-6.5 or 8.5-10.0
C) 4.0-5.0 or 10.0-10.3
D) < 4.0 or > 10.3

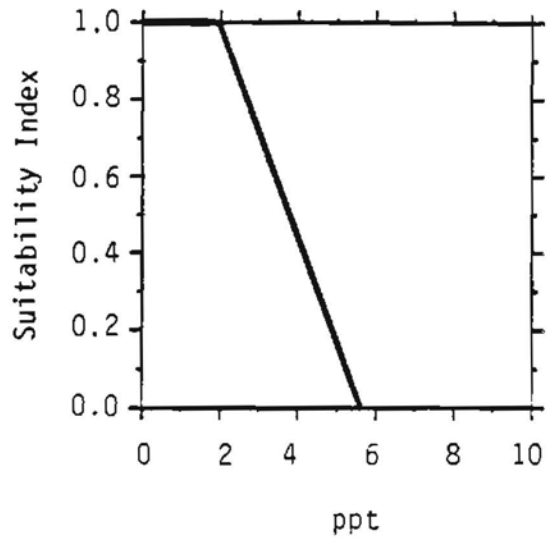
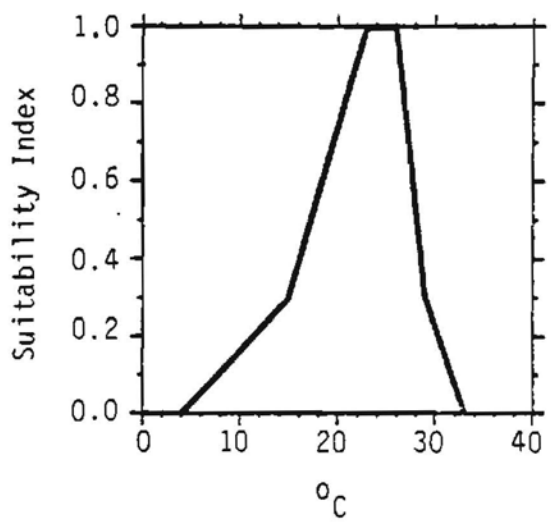
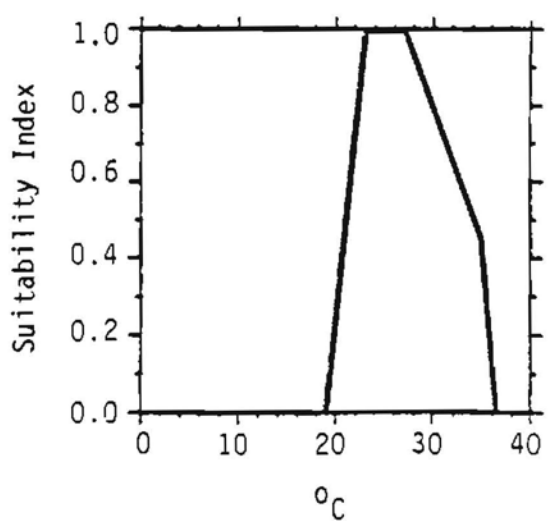


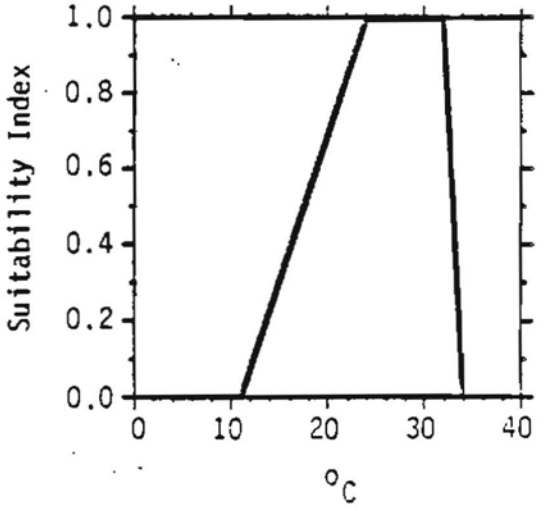
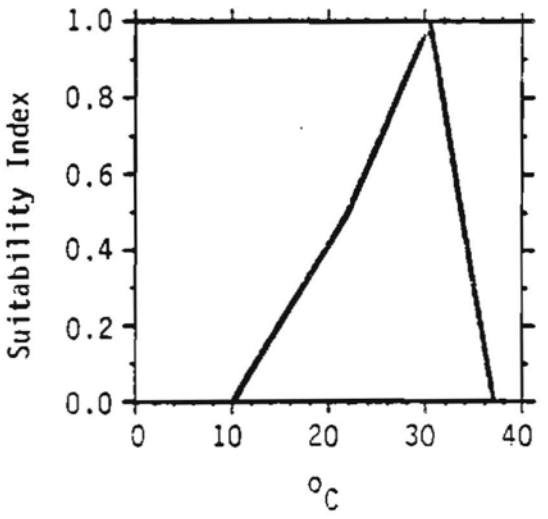
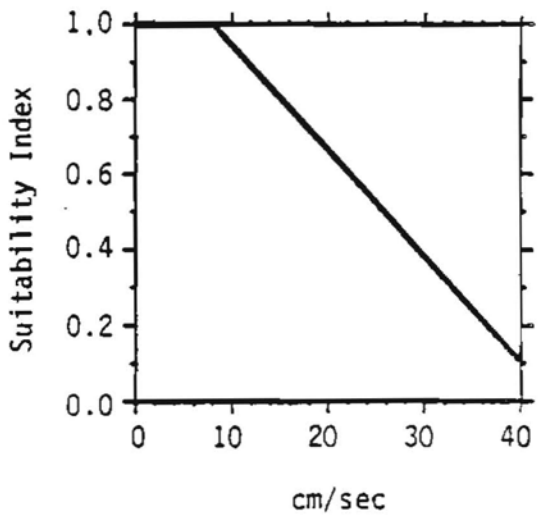
R,L V_7 Dissolved oxygen range during summer.

A) Seldom below 5.0 mg/l
B) Usually between 3.0 and 5.0 mg/l
C) Usually between 1.5 and 3.0 mg/l
D) Often below 1.5 mg/l

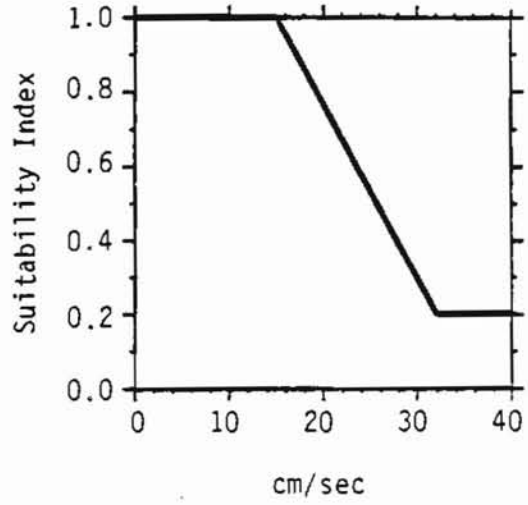
Note: Lacustrine DO levels refer to littoral areas; riverine DO refers to pools.



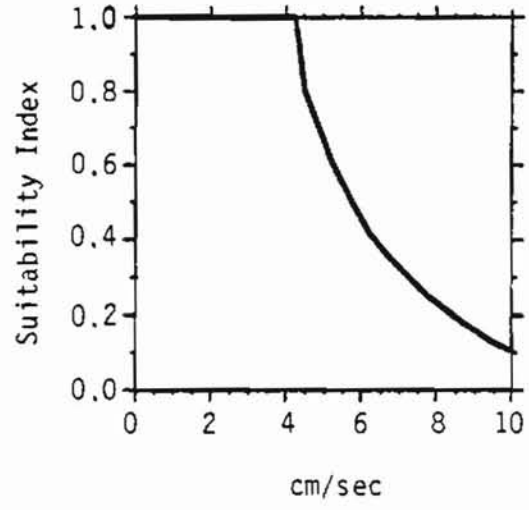
R,L	V_8	Maximum monthly average salinity during growing season.	
R,L	V_9	Maximum midsummer temperature within pools or littoral areas (Adult).	
R,L	V_{10}	Average of mean weekly water temperatures within pools or littoral areas during spawning (February-August; water temperature 19-34° C) (Embryo).	

R,L	V_{11}	Maximum early summer temperature within pools or littoral areas (Fry).	
R,L	V_{12}	Maximum midsummer temperature within pools or littoral areas (Juvenile).	
R	V_{13}	Average current velocity during growing season (Adult).	

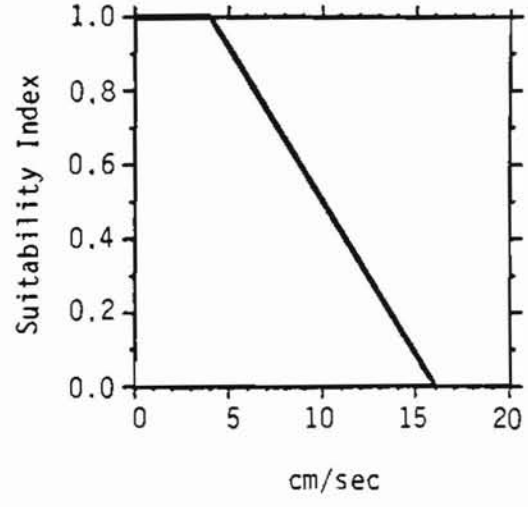
R	V_{14}	Average current velocity during spawning (Embryo).

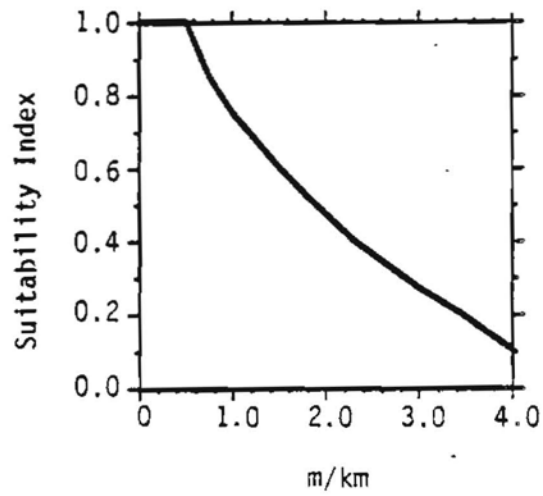
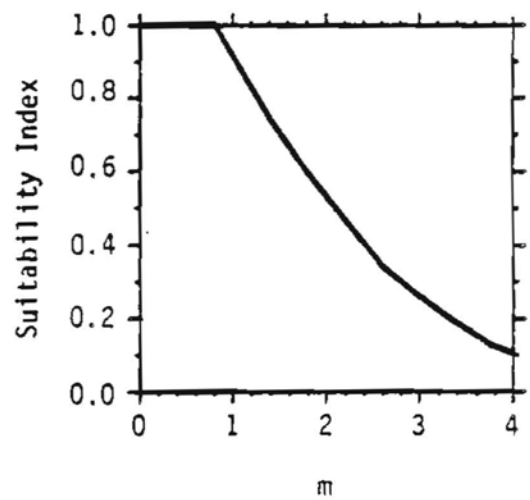
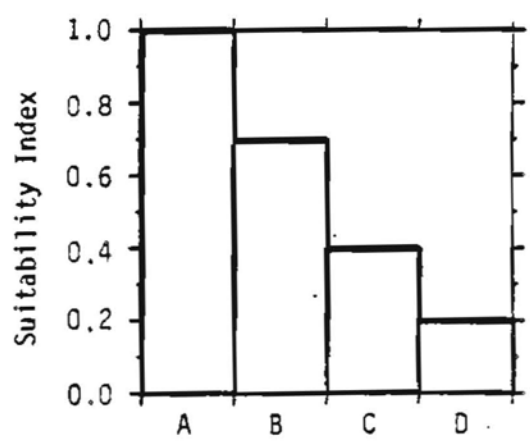


R	V_{15}	Average current velocity during early summer (Fry).



R	V_{16}	Average current velocity during growing season (Juvenile).



R	V_{17}	Stream gradient within representative reach.	
L	V_{18}	Reservoir drawdown during spawning (Embryo).	
R,L	V_{19}	Substrate composition within pools or littoral areas during spawning (Embryo). A) Fines and gravel predominate (> 50%) B) Fines and gravel present (25-50%) C) Fines and gravel noticeable (10-25%) D) Fines and gravel scarce (< 10%)	

Reservoir Habitat Suitability Index Model

$$C_F = (V_2 \times V_4)^{1/2}$$

$$C_C = (V_2 \times V_3^2)^{1/3}$$

$$C_{WQ} = \frac{V_5 + V_6 + 2V_7 + 2(V_9 \times V_{11} \times V_{12})^{1/3}}{6}$$

If V_7 or $(V_9 \times V_{11} \times V_{12})^{1/3} \leq 0.4$, C_{WQ} = the lowest of V_7, $(V_9 \times V_{11} \times V_{12})^{1/3}$, or above equation

$$C_R = (V_{10} \times V_{19})^{1/2}$$

$$HSI = (C_F \times C_C \times C_{WQ}^2 \times C_R)^{1/5}$$

Riverine Habitat Suitability Index Model

$$C_F = (V_1 \times V_2)^{1/2}$$

$$C_C = V_2$$

$$C_{WQ} = \frac{V_5 + V_6 + 2V_7 + V_8 + 2\,(V_9 \times V_{11} \times V_{12})^{1/3}}{7}$$

If V_7 or $(V_9 \times V_{11} \times V_{12})^{1/3} \leq 0.4$, C_{WQ} = lowest of V_7, $(V_9 \times V_{11}, \times V_{12})^{1/3}$, or above equation

$$C_R = (V_{10} \times V_{14} \times V_{19})^{1/3}$$

$$C_{OT} = \frac{\frac{V_{13} + V_{15} + V_{16}}{3} + V_{17}}{2}$$

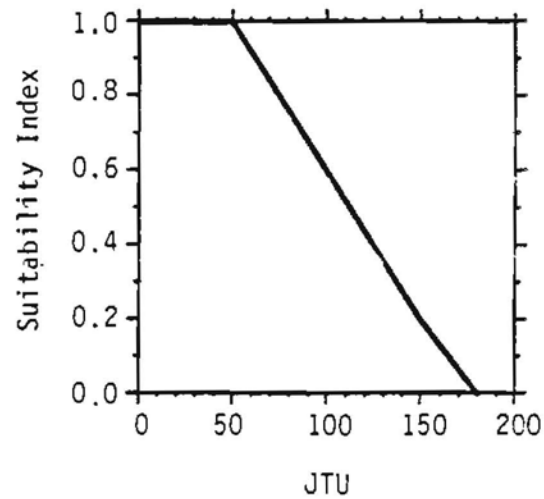
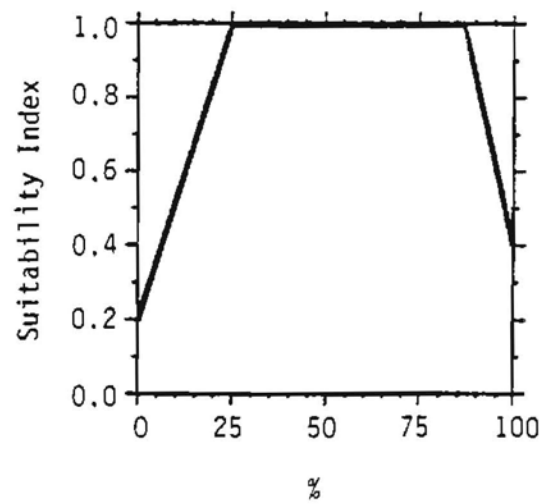
$HSI = (C_F \times C_C \times C_{WQ}{}^2\ C_R \times C_{OT})^{1/6}$ if all component ratings > 0.4

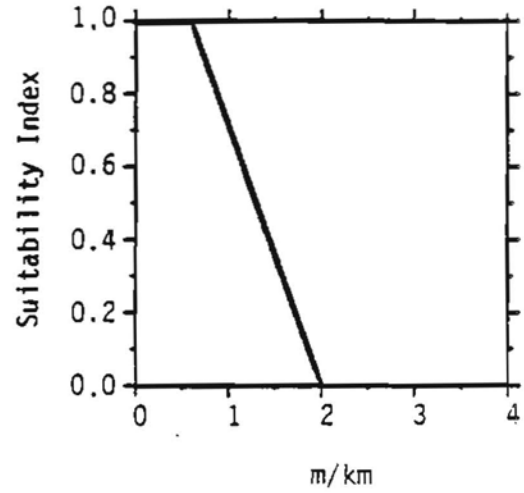
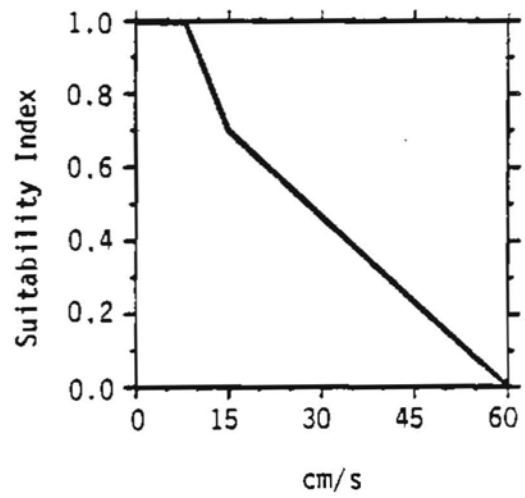
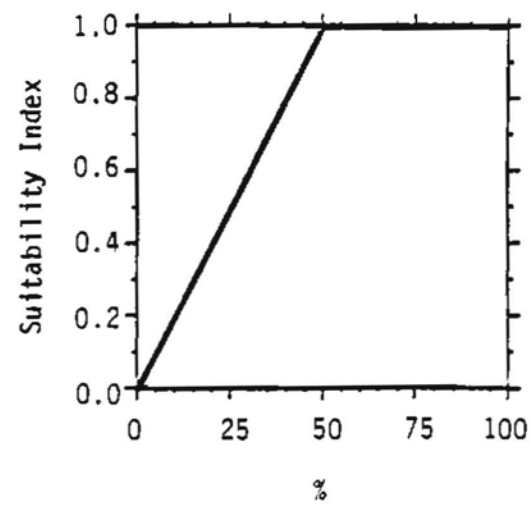
If C_{WQ} or $C_R \leq 0.4$, use lowest component rating as the HSI

