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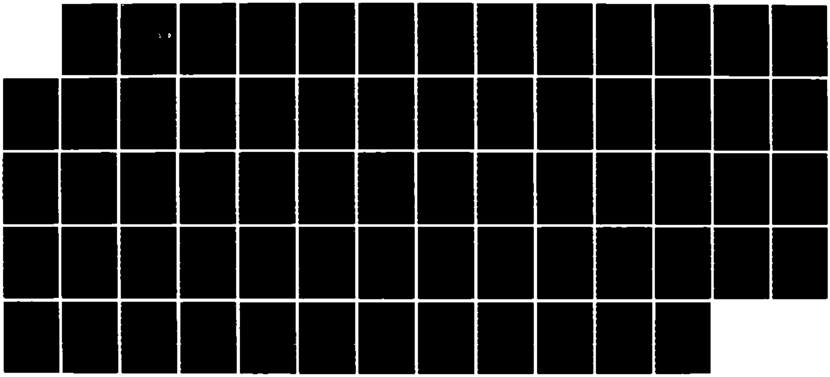

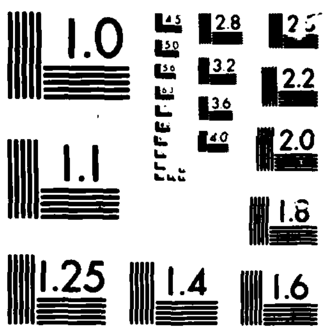

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AIRBORNE SENSOR POTENTIAL FOR HABITAT EVALUATION PROCEDURES (HEP)

by

Barry S. Payne, Katherine S. Long

Environmental Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
PO Box 631, Vicksburg, Mississippi 39180-0631

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Habitat Suitability Index (HSI) models of the US Fish and Wildlife Service's Habitat Evaluation Procedures (HEP) are reviewed with the objective of determining the necessary modifications to model requirements (if any) if data for the models are to be obtained from aerial photographic sensors. The white-tailed deer model was chosen for the conversion exercise because of its interest to human activities that can readily be translated to economic and recreational values.

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20. ABSTRACT (Continued).

Steps that must be included in an optimum remote sensing effort are outlined, with the relevance of each step to the HEP being illustrated where possible.

Forty-one HSI models that are species specific are reviewed to show the feasibility of gathering necessary input data by remote sensing. The guilds formed by grouping species of similar requirements are discussed.

PREFACE

This report provides guidelines for the development of airborne sensor applications to the US Fish and Wildlife Service's Habitat Evaluation Procedures (HEP). Development of the guidelines and procedures reported herein was initiated under the Environmental Impact Research Program (EIRP) Work Unit 31729, Testing of Habitat Evaluation Methods, in May 1982 and continued from October 1982 to May 1983 under Remote Sensing Work Unit 32234, Wildlife Habitat Identification and Mapping Using Airborne Sensors, Surveying and Satellite Applications Program. Both these programs are sponsored by the Office, Chief of Engineers (OCE).

Dr. Barry S. Payne, Aquatic Habitat Group (formerly assigned to the Environmental Analysis Group (EAG)), Environmental Resources Division (ERD), Environmental Laboratory (EL), conducted this study. Dr. Payne and Ms. Katherine S. Long (EAG) prepared this report under the direct supervision of Mr. J. K. Stoll, Chief, EAG. Future work in demonstration and evaluation of the guidelines for application of remote sensing to HEP will be conducted under Work Unit 32234, which remains the responsibility of Mr. Stoll and the EAG, now a part of the Environmental Systems Division (ESD), EL. During the period of this research and reporting, Mr. B. O. Benn was Chief, ESD, and Dr. C. J. Kirby was Chief, ERD; Dr. John Harrison was Chief, EL.

Technical reviews of this report were provided by Dr. Andrew C. Miller of the Aquatic Habitat Group; Mr. James W. Teaford and Ms. L. Jean O'Neil of the Wetlands and Terrestrial Habitat Group, ERD; and Dr. Adrian Farmer, US Fish and Wildlife Service HEP Group, Fort Collins, Colo. The report was edited by Ms. Jessica S. Ruff, WES Publications and Graphic Arts Division.

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CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
acres	4046.873	square metres
feet	0.3048	metres
inches	25.4	millimetres
pounds (mass)	0.4535924	kilograms
square feet	0.09290304	square metres
yards	0.9144	metres

AIRBORNE SENSOR POTENTIAL FOR HABITAT EVALUATION PROCEDURES (HEP)

PART I: INTRODUCTION

Background

1. Considered solely from a natural scientist's perspective and ignoring other cultural aspects of risk assessment, environmental impact assessment is difficult, even if only a fraction of the total system (for example, living organisms) is targeted for impact analysis. Any organism, or in fact any cell within a multicellular organism, is itself a highly evolved system. Each organism functions interdependently with virtually all variables in the environment. Any land-use change alters this environment and triggers responses by organisms in the near area, in the area adjacent to the near area, and so on. Furthermore, these responses can be observed over a long time, although the stochastic aspect of nature obscures the cause-and-effect relationship at a rate that increases exponentially as time elapses.

2. Some responses of organisms to changes in their environment are obvious and predictable. Trees adapted to dry soils will die if permanently flooded. At the other extreme, some responses are so subtle that they go unobserved. The subtlety of a response is due to the negligible effect of the change in habitat relative to the organism's habitat requirements or to the homeostatic tendencies of highly adapted systems, or both. The relative scarcity of methods to quantify cause and effect, as well as cost and time considerations, dictates that only relatively dramatic responses that occur rapidly and nearby will be targeted for consideration in environmental impact analyses of proposed land-use changes. Decisions based on these limited considerations are considered to be representative of those decisions that would have been made if the more subtle responses to environmental changes had been considered. Even with such restrictions, performance of an adequate environmental impact analysis remains a technically complicated task.

3. Analyses of biological impacts have often been approached by descriptively listing species in the vicinity of the proposed land-use change, without considering what would happen to these species once land-use changes

occurred. In other analyses, inferences have been made as to how land-use changes would alter habitats and thus affect species. However, the logic used in developing these inferences has not been presented in a scientifically defensible manner.

4. In an attempt to develop a more reconstructible method of performing and documenting biological impact analyses, the U. S. Fish and Wildlife Service (FWS) developed Habitat Evaluation Procedures (HEP) (USFWS 1980a). These procedures are recommended by FWS as an approach to evaluating the baseline conditions of wildlife habitat and predicting future conditions after specific land-use changes. The HEP represent the most comprehensive approach to habitat-based evaluation of land-use change impacts to wildlife that has been undertaken. The scientific validity of HEP rests on two assumptions:

a. Environmental factors that are predictably related to an area's value as habitat for selected wildlife species can be identified and measured.

b. Wildlife species can be sorted into groups that utilize a similar set of resources in a similar way (such a group is called a "guild" (Root 1967)). Thus, the value of an area as habitat for one species in a guild is likely to be positively and closely correlated to the same area's value to other species in the guild.

5. Clearly, the first assumption is the basis of habitat-based modeling of probable impacts to species due to habitat alteration. Mathematical models equating measurements of an area's characteristics to its suitability as habitat for a particular wildlife species are the basic units of HEP. Many habitat suitability index (HSI) models for predicting habitat quality have already been developed for use with HEP. Some of these models are being field tested in HEP-related research by both FWS and CE. Despite the lack of verification, implementation of HEP has progressed. However, verification of typical models is crucial.

6. The second assumption provides for a broad ecological perspective. If species in an area can be sorted into guilds such that all guilds represent the array of resource utilization patterns that occur, then once the impacts to a representative species from each guild have been predicted, a thorough basis for biological evaluation can be provided to decisionmakers. In some cases, a broad ecological perspective may not be an objective of impact analysis. Perhaps only human-use species, such as white-tailed deer, are of

interest. In this case, all patterns of resource utilization by wildlife need not be considered in the evaluation. However, knowing how the species selected for evaluation relates among possible resource utilization patterns is still useful.

7. Because the HEP suggest a definitive method to describe quantitatively the suitability of a given expanse of territory for supporting specific wildlife species (or "guilds" of wildlife species), they can be a valuable tool for assessing the impact of a given activity on that species or group of species. The HEP require as input certain measurable attributes of the terrain. Depending upon the level of detail required, the acquisition of such input may be infeasible in terms of cost and time if these data are to be acquired only by intensive ground survey. A need has arisen to modify the HEP so that all (or most) of the required input can be obtained by remote sensing, which generally sacrifices fine detail for the capability of acquiring information about a much larger area than would be practical with more precise ground survey techniques.

8. Engineer Pamphlet 70-1-1 (October 1979) sets forth six basic steps toward achieving a successful remote sensing mission. Briefly, these are as follows:

- a. Specify the problem.
- b. Acquire ground control data.
- c. Specify the variables of the remote sensing mission (including flight time, altitude, F-stop setting, etc.).
- d. Manipulate the data.
- e. Extract the data.
- f. Present the data.

In order to obtain the desired information (in this case, input variables for the HSI model(s)), the above scheme should be followed rigorously. Unfortunately, some of the variables required by the HSI models cannot be obtained directly from ordinary photographic imagery. Some variables, such as tree diameter, must be inferred from parameters such as tree crown diameter, assuming a predictable relation exists between the two. A portion of this report is directed to that problem.

Purpose and Scope

9. The purpose of this report is to demonstrate how the input requirements of existing HSI models can be translated from data more-or-less readily derived from aerial photographs, provided the photo-mission has been designed to allow discrimination and measurement of pertinent factors. To illustrate this procedure, a well-known FWS model has been examined for its amenability to the remote sensing technique.

