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:

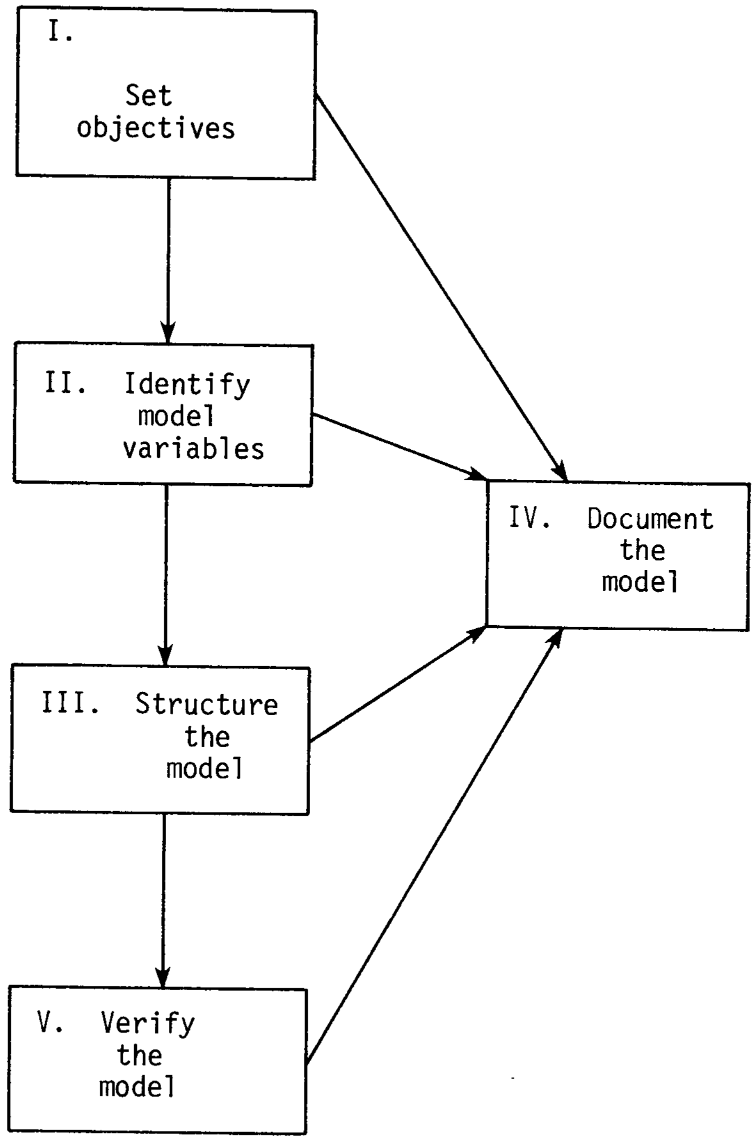

Figure 3-1. Five phases of HSI model construction.