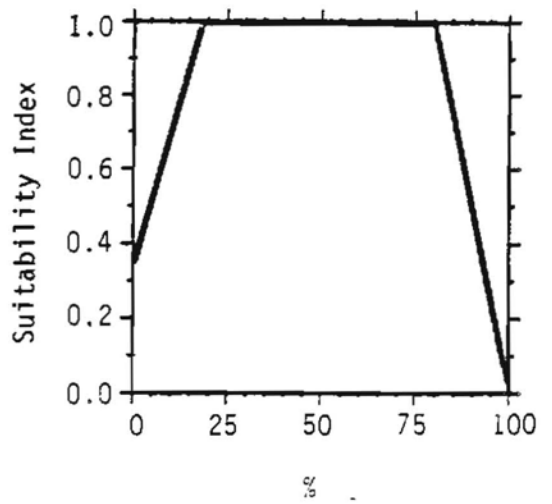
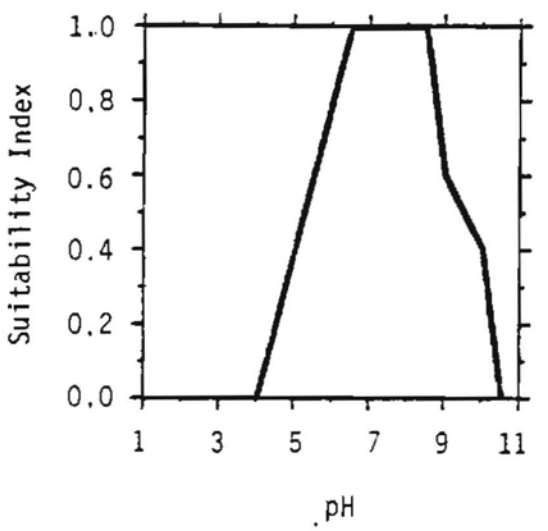
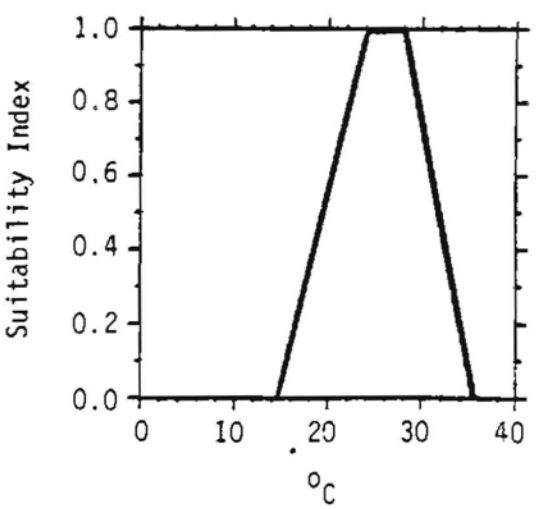
BLACK CRAPPIE

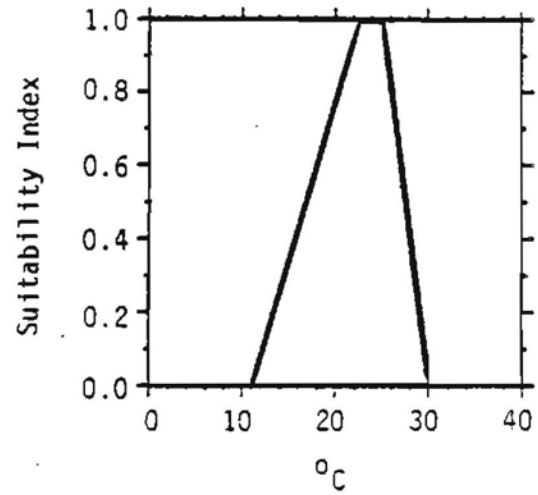
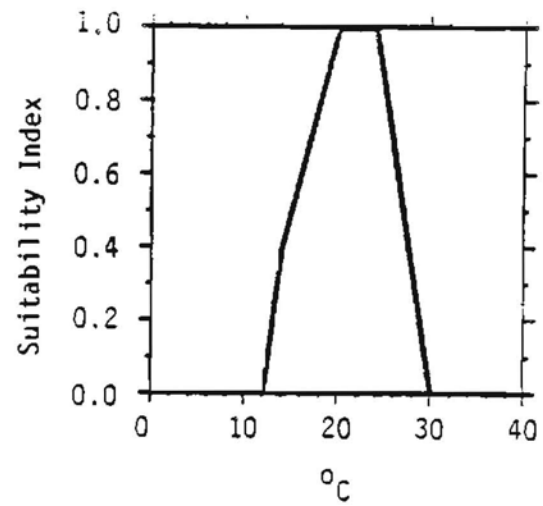
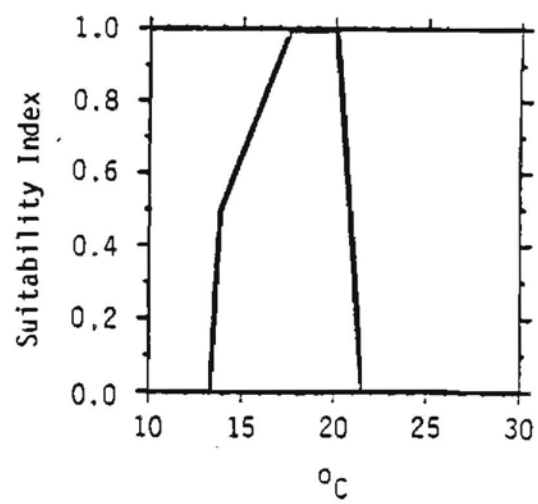
Suitability Index (SI) Graphs for Black Crappie Model Variables

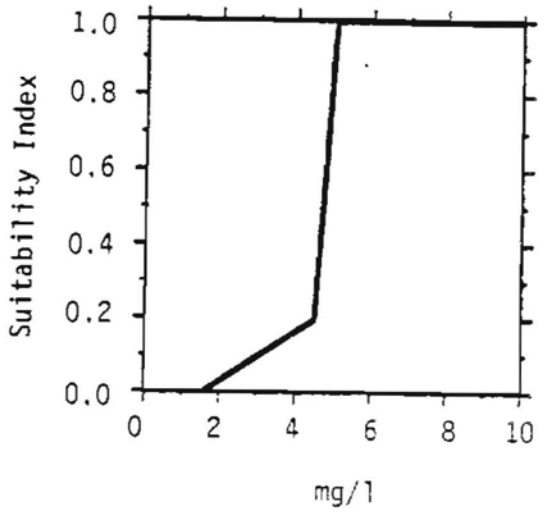
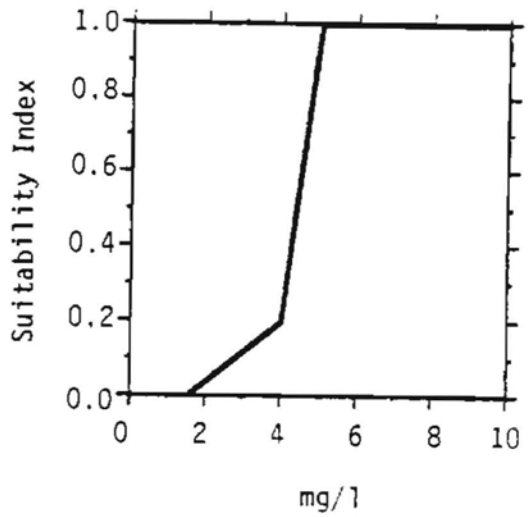
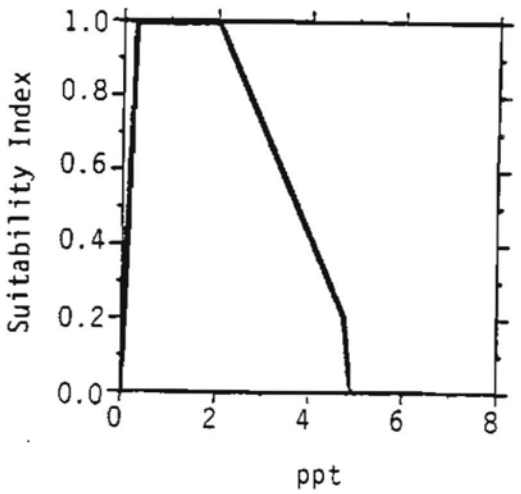
The "R" for riverine and "L" for lacustrine entered under the heading "habitat" describe where the variable should be measured.

Habitat	Variable		Suitability graph
R,L	V_1	Maximum monthly average turbidity during summer.	
R,L	V_2	Percent cover (e.g., vegetation, brush, debris, and standing timber) during mid-summer within pools, overflow areas, and backwaters (R), and the littoral zone (L).	

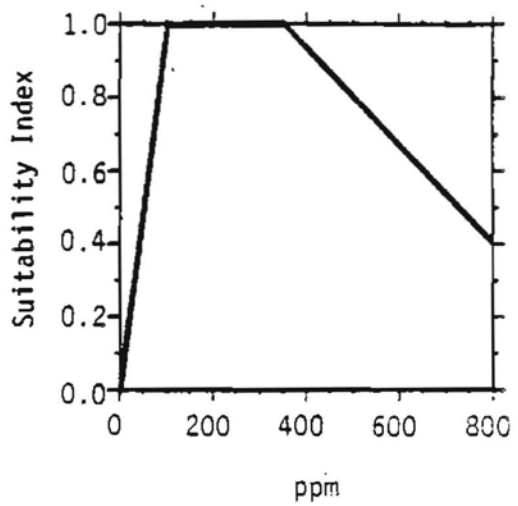
R	V_3	Stream gradient within study area.	
R	V_4	Average current velocity in pools and backwater areas during average summer flow.	
R	V_5	Percent pools and backwater areas during average spring and summer flow.	

L	V_6	Percent littoral area during spring and summer.	
R,L	V_7	pH levels during year.	
R,L	V_8	Most suitable water temperature within the epilimnion (L) or in pools and backwaters (R) during midsummer (Adult). <u>Note</u>: Choose the epilimnion area with highest SI rating for water temperature.	

R,L	V_9	Most suitable water temperature within the epilimnion (L) or in pools and backwaters (R) during midsummer (Juvenile). <u>Note</u>: Choose the epilimnion area with highest SI rating for water temperature.	
R,L	V_{10}	Average water temperature within littoral areas (L) or in pools and backwaters (R) during midsummer (Fry).	
R,L	V_{11}	Average water temperature within littoral areas (L) or backwaters (R) during spawning (Embryo).	

R,L	V_{12}	Minimum dissolved oxygen levels within temperature strata selected above (V_8, V_9, and V_{10}) during midsummer (Adult, Juvenile, Fry).	
R,L	V_{13}	Minimum dissolved oxygen levels within littoral areas (L) or backwaters (R) during spawning (Embryo/Fry).	
R,L	V_{14}	Maximum salinity during growing season. <u>Note</u>: (optional variable) V_{14} may be omitted if salinity is not considered to be a potential problem within the study area.	

L	V_{15}	Average TDS level during the growing season. Note: SI should be lowered 0.2 if ionic concentration of sulfate-chlorides exceeds that of carbonate-bicarbonates.



Reservoir Habitat Suitability Index Model

$$C_F = V_{15}$$

$$C_C = (V_2 \times V_6)^{1/2}$$

$$C_{WQ} = \frac{2(V_8 \times V_9 \times V_{10})^{1/3} + 2V_{12} + V_7 + V_1}{6}$$

If V_8, V_9, or $V_{10} \leq 0.4$, substitute the lowest variable value for $(V_8 \times V_9 \times V_{10})^{1/3}$.

If $(V_8 \times V_9 \times V_{10})^{1/3}$ or $V_{12} \leq 0.4$, C_{WQ} = the lowest of $(V_8 \times V_9 \times V_{10})^{1/3}$, V_{12}, or above equation.

$$C_R = (V_2 \times V_6 \times V_{11}^2 \times V_{13}^2)^{1/6}$$

$$HSI = (C_F \times C_C \times C_{WQ} \times C_R)^{1/4}$$

If C_F, C_C, C_{WQ}, or $C_R \leq 0.4$, the HSI = the lowest of the four component values.

Riverine Habitat Suitability Index Model

$$C_{F/C} = (V_2 \times V_5)^{1/2}$$

$$C_{WQ} = \frac{2\,(V_8 \times V_9 \times V_{10})^{1/3} + 2V_{12} + V_7 + V_1}{6}$$

If either V_8, V_9, or $V_{10} \leq 0.4$, substitute the lowest variable value for $(V_8 \times V_9 \times V_{10})^{1/3}$.

If $(V_8 \times V_9 \times V_{10})^{1/3}$ or $V_{12} \leq 0.4$, C_{WQ} = lowest of $(V_8 \times V_9 \times V_{10})^{1/3}$, V_{12}, or above equation.

Note: If V_{14} (optional salinity) is added:

$$C_{WQ} = \frac{2\,(V_8 \times V_9 \times V_{10})^{1/3} + 2V_{12} + V_7 + V_1 + V_{14}}{7}$$

with the same substitution rules described above.

$$C_R = (V_2 \times V_5 \times V_{11}^2 \times V_{13}^2)^{1/6}$$

$$C_{OT} = \frac{V_3 + V_4}{2}$$

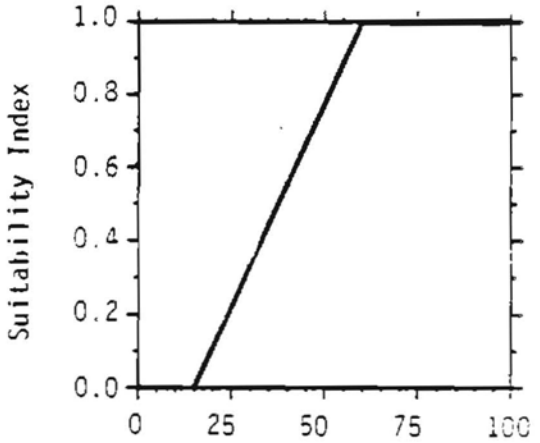
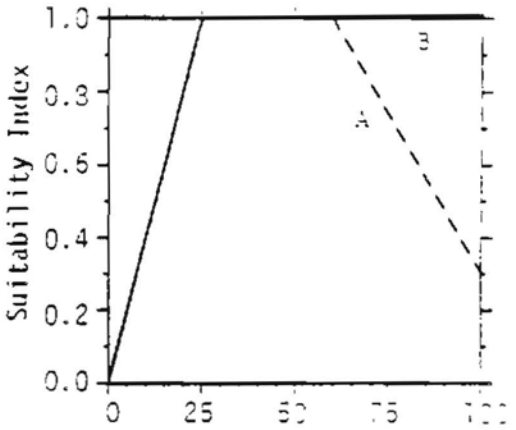
$$HSI = (C_{F/C} \times C_{WQ} \times C_R \times C_{OT})^{1/4}$$

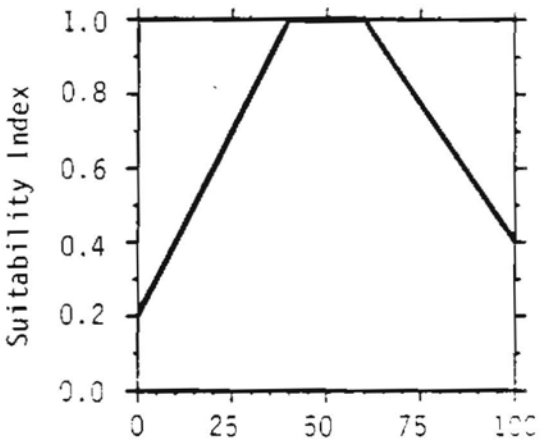
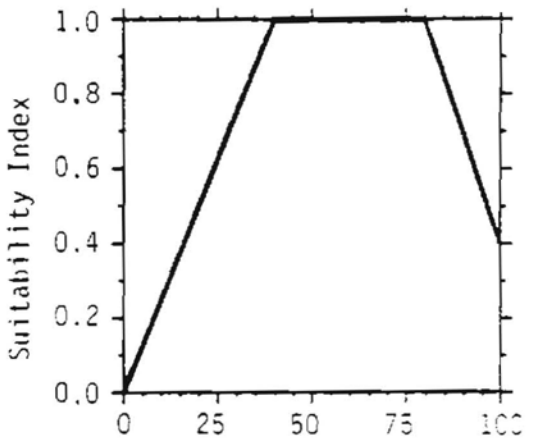
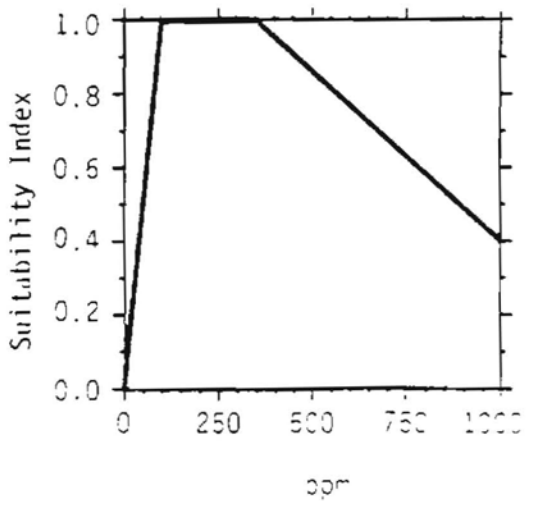
Except if C_{WQ} or $C_R \leq 0.4$, the HSI = the lowest of C_{WQ}, C_R, or above equation.

LARGEMOUTH BASS

Suitability Index (SI) Graphs for Largemouth Bass Model Variables

The "R" for riverine and "L" for lacustrine entered under the heading "habitat" describe where the variable should be measured.

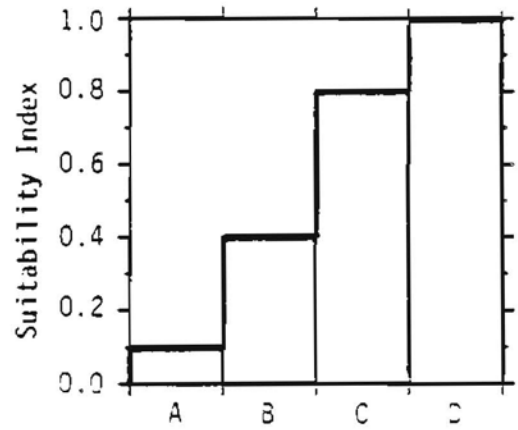
Habitat	Variable		Suitability graph
R	V_1	Percent pool and backwater area during average summer flow.	
L	V_2	Percent lacustrine area ≤ 6 m depth. Note: A regional consideration is made for bodies of water in more southern latitudes where overwintering requirements are not as rigorous. A. Northern latitudes B. Southern latitudes	

R,L	V_3	Percent bottom cover (e.g., aquatic vegetation, logs, and debris) within pools, backwaters, or littoral areas during summer (Adult, Juvenile).	
R,L	V_4	Percent bottom cover (e.g, aquatic vegetation, logs, and debris) within pools, backwaters, or littoral areas during summer (Fry).	
L	V_5	Average TDS concentration during growing season when carbonate-bicarbonate > sulfate-chloride ionic concentration. If sulfate-chloride concentration exceeds carbonate-bicarbonate, reduce SI for TDS by 0.2.	

