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PART	SUBJECT	RELEASE NUMBER
103 ESM	Ecological Services Manual-Standards for the Development of Habitat Suitability Index Models	1-81
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EXPLANATION OF MATERIAL TRANSMITTED:

Enclosed is the fifth release of the new Ecological Services Manual. It contains the following part:

103 ESM Standards for the Development of Habitat Suitability Index Models

This manual release is to be filed in your "Habitat Evaluation Procedures" binder.

Associate Director - Environment

FILING INSTRUCTIONS

Remove: Nothing.

Insert New Material: 103 ESM should be inserted between 102 ESM and 104 ESM in the Habitat Evaluation Procedures binder.

Transmittal Memorandum: File behind the Transmittal Memorandum 4-80 at the back of the Habitat Evaluation Procedures binder.

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Standards for the Development of

Habitat Suitability Index Models

103 ESM

Division of Ecological Services
U.S. Fish and Wildlife Service
Department of the Interior
Washington, D.C.

Preface

The U.S. Fish and Wildlife Service (USFWS) has been developing a habitat-based evaluation methodology since 1974 entitled the Habitat Evaluation Procedures for use in impact assessment and project planning (USFWS 1980). This work has culminated in the development of three documents. The first document, entitled "Habitat as a Basis for Environmental Assessment" (101 ESM), addresses the rationale for a habitat-based technique and discusses the conceptual approach to habitat assessment.

The second document, entitled "Habitat Evaluation Procedures" (102 ESM), serves as a further refinement of the Habitat Evaluation Procedures (HEP) first developed in 1976. 102 ESM describes how the concepts outlined in 101 ESM can be implemented in a standardized procedure for conducting habitat evaluations in the field. HEP provides a quantification of wildlife habitat that is based on two primary variables: 1) the Habitat Suitability Index (HSI); and 2) the total area of available habitat.

This document, "Standards for the Development of Habitat Suitability Index Models for Use with the Habitat Evaluation Procedures" (103 ESM), is the third document and provides guidance for the development of models that provide HSI values.

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1. Introduction

1.1 Purpose. The purpose of this manual part is to provide guidance and standards for the development of models or the adaptation of existing models to be used in determining Habitat Suitability Indices (HSI's) for use with the Habitat Evaluation Procedures (HEP) (102 ESM).

1.2 Scope. 103 ESM provides standards for the development of models to determine HSI values for terrestrial and inland aquatic evaluation species. These standards provide general guidance for the construction of HSI models and detailed descriptions of several modeling techniques appropriate for the level of effort and resolution required in a typical Federal water resource planning effort. An HSI model may be in graphical, word, or mathematical format and must clearly document the rules and assumptions used to calculate an HSI. Documentation throughout the development and use of a model helps to establish model credibility, optimize decisionmaking capabilities, and provides a permanent record of the basis for a decision. Studies by Ellis *et al*. (1979) confirmed that the use of documentation increases the repeatability of determining HSI values.

HSI models can be constructed from basic life history information or by modifying existing habitat models. It is recommended that this entire document be read at least once before proceeding with actual model construction. If an existing model is to be used, the reader should focus on 103 ESM 2, 3.2, 3.4, and 3.5. If a new model is to be constructed, the reader should focus on 103 ESM 3.

1.3 Objective. The objective of this manual part is to improve the reliability of HEP applications by providing guidance for the systematic development of HSI models.

1.4 Definitions. Habitat assessments using HEP are based upon Habitat Units (HU's) which are computed by the formula:

$$\text{Habitat Units} = (\text{HSI}) \times (\text{Area of available habitat}) \tag{1}$$

The area of available habitat is defined in 102 ESM 4.1 as the total area of all cover types used by the evaluation species.

The HSI is defined as a numerical index that represents the capacity of a given habitat to support a selected fish or wildlife species. An index, as defined by Inhaber (1976), is the ratio of a value of interest divided by a standard of comparison. For HEP purposes, the value of interest is an estimate or measure of habitat conditions in the study area, and the standard of comparison is the optimum habitat conditions for the same evaluation species. Therefore,

$$\text{Index Value} = \frac{\text{Value of Interest}}{\text{Standard of Comparison}}, \text{ or} \tag{2}$$

$$\text{HSI} = \frac{\text{Study Area Habitat Conditions}}{\text{Optimum Habitat Conditions}}$$

The HSI has a minimum value of 0.0 which represents totally unsuitable habitat and a maximum value of 1.0 which represents optimum habitat. An HSI model produces a 0-1.0 index with the assumption that there is a direct linear relationship between the HSI value and carrying capacity. Specifically, the use of HEP assumes that, for any evaluation species, a unit change in HSI will always have the same significance (i.e., will always correspond to the same change of carrying capacity units). This relationship is depicted in Figure 1-1 where an increase of 0.2 HSI units corresponds to an increase of "X" units of carrying capacity.

The assumption of linearity is not as restrictive as it may first appear because any <u>known relationship</u> between HSI and carrying capacity can be mathematically converted to a linear relationship. When the actual relationship between HSI and carrying capacity for a particular evaluation speices is not known, it must be assumed to be linear if the model is to be used with HEP.

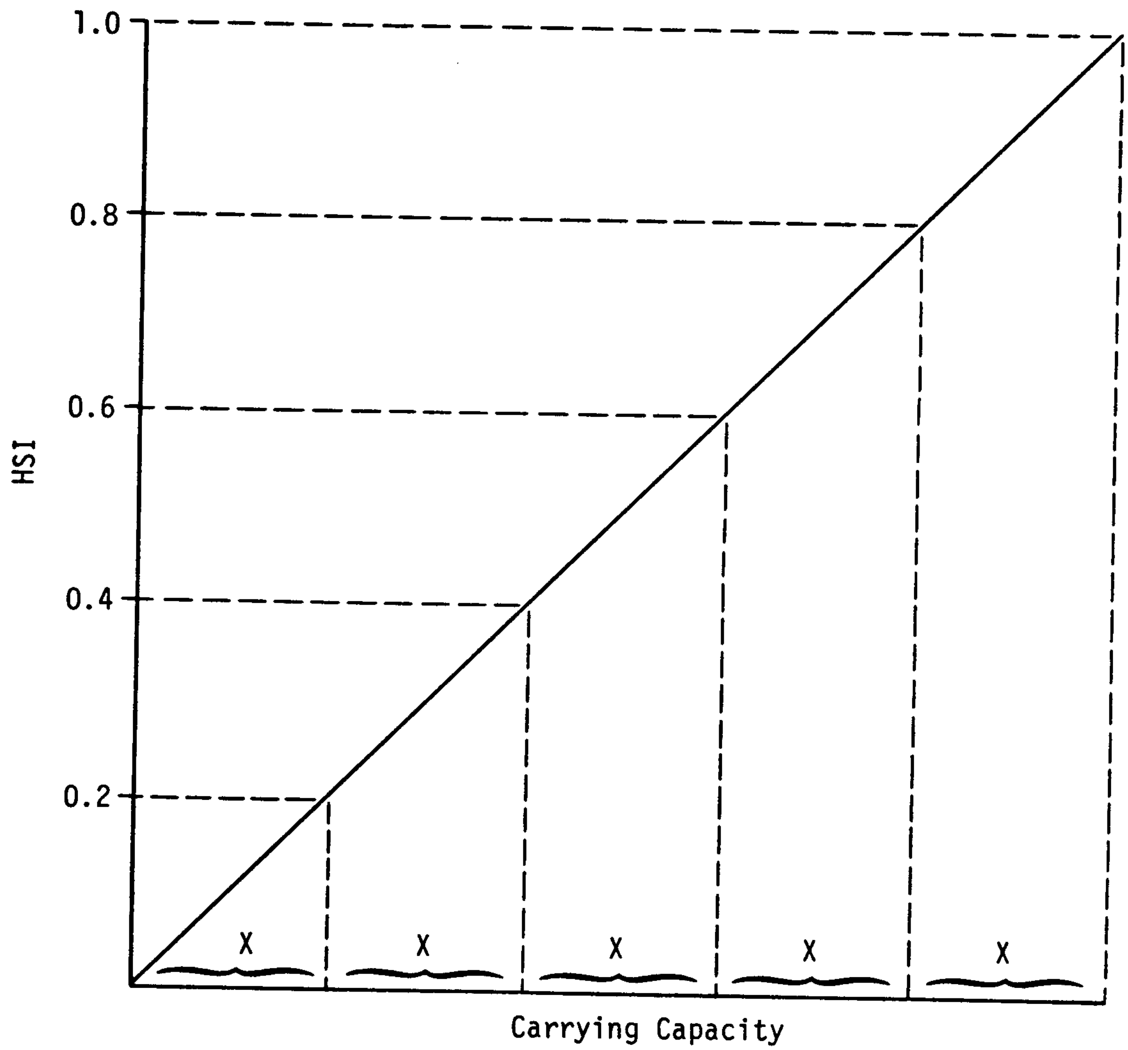

Figure 1-1. Linear relationship between HSI and carrying capacity.

2. Use of Existing Models to Obtain an HSI

The use of existing habitat models has the advantage of shortening the time required to develop an HSI model. Numerous species-habitat models are available in the literature and others are currently being developed by various researchers (Jenkins 1976; Bovee 1978; Robbins 1978; Aggus and Morais 1979; Binns and Eiserman 1979; Russell *et al*. 1980).

It is relatively easy to convert existing model outputs to an HSI. The most important step in converting a model output to an HSI is to define a standard of comparison for use in the following equation:

$$\text{HSI} = \frac{\text{Existing Model Output for Area of Interest}}{\text{Defined Standard of Comparison}} \quad (3)$$

The following examples demonstrate how some types of model outputs can be converted to an HSI using Formula 3. Note that these conversions do not change any of the assumptions, limitations, or accuracy of the original models.

2.1 Word rankings. Some models may rate habitat by word descriptors such as "excellent", "good", "average", or "below average." If the word descriptors are clearly defined they can be converted to a numerical ranking (Table 2-1). The HSI would equal the rank corresponding to a given model output divided by the highest rank the model could provide, or in this example:

$$\text{HSI} = \frac{\text{Output Rank for the Area of Interest}}{4} \quad (4)$$

Table 2-1. Example numerical rankings for outputs of a word model.

Output	Numerical Rank	HSI Value
Excellent	4	1.00
Good	3	0.75
Average	2	0.50
Below average	1	0.25

2. Use of Existing Models to Obtain an HSI

2.2 Models with defined output units. Models with outputs such as units of standing crop, productivity, or other population measures can easily be converted to an HSI. The basic task is to define a standard of comparison (denominator, Formula 3) that corresponds to the maximum regional value for the predicted measure. For example, the highest long term density observed in a region for a species may equal 60 individuals per square mile. Thus:

$$\text{HSI} = \frac{\text{Population Density Estimate (Existing Model Output)}}{60} \tag{5}$$

An HSI computed by this method is dependent upon the value used to represent the standard of comparison. Therefore, in order to make the proper comparisons between alternatives, it is important that one standard of comparison be used consistently throughout a study.

Several models with defined output units are available. Tested and scaled regression models relating habitat variables to population measures are available for reservoir fishes (Jenkins 1976; Leidy and Jenkins 1977) and some stream fishes (Binns and Eiserman 1979) and should be reviewed for potential HEP applications. Aggus and Morais (1979) presented a method for converting fish standing crop estimates in warmwater reservoirs to an HSI by using standing crop data; this is a nonlinear model that must be converted to a linear relationship for use in HEP. Robbins (1978) developed a model that predicts abundance for seven avian species in eastern deciduous forests. Models based on statistical methods that predict population densities of terrestrial species have been developed by Russell *et al*. (1980). These models use conditional probability statements derived through habitat observations in areas of both high and low population densities.

2.3 Models with undefined output units. The output of a model may be in the form of a numerical rating or an index. For example, habitats may be ranked from 1 to 5 with 5 being the best available habitat. In this example, the HSI would be computed by defining the denominator as the highest rank given by the model:

$$\text{HSI} = \frac{\text{Rank Provided by the Model for the Area of Interest}}{5} \tag{6}$$

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Baskett et al. (1980) compiled habitat models for eight game and nine nongame species found in central Missouri. These models output an undefined "Habitat Unit Value" for the various habitat types used by a particular species. The conversion of this output to an HSI requires the division of the Habitat Unit Value by the maximum possible value defined on the habitat type score form.

Another model with undefined output units has been developed by the USFWS's Cooperative Instream Flow Service Group. This method is used to assess a change in fish stream habitat potential in response to a change in stream flow or channel configuration (Bovee 1978; Stalnaker 1978; Stalnaker 1980). This method involves modeling habitat within selected stream reaches. The output of this model is Weighted Useable Area (WUA) for appropriate life stages (spawning, incubation, fry, juvenile, and adult) at monthly intervals (Stalnaker 1980). Conversion of WUA to an HSI for a given life stage involves two steps.

The first step is to convert the monthly WUA values to a single WUA value for the life stage. Suggested conversion techniques are: (1) select the WUA for a critical month; (2) calculate a mean WUA for a critical season; or (3) calculate a mean WUA for an entire 12-month period.

The second step in converting WUA to an HSI value is to use the WUA determined above and calculate a life stage HSI using the following formula:

$$HSI_i = \frac{\begin{array}{c}\text{Weighted Useable Area of Stream Reach}\\ \text{(Critical Month or Mean)}\end{array}}{\begin{array}{c}\text{Wetted Surface Area of the Same Stream Reach}\\ \text{(Critical Month or Mean)}\end{array}} \qquad (7)$$

where: i = Spawning, incubation, fry, juvenile, or adult life stage.

Individual life stage HSI values may be aggregated into a species HSI value using the techniques described in 103 ESM 3.3.

2.4 Sources of information. The species-habitat information needed to develop or modify habitat models is available from many sources, but is often difficult to locate. Many State and Federal natural resource agencies have file information that is useful in constructing habitat models. Other sources include standard library references and research institutions that are active in ecological studies. The following specific sources are included because of the known availability and uniqueness of the habitat information:

2. Use of Existing Models to Obtain an HSI

A. Bureau of Land Management. The Bureau of Land Management (BLM) published a series of Technical Notes that provide information on habitat requirements for many species. These Technical Notes can be obtained from:

Bureau of Land Management
U.S. Department of the Interior
Denver Service Center
Federal Center Building #50
Denver, Colorado 80225

B. U.S. Forest Service. The U.S. Forest Service is compiling habitat information for vertebrates under an effort entitled "Forest Service Fish and Wildlife Habitat Relationships System." This is an effort to compile basic ecological data that are useful for determining the value of habitat to wildlife for land use planning purposes. Information on this effort can be obtained from the Director of Fish and Wildlife Management at either the Washington Office or Regional Offices of the Forest Service.

U.S. Forest Service
P.O. Box 2417
Washington, D.C. 20013

C. Western Energy and Land Use Team. The Western Energy and Land Use Team (WELUT) of the USFWS has developed models for selected species of fish and wildlife. Lists of current models can be obtained by writing:

Western Energy and Land Use Team
U.S. Fish and Wildlife Service
2625 Redwing Road
Fort Collins, Colorado 80526

D. Eastern Energy and Land Use Team. A computerized procedure for storing fish and wildlife information data on a state-by-state basis has been developed by the Eastern Energy and Land Use Team. Current information concerning those States with available data can be obtained from:

Eastern Energy and Land Use Team
U.S. Fish and Wildlife Service
Kearneysville, West Virginia 25430

E. Migratory Bird and Habitat Research Laboratory. The USFWS Patuxent Wildlife Research Center has a large data base for migratory birds. This includes information on habitat requirements and other data useful in habitat modeling.

Migratory Bird and Habitat Research Laboratory
Patuxent Wildlife Research Center
Laurel, Maryland 20811

F. Boise District, BLM. Information is available for western birds of prey, including results from recent studies of habitat preference and home range.

Snake River Birds of Prey Study
Boise District, Bureau of Land Management
230 Collins Road
Boise, Idaho 83702

G. Appalachian Environmental Laboratory. Research has been conducted relating the vegetative characteristics and nest sites of woodland hawks.

Appalachian Environmental Laboratory
University of Maryland
Frostburg State College Campus
Frostburg, Maryland 21532

H. Waterways Experiment Station. Information is available concerning river and oxbow lake habitat requirements for fishes of the southeastern U.S.

Waterways Experiment Station
U.S. Army Corps of Engineers
Vicksburg, Mississippi 39180

2. Use of Existing Models to Obtain an HSI

I. National Reservoir Research Program. Information has been collected relating reservoir standing crop and harvest data to habitat variables.

U.S. Fish and Wildlife Service
National Reservoir Research Program
100 W. Rock Street
Fayetteville, Arkansas 72701

J. Cornell University. Data are available regarding breeding distribution, and nesting habitat and success for North American birds.

Nest-Record Card Program
Laboratory of Ornithology
Cornell University
Ithaca, New York 14850

K. Seattle National Fishery Research Center. Data have been collected on the winter habitat requirements of fishes in Alaska.

Seattle National Fishery Research Center
Bldg. 204, Naval Support Activity
Seattle, Washington 98115

3. Construction of HSI Models

This chapter describes techniques for constructing HSI models. This approach to model construction consists of five phases which occur in the basic sequence outlined in Figure 3-1. There is some procedural overlap of these phases. For example, Phase IV (document the model) must be partially completed in each of the other model construction phases. The model construction process should be looked at from a holistic point of view because the five phases do not always represent sequential, independent steps of model construction. Therefore, it is recommended that 103 ESM be read in its entirety before initiating model construction.

Several models are provided as examples in this document. Appendix A is a model for the gray squirrel. Appendix B is a model for the red-tailed hawk, which also is used as an example throughout this manual part. A detailed application of the red-tailed hawk model is provided in Appendix C. Appendix D contains a channel catfish model and an example application of the channel catfish model.

3.1 Phase I: Set model objectives. An HSI model is needed for each evaluation species used in a HEP analysis. As defined in 102 ESM, an evaluation species can be a single species, a group of species (e.g., a guild), a life stage, or a life requisite. Setting the model objectives involves the following: (1) defining the ideal and acceptable model outputs; (2) defining the geographic area to which the model is applicable; and (3) defining the season of the year for which the model is applicable.

A. Step 1. Define the ideal and acceptable model outputs. The ideal output of an HSI model is a 0-1.0 rating that has a direct linear relationship to carrying capacity (i.e., units of biomass/unit area or units of biomass production/unit area). A model should be structured such that its reliability can continually be improved by incorporating new information, thus moving the model output toward the ideal.

Since the ideal model output may rarely be obtainable, a more easily obtainable, yet acceptable model output must be defined. The acceptance output defines the level of reliability that the model should attain, considering the amount of time, information, and funding available. In other words, the acceptance output defines a level of reliability at which the model is ready for application.

The following are examples of several levels of model acceptance outputs:

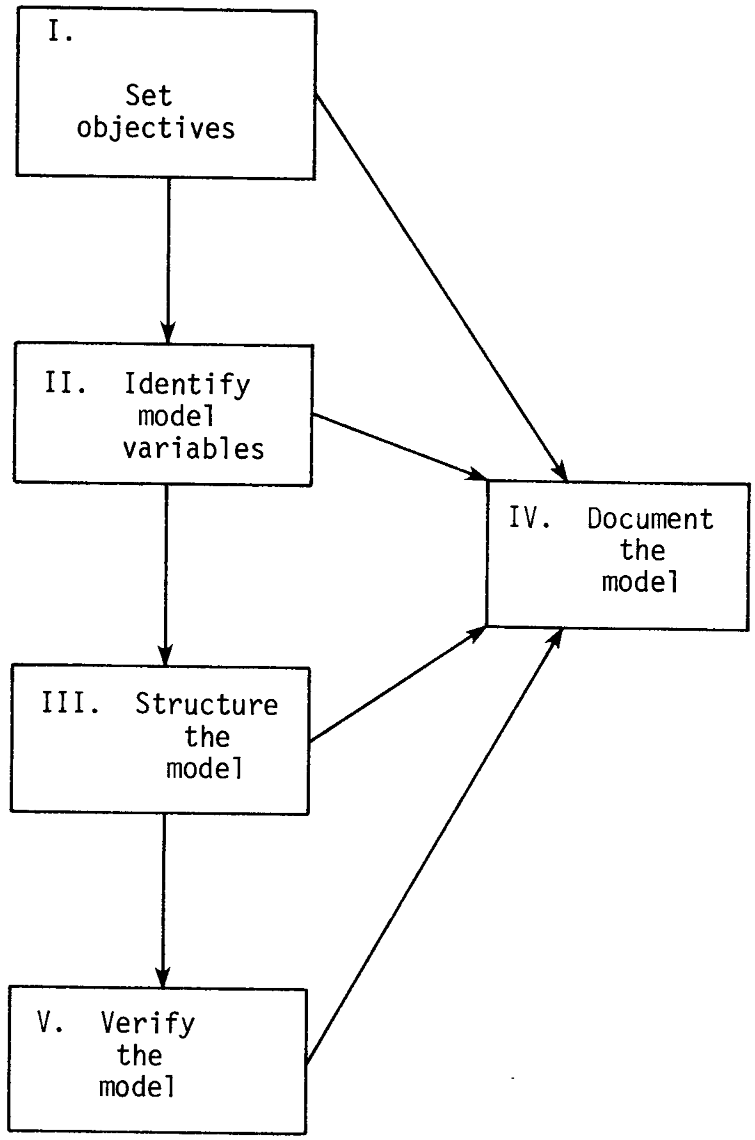

Figure 3-1. Five phases of HSI model construction.

- Model outputs based on sample data appear reasonable to the evaluation team.

- Model outputs based on sample data appear reasonable to a species authority.

- The model outputs rank study sites in a manner similar to a species authority's rankings (e.g., HSI is correlated with expert rankings).

- The output of the model is correlated with carrying capacity as measured by population estimates.

- The model outputs predict carrying capacity as measured by populations, within 10% with a confidence level of 90% (102 ESM, Appendix B).

The degree to which the model output meets the specified acceptance level is determined by the verification phase outlined in 103 ESM 3.5.

B. Step 2. Define the geographic area of model applicability. Every habitat model should be applicable to a defined geographic area within which it can be expected to yield consistently reliable HSI values. At a minimum, the geographic area of model applicability always should include the individual study sites that will be compared in a single impact assessment. However, it may be desirable to construct a model with applicability to a large geographic area for use in more than a single study. There may be a trade-off involved because, generally, the larger the desired area of geographic applicability, the more difficult it is to construct a model that yields consistently reliable results at the some level of reliability.

The geographic area of model applicability should be clearly defined for each species and may include the entire range of the species. For example, Noon *et al*. (1980) found no significant difference in breeding habitat preferences over the entire range of several forest bird species. However, if a species displays significant differences in habitat preference for different geographic areas, regional models may be appropriate for each area. The area of model applicability should be referenced to some standard units such as watersheds, State boundaries, or ecoregions. Suggested areas of reference are described below, although the homogeneity of these for habitat model application has not been fully tested.

(1) Terrestrial geographic areas. One system recommended for the development of terrestrial HSI models is "Ecoregions of the United States" (Bailey 1976). Bailey defines an ecoregion as a "...geographical area over which the environmental complex, produced by climate, topography, and soil, is sufficiently uniform to permit development of characteristic types of ecologic associations." Bailey defines nine levels of ecoregion classification based on climate, soils, and vegetation. Any of the nine levels may be appropriate to describe the geographic area of model applicability for a particular species.

(2) Aquatic geographic areas. One system recommended for the development of inland aquatic HSI models is the Hydrologic Unit Map prepared by the U.S. Geologic Survey (USGS) in cooperation with the U.S. Water Resources Council (Seaber et. al, 1974). These maps provide a standardized base for nationwide use by Federal and State water resource agencies. The maps also form the basis of a standard coding system for a number of computerized water use and aquatic biology data storage and retrieval systems being developed by Federal and State agencies. Hydrologic Unit Maps can be obtained from the following USGS Offices:

a) For States east of the Mississippi River:

Branch of Distribution
U.S. Geological Survey
1200 South Eads St.
Arlington, Virginia 22202

b) For States west of the Mississippi River:

Branch of Distribution
U.S. Geological Survey
Box 25286 Federal Center
Denver, Colorado 80225

C. Step 3. Define the seasonal applicability of the model. Defining the residency status of a species within the desired geographic area limits the life history information that must be collected for model construction. The residency status of a species can be determined quickly through a review of the literature and defines the season(s) of the year for which a model can be applicable. Even though a species may be a permanent resident in an area, a model may be

developed which is applicable for only part of the time the species is present. For example, a red-tailed hawk model may be constructed for the breeding season because breeding habitat is particularly important for the study at hand, even though red-tailed hawks are permanent residents within the study area.

3.2 Phase II: Identify model variables. Habitat variables are the building blocks of an HSI model. This phase of model construction answers the question: "What environmental variables, if modified, would be expected to affect the capacity of the habitat to support the evaluation species?"

The intended application of the model must be considered when identifying model variables. For example, a model intended for use with remote sensing data should be constructed with variables that can be easily measured through remote sensing. Every HSI model used for impact assessments must be applicable for evaluating both present and future habitat conditions. Therefore, the model should be based upon a set of habitat variables that can be measured under existing conditions and predicted for future conditions. Other factors which influence the selection of model variables include available time and budget constraints for model development and data collection.

The potential variables for a typical habitat assessment using HEP include measurable physical, chemical, or biological characteristics of the habitat. Species population variables are usually not included in a habitat model because they are costly to measure, difficult to predict, and often are not directly indicative of habitat suitability.

The generalized approach for identifying model variables consists of reviewing the literature on the species and selecting those variables that meet three criteria: (1) the variable is related to the capacity of the habitat to support the species; (2) there is at least a basic understanding of the relationship of the variable to habitat (e.g., what is the best and worst condition for the variable and how does the variable interact with other variables?); and (3) the variable is practical to measure within the constraints of the model application.

Application of these criteria to the process of identifying variables is described in detail in 103 ESM 3.3. The following section describes a structured technique that may simplify the identification of variables and facilitate the model construction process.

A. Identify variables using tree diagrams. Identification of habitat variables may be facilitated by using tree diagrams (Figure 3-2). A tree diagram can be used to separate habitat into less complex

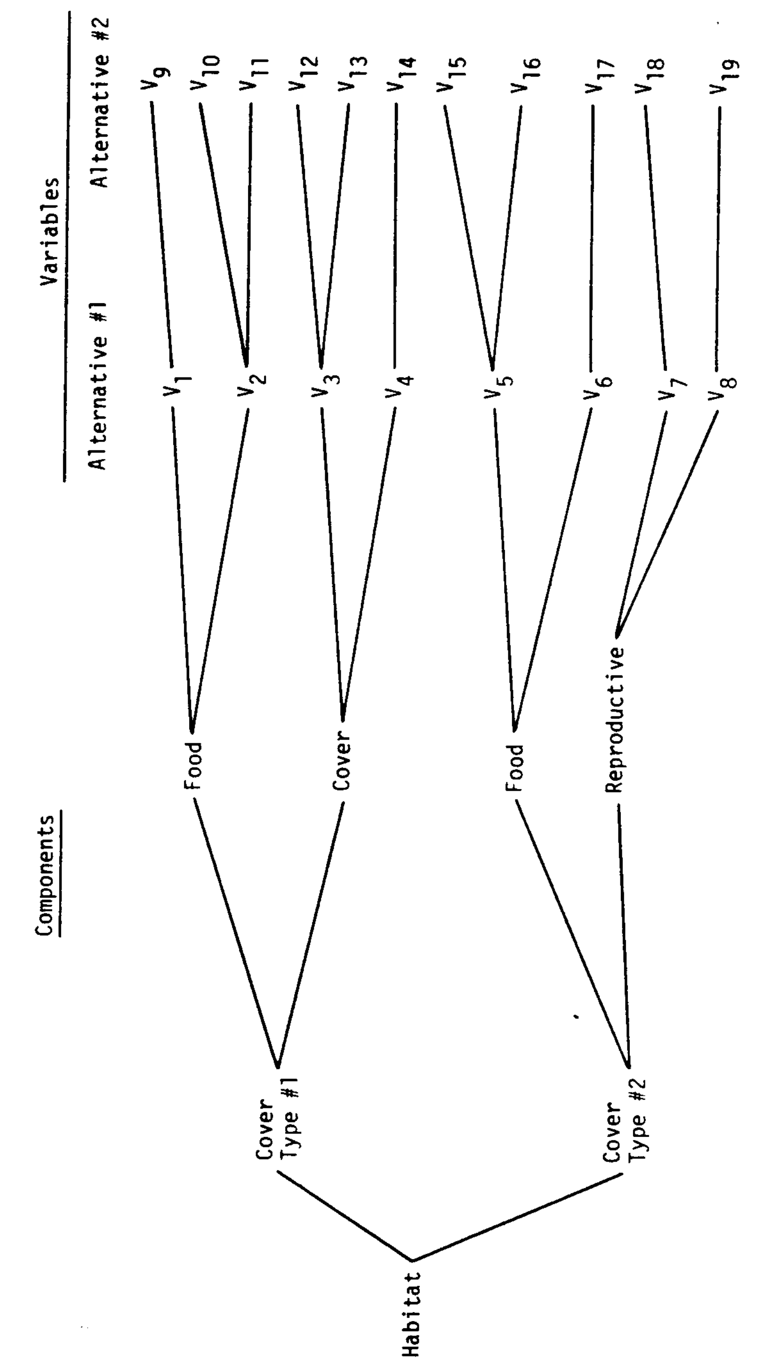

Figure 3-2. Identification of model variables through definition of habitat components.

components, each of which is related to a set of measurable variables. Additionally, definition of habitat components will be helpful when measurable variables must be inferred from general statements in the literature. Tree diagrams are useful for gaining an understanding of the relationship between two or more variables. Separating habitat into components divides the variables into related groups and greatly simplifies the understanding of functional relationships within the model.

The level to which a species' use of habitat is separated into components is left to judgement based on the quantity and quality of the available life history information. However, the process of dividing the habitat into components should continue to the point that each component is related to measurable variables (Figure 3-2). A measurable variable is one that can be quantitatively described with some degree of replicability using standard field sampling and mapping techniques. There may be alternative variables for the same component. For example, a measure of food availability for a species might be insect abundance during the summer. Various techniques are available for a direct measurement of insect abundance. However, the level of effort required to make measurements at the desired level of resolution may not be acceptable. In this situation an alternative set of indirect measures could be defined. For example, measures of vegetative structure may provide an indirect measure of insect abundance. Figure 3-2 depicts two alternative sets of variables. Alternative 1 variables denote the optimum method (e.g., insect abundance) whereas alternative 2 variables denote measures of vegetative structure as an indication of insect abundance. The selection of one variable from a set of alternative variables should be based upon practical considerations, including sampling constraints.

There are at least four types of components used to define habitat variables for an evaluation species: (1) seasonal habitat; (2) life requisites; (3) life stages; and (4) cover types. These are suggested because they represent habitat characteristics that are biologically definable and, to some degree, their significance to HSI is experimentally testable. A preponderance of the habitat information in the literature also is defined in related terms.

(1) Seasonal habitat. Seasonal habitat is the habitat used for a particular period during a species' annual life cycle (e.g., winter range or breeding season habitat).

(2) Life requisites. Life requisites include food, cover, water, reproductive, or special resources supplied by a species' habitat. Life requisite components can be further separated into categories such as seasonal foods, nesting habitat, or brood rearing habitat.

(3) Life stages. Life stages are typically utilized for aquatic models and include the egg, larval, fry, juvenile, and adult stages of a species.

(4) Cover types. A cover type is an area of land or water with similar physical, chemical, and biological characteristics that meet a specified standard of homogeneity. Cover types serve two primary purposes in a model. They segregate measurable variables into groups that simplify field data collection. For example, in Figure 3-2 only V_1, V_2, V_3, and V_4 are measured in cover type 1. Cover types also are used to define spatial relationships between habitat components. For example, in Figure 3-2, cover types are used to define habitat suitability based on the spatial relationships (interspersion) of food, cover, and reproductive resources. The use of cover types to define spatial relationships is described in 103 ESM 3.2B, Step 5.

The above four habitat components can be organized a number of ways. Figures 3-3(A) and 3-3(B) are terrestrial examples, and Figures 3-4(A) and 3-4(B) are aquatic examples. An example model for the red-tailed hawk, based on the tree diagram in Figure 3-3(A), is contained in Appendix B. An example model for channel catfish, based on the tree diagram in Figure 3-4(A), is presented in Appendix D.

The following example demonstrates the use of tree diagrams to identify variables related to the red-tailed hawk model in Appendix B. The example is divided into five steps, each of which involves a decision requiring red-tailed hawk life history information. With each additional step, the information required is more detailed than in the previous step. The variable identification process may require iterations through the five steps.

B. Identify variables: red-tailed hawk example

Step 1. Identify seasonal habitat components. If, during the desired season(s) of model applicability, the species displays a shift in habitat use patterns (i.e., a change in cover type usage or seasonal home range movements), the first consideration should be the seasonal

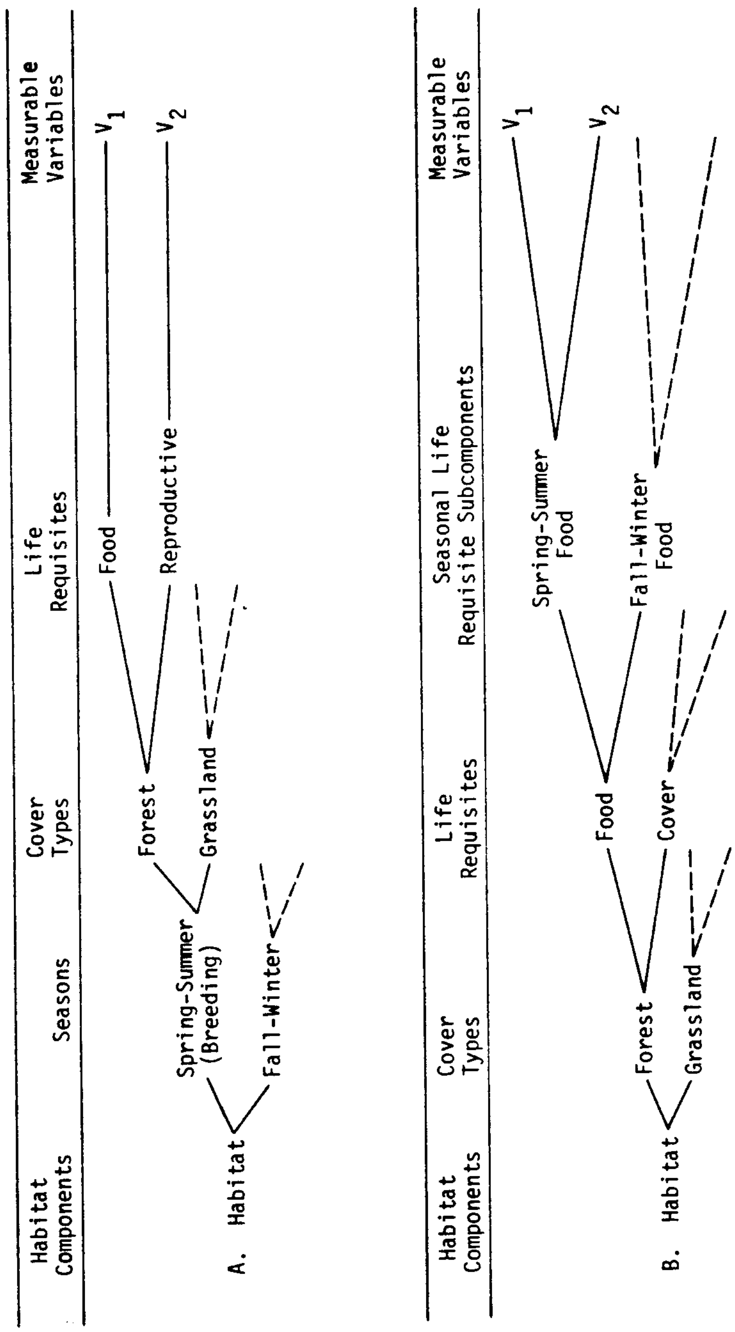

Figure 3-3. Example tree diagrams for terrestrial habitat.