- 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

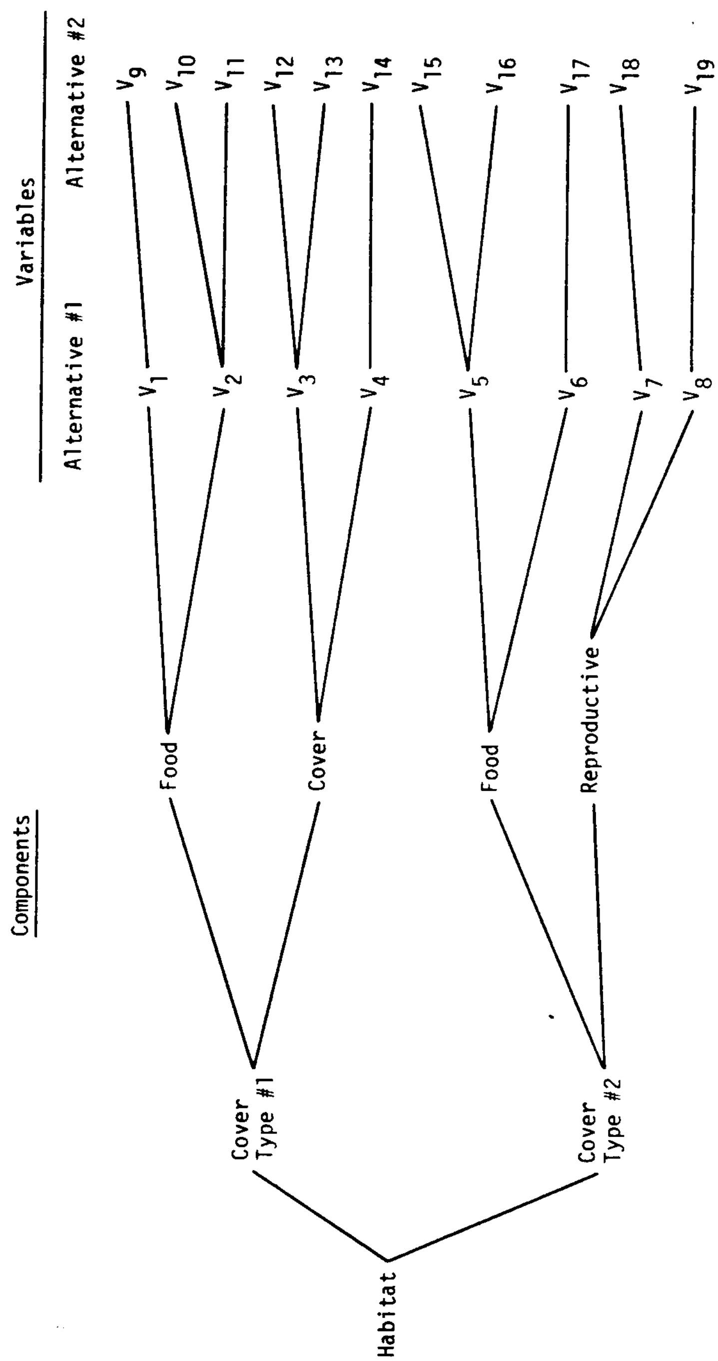

Figure 3-2. Identification of model variables through definition of habitat components.