R,L V_6

Minimum dissolved oxygen levels during midsummer within pools or littoral areas.

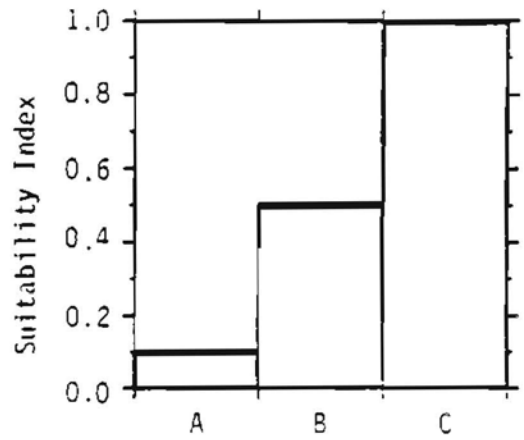
A) Frequently < 2 mg/l
B) Usually ≥ 2 and < 5 mg/l
C) Usually ≥ 5 and < 8 mg/l
D) Often > 8 mg/l



R,L V_7

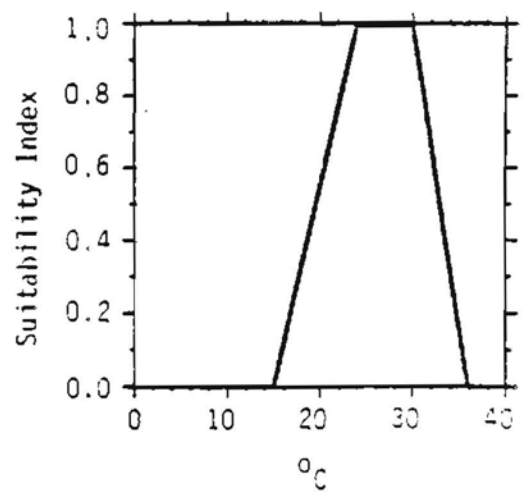
pH range during growing season.

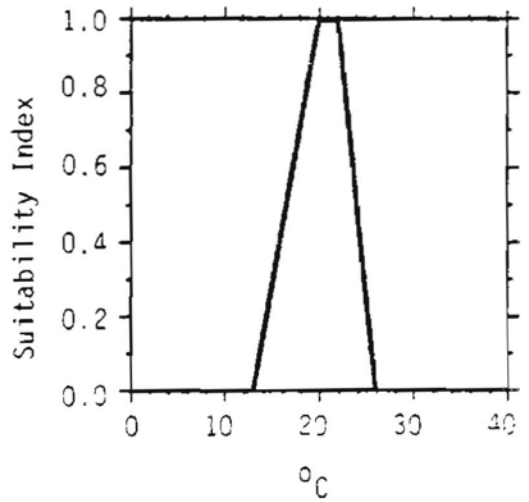
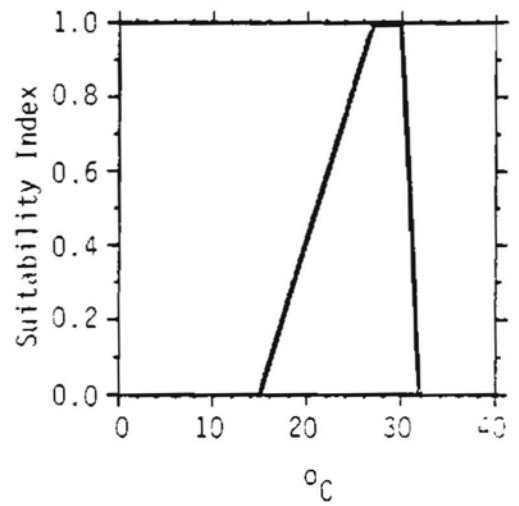
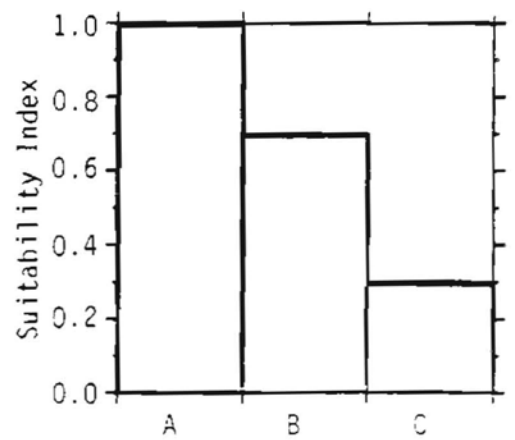
A) < 5.0 or > 10.0
B) ≥ 5 and < 6.5 or > 8.5 and ≤ 10.0
C) 6.5-8.5



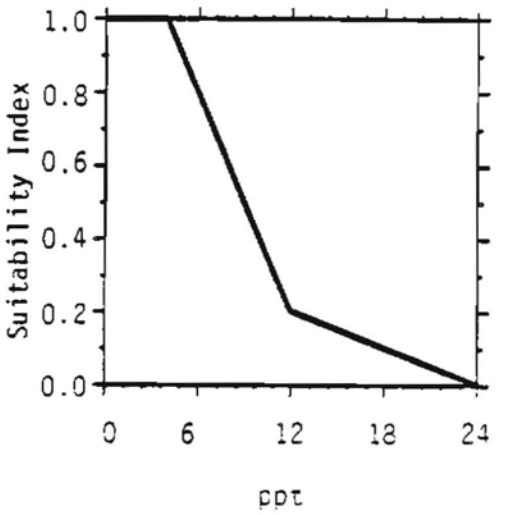
R,L V_8

Average water temperature within pools, backwaters, or littoral areas during the growing season (Adult, Juvenile).

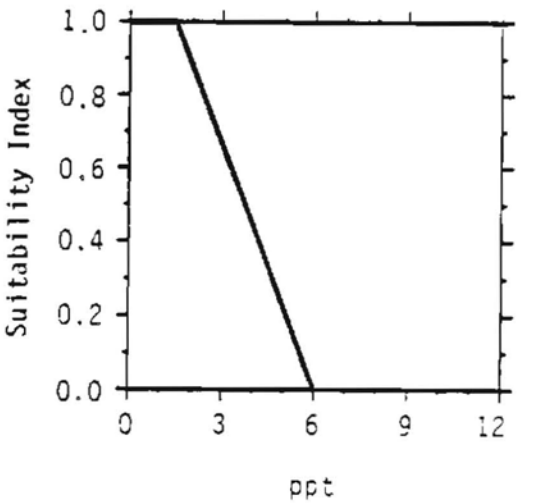


R,L	V_9	Average weekly mean temperature within pools or littoral areas during spawning and incubation (Embryo).	
R,L	V_{10}	Average water temperature within pools, backwaters, or littoral areas during the growing season (Fry).	
R,L	V_{11}	Maximum monthly average turbidity (suspended solids) during growing season. A) 5-25 ppm B) > 25 and ≤ 100 ppm C) < 5 ppm, > 100 ppm	

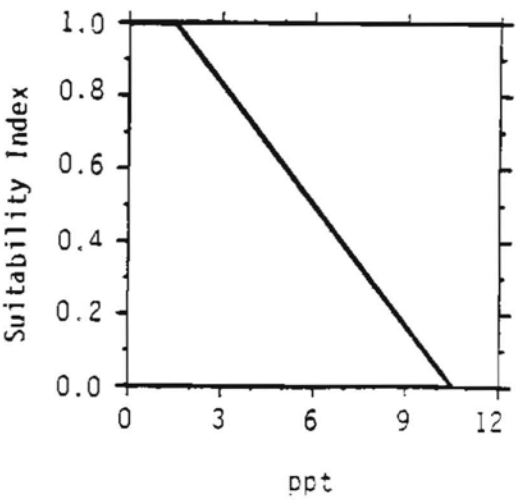
R,L V_{12} Maximum salinity during summer (Adult, Juvenile).



R,L V_{13} Maximum salinity during summer (Fry).

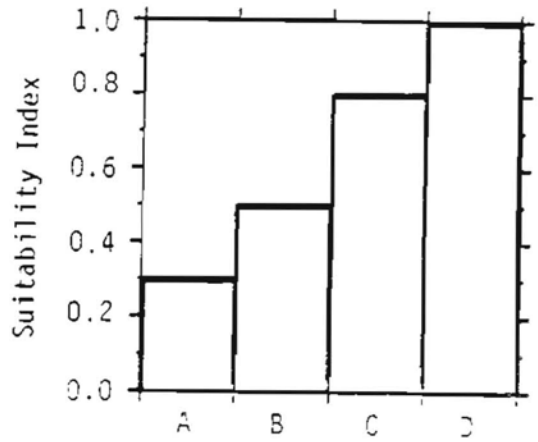


R,L V_{14} Maximum salinity during spawning and incubation (Embryo).

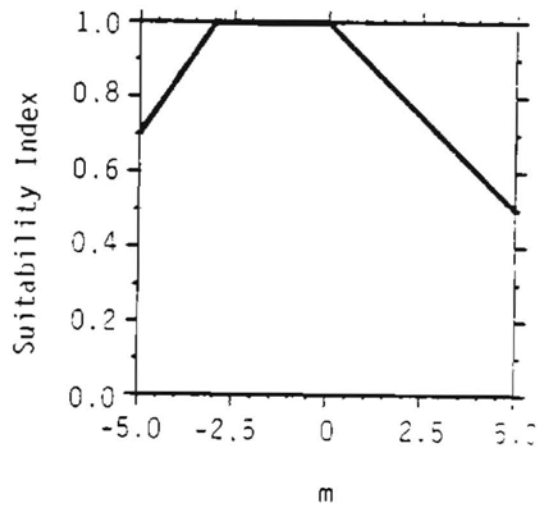


R,L V_{15} Substrate composition within riverine pools and backwaters or lacustrine littoral areas (Embryo).

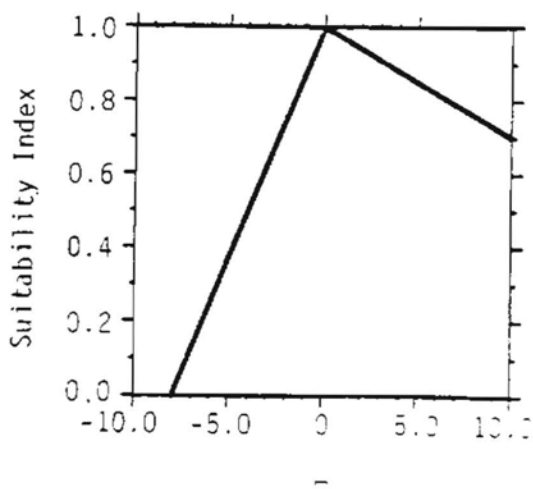
A) Boulders and bedrock predominate (≥ 50%)
B) Sand (0.062-2.0 mm) predominate
C) Silt and clay (< 0.062 mm) predominate
D) Gravel (0.2-6.4 cm) predominate

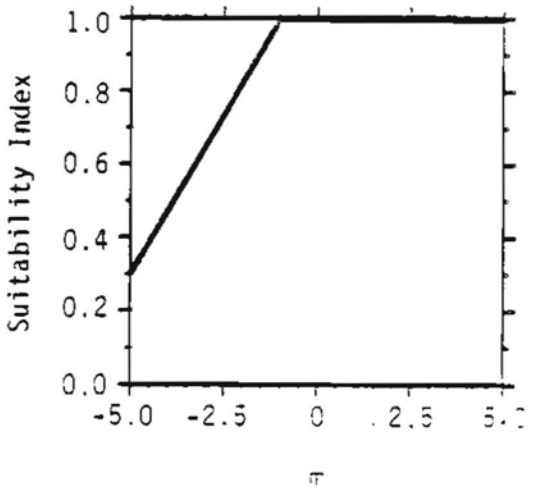
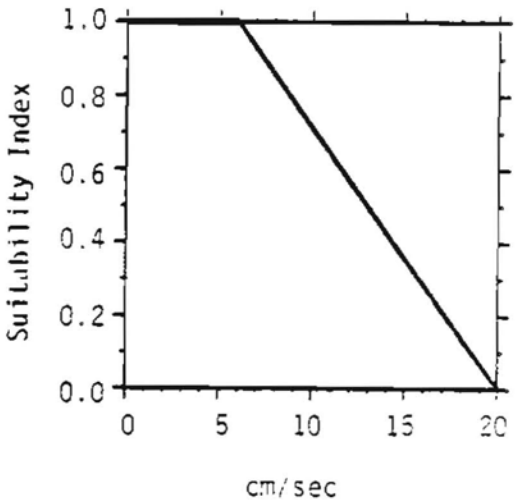
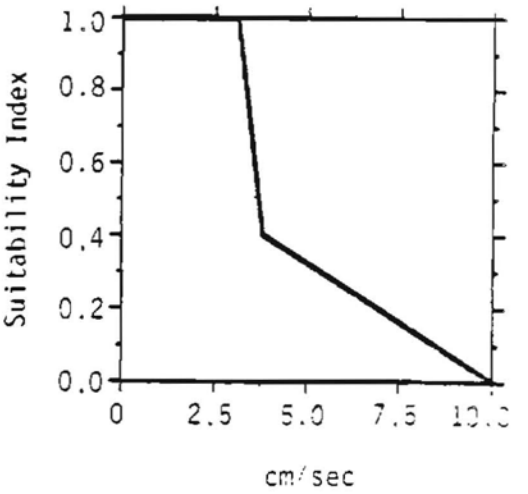


R,L V_{16} Average water level fluctuation during growing season (Adult, Juvenile).

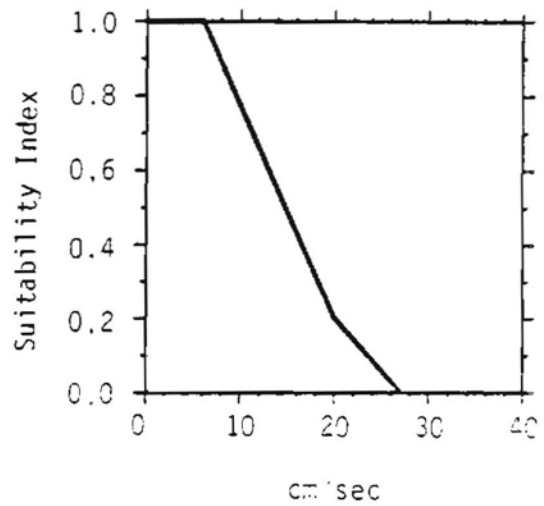


R,L V_{17} Maximum water level fluctuation during spawning (Embryo).

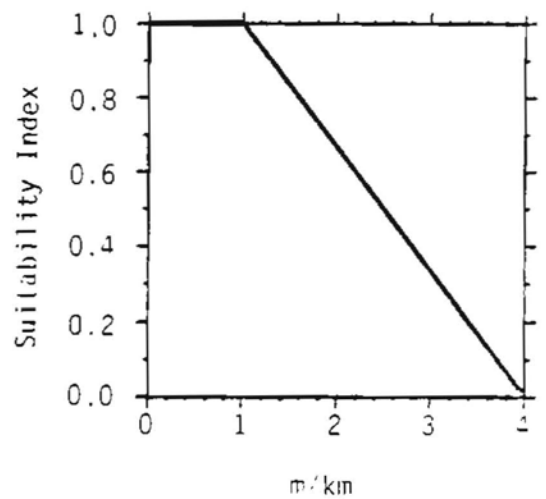


R,L	V_{18}	Average water level fluctuation during growing season (Fry).	
R	V_{19}	Average current velocity at 0.6 depth during summer (Adult, Juvenile).	
R	V_{20}	Maximum current velocity at 0.8 depth within pools or backwaters during spawning (May-June) (Embryo).	

R	V_{21}	Average current velocity at 0.6 depth during summer (Fry).



R	V_{22}	Stream gradient within representative reach.



Reservoir Habitat Suitability Index Model

$$C_F = V_5$$

$$C_C = \left(V_2 \times \frac{V_3 + V_4}{2} \times V_8 \times V_{16} \right)^{1/4}$$

$$C_{WQ} = \frac{2V_6 + V_7 + 2V_8 + V_{10} + V_{11}}{7} \quad \text{if } V_{12} \text{ or } V_{13} \text{ both} = 1.0$$

$$C_{WQ} = \frac{2V_6 + V_7 + 2V_8 + V_{10} + V_{11} + \frac{V_{12} + V_{13}}{2}}{8} \text{ if } V_{12} \text{ or } V_{13} < 1.00$$

$$C_R = (V_2 \times V_9 \times V_{15} \times V_{17})^{1/4} \text{ if } V_{14} = 1.0$$

$$C_R = (V_2 \times V_9 \times V_{14} \times V_{15} \times V_{17})^{1/5} \text{ if } V_{14} < 1.0$$

$$HSI = (C_F \times C_C \times C_{WQ} \times C_R)^{1/4}$$

If C_{WQ} or $C_R \leq 0.4$, the HSI = the lowest of C_{WQ}, C_R, or above equation.