10. This report presents an example of how existing models can be translated into versions amenable to airborne sensor data acquisition and explains how the translation process can be used to modify guild definitions. This guide shows how a relatively detailed species model can be generalized into a simpler cover type-preference model without changing the assumptions of the original model. The model becomes fully amenable to acquisition of habitat data obtained by airborne sensor procedures. Cover type-preference models, once several have been translated, can provide a basis for meaningful guilding of species as well as simpler models for use with HEP.

11. Numerous existing HSI models were reviewed to identify an efficient yet comprehensive approach to developing airborne sensor applications to HEP. Features of this proposed procedure include the following:

- a. Feasibility of using categorical similarities and differences among the habitat data requirements defined in selected HSI models to define a practical set in a representative illustration of airborne sensor applications.
- b. Amenability of existing HSI models to using habitat parameters obtained by remote sensing.
- c. Inability of existing HSI models to make broader than species-specific predictions of habitat suitability because of the disparity between HSI model contents and defined species guilds.
- d. Impact of the disparity mentioned in c above on the development and adaptation of remote sensing technology applied to HSI models.

12. The fundamental objective of both remote sensing procedures and HSI models is to obtain usable, practical information. By identifying the potential problems in using these as complementary techniques, this report lays the foundation for a more cost-effective method of obtaining the information needed to evaluate the environmental impacts of proposed land-use changes.

Organization

13. Part I of the report presents background information and outlines the study purpose and scope. Part II presents discussion of the six steps of a successful remote sensing mission. Part III presents examples of how input requirements for HSI models might be translated to definitively related parameters that can be obtained from remote sensing. Part IV examines other HSI models to find rationales for organizing species into guilds and for evaluating the models' ability to characterize habitats in terms of suitability for members of the specified guild. Methods of acquiring maximum data at minimum cost are also discussed. Part V presents conclusions regarding the feasibility of translating HSI models so that remotely sensed information could be employed to acquire at least some of their required input variables, as well as recommendations concerning how airborne sensor technology may be applied to HEP.

PART II: REMOTE SENSING AS A TOOL IN LANDSCAPE DESCRIPTION

14. As outlined in Part I, six basic steps should ideally be included in a remote sensing effort. The first of these, "problem specification," clearly must be accomplished before other steps can be taken. For the problem addressed in this report, the input data needed for the HSI models must be specified. For a given model, there may be few or many measurable parameters. It would then be appropriate to list the pertinent variables and note which of these are obtainable and at what scale and what film type. (The foregoing assumes that a photographic sensor will be used, which is very likely the case.) If some of the input variables probably cannot be obtained from the proposed imagery, the user can examine another scale and/or sensor to accomplish his aim, or he can translate the required input parameter into one that can be seen on the image. He also has the option of supplementing the remote sensor data with well-placed ground control plots. Parts III and IV address the model translation process as related to existing HSI models.

15. There are, of course, practical limits to which a photograph (or scale) may be enlarged. The ridiculous extreme approaches a ground survey, the use of which it is practical to minimize. The extreme in the other direction (i.e., toward the smallest scale) is that of the Landsat image whose resolution element is about an acre. Thus, the choice of remote sensors would logically depend on the size of the object that is to be imaged.

16. The next step is to acquire ground control data. This is a crucial step in most remote sensing efforts. Generally, if some feature cannot be detected on the ground, it probably cannot be sensed from a greater distance. (There are some exceptions. For example, areas of water-stressed vegetation may be difficult to distinguish on the ground because differences between areas of stressed and nonstressed plants may be too subtle to detect. However, a synoptic view might define stressed areas clearly.)

17. Relative to obtaining ground control data is the need to determine precisely the location of the selected plot on a recent map and on the proposed imagery. Generally, the greater the number of ground control plots, the greater the accuracy of the "factor maps" produced from the imagery. Of course, this procedure is often severely limited by time and/or cost constraints, since this phase is usually the most expensive of the six activities outlined.

18. The third step of a successful remote sensing mission is specifying the variables. This step includes defining the time-of-day and time-of-year the mission is to be flown, the stereo overlap required (if any), the altitude, focal length, and film type to be used, as well as many other less obvious specifications. The one who will extract and present the data obtained from the imagery should be sufficiently informed so that his selections among the variables will result in the most information that can be obtained given the time and cost constraints of a particular effort. The previously mentioned Engineer Pamphlet 70-1-1 provides excellent guidance in these and related matters.

19. Data manipulation after the images have been obtained is the next logical step. This is the procedure by which "raw" images are treated in such a way as to ease the photointerpreter's task of translating from the image to yield the specific data types required by the task. For example, contrast may be photographically or digitally enhanced to highlight feature(s) of interest (e.g., water bodies) so that they may be delineated more precisely. Another form of manipulation involves converting an image to digital form so that it can be automatically processed to yield a desired product.

20. The information extraction step is critical. For most applications, the skill of a human interpreter is relied upon more in this phase than in any other. Experience has shown that the more intimate the interpreter is with the ground conditions, the more accurate is the finished product. The most commonly used and most practical method of data extraction is by human observation, for in most applications this is sufficient. Other optical equipment to magnify or rectify the images are available and can be employed for special products; however, because these tools add still another level of complexity, they are best used when only a few frames are to be analyzed. Information can also be converted to digital form and processed by various kinds of software. Of course, the unit of resolution and the area to be analyzed determine the quantity of data that is to be processed, which influences the cost of the final product. Digital descriptions are especially helpful when such information as area of a particular kind of cover is required.

21. The information gained from analyzing the remotely sensed information often must be presented to a user in a form that he has specified. A popular mode of presentation is the transparent overlay that shows the

interpreted patches, or a "factor map." This overlay is usually in the same scale as a standard topographic map, which might also have been provided by the user. This arrangement has the obvious advantage of enabling one to locate a feature (or set of features) within a frame of reference such that it is easily relocated on the ground. Some users may not require a pictorial representation, but rather measurements of area occupied by certain classes (e.g., areas with forest canopy closure >70 percent) or other areal measurements specified by the nature of the problem to be addressed.

22. As will be illustrated in Part III, many of the input variables required by selected HSI models can be obtained using photographic remote sensing techniques. Those variables that at first appear to be unobtainable by such techniques often bear definite, predictable relationships to variables that can be obtained in this way.

PART III: SAMPLE TRANSLATION OF HSI MODEL: THE WHITE-TAILED DEER

Origin of the Model

23. The white-tailed deer model is translated here for two reasons. First, this model depicts the habitat requirements of an important human-use species. Often the HEP are used only to look at such species, and even the broader-perspective uses of HEP usually include at least some of these species. Thus, translation of this particular model is of immediate utility. In addition, the white-tailed deer model contains several variables common to or similar to those in many other HSI models. Hence, the deer model is not used here merely because it represents a particular group of models, nor is its use solely of species-specific interest.

24. Two white-tailed deer models have been prepared. The first was included in each of the three joint U. S. Fish and Wildlife Service/U. S. Army Corps of Engineers (FWS/CE) demonstration studies (USFWS 1980b, c, and d). The model was revised during a workshop sponsored by the FWS, and a new draft HSI model for the white-tailed deer (USFWS 1983) is under review. This revision implies that the modeling process can be somewhat dynamic and reaffirms the need for easily accessible, updatable, and reanalyzable habitat databases. While the two models differ, much of the data gathered for the first version was useful in the second.

25. The second version of the model was developed in a workshop on white-tailed deer ecology in the Piedmont region of the southeastern United States. This model assumed that fall and winter food requirements determine the suitability of habitats in the Piedmont for occupancy by deer populations. The model could probably be used in other areas where late fall and winter food is considered limiting. Figure 1 gives an overview of the model. The six habitat variables that affect the overall HSI are labeled V_1-V_6. One set of aggregation functions (column 4) shows how suitability indices (SIs) predicted from particular variables are weighted during computation of life requisite-specific SIs. Another aggregation function (column 5) shows the weighting given to each life requisite SI.

26. Figure 2 shows how each variable affects the SI prior to the weighting of effects. This model was developed with the intent of measuring