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

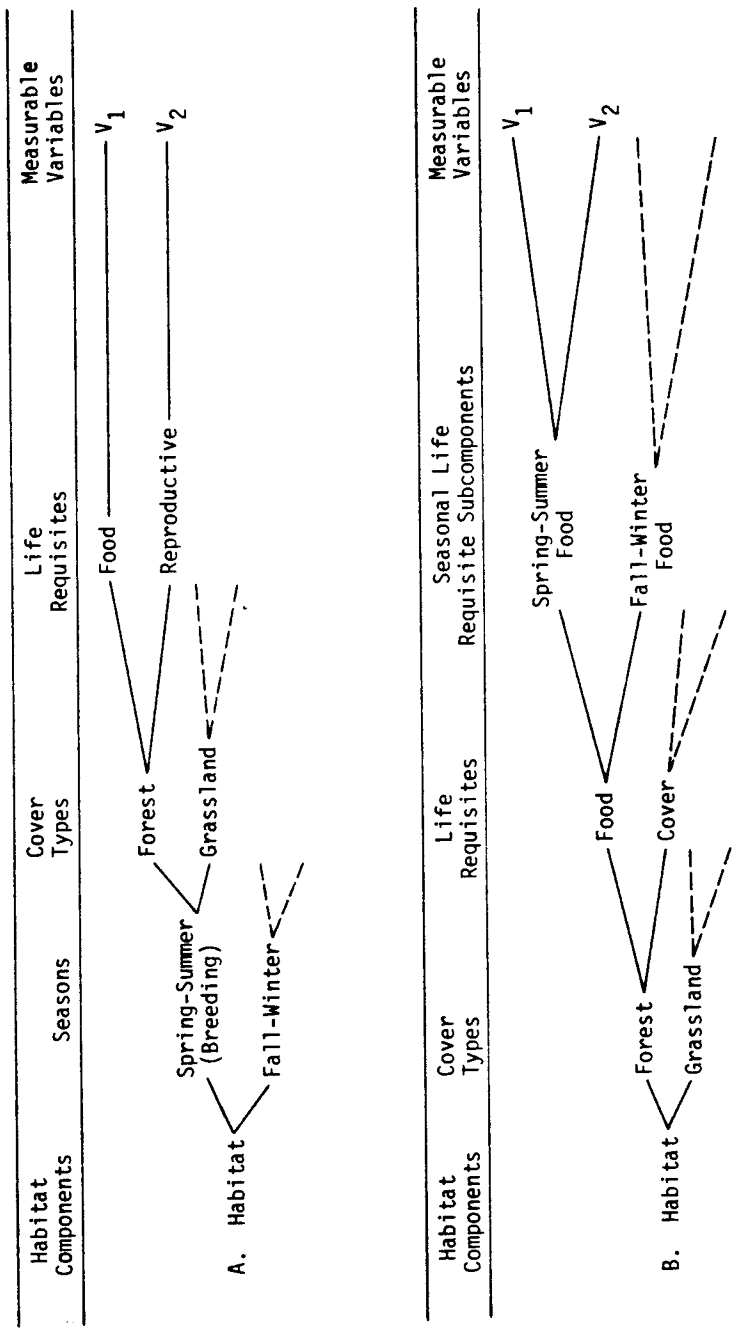

Figure 3-3. Example tree diagrams for terrestrial habitat.