Riverine Habitat Suitability Index Model

$$C_F = \left[V_1 \times \left(\frac{V_3 + V_4}{2} \right) \right]^{1/2}$$

$$C_C = \left[\left(\frac{V_3 + V_4}{2} \right) \times \left(\frac{V_{16} + V_{18}}{2} \right) \right]^{1/2}$$

$$C_{WQ} = \frac{2V_6 + V_7 + 2V_8 + V_{10} + V_{11}}{7} \text{ if } V_{12} \text{ or } V_{13} = 1.0$$

$$C_{WQ} = \frac{2V_6 + V_7 + 2V_8 + V_{10} + V_{11} + \frac{V_{12} + V_{13}}{2}}{8} \text{ if } V_{12} \text{ or } V_{13} < 1.0$$

If V_6, V_8, or $V_{10} \leq 0.4$, C_{WQ} = the lowest of V_6, V_8, V_{10}, or above equation

$$C_R = (V_1 \times V_9 \times V_{15} \times V_{17} \times V_{20})^{1/5} \text{ if } V_{14} = 1.0$$

$$C_R = (V_1 \times V_9 \times V_{14} \times V_{15} \times V_{17} \times V_{20})^{1/6} \text{ if } V_{14} < 1.0$$

<u>Note</u>: Because there is a correlation between stream gradient and current velocity, the user has two options for C_{OT}:

$$(1)\ C_{OT} = \frac{V_{19} + V_{21}}{2}$$

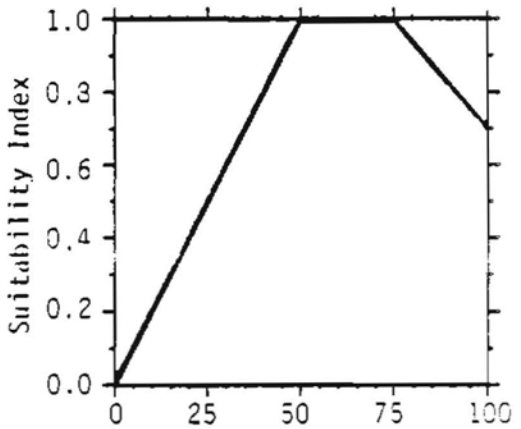
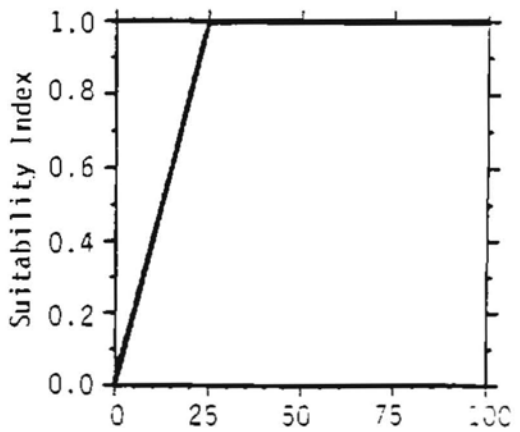
$$(2)\ C_{OT} = V_{22}$$

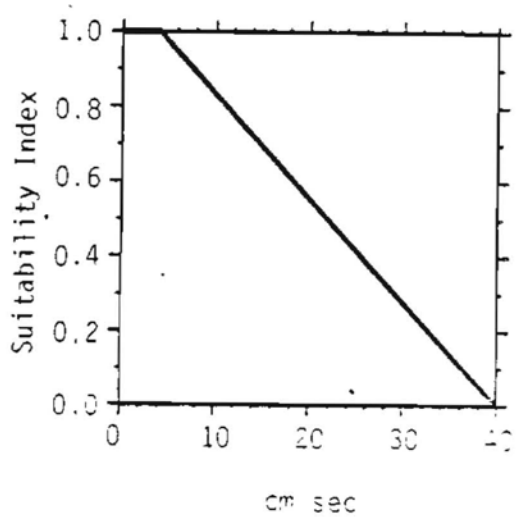
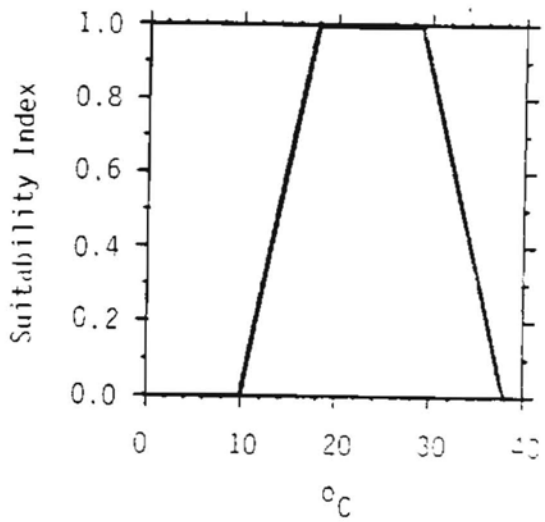
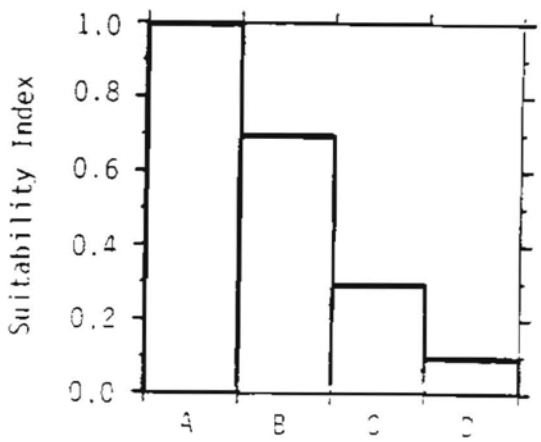
$$HSI = (C_F \times C_C \times C_{WQ} \times C_R \times C_{OT})^{1/5}$$

BLACK BULLHEAD

Suitability Index (SI) Graphs for Black Bullhead Model Variables

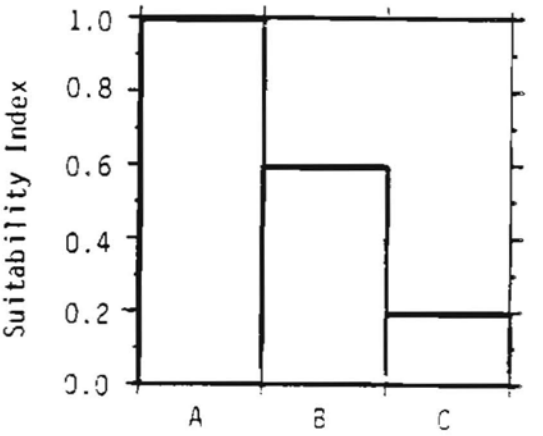
The "R" for riverine and "L" for lacustrine entered under the heading "habitat" describe where the variable should be measured.

Habitat	Variable		Suitability graph
R	V_1	Percent pools and backwaters during average summer flow.	
R,L	V_2	Percent cover objects (e.g., vegetation, brush, debris, etc.) within pools, backwaters, or littoral areas during summer.	

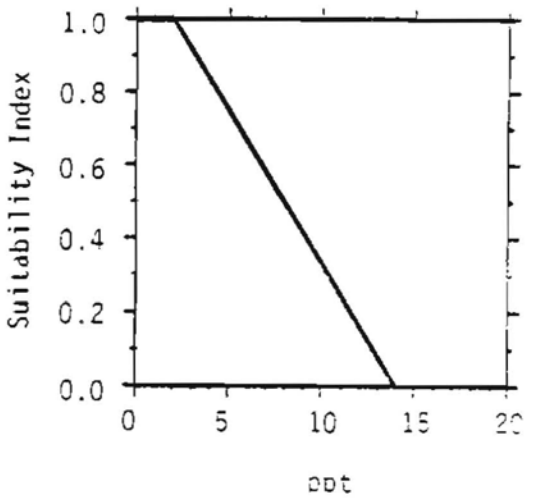
R	V_3	Average current velocity at 0.6 depth during average summer flow.	
R,L	V_4	Maximum midsummer water temperature within pools, backwaters, or littoral areas.	
R,L	V_5	Dissolved oxygen range within pools, backwaters, or littoral areas during summer. A) Seldom < 6 mg/l B) Usually 4-6 mg/l C) Usually 2-4 mg/l D) Frequently < 3 mg/l (near-lethal D.O. concentrations)	

R,L V_6 pH range during the year.

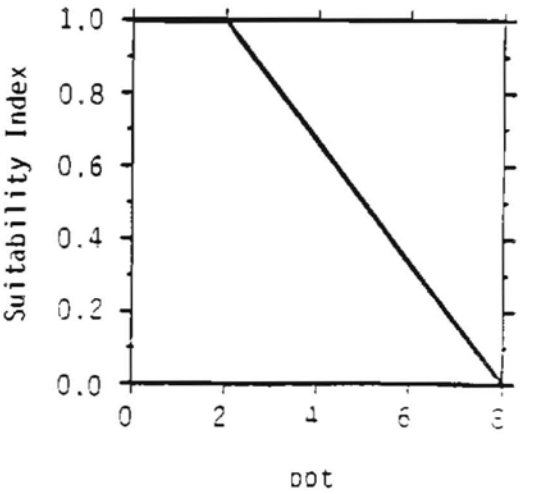
A) Usually 6.5-8.5
B) Usually 4.5-6.5 or 8.5-10.0
C) Frequently < 4.5 or > 10.0.



R,L V_7 Máximum salinity during summer (Adult, Juvenile).



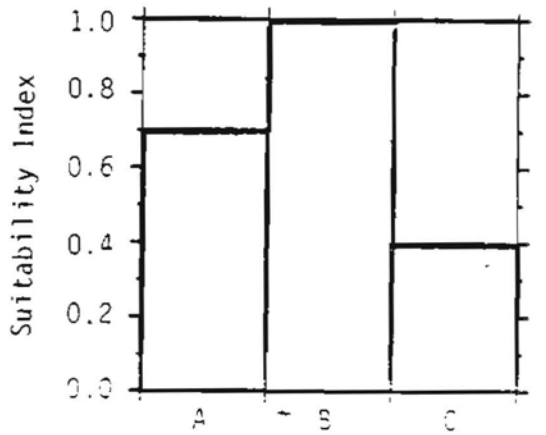
R,L V_8 Maximum salinity during early summer (May-July) (Embryo, Fry).



R,L V_9

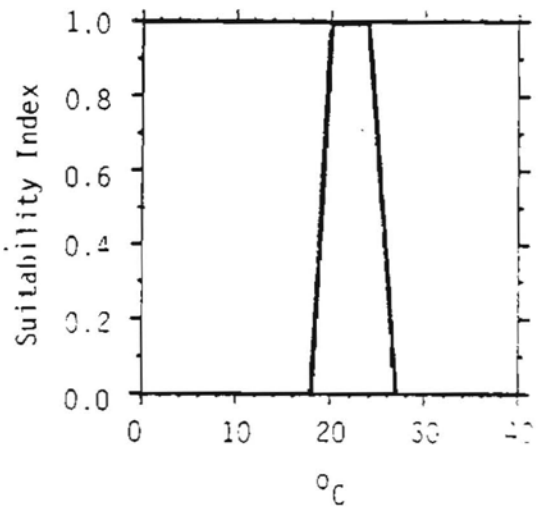
Maximum monthly average turbidity (suspended solids) during growing season.

A) Clear (< 25 ppm)
B) Moderate (25-100 ppm)
C) Turbid (> 100 ppm)



R,L V_{10}

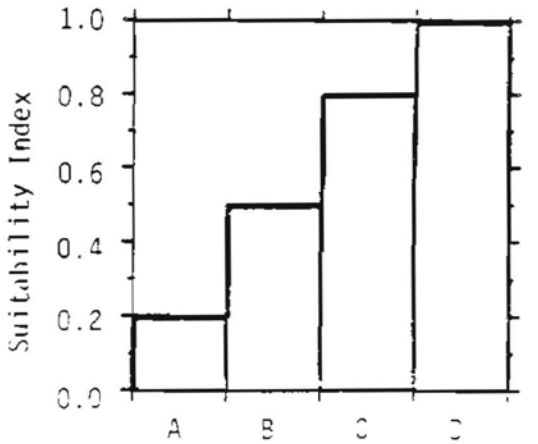
Average water temperatures within pools, backwaters, or littoral areas during spawning and embryonic development (Embryo).

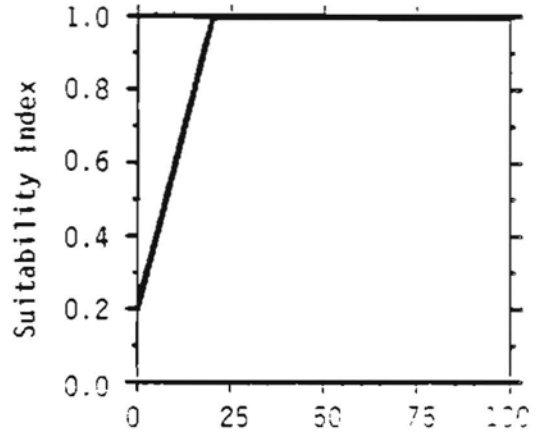
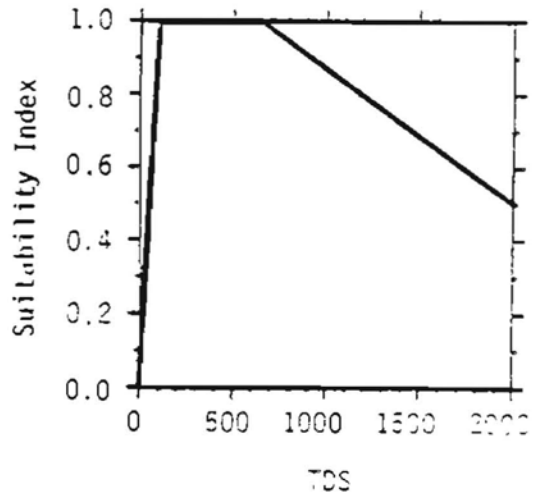
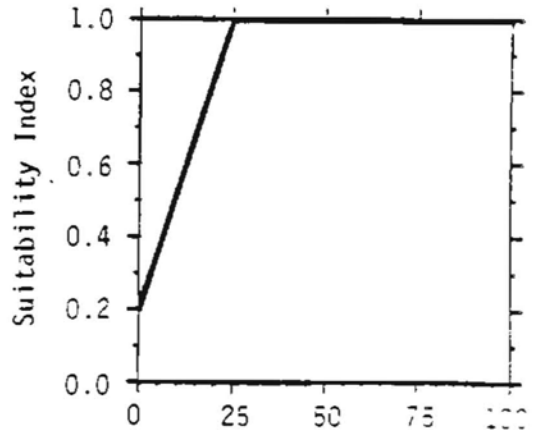


R,L V_{11}

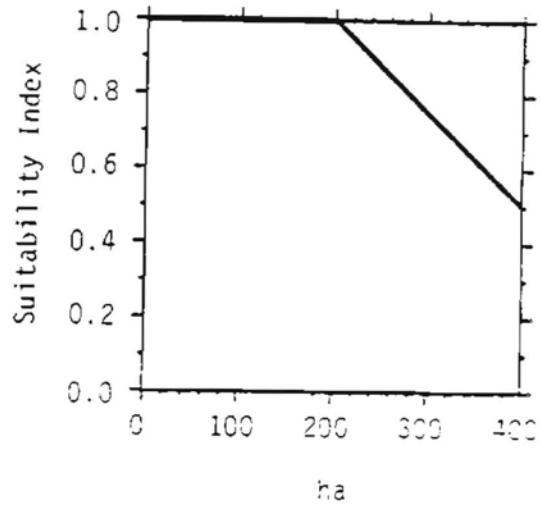
Dominant substrate type within pools, backwaters, or littoral areas for spawning (Embryo).

A) Fines and gravel insignificant (≤ 10%)
B) Fines noticeable (≤ 25%)
C) Fines and gravel present in equal amounts, combined (≤ 50%)
D) Fines dominant (≥ 50%)

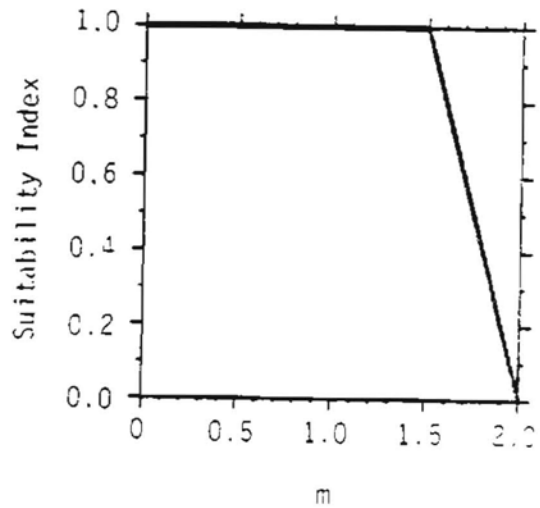


R,L	V_{12}	Percent cover objects (e.g., vegetation, brush, debris, etc.) within pools, backwaters, or littoral areas during spawning (Embryo).	
L	V_{13}	Average total dissolved solids (TDS) during summer. If the sulfide-chloride > carbonate-bicarbonate ion concentration, the SI should be reduced by 0.2.	
L	V_{14}	Percent littoral area during summer.	

L	V_{15}	Lake or reservoir size.



L	V_{16}	Reservoir drawdown during spawning and embryonic development (Embryo).



Reservoir Habitat Suitability Index Model

$$C_F = V_{13}$$

$$C_C = (V_2 \times V_{14} \times V_{15})^{1/3}$$

$$C_{WQ} = \frac{2V_4 + 2V_5 + V_6 - V_9}{6} \quad \text{if } V_7 \text{ and } V_8 \text{ both} = 1.0$$

C_{WQ} = lowest of V_4, V_5, or above equation if V_4 or $V_5 \leq 0.4$.

$$C_{WQ} = \frac{2V_4 + 2V_5 + V_6 + \frac{V_7 + V_8}{2} + V_9}{7} \quad \text{if } V_7 \text{ or } V_8 < 1.0$$

$$C_R = (V_{10} \times V_{11} \times V_{12} \times V_{14} \times V_{16})^{1/5} \text{ if } V_8 = 1.0$$

$$C_R = (V_8 \times V_{10} \times V_{11} \times V_{12} \times V_{14} \times V_{16})^{1/6} \text{ if } V_9 = 1.0$$

$$HSI = (C_F \times C_C \times C_{WQ} \times C_R)^{1/4}$$

If C_{WQ} or $C_R \leq 0.4$, the HSI = lowest of C_{WQ}, C_R, or the above equation.