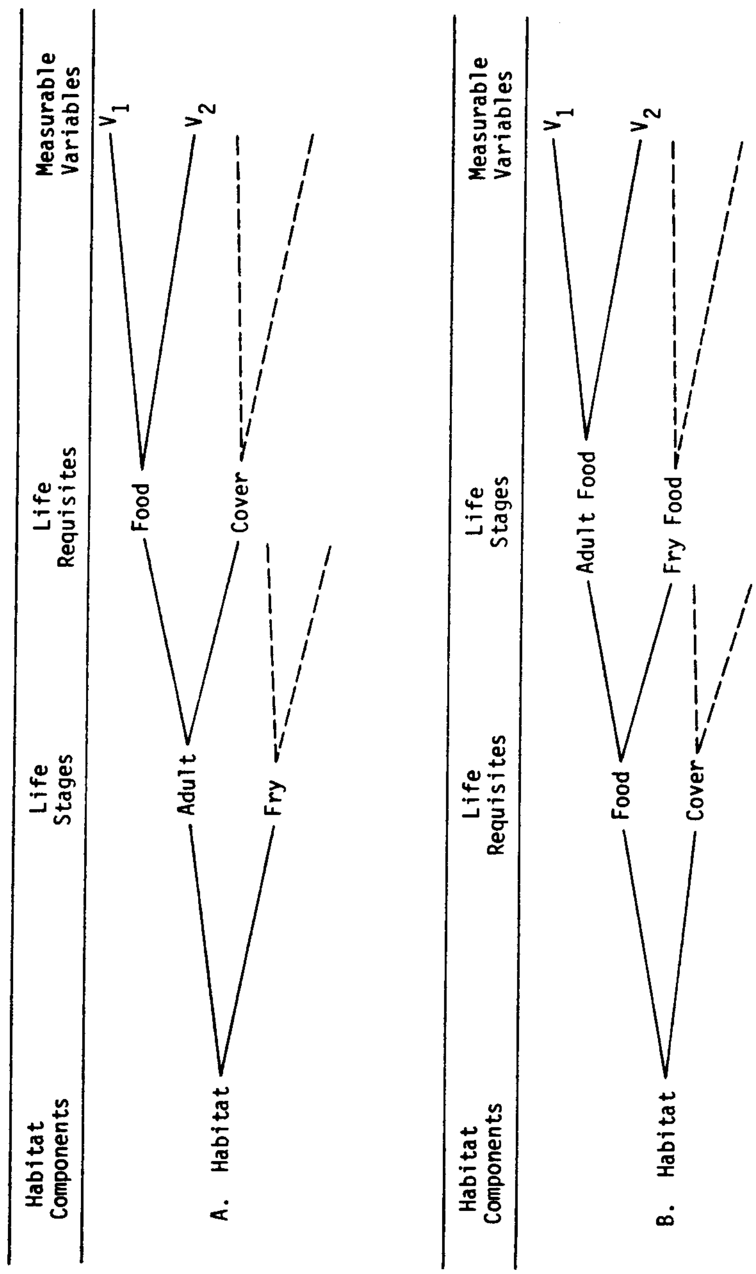

Figure 3-4. Example tree diagrams for aquatic habitat.

habitats. The red-tailed hawk model constructed in this example is a breeding season model. As such, the model addresses one season.

Step 2. Identify cover types related to each seasonal habitat. During a particular season, certain species may typically utilize one or more cover types in obtaining life requisite resources. Although the red-tailed hawk will utilize many cover types, only two have been considered to simplify the example. Figure 3-5 displays the cover types that contribute to breeding season habitat for the red-tailed hawk. Cover types provide a convenient way of segregating model variables into groups for field data collection. There are a number of cover type classification systems that can be used to construct habitat models. However, it is recommended that for terrestrial evaluations, a structural vegetation system, as described in Appendix E, be used. Suggested aquatic cover types for use in model construction also are provided in Appendix E.

Step 3. Identify life requisites (or life stages) related to each cover type. This step specifies the potential contribution of each cover type in providing the life requisites for evaluation species (e.g., food or cover). Figure 3-6 displays the life requisites for the breeding season habitat of the red-tailed hawk.

Step 4. Identify habitat variables related to each life requisite. There should be a defined set of measurable variables that describe the resources needed for each life requisite that are provided by each cover type. In some instances, the variables can be more easily identified if the life requisite is further subdivided. Specific situations where further subdivision of life requisites may be beneficial include those described below:

(a) Circumstances where more than one type of food or cover is utilized by a species and each type of food or cover is related to a different set of measurable variables. For example, escape cover for a species could be provided by either (1) vegetation; or (2) topographic features.

(b) Situations where life requisites have seasonal subcomponents (e.g., summer and winter food). These subdividions will be appropriate if seasonal components were not defined in Step 1 above.

Identifying measurable variables related to life requisite needs may involve a choice of alternative variables as described in 103 ESM 3.2A. For the red-tailed hawk model, food is related to small mammal

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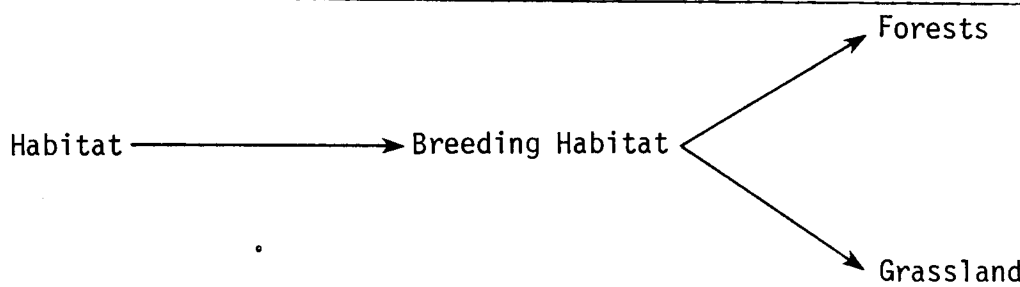

Figure 3-5. Cover type components for breeding season habitat for the red-tailed hawk.

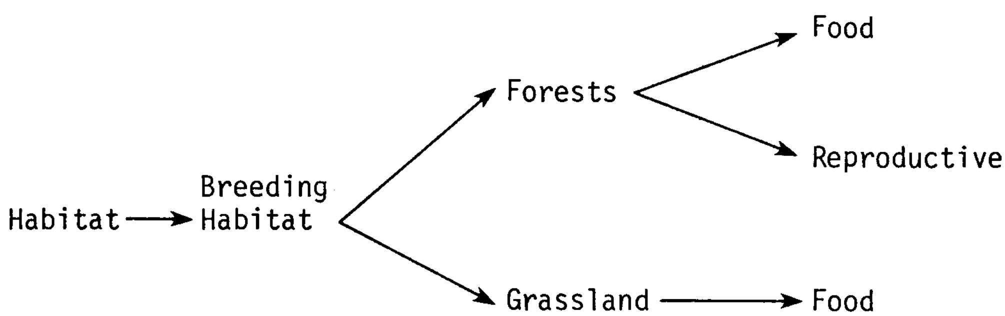

Figure 3-6. Cover type and life requisite components for breeding season habitat for the red-tailed hawk.

abundance and availability of perch sites. Two variables are identified as being related to the amount of food available: (1) net annual production of small mammals; and (2) percent of small mammal populations available to red-tailed hawks. Neither of these variables may be amenable to measurement within the constraints of the intended applications of the model. Among all the alternative variables related to small mammal production, one variable easily measured is percent herbaceous canopy cover. In using this variable the assumption is made that small mammal production can be inferred from the structure of the vegetation. Other measurable variables used in the red-tailed hawk model are shown in Figure 3-7.

Step 5. Identify spatial variables. In the steps above, measurable variables were identified for each life requisite. When these life requisites are identified in more than one cover type, additional variables may be required to relate the life requisites to overall habitat suitability. These additional variables are spatial variables (Figure 3-8). The spatial variables describe the relationship of cover types as an indication of life requisite interspersion and overall habitat suitability. The spatial variables should function within the model such that optimum habitat occurs when the following conditions exist:

(1) All life requisites are of high quality and are in close proximity to one another; and

(2) The portion (percent) of the study area providing a life requisite resource is at or above some defined level.

The spatial relationships are depicted in Figure 3-9. The overall suitability of the habitat increases (to a point) as life requisites occur closer together and as the overall quantity of a life requisite resource increases. These relationships, described in more detail in 103 ESM 3.3, can be incorporated into a model by identifying two spatial variables: (1) the distance between cover types; and (2) the relative quantity (expressed as a percent) of an area made up of specific cover types used by the species.

The distance between cover types can be measured by selecting points in each cover type and measuring the distance from these points to the nearest edge of each other cover type. This exercise will produce a set of measurements as depicted in Table 3-1.

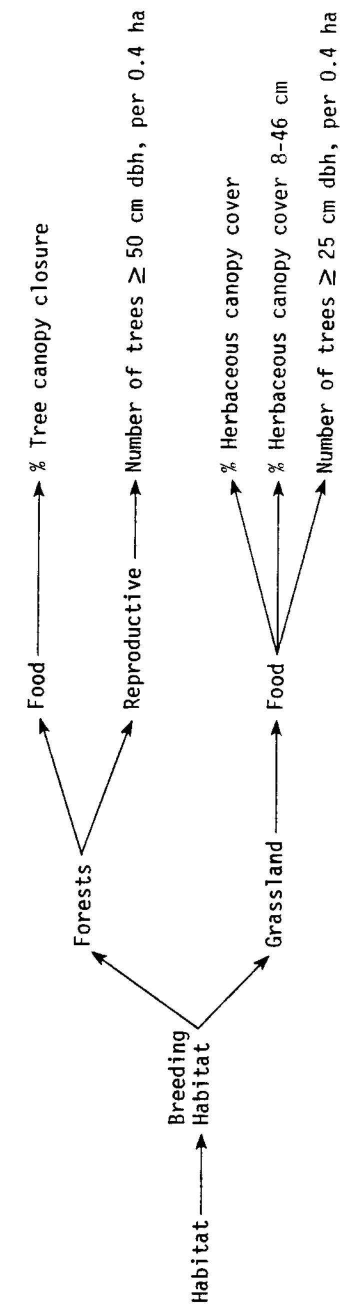

Figure 3-7. Cover types and life requisite components and measurable variables for breeding season habitat for the red-tailed hawk.

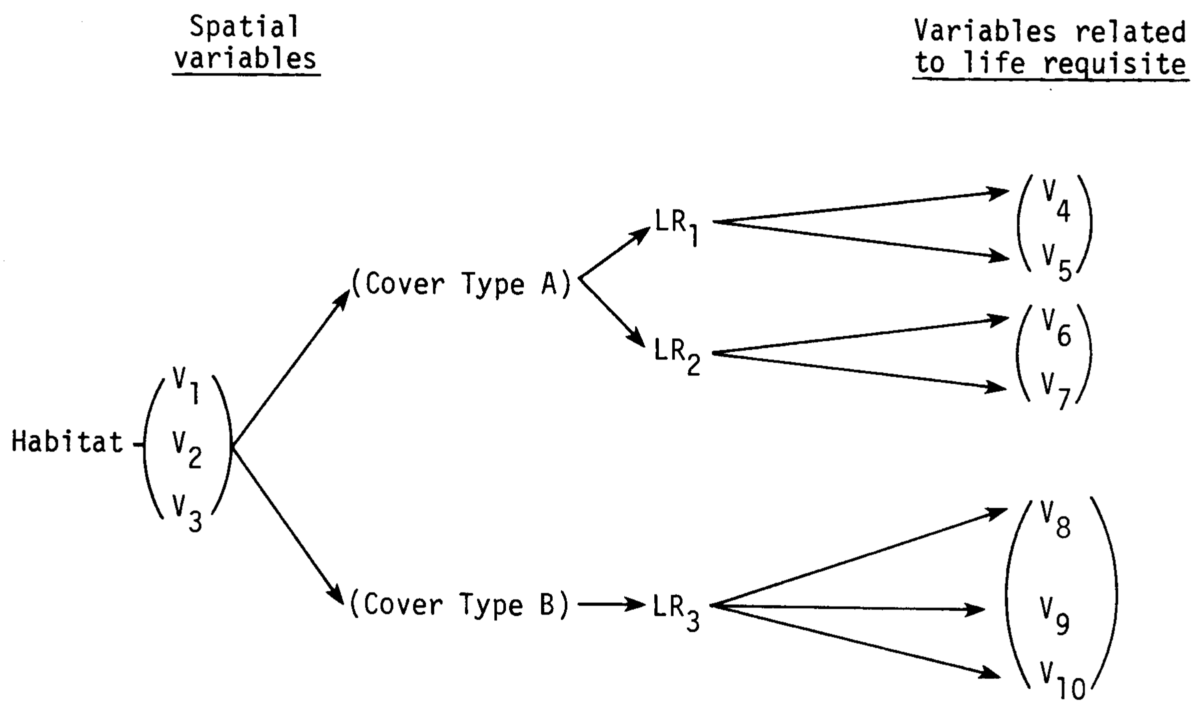

Figure 3-8. Relationship of life requisite and cover type components for a multi-cover type species.

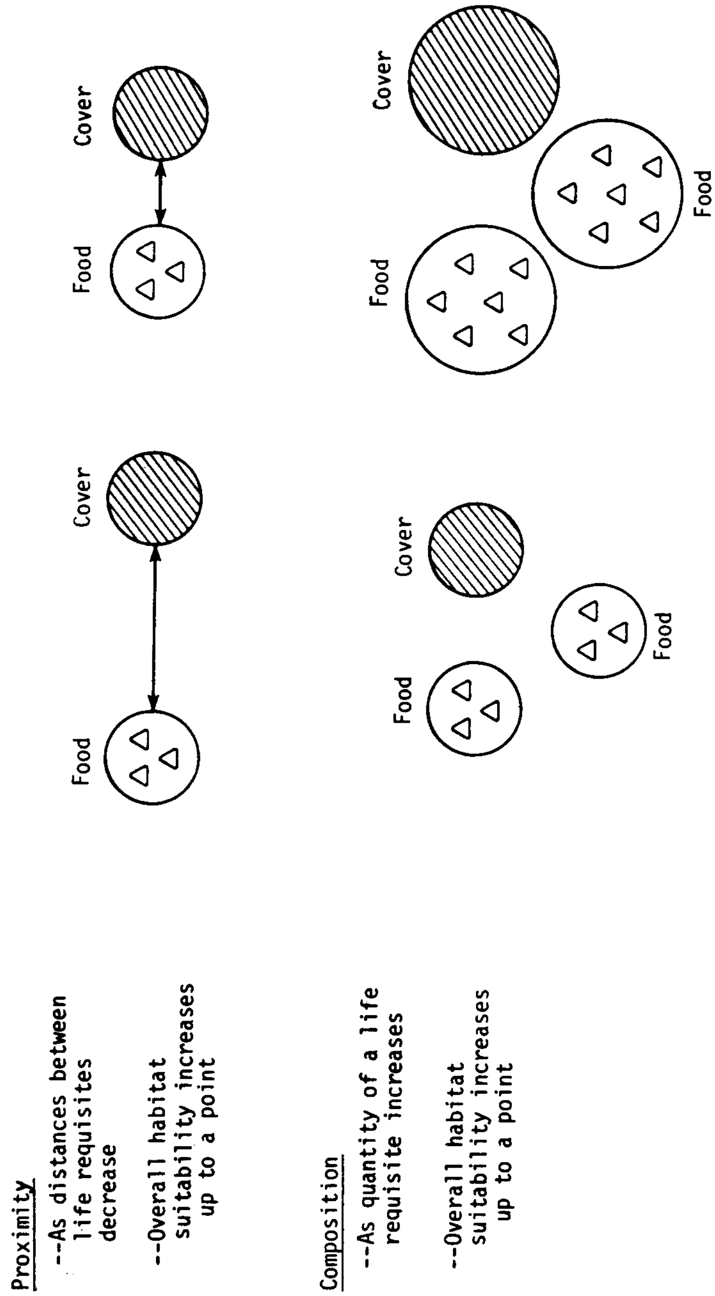

Figure 3-9. Stylized relationship of spatial and life requisite variables to overall habitat suitability.

Table 3-1. Distance measurements between cover types.

Distance (km)	From Point In:	To Nearest:
1.2	Grassland	Cropland
1.3	Grassland	Cropland
1.6	Grassland	Forest
1.4	Grassland	Forest
2.4	Cropland	Grassland
1.9	Cropland	Grassland
1.0	Cropland	Forest
0.4	Cropland	Forest
3.6	Forest	Grassland
1.1	Forest	Grassland
4.0	Forest	Cropland
3.2	Forest	Cropland

The relative percentage of each cover type is computed by dividing the area of the cover type by the total area of all cover types used by the species as follows:

$$\text{Cover Type Relative \%} = \frac{\text{Area of Cover Type}}{\text{Total Area of All Cover Types Used by the Species}} \qquad (8)$$

If more than one seasonal habitat component was identified as discussed in Step 4, these ultimately can be combined with spatial variables to produce one HSI value. The spatial variables are similar to those used to aggregate cover types and are: (1) the distance between seasonal habitats; and (2) the relative percentage of the study area occupied by each seasonal habitat. The use of these spatial variables within the model will be discussed in detail in 103 ESM 3.3.

An example application of these measurements to the red-tailed hawk model is provided in Appendix C.

The spatial variables and functions described in this manual part are devised to provide a generalized approach to habitat interspersion. Other spatial variables and relationships may be more applicable depending on the perceptions of the model builder. The spatial aspects of a habitat model ideally should meet two criteria:

(1) The spatial variables and functions should be applicable to habitat components for which interspersion is important (i.e., life requisites).

(2) The output of a spatial function should be calibrated to the interspersion requirements of the species involved.

Other spatial functions have been described by Baxter and Wolfe (1972), Patton (1975), Puglisi (1978), and Thomas *et al*. (1979). These functions were designed to handle interspersion of cover types and may be useful in some applications.

3.3 Phase III: Structure the model. Each variable identified in the previous model construction phase must be combined with the other model variables to produce an HSI. This is accomplished by defining relationships between the variables. A relationship can be in the form of a graphical display, a written statement, or a mathematical equation. The tree diagrams used in this chapter are examples of graphical relationships between variables.

A number of approaches can be used to establish model relationships. The approaches discussed herein are: (1) word models; (2) mechanistic models; (3) pattern recognition models; (4) Bayesian probability models; and (5) multivariate statistical models. Each is described in more detail below.

A. Word models. A word model is constructed by making sentence statements about the variables or various combinations of the variables. To be useful, a word model should assign a significance to particular measures of the variables.

The tree diagrams used to define model variables are also used to organize word statements. Each set of branches, represented by dashed line triangles in Figure 3-10, identifies a functional relationship. Word statements are developed for combining the set of variables at the right side of the functional relationship into the

component at the left side of the relationship. This process continues along each branch (from right to left in Figure 3-10) until all functional relationships are defined and the HSI can be determined. Word statements made about each functional relationship should be as clear as possible. Clear statements can be written by following a logical format that addresses: (1) the suitability of each measurable variable; and (2) the relationships between the variables.

(1) Describe the suitability of measurable variables. Each variable is described by stating the general form of a relationship between a measure of the variable and habitat suitability. The general form of the relationship describes the response of habitat suitability to a change in the variable. At the simplest level, the form of the relationship can be described as either a positive or a negative relationship. For example, the relationship of tree diameter to reproductive habitat for the red-tailed hawk is:

"The suitability of red-tailed hawk nesting habitat increases with tree diameter."

The above statement concerning red-tailed hawk nesting habitat may not provide the clarification required by the model. Additional resolution can be added to the statement by defining differences between various measurements of the variable. There are two basic approaches to defining these differences.

(a) Threshold value. The suitability of a variable is related to whether a measurement is above or below some prescribed value. This can be expressed verbally as:

"The best red-tailed hawk nesting locations are in > 50 cm dbh trees."

This threshold statement implies that all trees less than 50 cm dbh are not suitable (index of 0.0) and all trees of greater than 50 cm dbh are suitable (index of 1.0).

(b) Suitability classes. The suitable conditions of a variable may occur within a range of measurements, and the most suitable conditions may occur within a smaller subrange of measurements. A verbal expression of this condition is as follows:

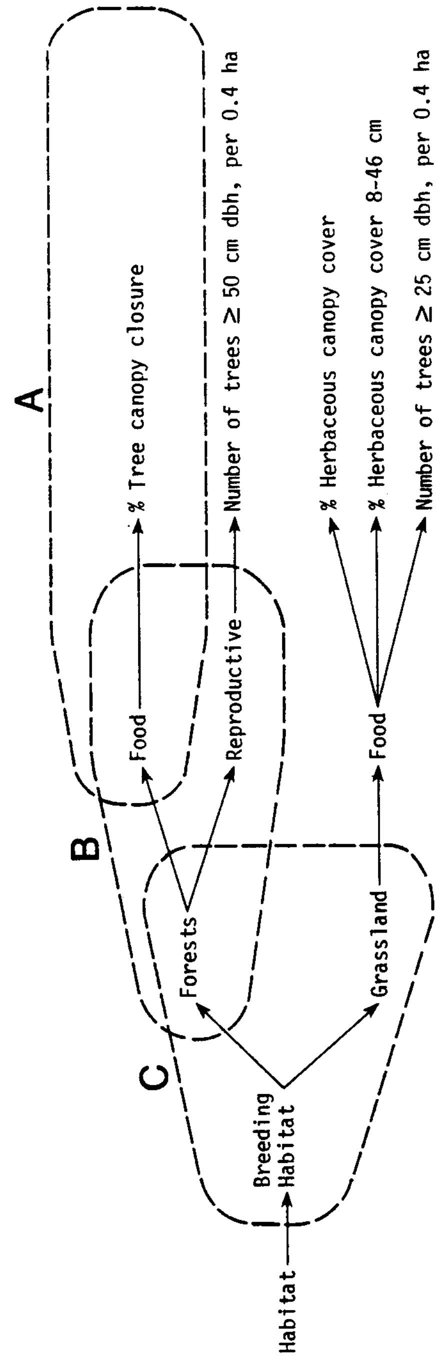

Figure 3-10. Three levels of functional relationships in the red-tailed hawk mechanistic model.

"Red-tailed hawk nests are in trees greater than 20 cm dbh and the optimum nest locations are in trees greater than 50 cm dbh."

(2) Describe relationships between variables. There are many possible relationships between variables. Four relationships that are commonly used in HSI models are described below.

(a) Limiting factors. This relationship is used when the variable with the lowest suitability is perceived to be so significant that it overrides all other factors in the functional relationship. For example, this relationship can be expressed verbally as:

"The overall habitat suitability for the red-tailed hawk is the suitability for reproduction or the suitability for cover or the suitability for food whichever is the smallest."

(b) Cumulative relationships. Cumulative or additive relationships are appropriate in circumstances where a threshold exists which can be met by any one, or a combination of, variables. For example, this relationship can be expressed verbally as:

"Reproductive habitat for red-tailed hawks is composed of the number of trees > 50 cm dbh plus rocky cliffs up to an optimum level of 0.78 nest sites per km² (2 per square mile)."

(c) Compensatory relationships. Compensatory relationships exist when a variable with marginal or low value is offset (or compensated for) by the high suitability of other variables. For example:

"The food value for red-tailed hawks in grasslands is related to the percent cover of the herbaceous canopy and the height of the herbaceous canopy between 8 and 46 cm in height."

(d) Spatial relationships. When a species' life requisite resources are found in two or more cover types, spatial relationships are required to complete the habitat model. Cover types are used to define spatial relationships between life requisites (Figure 3-11). The spatial relationships

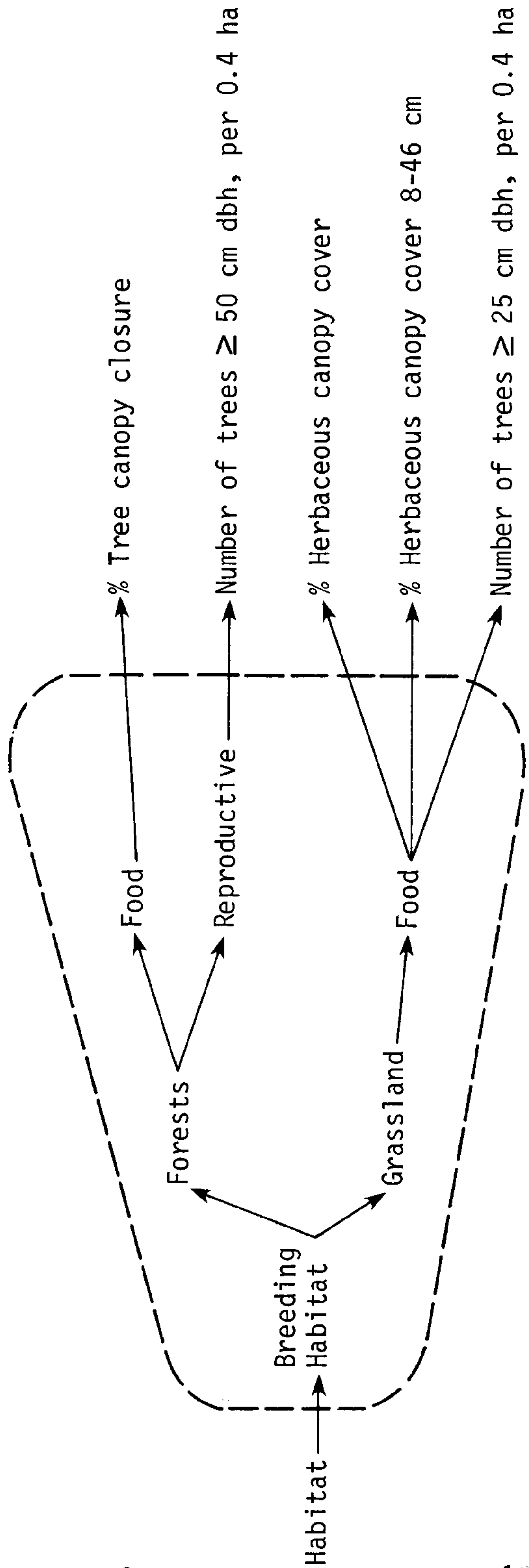

Figure 3-11. The spatial relationships in the red-tailed hawk model.

are built around two variables: (1) distances between cover types (or life requisites); and (2) the relative percent of the habitat area made up of each cover type. The distance relationship is based upon the assumption that there is some minimum linear distance within which all of the species' life requisite resources should be found in order to have optimally suitable habitat. It also is assumed that a maximum distance exists beyond which the habitat is no longer suitable for the species. However, an estimate of the minimum and maximum distance may not be available. Home range extremes reported in the literature can provide these estimates; the desired measure of home range is the major axis (largest length of a home range). Some conversion to linear distance must be made if the reported values are in terms of area. As an initial estimate of the major axis, use the diameter of a circular-shaped home range of equal size. The distance relationship can be expressed as follows:

> "Optimum red-tailed hawk habitat is composed of food-producing areas and areas which provide reproductive habitat which, on the average, are located within 1.2 kilometers of each other. Food and reproductive areas separated by more than 3.6 km are not suitable habitat."

The second spatial variable, percent of the study area made up of each cover type, must be compared to a perceived optimum percentage in order to compute habitat suitability. The optimum percentage defines the relative amount of an area required to provide each life requisite in order to have the best habitat. It may differ for each life requisite resource. This relationship can be expressed verbally for the red-tailed hawk as:

> "Optimum red-tailed hawk habitat is composed of at least 70% optimum food producing areas and at least 15% optimum cover-reproductive areas."

Finally, the two spatial relationships can be combined into one statement:

> "Optimum red-tailed hawk habitat is composed of at least 70% optimum food-producing areas (i.e., grasslands and forestlands) and at least 15% cover and reproductive habitat (i.e., forestlands) which are located within 1.2 km of each other. Food and reproductive areas separated by more than 3.6 km are not suitable habitat."

Table 3-2 is an example word model for the red-tailed hawk. This model was constructed using life history information contained in Appendix B. The variables were identified with the tree diagrams used in 103 ESM 3.2 and are summarized in Figure 3-7.

B. Mechanistic models. In the previous section on word models, word statements were made concerning each variable and the relationship between variables. If these word statements are expressed clearly, they can be translated into mathematical expressions. The advantage of a mathematical expression is the ease of interpretation for many measurements of the variables. This section describes how to convert a word model into a mechanistic model represented by simple mathematical equations.

This progression of defining relationships involves the same two processes that were discussed earlier: (1) the determination of a suitability index for each variable; and (2) the aggregation of suitability indices into a component suitability index.

(1) Describe the suitability of measurable variables. The suitability of a variable is described with a suitability index graph which displays the relationship between the variables and the index of suitability (Figure 3-12).

The horizontal axis of a suitability index graph is scaled to various measurements of the variable. The upper and lower limits of the variable can be defined as either the extreme possible measurements (e.g., 0 and 100 for a percent variable) or measures of the variable beyond which the suitability no longer changes. The vertical axis is bounded below by 0 (no suitability) and above by 1.0 (optimum suitability). "Suitability" is a term that by itself has no specific meaning since one cannot go out and directly measure a suitability level corresponding to a particular variable. However, in constructing this kind of graph an assumption is made that some observation (e.g., survival, standing crop, production, or relative abundance) that is indicative of habitat suitability can be related to the variable. The relationship between habitat suitability and the variable displayed on the graph is assumed independent of other variables which also can affect habitat suitability.

Two basic kinds of suitability graphs can be constructed. One is a continuous curve like that in Figure 3-12. In other circumstances, "measurements" of the variable may be more easily

Table 3-2. Example word model for the red-tailed hawk.

OVERALL HABITAT SUITABILITY

Red-tail breeding habitat is composed of a mixture of feeding areas (i.e., grassland and forests) and reproductive areas (i.e., forests) within a specified distance of each other.

(a) Optimum habitat is 70% optimum feeding areas and 15% optimum cover-reproductive areas on the average within 1.2 km of each other.

(b) Medium suitability habitat occurs when feeding areas occur over 35% of the area, nesting sites occur over 7% of the area or feeding and reproductive habitat is, on the average, separated by 2.4 km.

(c) Marginal suitability habitat occurs when food or cover-reproductive suitability is marginal or when food and cover-reproductive areas are separated, on the average, by more than 3.6 km.

FOREST SUITABILITY

The suitability for food is related to the presence of small mammals and hunting success, both of which are inferred from vegetation structure.

(a) Optimum food conditions cannot occur in forests.

(b) Medium suitability food conditions occur when percent canopy closure of overstory trees is less than 75%.

(c) Marginal habitat occurs when percent canopy closure approaches 100%.

The suitability of forests as cover-reproductive habitat is related to the availability of suitable nest trees.

(a) Optimum reproductive habitat occurs when the number of trees > 50 cm dbh equals or exceeds 25 per hectare (10 per acre).

(b) Medium suitability habitat occurs when the number of > 50 cm dbh trees is approximately 12.5 per hectare (5 per acre).

(c) Marginal suitability habitat occurs when there are no trees or trees are smaller than 50 cm dbh.

GRASSLAND SUITABILITY

Food value is inferred from vegetation structure:

(a) Optimum food suitability occurs when percent herbaceous canopy cover equals or exceeds 65% and at least 50% of herbaceous vegetation is between 8 and 46 cm in height, and 8 or more trees ≥ 25 cm dbh are present per hectare (3 per acre).

(b) Medium food suitability occurs when percent herbaceous canopy closure is 30% or when 25% of the herbaceous vegetation is between 8 and 46 cm in height, and when less than 8 trees ≥ 25 cm dbh are present per hectare.

(c) Marginal food suitability occurs when percent herbaceous canopy cover approaches zero or when none of the herbaceous vegetation is between 8 and 46 cm in height.

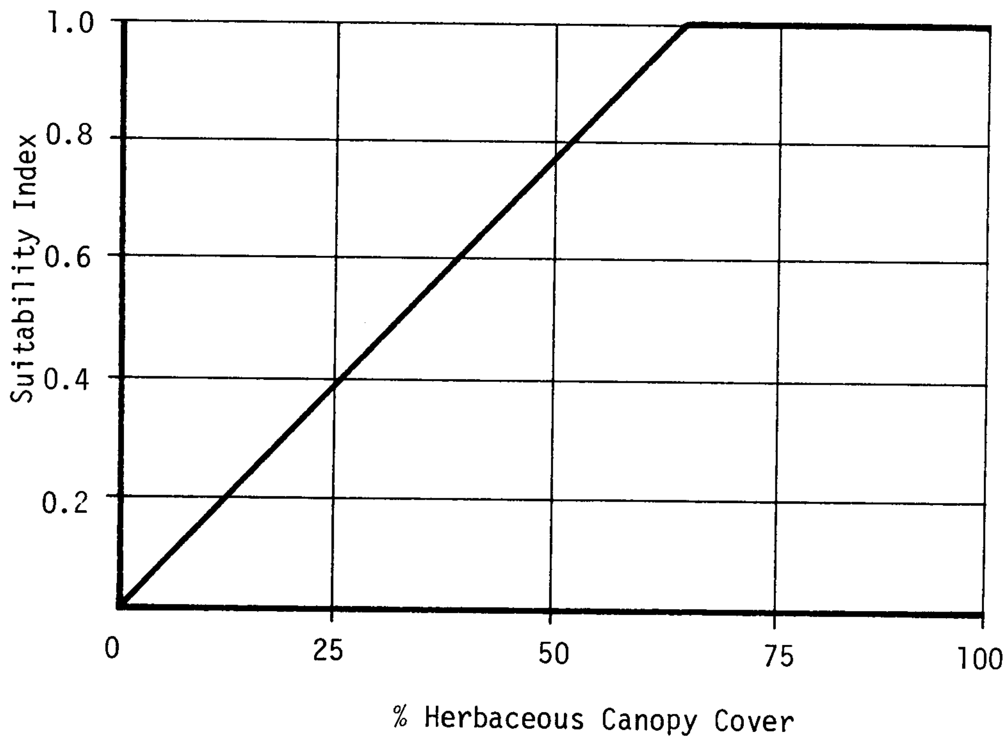

Figure 3-12. Suitability index graph for percent herbaceous canopy cover for the red-tailed hawk.

described in classes or categories. For example, the measure of the variable "availability of grain" could be categorical (abundant, moderate, or scarce). The suitability graph constructed for categorical variables is a histogram (Figure 3-13).