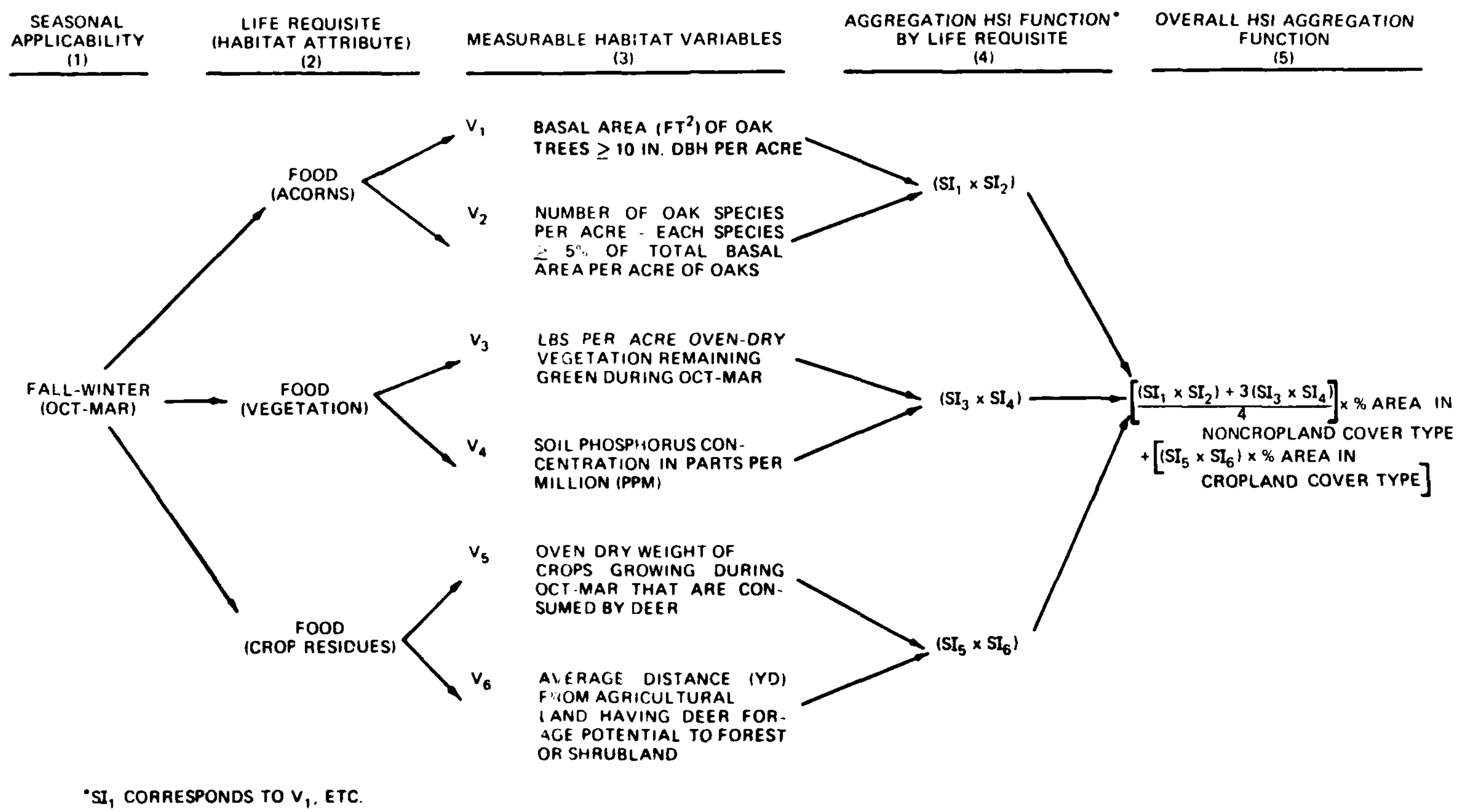

Figure 1. Overview of the white-tailed deer HSI model (adapted from USFWS 1983)

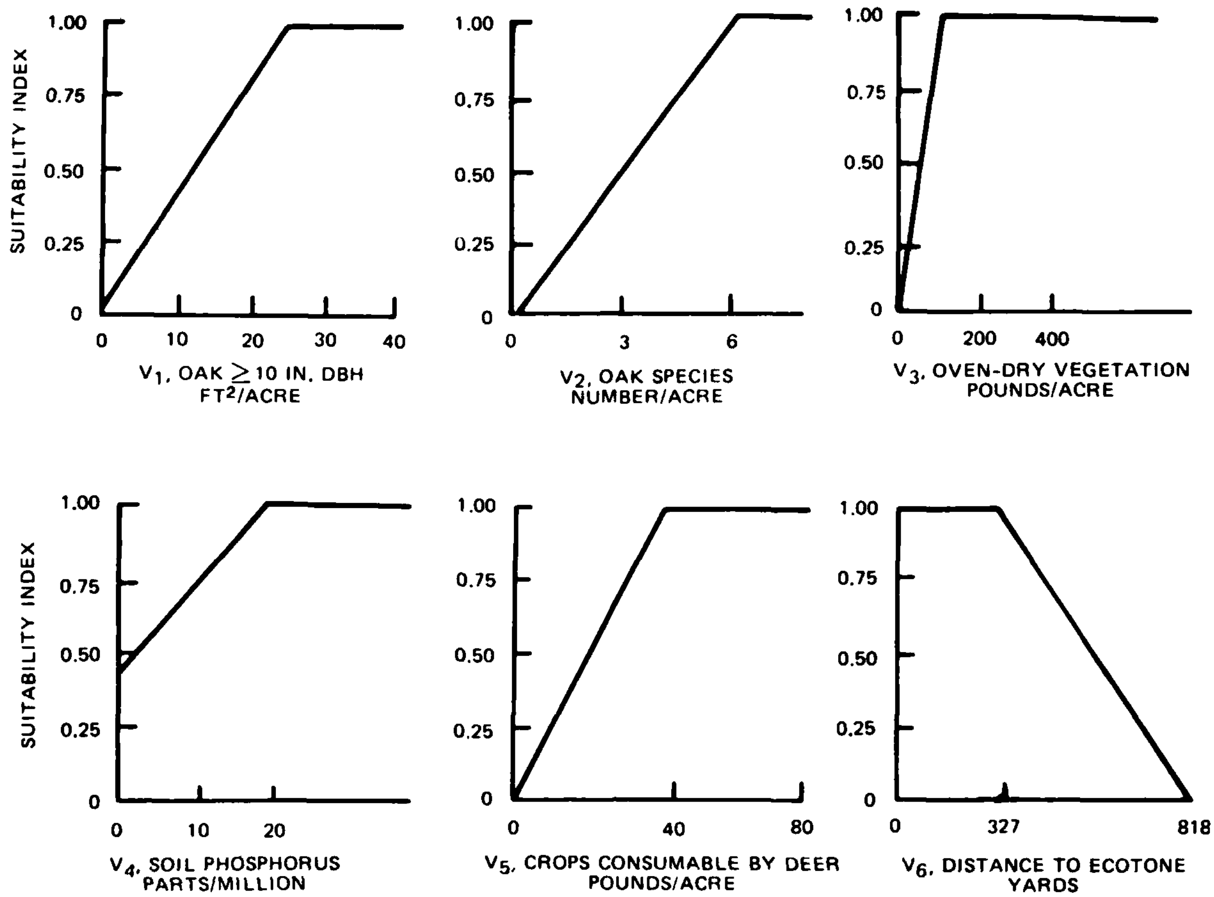

Figure 2. Individual effects of habitat variables on the suitability of habitat for the white-tailed deer (adapted from USFWS 1983)

V_1-V_5 on the ground using techniques referenced within the model text; V_6 was intended to be measured from available aerial photographs. To translate this model directly to one entirely amenable to aerial delineation of variables, V_1-V_5 must be correlated to aerially detectable variables.

Direct Translation

27. Measurements of both V_1 and V_2 are assumed to provide an indirect estimate of the yearly acorn yield per acre. Acorns are recognized as a preferred dietary component of deer. V_1 indirectly measures the density of acorn-yielding oak biomass per acre. A mature oak in the average Piedmont loblolly-pine dominated forest is assumed to have a diameter of breast height (dbh) of at least 10 in.* Other morphometric features of an oak tree, such

* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 3.

as height or crown size, could be equally related to maturation stage. However, average dbh is an easy-to-take field estimate of tree size. Crown diameter (or area) is relatively easy to measure from aerial photographs at intermediate scale (1:24,000). If a suitable relationship of dbh to crown area is available in the literature or can be developed empirically, V_1 can be readily translated to augment airborne-sensor applicability without significantly changing the original habitat variable-to-SI relationship.

28. Gingrich (1971) reported relationships between basal area, number of trees, average tree diameter, and stocking rates (forest canopy closure) for oaks in managed (even-aged) upland hardwood stands. From these relationships, one can derive a relationship between tree diameter and canopy area for different stocking rates (Figure 3). As shown in Figure 3, the canopy area per tree diameter increases at a slightly faster than linear rate with increases in tree diameter. For stocking rates of 50 to 100 percent (50 to 100 percent

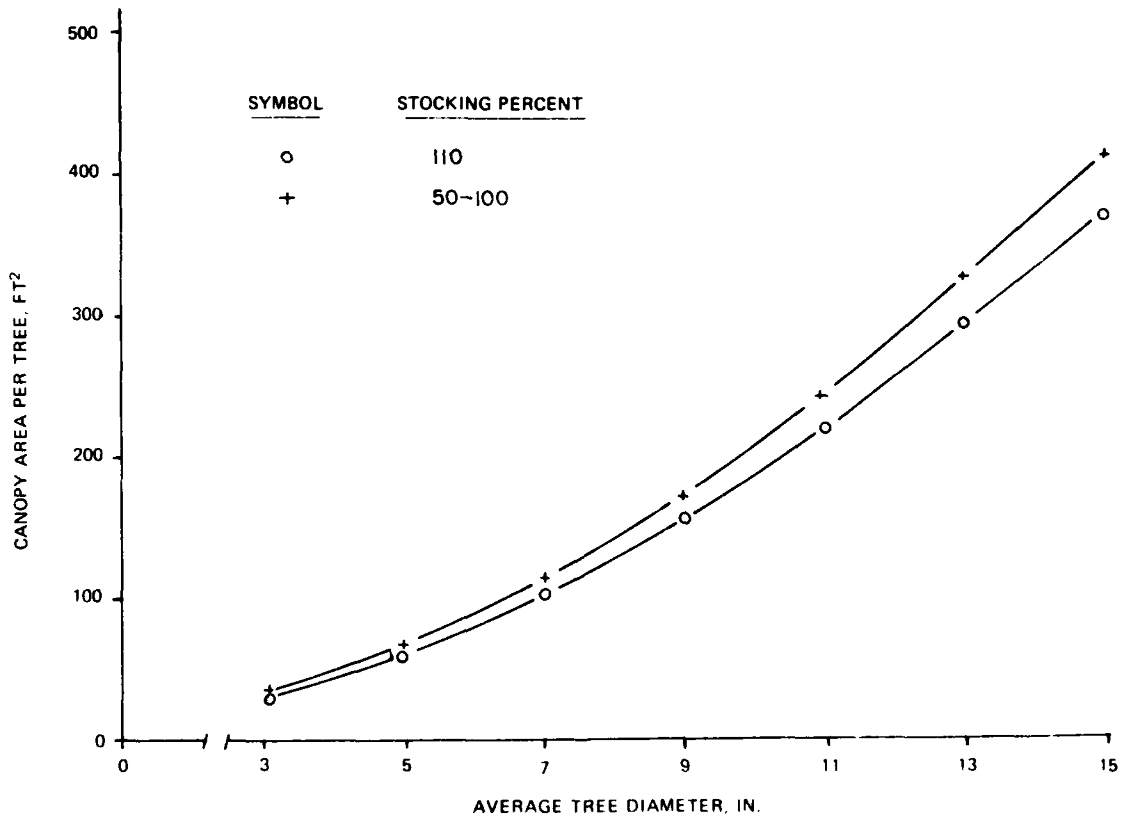

Figure 3. Effects of tree diameter and forest canopy closure on the canopy area of individual trees in roughly even-aged (managed) upland oak stands (adapted from Figure 1 in Gingrich 1971)

tree canopy closure), a single relationship of tree diameter to crown area is observed. In overstocked woods (100 percent canopy closure, but with some crowding that leads to competition for available light), the canopy area is reduced by about 10 percent for any size tree above 9 in. dbh.