<u>Riverine Habitat Suitability Index Model</u>

$$C_F = (V_1 \times V_2)^{1/2}$$

$$C_C = (V_1 \times V_2 \times V_3)^{1/3}$$

$$C_{WQ} = \frac{2V_4 + 2V_5 + V_6 + V_9}{6} \quad \text{if } V_7 \text{ and } V_8 \text{ both} = 1.0$$

If V_4 or $V_5 \leq 0.4$, C_{WQ} = the lowest of V_4, V_5, or above equation

$$C_{WQ} = \frac{2V_4 + 2V_5 + V_6 + \frac{V_7 + V_8}{2} + V_9}{7} \quad \text{if } V_7 \text{ or } V_8 < 1.0$$

If V_4 or $V_5 \leq 0.4$, C_{WQ} = the lowest of V_4, V_5, or above equation

$$C_R = (V_1 \times V_{10} \times V_{11} \times V_{12})^{1/4} \text{ if } V_8 = 1.0$$

$$C_R = (V_1 \times V_8 \times V_{10} \times V_{11} \times V_{12})^{1/5} \text{ if } V_8 < 1.0$$

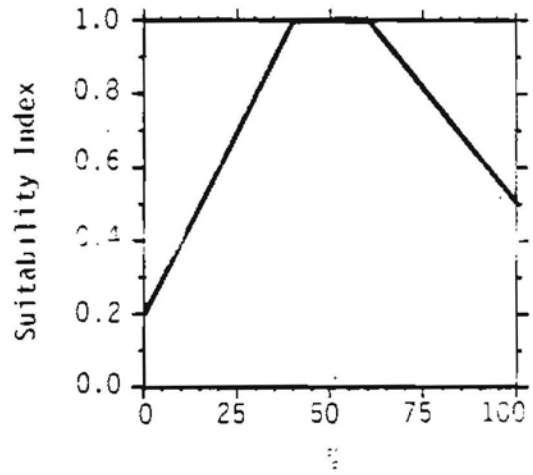
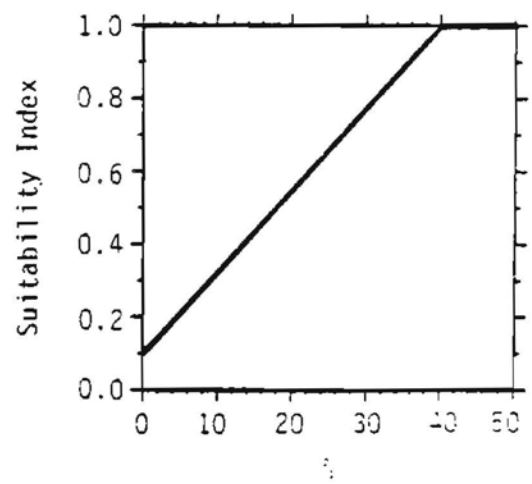
$$HSI = (C_F \times C_C \times C_{WQ} \times C_R)^{1/4}$$

If C_{WQ} or $C_R \leq 0.4$, the HSI = the lowest of C_{WQ}, C_R, or above equation

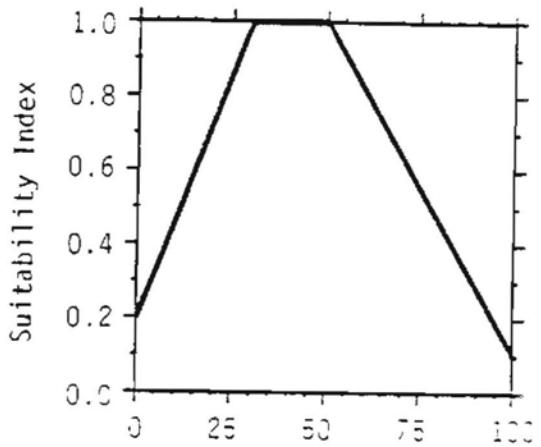
CHANNEL CATFISH

Suitability Index (SI) Graphs for Channel Catfish Model Variables

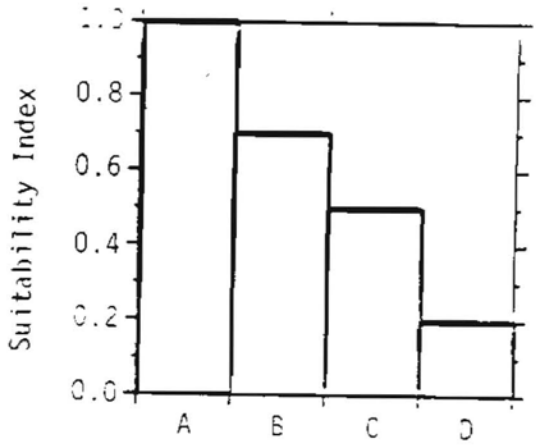
The "R" for riverine and "L" for lacustrine entered under the heading "habitat" describe where the variable should be measured.

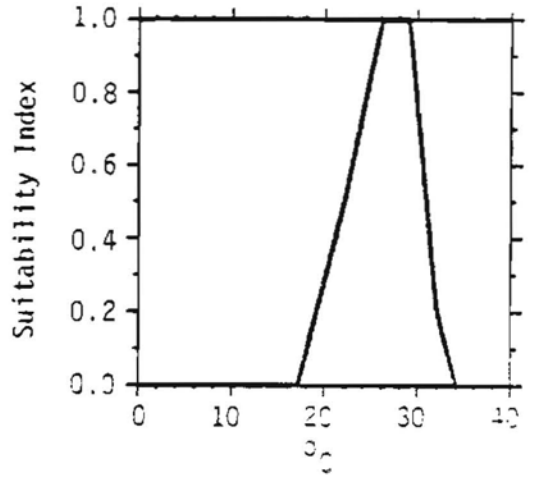
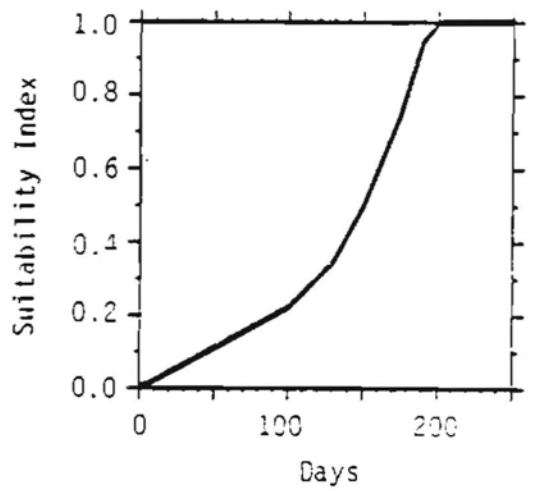
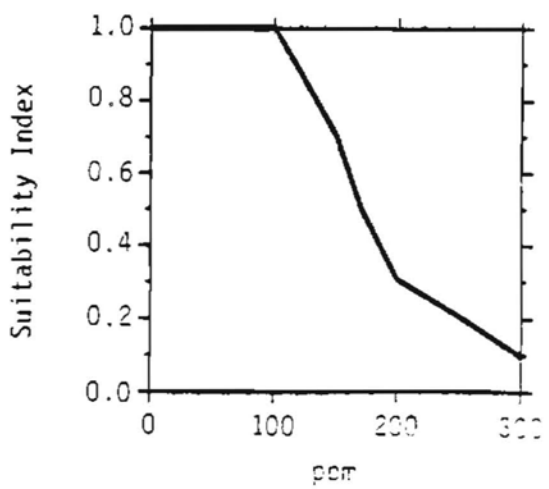
Habitat	Variable		Suitability graph
R	V_1	Percent pools during average summer flow.	
R,L	V_2	Percent cover (logs, boulders, cavities, brush, debris, or standing timber) during summer within pools, backwater areas, and littoral areas.	

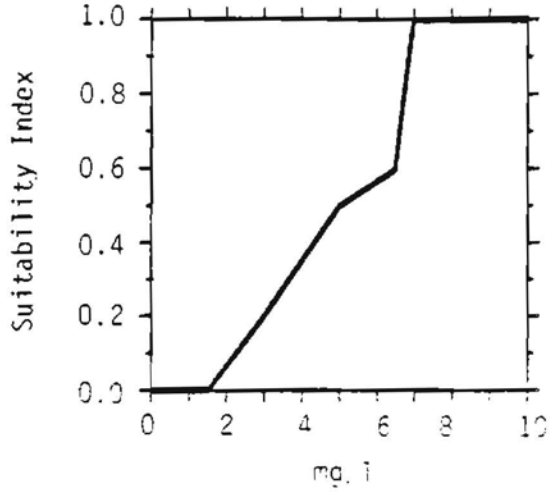
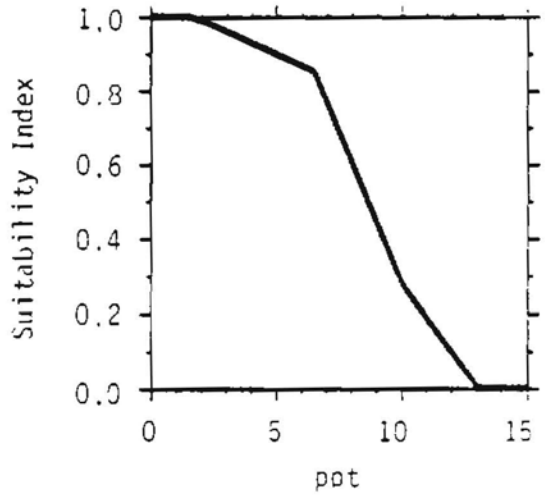
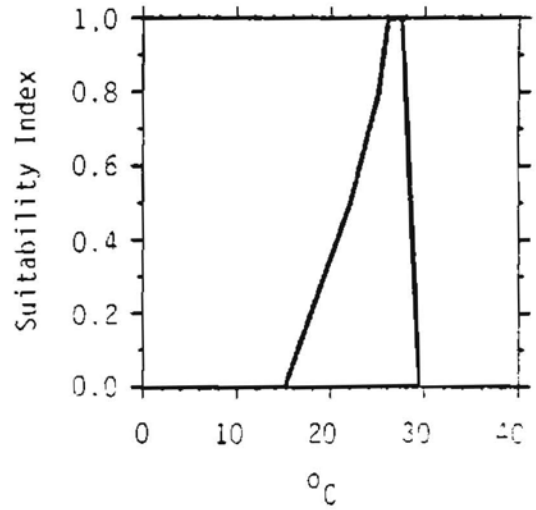
L	V_3	Percent littoral area during summer.

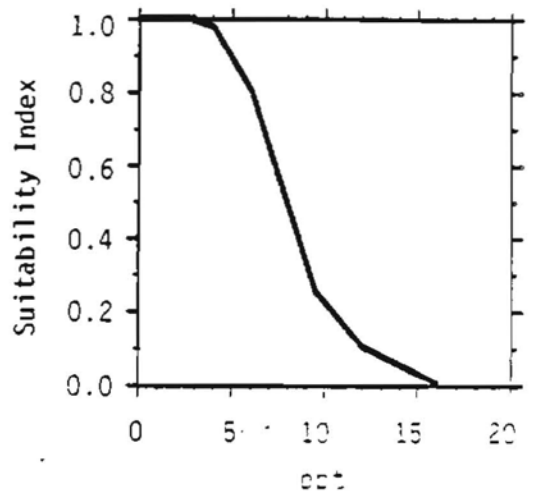
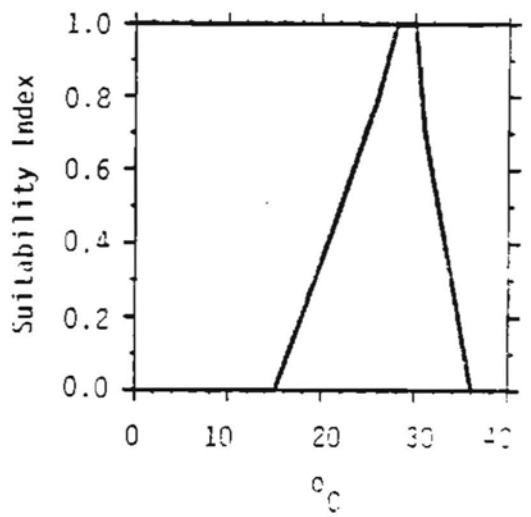
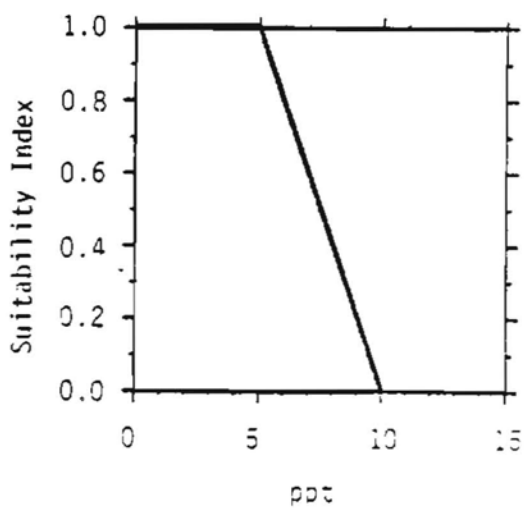


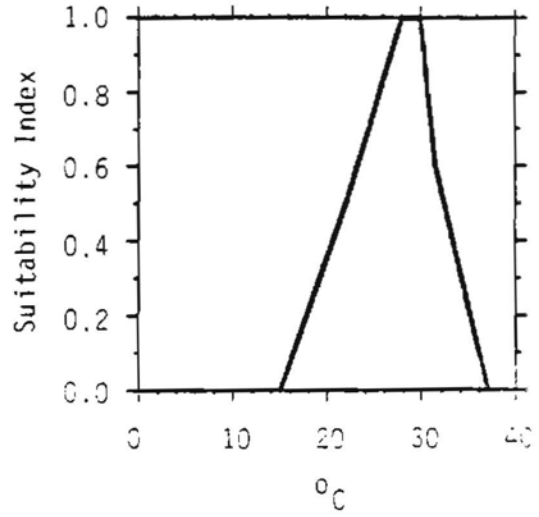
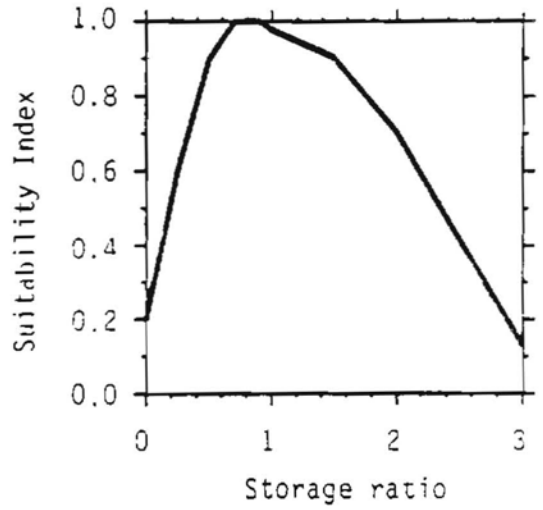
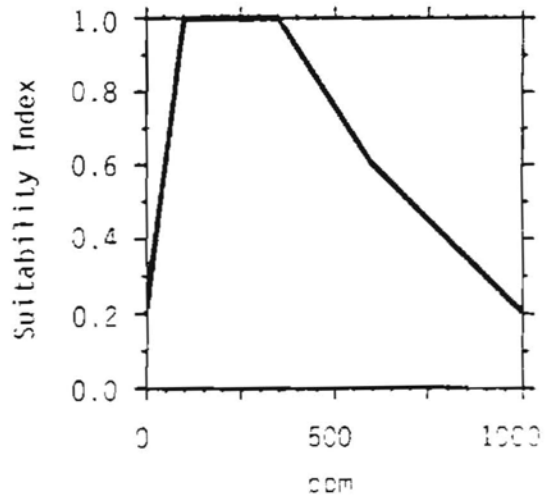
R	V_4	Food production potential is given by substrate type present during average summer flow. A) Rubble dominant in riffle-runs with some gravel and/or boulders present; fines (silt and sand) not common; aquatic vegetation abundant (≥ 30%) in pool areas. B) Rubble, gravel, boulders, and fines occur in nearly equal amounts in riffle-run areas; aquatic vegetation is 10-30% in pool areas. C) Some rubble and gravel present, but fines or boulders are dominant; aquatic vegetation is scarce (< 10%) in pool areas. D) Fines or bedrock are the dominant bottom material. Little or no aquatic vegetation or rubble present.



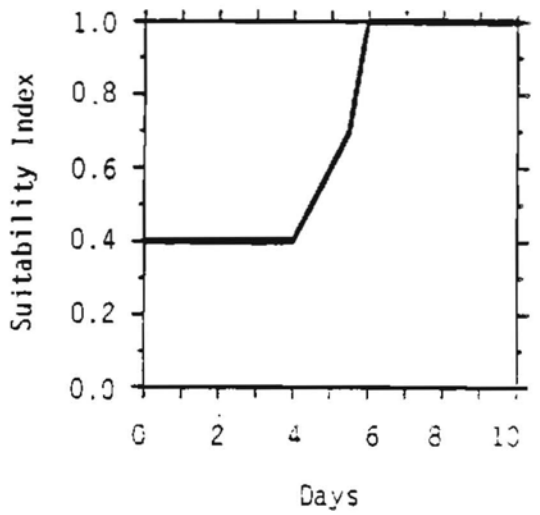
R,L	V_5	Average midsummer water temperature within pools, backwaters, or littoral areas (Adult).	
R,L	V_6	Length of agricultural growing season (frost-free days). <u>Note</u>: This variable is optional.	
R,L	V_7	Maximum monthly average turbidity during summer.	

R,L	V_8	Average minimum dissolved oxygen levels within pools, backwaters, or littoral areas during midsummer.	
R,L	V_9	Maximum salinity during summer (Adult).	
R,L	V_{10}	Average water temperatures within pools, backwaters, and littoral areas during spawning and embryo development (Embryo).	

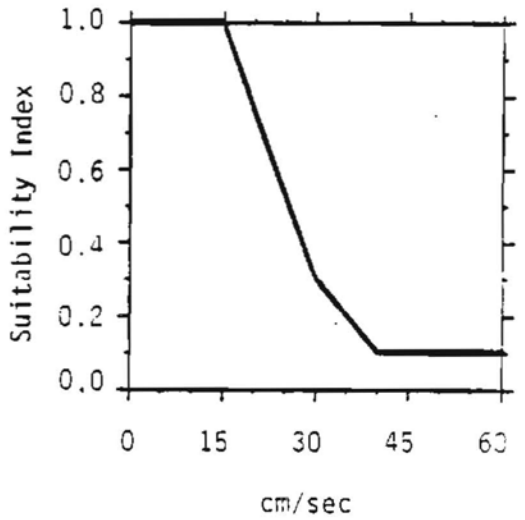
R,L	V_{11}	Maximum salinity during spawning and embryo development (Embryo).	
R,L	V_{12}	Average midsummer water temperature within pools, backwaters, or littoral areas (Fry).	
R,L	V_{13}	Maximum salinity during summer (Fry, Juvenile).	

R,L	V_{14}	Average midsummer water temperature within pools, backwaters, or littoral areas (Juvenile).	
L	V_{15}	Storage ratio.	
L	V_{16}	Monthly average TDS (total dissolved solids) during summer.	