At least three methods may be used to construct suitability index graphs:

a. Method 1. Plot variable measurements against species' response. A suitability index graph can be constructed by plotting specific habitat variable measurements against an observed measure of abundance, such as standing crop. A suitability score of 1.0 is assigned to the range of variable measurements corresponding to the maximum observed abundance. Other measures of the variable are assigned a suitability score equal to the observed abundance at that measured value of the variable divided by the maximum abundance. A limitation inherent to this method of graph construction is the frequent need to base the graph upon several independent studies conducted with different experimental conditions. If that is the case, there is no adequate method to combine this information except by subjective judgment.

b. Method 2. Base suitability index curves on general statements. Suitability graphs can be based upon general statements from the literature. For example, a suitability graph may be based upon integration of a set of statements such as: "The species prefers to nest in the tree canopy"; "Nest sites frequently occur in trees between 25 and 35 feet high"; and "Nest sites are usually found in trees above 15 feet in height." An example graph, constructed from these statements, is shown in Figure 3-14.

c. Method 3. Consult a species authority. "Expert" opinion can be used to define a suitability graph. However, the recommendations of species' authorities can be highly variable and may not be comparable.

(2) Use of the index graph to obtain a Suitability Index score. Suitability Index scores are obtained by comparing existing or predicted conditions in the study area with the relationship depicted by the suitability curve. Scores are interpolated directly from the Suitability Index graph. For example, Figure 3-15 depicts the relationship between percent canopy cover and habitat suitability; a measured 25% canopy cover would

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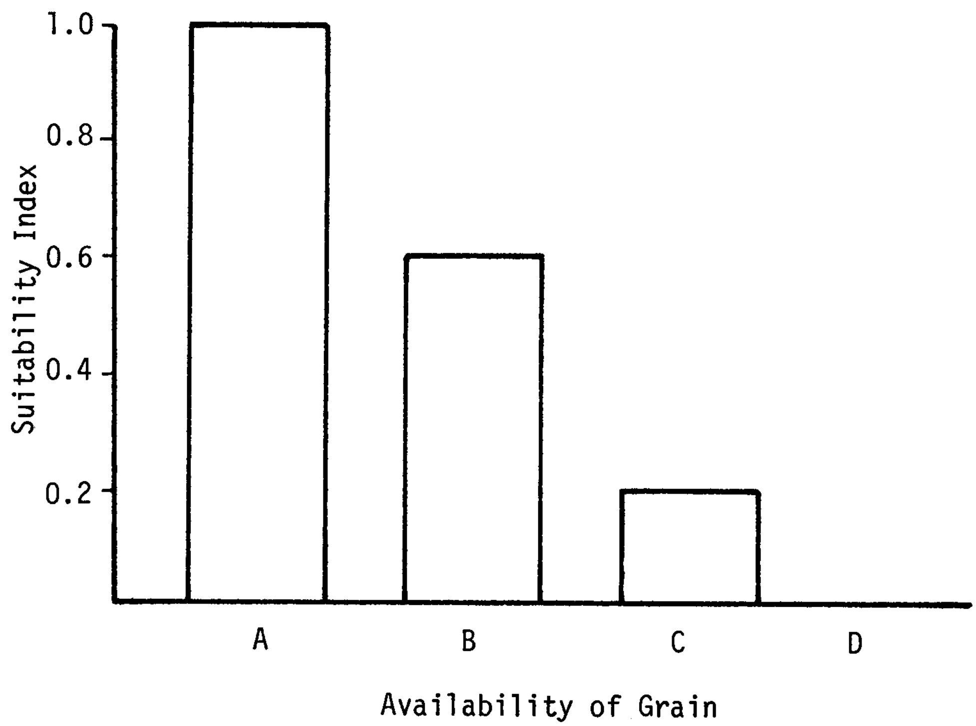

Figure 3-13. Example of a suitability histogram.

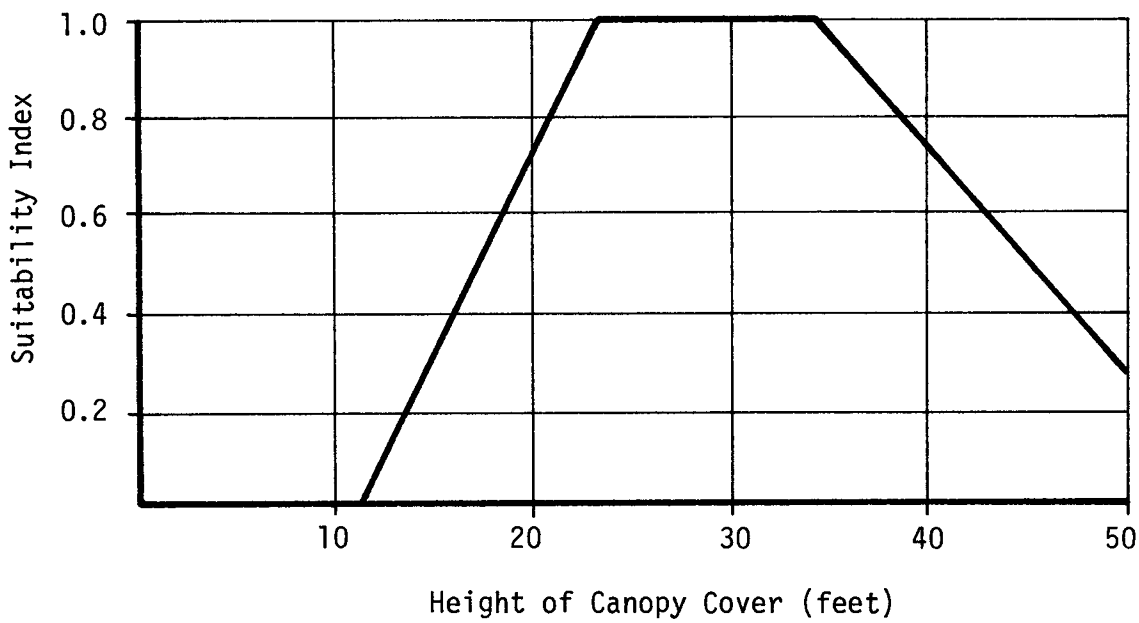

Figure 3-14. Example of a suitability index graph constructed from general statements about a species' habitat preferences.

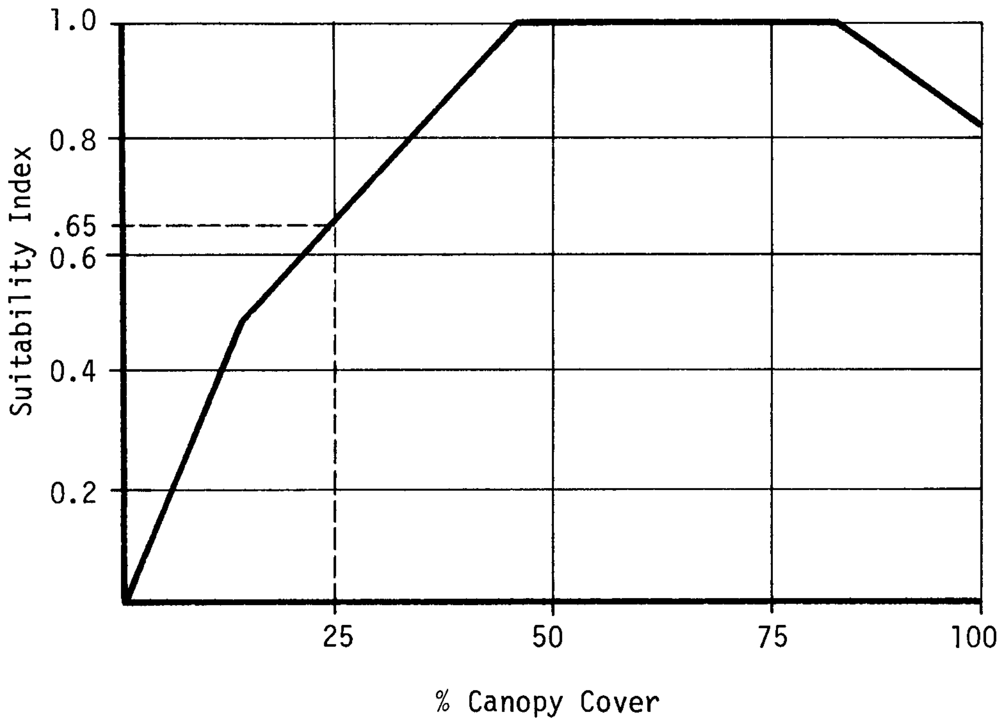

Figure 3-15. Deriving a suitability index for a variable.

receive a suitability index score of 0.65. This method utilizes a precise point relationship for each measurement of the variable. In many instances, the implied precision of this relationship will be greater than the biological data from which the suitability graph was constructed. Therefore, it is important to remember that a suitability graph does not increase the "real" biological precision of a relationship.

(3) Describe relationships between variables. After an index relationship for each variable has been defined, it must be aggregated with others into an index value for the next higher level component in the model. The rules described herein for aggregating indices are the same as those described in the section on word models (103 ESM 3.3A).

(a) Limiting factor method. This type of relationship exists when the variable with the lowest suitability overrides other variables in terms of limiting factor relationships setting the suitability index equal to the lowest variable index as follows:

$$CI = \text{minimum } (I_1, I_2, \ldots I_n) \tag{9}$$

where: CI = component index;

n = the number of variables; and

I_i = the suitability index score of variable i.

This expression allows one variable to be an absolute limiting factor but may be an oversimplification of a limiting factor situation.

An example of this relationship is used to determine the overall habitat suitability using spatial relationships for the red-tailed hawk (Appendix C).

(b) Cumulative relationships. Cumulative relationships occur when a threshold level exists which can be met by any one of several variables or a combination of variables. For example, the optimum density of 0.78 potential nest sites per square km for red-tailed hawks might be provided by

trees, cliffs, or both. (This does not apply to the red-tailed hawk model in Appendix B.) For cumulative relationships the index score may not go above 1.0 even though the density of total nest sites exceeds 0.78 per square km. The following mathematical relationship states this condition:

$$\text{score} = \sum_{i=1}^{n} I_i = (I_1 + I_2 + I_3 \cdots + I_n) \text{ if this sum} < 1.0 \quad (10)$$

$$= 1.0 \quad \text{if this sum} \geq 1.0$$

(c) Compensatory relationships. This type of relationship exists when a variable with marginal or low suitability is offset by the high suitability of other variables. A simple mathematical function that describes this relationship is the mean or average value of the individual suitability scores. There are two methods for obtaining an average value. The first method, the arithmetic mean, is expressed as follows:

$$CI = \sum_{i=1}^{n} I_i/n = \frac{(I_1 + I_2 + I_3 \ldots + I_n)}{n} \quad (11)$$

The second method, the geometric mean, is expressed as follows:

$$CI = (I_1 \cdot I_2 \cdot I_3 \cdot \ldots \cdot I_n)^{1/n} \quad (12)$$

where: CI = component index;

n = the number of variables; and

I_i = the suitability index score of variable i.

The following is an example of a compensating relationship for red-tailed hawk food in grassland:

$$\text{Food (Grassland)} = (I_1 \times I_2 \times I_3)^{1/3} \tag{13}$$

where:

I_1 = Index of percent herbaceous canopy cover.

I_2 = Index of percent herbaceous canopy between 8 and 46 cm tall.

I_3 = Index of number of trees $\geq$ 25 cm (10 in) dbh per 0.4 ha (1.0 acres).

The geometric mean typically produces a smaller score than the arithmetic mean because it is influenced more by low values for one of the variables. For example, when the suitability index scores of variables V_1 and V_2 equals 0.8 and 0.2, respectively, the geometric mean will provide an answer of 0.40 and the arithmetic mean an answer of 0.50. Therefore, one might choose to use the geometric mean when the compensatory relationship is perceived to be weak.

Often when the suitability of any variable is zero, regardless of compensating mechanisms, the CI score should be zero. For example, if both small mammals and birds are required food sources for red-tailed hawks, the suitability value for food should be 0 if the suitability of either food source is 0. The geometric mean will give a score of zero in these cases, whereas the arithmetic mean will not behave this way unless accompanied by the following specification:

$$CI = 0 \text{ if a specified } I_i = 0; \tag{14}$$

$$\text{otherwise } CI = \sum_{i=1}^{n} SI_i/n = \frac{(I_1 + I_2 + I_3 \cdots I_n)}{n}$$

Averaging functions tend to become insensitive to extremely low or high values in situations where four or more variables are used.

The preceding aggregation techniques assign equal weight to each variable. However, judgement may indicate that the variables are not equal in their significance to habitat suitability. For example, the percent of herbaceous canopy cover may be twice as important as the height of herbaceous vegetation for indicating red-tailed hawk food availability in grasslands. Relative importance of the variables can be considered with the two averaging functions described above by use of a weighted mean. For the arithmetic mean, the suitability index of each variable is multiplied by its weight (W_i) as described in the following equation:

$$CI = \sum_{i=1}^{n} (W_i \cdot I_i) / \sum_{i=1}^{n} w_i$$

$$= \frac{(W_1 I_1 + W_2 I_2 \ldots . + W_n I_n)}{W_1 + W_2 \ldots + W_n} \qquad (15)$$

where: CI = component index;

n = the number of variables;

SI_i = the suitability index score of variable i; and

w_i = the weight of variable i.

For the geometric mean, each suitability index is raised to the power of its weight as described by the equation:

$$CI = (I_1^{W_1} \cdot I_2^{W_2} \ldots I_n^{W_n})^{1/\Sigma W_i} \qquad (16)$$

where: CI = component index;

n = the number of variables;

SI_i = the suitability index score of variable i; and

w_i = the weight of variable i.

An example of the weighted geometric mean is the following equation for red-tailed hawk food value (Appendix B):

$$\text{Reproduction} = (V_1^2 \times V_2 \times V_3)^{1/4} \tag{17}$$

where: V_1 = percent herbaceous canopy cover;

V_2 = percent of herbaceous vegetation that is 8 to 46 cm tall; and

V_3 = number of trees $\geq$ 25 dbh per 0.4 ha.

The method of weighting should be well documented when weights are established for a variable. One frequently used method of establishing importance weights is by consensus of experts (Odum et al. 1976).

(d) Spatial relationships. The HSI aggregation technique must consider interspersion variables if the habitat model for an evaluation species contains two or more cover types. The suggested technique for incorporating interspersion variables was described in the section on word models (103 ESM 3.3A). The two interspersion variables are: (1) distances between cover types; and (2) percent of the study area composed of each cover type.

The relationship of the distance variable to habitat suitability is defined by a suitability index graph (Figure 3-16). This index graph indicates that optimum habitat, from a spatial perspective, will occur when all life requisites are found within a minimum distance (Hmin) of each other. If one or more life requisites are separated from the others by more than some maximum distance (Hmax), the suitability would be 0.0. If the spatial separation of life requisites is more than the minimum but

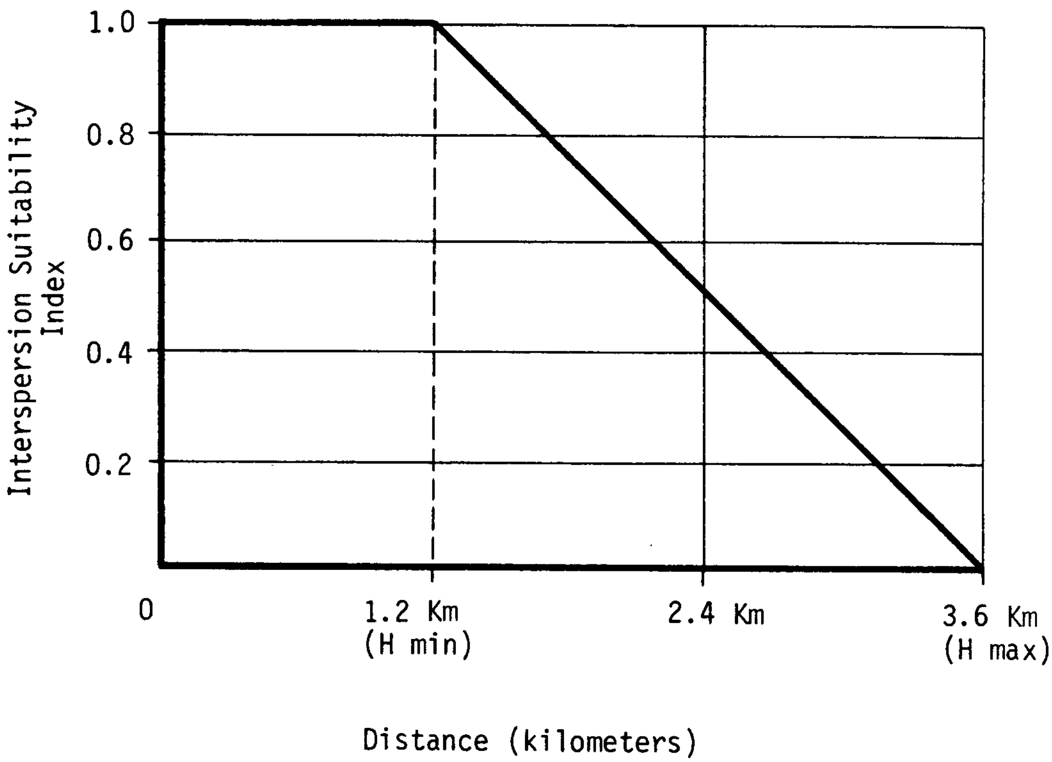

Figure 3-16. Interspersion suitability index graph for the red-tailed hawk.

less than the maximum distance, suitability will be between 0.0 and 1.0 (Figure 3-16). The minimum and maximum distances may be estimated using extremes of home range as reported in the literature.

The interspersion graph is used to adjust the cover type life requisite values. The suitability of the cover type life requisites are adjusted downward as the distance between life requisites (i.e., requisites within cover types) increases.

The percent of a study area composed of each cover type is used to define the proportion of the study area that provides each life requisite. The cover type percent data are combined to calculate percent of the study area providing each life requisite using the formula:

$$LR\% = \sum_{L=i}^{n} (AREA_i)(SI_i) \tag{18}$$

where: $LR\%$ = percent of the study area supplying the life requisite;

$AREA_i$ = the surface area of cover type i;

SI_i = the suitability index for the specified life requisite in cover type i (modified by interspersion graph); and

n = the number of cover types that provide the life requisite.

For each life requisite, the resultant from Formula (18) is compared to an optimum percentage to determine the overall life requisite suitability index. The data in Table 3-3 specify the optimum composition of red-tailed hawk habitat in terms of the percent of the habitat that should supply food, cover, and reproductive needs.

Table 3-3. Composition of study area life requisites required for optimum red-tailed hawk habitat.

Life Requisite	Optimum Percent of Area Needed to Meet Life Requisite Needs
Food	70%
Cover-reproductive	15%

Final determination of habitat suitability is made using the composition parameters. The closer a habitat approaches the optimum composition figures, the higher the suitability will be. For example, a habitat may provide all life requisite resources within specified distances of each other, but food may be located in small plots of low quality. If the size of the plots and the quality of the food are increased, the habitat suitability will increase up to the point where food resources are not limiting and are in balance with other life requisite needs.

An example of a model constructed by this approach for the red-tailed hawk is given in Appendix B, and an example application of distance and composition figures in this habitat model is provided in Appendix C.

C. Pattern recognition models. Pattern recognition models are similar to the previous word model developed for the red-tailed hawk. However, in pattern recognition models, the HSI changes depending upon the pattern of answers for all questions in the models. For example, each of the four questions in Table 3-4 has two possible answers: "Yes" or "No". A set of answers for each situation can be displayed as a distinct pattern (circles in Table 3-4), and each pattern is assigned an HSI. The HSI for each pattern of answers is assigned by expert opinion, based upon information from the literature,

Table 3-4. Graphical display of a pattern recognition model for two habitat conditions.

Question	Condition A		Condition B	
1	Yes	No	Yes	No
2	Yes	No	Yes	No
3	Yes	No	Yes	No
4	Yes	No	Yes	No

or is assigned by some other method. For example, food (small mammals) in grasslands for the red-tailed hawk could be evaluated by a pattern recognition model as follows. Two variables, percent herbaceous canopy cover and percent of herbaceous canopy between 8 and 46 cm tall, can be divided into two categories each (Table 3-5). Four possible answer patterns can be identified and a food value determined for each. Table 3-6 displays the food value for each answer pattern and documents the reason for the established value.

Variables for pattern recognition models can be defined such that they are easy to measure from aerial photographs or reconnaissance flights over a study area. Thus, these simple models are useful in early stages of project planning.

Pattern recognition models with a large number of variables or a large number of categories for each variable, or both, are more difficult to build and apply. For example, a pattern recognition model with just four questions and three categories has 81 possible answer patterns (3^4). A Suitability Index must be established and documentation provided for each pattern. Adding one additional question with 3 categories increases the number of possible patterns to 243 (3^5); however, it may not be necessary to document all possible patterns.

Table 3-5. Pattern recognition model to evalute red-tailed hawk food in grasslands.

Variable 1	Variable 2
1. Percent herbaceous canopy cover:	2. Percent of herbaceous canopy between 8 and 46 cm tall:
A. Less than (or =) 65%	A. Less than (or =) 50%
B. Greater than 65%	B. Greater than 50%

Table 3-6. Answers for pattern recognition model for red-tailed hawk food in grasslands.

Pattern Number	Food Suitability Index	Reason
1. A,A	0.2	Assumed that little food is available because low food supply for small mammals. Also vegetative cover is too thick (where it does exist) for capturing prey.
2. A,B	0.3	Little food available. However, what is available is easier to catch than in situation 1.
3. B,A	0.6	Good supply of food, yet difficult to capture.
4. B,B	1.0	Good food supply which is easy to capture.

D. Bayesian probability models. One logical extension of pattern recognition models is based upon the use of Bayesian probabilities. This technique, which eliminates the complexity of having to establish different answer patterns, has been described by Russell et al. (1980) as PATREC models and involves answering the following questions:

(1) What are the highest long-term population densities of this species that can be found in the geographic unit? Either recent or historic densities are appropriate. Record this number as the high density standard.

(2) What are the lowest (but not zero) long-term population densities of this species that can be found in this geographic unit? Record this number as the low density standard.

(3) What is the mid-point of the range between the lowest and highest population densities?

$$\frac{\text{Low} + \text{High}}{2} = \text{Midpoint} \qquad (19)$$

(4) What percent of the total habitat within the geographic unit supports population densities higher than the midpoint of the range of densities calculated earlier? Record this number as the prior probability for High.

(5) What is the difference between 1.0 and the prior probability for High? Record this number as the prior probability for Low.

(6) Are any of the variables identified in the variable identification phase of modeling (103 ESM 3.2) related to each other (e.g., are any of the variables directly a consequence of or an extension of any other variable)?

(7) If the answer is yes for one or more variables in the preceding step, which of the two do you think has a more direct influence on population density, or is more readily measured? Remove the other related variables from the list. If the answer is no, continue with question (8).

(8) Which, if any, of the variables remaining on the list have no apparent diagnostic value (e.g., is present in about the same amount in locations where the population density is low as well as where it is high)? Remove any such variables from the list.

(9) Beginning with any variable on the list, in what unit is the variable measurable? Choices include English units, metric units, percent, degrees (e.g., compass, slope, temperature), and presence or absence.

(10) What is the range of possible measurements for the variable (e.g., the range of possible measurements for dbh is 0-100 cm). Within this range, are there subranges where the variable has a different effect on population density (e.g., a dbh of greater than 50 cm is optimum for red-tailed hawk nesting)? Record each range and label as a, b, etc. (e.g., a = dbh of 0-50 cm; b = dbh of greater than 50 cm).

(11) What is the relative frequency with which subrange increment "a" is associated with a high population density (e.g., what percent of high density areas have trees of average dbh between 0 and 50 cm)?

(12) What is the relative frequency with which subrange increment "a" is associated with a low population density (e.g., what percent of low density areas have trees of average dbh between 0 and 50 cm)?

(13) Repeat questions 11 and 12 for each subrange increment.

(14) For all subranges, the relative frequencies in the "High" column must sum to exactly 1.0. If not, adjust the relative frequencies until they equal 1.0.

(15) For all subranges, the relative frequencies in the "Low" column also must sum to exactly 1.0. If not, adjust the relative frequencies until they equal 1.0.

(16) Select the next variable and repeat questions 9 through 15. Continue this procedure until all of the variables (and subranges of their values) have been assigned relative frequencies for both high and low population areas.

An example PATREC model is shown in Table 3-7.

Table 3-7. Example PATREC model for the red-tailed hawk.

Variable	Measurement	Subrange	Probability Given High Population	Probability Given Low Population
1. % herbaceous canopy	≥70%	a	0.6	0.2
	<70%	b	0.4	0.8
2. Proportion of herbaceous canopy between 8 and 46 cm	≥50%	a	0.7	0.1
	<50%	b	0.3	0.9
		Prior Probabilities:	0.6	0.4

The above PATREC model is based upon the following:

(1) Prior probabilities are assumed to be: High = 0.60; Low = 0.40.

(2) The variables (and their subranges) are those depicted in Table 3-7.

(3) The high density standard is 20 hawks/10 km^2 and the low density standard is 1 hawk/10 km^2.

Application of the PATREC model is illustrated by the following example. Suppose that the two variables are measured in a hypothetical study area. The average values are 50% herbaceous canopy cover (subrange b of Variable 1) and 50% of herbaceous canopy between 8 and 46 cm (subrange a of Variable 2). The subranges for each variable identify probability estimates in both the high population and low population columns of Table 3-7. For both the high and low probability columns, the identified probabilities are multiplied together with the prior probability as follows:

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$$\text{Product of high} = (0.4)(0.7)(0.6) = 0.168 \quad (20)$$

$$\text{Product of low} = (0.8)(0.1)(0.4) = 0.032 \quad (21)$$

The probability of a high population potential is calculated by dividing the product of high (equation 20) by the sum of the products (equation 20 and 21) as follows:

$$\text{Probability of high} = \frac{0.168}{0.168 + 0.032} = 0.84 \quad (22)$$

The probability of a low population potential is computed by dividing the product of low (equation 21) by the same sum as follows:

$$\text{Probability of low} = \frac{.032}{0.168 + 0.032} = 0.16 \quad (23)$$

(note: probability of low = 1.0 - probability of high)

The predicted population potentially supported by the study area is computed by the following equation:

$$\begin{aligned}\text{Potential population} &= (\text{High Density Standard})\ (\text{Prob. of high}) + \\ &\quad (\text{Low Density Standard})\ (\text{Prob. of low}) \quad (24)\\ &= 20(.84) + 1(.16)\\ &= 16.8 + .16\\ &= 16.96\end{aligned}$$

The result from the PATREC calculations indicates a potential density of 16.96/10 km^2. This output from a PATREC model, although expressed in units of population density, is not a prediction of actual populations. It is an expression of the habitat conditions as defined by equation (2). This figure is converted to an HSI by dividing by the high density standard (standard of comparison) as described in 103 ESM 2. The HSI would be 16.96/20 or 0.85.

The proper use of PATREC models requires a knowledge of methods for establishing conditional probabilities (Questions 10, 11, and 12 above). The most desired method for establishing probabilities is by actual field observations. Conditional probabilities established subjectively in the absence of field work may be incorrect because of the complex nature of conditional probabilities. For further details on the use of PATREC, refer to Kling (1980) and Russell _et al_. (1980).

E. _Multivariate statistical models_. Values such as standing crop (or biomass) or expert ratings are often predictable using statistical models which are based upon sets of easily measured habitat variables. Usually, a large number of habitat variables are defined in Phase II of model construction (103 ESM 3.2). Statistical methods are used to mathematically determine which variables have the greatest influence on habitat potential as defined, for example, by standing crop. A condensed set of variables can then be used to predict potential standing crop or biomass values. Model outputs which predict standing crop or biomass can be converted to HSI by using equation (25).

$$HSI = \frac{\text{Predicted Standing Crop (or biomass)}}{\text{Maximum Observed Standing Crop value}} \quad (25)$$

There are at least two statistical techniques which can be used to construct HSI models for an evaluation species: (1) regression; and (2) discriminant analysis.

(1) _Regression models_. Standing crop or biomass of a species is often predictable based upon a set of measurable habitat variables. For example, height and density of forest canopy, tree size, percent coniferous cover, and number of shrubs per acre were found by researchers to greatly influence the density of male Acadian flycatchers during the nesting season. These and other habitat variables were used to produce a multiple regression equation (equation (26)) which accurately predicted population densities of seven avian species (Robbins 1978).

$$N = 20.816 + (-2.349\ V_1) + (-0.341\ V_2) + (0.985\ V_3) + (1.988\ V_4) + (-0.000371\ V_5) + (-0.286\ V_6) + (-0.746\ V_7) \quad (26)$$

where N = male breeding density of Acadian flycatchers;

V_1 = degrees of latitude north or south of 38° after correcting for elevation; departure always given as a positive number;

V_2 = percent of canopy cover expressed as a whole number;

V_3 = mean canopy height in feet;

V_4 = number of trees per acre greater than 21 inches (53.3 cm) dbh;

V_5 = estimated number of shrub stems per acre at breast height;

V_6 = percent of coniferous trees (3 inches dbh or greater) expressed as a whole number; and

V_7 = percent of standing dead trees (3 inches dbh or greater).

Determination of HSI by use of regression models involves two steps: (1) developing a regression equation which predicts the value of interest (e.g., standing crop or biomass for the study area); and (2) converting the standing crop estimate to HSI by use of equation (25) above. Developing a regression equation is dependent upon the availability of adequate data which includes estimates of standing crop or biomass for a number of areas from which corresponding habitat measures also were collected. Two good references covering statistical techniques for developing regression models are Draper and Smith (1966) and Freese (1974).

(2) Discriminant analysis models. Measures of species density or expert ratings could be predicted with a point estimate by use of a regression equation as described above or predicted with a "group" estimate by use of discriminant analysis. For an evaluation species, discriminant functions can be used to predict the population group to which a particular study area belongs (e.g., Table 3-8).

Table 3-8. Example set of population groups for use in a model developed by discriminant analysis.

Population Category	Group Number
Very high (76-80 animals/ha)	4
High (50 to 75 animals/ha)	3
Medium (25 to 49 animals/ha)	2
Low (1 to 24 animals/ha)	1
None (0 animals/ha)	0

The use of discriminant analysis is based upon the assumption that certain habitat characteristics are unique to each population group and thus can be used to predict whether or not the population in a particular study area is likely to occur within that group.

There are two steps for computing HSI using discriminant analysis: (1) develop a set of discriminant functions for predicting group membership; and (2) convert the discriminant model output to HSI. Nie et al. (1975) provided a good, general description of discriminant analysis. For a more technical discussion, see Morrison (1976). Conversion of a discriminant model output to an HSI is accomplished by dividing the model output by the group number representing the "best" group (Equation (27)).

$$HSI = \frac{\text{Number Representing Group the Study Area is Most Likely to Fall In}}{\text{Number Representing the Optimum Group}}$$

$$= 1/4 \qquad (27)$$
$$= 0.25$$

An example showing the development and calculations involved in a discriminant model is provided in Appendix F.

Both regression and discriminant analysis models are based upon empirical observation or statistical inference concerning habitat variables rather than from theoretical relationships. Statistical models often lack causal structure and may be difficult to modify in an operational situation. Habitat changes related to variables that were not statistically important or ranges of variables in model construction beyond those considered may lead to inadequate predictions.

3.4 Phase IV: Document the model. The fourth phase in model development is to document the HSI model, its structure and assumptions, and the complete set of steps needed to implement the model. Documentation is important because: (1) the user must understand the model, its objectives, its basic biological assumptions, and the basis for its construction; (2) documentation of a model aids in the understanding of how habitat is used by the evaluation species; (3) the user should know what to expect from the model; and (4) documentation provides the basis for understanding how the model may be adapted to other applications.

Two levels of documentation take place concurrently throughout HSI model construction. One level represents the gathering of habitat use information about a particular evaluation species, information which ultimately will be used to construct the HSI model. The second level of documentation describes how the species-habitat information is used to construct the HSI model and the steps for using the model. This also describes the conditions under which the model is applicable.

A. Document habitat use information. Species-habitat relationships and life history information are the basic data sources used for developing the HSI model. Documentation should provide a characterization of the general and specific habitat requirements of the evaluation species. The following habitat requirements may be described in model documentation when building the HSI model:

(1) General habitat requirements

(a) Distribution. Brief information on the general distribution of the species or subspecies, and the specific distribution of the species within a given region (e.g., restricted to northern half of region or elevation above 1,500 m).

(b) Cover types in which the species may be found and the resources (e.g., food and cover) provided by each cover type.

(2) Specific habitat requirements. List quantitative and qualitative data on the habitat requirements of the species. Emphasize any seasonal or life stage differences. Example categories of habitat requirements include the following:

(a) Food requirements. Describe the major food items consumed by the species, the foods of young when different from that of adults, and seasonal food preferences.

(b) Water requirements. Describe the dependence of the species on free water for drinking, seasonal differences in water requirements, or water quality characteristics which may be significant to the species.

(c) Reproductive requirements. Describe the specialized habitat needs associated with reproductive activities (e.g., nest trees with dbh greater than 25 cm or gravel bottom for spawning).

(d) Interspersion or home range requirements. List the optimal mix of life requisites, cover types, or life stages, and the home range sizes. Include seasonal differences if appropriate.

B. Document model construction and use. Model documentation is used to substantiate decisions made in the construction process and to identify necessary assumptions and why they were made. It also may be important to document why certain types of information or existing models were not used.