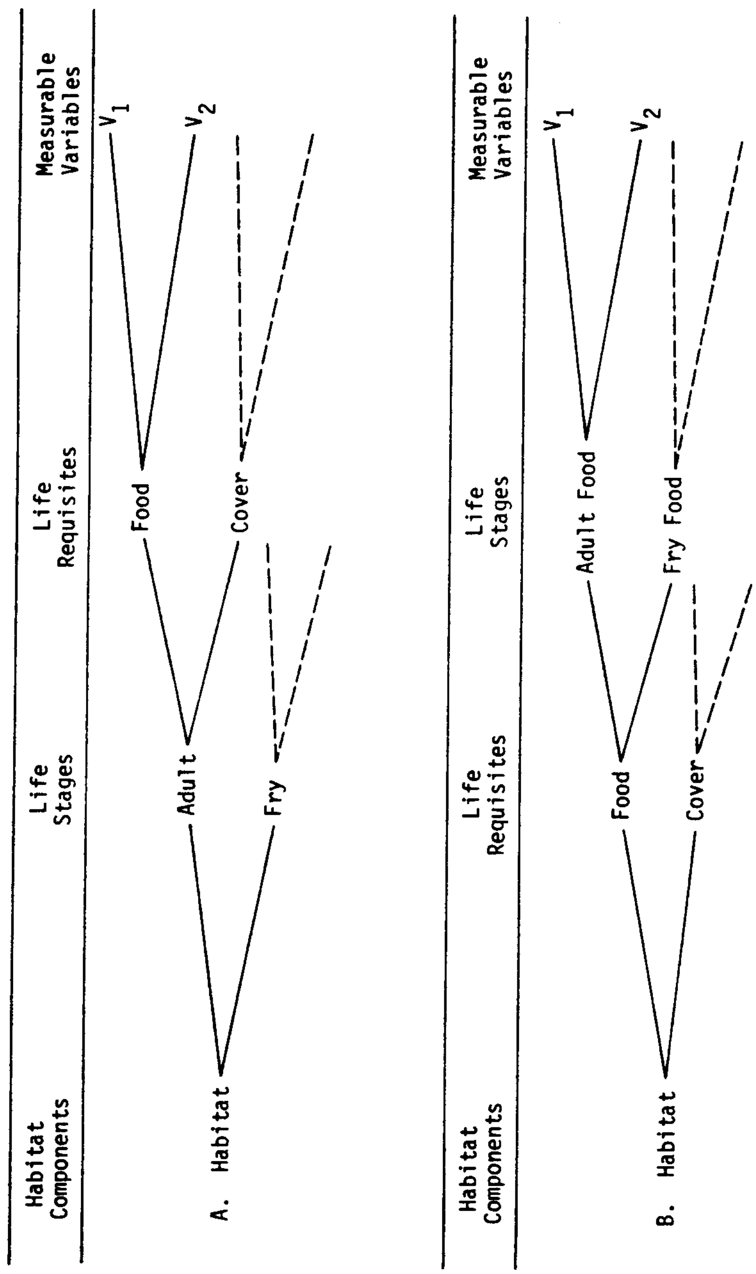

Figure 3-4. Example tree diagrams for aquatic habitat.

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.

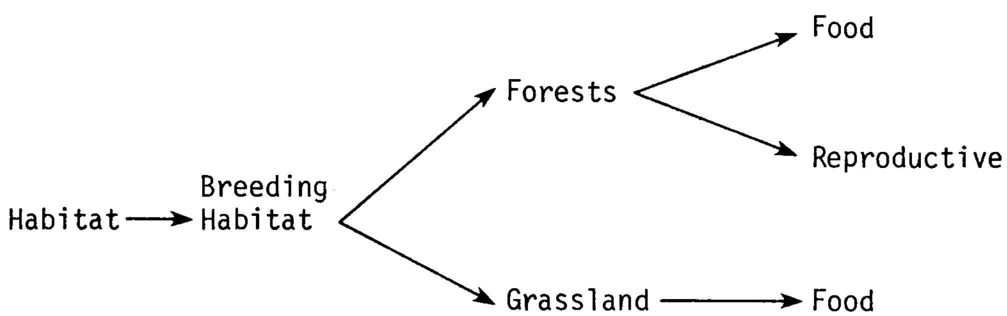

Figure 3-6. Cover type and life requisite components for breeding season habitat for the red-tailed hawk.

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.

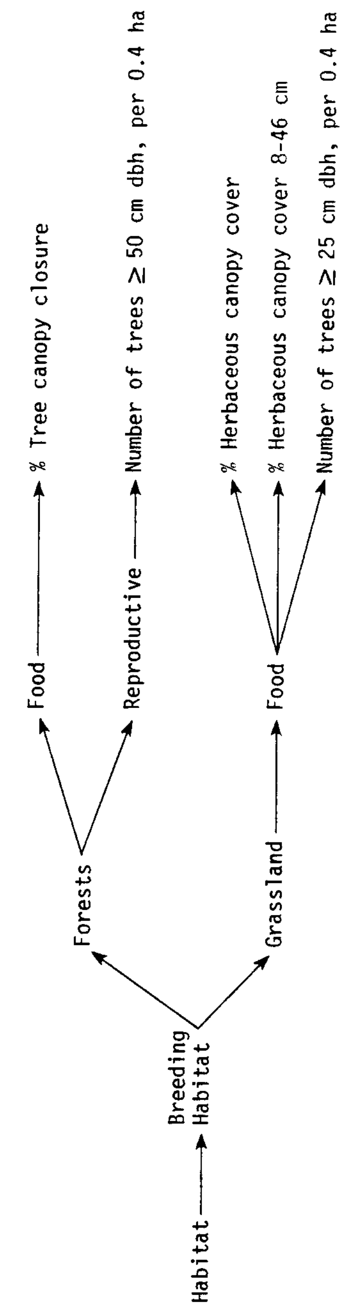

Figure 3-7. Cover types and life requisite components and measurable variables for breeding season habitat for the red-tailed hawk.