L	V_{17}	Reservoir flushing rate while fry are present (Fry).



R	V_{18}	Average current velocity in cover areas during average summer flow.



Reservoir Habitat Suitability Index Model

$$C_F = \frac{V_2 + V_3 + V_{16}}{3}$$

$$C_C = (V_2 \times V_3)^{1/2}$$

$$C_{WQ} = \frac{2\left(\frac{V_5 + V_{12} + V_{14}}{3}\right) + V_7 + 2V_8 + V_9 + V_{13}}{7}$$

If V_5, V_{12}, V_{14}, V_8, V_9, or $V_{13} \leq 0.4$, C_{WQ} = the lowest of V_5, V_{12}, V_{14}, V_8, V_9, V_{13} or above equation.

Note: When temperature data are unavailable, $2V_6$ (SI for length of agricultural growing season) can be substituted for the term:

$$2\left(\frac{V_5 + V_{12} + V_{14}}{3}\right)$$

The above option was used to calculate C_{WQ} for Lakes Lanier, West Point, Shelbyville, and Sangchris.

$$C_R = (V_2^2 \times V_3 \times V_8^2 \times V_{10}^2 \times V_{11})^{1/8}$$

If V_8, V_{10}, or $V_{11} \leq 0.4$, C_R = the lowest of V_8, V_{10}, V_{11}, or the above equation.

$$C_{OT} = \frac{V_{15} + V_{17}}{2}$$

$$HSI = (C_F \times C_C \times C_{WQ}^2 \times C_R^2 \times C_{OT})^{1/7}$$

If C_{WQ} or $C_R \leq 0.4$, the HSI = the lowest of C_{WQ}, C_R, or above equation.

Riverine Habitat Suitability Index Model

$$C_F = \frac{V_2 + V_4}{2}$$

$$C_C = (V_1 \times V_2 \times V_{18})^{1/3}$$

$$C_{WQ} = \frac{2\left(\frac{V_5 + V_{12} + V_{14}}{3}\right) + V_7 + 2V_8 + V_9 + V_{13}}{7}$$

If V_5, V_{12}, V_{14}, V_8, V_9, or $V_{13} \leq 0.4$, C_{WQ} = the lowest of V_5, V_{12}, V_{14}, V_8, V_9, V_{13}, or above equation.

<u>Note</u>: If temperature data are unavailable, $2V_6$ (length of agricultural growing season) can be substituted for the term:

$$2\left(\frac{V_5 + V_{12} + V_{14}}{3}\right)$$

$$C_R = (V_1 \times V_2^2 \times V_8^2 \times V_{10}^2 \times V_{11})^{1/8}$$

If V_8, V_{10}, or $V_{11} \leq 0.4$, C_R = the lowest of V_6, V_{10}, V_{11}, or above equation.

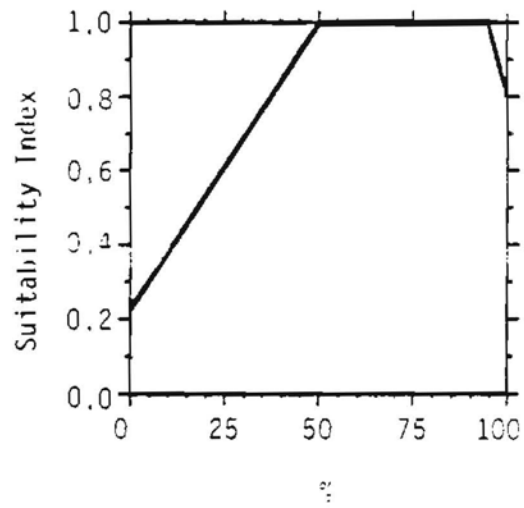
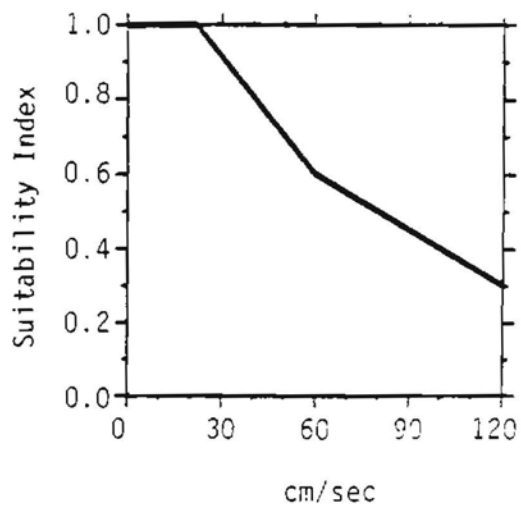
$$HSI = (C_F \times C_C \times C_{WQ}^2 \times C_R^2)^{1/6}$$

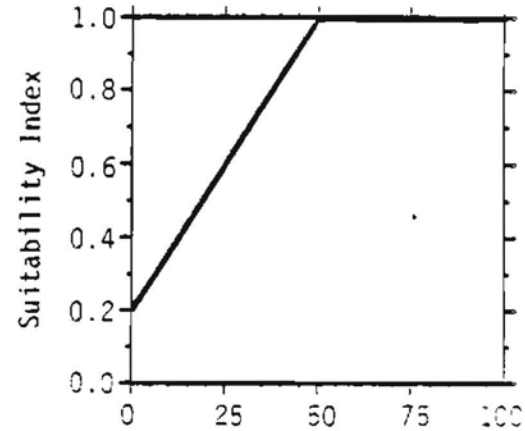
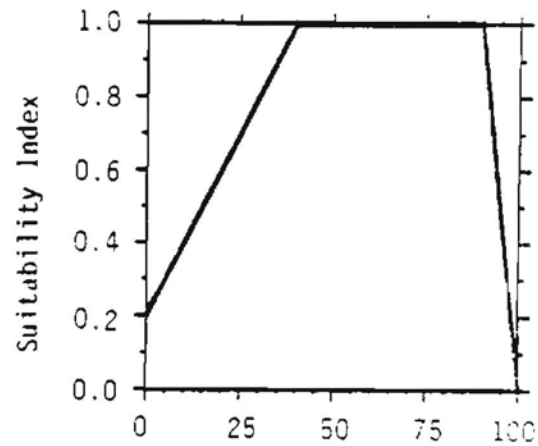
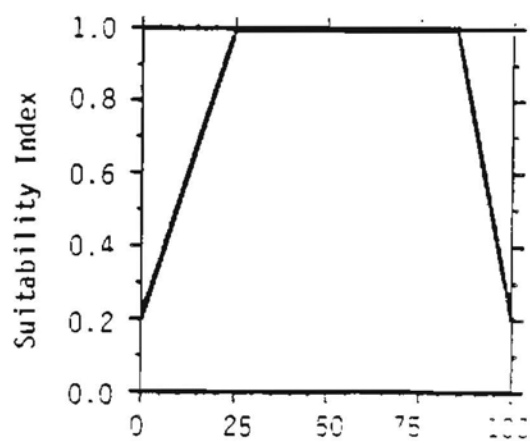
If C_{WQ} or $C_R \leq 0.4$, the HSI = the lowest of C_{WQ}, C_R, or above equation.

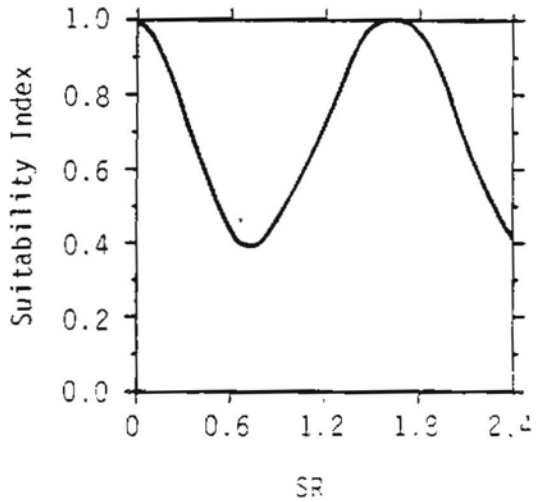
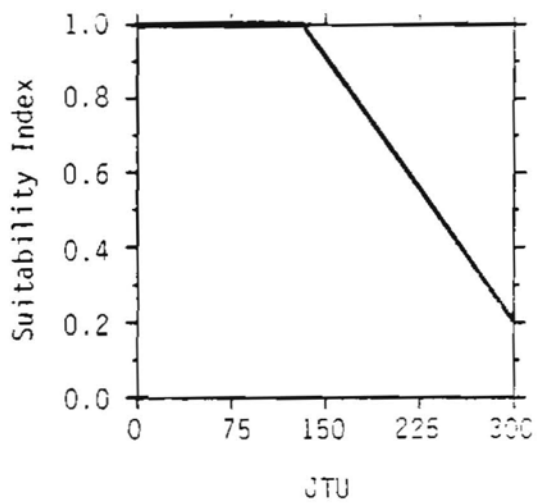
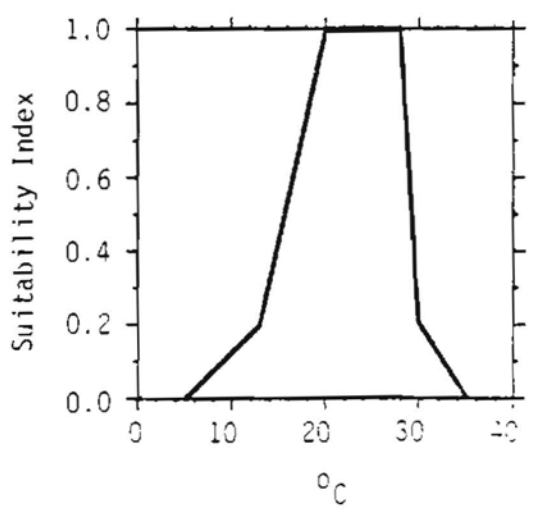
COMMON CARP

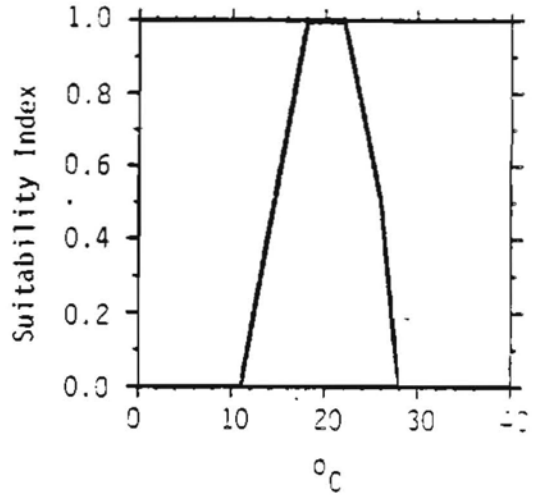
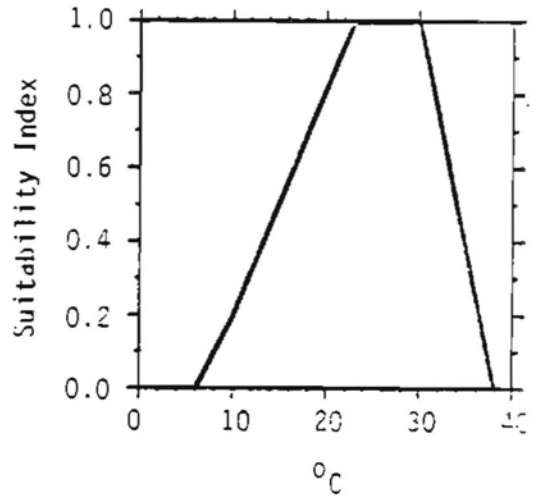
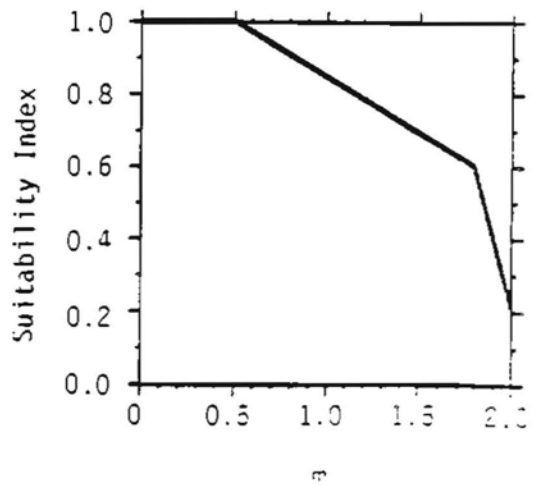
Suitability Index (SI) Graphs for Common Carp Model Variables

The "R" for riverine and "L" for lacustrine entered under the heading "habitat" describe where the variable should be measured.

Habitat	Variable		Suitability graph
R,L	V_1	Percent vegetative cover in shallow areas during spring and summer.	
R	V_2	Average velocity during average summer flow.	

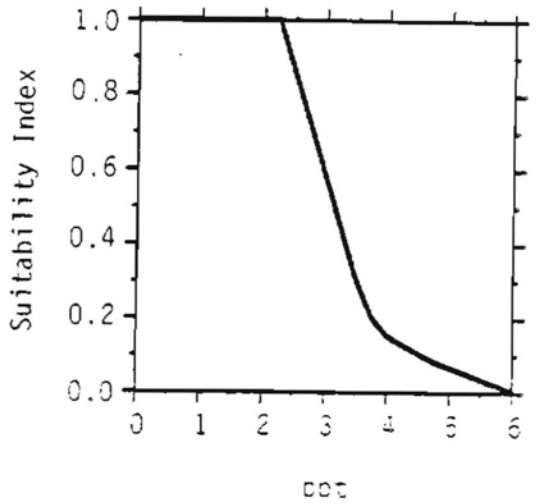
R	V_3	Percent cover in deeper pools (e.g., logs, brush, submerged objects, and depth).	
R	V_4	Percent pools, backwaters, and marsh areas during average summer flow.	
L	V_5	Percent littoral area during spring and summer.	

R	V_6	Storage ratio.	
R,L	V_7	Maximum monthly average turbidity during average summer flow or summer stratification.	
R,L	V_8	Maximum midsummer water temperature (Adult).	

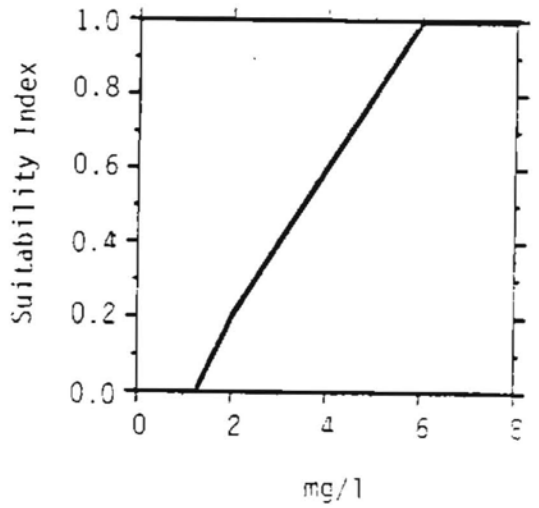
R,L	V_9	Average water temperatures during spawning within specified areas (Embryo).	
R,L	V_{10}	Maximum midsummer water temperature during average summer flow or summer stratification within pools, backwaters, or littoral areas (Juvenile, Fry).	
R,L	V_{11}	Maximum depth of littoral (L) area or pools, marshes, and backwaters (R) during spawning.	

R,L V_{12} Maximum salinity.

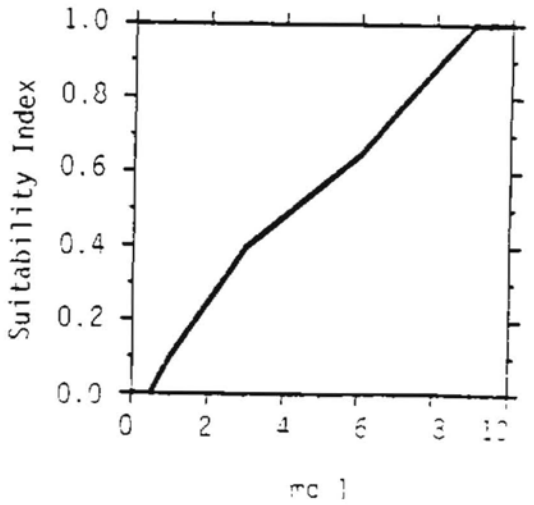
Note: Optional variable. V_{11} should be used in the model only if salinity is considered to be a potential problem within the study area.



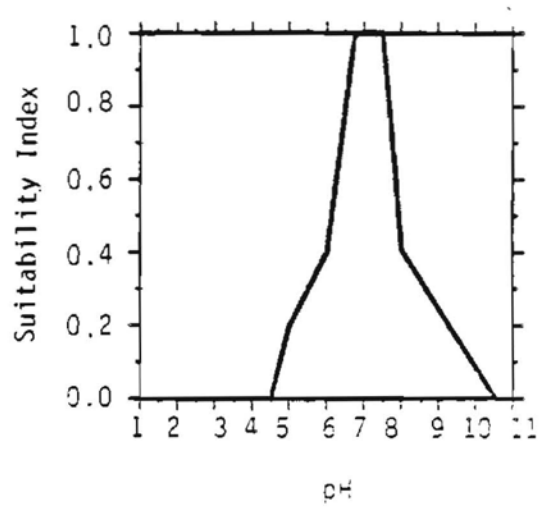
R,L V_{13} Minimum dissolved oxygen levels during midsummer (Fry, Juvenile, Adult).



R,L V_{14} Minimum dissolved oxygen levels within specified areas during spawning (March-June) (Embryo).



R,L	V_{15}	pH levels during the year.



Reservoir Habitat Suitability Index Model

$$C_{C/F} = \frac{V_1 + V_5}{2}$$

$$C_{WQ} = \frac{V_7 + 2(V_8 \times V_{10})^{1/2} + 2V_{13} + V_{15}}{6}$$

If V_8, V_{10}, or $V_{13} \leq 0.4$, C_{WQ} = the lowest of V_8, V_{10}, V_{13}, or the above equation.

NOTE: If V_{12} (optional salinity variable) is added:

$$C_{WQ} = \frac{V_7 + 2\,(V_8 \times V_{10})^{1/2} + 2V_{13} + V_{15} + V_{12}}{7}$$

$$C_R = (V_1 \times V_5 \times V_9 \times V_{14})^{1/4}$$

$$C_{OT} = V_6$$

$$HSI = (C_{C/F} \times C_{WQ} \times C_R \times C_{OT})^{1/4}$$

If C_{WQ} or $C_R \leq 0.4$, the HSI = the lowest of C_{WQ}, C_R, or above equation.