29. Averaging the canopy area predictions for trees ≥10 in. dbh in overstocked and understocked to fully stocked forests, the habitat variable "basal area of oaks ≥10 in. dbh per acre" can be converted to "percent canopy coverage of oaks ≥200 ft^2 canopy area." Figure 4 shows the translation of this variable in terms of SI predictions. The basal area of oaks ≥10 in. dbh per acre is used to estimate, in part, the probable yield of acorns. The total canopy area (expressed as percent canopy cover) of oaks of this size range should be an equally valid estimation of the probable yield of acorns, and the new variable is detectable in a vertical view of a forest canopy.

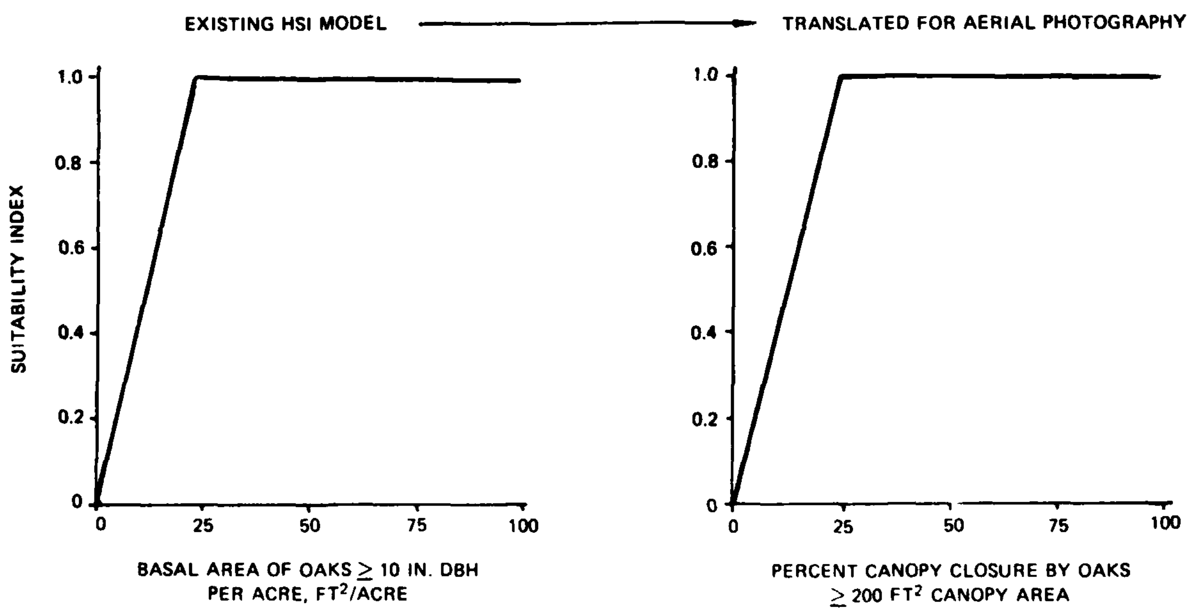

Figure 4. Conversion of tree basal area to canopy area per acre to allow aerial evaluation of habitat suitability for the white-tailed deer (based on data in Gingrich 1971)

30. Still, there remain problems related to the accurate aerial delineation of the percent canopy coverage of oaks ≥200 ft^2 in canopy area. First, oak trees must be distinguished from other components of the forest overstory. Using large-scale photographs (about 1:5,000) and with extremely cautious photointerpretation guided by ground truth data, some investigators report substantial success in identifying deciduous tree species (Thorley 1975 and

references within). However, more often, estimates of the percent representation of oaks in the overstory will require the gathering of some ground-survey data. Within restricted regions (generally, areas of a size applicable to habitat analysis related to most land-use change projects (10^3 to 10^5 acres) will fall within this category), the relative dominance of oaks in the deciduous component of an upland or bottomland overstory may be relatively constant and perhaps even predictable without ground data. For example, many southern upland deciduous forests are so heavily dominated by oaks that the percent contribution of oaks to the overstory of a 10^3- to 10^5-acre tract of forest, for which there has probably been some on-site visitation in relation to the project, may be estimated with considerable confidence without acquiring detailed ground-survey data. While a risk is obviously associated with using photointerpretation guided by limited ground truth data, this risk will often be acceptable in light of p ject-related time and cost constraints.

31. While the relative contribution of oaks to a deciduous overstory is often reasonably predictable within a small tract of forest, the size and spatial distribution of overstory trees is not easy to predict without some specific data. Even if a forest has a uniform canopy coverage (and most do not), the task of quantitatively predicting the size-specific spatial distribution of overstory trees is usually more difficult than predicting predominant tree species. Interestingly, the white-tailed deer HSI model (USFWS 1983) recognizes two kinds of habitat variables: spatial and nonspatial. Measurements of V_1, V_3, and V_5 (Figure 2) are all characterizations, indirectly at least, of plant biomass per unit area. V_2 and V_4 are quality modifiers for oak mast and forage, respectively. These variables are referred to as "nonspatial" in the white-tailed deer model. V_6, which represents the distribution of specific agricultural crops among natural plant associations, is a "spatial variable."

32. The distribution of plant biomass in natural plant associations is rarely homogeneous, except when considered for a very small area. Thus, the nonspatial variables do indeed have a spatial component that must be considered. With careful design of a study, ground truth data that are sensitive to the heterogeneity of plant biomass distribution can be collected. This may also require careful review of available aerial photography to help position sampling stations. Thus, if these nonspatial variables can be measured directly from aerial photographs, after the variables have been translated as

described above for V_1, their spatial distribution can be seen while it is measured and does not have to be accounted for via careful placement of sampling stations.

33. When habitat features are likely to be highly heterogeneous in their spatial distribution, the need for accurate measurement of variables is a compelling reason for using aerial photography to delineate variables or translations of them. If the cost of data acquisition is consequently reduced by greater reliance on aerial photography, then increased accuracy of the database is not the only benefit.

34. V_4 in the deer model requires the measurement of soil phosphorus concentration. Presumably, soil phosphorus is related to site quality. If one assumes that soil phosphorus is positively correlated to the nutritive quality of overwinter foliage on herbaceous evergreens in the understory, then at sites with high soil phosphorus, the quality of the vegetation will be greater than at similar sites with lower soil phosphorus. Production is directly measured by V_3. V_4, an indicator of nutritive value of the understory vegetation, is probably not independent of V_3, although the model seems to assume this. The model narrative does not support this assumption, however. Thus, what V_4 actually contributes remains unclear. Complete independence of V_3 and V_4 is probably not a valid assumption and it is possible that V_3 alone could be used.

35. V_1 in the white-tailed deer model has been shown to be correlated to the percent canopy coverage of mature oaks. Several methods of estimating the prevalence of oaks in a deciduous overstory have been discussed. A second problem remains. Photointerpretation of the distribution of percent canopy coverage by oaks with canopies $\geq$ 200 ft^2 requires that individual tree canopies be detectable in aerial photographs. Photographic scales of 1:24,000 will usually allow this. Photograph acquisition costs for a 10^3- to 10^5-acre target can be expected to decrease as photographic scale decreases. If two aircraft use cameras with the same focal length lens but one flies twice as high as the other, four times as many frames must be exposed by the camera in the lower flying aircraft to provide images of the same area. However, photointerpretation can become more difficult (time-consuming and potentially less accurate) as photographic scale decreases. Therefore, the trade-offs between the photographic scale and accuracy versus cost of variable delineation must be determined for all variables (or categories of these based on expected

resolvability) that are proposed for aerial delineation.

36. The second habitat variable in the deer HSI model, species richness of oaks, requires translation only in a restricted sense. As written, the model states that only those oak species be counted that contribute at least 5 percent to the basal area of oaks $\geq$ 10 in. dbh per acre. Obviously, replacing the phrase "basal area of oaks $\geq$ 10 in. dbh per acre" with "percent canopy coverage of oaks $\geq$ 200 ft^2 canopy area" provides the necessary translation. As discussed, difficulty will be experienced in distinguishing oaks from other deciduous trees. Therefore, species-specific recognition of oaks is, based on cost if not technical constraints, an unreasonable expectation of conventional photointerpretation. Oak species richness must be estimated on the ground or based on biologists' fundamental familiarity with the forest photographed.