The proper use of a model is largely dependent on adequate instructions for model application and a knowledge of the assumptions and limitations involved in model construction. There are several areas where documentation is advised to ensure proper model construction and use:

(1) Information pertaining to the applicability of the model should be clearly defined. This includes the geographic area of applicability, season of applicability, and the verification level of the model (see 103 ESM 3.5).

(2) The selected variables must be justified, with an explanation of why each is important. Describe how each variable is related to the model components. This task may be accomplished by a graphical display (tree-diagram) and a verbal description of the model (see 103 ESM 3.2).

(3) Assumptions made in defining model relationships should be explained. The method for determining suitability for each variable should be explained when suitability indices are established for model variables. Explanations should be provided to substantiate the aggregation techniques used in the mathematical formulation of the model (see 103 ESM 3.3). For many existing models, instructions for converting the model output to an HSI are necessary. These instructions, along with assumptions and limitations of the conversion process, should be clearly explained.

(4) There should be adequate and complete documentation of steps needed to apply the model, including when, where, and how each variable is measured in the field. The documentation should include detailed instructions for converting study area data collected for each variable into model inputs and instructions for mathematical calculations involved in determining an HSI.

(5) Instructions for interpretation of model outputs should be provided, if appropriate.

3.5 Phase V: Verify the model. The purpose of model verification is to ensure that the model produces an output at the acceptance level established in the first phase, setting model objectives (103 ESM 3.1). Verification serves as a quality check on the model and can be used to further refine or advance a model to a higher acceptance level.

A. Four steps of model verification. Verification includes four progressive steps (Figure 3-17). The degree to which model verification proceeds through these steps depends upon the specified acceptance level.

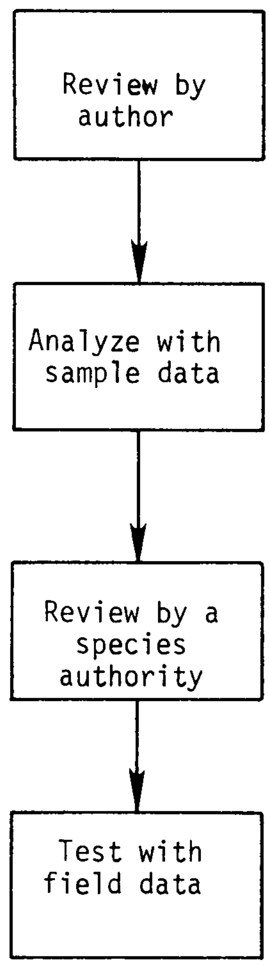

Figure 3-17. Four steps of model verification.

(1) Step 1: Review by author. The author should check model components and the relationships identified in the second modeling phase (Variable Identification, 103 ESM 3.2). The author should ensure that the appropriate variables were used and the relationships between variables were accurately portrayed. The mathematics and graphs used should be checked to make certain that they are consistent with the perceived habitat relationships in the model. The symbols, operations, and signs used in each equation should be verified. It also is important to verify that all model assumptions and limitations were stated correctly. As a result of this review, the model assumptions and variable relationships may need to be reformulated.

(2) Step 2: Analyze with sample data. The model is applied to sample data sets (either real or hypothetical) which mimic various habitat conditions (e.g., high, medium, and low suitability). Inspection of the HSI outputs reveal how well the model reflects the habitat condition for each data set. If necessary the model should be calibrated to give what appears to be a reasonable prediction for each set of conditions.

(3) Step 3: Review by a species authority. The model, its documentation, and the results of the sample data analysis are reviewed by an authority on the species. The objective of this review is to increase the reliability of the model. Any weak or questionable parts of the model should be identified so that improvements can be made. Also, supporting information such as a description of how the model is to be used and the required level of resolution may be helpful in this review.

(4) Step 4: Test with field data. Testing the model against actual field data should occur only after the model has gone through the first three steps of verification. Field data must be available that provide both measurements of habitat variables and measures which represent habitat suitability (e.g., standing crop estimates or habitat ratings by a species authority). Statistical expertise is required to design and perform the appropriate test(s).

Tests utilizing field data may lead to a refinement or updating of the model because more habitat data may be obtained in the tests than were available for initial model construction. Updating the model could mean that the model is revised to meet a new acceptance level.

B. Application of the verification steps. The four verification steps described above are used to ensure that the model meets the desired level of acceptance. However, all four steps need not be applied in every situation. The specified acceptance level defines which of the verification steps are to be performed in a model test. For example, Table 3-9 displays which verification steps should be performed for three potential acceptance levels established for an HSI model.

Table 3-9. Verification steps required for various acceptance levels.

Acceptance level	Verification steps to be applied
1. The model appears to be reasonable to an evaluation team (the author).	1, 2
2. The model appears to be reasonable to a species authority	1, 2, 3
3. The model is applied at several sites and the HSI tends to be correlated with standing crop estimates at each site.	1, 2, 3, 4

C. Summary. The results of the verification process should be well documented to ensure that the utility of the model does not fall short of preconceived expectations and that future model enhancements benefit from past testing. A model can be applied once it has been shown to operate at the desired acceptance level. Future applications may require that the model meet a higher acceptance level. In this case, the verification process is repeated at the higher level but should benefit from prior documentation.

If the acceptance level cannot be met, the problem(s) with the model must be diagnosed. If the problem(s) are not readily solvable, the model's acceptance level can be lowered, and the model applied at the

lower acceptance level. If problems with the model are not solvable and the acceptance level cannot be lowered, the model should not be applied.

The modeling approaches discussed in 103 ESM 3.3 are relatively simplistic and seem appropriate for assessment level habitat models based on currently available data. Because of the general lack of data for most fish and wildlife species, modelers must often rely on intuition or professional interpretation of basic habitat data. In such circumstances, the reliability of a model may be more limited by the lack of data than our ability to describe complex relationships. Realizing these basic limitations, testing should not continue past the point where further improvements can be made in the model.

Appendix B. Habitat Use Information and HSI Model for the Red-tailed Hawk

B.1 Introduction. HSI models should be adequately documented so that the HSI estimates can be properly interpreted. This appendix provides an example red-tailed hawk model with documentation as described in 103 ESM 3.4. Section B.2 below provides documentation of habitat use information, and B.3 describes the HSI model, including model assumptions and limitations. Section B.4 contains information for applying the model.

B.2 Habitat use information

A. General. The red-tailed hawk (*Buteo jamaicensis*) inhabits all of the continental United States (Brown and Amadon 1968). In more northern parts of its range, it is quite migratory, although breeding pairs were found to be year-round residents in areas as far north as Wisconsin (Petersen 1979) and Michigan (Craighead and Craighead 1956). Commonly used habitat consists of woodlots, scattered trees, or tracts of mature woodland, often interspersed with, or adjoining, large expanses of open fields (Brown and Amadon 1968). Red-tailed hawks are rare in areas characterized by extensive unbroken forest. The red-tailed hawk has the widest ecological tolerance and geographic distribution of any buteo in North America. This species has not suffered the detrimental eggshell thinning observed in many other raptors, due to its predominantly mammalian diet (Hickey and Anderson 1968; Petersen 1979).

B. Food requirements. The red-tailed hawk is an opportunistic predator, feeding primarily on prey species which are locally common (Bohm 1978). It feeds on a variety of animals, but mostly small and medium-sized rodents, rabbits, and other mammals (Brown and Amadon 1968). Other important food items include medium-sized birds, large insects, and reptiles. Both adults and juveniles will feed on carrion (Errington and Breckenridge 1938). A winter diet of red-tailed hawks in Wisconsin averaged 44% cottontail rabbits (*Sylvilagus* spp.), 28% microtines (*Microtus* spp.), and 10% pheasants (*Phasianus colchicus*) (in percent biomass) (Petersen 1979).

Red-tailed hawks commonly hunt from perches overlooking open areas and by soaring above fields (Tyler and Saetveit 1969; Bohm 1978). Schnell (1968) found that red-tailed hawks prefer to hunt from tree perches, allowing the raptor to strike down on ground dwelling prey. Foraging sites in southern Michigan were open areas such as grassland and abandoned and cultivated fields (Craighead and Craighead 1956). In Wisconsin, lowland pastures with scattered trees were

heavily used by hunting red-tailed hawks, whereas cover types without trees for hunting perches were seldom used (Petersen 1979). Results from an Ohio study suggest that red-tailed hawk productivity may be partially related to the percent of hunting territory in fallow pasture (Howell _et al_. 1978). Highly productive sites typically had over twice as much fallow pasture (69% average) around them as low productive sites. Hunting areas in New York were recently abandoned fields with matted, grassy cover (Bart 1977). Grassland and corn stubble were equally utilized as winter foraging sites in Illinois (Schnell 1968). Plowed fields were avoided. A comparison of cover types comprising home ranges of red-tailed hawks in Wisconsin suggests selection for predominantly graminoid cover of pastures and grasslands (Petersen 1979). Areas with grass less than 10 cm (4 in) high were generally preferred, but adults occasionally hunted over much taller vegetation. Pastures with abundant grasses were preferred.

Red-tailed hawks have been known to nest and hunt in woodlots (Luttich _et al_. 1970) and in extensive, unbroken forests (Titus and Mosher In press). Due to the lower availability of food (chipmunks, mice, and squirrels) and the natural obstacles presented by standing timber, these extensively forested regions probably cannot support as many red-tailed hawks as more open areas characterized by a woodlot-field mix (Mosher pers. comm.). Compared to random samples of surrounding habitat, red-tailed hawks nesting and feeding in extensive forests in Maryland were found on sites with a higher number of large trees [≥ 50 cm (20 in) dbh] and a lower percentage of tree canopy cover (Titus and Mosher In press).

C. _Water requirements_. Water does not appear to be limiting to the red-tailed hawk (Bartholomew and Cade 1962). Most water is supplied by the metabolic process of digesting food.

D. _Cover requirements_. Red-tailed hawks wintering in Iowa used open wooded areas along stream bottoms to satisfy cover requirements (Weller 1964). Winter perches in Illinois were in groups of trees > 9 m (30 ft) tall (Schnell 1968). Both upper and midcanopy portions of trees are used for daily activities and night roosting (Dunstan and Harrell 1973). Dense timber, particularly conifers, is frequently used for night and winter roosts (Brown and Amadon 1968). The availability of suitable cover does not appear to be limiting to the red-tailed hawk as long as suitable reproductive habitat is available.

E. Reproductive requirements. Red-tailed hawk nests are generally located in mature trees and are found more frequently in open woodlots and woodland edges rather than in closed dense woodlots or woodland interiors (Orians and Kuhlman 1956; Gates 1972; Misztal 1974 cited by Howell *et al*. 1978). Groves used by nesting red-tailed hawks in Wisconsin were generally less than 0.4 ha (1 ac) in size (Gates 1972). The size of the tree and the height at which the nest may be placed is more important in site selection than the degree of concealment afforded by the surrounding timber (Bailey 1918).

Nest trees in Michigan were large, averaging 23.6 ± 3.3 m (77.8 ± 10.9 ft) tall and 52.3 ± 15.0 cm (20.9 ± 6 in) dbh (Belyea 1976). The average dbh of nest trees was 58 cm (23 in) [range 41 to 71 cm (16 to 28 in)] in southeastern Minnesota (Le Duc 1970) and 64 cm (25 in) [range 38 to 127 cm (15 to 50 in)] in Ohio (Misztal 1974 cited by Howell *et al*. 1978). The importance (relative frequency) of any one tree species may affect nest site selection, but appears to have no direct relationship to productivity (Howell *et al*. 1978). Nests are often re-used year after year (Brown and Amadon 1968).

F. Special habitat requirements. The availability of adequate perches is vital. During nonbreeding periods, red-tailed hawks commonly perch conspicuously on dead snags (Brown and Amadon 1968) and lone trees (Schnell 1968). Red-tailed hawks occasionally nest in isolated trees along fencelines and ditchbanks (Gates 1972); however, isolated trees are used mainly as hunting lookout posts.

G. Interspersion requirements. Red-tailed hawk home ranges in Wisconsin containing large amounts of woodland were larger than home ranges enclosing small, scattered woodlots (Petersen 1979). Austing (1964) concluded that red-tailed hawks occupying "fringe" habitat maintained larger home ranges in order to find sufficient prey. Data from an Ohio study suggests a correlation between the amount of woodland-forest comprising a study area and breeding density and breeding success (Howell *et al*. 1978). In this study, highly productive red-tailed hawk nest sites had an average of 8.1% of the home range in woodlot, whereas sites with low productivity had over twice as much (20.8%) wooded area.

While it is generally accepted that the availability of nest sites is critical to breeding red-tailed hawks, the optimum mix of habitat types needed to provide sufficient amounts of both nest sites (woodlots, forested areas, isolated trees) and hunting areas remains unclear. Data from recent population studies of red-tailed hawks

suggest that study areas comprised of large percentages of woodland-forests support lower breeding population densities than study areas that are comprised of approximately 10% woodland. Study areas that are composed of very small percentages of habitat types that provide potential nest sites also support low densities of breeding red-tailed hawks (Table B-1). Austing (1964) characterized a study area in Ohio composed roughly of 70% river valley (pasture-grassland-cropland) and 30% woodland as prime habitat.

Territory size is affected by the degree of interspersion of cover types (Petersen 1972, 1979). In Michigan, the size of red-tailed hawks' winter range was inversely proportional to the food supply (Craighead and Craighead 1956). Red-tailed hawks generally maintain circular or oval home ranges which vary spatially according to various habitat variables (Fitch et al. 1946). Red-tailed hawks in an area of Wisconsin with significant amounts of cropland and pasture had year-round territories averaging 119 ha (298 ac), whereas territories without these two cover types averaged 154 ha (384 ac) (Petersen 1972). The average home range size of red-tailed hawks in another Wisconsin study was 137 ha (338 ac) with the largest home range being reported in fall [390 ha (963 ac)] (Petersen 1979). Breeding territories in southeastern South Dakota and northwestern Iowa averaged 256 ha (640 ac) (Tyler and Saetveit 1969). Craighead and Craighead (1956) reported a hunting range radius of 1.19 km (0.75 mi). The average home range of nesting red-tailed hawks in southern Wisconsin was 3.75 km^2 (1.5 mi^2) with an average maximum diameter of 3.2 km (2 mi). A maximum diameter of a red-tailed hawk's home range was reported to be 4 km (2.5 mi).

H. Special considerations. The red-tailed hawk is more tolerant of civilization than most raptor species (Jackman and Scott 1975). Nonetheless, Michigan red-tailed hawks did not nest within 370 m (411 yd) of occupied human dwellings (Belyea 1976). Nest desertion in four out of seven cases in Wisconsin was attributed to human interference (Petersen 1972).

B.3 Habitat Suitability Index (HSI) model for the red-tailed hawk (*Buteo jamaicensis*)

A. Model applicability

(1) Geographic area. This model was developed primarily for the entire eastern half of the United States, classified by Bailey (1978) as the humid temperate domain.

Table B-1. Comparison between habitat composition and breeding density of red-tailed hawks.

Source and Study Area	Density of Active Breeding Red-tailed Hawks in km² per pair	Composition of Study Area in Cover Type Percentage	
Gates (1972) (Wisconsin)	10.6	Cropland-Pasture	85%
		Lakes, Marshes	10%
		Forest-Woodland	.3%
Hager (1957) (New York)	7.9	Cropland-Pasture approximately	50%
		Forest-Woodland approximately	50%
McInvaille and Keith (1974) (Central Alberta)	7.6	Cropland-Pasture approximately	41%
		Forest-Woodland approximately	34%
Luttich et al. (1970) and (1971) (Central Alberta)	7.0	Cropland-Pasture	50%
		Lakes, Marshes	5%
		Forest-Woodland	45%
Petersen (1979) (Wisconsin)	4.7	Cropland-Pasture	71%
		Lakes, Marshes	16%
		Forest-Woodland	8%

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(2) Season. This model will produce HSI values based upon breeding habitat needs for the red-tailed hawk.

(3) Cover types. The red-tailed hawk is an adaptable, opportunistic raptor that utilizes a wide variety of cover types. Since this model is a prototype, cover type consideration has been limited to the following two types: Grassland (G) and Deciduous Forest (DF).

(4) Minimum habitat area. Minimum habitat area is defined as the minimum amount of contiguous suitable habitat that is required for a species to successfully live and reproduce. This information was not found in the literature for the red-tailed hawk. If local information is available to define the minimum habitat area, the HSI for the species will be zero if less than this amount of area is available.

(5) Verification level. This model was critiqued by James Mosher, University of Maryland, who concluded it was as reasonable as can be expected given the variety of habitat types encompassed in the applicable range. His review comments have been incorporated into the current model. No field tests have been conducted.

B. Model description

(1) Graphic overview. This HSI model for the red-tailed hawk considers the quality of the life requisites found in each cover type and interspersion of life requisites when the habitat is composed of two or more cover types. Figure B-1 shows how the HSI is related to cover types, life requisites, and specific habitat variables. Food and reproduction are the only life requisites considered in this model. It is assumed that cover needs are met by adequate reproductive habitat and that water is not limiting.

(2) Life requisite components

a) Food. Food suitability for the red-tailed hawk is related to the abundance and accessibility of suitable prey. This relationship is based upon the premise that optimum conditions for prey do not necessarily reflect optimum conditions for the predator. For this reason, coupled with the fact that many species fall into the broad category of "prey", a general approach to modeling food suitability for this predator is presented.

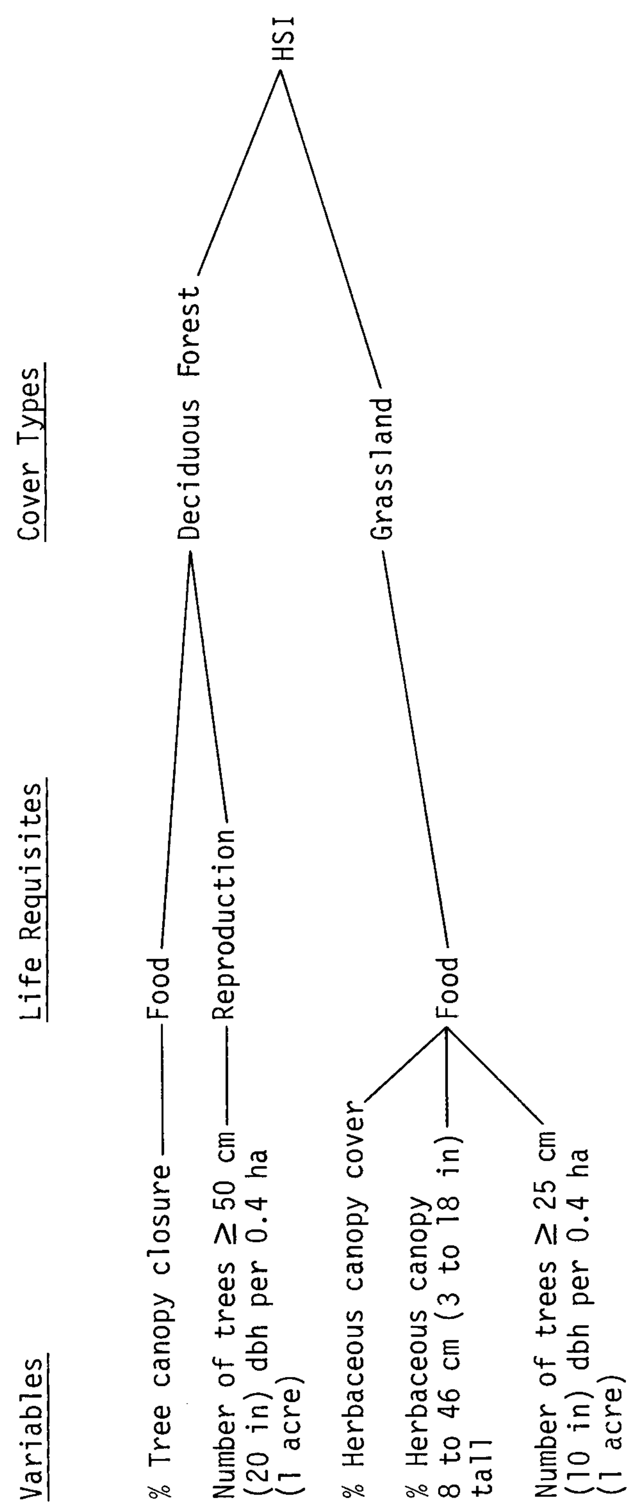


Figure B-1. Tree diagram showing relationship of habitat variables, life requisites, and cover types to the HSI for the red-tailed hawk.

It is assumed that the abundance of prey in grasslands is related to the structure of the herbaceous vegetation which can be estimated by measuring the density and height of herbaceous cover. The accessibility of prey is related to the level of concealment provided for prey by herbaceous vegetation and the degree of access by the hawk to all "huntable" areas. The accessibility of prey can be estimated by measuring the height of herbaceous vegetation and the availability of suitable hunting perch sites. It is assumed that moderately high to high densities of herbaceous vegetation will support dense populations of prey species. It also is assumed that dense stands of herbaceous vegetation will not dramatically reduce the success rate of prey capture by this opportunistic predator. Herbaceous vegetation between 8 and 46 cm tall is considered optimum. If a large proportion of all the herbaceous vegetation present in a grassland is in this height class, conditions will be optimum. Very short vegetation will limit the abundance of prey, whereas very tall vegetation will maximize concealment for prey and thereby limit prey accessibility. It is assumed that three or more suitable perch sites per 0.4 ha will provide optimum hunting conditions. The lack of suitable perch sites will not be completely limiting since red-tailed hawks will hunt by gliding over fields.

Overall food suitability for red-tails in grassland habitats is related to the density and height of herbaceous vegetation and availability of perch sites. Herbaceous density is the most important factor in determining abundance of prey and thus, food quality. No food will be provided in habitats with either a total lack of herbaceous cover or herbaceous cover that is all too short or too tall.

Hunting strategies of the red-tailed hawk in forested areas have not been documented, and the relationships influencing the abundance of prey is unknown. It is assumed that red-tails will hunt in forests and that they feed upon both ground and canopy dwelling mammals. It is assumed that, in the forest, the most critical factor influencing food suitability for the red-tailed hawk is prey accessibility.

Dense stands of trees would likely interfere with the flight patterns of this large buteo, which is best suited for hunting from a lookout perch or soaring slowly over open fields. Conversely, an "open" forest would maximize utilization of all vegetative strata by the red-tailed hawk. It is assumed that prey accessibility can be estimated by measuring the canopy closure of trees, and that canopy closures of less than 50% provide the best prey accessibility and canopy closures of 100% provide poor accessibility (no suitability). It is further assumed that even the best forests provide limited prey availability for red-tailed hawks.

b) Reproduction. Reproductive value is related to the availability of suitable nest trees. It is assumed that the availability of suitable nest trees can be adequately assessed by measuring the density of large trees. It is assumed that a minimum of 10 trees per 0.4 ha (1.0 ac) greater than 50 cm (20 in) dbh are needed to provide optimal suitability, and that if no large trees are available, reproductive suitability will be absent. These statements are based upon the assumption that suitable cliff sites are not available for potential nest sites in the eastern United States.

Human disturbances may have a severe negative impact on nesting red-tailed hawks. The field user must assess each situation with respect to human interference during nesting and, if necessary, adjust the reproductive value accordingly.

(3) Interspersion of life requisites. It is assumed that the best habitat for the red-tailed hawk contains high quality food over 70% of the habitat and high quality reproductive habitat over 15% of the area. These estimates are based upon data indicating that red-tailed hawks generally hunt over large portions of their home range but restrict reproductive activities to isolated and small woodlots and forested areas. High quality food is not required over 100% of the area because the effective hunting range is usually smaller than the home range, i.e., hunting activities are concentrated in areas where prey capture success rates are highest.

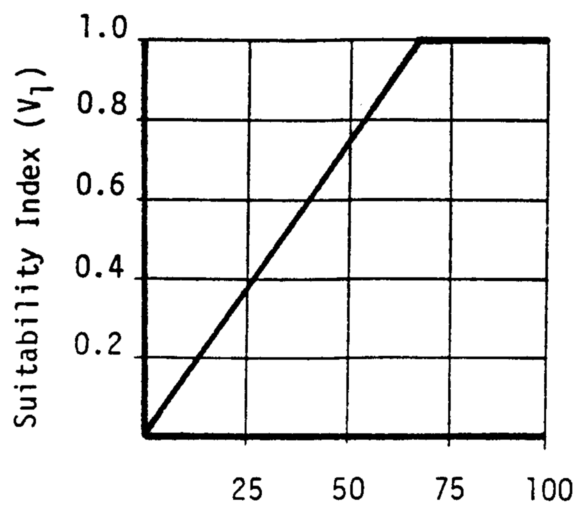
The effective amount of food and reproductive resources is determined by considering the distance between cover types

which provide the resources. Since food and reproductive resources may be provided by different cover types, the distances between cover types can be used to determine the amount of useable area. It is assumed that the optimum distance between food and reproductive resources is equal to or less than 1.2 km. It is also assumed that if food and reproductive resources are distributed at three times this distance, or 3.6 km, then they exceed the distance that red-tailed hawks will fly during the breeding season to obtain them. These distance measurements were estimated using information in the literature pertaining to average home range size and maximum diameters of home ranges.

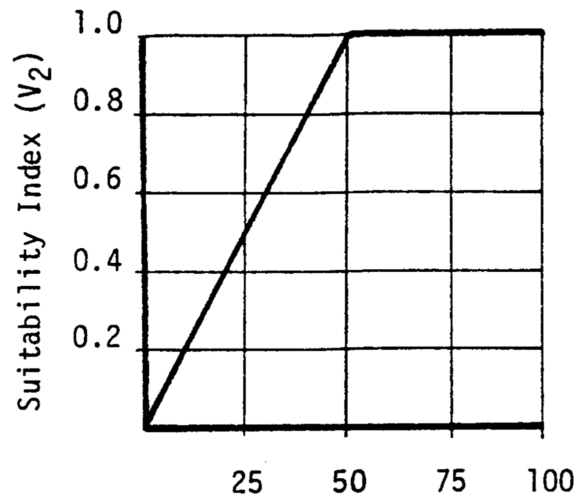
C. Model relationships. This section contains suitability index curves and equations to quantitatively describe the relationships discussed in the previous section. These curves and equations can be used to produce an HSI for the red-tailed hawk.

(1) Suitability index curves

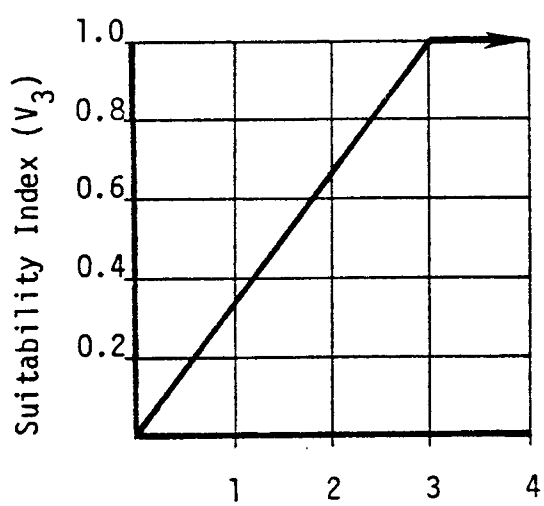
Cover Type	Variable	
Grassland	(V_1)	Percent herbaceous canopy cover.



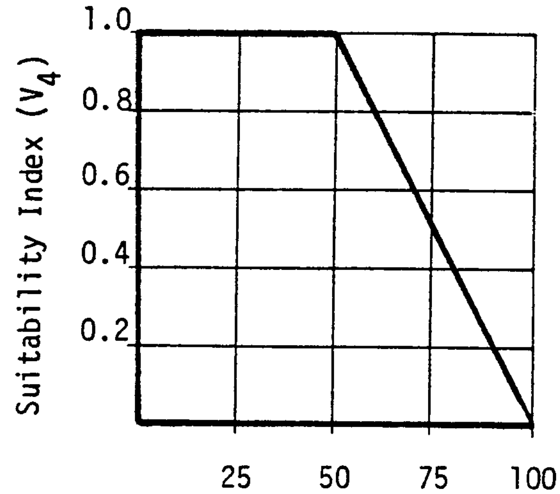
Grassland (V_2) Percent herbaceous canopy 8 to 46 cm (3 to 18 in) tall.



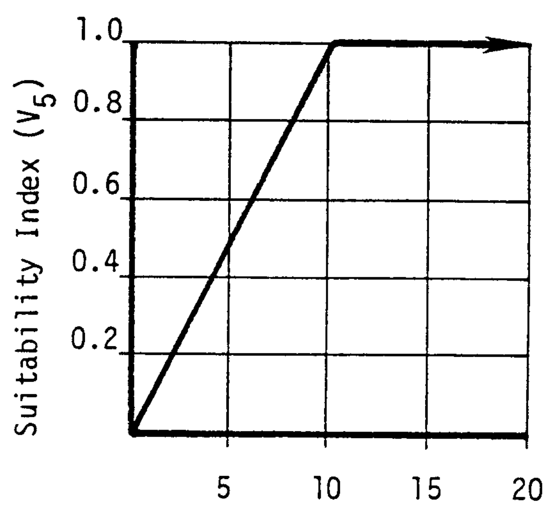
Grassland (V_3) Number of trees $\geq$ 25 cm (10 in) dbh per 0.4 ha (1.0 ac).



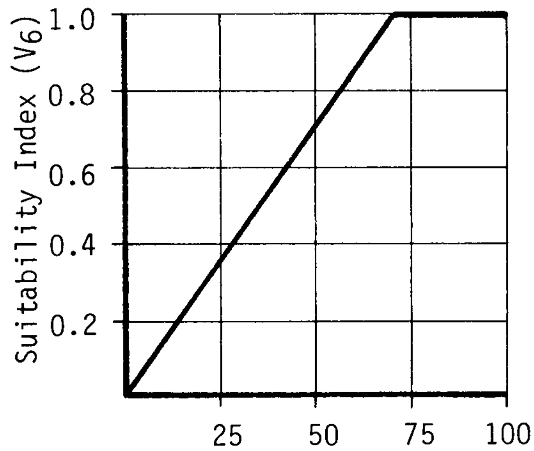
Deciduous Forest (V_4) Percent tree canopy closure.



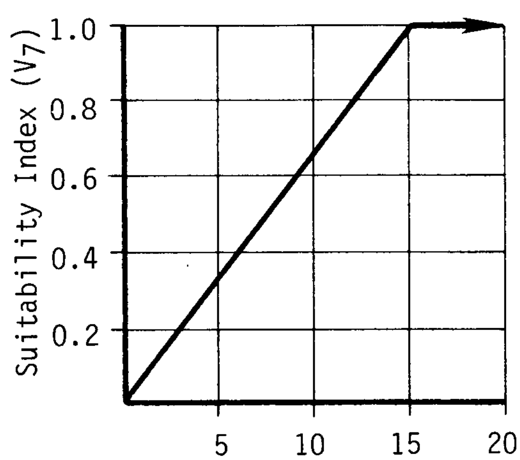
Deciduous Forest (V_5) Number of trees $\geq$ 50 cm (20 in) dbh per 0.4 ha (1.0 ac).



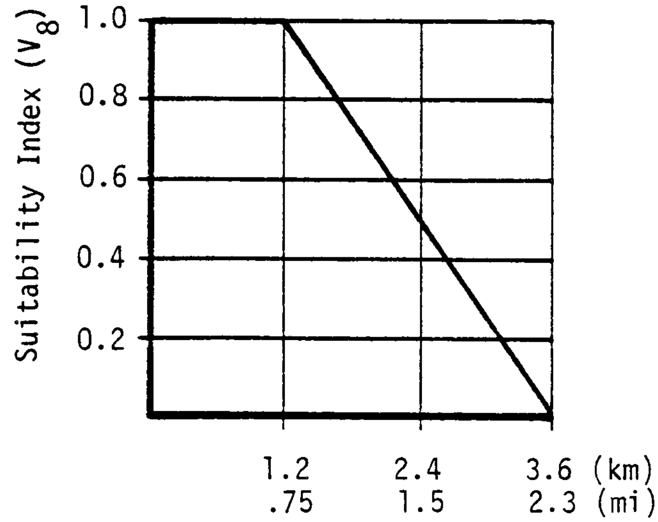
All (V_6) Percent area in equivalent optimum food.



All (V_7) Percent area in equivalent optimum reproduction.



All (V_8) Distance between cover types.



(2) Equations

a) Equations for food component. The following equations integrate index values for each variable to obtain a life requisite value for food in each cover type.

Cover Type	Equation
G	Food Value = $(V_1^2 \times V_2 \times V_3)^{1/4}$
DF	Food Value = $(V_4 \times 0.6)$

b) Equations for reproduction component.

Cover Type	Equation
DF	Reproductive Value = V_5

D. HSI determination. The following calculations must be made to determine an HSI.

(1) Determine if all life requisites are provided at some level greater than zero, considering all cover types under consideration. If any life requisite is not provided, the HSI will equal zero and no further calculations are necessary.

(2) Compute the life requisite values for each cover type by collecting field data for each variable and entering this data into the proper suitability index curve and using the resulting index values in the appropriate life requisite equations.

(3) Determine the relative area (%) of each cover type within the study area as follows:

$$\text{Relative Area (\%) for Cover Type A} = \frac{\text{Area of Cover Type A}}{\text{Total Area of All Cover Types used by the Species}} \times 100$$

Be certain that only those cover types used by the species are considered in determining this percentage.

(4) Determine which cover types are not providing one or more life requisites. For each of these cover types, an interspersion index must be computed. This is accomplished as follows:

a) Select random points on a map in each cover type missing a life requisite and measure the distance to the edge of the nearest other cover type (or cover types, where two or more life requisites are missing) that provide(s) the missing life requisite(s).

b) Enter each of these distance measurements into the Suitability Index Curve titled "Distance between Cover Types", record the individual interspersion indices, and use these to calculate the average interspersion index for each cover type. Where two or more life requisites are missing from a cover type, use the lowest average interspersion index in the next calculation.

(5) Modify the relative area (%) of each cover type missing a life requisite by multiplying the relative area by the average interspersion index for that cover type. This determines the useable area (%) of each cover type. For those cover types that provide all life requisites the useable area (%) is the same as the relative area (%).

(6) To determine the % area in equivalent optimum condition for any life requisite, first multiply the useable area (%) for each cover type by the life requisite values for that cover type (from 2 above). Sum the products of this multiplication across all cover types for each life requisite. This sum for each life requisite is the equivalent percent of the area that provides that life requisite at optimum levels (this is actually an equivalent figure, i.e., 100% of the area at a 0.5 value is equal to 50% of the area at an optimum, 1.0 value).

(7) To determine overall life requisite values, enter the percent area for each life requisite (Step 6) into the appropriate life requisite composition Suitability Index Curve. The index value obtained is the overall life requisite value.

(8) The HSI is equal to the lowest of the overall life requisite values.