Riverine Habitat Suitability Index Model

$$C_F = (V_1 \times V_4)^{1/2}$$

$$C_C = (V_1 \times V_3 \times V_4)^{1/3}$$

$$C_{WQ} = \frac{V_7 + 2\,(V_8 \times V_{10})^{1/2} + 2V_{13} + V_{15}}{6}$$

Note: If V_{12} (optional salinity variable) is added:

$$C_{WQ} = \frac{V_7 + 2\,(V_8 \times V_{10})^{1/2} + 2V_{13} + V_{15} + V_{12}}{7}$$

If V_8, V_{10}, or $V_{14} \leq 0.4$, C_{WQ} = the lowest of V_8, V_{10}, V_{14}, or the above equations

$$C_R = (V_1 \times V_4 \times V_9 \times V_{11} \times V_{14})^{1/5}$$

$$C_{OT} = V_2$$

$$HSI = (C_F \times C_C \times C_{WQ} \times C_R \times C_{OT})^{1/5}$$

APPENDIX B

ENVIRONMENTAL DATA FOR SELECTED RESERVOIRS AND RIVERS

Table B-1. Environmental data for green sunfish in selected reservoirs.

Variable	Reservoir					
	West Point	Oconee	Lanier	Center Hill	Shelbyville	Sangchris
Model variable SI						
V_1	0.3	0.7	0.2	1.0	0.7	1.0
V_4	1.0	0.7	1.0	1.0	1.0	1.0
V_5	1.0	1.0	0.5	0.5	0.5	0.5
V_6	0.3	1.0	0.7	1.0	1.0	0.7
V_7	0.8	0.5	0.8	1.0	1.0	0.8
V_8	0.4	0.2	0.3	0.8	0.8	0.4
V_9	0.5	0.8	0	1.0	0.8	0
V_{10}	0.9	0.8	0.9	0.2	0.8	0.8
V_{15}	0.5	0.5	0.6	0.8	0.9	1.0
V_{16}	1.0	1.0	1.0	0.4	1.0	1.0
V_{17}	0.7	0.75	1.0	0	0	1.0
Component SI						
C_F	0.50	0.50	0.60	0.80	0.90	1.00
C_C	0.55	0.84	0.50	0.40	0.84	1.00
C_{WQ}	0.75	0.20	0.73	0.90	0.88	0.40
C_R	0.70	0.78	0	0	0	0
HSI (orig.)	0.62	0.20	0	0	0	0
HSI (mod.)	0.64	0.50	0.67	0.54	0.85	0.75
Standing crop (kg/ha)	4.70	13.66	1.46	1.91	0.30	2.70

Table B-2. Environmental data for warmouth in selected reservoirs.

Variable	Reservoir					
	West Point	Oconee	Lanier	Center Hill	Shelbyville	Sangchris
Model variable SI						
V_1	1.00	0.70	1.00	0.70	0.70	0.70
V_3	1.00	0.70	1.00	1.00	0.70	1.00
V_6	0.70	1.00	1.00	0.70	1.00	0.70
V_7	1.00	1.00	1.00	1.00	1.00	1.00
V_8	1.00	1.00	1.00	1.00	1.00	1.00
V_9	1.00	1.00	1.00	1.00	1.00	1.00
V_{10}	1.00	0.95	1.00	1.00	1.00	1.00
V_{12}	1.00	1.00	1.00	0.50	0.50	1.00
V_{13}	0.40	0.30	0.40	0.50	1.00	1.00
V_{14}	0.30	0.80	0.25	0.30	0.50	0.90
V_{15}	0.70	0.70	0.30	0.30	1.00	1.00
Component SI						
C_F	0.47	0.60	0.32	0.37	0.83	0.97
C_C	0.50	0.83	0.37	0.34	0.59	0.95
C_{WQ}	0.96	0.88	1.00	0.93	0.80	0.93
C_R	1.00	1.00	1.00	0.71	0.71	1.00
HSI	0.77	0.85	0.37	0.34	0.76	0.96
Standing crop (kg/ha)	2.69	5.26	1.68	0.21	a	a

[a]May have been lumped under "miscellaneous sunfish".

Table B-3. Environmental data for bluegill in selected reservoirs.

Variable	Reservoir					
	West Point	Oconee	Lanier	Center Hill	Shelbyville	Sangchris
Model variable SI						
V_2	0.30	1.00	0.25	0.25	0.50	1.00
V_3	0.80	0.80	1.00	0.35	1.00	1.00
V_4	0.50	0.25	0.50	0.80	0.90	1.00
V_5	1.00	1.00	1.00	1.00	1.00	1.00
V_6	0.70	1.00	0.70	1.00	1.00	0.70
V_7	1.00	1.00	1.00	1.00	1.00	1.00
V_8	1.00	1.00	1.00	1.00	1.00	1.00
V_9	0.20	0	0.10	1.00	0.60	0.10
V_{10}	1.00	1.00	1.00	1.00	1.00	1.00
V_{11}	1.00	1.00	1.00	1.00	1.00	1.00
V_{12}	1.00	0.40	0.80	0.80	0.85	0.80
V_{18}	1.00	1.00	1.00	0.30	0.10	1.00
Component SI						
C_F	0.39	0.50	0.35	0.45	0.67	1.00
C_C	0.58	0.86	0.40	0.31	0.79	1.00
C_{WQ}	0.81	0	0.77	0.98	0.93	0.93
C_R	0.68	0	0.61	0.39	0.73	0.97
HSI	0.68	0	0.61	0.39	0.73	0.97
Standing crop (kg/ha)	57.8	6.4	16.1	8.2	22.7	22.8

Table B-4. Environmental data for black crappie in selected reservoirs.

Variable	Reservoir					
	West Point	Oconee	Lanier	Center Hill	Shelbyville	Sangchris
Model variable SI						
V_1	1.00	0.95	1.00	1.00	1.00	1.00
V_2	0.40	1.00	0.25	0.40	1.00	1.00
V_6	1.00	1.00	0.30	0.40	1.00	1.00
V_7	0.50	1.00	0.70	0.60	0.70	0.55
V_8	0.80	1.00	1.00	1.00	1.00	1.00
V_9	0.40	0.50	0.40	0.60	1.00	1.00
V_{10}	0.40	0.40	0.40	0.60	0.80	0.80
V_{11}	1.00	1.00	1.00	1.00	1.00	1.00
V_{12}	1.00	0.20	1.00	1.00	1.00	1.00
V_{13}	1.00	0.20	1.00	1.00	1.00	1.00
V_{15}	0.40	0.40	0.50	0.80	0.90	1.00
Component SI						
C_F	0.40	0.40	0.50	0.80	0.90	1.00
C_C	0.63	1.00	0.27	0.40	1.00	1.00
C_{WQ}	0.65	0.20	0.80	0.84	0.93	0.90
C_R	0.86	0.58	0.65	0.74	1.00	1.00
HSI	0.40	0.20	0.27	0.67	0.96	0.97
Standing crop (kg/ha)	12.2	32.5	6.8	-	2.5	-

Table B-5. (concluded).

Variable	Reservoir					
	West Point	Oconee	Lanier	Center Hill	Shelbyville	Sangchris
Component SI						
C_F	0.50	0.45	0.55	0.80	0.95	1.00
C_C	0.69	0.94	0.69	0.53	0.78	0.85
C_{WQ}	0.89	0.87	0.79	0.89	0.76	0.70
C_R	0.92	0.75	0.97	0.49	0.83	0.95
HSI	0.73	0.72	0.73	0.66	0.83	0.87
Standing crop (kg/ha)	17.02	33.6	6.16	-	12.6	3.5

Table B-5. Environmental data for largemouth bass in selected reservoirs.

Variable	Reservoir					
	West Point	Oconee	Lanier	Center Hill	Shelbyville	Sangchris
Model variable SI						
V_2	1.00	1.00	1.00	0.30	1.00	1.00
V_3	0.40	0.70	0.30	0.40	0.70	0.75
V_4	0.25	1.00	0.15	0.29	0.65	1.00
V_5	0.50	0.45	0.55	0.50	0.95	1.00
V_6	1.00	0.80	1.00	1.00	0.80	1.00
V_7	0.50	1.00	0.50	1.00	1.00	0.50
V_8	1.00	1.00	1.00	0.80	0.60	0.60
V_9	1.00	1.00	1.00	1.00	1.00	1.00
V_{10}	1.00	0.80	0.75	0.60	0.50	0.50
V_{11}	0.70	0.70	0.30	1.00	1.00	0.70
V_{12}	1.00	1.00	1.00	1.00	1.00	1.00
V_{13}	1.00	1.00	1.00	1.00	1.00	1.00
V_{14}	1.00	1.00	1.00	1.00	1.00	1.00
V_{15}	0.80	0.65	0.90	0.30	0.80	0.80
V_{17}	0.90	0.95	1.00	0.65	0.60	1.00
V_{18}	0.30	1.00	0.80	0.65	0.65	1.00

Table B-7. Environmental data for channel catfish in selected reservoirs.

Variable	Reservoir					
	West Point	Oconee	Lanier	Center Hill	Shelbyville	Sangchris
Model variable SI						
V_2	0.3	1.0	0.2	1.0	0.5	1.0
V_3	1.0	1.0	0.3	0.4	0.5	0.5
V_5	1.0	1.0	-	1.0	1.0	1.0
V_6	1.0	1.0	1.0	0.8	0.8	0.8
V_7	0.5	1.0	1.0	1.0	1.0	1.0
V_8	1.0	0.4	1.0	1.0	0.5	1.0
V_9	1.0	1.0	1.0	1.0	1.0	1.0
V_{10}	1.0	1.0	1.0	1.0	1.0	1.0
V_{11}	1.0	1.0	1.0	1.0	1.0	1.0
V_{12}	-	1.0	-	0.9	0.9	0.9
V_{13}	1.0	1.0	1.0	1.0	1.0	1.0
V_{14}	-	1.0	-	0.9	0.9	0.9
V_{15}	1.0	0.5	0.9	0.9	0.6	0.2
V_{16}	0.5	0.5	0.7	0.9	0.9	1.0
V_{17}	1.0	1.0	1.0	1.0	1.0	1.0

Table B-6. Environmental data for bullheads in selected reservoirs.

Variable	Reservoir					
	West Point	Oconee	Lanier	Center Hill	Shelbyville	Sangchris
Model variable SI						
V_2	0.35	1.00	0.10	0.40	1.00	1.00
V_4	0.80	1.00	0.60	1.00	1.00	1.00
V_5	1.0	1.0	1.0	1.0	1.0	1.0
V_6	0.60	1.00	1.00	1.00	1.00	1.00
V_7	1.00	1.00	1.00	1.00	1.00	1.00
V_8	1.00	1.00	1.00	1.00	1.00	1.00
V_9	1.00	0.70	0.70	0.70	1.00	1.00
V_{10}	1.00	1.00	1.00	1.00	1.00	1.00
V_{11}	1.00	0.20	0.80	0.20	1.00	1.00
V_{12}	0.50	1.00	0.30	1.00	1.00	1.00
V_{13}	0.50	0.80	0.60	0.80	1.00	1.00
V_{14}	1.00	0.40	1.00	0.40	1.00	1.00
V_{15}	0.50	0.50	0.50	0.50	0.50	0.50
V_{16}	1.00	0	1.00	0	0	1.00
Component SI						
C_F	0.50	0.25	0.60	0.80	1.00	1.00
C_C	0.56	0.79	0.39	0.43	0.79	0.79
C_{WQ}	0.87	0.73	0.82	0.78	1.00	0.87
C_R	0.87	0.87	0.75	0	0	1.00
HSI	0.68	0.59	0.62	0	0	0.91
Standing crop (kg/ha)	16.35	0	0.67	-	0.6	1.8

Table B-8. Environmental data for common carp in selected reservoirs.

Variable	Reservoir					
	West Point	Oconee	Lanier	Center Hill	Shelbyville	Sangchris
Model variable SI						
V_1	0.40	1.00	0.20	0.55	0.60	1.00
V_5	1.00	1.00	0.75	0.45	1.00	1.00
V_6	0.40	0.80	0.75	1.00	0.40	1.00
V_7	1.00	1.00	1.00	1.00	1.00	1.00
V_8	0.10	0.025	0	1.00	1.00	0
V_9	1.00	1.00	1.00	1.00	1.00	1.00
V_{10}	0.60	0.45	0.50	1.00	1.00	0.50
V_{13}	1.00	0.90	1.00	1.00	0.80	1.00
V_{14}	1.00	1.00	1.00	1.00	0.60	0.80
V_{15}	1.00	1.00	1.00	1.00	1.00	1.00
Component SI						
C_{WQ}	0.10	0.025	0	1.00	0.93	0
C_R	0.80	1.0	0.62	0.71	0.77	0.95
C_{OT}	0.40	0.80	0.75	1.00	0.75	1.00
$C_{C/F}$	0.70	1.00	0.48	0.50	0.80	1.00
HSI	0.10	0.025	0	0.77	0.81	0
Standing crop (kg/ha)	25.76	36.85	8.06	21.08	70.80	27.00

Table B-7. (concluded).

Variable	Reservoir					
	West Point	Oconee	Lanier	Center Hill	Shelbyville	Sangchris
Component SI						
C_F	0.60	0.83	0.40	0.53	0.65	0.83
C_C	0.55	1.00	0.24	0.35	0.50	0.71
C_{WQ}	0.87	0.40	1.00	0.97	0.80	0.94
C_R	0.64	0.40	0.58	0.66	0.65	0.60
C_{OT}	1.00	0.75	0.95	0.95	0.80	0.65
HSI	0.72	0.40	0.61	0.69	0.68	0.83
Standing crop (kg/ha)	4.26	3.47	1.79	0.18	2.60	9.50

Table B-9. (concluded).

Variable	River					
	Altamaha (Mainstream A)	Altamaha (Mainstream B)	Altamaha (Oxbow)	Ocmulgee (Mainstream)	Ocmulgee (Slough)	Flint
Component SI						
$C_{F/C}$	0.50	0.57	0(1.00)	0(0.45)	0.59	0.35
C_{WQ}	0.95	0.93	0.94	0.97	0.96	1.00
C_R	0(0.69)	0(0.28)	0(0.46)	0(0.89)	0(0.55)	0(0.45)
C_{OT}	0.52	0.52	0.52	0.52	0.52	0.52
HSI	0	0	0	0	0	0
HSI	0.64	0.53	0.69	0.67	0.63	0.53
Standing crop (kg/ha)	0	0	0	0	0	0.005
Modified variable(s)	V_{13}	V_{12}	V_2, V_{12}	V_{12}	V_{12}	

Table B-9. Environmental data for green sunfish in selected riverine habitats. Numbers in parentheses represent values obtained after model modifications.

Variable	River					
	Altamaha (Mainstream A)	Altamaha (Mainstream B)	Altamaha (Oxbow)	Ocmulgee (Mainstream)	Ocmulgee (Slough)	Flint
Model variable SI						
V_1	0.85	0.32	1.00	0.45	0.70	0.32
V_2	0.30	1.00	0	0	0.60	0.03
V_3	1.00	1.00	1.00	1.00	1.00	1.00
V_4	1.00	1.00	1.00	1.00	1.00	1.00
V_5	1.00	1.00	1.00	1.00	1.00	1.00
V_6	1.00	1.00	1.00	1.00	1.00	1.00
V_7	1.00	1.00	1.00	1.00	1.00	1.00
V_8	0.65	0.50	0.60	0.82	0.70	1.00
V_9	0.60	0.10	0.27	1.00	0.38	1.00
V_{10}	0.80	0.80	0.80	0.80	0.80	0.20
V_{11}	0	0	0	0	0	0
V_{12}	0	0	0	0	0	0
V_{13}	0	0	0	0	0	0
V_{14}	0.60	0.60	0.60	0.60	0.60	0.60
V_{18}	1.00	1.00	1.00	1.00	1.00	1.00

Table B-10. Environmental data for warmouth in selected riverine habitats. Component SI's in parentheses were derived from modified models. Numbers in parentheses represent values obtained after model modifications.

Variable	River					
	Altamaha (Mainstream A)	Altamaha (Mainstream B)	Altamaha (Oxbow)	Ocmulgee (Mainstream)	Ocmulgee (Slough)	Flint
Model variable SI						
V_1	1.00	1.00	1.00	1.00	1.00	1.00
V_2	1.00	0.34	1.00	0.34	1.00	0.45
V_3	1.00	1.00	1.00	1.00	1.00	1.00
V_4	1.00	1.00	1.00	1.00	1.00	1.00
V_5	0.20	1.00	0.10	0.10	0.30	0.30
V_6	1.00	1.00	1.00	1.00	1.00	1.00
V_7	1.00	1.00	1.00	1.00	1.00	1.00
V_8	1.00	1.00	1.00	1.00	1.00	1.00
V_9	1.00	1.00	1.00	1.00	1.00	1.00
V_{10}	1.00	1.00	1.00	1.00	1.00	1.00
V_{11}	0	0	0	0	0	0
V_{12}	0.50	0.50	0.50	0.50	0.50	0.50

Table B-10. (concluded).

Variable	River					
	Altamaha (Mainstream A)	Altamaha (Mainstream B)	Altamaha (Oxbow)	Ocmulgee (Mainstream)	Ocmulgee (Slough)	Flint
Component SI						
C_F	0.60	0.67	0.55	0.22	0.68	0.38
C_C	0.46	0.57	0.35	0.23	0.54	0.39
C_{WQ}	1.00	1.00	1.00	1.00	1.00	1.00
C_R	0.84	0.64	0.84	0.64	0.84	0.69
C_{OT}	0(1.00)	0(1.00)	0(1.00)	0(1.00)	0(1.00)	0(1.00)
HSI	0	0	0	0	0	0
HSI (modified)	0.79	0.77	0.75	0.57	0.82	0.68
Standing crop (kg/ha)	10.7	1.3	15.33	0.15	3.61	0.05
Modified variable	V_{11}	V_{11}	V_{11}	V_{11}	V_{11}	V_{11}

Table B-11. Environmental data for bluegill in selected riverine habitats.