37. V_2 may have only marginal importance in the HSI model. The actual bearing that V_2 has on acorn yield is less clear than the aggregation function ($SI_1 \times SI_2$) suggests. The species richness of oaks is included in the HSI model because black and white oaks have different acorn production cycles. The black oak produces acorns on last year's wood; thus, a given acorn crop is the result of energy allocations made over two growing seasons. In comparison, the white oak produces acorns on this year's growth. The logic for including a species richness variable in the model is that a single harsh winter or poor growing season might have different effects on the acorn yield of white versus black oaks. Thus, high oak species richness is assumed to represent increased probability of stable acorn yields over several years. However, V_2, oak species richness, is not the same as the ratio of white to black oaks. Perhaps the modelers recognized this discrepancy and attempted to simplify measurement of V_2 by not requiring separation of oak species into the white versus black groups once species numbers are tabulated. Nevertheless, the importance of accurate measurement of V_2, based on the technical discrepancy summarized above, is particularly questionable. Also, the combined role of V_1 and V_2 in the overall HSI aggregation function is given low weighting.

38. The oven-dry weight per acre of evergreen foliage in the 0- to 6.6-ft height zone at the onset of winter, V_3, cannot easily be translated to a variable more amenable to aerial delineation.

39. Nevertheless, the task remains to translate directly the existing V_3-to-SI relationship into one more amenable to aerial evaluation. Conroy, Oderwald, and Sharik (1982); Wiggers et al. (1978); and Blair and Enghardt

(1976), as well as references within these publications, all concluded that deer-forage production in a forest is generally inversely proportional to the percent tree canopy closure. However, both Conroy and his associates and Wiggers et al. modified this conclusion. Conroy showed that, in the Virginia Piedmont, soil moisture and solar insolation gradients can affect forage yield for sites with a single canopy closure. Wiggers et al. suggested that the general inverse relationship between forage production and canopy closure (or basal area of overstory trees) is not simply linear. Instead, as the forest overstory closure increases, the rate of decrease in forage production is reduced until further increases in basal area of overstory trees are associated with a slight increase in production in fully closed-canopy forests. However, both investigations concluded that the overstory parameters mainly show an inverse proportional relationship to forage production.

40. If the V_3-to-SI relationship in the existing deer model is accepted as valid, then based on the information summarized in the preceding paragraph, percent tree canopy closure can be related to V_3 as depicted in Figure 5. This new relationship assumes that 200 lb per acre of evergreen foliage will be observed only in forests with minimum canopy closure (25 percent). The slope change predicted at about 60 percent canopy closure is based on the observation by Wiggers et al. (1978) that as the forest canopy becomes more closed, the rate of decrease in deer forage yield is slowed. A minimum winter forage yield of 40 lb per acre has been assumed based on data presented by Wiggers et al. and Hurst, Campo, and Brooks (1981).

41. Admittedly, the relationship drawn in Figure 5 is based on a speculative series of assumptions. The assumption of a generally inverse linear relationship between percent tree canopy closure and forage yield, and even of the slope of this relationship, is largely supported by the available pertinent literature. Assuming that Figure 5 represents a valid hypothesis, the obvious translation of the existing SI model, relative to V_3, is outlined in Figure 6.

42. No single way exists to translate V_5 (oven-dry weight density, in pounds per acre, of crops growing during October through March that are consumed by deer) into a variable amenable to remote sensing. First, the values of V_5 in any region must vary greatly from October through March. A narrower time period for measurement of V_5 is needed. Then, for any specific land region of interest, V_5 probably can be related to the percent agricultural

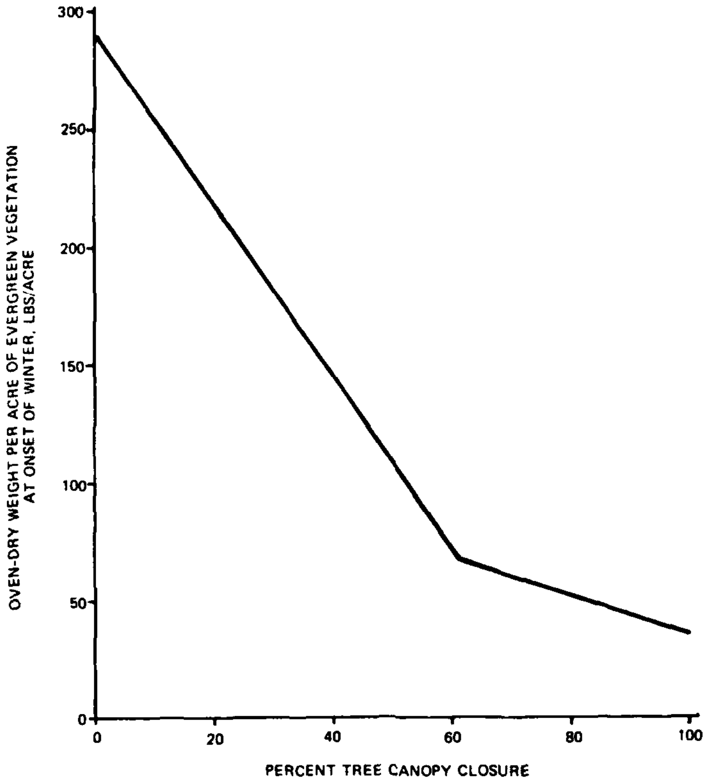

Figure 5. Effect of tree canopy closure on the production of evergreen vegetation in the 0 to 6.6-ft height zone (based on conclusions of Blair and Enghardt 1976; Conroy, Oderwald, Sharik 1982; and Wiggers et al. 1978)

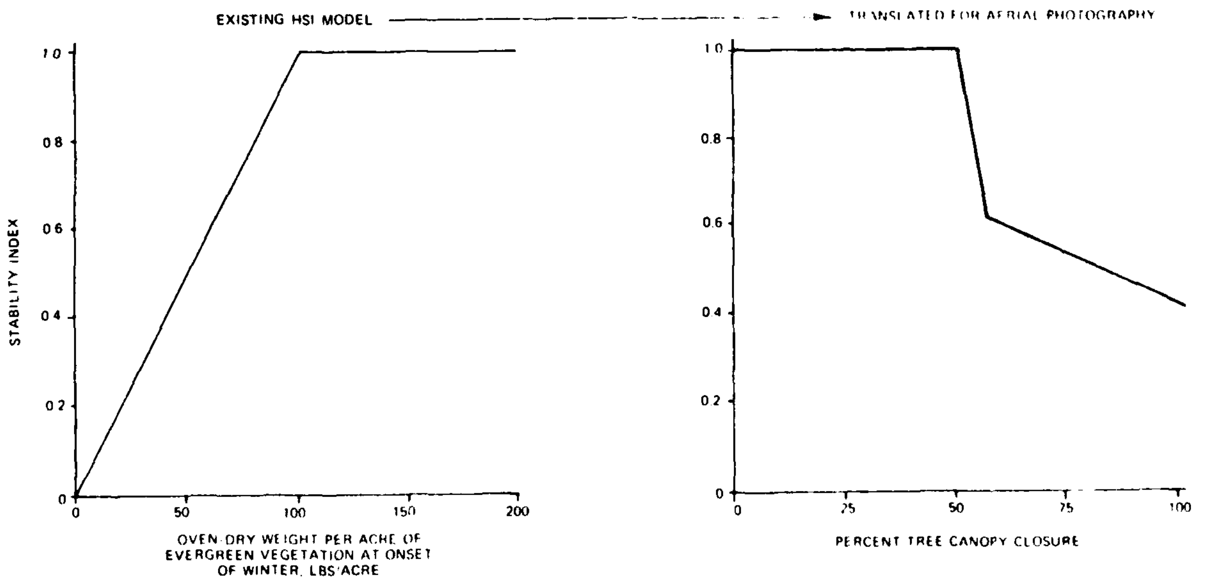

Figure 6. Conversion of prewinter production of evergreen vegetation to percent tree canopy closure to allow aerial evaluation of habitat suitability

lands--a variable fully amenable to remote sensing. Coordination with agricultural extension service agents and other professionals in related areas will probably allow definition of a relationship that can be applied within a given region. As a general example, a hypothetical relationship between V_5 and percent agricultural lands is shown in Figure 7. Figure 8 then shows the effect of this variable translation in terms of predicting habitat suitability.

43. As mentioned earlier, V_6 in the existing deer model, is already amenable for aerial delineation and the existing model narrative addresses its measurement.

General Translation

44. A generalized version of the direct aerial translation of the white-tailed deer model must trade off potential model accuracy with data acquisition costs. Then, less costly options for HEP implementation can be provided. To do this, measurement of habitat variables on a continuous scale needs to be replaced by quick estimation of class ranges of habitat variables (and, thus, of ranges of and median SIs) that apply to vegetation cover types that are distinguishable in an aerial photograph. Once class ranges are set, the variable does not have to be estimated for the entire photographed landscape. The intent, of course, is to minimize photointerpretation time and maximize the allowable photographic scale. Both outcomes will reduce data acquisition costs.

Life requisite-acorns

45. Recall that two variables affect acorn yields of habitats, V_1 and V_2 (Figure 1). Also, recall that the combined role of both V_1 and V_2 in prediction of the overall HSI (Figure 1) is of reduced weighting relative to V_3 and V_4. Furthermore, V_2 may not measure the aspect of species richness that is of importance, and cannot be measured from an aerial photograph. Clearly, to reduce data acquisition costs, V_2 should be eliminated from the generalized aerial model.