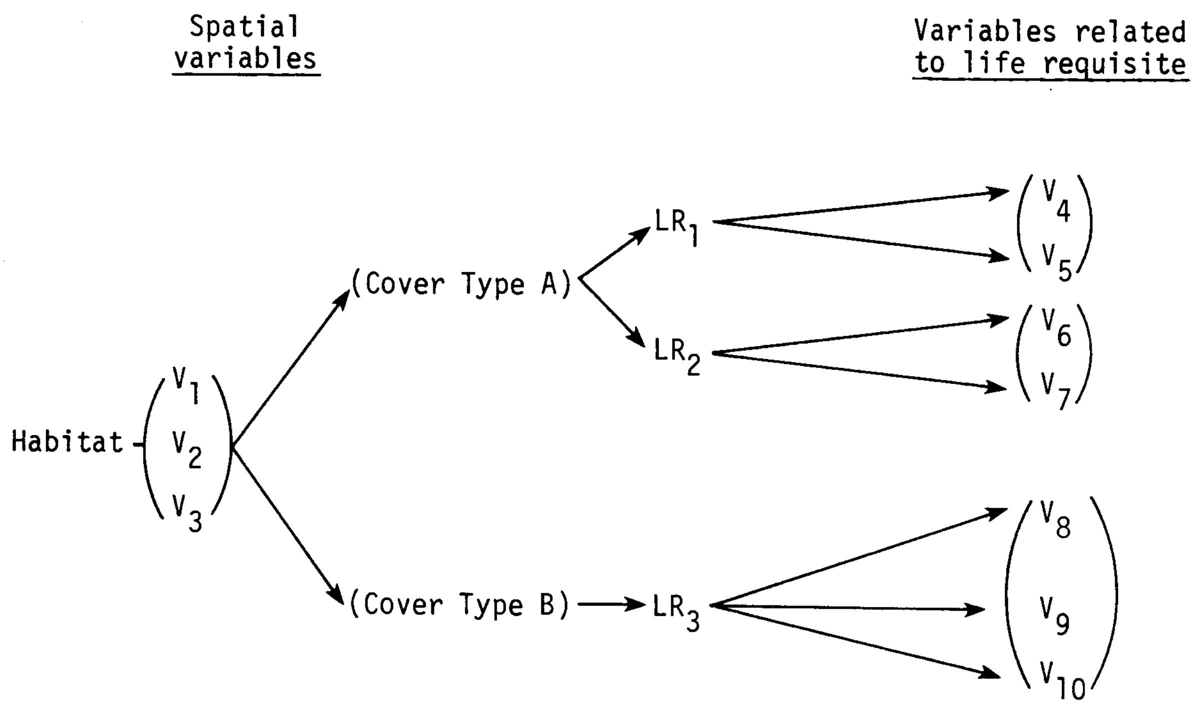

Figure 3-8. Relationship of life requisite and cover type components for a multi-cover type species.