B.4 Application of the model. The level of detail needed for a particular application of this model will depend on time, money, and accuracy constraints. Detailed field sampling of all variables will provide the most reliable and replicable HSI values. Any or all variables can be estimated, in order to reduce the amount of time required to apply the model. Increased use of subjective estimates decreases reliability and replicability, and these estimates should be accompanied by appropriate documentation to insure that decisionmakers understand both the method of HSI determination and quality of the data used in the HSI model.

The measurement techniques in Table B-2 are suggested for the variables used in this model. A field form can be developed from this list.

Table B-2. Suggested measurement techniques and definition of habitat variables.

	Variable (Definition)	Cover Types	Suggested Technique
(V_1)	Percent herbaceous canopy cover [the percent of the ground surface that is shaded by a vertical projection of all non-woody vegetation (grasses, forbs, sedges, etc.)]	G	Line transect and Daubenmire plot frame
(V_2)	Percent of herbaceous vegetation that is 8 to 46 cm (3 to 18 in) tall (self explanatory)	G	Line transect, Daubenmire plot frame, and meter stick
(V_3)	Number of trees ≥ 25 cm (10 in) dbh per 0.4 ha (1.0 ac) (self explanatory)	G	Line transect and dbh tape
(V_4)	Percent tree canopy closure (the percent of the ground surface that is shaded by a vertical projection of the canopies of all trees)	DF	Line intercept
(V_5)	Number of trees ≥ 50 cm (20 in) dbh per 0.4 ha (1.0 ac) (self explanatory)	DF	Line transect and dbh tape

B.5 Sources of other models. No other habitat models for the red-tail were identified during the development of this model.

B.6 References cited

Austing, G. R. 1964. The world of the red-tailed hawk. J. B. Lippincott Co., Philadelphia and New York. 128 pp.

Bailey, B. H. 1918. The raptorial birds of Iowa. Iowa Geol. Surv. Bull. 6:93-107.

Bailey, R. G. 1978. Descriptions of the ecoregions of the United States. U.S.D.A., For. Serv. Intermtn. Region. Ogden, Utah. 77 pp.

Bart, J. 1977. Winter distribution of red-tailed hawks in central New York State. Wilson Bull. 89(4):623-628.

Bartholomew, G. A., and T. J. Cade. 1963. The water economy of land birds. Auk 80(3):504-539.

Belyea, G. Y. 1976. A nesting study of the red-tailed hawk in southern Michigan. Ph.D. Diss., Michigan State Univ., East Lansing.

Bohm, R. T. 1978. Observation of nest decoration and food habits of the red-tailed hawk. Loon 50(1):6-8.

Brown, L., and D. Amadon. 1968. Eagles, hawks and falcons of the world. McGraw-Hill Book Co., N.Y. 945 pp.

Craighead, J. J., and F. C. Craighead, Jr. 1956. Hawks, owls, and wildlife. Dover Publ., Inc., New York. 443 pp.

Dunstan, T. C., and B. E. Harrell. 1973. Spatio-temporal relationships between breeding red-tailed hawks and great horned owls in South Dakota. Raptor Res. 7(2):49-54.

Errington, P. L., and W. J. Breckenridge. 1938. Food habits of buteo hawks in the north-central United States. Wilson Bull. 50:113-121.

Fitch, H. S., F. Swenson, and D. F. Tillotson. 1946. Behavior and food habits of the red-tailed hawk. Condor 48(5):205-237.

Gates, J. M. 1972. Red-tailed hawk populations and ecology in east-central Wisconsin. Wilson Bull. 84(4):421-433.

Hager, D. C., Jr. 1957. Nesting populations of red-tailed hawks and horned owls in central New York State. Wilson Bull. 69(3):263-272.

Hickey, J. J., and D. W. Anderson. 1968. Chlorinated hydrocarbons and egg-shell changes in raptorial and fish-eating birds. Science 162(3850):271-273.

Howell, J., B. Smith, J. B. Holt, Jr., and D. R. Osborne. 1978. Habitat structure and productivity in red-tailed hawks. Bird Banding 49(2):162-171.

Jackman, S. M., and J. M. Scott. 1975. Literature review of twenty three selected forest birds of the Pacific Northwest. U.S.D.A. For. Serv., Region 6, Portland, Oregon. 382 pp.

Le Duc, P. V. 1970. The nesting ecology of some hawks and owls in south-eastern Minnesota. Loon 42(2):48-62.

Luttich, S. M., D. A. Rusch, E. D. Meslow, and L. B. Keith. 1970. Ecology of red-tailed hawk predation in Alberta. Ecology 51:190-203.

Luttich, S. M., L. B. Keith, and J. D. Stephenson. 1971. Population dynamics of the red-tailed hawk (Buteo jamaicensis) at Rochester, Alberta. Auk 88(1):75-87.

McInvaille, W. B., Jr., and L. B. Keith. 1974. Predator-prey relations and breeding biology of the great horned owl and red-tailed hawk in central Alberta. Can. Field-Nat. 88(1):1-20.

Misztal, A. 1974. The population and nesting of red-tailed hawks (Buteo jamaicensis) and great horned owls (Bubo virginianus) on the Wisconsin till plains of western Ohio. M.S. Thesis, Ohio State Univ., Columbus. Cited by Howell et al. 1978.

Mosher, J. A. 1980. Personal communication. University of Maryland, Frostburg, Maryland 21532.

Orians, G., and F. Kuhlman. 1956. Red-tailed hawk and horned owl populations in Wisconsin. Condor 58:371-385.

Petersen, L. R. 1972. Biology of raptors in southern Wisconsin. Wisconsin Dept. Nat. Resour. P-R Proj. Rep. W-141-R7. 8 pp.

____________. 1979. Ecology of great horned owls and red-tailed hawks in southeastern Wisconsin. Wisconsin Dept. Nat. Resour. Tech. Bull. 111. 63 pp.

Schnell, G. D. 1968. Differential habitat utilization by wintering rough-legged and red-tailed hawks. Condor 70:373-377.

Titus, K., and J. A. Mosher. In press. Nest site habitat selected by woodland hawks in the central Appalachians. Appalachian Environmental Laboratory, Frostburg, Maryland. 33 pp.

Tyler, H., and P. Saetveit. 1969. The ecology of the great horned owl and the red-tailed hawk. South Dakota Bird Notes 21:77-84, 96.

Weller, M. W. 1964. Habitat utilization of two species of buteos wintering in Iowa. Iowa Bird Life 34:58-62.

Appendix C. Example Application of Model for the Red-tailed Hawk

C.1 Introduction. This appendix provides a sample data set which has been applied to the red-tailed hawk model (Appendix B) to calculate a Habitat Suitability Index. The data set is hypothetical and to some degree represents a realistic model application.

A hypothetical project area has been used to facilitate this application, consisting of 1,600 ha (4,000 ac) of available habitat for the red-tailed hawk. This is comprised of 1,000 ha (2,500 ac) of deciduous forest and 600 ha (1,500 ac) of grassland. Example data (Table C-1) are presented for three sample sites in forest and two sites in grassland cover types. The symbol "N/A" in Table C-1 indicates a specific variable which does not apply to the HSI model in that cover type.

Table C-1. Example field data for hypothetical project area.

		Sites				
		Forest			Grassland	
	Variable	1	2	3	1	2
V_1	% herbaceous canopy cover	N/A	N/A	N/A	20%	42%
V_2	% of herbaceous vegetation that is 8 to 46 cm (3 to 18 in) tall	N/A	N/A	N/A	10%	18%
V_3	Number of trees $\geq$ 25 cm (10 in) dbh per 0.4 ha (1 ac)	N/A	N/A	N/A	1	2
V_4	% tree canopy closure	65%	80%	35%	N/A	N/A
V_5	Number of trees $\geq$ 50 cm (20 in) dbh per 0.4 ha (1 ac)	4	12	2	N/A	N/A

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Appendix C. Example Application of Model for the Red-tailed Hawk

HSI determination for a multi-cover type species, such as the red-tailed hawk, consists of three major steps: 1) Life requisite values must be determined for each cover type; 2) interspersion of life requisites must be considered; and 3) the relationship of life requisites to HSI must be defined.

These three steps are outlined in detail below.

C.2 Step 1. Calculate life requisite values in each cover type.

A. Example field data are entered for all sites in Figs. C-1 and C-2, Block 9. Mean values for field data from each variable are then calculated and entered in Block 10. Suitability Index (SI) values are determined for each variable by applying this mean value to the Suitability Index Curves provided in the HSI model. The resulting SI value is entered in Block 11.

B. Life requisite values are determined by entering the mean SI value into the appropriate aggregation functions, as provided in the HSI model and also displayed in Block 13. The computed life requisite values are entered in Block 14. For single cover type users, HSI equals the lowest life requisite value, and is entered in Block 15. For multi-cover type species life requisite values are computed and recorded (Figs. C-1 and C-2) by cover type. The life requisite values for each cover type are summarized in Fig. C-3. Additional calculations (Figs. C-4 to C-7) are required to integrate life requisite values from each cover type through consideration of interspersion parameters.

C.3 Step 2. Consider interspersion of life requisites

Two additional factors must be considered before an HSI can be determined: 1) The distance between cover types must be considered when one or more cover types is missing a life requisite. If the distance between life requisites exceeds the ability of the species to obtain them, then there is effectively less useable area of the habitat. 2) The relative amount (% area) of cover types actually providing each life requisite must be considered. These two factors are quantitatively considered and an HSI calculated using the forms in Figs. C-4 through C-7.

Figure C-4 is used to assess the distance between cover types and to compute an interspersion index. A separate form is used for each cover type that is missing a life requisite. In this example, the project area

consists of two cover types, both of which are used by the red-tailed hawk. The deciduous forest cover type provides all life requisites for the hawk whereas grassland provides only food. To determine the distance from grassland (food) to forest (reproduction), random points are selected in grassland, and a measurement is taken from each point to the edge of the nearest deciduous forest. These measurements are recorded in the upper right hand portion of Block 9 in Fig. C-4. Each of these distance measurements is then entered into the suitability index curve titled "Distance between cover types" in the red-tailed hawk model. The resulting index value is recorded in the lower right hand portion of Block 9. These index values are then averaged to produce the average interspersion index which is recorded in Block 10 and Block 11.

The average interspersion index is used to modify the relative amount (%) of each cover type to determine the effective amount of useable area (%) as shown in Fig. C-5. The area of each cover type used by the red-tailed hawk is recorded in Block 7 of Fig. C-5, and the relative area (%) of each is calculated and noted in Block 9. The relative area (%) is multiplied by the interspersion index to determine the useable area (%) for each cover type which is recorded in Block 11.

To determine the overall life requisite value, the useable area (%) of each cover type must be integrated with the life requisite quality for each cover type. Fig. C-6 shows the computations used to determine the overall life requisite value for food for the red-tailed hawk in all cover types. Cover types are listed in Block 7, useable area (%) in Block 8, and life requisite values for each cover type in Block 9. For each cover type, the value in Block 8 is multiplied by the value in Block 9 to yield a percent. These percents are then summed and recorded in Block 11 as % area in equivalent optimal condition. The total % area in equivalent optimal condition is entered into the suitability index curve titled "Percent area in equivalent optimum food" in the red-tailed hawk model to determine the overall life requisite value for food, which is recorded in Block 12.

Fig. C-7 shows the calculations to determine the overall reproductive life requisite value for the red-tailed hawk.

C.4 Step 3. Determine relationships of life requisite values to HSI

The final step in applying the red-tailed hawk model is to determine the relationship of the life requisite values to the HSI. For this model, this determiantion is based on the limiting factor concept, and it is assumed that the HSI is equal to the lowest of the overall life requisite values. The HSI for the red-tailed hawk using the data in this hypothetical project area is thus equal to the food value, which is 0.59.

Appendix C. Example Application of Model for the Red-tailed Hawk

1. Study Hypothetical Project Area	2. Proposed action Baseline
3. Evaluation species Red-tailed hawk	4. Sample date
5. Target year 0	6. Cover type Deciduous Forest
7. Habitat use pattern Multi-cover type species	

8. Variable	9. Sample site value								10. Mean value	11. SI value
	1	2	3	4	5	6	7	8		
V_4	65	80	35						60	0.8
V_5	4	12	2						6	0.6

Life requisite value computations

12. Life requisite	13. Aggregation function	14. Computed life requisite value
Food	V_4 x 0.6)	0.48
Reproduction	V_5	0.6

15. For Single cover type users, HSI = Lowest life requisite value = ______

16. For multi-cover type users, use Forms 2, 3, 4, and 5 to compute HSI.

Figure C-1. Form 1. Tabulation form: Determination of HSI for single cover type species or determination of life requisite values by cover type for multi-cover type species.

Appendix C. Example Application of Model for the Red-tailed Hawk

1. Study Hypothetical project area	2. Proposed action Baseline
3. Evaluation species Red-tailed hawk	4. Sample date
5. Target year 0	6. Cover type Grassland
7. Habitat use pattern Multi-cover type user	

8. Variable	9. Sample site value								10. Mean value	11. SI value
	1	2	3	4	5	6	7	8		
V_1	20	42							31	0.45
V_2	10	18							14	0.3
V_3	1	2							1.5	0.75

Life requisite value computations

12. Life requisite	13. Aggregation function	14. Computed life requisite value
Food	$(V_1^2 \times V_2 \times V_3)^{1/4}$	0.46

15. For single cover type users, HSI = Lowest life requisite value = ________

16. For multi-cover type users, use Forms 2, 3, 4, and 5 to compute HSI.

Figure C-2. Form 1. Tabulation form: Determination of HSI for single cover type species or determination of life requisite values by cover type for multi-cover type species.

Appendix C. Example Application of Model for the Red-tailed Hawk

1. Study Hypothetical project area	2. Proposed action Baseline

3. Evaluation species Red-tailed hawk	4. Sample date	5. Target year 0

Fill in the matrix below with cover types and life requisite values summarized from Form 1, for all available cover types used by the species. If any life requisite is not present, or present at a 0.0. value in all cover types, the HSI = 0.0. If life requisites are all present at > 0.0, continue with Forms 3, 4, and 5.

	6. Life requisite category							
7. Cover type	Food Value	Reproduction Value						
Deciduous Forest	0.48	0.6						
Grassland	0.46	NA						

Figure C-3. Form 2. Summary of life requisite values for multi-cover type species.

Appendix C. Example Application of Model for the Red-tailed Hawk

1. Study Hypothetical project area	2. Proposed Action Baseline
3. Evaluation Species Red-tailed hawk	4. Sample date
5. Target year 0	6. Cover type Grassland

7. Cover type(s) providing life requisite(s).	8. Life Requisite(s) Provided	9. Display of distance measurements and corresponding interspersion indices. 1	2	3	4	5	6	7	8	9	10	10. Average of indices in each row of column 9.
Deciduous Forest	Reproductive	1.0 km / 1.0	1.6 km / 0.83	0.8 km / 1.0	4.3 km / 0.0	3.0 km / 0.25						0.62

11. Interspersion Index = 0.62

Figure C-4. Form 3. Determination of interspersion index for multi-cover type species.

Appendix C. Example Application of Model for the Red-tailed Hawk

1. Study Hypothetical project area		2. Proposed Action Baseline		
3. Evaluation Species Red-tailed hawk		4. Date	5. Target year 0	
6. Cover type	7. Area of Cover Types	9. Relative Area (%)	10. Interspersion Index (from Form 3) for each cover type	11. Useable Area (%)
Deciduous Forest	2,500	62.5%	1.0	62.5%
Grassland	1,500	37.5%	0.62	23%
8. Σ =	4,000			

Figure C-5. Form 4. Determination of Useable Area (%).

1. Study Hypothetical project area		2. Proposed Action Baseline	
3. Evaluation Species Red-tailed hawk		4. Date	
5. Target year 0		6. Life Requisite Food	
7. Cover Type	8. Useable Area (%) (Form 4)	9. Life Requisite Value (Form 2)	10. Column 8 x Column 9
Deciduous Forest	62.5%	0.48	30%
Grassland	23%	0.46	11%
		11. % Area in equivalent optimal condition =	41%

12. Overall life requisite value = .59

HSI Determination. The HSI is equal to the lowest of the overall life requisite values (from Block 12 of each Form 5 used).

HSI = .59

Figure C-6. Form 5. Determination of overall Life Requisite Values and HSI

Appendix C. Example Application of Model for the Red-tailed Hawk

1. Study Hypothetical project area		2. Proposed Action Baseline	
3. Evaluation Species Red-tailed hawk		4. Date	
5. Target year 0		6. Life Requisite Reproduction	
7. Cover Type	8. Useable Area (%) (Form 4)	9. Life Requisite Value (Form 2)	10. Column 8 x Column 9
Deciduous Forest	62.5%	0.6	37.5%
		11. % Area in equivalent optimal condition =	37.5%

12. Overall life requisite value = 1.0

HSI Determination. The HSI is equal to the lowest of the overall life requisite values (from Block 12 of each Form 5 used).
HSI = .59

Figure C-7. Form 5. Determination of overall Life Requisite Values and HSI

Appendix D. Habitat Use Information and HSI Model for the Channel Catfish

D.1 Introduction. HSI models should be documented so that the model can be consistently applied and improved, and the HSI outputs estimated by the model can be properly interpreted. This appendix provides an example HSI model for channel catfish with documentation as described in 103 ESM 3.4. Section D.2 below provides documentation of habitat use information. Section D.3 provides an HSI model derived from this information, and includes assumptions and limitations of the model.

An HSI model used in HEP does not have to be of the same type as the one presented in this appendix. Other HSI models for channel catfish are available in Aggus and Morais (1979) or could be developed from the information presented in D.2.

D.2 Habitat use information for channel catfish

A. Distribution. The native range of channel catfish (*Ictalurus punctatus*) extends from the southern portions of the Canadian prairie provinces south to the Gulf States, west to the Rocky Mountains, and east to the Appalachian Mountains (Trautman 1957; Miller 1966; Scott and Crossman 1973). They have been widely introduced outside this range and occur in essentially all of the Pacific and Atlantic drainages in the 48 conterminous States (Moore 1968; Scott and Crossman 1973). The greatest abundance of channel catfish generally occurs in the open (unleveed) floodplains of the Mississippi and Missouri River drainages (Walden 1964).

B. Habitat. Channel catfish populations occur over a broad range of environmental conditions, although they are most abundant in large riverine systems (Sigler and Miller 1963; Scott and Crossman 1973). Optimal riverine habitat for channel catfish consists of warm temperatures (Clemens and Sneed 1957; Andrews et al. 1972; Biesinger et al. 1979) and a diversity of velocities, depths, and structural features that provide cover and food (Bailey and Harrison 1948). They thrive in large, clear, moderately swift prairie streams with rocky substrates (Scott and Crossman 1973; Pflieger 1975), and large, sluggish, moderate-to-low gradient, turbid rivers, such as the Mississippi and Missouri Rivers (Hanson and Campbell 1963; Miller 1966; Bryan et al. 1975). They are rarely found in small or high-gradient streams (Pflieger 1971).

Adults in rivers are found near the bottom during the day in large, deep pools and near cover of logs, boulders, and debris. They move to shallower, faster areas of riffles and runs at night to feed (McCammon 1956; Davis 1959; Pflieger 1971, 1975). Fry and juveniles

occupy shallow areas strewn with rocks or other cover (Davis 1959; Pflieger 1971, 1975; Cross and Collins 1975). They overwinter under boulders in riffles (Miller 1966) or move to cover in deeper water (Cross and Collins 1975).

Channel catfish also thrive in a variety of lacustrine environments including reservoirs (LaRivers 1962; Jester 1971), lakes (Scott and Crossman 1973), bayous (Lantz 1970; Bryan et al. 1975), and farm ponds (Régier 1963). Adults in reservoirs and lakes favor reefs and deep, protected areas with rocky substrates or other cover. They move to shallow shoreline areas and tributaries at night to feed (Davis 1959; Jester 1971; Scott and Crossman 1973). Fry and juveniles are on the bottom in cover during the day (Marzolf 1957; Brown et al. 1970; Cross and Collins 1975). Optimal reservoir habitat for channel catfish appears to be large, fertile, warm reservoirs with clear to moderate turbidities, and with abundant cover of logs, boulders, and cavities (Davis 1959; Pflieger 1975).

Channel catfish are quite mobile (Harrison 1953; Ziebell 1973) and disperse readily to favorable habitats in riverine (Bailey and Harrison 1948; Pflieger 1971) and lacustrine (LaRivers 1962) environments. They strongly prefer warm temperatures and concentrate in the warmest sections of rivers and reservoirs (Ziebell 1973; Stauffer et al. 1975; McCall 1977). Movements become restricted during winter (McCammon 1956; Jester 1971) and they apparently move to deep water to overwinter (Jester 1971) as temperatures drop below 5-10° C (Bailey and Harrison 1948). They are generally inactive and in cover at temperatures < 4° C (Brown et al. 1970).

C. <u>Age, growth, and food</u>. Age at maturity in channel catfish is variable. Catfish from southern areas with longer growing seasons mature earlier and at smaller sizes than those from northern areas (Davis and Posey 1958; Scott and Crossman 1973). Southern catfish mature at age V or less (Scott and Crossman 1973; Pflieger 1975) while northern catfish mature at age VI or greater for males and at age VIII or greater for females (Starostka and Nelson 1974).

Young-of-the-year (age 0) catfish feed predominantly on plankton and aquatic insects (Bailey and Harrison 1948; Walburg 1975). Adults are opportunistic feeders and are able to locate suitable food in a variety of habitats. They have an extremely varied diet, including terrestrial and aquatic insects, detrital and plant material, crayfish, and molluscs (Bailey and Harrison 1948; Miller 1966; Starostka and Nelson 1974). Fish may form a major part of the diet of catfish

> 500 cm in length (Starostka and Nelson 1974). Channel catfish diet in rivers and reservoirs does not appear to be significantly different (Bailey and Harrison 1948; Starostka and Nelson 1974). Feeding is done by both vision and chemosenses (Davis 1959) and occurs primarily at night (Pflieger 1975). Bottom feeding is more characteristic but food is also taken at the surface (Scott and Crossman 1973).

D. Reproduction. Channel catfish spawn in late spring and early summer (generally late May through mid-July) when temperatures reach about 21° C (Clemens and Sneed 1957; Marzolf 1957; Pflieger 1975). Spawning requirements appear to be a major factor in determining habitat suitability for channel catfish (Clemens and Sneed 1957). Spawning is greatly inhibited if suitable nesting cover is unavailable (Marzolf 1957).

E. Specific habitat requirements

(1) Species in general. All life stages of channel catfish strongly seek cover, but precise quantitative data on cover requirements of channel catfish in rivers and reservoirs are not available. Debris, logs, cavities, boulders, and cutbanks in low velocity (< 15 cm/sec) areas of deep pools and backwaters will provide cover for channel catfish (Bailey and Harrison 1948). Cover of boulders and debris in deep water is important as overwintering habitat (Miller 1966; Jester 1971; Cross and Collins 1975). Deep pools and littoral areas (≤ 5 m deep) with ≥ 40% suitable cover are assumed optimal for all life stages. Turbidities > 25 ppm but < 100 ppm may somewhat moderate the need for fixed cover (Bryan et al. 1975).

High velocity riffle and run areas of rivers (velocities of ≥ 30 cm/sec) with rubble substrate (≥ 60% of bottom) and overhanging vegetation, and quiet areas with debris and aquatic vegetation, provide optimal conditions for food production (Bailey and Harrison 1948). Channel catfish prefer a diversity of velocities and structural features, therefore it is assumed that a riverine habitat with 40-60% pools would be optimal. It is assumed that at least 20% of lake or reservoir surface area should consist of littoral areas (≤ 5 m deep) to provide adequate area for spawning, fry and juvenile rearing and feeding habitat for channel catfish.

Total dissolved solids (TDS) provides an index of fish production (Ryder 1965) and water fertility. Jenkins (1976) found high standing crops of warmwater fish correlated with a range of TDS in reservoirs of 100-350 ppm (with ionic concentrations of carbonate-bicarbonate exceeding those of sulfate-chloride). Thus, it is assumed that high standing crops of channel catfish in lakes or reservoirs will, on the average, correspond to this TDS level.

Turbidity in rivers and reservoirs and reservoir size are other factors that may influence habitat suitability for channel catfish populations. Channel catfish are abundant in rivers and reservoirs with varying levels of turbidity and siltation (Cross and Collins 1975). However, clear to moderate turbidities (< 100 ppm) are probably optimal for both survival and growth (Finnell and Jenkins 1954; Buck 1956; Marzolf 1957). Larger reservoirs (> 200 ha) are probably more suitable reservoir habitat for channel catfish populations because survival and growth are better than in smaller reservoirs (Finnell and Jenkins 1954; Marzolf 1957). Other factors that may affect reservoir habitat suitability for channel catfish are mean depth, storage ratio (SR), and length of agricultural growing season. Jenkins (1974) found that high mean depths were negatively correlated with standing crop of channel catfish. Mean depths are an inverse correlate of shoreline development (Ryder et al. 1974), thus higher mean depths may mean less littoral area would be available. Jenkins (1976) also reported that standing crops of channel catfish peaked at an SR of 0.75. Finally, standing crops of channel catfish were positively correlated to growing season length (Jenkins 1970), with highest standing crops reported in reservoirs with ≥ 200 frost-free days (Jenkins and Morais 1971).

Dissolved oxygen (DO) levels of 5 mg/l are adequate for growth and survival of channel catfish, but DO levels of ≥ 7 mg/l are optimal (Andrews et al. 1973; Carlson et al. 1974). Dissolved oxygen levels < 3 mg/l retard growth (Simco and Cross 1966) and feeding is reduced at DO levels < 5 mg/l (Randolph and Clemens 1976).

(2) Adult. The optimal temperature range for growth of adult channel catfish is 26-29° C (Shrable et al. 1969; Chen 1976). Growth is poor at temperatures < 21° C (McCammon and LaFaunce 1961; Macklin and Soule 1964; Andrews and Stickney 1972) and

ceases at < 18° C (Starostka and Nelson 1974). An upper lethal temperature of 33.5° C has been reported for catfish acclimated at 25° C (Carlander 1969).

Adult channel catfish were most abundant in habitats with salinities < 1.7 ppt in Louisiana, although they occurred in areas with salinities up to 11.4 ppt (Perry 1973). Salinities ≤ 8 ppt are tolerated with little or no effect, but growth slows above this level and does not occur at salinities > 11 ppt (Perry and Avault 1968).

Adults do not have strict substrate requirements but they are most abundant in areas with sand, gravel, or rubble substrates which may be mixed with silt. When they are found over silt substrates the water is usually flowing (Bailey and Harrison 1948).

(3) Embryo. Dark and secluded areas are used for nesting (Marzolf 1957); males build and guard nests in cavities, burrows, under rocks, and in other protected sites (Davis 1959; Pflieger 1975). Nesting in large impoundments generally occurs among rubble and boulders along protected shorelines at depths of about 2-4 m (Jester 1971). Catfish in large rivers are likely to move into shallow, flooded areas to spawn (Bryan et al. 1975). Lawler (1960) reported that spawning in Utah Lake, Utah, was concentrated in sections of the lake with abundant spawning sites of rocky outcrops, trees, and crevices. The male catfish fans embryos for water exchange and guards the nest from predators (Miller 1966; Minckley 1973). Embryos can develop in the temperature range of 15.5 to 29.5° C, with the optimum about 27° C (Brown 1942; Clemens and Sneed 1957). They do not develop at temperatures < 15.5° C (Brown 1942). Embryos hatch in 6-7 days at 27° C (Clemens and Sneed 1957).

Laboratory studies indicate that embryos three days old and older can tolerate salinities up to 16 ppt until hatching, when tolerance drops to 8 ppt (Allen and Avault 1970). However, 2 ppt salinity is considered the upper limit for embryo habitat suitability because it is the highest level in which successful spawning in ponds has been observed (Perry 1973). Embryo survival and production in reservoirs will probably be high in areas that are not subject to disturbance by heavy wave action or rapid water drawdown.

(4) Fry. The optimal temperature range for growth of channel catfish fry is 29-30° C (West 1966). Some growth does occur down to temperatures of 18° C (Starostka and Nelson 1974), but growth generally is poor in cool waters with average summer temperatures < 21° C (McCammon and LaFaunce 1961; Macklin and Soule 1964; Andrews et al. 1972) and in areas with short growing seasons (Starostka and Nelson 1974). Upper incipient lethal levels for fry are about 35-38° C, depending on acclimation temperature (Moss and Scott 1961; Allen and Strawn 1968). Optimal salinities for fry range from 0-5 ppt and salinities ≥ 10 ppt are marginal for fry as growth is greatly reduced at this level (Allen and Avault 1970).

Fry habitat suitability in reservoirs is related to flushing rate of reservoirs in mid-summer. Walburg (1971) found abundance and survival of fry greatly decreased at flushing rates < 6 days in July-August.

Channel catfish fry have strong shelter-seeking tendencies (Brown et al. 1970) and cover availability will be important in determining habitat suitability. Newly hatched fry remain in the nest for 7-8 days (Marzolf 1957) and then disperse to shallow water areas with cover (Cross and Collins 1975). Fry are commonly found aggregated near cover in protected, slow-flowing (velocity < 15 cm/sec) areas of rocky riffles, debris-covered gravel, or sand bars in clear streams (Davis 1959; Cross and Collins 1975), and in very shallow (< 0.5 m) mud or sand substrate edges of flowing channels along turbid rivers and bayous (Bryan et al. 1975). Dense aquatic vegetation generally does not provide optimum cover because predation on fry by centrarchids is high under these conditions, especially in clear water (Marzolf 1957; Cross and Collins 1975).

(5) Juvenile. Optimal habitat for juveniles is assumed to be similar to that for fry. The temperature range most suitable for juvenile growth is reported to be 28-30° C (Andrews et al. 1972; Andrews and Stickney 1972). Upper lethal temperatures are assumed to be similar to those for fry.

D.3 HSI model for channel catfish

A. Model applicability:

(1) Geographic area: The model provided in Section C is applicable throughout the 48 conterminous States. The standard of comparison for each individual variable suitability index is the optimum value of the variable that occurs anywhere within the 48 conterminous States. Therefore, the model will never provide an HSI of 1.0 when applied to water bodies in the northern States where temperature-related variables do not reach the optimum values found in the southern States.

(2) Season. The model provides a rating for a water body based on its ability to support a reproducing population of channel catfish through all seasons of the year.

(3) Cover types. The model is applicable in Riverine, Lacustrine, Palustrine, and estuarine habitats, as described by Cowardin *et al*. (1979).

(4) Minimum habitat area. Minimum habitat area is defined as the minimum area of contiguous suitable habitat that is required for a species to successfully live and reproduce. No attempt has been made to establish a minimum habitat size for channel catfish, although this species prefers larger water bodies.

(5) Verification. The acceptable output of this channel catfish model is to produce an index between 0 and 1 which the author believes has a positive relationship to carrying capacity. In order to verify that the model output was acceptable, the author developed data sets and habitat suitability indices were then calculated for each data set (Tables D-1, D-2, D-3, and D-4).

The data sets are not from actual field measurements, but represent combinations of variable values the author believes could occur in a water body. The HSI's calculated from the data reflect what the author thought carrying capacity trends would be in water bodies with the listed characteristics. Thus, the model meets the acceptance goal.

B. Model description. The model is based on the assumption that any variable that has been shown to have an impact on the growth, survival, distribution, abundance or other measure of well being of

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Table D-1. Sample data sets using the riverine HSI model.

Variable		Data Set 1		Data Set 2		Data Set 3	
		Data	SI	Data	SI	Data	SI
% pools	V_1	60%	1.0	90%	0.6	15%	0.5
% cover	V_2	50%	1.0	15%	0.4	5%	0.2
Substrate for food production	V_4	silt-gravel	0.6	silt-sand	0.3	sand	0.2
Temperature (Adult)	V_5	26° C	1.0	32° C	0.4	23° C	0.5
Growing season	V_6	180	0.8	-	-	-	-
Turbidity	V_7	50	1.0	170	0.5	130	0.8
Dissolved oxygen	V_8	5.5	0.6	5.0	0.5	5.0	0.5
Salinity (Adult)	V_9	< 1	1.0	< 1	1.0	< 1	1.0
Temperature (Embryo)	V_{10}	24° C	0.8	22° C	0.5	28° C	0.5
Salinity (Embryo)	V_{11}	< 1	1.0	< 1	1.0	< 1	1.0
Temperature (Fry)	V_{12}	26° C	0.8	32° C	0.7	24° C	0.5
Salinity (Fry/Juvenile)	V_{13}	< 1	1.0	< 1	1.0	< 1	1.0
Temperature (Juvenile)	V_{14}	29° C	1.0	32° C	0.7	23° C	0.5
Velocity - Cover	V_{19}	15	1.0	5	1.0	30	0.3

Table D-1. Sample data sets using the riverine HSI model.

Variable		Data Set 1		Data Set 2		Data Set 3	
		Data	SI	Data	SI	Data	SI
% pools	V_1	60%	1.0	90%	0.6	15%	0.5
% cover	V_2	50%	1.0	15%	0.4	5%	0.2
Substrate for food production	V_4	silt-gravel	0.6	silt-sand	0.3	sand	0.2
Temperature (Adult)	V_5	26° C	1.0	32° C	0.4	23° C	0.5
Growing season	V_6	180	0.8	-	-	-	-
Turbidity	V_7	50	1.0	170	0.5	130	0.8
Dissolved oxygen	V_8	5.5	0.6	5.0	0.5	5.0	0.5
Salinity (Adult)	V_9	< 1	1.0	< 1	1.0	< 1	1.0
Temperature (Embryo)	V_{10}	24° C	0.8	22° C	0.5	28° C	0.5
Salinity (Embryo)	V_{11}	< 1	1.0	< 1	1.0	< 1	1.0
Temperature (Fry)	V_{12}	26° C	0.8	32° C	0.7	24° C	0.5
Salinity (Fry/Juvenile)	V_{13}	< 1	1.0	< 1	1.0	< 1	1.0
Temperature (Juvenile)	V_{14}	29° C	1.0	32° C	0.7	23° C	0.5
Velocity - Cover	V_{18}	15	1.0	5	1.0	30	0.3

Table D-2. HSI calculation using data from Table D-1.

Component	Data Set 1 SI	Data Set 2 SI	Data Set 3 SI
C_F =	0.80	0.35	0.20
C_C =	1.00	0.62	0.31
C_{WQ} =	0.81	0.40*	0.56
C_R =	0.81	0.48	0.38*
HSI =	0.84	0.40*	0.38*

*Note: $C_{WQ} \leq 0.4$, therefore HSI = C_{WQ} in Data Set 2.

$C_R \leq 0.4$, therefore HSI = C_R in Data Set 3.