Variable	River					
	Altamaha (Mainstream A)	Altamaha (Mainstream B)	Altamaha (Oxbow)	Ocmulgee (Mainstream)	Ocmulgee (Slough)	Flint
Model variable SI						
V_1	0.35	1.00	0.15	0.15	0.45	0.40
V_2	0.70	0.30	0.85	0.45	0.59	0.33
V_5	1.00	1.00	1.00	1.00	1.00	1.00
V_6	1.00	1.00	1.00	1.00	1.00	1.00
V_7	1.00	1.00	1.00	1.00	1.00	1.00
V_8	1.00	1.00	1.00	1.00	1.00	1.00
V_9	0.50	0.10	0.20	0.80	0.50	0.63
V_{10}	1.00	1.00	1.00	1.00	1.00	1.00
V_{11}	1.00	1.00	1.00	1.00	1.00	1.00
V_{12}	0.95	1.00	1.00	0.85	0.90	0.90
V_{13}	0.10	0.10	0.10	0.10	0.10	0.10
V_{14}	0.20	0.10	0.20	0.10	0.10	0.20
V_{15}	0.10	0.10	0.10	0.10	0.10	0.10
V_{16}	0	0	0	0	0	0
V_{17}	1.00	1.00	1.00	1.00	1.00	1.00
V_{19}	1.00	1.00	1.00	1.00	1.00	0.70

Table B-11. (concluded).

Variable	River					
	Altamaha (Mainstream A)	Altamaha (Mainstream B)	Altamaha (Oxbow	Ocmulgee (Mainstream)	Ocmulgee (Slough)	Flint
Component SI						
C_F	0.50	0.55	0.36	0.26	0.52	0.36
C_C	0.70	0.30	0.85	0.28	0.59	0.33
C_{AQ}	0.94	0.85	0.88	0.97	0.93	0.95
C_R	0.59	0.46	0.59	0.46	0.46	0.52
C_{OT}	0.53	0.53	0.53	0.53	0.53	0.53
HSI	0.68	0.55	0.65	0.51	0.63	0.56
Standing crop (kg/ha)	16.7	8.5	23.6	2.2	27.8	0.38

Table B-12. Environmental data for black crappie in selected riverine habitats.

Variable	River					
	Altamaha (Mainstream A)	Altamaha (Mainstream B)	Altamaha (Oxbow)	Ocmulgee (Mainstream)	Ocmulgee (Slough)	Flint
Model variable SI						
V_1	1.00	1.00	1.00	1.00	1.00	1.00
V_2	1.00	0.28	1.00	0.28	1.00	0.53
V_3	1.00	1.00	1.00	1.00	1.00	1.00
V_4	0.20	0.39	0.28	0	0.17	0.30
V_5	0.42	1.00	0.19	0.19	0.59	0.50
V_7	1.00	1.00	1.00	1.00	1.00	1.00
V_8	1.00	0.70	0.85	1.00	0.82	1.00
V_9	0.50	0	0.10	0.75	0.10	0.37
V_{10}	0.30	0	0.10	0.60	0.10	0.37
V_{11}	1.00	1.00	1.00	1.00	1.00	1.00
V_{12}	1.00	1.00	1.00	1.00	1.00	1.00
V_{13}	1.00	1.00	1.00	1.00	1.00	1.00

Table B-12. (concluded).

Variable	River					
	Altamaha (Mainstream A)	Altamaha (Mainstream B)	Altamaha (Oxbow)	Ocmulgee (Mainstream)	Ocmulgee (Slough)	Flint
Component SI						
$C_{F/C}$	0.65	0.53	0.44	0.23	0.77	0.54
C_{WQ}	0.84	0	0.20	0.92	0.10	0.84
C_R	0.87	0.81	0.76	0.61	0.92	0.81
C_{OT}	0.60	0.70	0.64	0.50	0.59	0.65
HSI (orig.)	0.73	0	0.45	0.51	0.45	0.70
HSI (mod.)	-	0	-	-	-	-
Standing crop (kg/ha)	4.2	4.2	47.0	1.2	12.4	0
Modified variable	-	V_9, V_{10}	-	-	-	-

Table B-13. Environmental data for largemouth bass in selected riverine habitats. Numbers in parentheses represent values obtained after model modifications.

Variable	River					
	Altamaha (Mainstream A)	Altamaha (Mainstream B)	Altamaha (Oxbow)	Ocmulgee (Mainstream)	Ocmulgee (Slough)	Flint
Model variable SI						
V_1	0.10	1.00	0	0	0.35	0.24
V_3	1.00	0.40	1.00	0.40	0.80	0.40
V_4	1.00	0.25	1.00	0.25	0.75	0.25
V_6	0.80	0.80	0.80	0.80	0.80	0.80
V_7	1.00	1.00	1.00	1.00	1.00	1.00
V_8	1.00	1.00	1.00	1.00	1.00	1.00
V_9	1.00	1.00	1.00	1.00	1.00	1.00
V_{10}	0.87	1.00	0.86	0.80	0.87	0.95
V_{11}	0.70	1.00	0.70	0.70	0.70	0.80
V_{12}	1.00	1.00	1.00	1.00	1.00	1.00
V_{13}	1.00	1.00	1.00	1.00	1.00	1.00
V_{14}	1.00	1.00	1.00	1.00	1.00	1.00
V_{15}	0.50	0.50	0.50	0.50	0.50	0.30
V_{16}	0.70	0.70	0.70	0.70	0.70	0.85
V_{17}	0.90	0.85	0.90	0.90	0.90	0.85
V_{18}	1.00	1.00	1.00	1.00	1.00	1.00
V_{19}	0	0	0	0	0	0

Table B-13. (concluded).

Variable	River					
	Altamaha (Mainstream A)	Altamaha (Mainstream B)	Altamaha (Oxbow)	Ocmulgee (Mainstream)	Ocmulgee (Slough)	Flint
V_{20}	0	0	0	0	0	0
V_{21}	0	0	0	0	0	0
V_{22}	1.00	1.00	1.00	1.00	1.00	1.00
Component SI						
C_F	0.32	0.57	0	0(0.33)	0.52	0.28
C_C	0.92	0.53	0.92	0.53	0.81	0.55
C_{WQ}	0.88	0.94	0.88	0.99	0.88	0.91
C_R	0(0.46)	0(0.57)	0	0(0.73)	0(0.63)	0(0.50)
C_{OT}	1.00	1.00	1.00	1.00	1.00	1.00
HSI (orig.)	0	0	0	0	0	0
HSI (mod.)	0.65	0.69	-	0.66	0.75	0.59
Standing crop (kg/ha)	18.6	5.2	25.4	3.5	13.5	1.3
Variables modified	V_{20}	V_{20}	-	V_1, V_{20}	V_{20}	V_9, V_{20}

Table B-14. Environmental data for black bullhead in selected riverine habitats.

Variable	River					
	Altamaha (Mainstream A)	Altamaha (Mainstream B)	Altamaha (Oxbow)	Ocmulgee (Mainstream)	Ocmulgee (Slough)	Flint
Model variable SI						
V_1	0.45	0.90	0.15	0.10	0.55	0.50
V_2	1.00	0.10	1.00	0.20	1.00	0.45
V_3	0	0.20	0	0	0	0
V_4	1.00	0.80	0.90	1.00	1.00	1.00
V_5	1.00	0.70	1.00	1.00	1.00	0.70
V_6	1.00	1.00	1.00	1.00	1.00	1.00
V_7	1.00	1.00	1.00	1.00	1.00	1.00
V_8	1.00	1.00	1.00	1.00	1.00	1.00
V_9	1.00	1.00	1.00	1.00	1.00	1.00
V_{10}	0	1.00	0.70	1.00	0.60	0.99
V_{11}	1.00	1.00	1.00	1.00	1.00	1.00
V_{12}	1.00	0.30	1.00	0.40	1.00	0.80

Table B-14. (concluded).

Variable	River					
	Altamaha (Mainstream A)	Altamaha (Mainstream B)	Altamaha (Oxbow)	Ocmulgee (Mainstream)	Ocmulgee (Slough)	Flint
Component SI						
C_F	0.67	0.30	0.39	0.14	0.74	0.47
C_C	0(0.67)	0.26	0(0.39)	0(0.14)	0(0.74)	0(0.47)
C_{WQ}	1.00	0.83	0.93	1.00	1.00	1.00
C_R	0(0.77)	0.72	0.57	0.45	0.76	0.75
HSI (orig.)	0	0.46	0	0	0	0
HSI (mod.)	0.77	-	0.53	0.31	0.80	0.62
Standing crop						
bl. bull.	0	0	0	0	0	0
brn. bull.	47.4	42.3	0.14	0	4.1	41.4
Modified variable(s)	V_3, V_{10}	-	V_3	V_3	V_3	V_3

Table B-15. Environmental data for channel catfish in selected riverine habitats.

Variable	River					
	Altamaha (Mainstream A)	Altamaha (Mainstream B)	Altamaha (Oxbow)	Ocmulgee (Mainstream)	Ocmulgee (Slough)	Flint
Model variable SI						
V_1	1.00	0.35	1.00	0.35	1.00	0.75
V_2	0.50	1.00	0.30	0.55	0.80	0.20
V_4	0.20	0.20	0.20	0.20	0.20	0.50
V_5	1.00	1.00	0.90	1.00	1.00	1.00
V_6	1.00	1.00	1.00	1.00	1.00	1.00
V_7	1.00	1.00	1.00	1.00	1.00	1.00
V_8	0.55	0.55	0.60	0.60	0.60	0.50
V_9	1.00	1.00	1.00	1.00	1.00	1.00
V_{10}	0.50	0.75	1.00	0.82	0.90	0.80
V_{11}	1.00	1.00	1.00	1.00	1.00	1.00
V_{12}	1.00	1.00	1.00	1.00	1.00	1.00
V_{13}	1.00	1.00	1.00	1.00	1.00	1.00
V_{14}	1.00	1.00	1.00	0.90	1.00	1.00
V_{18}	1.00	0.30	0.10	0.10	0.10	0.10

Table B-16. (concluded).

Variable	River					
	Altamaha (Mainstream A)	Altamaha (Mainstream B)	Altamaha (Oxbow)	Ocmulgee (Mainstream)	Ocmulgee (Slough)	Flint
Component SI						
C_F	0.44	0.55	0.52	0.37	0.57	0.45
C_C	0.39	0.45	0.38	0.34	0.46	0.45
C_{WQ}	0.82	0.38	0.84	1.00	1.00	0.93
C_R	0.50	0.56	0.49	0.45	0.50	0.50
C_{OT}	0.78	0.88	0.78	0.52	0.70	0.80
HSI	0.56	0.54	0.55	0.49	0.62	0.60
Standing crop (kg/ha)	0	136.4	35.0	2.2	78.8	0

HABITAT MODEL VALIDATION CONCEPTS

by

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Models are simplifications of real systems and, therefore, can always be invalidated under certain conditions. Because of this, validation should be defined as delineating the domain within which a model can be expected to provide realistic results. Defining the domain of model reliability may require substantial resources and multiple field tests. However, the Habitat Evaluation Procedures (HEP) Group, Habitat Suitability Index (HSI) model validation program seems to have been aimed at proving models fundamentally correct (or incorrect) based on a single field trial. Many of these validation efforts have not resulted in defensible conclusions about individual hypotheses. Thus, it may be time to critically review the HEP Group model validation guidelines within which the testing efforts reported in this workshop were carried out.

Habitat information that can be used to construct HSI models is extremely limited. Generally, the available data are site specific and unrelated. Synthesizing these data into model relationships requires considerable judgment by the model builder. Consequently, HSI models are typically based on numerous, untested hypotheses, any one of which can be invalid for a particular application. When a model fails to depict reality, it may be impossible to pinpoint the exact reasons for failure.

The HEP Group HSI model validation program has focused on the output from HSI models, ignoring the many assumptions made in computing an HSI. Model outputs (i.e., HSI's) have been compared to observed animal densities on independent areas, usually selected on the basis of available density data. When model output fails to correlate with population density data, alternative model(s) frequently are constructed by fitting model relationships to the test data using intuition or multivariate techniques. However, data fitting may be a poor strategy for model validation. Most models can be adjusted to fit any given data set, but the adjusted model may not be reliable when applied to new conditions, such as a major land use change (Holling 1978). In short, the "data fitting" approach may provide only illusions about the model's reliability.

More fundamentally, it seems questionable to fit a habitat model to density data unless it is certain that the density estimates are representative of limits imposed by the habitat (i.e., carrying capacity). Edwards and Fowle (1955:597) pointed out that carrying capacity is not a static property of the environment; rather, it fluctuates "...in response to the ebb and flow of interactions going on within it". One consequence of temporal dynamics is that populations may be limited by environmental conditions that operate during critical periods of time (e.g., winter). Current environmental conditions (i.e., "current" carrying capacity) may be quite different than conditions during the critical periods. Wildlife populations do not respond instantaneously to temporal changes in carrying capacity, and density observed at one point in time may have little direct relationship to carrying capacity at that time. Thus, it may be illogical to fit a habitat model to density data based on point-in-time habitat observations.

Edwards and Fowle (1955) also pointed out that critical environmental factors may vary spatially. The conditions of an area must be well understood in order to properly identify the critical factors that have influenced population size in that area. For example, Mule (1982) discussed the disagreement between assessment of habitat suitability by experts and by HSI models for his Alaskan study area. He pointed out, however, that much of the information used to develop the models was from sites geographically removed from his study area and may not have been representative of Alaskan habitats.

A model must include the system variables that are critical in determining carrying capacity in order to be realistic. If a model is to be useful in impact assessment, it must also address factors that may be critical under future conditions. It is probably unrealistic to expect a single habitat model to include the critical factors and interrelationships for all possible combinations of beginning and future habitat conditions. Because of the spatial and temporal variation in carrying capacity, there may be many alternative models, each of which is better suited to a particular land use and geographic area.

If there are alternative models for use in different situations, then it follows that there may be no definitive procedure for proving that a particular model is generally valid (or invalid). The validation of an HSI model is largely a problem-specific process. Defining the domain of reality for a model may require extensive field work over many years and in many situations.

If, on the other hand, we are interested in model validations that may pay off in rapid model improvement, I suggest that our testing efforts address individual model assumptions and hypotheses rather than the model as a whole. Many HSI models are built on similar assumptions. For example, many terrestrial species models are based on the assumption that food abundance (or production) is related to vegetation structure. Blendon (1982) tested this hypothesis in Missouri and developed relationships that may be generally applicable for many insectivorous species. At the very least, individual model assumptions should be tested prior to attempted validation of the entire model (i.e., the HSI).

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16. Abstract (Limit: 200 words)

The results of fish habitat suitability index model tests and the discussion and recommendations of workshop participants on habitat model testing are presented. Models based solely on habitat characteristics often were incapable of accurately predicting responses such as standing crop. Alternative methods of using suitability curves without aggregating the curves into a Habitat Suitability Index (HSI) and examples of statistical methods for simplifying and developing habitat models are presented. The workshop results emphasize the need to test and develop habitat models under conditions similar to those at the application site. Problems with evaluating carrying capacity indicate a need for alternatives to carrying capacity for evaluating performance.

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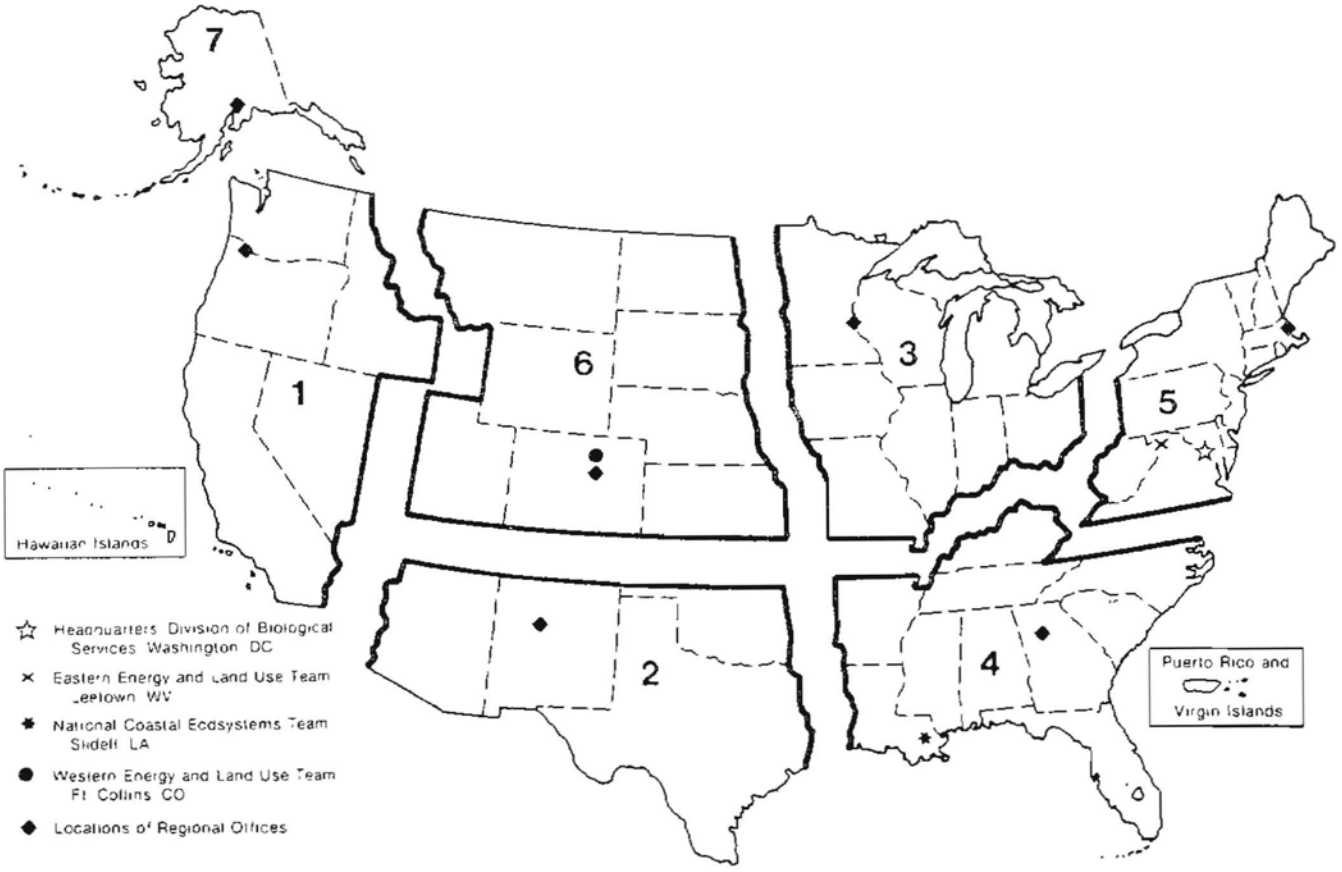

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