46. Considering just V_1, any cover type that is likely to have $\geq$20 percent canopy coverage by mature oaks will usually provide a good acorn crop (SI ranges from 0.65 to 1.00; median = 0.83; see Figure 4). Cover types with canopy coverage by mature oaks ranging from 10 to 20 percent will provide a fair crop (SI ranges from 0.35 to 0.65; median = 0.50). Poor acorn yields can

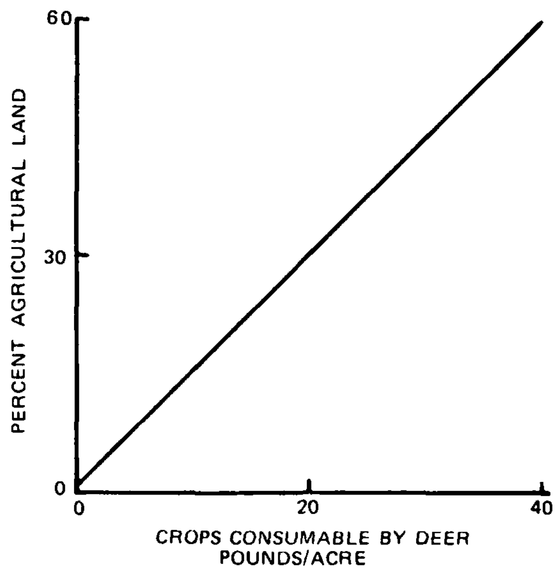

Figure 7. Hypothetical region-specific relationship of percent agricultural land to crops consumable by deer

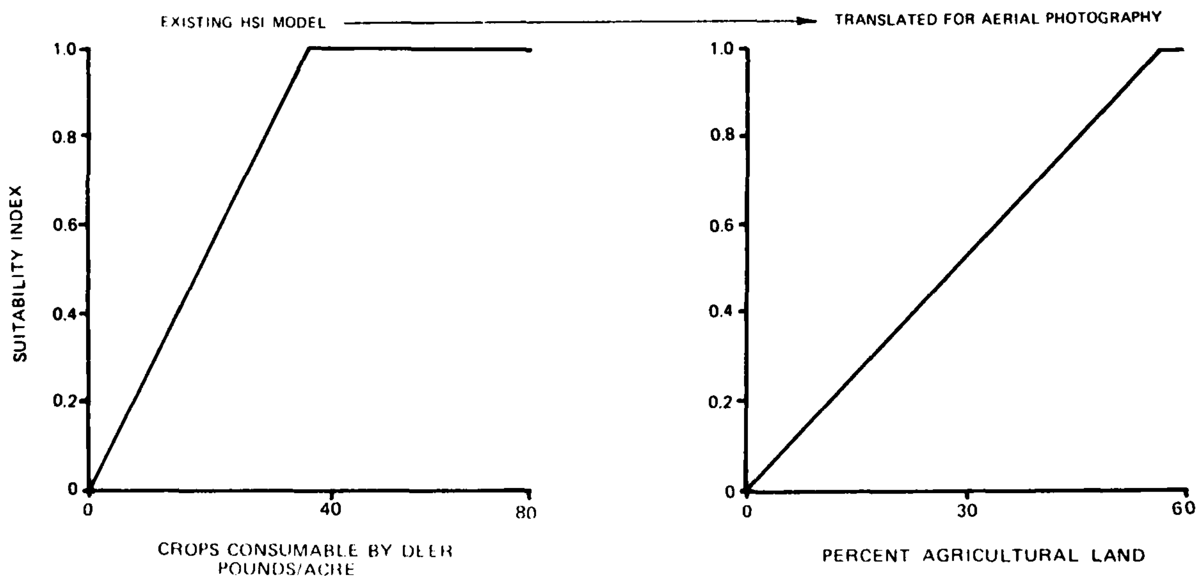

Figure 8. Conversion of crops consumable by deer to percent agricultural land to allow aerial evaluation of habitat suitability

be expected in cover types that usually provide <10 percent canopy coverage by mature oaks (SI ranges from 0.00 to 0.35; median = 0.18).

47. Four aspects of cover types containing trees need to be estimated in order to map those that are directly interpretable in the terms described above:

a. Maturity (roughly, if oaks are present in the overstory, are they likely to average $\geq$200 ft^2 canopy area?).

b. Canopy closure.

c. Deciduousness.

d. Oak prevalence among the deciduous component of the overstory.

48. First, a tree-containing cover type must be assigned to a maturity class. For most applications, the tree overstory is on average either old (tall) enough that essentially all oaks in that overstory have individual canopies $\geq$200 ft^2 or so young (short) that overstory oaks are not $\geq$200 ft^2 in canopy area.

49. The second aspect that requires estimation is the average percent tree canopy closure. Arbitrarily, four classes of tree-containing cover types can be mapped: closed forests have >75 percent canopy closure; moderately closed forests have >50-75 percent canopy closure; open forests have $\geq$25-50 percent canopy closure; savannahs have <25 percent canopy closure.

50. Deciduous forests or savannahs are obviously more likely to yield acorns than are pine forests or savannahs. Thus, the relative deciduousness is an important estimate. If a deciduous or pine forest or savannah is defined as having $\geq$75 percent of the tree canopy closure in deciduous or pine trees, respectively, a mixed forest or savannah is one with $\geq$25 to 75 percent of the tree canopy as either deciduous or coniferous.

51. The final aspect of a forest or savannah, the prevalence of oaks among the deciduous component of the tree overstory, requires some on-site familiarity. Arbitrarily, three classes are suggested: an oak-dominated deciduous canopy has >75 percent of the deciduous canopy as oaks; oak common has $\geq$25-75 percent; oak rare has <25 percent. These estimates of oak prevalence are less demanding than providing a precise measurement on a scale of 0 to 100 percent. Based on these class range definitions and on the relationship of percent canopy closure of mature oaks to the acorn life requisite SI (Figure 4), minimum, maximum, and median SIs can be readily assigned to 36 mature forest or savannah cover types (immature forests or savannahs, by

definition, all receive an SI of zero). Table 1 summarizes these quality point assignments.

52. The tree canopy descriptions in Table 1, with the exception of oak prevalence, can be quickly estimated from aerial photographs with virtually no on-site familiarity. Estimation of oak prevalence requires some on-site familiarity. However, by setting rather large ranges for estimates of this parameter (at the expense of SI prediction accuracy), the degree of on-site familiarity required can be minimized. Reach boundaries for class ranges of the three tree canopy descriptions (plus maturity to make four) can be envisioned as four maps that can be quickly produced as overlays to the aerial photographs. All four maps, when simultaneously overlaid, allow construction of a complex factor map showing the spatial distribution of the 36 mature forest or savannah cover types. The median SI predicted for each type (Table 1) can be multiplied by the cumulative area of each cover type to provide a quick estimate of the overall habitat quality (relative to the acorn life requisite) of any area of interest. By adjusting class ranges and ground truth data acquisition (to guide photointerpretation), this approach can be scaled to suit project priorities.

Life requisite-vegetation

53. The data requirements for predicting the vegetation life requisite (Figure 1) are more easily generalized. Variables V_3 and V_4 affect this life requisite. For the same reasons detailed for V_2, V_4 should be eliminated from the generalized model. Thus, only percent tree canopy closure (V_3) must be estimated to predict the second life requisite SI. The relationship of V_3 to this SI, as developed in the direct translation of the deer model, is shown in Figure 6. Roughly, when percent tree canopy closure is ≤ 60, the predicted SI ranges from 0.60 to 1.0 (median = 0.80). That is, areas with tree canopy closures of 60 percent or less generally provide good vegetation forage. Forests with percent tree canopy coverage ranging from 60 to 100 generally provide fair vegetation forage (HSI ranges from 0.40 to 0.60; median = 0.50). Interestingly, habitats of poorer quality cannot be predicted given the original V_3-to-SI relationship viewed in light of information presented in paragraph 40.

54. The slope of the relationship of percent tree canopy closure to the vegetation life requisite is steep from 50 to 60 percent canopy closure. At 50 percent closure, an SI of 1.0 is predicted, while at 60 percent the

predicted SI is 0.6. At about 59 percent closure, an SI of 0.65 is predicted. This SI value is the one arbitrarily used to separate good from medium quality habitat with respect to the acorn life requisite (paragraphs 45-52). Obviously, using 60 percent canopy closure and an SI of 0.6 makes more sense than trying to discern 59 percent closure just so that an SI of 0.65 can be predicted for the vegetation life requisite. Thus, the values of SI used to define good quality habitat for the vegetation life requisite cover a slightly larger range than for the acorn life requisite.

55. Both the acorn and vegetation life requisite SI predictions require map overlays of percent tree canopy closure. However, the classes of canopy closures needed for the acorn life requisite have so far been defined as >75, >50-75, >25-50, and <25 percent closure, while for the vegetation life requisite, classes of >60 and 0-60 are required. Maximum precision in predicting SIs for both life requisites results from combining information from the two maps. Then, required canopy closure classes run >50, >60-75, >50-60, >25-50, and <25 for the acorn life requisite and >60, >50-60, and 0-50 for the vegetation life requisite.

56. Table 2 shows the modifications that must be made to Table 1 to incorporate this more detailed information. Table 3 shows the vegetation life requisite SI predictions that are possible by maximizing use of the available data on percent tree canopy closure and based on the relationship shown in Figure 6.

Life requisite-crop residues

57. This life requisite is affected by V_5, the oven-dry weight of agricultural crops growing during the period October to March that are consumable by deer, and V_6, the average distance from any area to the edge of agricultural land having deer forage potential. For a specific land region of interest, V_5 can be related to percent agricultural lands (Figure 7). Then this translation of V_5 can be used to predict SI_5 as shown in Figure 8. The relationship of V_6, which is amenable to aerial evaluation, to SI_6 is shown in Figure 2. Recall that the aggregation function used to weight the two SIs and compute the crop residue life requisite SI is $(SI_5 \times SI_6)$ (Figure 1). Based on just V_5, good (SI ranges from 0.65 to 1.00; median = 0.83), fair (SI ranges from 0.35 to 0.65; median = 0.50), and poor (SI ranges from 0.00 to 0.35; median = 0.18) quality habitats have >35, >20-35, and $\leq$ 20 percent agricultural lands, respectively (Figure 8). With respect to V_6 only, areas where the distance

from random points to the edge of agricultural land having deer forage potential is less than 500 yd provide good habitat (SI ranges from 0.65 to 1.00; median = 0.83); areas where this distance is 500-660 yd provide fair habitat (SI ranges from 0.35 to 0.65; median = 0.50); areas where this distance is greater than 660 yd provide poor habitat (SI ranges from 0.00 to 0.35; median = 0.18). Table 4 shows the crop residue life requisite SIs that are associated with the nine possible terrestrial cover types outlined above (three for percent agricultural lands times three for the distance to the edge of agricultural lands).