Table D-4. HSI calculation using data from Table D-3.

Component	Data Set 1 SI	Data Set 2 SI	Data Set 3 SI
C_F =	1.00	0.70	0.47
C_C =	1.00	0.46	0.60
C_{WQ} =	0.74	0.30*	0.20*
C_R =	0.81	0.52	0.30
C_{OT} =	0.95	0.55	1.00
HSI =	0.86	0.30*	0.20*

*Note: $C_{WQ} \leq 0.4$, therefore HSI = C_{WQ} in Data Sets 2 and 3.

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channel catfish, or closely related species, can be expected to have an impact on the carrying capacity of channel catfish habitat. Channel catfish habitat is assumed to consist of four major components: food, cover, water quality, and reproduction. Variables that affect habitat quality, which do not easily fit in these major components, are considered as a minor "other" component. A schematic diagram of the relationship of these components to habitat suitability is provided in Figure D-1. A rating is provided for each component by combining ratings for selected variables, and the component ratings combined into a species HSI.

The component with the lowest rating is assumed to have the greatest impact on the suitability for the species. This assumption can easily be quantified in one of two ways. The first is by use of a geometric mean, which responds more to a change in the lowest value used to calculate the mean than to a change in the other values. The second is a limiting factor approach, whereby the lowest component score is selected as the HSI. The limiting factor approach is used only where there is evidence that a low value cannot be compensated by higher values of another component. This occurs in the water quality and reproduction components because poor water quality causes stress and poor reproductive success would depress populations. If these component ratings are less than or equal to 0.4, the limiting factor approach is used to quantify the assumption that water quality or reproduction is limiting at some low level of suitability. No precise information exists on how the components interact to determine habitat suitability. However, channel catfish occur in a wide variety of habitats and it is likely that a low rating for one component can be compensated by a higher rating in another component, except for low suitabilities for water quality and reproduction.

The model provides a method of rating habitat suitability utilizing the results of both laboratory and field studies on a variety of physiological and population responses to variable changes. The greatest weakness of the model is that the validity of the assumed relationships between the measurable physiological or population response and habitat suitabilities are unknown.

Each variable identified as important in the documentation of species habitat use information was placed in the appropriate component as shown in Figures D-2 and D-3. Some variables (e.g., oxygen concentration) vary on a diurnal or seasonal basis and must be precisely defined so that they may be estimated from field data.

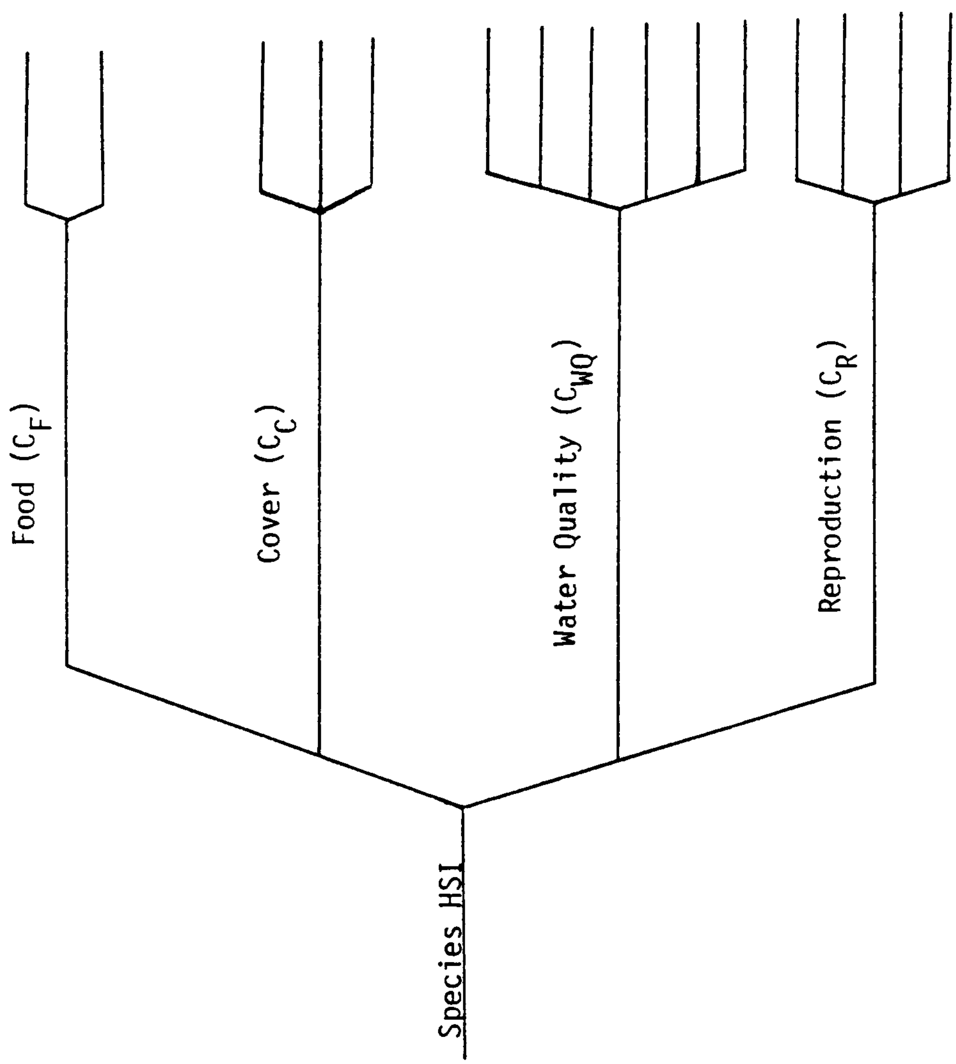


Figure D-1. Schematic diagram of channel catfish habitat model.

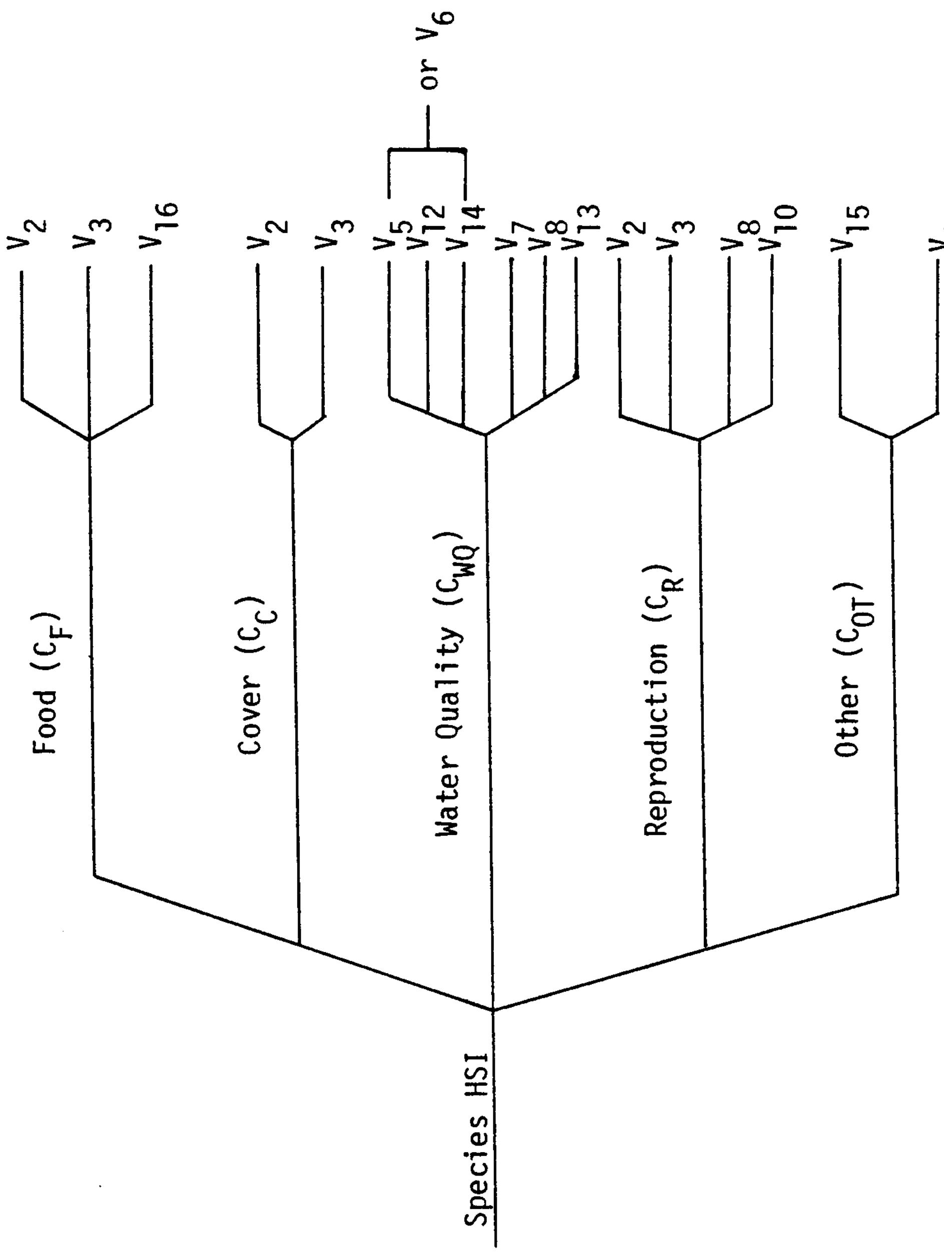


Figure D-2. Variables for each component of the lacustrine version of the channel catfish model.

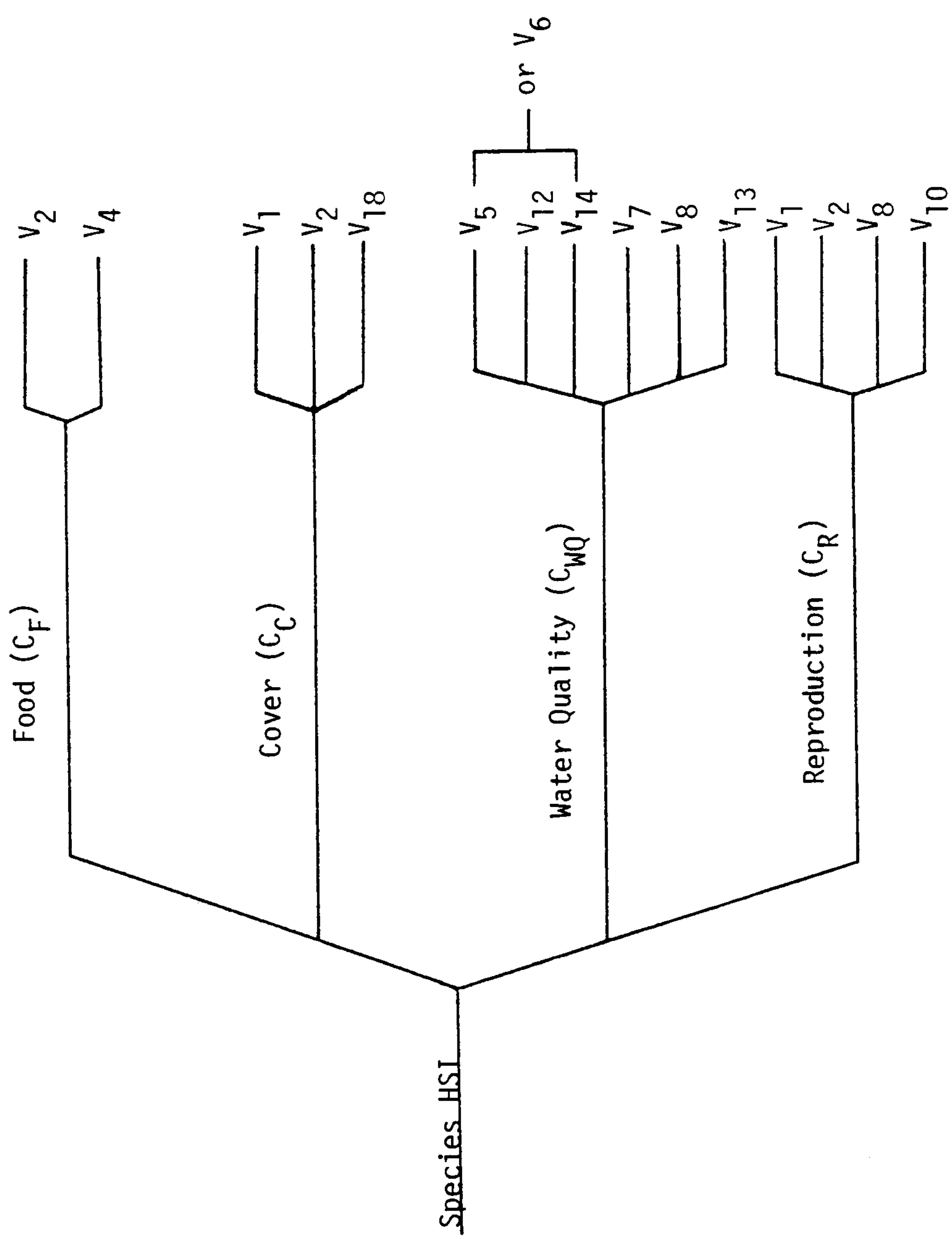


Figure D-3. Variables for each component of the riverine version of the channel catfish model.

Suitability index graphs are based on the assumption that the suitability of a variable can be represented by a two dimensional response surface that is independent of the values of other variables that contribute to overall habitat suitability. This is a critical assumption, because the impact of the variable on the measurable response from which the graphs are derived is often dependent on the value of other variables. For example, the effect of temperature on growth may vary depending on availability of food and the oxygen concentration. Interaction of variables in determining habitat suitability is represented by different aggregation techniques used to combine individual suitability indices. Thus, each graph represents habitat suitability for the variable independent of other variables unless otherwise noted. Weights were assigned to variables based on the opinion of the author (Tom McMahon, Western Energy and Land Use Team, Ft. Collins, Colorado). Sources of data, and assumptions made in drawing each graph are given in Table D-5.

(1) Food component. Percent cover (V_2) is assumed to be important in all habitats for rating the food component because if cover is available, fish would be more likely to occupy an area and utilize the food resources. Substrate (V_4) is included for riverine habitats because substrate type in streams and rivers has a great impact on production of aquatic insects which are consumed directly by both channel catfish and channel catfish prey species. Percent littoral area (V_3) is included because littoral areas generally produce the greatest amount of food for catfish. Total Dissolved Solids (TDS) (V_{16}) is in the food component because adult channel catfish eat fish and fish production is correlated to TDS. The component rating is derived by taking an arithmetic mean of the variable ratings because it was assumed that food produced from one source would be just as valuable as food produced from another source.

(2) Cover component. Percent pools (V_1) is included because channel catfish seek cover in deep water, and pools tend to be the deepest portions of riverine habitats. Percent cover (V_2) is an index of all types of objects, including logs and debris, used for cover in lakes and streams. Percent littoral area (V_3) is in the cover component because littoral areas tend to have vegetation that serves as cover, and the cover is especially important when it is near an area likely to produce food. Average current velocity in cover areas (V_{18}) is important since the useable habitat near a cover object decreases if cover objects are surrounded by high velocities.

Table D-5. Data sources and assumptions for channel catfish suitability indices.

	Variable and Source	Assumption
V_1	Bailey and Harrison 1948	Optimum diversity of velocities, depths, and structural features will be found when there are approximately equal amounts of pools and riffles.
V_2	Bailey and Harrison 1948 Marzolf 1957 Cross and Collins 1975	Cover seeking behavior indicates that some cover must be present to reach maximum carrying capacity.
V_3	Bailey and Harrison 1948 Marzolf 1957 Cross and Collins 1975	Food and cover adequate to support maximum population levels can be provided by less than 100% littoral area
V_4	Bailey and Harrison 1948	The substrate that produces the greatest number of insects is considered optimum.
V_5	Clemens and Sneed 1957 West 1966 Shrable et al. 1969 Starostka and Nelson 1974 Biesinger et al. 1979	Temperatures at the warmest time of year must reach levels that permit growth in order for habitat to be suitable. Optimum temperatures are those when maximum growth occurs.
V_6	Jenkins 1970 Jenkins and Morais 1971	Growing seasons that are correlated with high standing crops are optimum.
V_7	Finnell and Jenkins 1954 Buck 1956 Marzolf 1957	High turbidity levels are associated with reduced standing crops and therefore are less suitable.
V_8	Moss and Scott 1961 Andrews et al. 1973 Carlson et al. 1974 Randolph and Clemens 1976	Near-lethal levels of dissolved oxygen are unsuitable. D.O. levels that reduce feeding are suboptimal.

Table D-5. (continued)

Variable	Source	Assumption
V_9	Perry and Avault 1968 Perry 1973	Salinity levels where adults are most abundant are optimum. Any salinity level at which adults have been reported has some suitability.
V_{10}	Brown 1942 Clemens and Sneed 1957	Optimum temperatures are those which result in optimum growth. Temperatures that result in death or no growth are unsuitable.
V_{11}	Perry and Avault 1968 Perry 1973	Salinity levels at which spawning has been observed are suitable.
V_{12}	McCammon and LaFaunce 1961 Moss and Scott 1961 Macklin and Soule 1964 West 1966 Allen and Strawn 1968 Andrews 1972 Starostka and Nelson 1974	Optimum temperatures for fry are those when growth is best. Temperatures that result in no growth or death are unsuitable.
V_{13}	Allen and Avault 1970	Salinities that do not reduce growth of fry and juvenile are optimal, salinities that greatly reduce growth are unsuitable.
V_{14}	Andrews et al. 1972 Andrews and Stickney 1972	Temperatures at which growth of juveniles is best are optimal. Temperatures that result in no growth or death are unsuitable.
V_{15}	Jenkins 1976	Storage ratios correlated with maximum standing crops are optimum; those correlated with lower standing crops are suboptimum.

Table D-5. (continued)

Variable and Source		Assumption
V_{16}	Jenkins 1976	Total dissolved solids (TDS) levels correlated with high standing crops of warmwater fish are optimum; those correlated with lower standing crops are suboptimum. The data used to develop this graph are primarily from southeastern reservoirs.
V_{17}	Walburg 1971	Flushing rates correlated with reduced levels of fry abundance are suboptimal.
V_{18}	Miller 1966 Lantz 1970 Scott and Crossman 1973 Cross and Collins 1975	High average velocities near cover objects will decrease the amount of useable habitat around the objects. Even with high average current velocities, some habitat will be available because velocities immediately behind cover objects will be low.

It is assumed that the lowest individual variable rating in the cover component will be the most important. Some compensation should occur; therefore, a geometric mean is used to combine variable ratings.

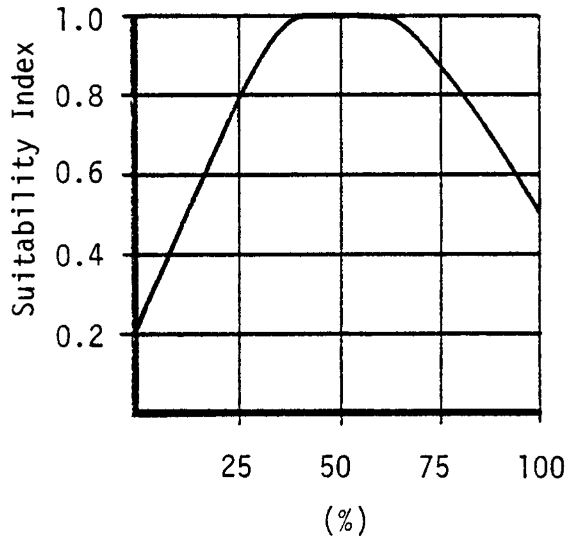
(3) Water quality component. The water quality component is limited to temperature, oxygen, turbidity, and salinity measurements. These parameters have been shown to effect growth or survival, or have been correlated with changes in standing crop, as documented in D.2. Variables related to temperature, oxygen, and salinity were assumed to be limiting when they reach near-lethal levels. Toxic substances are not considered in this model.

(4) Reproductive component. Percent pools during average summer flow (V_1) is in the reproductive component because channel catfish spawn in shallow flooded areas in rivers, and these types of areas are likely to occur if pools (i.e., wide low gradient areas) are present in the summer. Percent cover (V_2) is in the reproductive component since channel catfish use cover to spawn, and if cover objects are inundated during summer water levels, they also should be inundated in spring when the fish spawn. If average minimum dissolved oxygen (D.O.) levels within pools, backwaters, or littoral areas during midsummer (V_8) are adequate during midsummer, they should be adequate during spawning, which occurs earlier in the year. D.O. levels measured during spawning and embryo development could be substituted for V_8. Two additional variables, average water temperatures within pools, backwaters, and littoral areas during spawning and embryo development (V_{10}) and maximum salinity during spawning and embryo development (V_{11}) are selected that describe water quality conditions that effect embryo development.

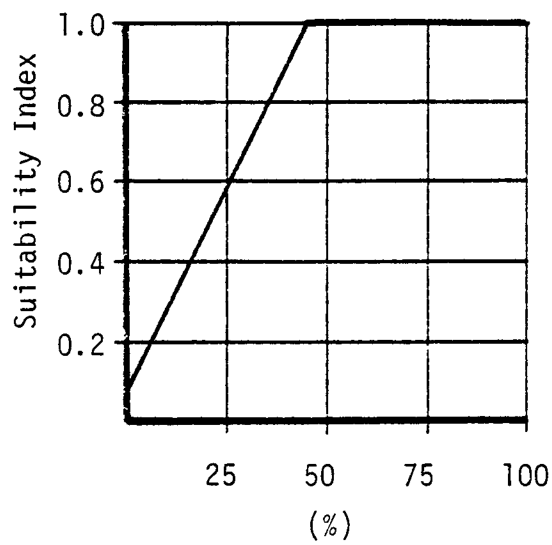
(5) Other component. For reservoirs, the variables storage ratio (V_{15}) and flushing rate when fry are present (V_{17}) were placed in the optional "other" component. Storage ratio may effect standing crop, and the flushing of fry out of a reservoir does not mean reproductive failure, only that the fry are removed from the reservoir.

C. Model relationships. This section contains suitability index graphs for the 18 variables described above, and equations for combining selected variables into a species HSI using the component approach.

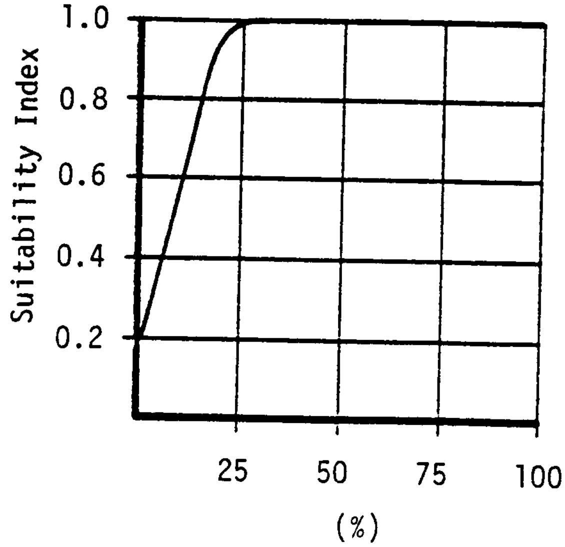
Habitat	Variable	
R	(V_1)	Percent pools during average summer flow.



R,L	(V_2)	Percent cover (logs, boulders, cavities, brush, debris, or standing timber) during summer within pools, backwater areas, and littoral areas.

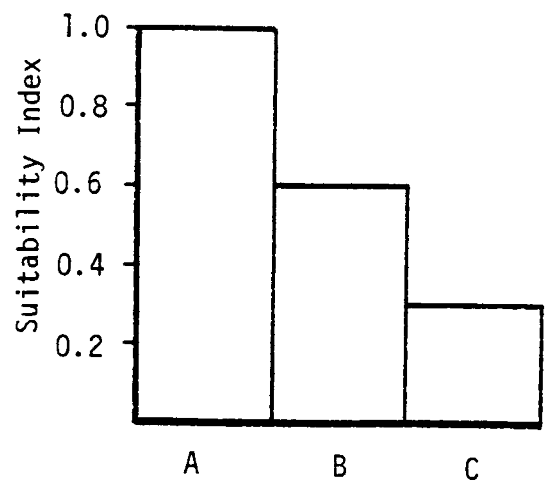


L (V_3) Percent littoral area during summer.

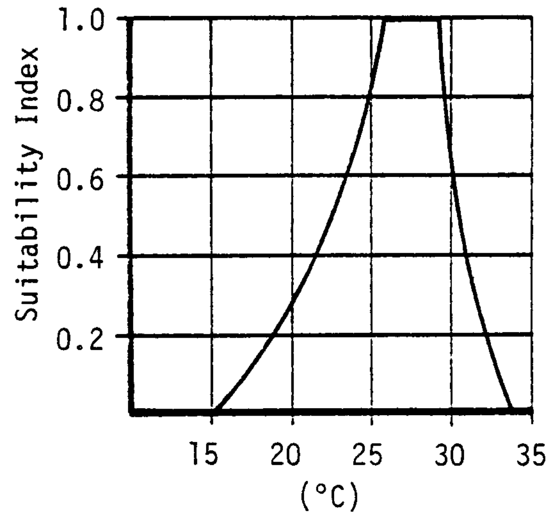


R (V_4) Dominant substrate type--for food production.

A) Rubble, or aquatic vegetation in spring areas, dominant with limited amounts of gravel and small boulders. Fines and bedrock are not common in riffle/run areas.
B) Rubble, gravel, boulders, and fines occur in approximately equal amounts. Aquatic vegetation may or may not be present.
C) Fines, bedrock, or boulders are dominant. Rubble and gravel are insignificant (≤ 10%).

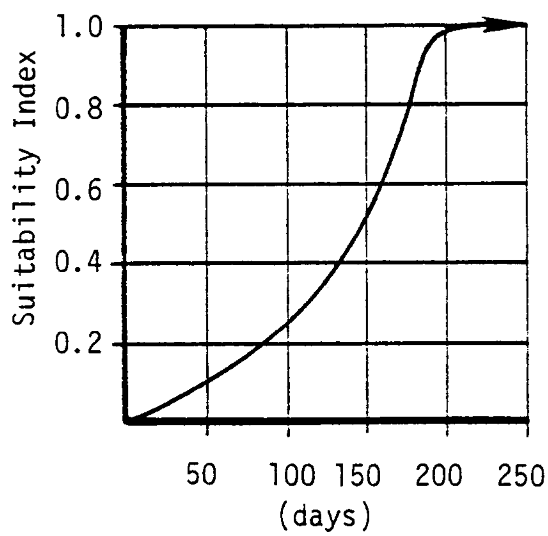


R,L (V_5) Average midsummer water temperature within pools, backwaters, or littoral areas (Adult).

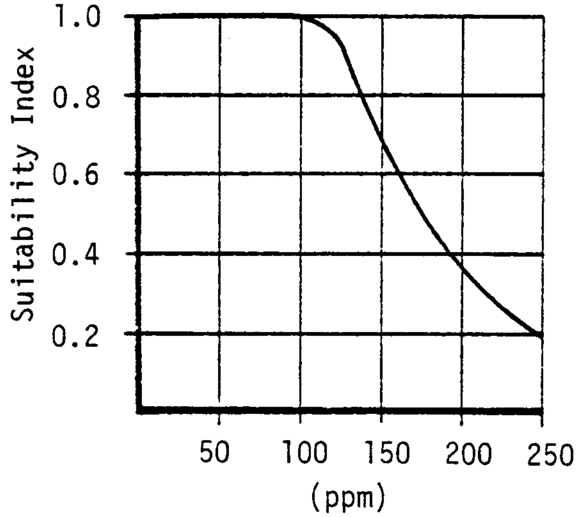


R,L (V_6) Length of agricultural growing season (frost-free days).

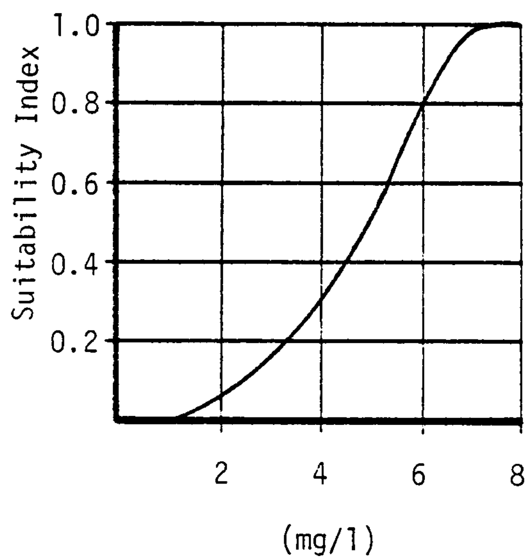
Note: This variable is optional--see Riverine model.



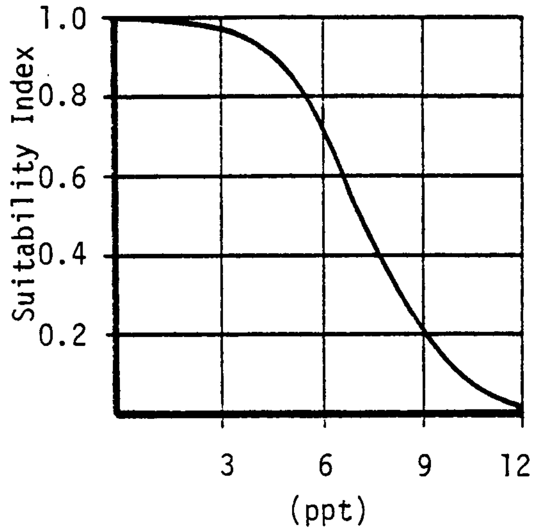
R,L (V_7) Maximum monthly average turbidity during summer.



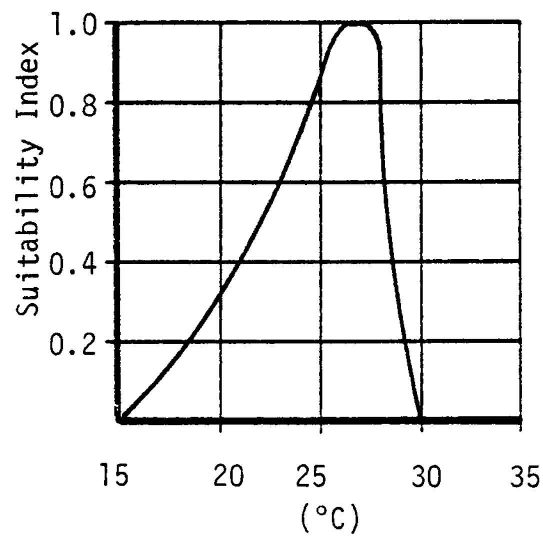
R,L (V_8) Average minimum dissolved oxygen levels within pools, backwaters, or littoral areas during midsummer.



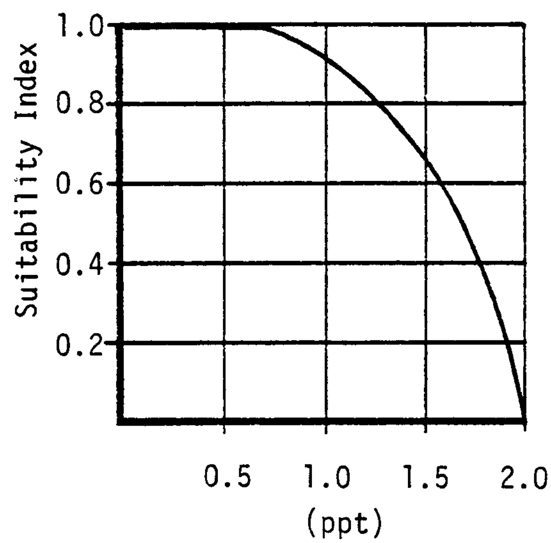
R,L (V_9) Maximum salinity during summer (Adult).



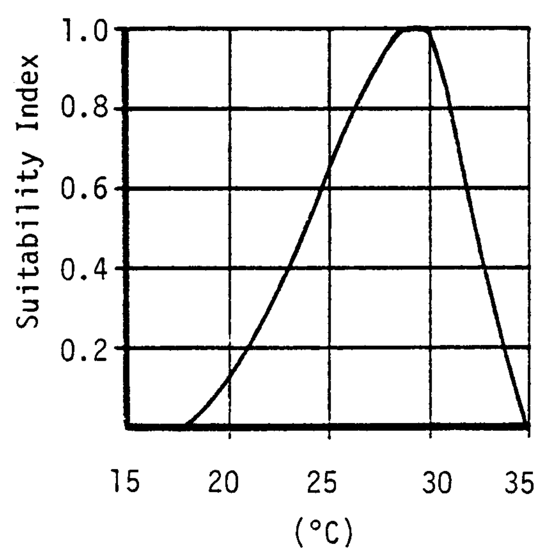
R,L (V_{10}) Average water temperatures within pools, backwaters, and littoral areas during spawning and embryo development (Embryo).



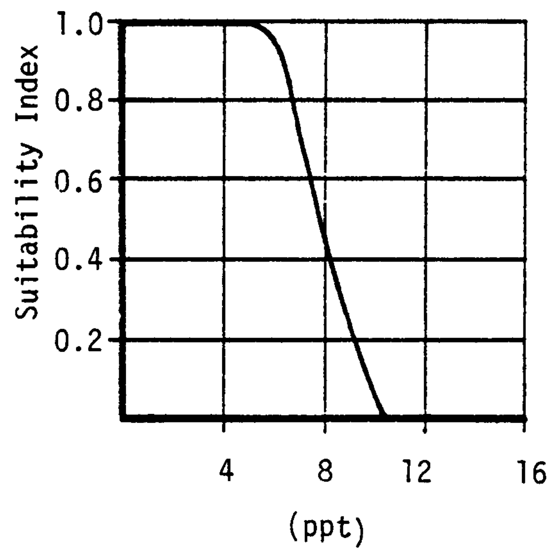
R,L (V_{11}) Maximum salinity during spawning and embryo development.



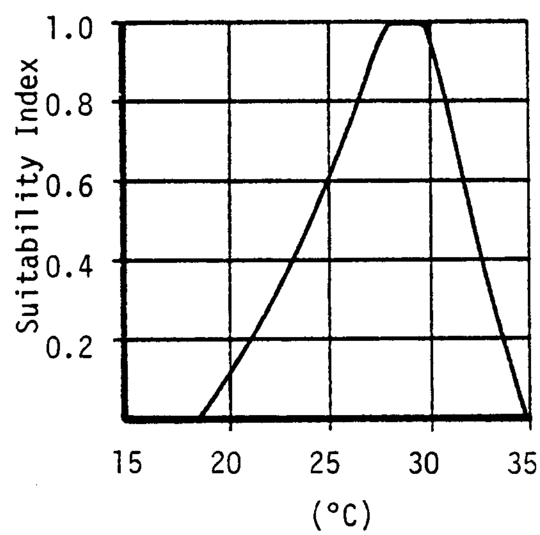
R,L (V_{12}) Average midsummer water temperature within pools, backwaters, or littoral areas. (Fry)



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).