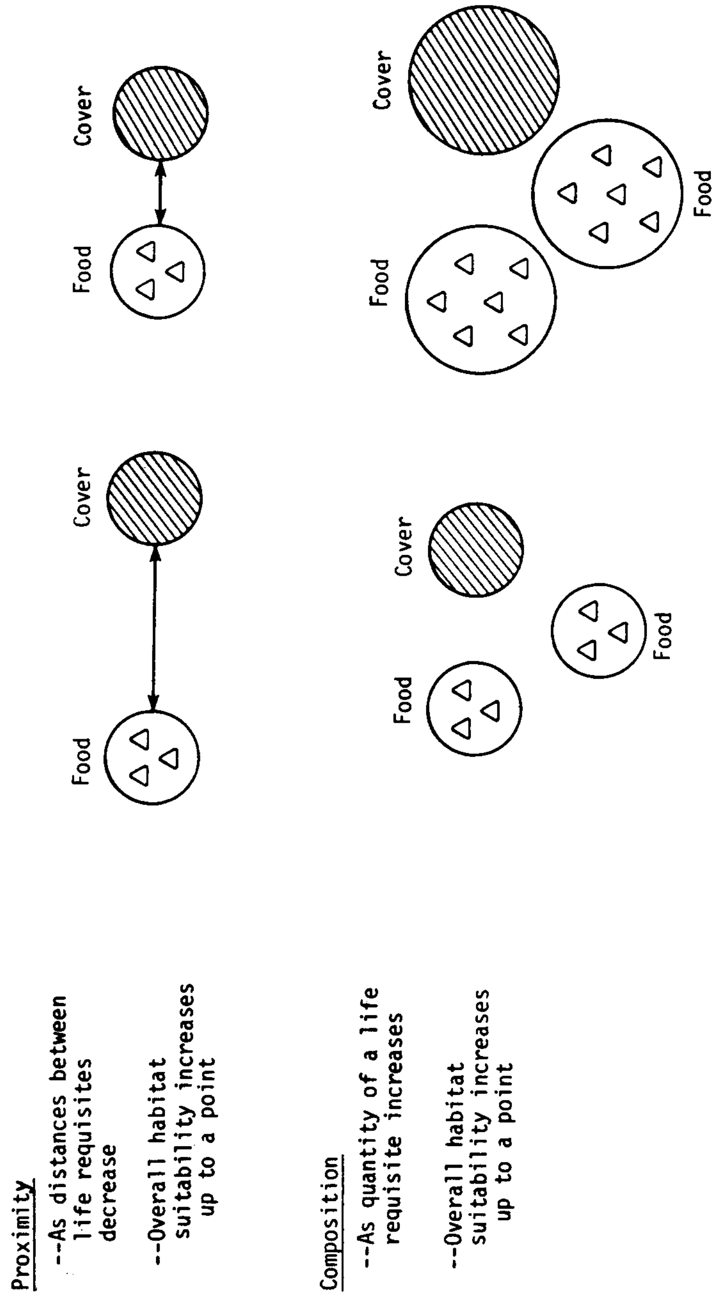

Figure 3-9. Stylized relationship of spatial and life requisite variables to overall habitat suitability.

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:

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

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:

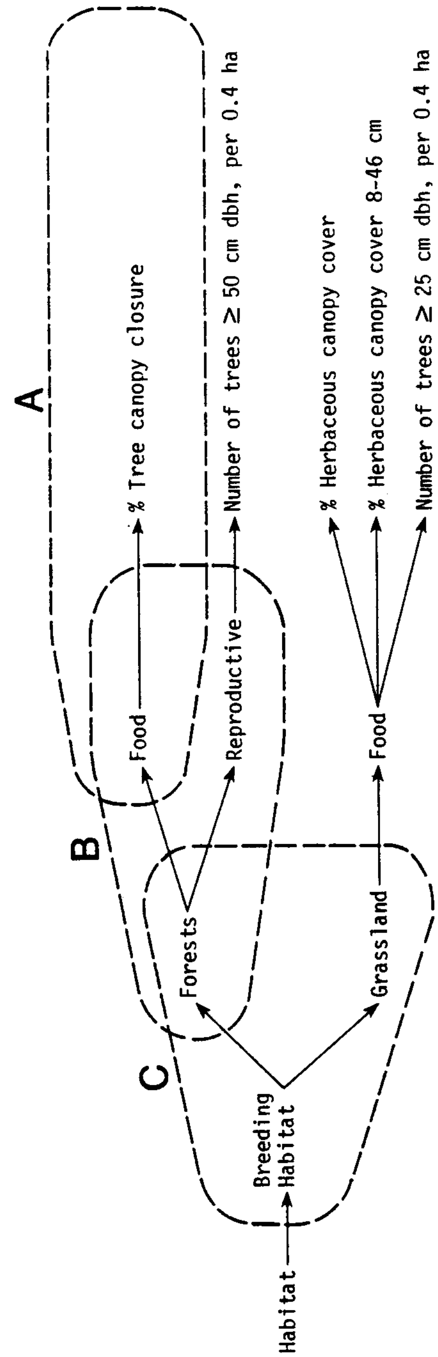

Figure 3-10. Three levels of functional relationships in the red-tailed hawk mechanistic model.