58. As discussed for similar situations, reach boundaries for lands with low, medium, and high values for percent agricultural lands can be easily estimated from aerial photographs and drawn as an overlay to the photography. Likewise, reach boundaries for short, medium, and long average distances from any area to the edge of agricultural land can be easily drawn as a map overlay. These two overlays, placed over the aerial photography simultaneously, can be used to construct a complex factor map showing the distribution of the nine cover types outlined in Table 4.

PART IV: ANALYSIS OF OTHER SELECTED HSI MODELS

59. Based on the background presented in Part I, two objectives for HEP research are apparent:

- a. Provide valid methods for sorting species into guilds.
- b. Provide valid species-specific habitat evaluation models for representatives from each guild.

60. Two other research objectives can easily be added. These focus on minimizing the cost of acquiring habitat data and maximizing the use of such data. Both aims are commonly expressed needs and do not require further justification for research. These two additional objectives are:

- a. Develop methods of habitat data acquisition that allow accurate predictions of habitat suitability at minimum cost.
- b. Develop data storage and analysis methods that allow ready access and reuse of habitat data.

61. A third additional objective of HEP research is to apply the use of airborne sensors to delineating and mapping habitat characteristics, since this has been found to reduce the need for detailed on-ground measurement efforts while enhancing the sensitivity of a data set to spatial patterns of landscape features. If flexible reuse of the data is desired, spatially arranged databases can now be routinely constructed, modified, and reanalyzed using automated systems readily available to U. S. Army Corps of Engineer (CE) Districts. Airborne sensor data are commonly used in such systems, but any kind of spatially arranged data may be used.

62. Clearly, efforts to accomplish the first two research objectives have affected airborne sensor applications. Therefore, a summary review of the status of guild and model research is appropriate. Since more attention has been paid to modeling, these efforts will be reviewed first.

Status

HSI modeling

63. Species-specific HSI models are planned, being developed, or are complete for 8 mollusks and crustaceans, 6 reptiles and amphibians, 54 fish, 77 birds, and 28 mammals (Roberts, O'Neil, and Jabour 1983). Like the white-tailed deer model described in Part III, each model relates an index value for observed versus optimum habitat conditions (optimum habitat and unsuitable

habitat equal 1 and 0, respectively) to specific environmental variables. This is done separately for each variable that is assumed to affect an important life requisite, such as food, water, cover, or reproductive requirements. For some species, models focus fairly equally on all life requisites. In many models, food or cover requirements totally or heavily dominate the habitat quality considerations.

64. An aggregation function combines the suitability indices that are determined from each environmental variable for all suitability indices related to a single life requisite. A new SI is thus computed that is an estimate of habitat value for a single life requisite based on the combined effects of all variables. A second aggregation function is used to weigh the relative importance of each life requisite SI. Then, a final HSI is computed to estimate the overall suitability of an area to support the species.

65. HSI models that have been constructed so far can be modified or built anew to fit project-specific settings (USFWS 1981a). However, real and perceived time and cost constraints can prevent new model construction or substantive modification of extant models by individuals who must implement HEP. Realistically, the HSI models that have been and are being produced by research units of the FWS and the CE are perhaps best considered as volumes being filed into a library of state-of-the-art HSI models. Therefore, a brief review of these models is appropriate.

66. Three joint FWS/CE demonstration studies of operational aspects of applying HEP to early stage planning of land-use changes form the basis for most of the forthcoming review of 41 HSI models. The projects for which these studies were conducted were Big Sandy Creek, Texas; Dan River Basin, Virginia; and Little Calumet River, Indiana (USFWS 1980b, c, and d). For each of these projects, several HSI models were used to evaluate wildlife impacts that might be associated with several alternative plans. CE Division and District and FWS Regional and Field Office personnel implemented HEP (USFWS 1980b, c, and d) and then reported on the merits and limitations of using HEP (USACE and USFWS 1982; USFWS 1981b; and Slowinski, Staples, and Nelson 1981).

67. The implementation reports represent some of the few sources of written accounts of several HSI models. These models were constructed by a process of literature review and consultation with species experts, the process that is still used. Thus, the insights that can be obtained by reviewing these demonstration studies are useful.

68. Tables 5, 6, 7, and 8 were compiled from the three studies and show the forest and tree, shrub, herbaceous vegetation and ground surface, and waterbody and wetland characteristics, respectively, that must be measured as inputs to each species' HSI model. The species evaluated (columns) are arranged from left to right in descending order of the number of habitat variables required by the species models. Variables (rows) are arranged by natural categories; within each category, variables are listed from top to bottom in roughly increasing order of detail. Initial inspection of these tables reveals the following information:

a. Most variables are used in more than one model (e.g., average height of overstory trees must be measured for four species: Carolina chickadee, black-capped chickadee, wood thrush, and barred owl).

b. Many variables that are listed individually are, in essence, subtle variations of the same habitat feature (e.g., average height of overstory trees, average dbh of overstory trees, and forest overstory size class are all measurements of the size of the forest overstory).

c. Most variables must be measured by field crews on the ground (e.g., the average dbh of overstory trees and the numbers of snags and potential nest cavities can be directly measured only by close inspection from within a woodland).

d. Nearly all species-specific models are built around a largely species-unique set of variables, especially if variables described in subparagraph b are considered to be unique and require independent measurement (e.g., while the hairy woodpecker, Carolina chickadee, gray squirrel, black-capped chickadee, Cooper's hawk, fox squirrel, wood thrush, barred owl, central newt, and white-tailed deer models all include the variable called "percent tree canopy closure," if the entire set of variables in each model is compared across species, little other similarity is apparent).

e. Usually, only the more general variables are shared in several models (e.g., average size of overstory trees, percent tree canopy closure, percent shrub canopy coverage, average height of herbaceous vegetation, percent canopy coverage by herbaceous vegetation, water regime, and water current).

f. Most HSI models are based on only a few habitat variables. If each HSI model represents an operational definition of a species' resource requirements, then the definitions are greatly abridged. For example, the pine warbler's habitat needs are defined in the draft model by just two variables, the percent canopy closure of pines and forest overstory size class.

69. Table 9 summarizes the information presented in Tables 5-8 and

shows the percent contribution made to each species' HSI model by the four major types of habitat variables. In Table 9, generally, species in the top rows are more dependent on tree or forest measurements; species in the middle rows are more dependent on shrubland and openland variables; and species at the bottom of the table are more reliant on waterbody or wetland characteristics. The total number of variables in each model is provided in Table 9. Observations that can readily be drawn from Table 9 include:

a. Most (28 of 41) of the models depend on more than one of the four major types of variables.

b. Several models rely entirely on forest (6) or waterbody and wetland (4) variables; few models rely entirely on shrub (2) or grass, forb, and ground surface (1) characteristics.

c. In 9 models, at least 50 percent of the variables characterize forests or trees; only 5 models have at least 50 percent shrub-related variables; 18 have at least 50 percent grass, forb, and ground-surface variables; 10 have at least 50 percent waterbody or wetland related variables.

70. Some of the individual models will be reviewed in more detail below. First, the relationship of guilds to the application of HSI models is discussed.

Guilds

71. Available guidance on guild use. In the FWS manual on implementation of HEP (USFWS 1980a), a method is presented for sorting potential evaluation species into guilds. Beyond this guidance, little technical attention has been given to further development of guilding methods that bear directly on HEP. In the FWS manual, two types of guilds are proposed: feeding and reproductive guilds. Animals are sorted into feeding guilds according to differences in modes of feeding (e.g., carnivores versus herbivores) and the strata in which they feed (e.g., tree canopy versus terrestrial surface). Reproductive guilds are constructed based only on strata locations, but otherwise are similar to feeding guilds for the purposes of the following discussion.

72. Strata locations and feeding mode descriptors can be used at various levels of detail (Figures 9 and 10). By hierarchically arranging guild descriptors according to their level of detail, the FWS proposes to provide a method that allows scaling of the intensity of HEP implementation in response to the priority of a land-use change project (as but one example of a factor affecting the funds available for conducting a HEP analysis).