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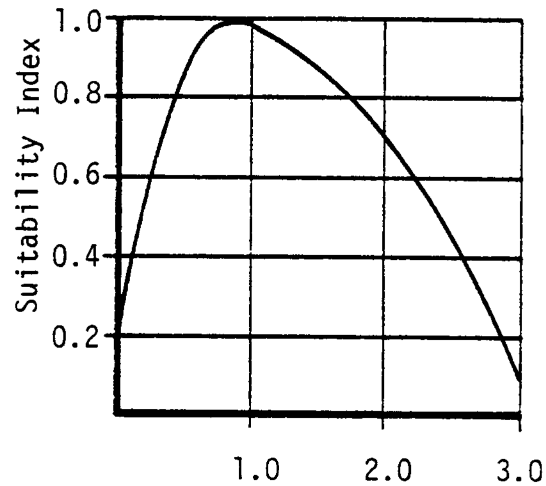
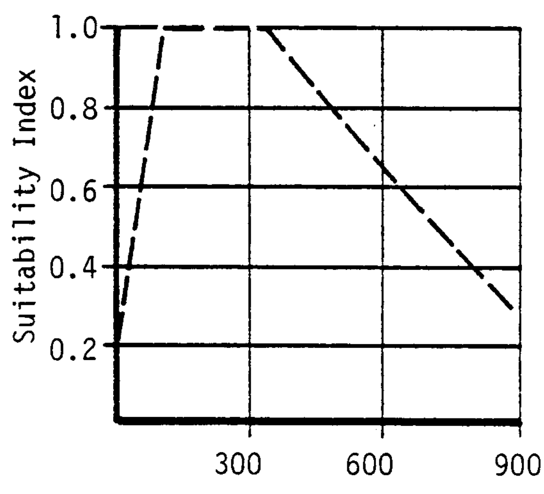
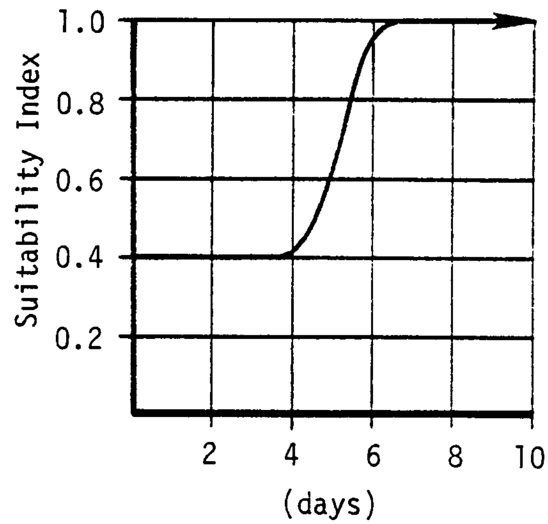
L (V_{15}) Storage ratio.



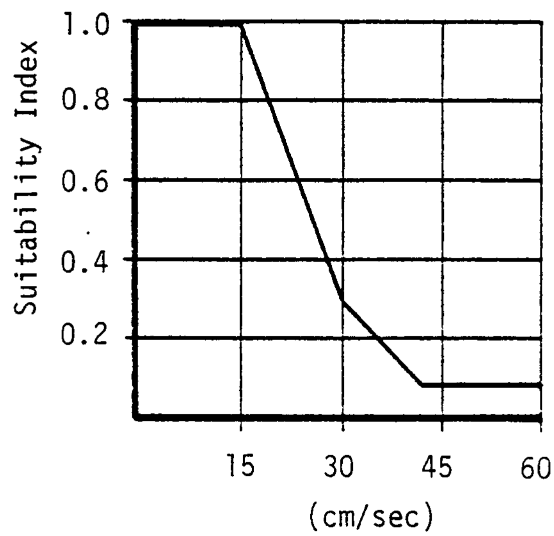
L (V_{16}) Monthly average TDS (total dissolved solids) during summer.



L (V_{17}) Reservoir flushing rate while fry present.



R (V_{18}) Average current velocity in cover areas during average summer flow.



D.4 Riverine habitat suitability index equation

A. This equation utilizes the life requisite approach and consists of four components: Food, Cover, Water Quality, and Reproduction.

(1) Food (C_F)

$$C_F = \frac{V_2 + V_4}{2}$$

(2) Cover (C_C)

$$C_C = (V_1 \times V_2 \times V_{18})^{1/3}$$

(3) Water Quality (C_{WQ})

If V_9 and V_{13} both have 1.0 ratings,

$$C_{WQ} = \frac{\dfrac{2(V_5 + V_{12} + V_{14})}{3} + V_7 + 2(V_8)}{5}, \text{ or}$$

If V_9 and V_{13} have < 1.0 ratings, then

$$C_{WQ} = \frac{\dfrac{2(V_5 + V_{12} + V_{14})}{3} + V_7 + 2(V_8) + V_9 + V_{13}}{7}$$

Also, for both equations, if V_5, V_6, V_{12}, V_{14}, or V_8 is ≤ 0.4, then C_{WQ} equals the lowest of the following: V_5, V_6, V_{12}, V_{14}, V_8, or the above equations.

Note: If temperature data are unavailable, V_6 (length of agricultural growing season) may be substituted for the term

$$\frac{(V_5 + V_{12} + V_{14})}{3} \text{ in the above equation}$$

(4) Reproduction (C_R)

If V_{11} rating is 1.0, then

$$C_R = (V_1 \times V_2^2 \times V_8^2 \times V_{10}^2)^{1/7}$$

If V_{11} rating is < 1.0, then

$$C_R = (V_1 \times V_2^2 \times V_8^2 \times V_{10}^2 \times V_{11})^{1/8}$$

(5) HSI determination

$$HSI = (C_F \times C_C \times C_{WQ}^2 \times C_R^2)^{1/6}, \text{ or}$$

If C_{WQ} or C_R is ≤ 0.4, then the HSI equals the lowest of the following: C_{WQ}, C_R, or the above equation.

B. Lacustrine habitat suitability index equation. This equation utilizes the life requisite approach and consists of five components: Food, Cover, Water Quality, Reproduction, and Other.

(1) Food (C_F)

$$C_F = \frac{V_2 + V_3 + V_{16}}{3}$$

(2) Cover (C_C)

$$C_C = (V_2 \times V_3)^{1/2}$$

(3) Water Quality (C_{WQ})

C_{WQ} = same as in Riverine HSI Model

(4) Reproduction (C_R)

If V_{11} rating is 1.0,

$$C_R = (V_2^2 \times V_3 \times V_8^2 \times V_{10}^2)^{1/7}$$

If V_{11} rating is < 1.0, then

$$C_R = (V_2^2 \times V_3 \times V_8^2 \times V_{10}^2 \times V_{11})^{1/8}$$

(5) Other (C_{OT})

$$C_{OT} = \frac{V_{15} + V_{17}}{2}$$

(6) HSI determination

$$HSI = (C_F \times C_C \times C_{WQ}^2 \times C_R^2 \times C_{OT})^{1/7}, \text{ or}$$

If C_{WQ} or C_R is ≤ 0.4, then the HSI equals the lowest of the following: C_{WQ}, C_R, or the above equation.

D.5 Application of the model

A. Step 1: Select the appropriate model for either riverine or lacustrine-palustrine environments.

B. Step 2: Determine if the model is appropriate to the problem. The model must be sensitive to proposed changes if used for impact assessment, and variable values under future conditions must be predictable. The model is a habitat model, not a population model, and if it is necessary to predict population levels at any point in time a different model may be more appropriate.

C. Step 3: Determine which variables to use in the model. For example, if the average summer temperatures (variables V_5, V_{12}, and V_{14}) cannot be estimated within time and budget constraints, the length of growing season (variable V_6) may be substituted.

D. Step 4: Estimate each variable in the study area based upon the descriptors included in the variable description. Model variables based on parameters that are expected to have spatial variability (e.g. V_{15}, average current velocity during average summer flow), should be calculated from measurements taken along transects. Stream measurements should be taken within a representative reach. Lacustrine-palustrine measurements associated with the shore should be taken within a shore area that is representative of the entire water body. When shore areas are heterogeneous, different sampling strata should be identified. Each variable in the model may be estimated by normally accepted field procedures, data from similar water bodies, or estimates based on experience or visual inspection. The method used to obtain the variable estimate must be recorded. Otherwise, it is impossible to determine if accurate or inaccurate HSI values are due to factors intrinsic or extrinsic to the model.

D.6 Interpreting model output. Habitats with an HSI of 0 may contain some channel catfish; habitats with a high HSI may contain few. If the model is a good representation of channel catfish habitat, then in water bodies where channel catfish population levels are due primarily to habitat related factors, the model should be correlated to long-term, average population levels. However, this has not been tested. The proper interpretation of the HSI produced by the model is one of comparison. If two water bodies have different HSI's then the one with the higher HSI should be able to support more catfish than the water body with the lower HSI, given that model assumptions have not been violated.

The HSI is based on how well the sampled area meets all of the requirements of a channel catfish for completing its life cycle. The channel catfish HSI determined by use of this model will not necessarily represent the population of channel catfish present in the sample area. This is because the population of a sample area of a stream or lake does not depend on the ability of that area to meet all life requisite requirements of the species, as is assumed by the model.

D.7 Additional habitat suitability index models. The regression equations for catfishes (Ictaluridae) standing crop developed by Aggus and Morais (1979) may be used to calculate an HSI.

D.8 References cited

Aggus, L. R., and D. I. Morais. 1979. Habitat suitability index equations for reservoirs based on standing crop of fish. Natl. Reservoir Res. Program. Rept. to U.S. Fish Wildl. Serv., Habitat Eval. Proj., Ft. Collins. 120 pp.

Allen, K. O., and J. W. Avault. 1970. The effect of salinity on growth of channel catfish. Proc. Annu. Conf. Southeast. Assoc. Game Fish Comm. 23:319-331.

Allen, K. O., and K. Strawn. 1968. Heat tolerance of channel catfish, *Ictalurus punctatus*. Proc. Annu. Conf. Southeast. Assoc. Game Fish Comm. 21:399-411.

Andrews, J. W., L. H. Knight, and T. Murai. 1972. Temperature requirements for high density rearing of channel catfish from fingerlings to market size. Prog. Fish-Cult. 34:240-242.

Andrews, J. W., T. Murai, and G. Gibbons. 1973. The influence of dissolved oxygen on the growth of channel catfish. Trans. Am. Fish. Soc. 102(4):835-838.

Andrews, J. W., and R. R. Stickney. 1972. Interactions of feeding rates and environmental temperature on growth, food conversion and body composition of channel catfish. Trans. Am. Fish. Soc. 101(1):94-99.

Bailey, R. M., and H. M. Harrison, Jr. 1948. Food habits of the southern channel catfish (*Ictalurus lacustris punctatus*) in the Des Moines River, Iowa. Trans. Am. Fish. Soc. 75:110-138.

Biesinger, K. E., R. B. Brown, C. R. Bernick, G. A. Flittner, and K. E. F. Hokanson. 1979. A national compendium of freshwater fish and water temperature data. Vol. I. U.S. Environ. Protection Agency Rep. Environ. Res. Lab., Duluth, Minn. 207 pp.

Brown, B. E., I. Inman, and A. Jearld, Jr. 1970. Schooling and shelter seeking tendencies in fingerling catfish behavior. Trans. Am. Fish. Soc. 99(3):540-545.

Brown, L. 1942. Propagation of the spotted channel catfish (*Ictalurus lacustris punctatus*). Trans. Kansas Acad. Sci. 45:311-314.

Bryan, C. F., F. M. Truesdale, and D. S. Sabins. 1975. A limnological survey of the Atchafalaya Basin, annual report. Louisiana Coop. Fish. Res. Unit, Baton Rouge. 203 pp.

Buck, H. D. 1956. Effects of turbidity on fish and fishing. Trans. N. Am. Wildl. Conf. 21:249-261.

Carlander, K. C. 1969. Channel catfish. pp. 538-554 *In* Handbook of freshwater fishes of the United States and Canada, exclusive of the Perciformes. Iowa State Univ. Press, Ames. 752 pp.

Carlson, A. R., R. E. Siefert, and L. J. Herman. 1974. Effects of lowered dissolved oxygen concentrations on channel catfish (*Ictalurus punctatus*) embryos and larvae. Trans. Am. Fish. Soc. 103(3):623-626.

Chen, T. H. 1976. Cage culture of channel catfish in a heated effluent from a power plant, Thomas Hill reservoir. Ph.D. Dissertation, Univ. Missouri, Columbia. 98 pp.

Clemens, H. P., and K. E. Sneed. 1957. Spawning behavior of channel catfish, *Ictalurus punctatus*. U.S. Fish Wildl. Serv. Spec. Sci. Rep. Fish. 219. 11 pp.

Cowardin, L. M., V. Carter, F. C. Golet, and E. T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. USDI Fish and Wildlife Service, FWS/OBS-79/31. 103 pp.

Cross, F. B., and J. T. Collins. 1975. Fishes in Kansas. Univ. Kansas Mus. Nat. Hist. Publ. Educ. Ser. 3. 180 pp.

Davis, J. 1959. Management of channel catfish in Kansas. Univ. Kansas Mus. Nat. Hist. Misc. Publ. 21. 56 pp.

Davis, J. T., and L. E. Posey, Jr. 1958. Length at maturity of channel catfish (Ictalurus lacustris) in Louisiana. Proc. Southeastern Assoc. Game and Fish. Commissioners 21:72-74.

Finnell, J. C., and R. M. Jenkins. 1954. Growth of channel catfish in Oklahoma waters: 1954 revision. Oklahoma Fish. Res. Lab., Rept. 41. 37 pp.

Hanson, W. D., and R. S. Campbell. 1963. The effects of pool size and beaver ativity on distribution and abundance of warmwater fishes in a North Missouri stream. Am. Midl. Nat. 69(1):136-149.

Harrison, H. M. 1953. Returns from tagged channel catfish in the Des Moines River, Iowa. Proc. Iowa Acad. Sci. 60:636-644.

Jenkins, R. M. 1970. The influence of engineering design and operation and other environmental factors on reservoir fishery resources. Water Res. Bull. 6(1):110-119.

Jenkins, R. M. 1974. Reservoir management prognosis: migraines or miracles. Proc. Annu. Conf. Southeast. Assoc. Game Fish Comm. 27:374-385.

Jenkins, R. M. 1976. Prediction of fish production in Oklahoma reservoirs on the basis of environmental variables. Ann. Oklahoma Acad. Sci. 5:11-20.

Jenkins, R. M., and D. I. Morais. 1971. Reservoir sport fishing effort and harvest in relation to environmental variables. pp. 371-384 In G. E. Hall (ed.), Reservoir fisheries and limnology. Am. Fish. Soc. Spec. Publ. 8.

Jester, D. B. 1971. Effects of commercial fishing, species introductions, drawdown control on fish populations in Elephant Butte Reservoir, New Mexico. Pages 265-285 in G. E. Hall, ed. Reservoir fisheries and limnology. Am. Fish. Soc. Spec. Publ. 8.

Lantz, K. 1970. An ecological survey of factors affecting fish production in a Louisiana natural lake and river. Louisiana Wildl. Fish. Comm., Fish. Bull. 6. 92 pp.

LaRivers, I. 1962. Fish and fisheries of Nevada. Nevada State Fish Game Comm. Carson City. 781 pp.

Lawler, R. E. 1960. Investigations of the channel catfish of Utah Lake. Utah Dept. Fish Game. Inf. Bull. 60-8. 69 pp.

Macklin, R., and S. Soule. 1964. Feasibility of establishing a warmwater fish hatchery. Calif. Fish Game, Inland Fish. Admin. Rept. 64-14. 13 pp.

Marzolf, R. C. 1957. The reproduction of channel catfish in Missouri ponds. J. Wildl. Manage. 21(1):22-28.

McCall, T. C. 1977. Movement of channel catfish, Ictalurus punctatus, in Cholla Lake, Arizona, as determined by ultrasonic tracking. West. Assoc. Game Fish. Comm. 57:359-366.

McCammon, G. W. 1956. A tagging experiment with channel catfish (Ictalurus punctatus) in the lower Colorado River. Calif. Fish Game 42(4):323-335.

McCammon, G. W., and D. A. LaFaunce. 1961. Mortality rates and movement in the channel catfish population of the Sacramento Valley. Calif. Fish Game 47(1):5-26.

Miller, E. E. 1966. Channel catfish. pp. 440-463 In A. Calhoun (ed.), Inland fisheries management. Calif. Fish Game Res. Agency, Sacramento. 546 pp.

Minckley, W. L. 1973. Fishes of Arizona. Arizona Fish Game Publ., Phoenix. 293 pp.

Moore, G. A. 1968. Vertebrates of the United States. McGraw-Hill, New York.

Moss, D. D., and D. C. Scott. 1961. Dissolved oxygen requirements of three species of fish. Trans. Am. Fish. Soc. 90(4):377-393.

Perry, W. G. 1973. Notes on the spawning of blue and channel catfish in brackish water ponds. Prog. Fish-Cult. 35(3):164-166.

Perry, W. G., and J. W. Avault. 1968. Preliminary experiments on the culture of blue, channel, and white catfish in brackish water ponds. Proc. Annu. Conf. Southeast. Assoc. Game Fish Comm. 22:396-406.

Pflieger, W. L. 1971. A distributional study of Missouri fishes. Univ. Kansas Mus. Nat. Hist. Publ. 20(3):225-570.

Pflieger, W. L. 1975. Fishes of Missouri. Missouri Dept. Conserv. Publ., Columbia. 343 pp.

Randolph, K. N., and H. P. Clemens. 1976. Some factors influencing the feeding behavior of channel catfish in culture ponds. Trans. Am. Fish. Soc. 105(6):718-724.

Regier, H. A. 1963. Ecology and management of channel catfish in farm ponds in New York. J. N.Y. Fish Game 10(2):170-185.

Ryder, R. A. 1965. A method for estimating the potential fish production of north-temperate lakes. Trans. Am. Fish. Soc. 94(3):214-218.

Ryder, R. A., S. R. Kerr, K. H. Loftus, and H. A. Regier. 1974. The morphoedaphic index, a fish yield estimator - review and evaluation. J. Fish. Res. Board Can. 31(5):663-688.

Scott, W. B., and E. J. Crossman. 1973. Freshwater fishes of Canada. Fish. Res. Board Can. Bull. 184. 966 pp.

Shrable, J. B., O. W. Tiemeier, and C. W. Deyoe. 1969. Effects of temperature on rate of digestion by channel catfish. Prog. Fish-Cult. 31(3):131-138.

Sigler, W. F., and R. R. Miller. 1963. Fishes of Utah. Utah Fish Game, Salt Lake City. 203 pp.

Simco, D. A., and F. B. Cross. 1966. Factors affecting growth and production of channel catfish, Ictalurus punctatus. Univ. Kansas Mus. Nat. Hist. Publ. 17(4):191-256.

Starostka, V. J., and W. R. Nelson. 1974. Channel catfish in Lake Oahe. U.S. Fish Wildl. Serv. Tech. Pap. 81. 13 pp.

Stauffer, J. R., Jr., K. L. Dickson, J. Cairns, Jr., W. F. Calhoun, M. T. Masnik, and R. H. Myers. 1975. Summer distribution of fish species in the vicinity of a thermal discharge, New River, Virginia. Arch. Hydrobiol. 76(3):287-301.

Trautman, M. B. 1957. Fishes of Ohio. Ohio State Univ. Press. 683 pp.

Walburg, C. H. 1971. Loss of young fish in reservoir discharge and year-class survival, Lewis and Clark Lake, Missouri River. pp. 441-448 In G. E. Hall (ed.), Reservoir fisheries and limnology. Am. Fish. Soc. Spec. Publ. 8.

Walburg, C. H. 1975. Food of young-of-year channel catfish in Lewis and Clark Lake, a Missouri River reservoir. Am. Midl. Nat. 93(1):218-221.

Walden, H. T. 1964. Familiar freshwater fishes of America. Harper and Row, New York. 324 pp.

West, B. W. 1966. Growth, food conversion, food consumption and survival at various temperatures of the channel catfish, *Ictalurus punctatus* (Rafinesque). M.S. Thesis. Univ. Arkansas, Fayetteville.

Ziebell, C. 1973. Ultrasonic transmitters for tracking channel catfish. Prog. Fish-Cult. 35(1):28-32.

Appendix E. Cover Types for Model Building

E.1 Introduction. This appendix contains a cover type classification system intended to provide an ecological stratification to assist in the development of habitat suitability models. We have found by experience that it is necessary to subdivide habitats into general cover types within which fish and wildlife species respond in ways that can be readily modeled. (For a discussion of cover type mapping for applying the models, see section E.2 below.)

Because of the narrow objective of this classification system, differences exist between it and the general-purpose classifications (e.g., Cowardin et al. 1979 and Bailey 1976). This does not imply that the general purpose classifications are obsolete or unnecessary. However, the constraints on a classification for model building are not adequately met by any other classification available. Constraints include: 1) exhaustiveness - all types of cover must be considered; 2) mutual exclusiveness - no site should be included in more than one category (at a given level in the hierarchy); 3) recognizability - one should be able to determine the type of site from the information typically included in research reports on fish or wildlife-habitat relationships; 4) currentness - the classification must refer to existing conditions, not the future or potential of a site; 5) simplicity - no more types should be recognized than absolutely necessary; and 6) relevance - breaks between types must correspond to the factors related directly or indirectly to the essentials driving fish or wildlife-habitat relationships.

The wetlands and deepwater habitats portion of this classification was adapted directly from Cowardin et al. (1979), to facilitate application of National Wetland Inventory maps and data bases. For model development purposes, the "class" level described by Cowardin et al. (1979) is most appropriate for wildlife, whereas the "system" level is usually better for fish. Certain classes have been combined to minimize the number of types while retaining a high degree of relevance to habitat model development.

E.2 Cover type mapping. During a HEP application, project areas should be mapped using a surface cover type classification tailored to the area. The cover types described in this appendix may not provide the resolution required by some studies. If existing maps are available, such as National Wetland Inventory maps, they should be used if possible. In any case, habitat models developed around the broad cover types in this appendix should easily cross reference to other mapping categories. For example, one may construct a habitat model for deciduous forest and apply

the model to a study area that has been mapped with oak-hickory, beech-maple, and cottonwood-willow cover types. In this case the model should be equally applicable to the three deciduous forest types. However, the HSI derived with the model may differ between the three forest types depending on the biological relationships included in the model.

E.3 Cover types

A. Introduction. The Cover Type Classification (Table E-1) contains two major categories: 1) Uplands; and 2) Wetlands and Deepwater Habitats. These are subdivided into 30 types, using four levels of resolution.

Several terms used in this classification system are defined below. A particular group of plants (such as the tree stratum or layer, or the grasses) is said to be "dominant" if its canopy cover is greater than that of any other group (excluding plants that are directly underneath other plants). "Evergreen" types are those in which at least 50% of the total canopy cover of the dominant stratum (layer) consists of species that retain green foliage throughout the year. "Deciduous" types are those in which at least 50% of the total canopy cover of the dominant stratum (layer) consists of species that completely shed their foliage during part of the year. All tree-dominated and shrub-dominated types may be classified as either evergreen or deciduous. "Wetlands are lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water. ...wetlands must have one or more of the following three attributes: (1) at least periodically, the land supports predominantly hydrophytes; (2) the substrate is predominantly undrained hydric soil; and (3) the substrate is nonsoil and is saturated with water or covered by shallow water at some time during the growing season of each year" (Cowardin et al. 1979, p. 3). "Emergents" are "erect, rooted, herbaceous angiosperms that may be temporarily to permanently flooded at the base but do not tolerate prolonged inundation of the entire plant; e.g., bulrushes (*Scirpus* spp.), saltmarsh cordgrass" (Cowardin *et al*. 1979, p. 42). "Farmed" wetlands have had the soil surface "... mechanically or physically altered for the production of crops ..." (Cowardin *et al*., p. 26) but the water regime is still that of a wetland.

In using this classification, note that anything in the definition of a primary division refers as well to all its subdivisions. Consider both, since the definitions of subdivisions do not repeat redundant material from the primary divisions.

Appendix E. Cover Types for Model Building

Table E-1. Summary of the cover type classification system for model building.

UPLANDS (Nonwetlands)
- Agricultural and Built-up Land
  - Orchard
  - Vineyard
  - Cropland
  - Pasture and Hayland
  - Mining Area
  - Urban and Built-up Land
- Undeveloped Uplands
  - Forest
    - Evergreen Forest
    - Deciduous Forest
  - Tree Savanna
    - Evergreen Tree Savanna
    - Deciduous Tree Savanna
  - Shrubland
    - Evergreen Shrubland
    - Deciduous Shrubland
  - Shrub Savanna
    - Evergreen Shrub Savanna
    - Deciduous Shrub Savanna
  - Grassland
  - Forbland
  - Desertic Woodland
  - Desertic Shrubland
  - Desertic Herbland
  - Barren Lands

WETLANDS AND DEEPWATER HABITATS
- Wetlands
  - Forested Wetland
    - Evergreen Forested Wetland
    - Deciduous Forested Wetland
  - Scrub-Shrub Wetland
    - Evergreen Scrub-Shrub Wetland
    - Deciduous Scrub-Shrub Wetland
  - Herbaceous Wetland
  - Shore, Bottom Wetland
- Deepwater Habitats
  - Riverine
  - Lacustrine
  - Estuarine
  - Marine

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B. UPLANDS (Nonwetlands). Uplands are not periodically flooded with water, and have a water table that is rarely at or near the surface. They are not dominated by hydrophytes, the soils are not hydric (or if they are hydric soils, they have been drained).

(1) Agricultural and Built-up Land. Types within this division refer to lands that are periodically plowed and planted, or mowed for hay at least once per year, or support buildings or other man made structures.

a. Orchard. The Orchard type has trees planted and cultivated for the production of fruit or nut crops.

b. Vineyard. The Vineyard type has vines or shrubs planted and cultivated for the production of fruit crops.

c. Cropland. The Cropland type is utilized for the growth of agricultural crops that are planted and harvested annually, excluding pasture and hayland.

d. Pasture and Hayland. The Pasture and Hayland type is dominated by perennial grasses or forbs (usually legumes), native or introduced, that are mowed at least once per year or periodically plowed and planted primarily for livestock grazing. These areas are usually dominated by one or a few species of grasses or legumes. This type excludes native rangeland.

e. Mining Area. The Mining Area type is currently being mined for extraction of natural resources or recently abandoned. Reclaimed areas may be classified as other cover types depending on the extent and success of reclamation efforts.

f. Urban and Built-up Land. The Urban and Built-up Land type "... is comprised of areas of intensive use with much of the land covered by structures." (Anderson et al. 1976, p. 10)

(2) Undeveloped Uplands. Types within this division refer to non-wetlands that are not converted to agriculture or built-up land.

a. Forest. The Forest type is dominated by trees (taller than 5 m), and have a tree canopy cover of at least 25%.

b. Tree Savanna. The Tree Savanna type has a canopy cover of trees (taller than 5 m) between 5% and 25%, but has a total canopy cover of all vegetation of at least 25%. The area between trees is typically dominated by grasses or other herbaceous vegetation.

c. Shrubland. The Shrubland type is dominated by shrubs (including small trees shorter than 5 m), and has a shrub canopy cover of at least 25%.

d. Shrub Savanna. The Shrub Savanna type has a canopy cover of shrubs (including small trees shorter than 5 m) between 5% and 25%, but has a total canopy cover of all vegetation of at least 25%. The area between shrubs is typically dominated by grasses or other herbaceous vegetation.

e. Grassland. The Grassland type has a canopy cover of all vegetation of at least 25%, and is dominated by nonwoody plants (including bryoids, e.g. lichens and mosses), of which grasses, native or introduced, are dominant. This type includes most prairies, range, and upland subalpine mountain meadows.

f. Forbland. The Forbland type has a canopy cover of all vegetation of at least 25%, and is dominated by nonwoody plants (including bryoids, e.g. lichens and mosses), of which species other than grasses are dominant. This cover type includes many weedy fields, old fields, and other types in early successional stages.

g. Desertic Woodland. The Desertic Woodland type has 1-25% total vegetation cover, with trees (taller than 5 m) forming the dominant vegetation stratum. It includes sparsely vegetated types in non-desert areas.

h. Desertic Shrubland. The Desertic Shrubland type has 1-25% total vegetation cover with shrubs (and small trees shorter than 5 m) forming the dominant vegetation stratum. It includes sparsely vegetated types in non-desert areas.

i. Desertic Herbland. The Desertic Herbland type has 1-25% total vegetation cover with nonwoody plants (including bryoids and lichens) forming the dominant vegetation stratum. It includes sparsely vegetated types in non-desert areas. Identification of Desertic Herbland in

desert areas should be based on average conditions, rather than on conditions during peak growth of short-lived plants, when total cover may exceed 25%.

j. Barren Land. The Barren Land type has less than 1% total vegetation cover. It includes sand dunes, rock outcrops, snow fields, etc.

C. WETLANDS AND DEEPWATER HABITATS. Types within this division refer to wetlands (see section A above), or areas where "... surface water is permanent and often deep, so that water, rather than air, is the principal medium within which the dominant organisms live ..." (Cowardin *et al*. 1979, p. 3).

Modifiers exist which can be used to subdivide types more finely where that is desirable for modeling a particular species. Cowardin *et al*. 1979 (pp. 23-26) includes 12 modifiers for water regime (including "Artificially Flooded"), 10 modifiers for water chemistry (covering salinity and pH), two modifers for soil ("Mineral" and "Organic") and six "special modifiers" ("Excavated", "Impounded", "Diked", "Partly Drained", "Farmed", and "Artificial"). This classification includes additional modifiers for Deepwater Habitats (size and water temperature, see Table E-2).

(1) Wetlands. The definition of the boundary between wetland and upland is contained in section E.1. The boundary between wetland and deepwater habitats "... in the Marine and Estuarine systems coincides with the elevation of the extreme low water of spring tide; permanently flooded areas are considered deepwater habitats in these systems. The boundary between wetland and deepwater habitats in the Riverine, Lacustrine, and Palustrine systems lies at a depth of 2 m (6.6 feet) below low water; however, if emergents, shrubs or trees grow beyond this depth at any time, their deepwater edge is the boundary." (Cowardin *et al*., p. 4).

a. Forested Wetland. The Forested Wetland type is dominated by woody vegetation that is 6 m (20 feet) tall or taller It has a total vegetation cover greater than 30%.

b. Scrub-Shrub Wetland. The Scrub-Shrub Wetland type is dominated by woody vegetation less than 6 m (20 feet) tall. It has a total vegetation cover greater than 30%.

Table E-2. Modifiers for Deepwater Habitats.

Temperature (maximum)	
cold	(< 20° C)
cool	(20-28° C)
warm	(> 28° C)
Size (Riverine)	
small	(≤ 5 m mean width, or stream order 1-3)
medium	(5-30 m mean width, or stream order 2-5)
large	(> 30 m mean width, or stream order ≥ 6)
Size (Lacustrine)	
small	(< 100 ha in area)
medium	(100-200 ha in area)
large	(> 200 ha in area)

c. Herbaceous Wetland. The Herbaceous Wetland type is dominated "... by erect, rooted, herbaceous hydrophytes ...", including "... areas where mosses or lichens cover substrates other than rock ..." (Cowardin *et al*. 1979, p. 21) and "... plants that grow principally on or below the surface of the water for most growing seasons in most years." (Cowardin *et al*., p. 16) It has a total vegetation cover (excluding "... pioneer species that briefly invade wetlands when conditions are favorable ...") (Cowardin *et al*. 1979, p. 13) of greater than 30%. Note, this includes the "Emergent Wetland" and "Moss-Lichen Wetland" classes, and the "Aquatic Bed" class (when it occurs in wetland) of Cowardin *et al*. 1979.

d. Shore and Bottom Wetland. The Shore and Bottom Wetland type includes the following of Cowardin *et al*. (1979): "Unconsolidated Shore"; "Rocky Shore"; and "Streambed" in total; plus Unconsolidated Bottom, Rock Bottom and Reef classes when they occur in wetland. For practical purposes, this can be taken as characterized by wetland having less than 30% cover by vegetation (excluding "pioneers", see "Herbaceous Wetland" above).

(2) Deepwater Habitats. The Deepwater Habitats type includes the following classes of Cowardin *et al*. (1979): "Reef"; "Aquatic Bed"; "Unconsolidated Bottom"; and "Rock Bottom" when they occur in Deepwater Habitats (see "(1) Wetlands", above). For practical purposes, this can be taken as deepwater having a total cover of less than 30% of emergents, trees, and shrubs.

a. Riverine. "The Riverine [cover type] includes all wetlands and deepwater habitats contained within a channel, with two exceptions: (1) wetlands dominated by trees, shrubs, persistent emergents, emergent mosses, or lichens, and (2) habitats with water containing ocean-derived salts in excess of 0.5 [parts per thousand]. A channel is 'an open conduit either naturally or artificially created which periodically or continuously contains moving water, or which forms a connecting link between two bodies of standing water' (Langbein and Iseri 1960:5).

"[It] is bounded on the landward side by upland, by the channel bank (including natural and man-made levees), or by wetland dominated by trees, shrubs, persistent emergents, emergent mosses, or lichens. In braided streams, the system is bounded by the banks forming the outer limits of the depression within which the braiding occurs.

"The Riverine [cover type] terminates at the downstream end where the concentration of ocean-derived salts in the water exceeds 0.5 [parts per thousand] during the period of annual average low flow, or where the channel enters a lake. It terminates at the upstream end where tributary streams originate, or where the channel leaves a lake. Springs discharging into a channel are considered part of the Riverine [cover type]." (Cowardin *et al*. 1979, pp. 9-10).

b. Lacustrine. "The Lacustrine [cover type] includes wetlands and deepwater habitats with all of the following characteristics: (1) situated in a topographic depression or a dammed river channel; (2) lacking trees, shrubs, persistent emergents, emergent mosses or lichens with greater than 30% areal coverage; and (3) total area exceeds 8 ha (20 acres). Similar wetland and deepwater habitats totaling less than 8 ha are also included in the Lacustrine System if an active waveformed or bedrock shoreline feature makes up all of part of the boundary, or if the water depth in the deepest part of the basin exceeds 2 m (6.6 feet) at low water. Lacustrine waters may be tidal or nontidal, but ocean-derived salinity is always less than 0.5 [parts per thousand]." (Cowardin et al. 1979, pp. 11-12) (Note that only the "Limnetic" subsystem of Cowardin et al. is a "Deepwater Habitat". The "Littoral" subsystem is included in "Wetlands".)

c. Estuarine. "The Estuarine [cover type] consists of deepwater tidal habitats and adjacent tidal wetlands that are usually semienclosed by land but have open, partly obstructed, or sporadic access to the open ocean, and in which ocean water is at least occasionally diluted by freshwater runoff from the land. The salinity may be periodically increased above that of the open ocean by evaporation. Along some low-energy coastlines there is appreciable dilution of sea water. Offshore areas with typical estuarine plants and animals, such as red mangroves *(Rhizophora mangle)* and eastern oysters *(Crassostrea virginica)*, are also included in the Estuarine [cover type]."

"[The Estuarine cover type] extends (1) upstream and landward to where ocean-derived salts measure less than 0.5 [parts per thousand] during the period of average annual low flow; (2) to an imaginary line closing the mouth of a river, bay, or sound; and (3) to the seaward limit of wetland emergents, shrubs, or trees where they are not included in (2). The Estuarine [cover type] also includes offshore areas of continuously diluted sea water." (Cowardin et al. 1979, pp. 4-5) (Note that only the "Subtidal" subsystem of Cowardin et al. is a "Deepwater Habitat". The "Intertidal" subsystem is included in "Wetlands".)

d. Marine. "The Marine [cover type] consists of the open ocean overlying the continental shelf and its associated high-energy coastline. Marine habitats are exposed to the waves and currents of the open ocean and the water regimes are determined primarily by the ebb and flow of oceanic tides. Salinities exceed 30 [parts per thousand], with little or no dilution except outside the mouths of estuaries. Shallow coastal indentations or bays without appreciable freshwater inflow, and coasts with exposed rocky islands that provide the mainland with little or no shelter from wind and waves, are also considered part of the Marine [cover type] because they generally support typical marine biota.

"The Marine [cover type] extends from the outer edge of the continental shelf shoreward to one of three lines: (1) the landward limit of tidal inundation (extreme high water of spring tides), including the splash zone from breaking waves; (2) the seaward limit of wetland emergents, trees, or shrubs; or (3) the seaward limit of the Estuarine [cover type] where this limit is determined by factors other than vegetation. Deepwater habitats lying beyond the seaward limit of the Marine [cover type] are outside the scope of this classification system." (Cowardin *et al*. 1979, p. 4) (Note that only the "Subtidal" subsystem of Cowardin *et al*. is a "Deepwater Habitat". The "Intertidal" subsystem is included in "Wetlands".)

E.5 References cited

Anderson, J. R., E. E. Hardy, J. T. Roach, and R. E. Witmer. 1976. A land use and land cover classification system for use with remote sensor data. USDI Geological Survey, Professional Paper 964. 28 pp.

Bailey, R. G. 1976. Ecoregions of the United States. USDA Forest Service, Intermountain Region. Ogden, Utah.

Barbour, C., and J. Brown. 1974. Fish species diversity in lakes. Am. Nat. 108(962):473-489.

Biesinger, K. E., R. P. Brown, C. R. Bernick, G. A. Flittner, and K. E. F. Hokanson. In press. A national compendium of freshwater fish and water temperature data. Vol. I. U.S. Environ. Protection Agency. Environ. Res. Lab, Duluth, Minnesota. 207 pp.

Cowardin, L. M., V. Carter, F. C. Golet, and E. T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. USDI Fish and Wildlife Service, FWS/OBS-79/31. 103 pp.

Hokanson, K. E. F. 1977. Temperature requirements of some percids and adaptations to the seasonal temperature cycle. J. Fish. Res. Board Can. 34:1524-1550.

Horton, R. E. 1945. Erosional development of streams and their drainage basins - hydrophysical approach to quantitative morphology. Geol. Soc. Am. Bull. 56(3):275-370.

Hynes, H. B. N. 1970. The ecology of running waters. Univ. Toronto Press. 555 pp.

Strahler, A. N. 1952. Dynamic basis of geomorphology. Geol. Soc. Am. Bull. 63:923-938.

________. 1957. Quantitative analysis of watershed geomorphology. Trans. Am. Geophys. Union 38(6):913-920.

Appendix F. HSI Models Based on Discriminant Analysis

The process of building a mechanistic Habitat Suitability Index (HSI) model from individual "suitability index" curves can be a good approach to HSI model building when only scattered data are available on the effects of individual variables. However, a more direct approach may be taken to develop an HSI model when concurrent measures of several habitat variables and quantitative or qualitative estimates of carrying capacity (e.g., standing crop or biomass) are available for a given area. One approach to consider is discriminant analysis.

Discriminant analysis can be used to predict what suitability group (e.g., high, medium, or low) a particular habitat belongs to, based on a set of equations derived from variable measurements taken from various habitats. Discriminant analysis can be used to develop a species or species group HSI model using the steps described below.

F.1 Step 1. Identify areas of "known" habitat suitability and assign them to a suitability group. This step requires that selected areas, such as certain lakes, or areas of forest be assigned to a specific habitat suitability group. Four or five would be the optimal number of distinct groups to use. For simplicity, the highest group number should be used to represent the best habitat. For example, if 4 groups are used, group 4 would represent the best habitat and group 1 the least suitable. The type of data used to define group membership could be anything from expert opinion to high quality, long-term population data. For example, a lake could be classified as group 4 for walleye, based on the opinion of the local fisheries biologist. If adequate standing crop data were available a lake could be placed in group 4 because the standing crop of walleyes was greater than a specified value such as 2.5 kg/ha. The method used to define group membership for "known" habitat does not influence the method used to analyze environmental data and predict group membership for "unknown" habitats. However, the more precise definitions of each group make the classification more meaningful. One of the advantages of discriminant analysis is that it can utilize qualitative "expert opinion" types of group ratings without requiring the expert to precisely define what a rating means in terms of animal numbers.

F.2 Step 2. Measure the selected environmental variables in habitats that have been assigned to a group, and analyze the data. The Statistical Program for Social Sciencies (Nie et al., 1975) contains a discriminant function subprogram that displays predicted and actual group membership for the groups entered. The classification function coefficients listed by the program are used to predict group membership for other areas of interest.

F.3 Step 3. Perform sensitivity analysis. If the model produced in Step 3 does an adequate job of predicting group membership, then selected habitat variables in the "known" habitats should be varied to see if predicted group membership also varies in a logical manner.

F.4 Step 4. Apply the model to habitats with unknown group membership. After Step 4 is completed the model is ready to use in predicting group membership in habitats other than those used to develop the model. The model will provide for each group into which a habitat could be classified a series of coefficients to multiply times the value of each habitat variable measured. In order to determine group membership of a habitat, the habitat variables are measured, multiplied by the appropriate coefficient for each group, and the habitat assigned to the group which receives the highest score. A simplified example is provided below based upon the classification function coefficients given in Table F-1.

Table F-1. Classification function coefficients for an example discriminant analysis HSI model.

	Classification function coefficients		
	Group 1	Group 2	Group 3
Variable	"Unproductive"	"Moderately Productive"	"Very Productive"
A	28	23	20
B	13	14	10
C	12	10	8
Constant	-40	-30	-20

In a certain lake, variable A had a value of 1, variable B a value of 1, and variable C a value of 1. The following scores would be developed for each group

$$\text{Group 1} = (1)(28) + (1)(13) + (1)(12) - 40 = 13$$

$$\text{Group 2} = (1)(23) + (1)(14) + (1)(10) - 30 = 17$$

$$\text{Group 3} = (1)(20) + (1)(10) + (1)(8) - 20 = 18$$

The lake would be assigned to group 3 because it received the highest classification score for group 3.

A lake where variable A had a value of 1, variable B a value of 1, and variable C a value of 2 would be classified as follow:

Group 1 = (1)(28) + (1)(13) + (2)(12) - 40 = 25

Group 2 = (1)(23) + (1)(14) + (2)(10) - 30 = 27

Group 3 = (1)(20) + (1)(10) + (2)(8) - 20 = 26

This lake would be assigned to group 2.

Group values may be converted to HSI by the formula

$$HSI = \frac{\text{Predicted Group Value}}{\text{Higest Group Value}} = 2/3 = 0.67$$

The classification coefficients will have 6 to 8 significant figures in actual practice and application of the model to a larger number of habitats will be tedious unless a simple computer program is developed to do the multiplications.

F.5 References cited

Nie, N. H., C. H. Hull, J. G. Jenkins, K. Steinbrenner, D. H. Brent. 1975. Statistical package for the social sciences. New York. McGraw-Hill Book Co. 675 pp.

Appendix G. Glossary

Aquatic cover types - A classification of riverine and lacustrine environments based on average temperature (cold, cool, warm) and water body size (small, medium, large).

Assessment - An activity designed to identify, predict, and quantify information about the impact of an action. Such assessments should address all physical, biological, economic, and social parameters relevant to the change expected to result from the action.

Available habitat - An area of land or water, or both, composed of one or more cover types, capable of providing direct support for an evaluation species.

Carrying capacity - The units of biomass/unit area or units of biomass production/unit area that can be supported by an area over a long, but defined, period of time (see Giles 1978 for more discussion).

Cover type - An area of land or water with similar physical, chemical, and biological characteristics that meet a specified standard of homogeneity.

Evaluation - Value judgements made following examination of information from an assessment.

Evaluation species - Individual animal species, a group of species, life stage of a species, or life requisite of a species.

Guild - A group of species that share a common habitat resource.

Habitat suitability - The potential of a specific area to support a selected evaluation species.

Habitat Suitability Index (HSI) - A unitless number bounded by 0.0 and 1.0 where 0.0 represents unsuitable habitat and 1.0 represents optimal habitat.

Habitat Suitability Index model - The rules, in either written or mathematical form, by which a Habitat Suitability Index is determined for a particular evaluation species at a particular location. The HSI model consists of two parts: a value of interest (numerator) and a standard of comparison (denominator). The denominator is a description of optimal habitat; the numerator is a description of habitat in the area of interest.

Habitat Units (HU) - A value derived by multiplying the Habitat Suitability Index for an evaluation species by the size of the area for which the HSI was calculated. The HU provides a standardized basis for comparing habitat changes over time and space.

Appendix G. Glossary

Habitat variable - A measurable characteristic of an evaluation species' habitat used in the determination of a Habitat Suitability Index.

Interspersion - The spatial relationship of habitat resources to one another. Interspersion is considered for species that typically utilize more than one cover type to meet all of its life requisites.

Life requisite - Food, water, cover, reproductive, or special requirements supplied by the habitat.

Life stage - Embryo, fry, juvenile, or adult stage of a species.

Terrestrial cover type - Relatively homogeneous units based primarily on structural categories such as vegetation height or density, and leaf persistence.

Variable - A characteristic of habitat which can be directly measured and around which a habitat model is constructed.

Weighted Useable Area (WUA) - The product of the total surface area of the sampled unit of a stream (i.e., representative reach) and a composite weighting factor which represents the combination of hydraulic conditions present.

Wildlife - Wildlife includes all nondomesticated aquatic and terrestrial animal species.

Word model - A word description of habitat requirements that can be used to determine the Habitat Suitablity Index for an evaluation species.

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4. References Cited

Aggus, L. R., and D. I. Morais. 1979. Habitat suitability index equations for reservoirs based on standing crop of fish. Unpublished report to U.S. Fish and Wildlife Service. 134 pp.

Bailey, R. G. 1976. Ecoregions of the United States. USDA Forest Service, Ogden, Utah. map.

Baskett, T. S., D. A. Dorrow, D. L. Hallet, M. J. Armbruster, J. A. Ellis, B. F. Sparrowe, and P. A. Kaste. 1980. A handbook for terrestrial habitat evaluation in central Missouri. USDI, Fish and Wildlife Service, Resource Publ. 133. 155 pp.

Baxter, William L., and Carl W. Wolfe. 1972. An interspersion index as a technique for evaluation of bobwhite quail habitat. Nebraska Game and Parks Comm. Fed. Aid Project W-15-R. 12 pp.

Binns, N. A., and F. M. Eiserman. 1979. Quantification of fluvial trout habitat in Wyoming. Trans. Am. Fish. Soc. 108(3):215-228.

Bovee, K. D. 1978. The incremental method of assessing habitat potential for coolwater species, with management implications. pp. 340-346. In R. L. Kendall, ed. Selected coolwater fishes of North America. Am. Fish. Soc. Spec. Publ. No. 11. Washington. 437 pp.

Draper, N. R., and H. Smith. 1966. Applied regression analysis, New York John Wiley & Sons, Inc. pp.

Ellis, J. A., J. N. Burroughs, M. J. Armbruster, D. L. Hallet, P. A. Korte, and T. S. Baskett. 1979. Appraising four field methods of terrestrial habitat evaluation. Trans. N. Am. Wildl. Nat. Resour. Conf: 44:369-379.

Freese, F. 1974. Elementary statistical methods for foresters. Agriculture Handbook 317. U.S.D.A. - Forest Service. 87 pp.

Giles, R. H. 1978. Wildlife management. W. H. Freeman and Company. San Francisco. 416 pp.

Horton, R. E. 1945. Erosional development of streams and their drainage basins - hydrophysical approach to quantitative morphology. Geol. Soc. Am. Bull. 56(3):275-370.

Inhaber, H. 1976. Environmental indices. John Wiley and Sons. New York. 178 pp.

4. References Cited

Jenkins, R. M. 1976. Prediction of fish production in Oklahoma reservoirs on the basis of environmental variables. An.. Okla. Acad. Sci. 5:11-20.

Kling, C. L. 1980. Pattern recognition for habitat evaluation. M.S. Thesis. Colo. State Univ. Fort Collins, Colo. 244 pp.

Leidy, G. R., and R. M. Jenkins. 1977. The development of fishery compartments and population rate coefficients for use in reservoir ecosystem modeling. U.S. Army Corps of Engineers Waterways Experiment Station Contract Report Y-77-1. Memeo report.

Morrison, D. F. 1976. Multivariate statistical methods. 2nd Edition. McGraw-Hill Book Co. 415 pp.

Nie, N. H., C. H. Hull, J. G. Jenkins, K. Steinbrenner, D. H. Brent. 1975. Statistical package for the social sciences. New York. McGraw-Hill Book Co. 675 pp.

Noon, B. R., D. Dawson, D. B. Inkley, C. S. Robbins, and S. N. Anderson. 1980. Consistency in habitat preference of forest birds. Transactions of the North American Wildlife and Natural Resources Conference, 1980. Wildlife Management Institute, Washington, D.C.

Odum, E. P., G. A. Brambett, A. Ike, J. R. Champlin, J. C. Ziemank, and H. H. Shugart. 1976. Totality Indexes for Evaluating Environmental Impacts of Highway Alternatives. Published in Transportation Research Record No. 461. Trans. Res. Board, Spring 1976. Natl. Academy of Science.

Patton, David R. 1975. A diversity index for quantifying habitat edge. Wildl. Soc. Bull. 3(4):171-173.

Puglisi, Michael J. 1978. An acetate survey guide for forest wildlife habitat improvement. Wildl. Soc. Bull. 6(1):40-42.

Robbins, C. S. 1978. Determining habitat requirements for nongame species in Transactions of the 43rd North American Wildlife and Natural Resources Conference, 1978. Wildlife Management Institute, Washington, D.C.

Russell, K. R., G. L. Williams, B. A. Hughes, and D. S. Walsworth. 1980. PATREC and MANALT systems demonstrated on oil shale development. Colorado Coop. Wildlife Research Unit, Colorado State Univ., Ft. Collins, Colorado. 264 pp. Unpublished report.

Seaber, Paul R., F. Paul Kapinos, John A. Shanton, and Susan V. Moss. 1974. National project to depict hydrological units. WRD Bulletin, U.S. Geological Survey, Reston, Va. 49 pp.

4. References Cited

Stalnaker, C. B. 1978. Methodologies for preserving instream flows, the incremental method. pp. 1-9 In Symposium proceedings instream flow management - state of the art. Upper Mississippi River Basin Commission. Nov. 14, 1978.

__________. 1980. The use of habitat structure preferenda for establishing flow regimes necessary for maintenance of fish habitat. In the Ecology of Regulated Streams. Edited by James V. Ward and Jack A. Stanford (Plenum Publishing Corporation, 1980).

Thomas, J. W., C. Maser, and J. E. Rodiell. 1979. Wildlife habitats in managed rangelands -- The Great Basin of southeastern Oregon. General Technical Report PNW-85. U.S.D.A. - Forest Service. 17 pp.

Appendix A. Habitat Use Information and HSI Model for the Gray Squirrel

A.1 Introduction. HSI models should be adequately documented so that the HSI estimates can be properly interpreted. This appendix provides an example gray squirrel model with documentation as described in 103 ESM 3.4. Section A.2 below provides documentation of habitat use information, and A.3 describes the HSI model, including model assumptions and limitations. Section A.4 provides information for applying the model.

A.2 Habitat use information

A. General. The gray squirrel (*Sciurus carolinensis*) prefers bottomland hardwood and mixed coniferous hardwood forests (Uhlig 1955; Golley 1962). The species also inhabits small woodlots, wooded fencerows, parks, and residential areas.

B. Food requirements. Fruits, floral parts, buds, bark, roots, fungi, and animal matter are seasonally important foods for the gray squirrel (U.S. Forest Service 1971). However, the species depends heavily upon mast, particularly acorns. Late summer, fall, and winter foods consist mainly of hickory (*Carya* spp.), beech (*Fagus* spp.), and oak (*Quercus* spp.) mast; the spring and summer diet shifts to herbaceous vegetation (Nixon *et al*. 1968).

Nixon *et al*. (1975) reported that a significant relationship existed between the annual seed crop and subsequent squirrel densities on their Ohio study area. When the seed crop fell below 145.7 kg of sound seed per ha (130 lb/ac), the survival of summer-born juveniles was drastically reduced due to increased competition from older individuals and other wildlife species. To sustain reasonably high squirrel densities, it was believed that mast production should exceed 168 kg/ha (150 lb/ac). Approximately 8.5 m^2 (10.2 yd^2) of basal area in trees of seed producing size ($\geq$ 25.4 cm (10 in) dbh) would be needed to produce this amount of seed.

Hickory mast was reported to be the first choice food for squirrels in Ohio (Nixon *et al*. 1968); however, a variety of mast producing species should be present over a range of sites in order to minimize the likelihood of crop failures (Nixon *et al*. 1975). Variable mast crops are not uncommon due to the influences of weather, yearly variance in seed production by individual trees, and the temporal difference in acorn maturation between the red and white oak groups.

C. Water requirements. Eastern gray squirrels can satisfy water needs from free water or succulent plant materials (U.S. Forest Service 1971).

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D. Cover requirements. Gray squirrels utilize tree cavities and temporary leaf nests for cover and litter rearing. Leaf nests are usually used for temporary summer shelter; however, they also may provide winter shelter and sites for brood-rearing (U.S. Forest Service 1971). The most critical demand for dens is for litter rearing and winter shelter (Nixon *et al*. 1968). One den per 0.8 ha (2 ac) was recommended as the minimum necessary to ensure suitable winter shelter for gray squirrels (Sanderson 1975); however, more optimum reproductive and refuge cover would be provided by 2 to 5 den trees per 0.4 ha (2 to 5/ac) (Brown and Yeager 1945; U.S. Forest Service 1971).

Ash (*Fraxinus* spp.), elms (*Ulmus* spp.), oaks, hickories, beech, cypress (*Taxodium distichum*), sycamore (*Platanus occidentalis*), sassafras (*Sassafras albidum*), and basswood (*Tilia* spp.) have been most commonly identified as potential den trees for gray squirrels in the eastern United States (Goodrum 1937; Nixon 1968). Blackgum (*Nyssa sylvatica*), beech, and maple (*Acer* spp.) were reported to be the most prolific producers of cavities suitable for gray squirrels in Georgia, although oaks, which were more common, may have been the most important trees which provided shelter (Golley 1962).

Gray squirrels in West Virginia were reported to most commonly nest in live trees which had a dbh of at least 40.0 cm (15.7 in) (Sanderson *et al*. 1975). Eighty-eight percent of gray squirrel dens recorded in eastern Texas were located in trees which were equal to or greater than 30.5 cm (12 in) dbh (Baker 1944).

The gray squirrel in eastern Texas was reported to be more numerous in forests of mixed composition than in stands providing low species diversity (Goodrum 1937). Habitats with moderate to dense brushy undergrowth will provide more valuable habitat for gray squirrels than sites with little to no understory (U.S. Forest Service 1971).

E. Reproductive requirements. The reproductive requirements of the gray squirrel are synonymous with its cover requirements as described above.

F. Interspersion requirements. The home range of the gray squirrel in Missouri ranged from 4 to 16 ha (10 to 40 ac) (Schwartz and Schwartz 1974). The mean minimum home range for gray squirrels in Virginia was reported as being 0.49 ha (1.2 ac) (Doebel and McGinnes 1974). Male gray squirrels generally have larger ranges than do females (Bakken 1959). The ranges of adult males often overlap with those

of other adult males and females. In contrast, breeding females will defend their territory against other female gray squirrels (Nixon et al. 1975).

G. Special considerations. Even-aged stands of hardwoods of less than 30 to 40 years in age do not produce sufficient mast or cavities to support gray squirrel populations (U.S. Forest Service 1971). Hardwood stands exceeding 60 years in age provide optimum gray squirrel habitat.

Livestock grazing may reduce understory vegetation utilized for cover by foraging gray squirrels (Flood et al. 1977). Croplands interspersed with forests or woodlots add to the available food supply and may supplement the diet of gray squirrels in low mast production years.

A.3 Habitat Suitability Index (HSI) model for the gray squirrel (*Sciurus carolinensis*)

A. Model applicability

(1) Geographic area. This model is applicable to the cover types indicated below within the geographic range of the species.

(2) Season. This model will produce HSI values for year-round habitat needs of the gray squirrel.

(3) Cover types. The following cover types are utilized by the gray squirrel: Deciduous Forest (DF), Deciduous Forested Wetlands (DFW), and Evergreen Forest (EF)

(4) Minimum habitat area. Minimum habitat area is defined as the minimum amount of contiguous habitat that is required for a species to successfully live and reproduce. The mean minimum home range for the gray squirrel has been reported to be 0.49 ha (1.2 ac). For purposes of this model, it is assumed that a habitat of less than 0.4 ha (1 acre) will provide no suitability, and the HSI will equal zero in such areas.

(5) Verification level. This model has been reviewed within the Habitat Evaluation Procedures Group and meets their quality standards. It has not been tested under field conditions.

B. Model description

(1) Graphic overview. This HSI model for the gray squirrel considers specific variables and their relationship to life requisites and the HSI, as shown in Figure A-1. Cover and reproductive needs are assumed to be the same, and it is assumed that water is not limiting.

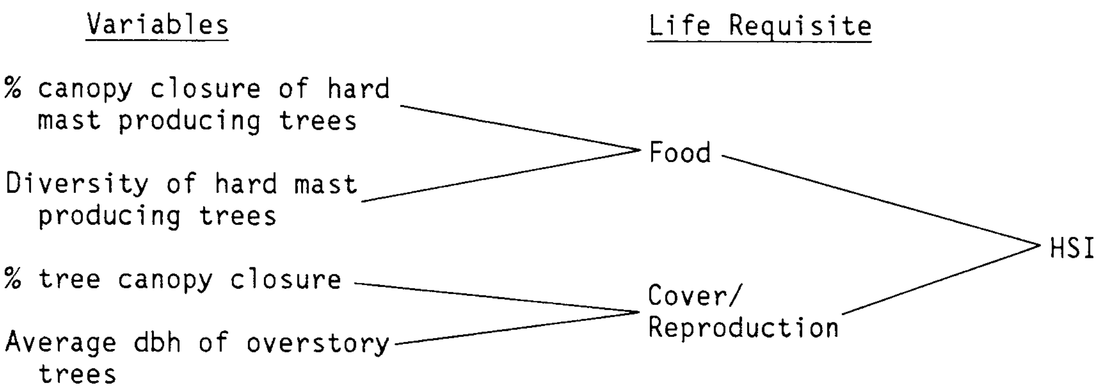


Figure A-1. Tree diagram showing relationship of habitat variables and life requisites to the HSI for the gray squirrel.

(2) Life requisite components

a) Food. A wide variety of vegetative food is consumed by the gray squirrel during the spring and summer. The late summer, fall, and winter diet is comprised chiefly of hickory, beech, and oak mast. It is assumed that the fall and winter diet will always be more limiting than the spring and summer diet. Mixed forest stands will provide a more stable food supply than stands dominated by one mast producing species. It has been reported that to sustain reasonably high squirrel densities approximately 8.5 m^2 per hectare of basal area of seed producing trees ($\geq$ 25.4 cm dbh) should be present in the stand. It is assumed that greater than 75% canopy closure of hard mast producing trees exceeding 25.4 cm (10 in) dbh will be of optimal value.

Overall food suitability is related to the density and diversity of hard mast producing trees. Habitats with a lack of hard mast trees will provide no food. Areas with low diversity will be more valuable if they have high densities, and areas with low densities will be more valuable with accompanying high diversity.

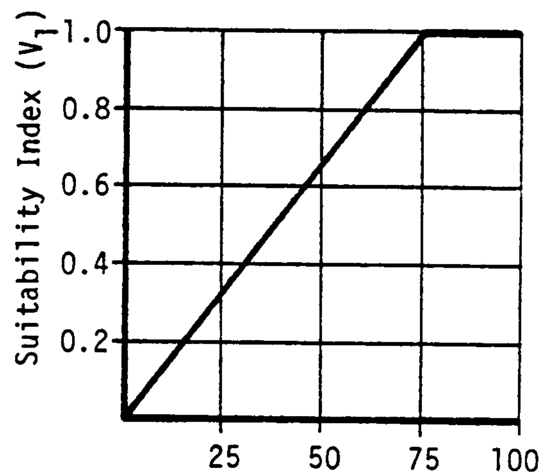
b) Cover/Reproduction. Gray squirrels utilize temporary leaf nests and tree cavities for litter rearing and shelter. The most critical aspect of cover for this species is the availability of tree cavities. It is assumed that if large diameter trees are available, cavities will be present to provide winter and reproductive cover for the gray squirrel. Cover requirements for the gray squirrel are assumed to be optimum where the percent tree canopy closure exceeds 40%, and the average dbh of overstory trees is equal to or exceeds 30.5 cm (12 in).

Overall cover/reproductive suitability is related to the size and density of trees. It is assumed that any size and density combination has some value to gray squirrels. It is further assumed that habitats with low tree densities will be more valuable if they have large diameters, and areas with lower tree diameters will be more valuable if they have high canopy closures.

C. Model relationships. This section contains suitability index curves and equations to quantitatively describe the relationships discussed in the previous section. These curves and equations can be used to produce an HSI for the gray squirrel.

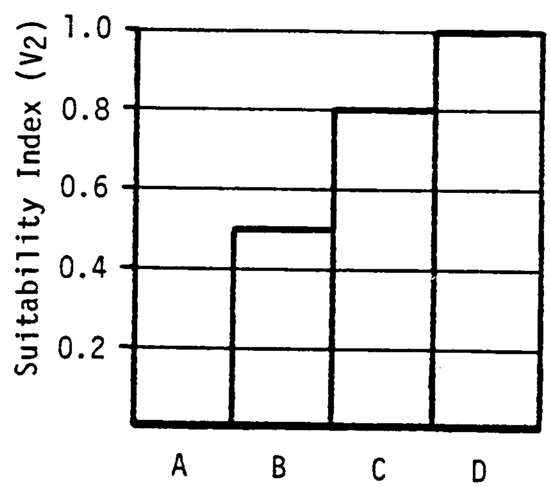
(1) Suitability index curves

Cover Type	Variable	
DF, DFW, EF	(V_1)	Percent canopy closure of hard mast producing trees (oak, hickory, walnut, pecan, beech, and others) which are $\geq$ 25.4 cm (10 in) dbh.

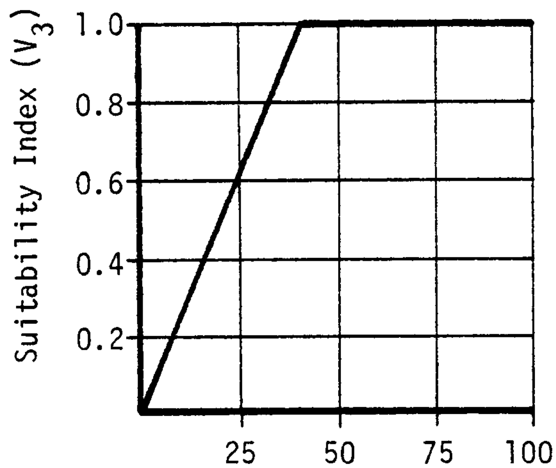


DF, DFW, EF	(V_2)	Diversity of hard mast producing trees (oak, hickory, walnut, pecan, beech, and others).

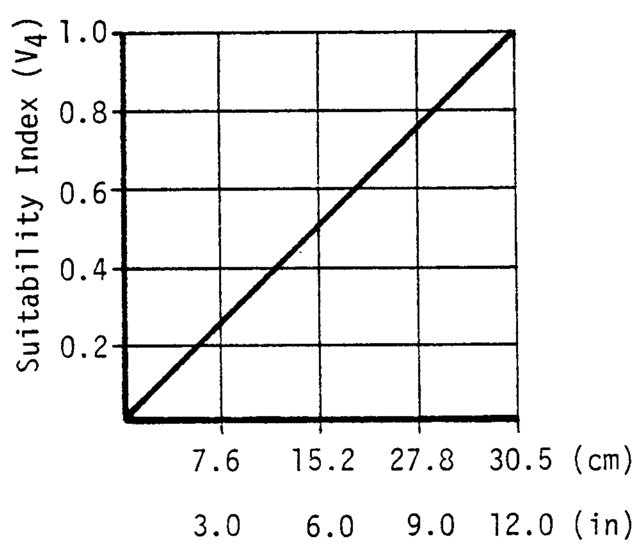
A) None present in forest or stand.
B) 1 species present.
C) 2 species present.
D) $\geq$ 3 species present.



DF,DFW, EF (V_3) Percent tree canopy closure.



DF,DFW, EF (V_4) Average dbh of overstory trees.



(2) Equations

a) Equation for food component. The following equation integrates the index values for each variable to obtain a life requisite value for food in each cover type.

$$\text{Food Value} = (V_1 \times V_2)^{1/2}$$

b) Equation for cover/reproduction component. The following equation integrates the index values for each variable to obtain a life requisite value for cover/reproduction in each cover type.

$$\text{Cover/Reproduction Value} = (V_3 \times V_4)^{1/2}$$

D. HSI determination. Based on the limiting factor concept, the HSI is equal to the lowest life requisite value.

A.4 Application of the model. The level of detail needed for a particular application of this model will depend on time, money, and accuracy constraints. Detailed field sampling of all variables will provide the most reliable and replicable HSI values. Any or all variables can be estimated, in order to reduce the amount of time required to apply the model. Increased use of subjective estimates decreases reliability and replicability, and these estimates should be accompanied by appropriate documentation to insure that decisionmakers understand both the method of HSI determination and quality of the data used in the HSI model.

The measurement techniques in Table A-1 are suggested for the variables used in this model. A field form can be developed from this list.

Table A-1. Suggested measurement techniques and definition of habitat variables.

Variable (Definition)	Cover Types	Suggested Technique
(V_1) Percent canopy closure of hard mast producing trees (the percent of the ground that is shaded by a vertical projection of the canopies of trees which produce a hard shelled fruit, and are equal to or exceed 25.4 cm [10 in] dbh)	DF,DFW,EF	Transect, line intercept
(V_2) Diversity of hard mast producing trees (the number of hard mast producing tree species present in the stand)	DF,DFW,EF	Transect, tally, ocular estimate
(V_3) Percent tree canopy closure (the percent of the ground surface that is shaded by a vertical projection of the canopies of all trees)	DF,DFW,EF	Transect, line intercept
(V_4) Average dbh of overstory trees (the average diameter at breast height [1.4 m/ 4.5 ft] above the ground of those trees that comprise the uppermost canopy in a forest or stand)	DF,DFW,EF	Transect, line intercept, dbh tape

A.5 Sources of other models. No other habitat models were located for the gray squirrel during literature searches.

A.6 References cited

Baker, R. H. 1944. An ecological study of tree squirrels in eastern Texas. J. Mammal. 25(1):8-24.

Bakken, A. 1959. Behavior of gray squirrels. Proc. Southeastern Assoc. Game and Fish Commissioners 13:393-407.

Brown, L. G., and L. E. Yeager. 1945. Fox squirrels and gray squirrels in Illinois. Illinois Nat. Hist. Surv. Bull. 23(5):449-536.

Doebel, J. H., and B. S. McGinnes. 1974. Home range and activity of a gray squirrel population. J. Wildl. Manage. 38(4):860-867.

Flood, B. S., M. E. Sangster, R. D. Sparrowe, and T. S. Baskett. 1977. A handbook for habitat evaluation procedures. U.S.D.I. Fish and Wildl. Serv. Resour. Publ. 132. 77 pp.

Golley, F. B. 1962. Mammals of Georgia, a study of their distribution and functional role in the ecosystem. Univ. Georgia Press, Athens. 218 pp.

Goodrum, P. 1937. Notes on gray and fox squirrels of eastern Texas. Trans. N. Am. Wildl. Conf. 2:499-504.

Nixon, C. M. 1968. Squirrel management guidelines for wildlife areas. Ohio Dept. Nat. Resour. Div. Wildl. Inservice Document 55. 8 pp.

Nixon, C. M., M. W. McClain, and R. W. Donohoe. 1975. Effects of hunting and mast crops on a squirrel population. J. Wildl. Manage. 39(1):1-25.

Nixon, C. M., D. M. Worley, and M. W. McClain. 1968. Food habits of squirrels in southeast Ohio. J. Wildl. Manage. 32(2):294-304.

Sanderson, H. R. 1975. Den-tree management for gray squirrels. Wildl. Soc. Bull. 3(3):125-131.

Sanderson, H. R., W. M. Healy, J. C. Polk, J. D. Gill, and J. W. Thomas. 1975. Gray squirrel habitat and nest-tree preference. Proc. Southeastern Assoc. Game and Fish Commissioners 29:609-616.

Schwartz, C. W., and E. R. Schwartz. 1974. The wild mammals of Missouri. Univ. Missouri Press and Missouri Dept. of Conserv., Columbia. 341 pp.

Uhlig, H. G. 1955. The gray squirrel, its life history, ecology, and population characteristics in West Virginia. West Virginia Conserv. Comm. 182 pp.

U.S. Forest Service. 1971. Wildlife habitat management handbook. U.S.D.A. For. Serv., Southern Region. FSH 2609.23R. Unpaged.