73. Figure 11 shows a feeding guild matrix for a few terrestrial species

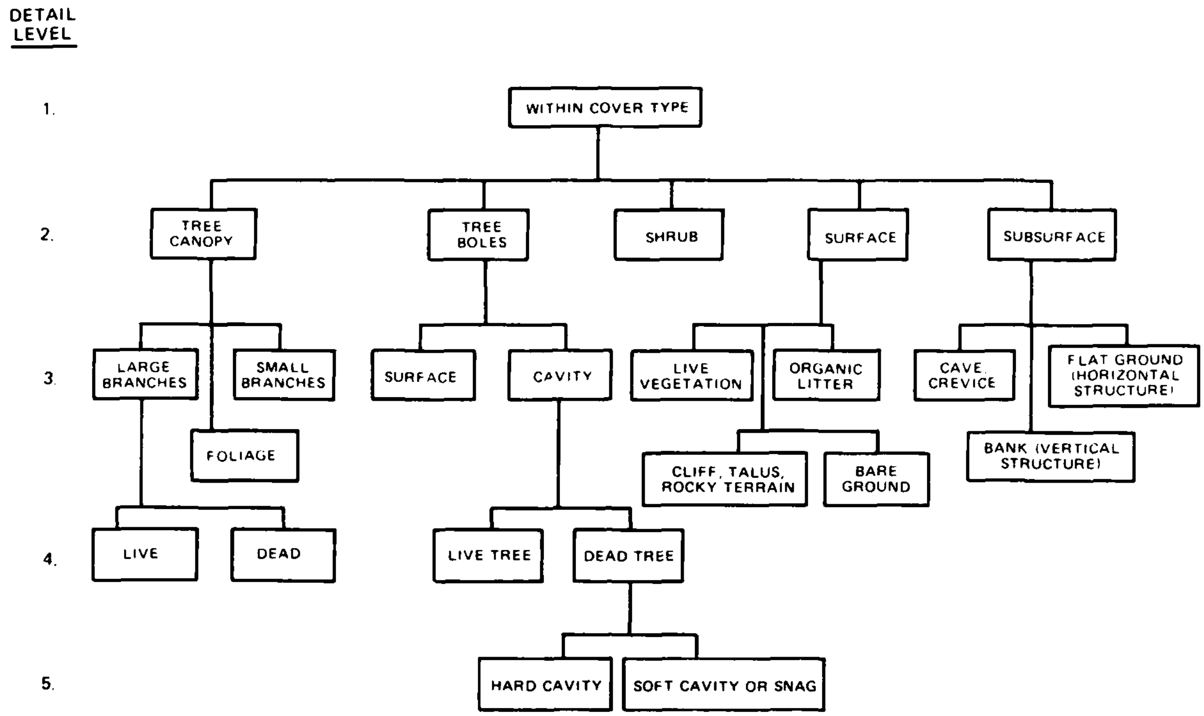

Figure 9. Strata location descriptors at various levels of detail (adapted from USFWS 1980a)

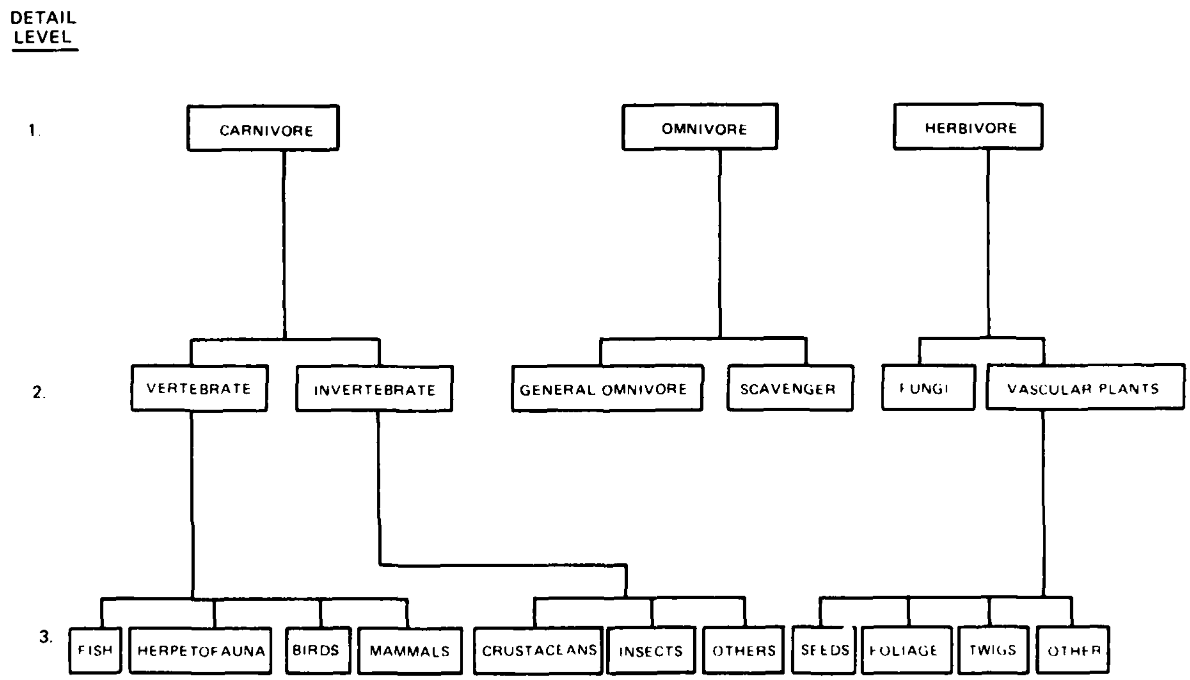

Figure 10. Feeding mode descriptors at various levels of detail (adapted from USFWS 1980a)

STRATA LOCATION	FEEDING MODE					
	VERTEBRATE CARNIVORE	INVERTEBRATE CARNIVORE	GENERAL OMNIVORE	SCAVENGER	HERBIVORE (FUNGI)	HERBIVORE (VASCULAR PLANTS)
TREE CANOPY		HAIRY WOODPECKER				FOX SQUIRREL GRAY SQUIRREL
TREE BOLES		HAIRY WOODPECKER	PILEATED WOODPECKER CAROLINA CHICKADEE			
SHRUB LAYER						WHITE-TAILED DEER EASTERN COTTONTAIL EASTERN WOODRAT
TERRESTRIAL SURFACE	BOBCAT RED-TAILED HAWK RED-SHOULDERED HAWK BARRED OWL	NINE-BANDED ARMADILLO	GRAY FOX RACCOON			WHITE-TAILED DEER EASTERN COTTONTAIL EASTERN WOODRAT GOLDEN MOUSE FOX SQUIRREL
TERRESTRIAL SUBSURFACE						

Figure 11. Feeding guild matrix for terrestrial species in a Southeastern deciduous forest (adapted from USFWS 1980a)

that might occur in a Southeastern deciduous forest. This matrix represents a product of the HEP guilding procedure using feeding mode and strata location descriptors of level 2 detail. According to the FWS guidance on scaling of species selection in response to project constraints, this matrix would be elaborated by using level 3 descriptors or simplified by using level 1 descriptors. At level 1 there are 3 potential guilds; at level 2 there are 30; and at level 3 there are 132. Thus, to provide a broad ecological perspective using this approach to scaling, theoretically a range from at least 3 to as many as 132 species could be evaluated using species-specific HSI models. Many theoretical guilds will contain no occupants. For example, wildlife species that feed on fish while located in a cave are not likely occupants of a typical Southeastern deciduous forest. However, it remains true that as guilds become more specifically described, many more species must be evaluated to maintain the broadest ecological perspective.

74. Critical evaluation of guidance on guild use. Presumably, as a guild matrix becomes more detailed, so does the confidence with which a species-specific habitat quality evaluation study can be assumed to reflect habitat requirements for other unstudied members of a guild. This assumes

that the HSI models for species that are all members of more detailed guilds bear increased similarity. A cursory review of several existing HSI models in light of the proposed guilding procedures shows that this assumption is invalid.

75. The three joint FWS/CE demonstration projects mentioned in paragraph 64 included six terrestrial and mainly carnivorous wildlife species that forage almost exclusively in the forest (single-cover users in the language of HEP). The six species are the hairy woodpecker, Carolina chickadee, black-capped chickadee, wood thrush, barred owl, and Cooper's hawk. All six birds are members of a single feeding guild, if considered at the first level of specificity and for a single cover type such as deciduous forest; they are all "terrestrial carnivores" (Figure 12). Both the chickadees and the thrush are partially herbivorous, but these birds feed mostly on insects and other small invertebrates. When the six species models are reviewed specifically for the food life requisite, substantial commonality among the models is apparent.

		CARNIVORE		OMNIVORE		HERBIVORE	
		VERTEBRATE	INVERTEBRATE	GENERAL	SCAVENGER	FUNGI	VASCULAR*
TERRESTRIAL	CANOPY		HAIRY WOODPECKER CAROLINA CHICKADEE BLACK-CAPPED CHICKADEE				CAROLINA CHICKADEE BLACK-CAPPED CHICKADEE
	BOLE		HAIRY WOODPECKER CAROLINA CHICKADEE BLACK-CAPPED CHICKADEE				CAROLINA CHICKADEE BLACK-CAPPED CHICKADEE
	SHRUB		CAROLINA CHICKADEE BLACK-CAPPED CHICKADEE				CAROLINA CHICKADEE BLACK-CAPPED CHICKADEE
	SURFACE	COOPER'S HAWK BARRED OWL	WOOD THRUSH BARRED OWL				WOOD THRUSH

* FEEDING FROM THIS GUILD IS LESS THAN FROM OTHER GUILDS

Figure 12. Feeding guild matrix for six mainly carnivorous and terrestrial species that forage almost entirely in forests (adapted from USFWS 1980b, c, and d)

76. Five of the models (all but the black-capped chickadee) include two variables, percent tree canopy closure and forest overstory size (as either average height or dbh of the overstory trees), in the aggregate function relating habitat variables to food value of the habitat. Furthermore, the relationships of these two variables to habitat suitability are virtually identical in all five models (Figures 13 and 14). The black-capped chickadee model considers only percent tree canopy closure to be related to food value of the habitat, and the relationship of this variable to habitat suitability is slightly different than for the other five species because full canopy closure is not considered optimum habitat (Figure 13c). That the black-capped chickadee model requires only one variable and the other five birds (especially the congeneric and functionally similar Carolina chickadee) require at least two variables is unexplained by the brief literature reviews that accompany the mathematical models. The models for the other five birds equate food value with cover or cover and reproductive value of a habitat. The authors of the black-capped chickadee model chose instead to single out one habitat variable

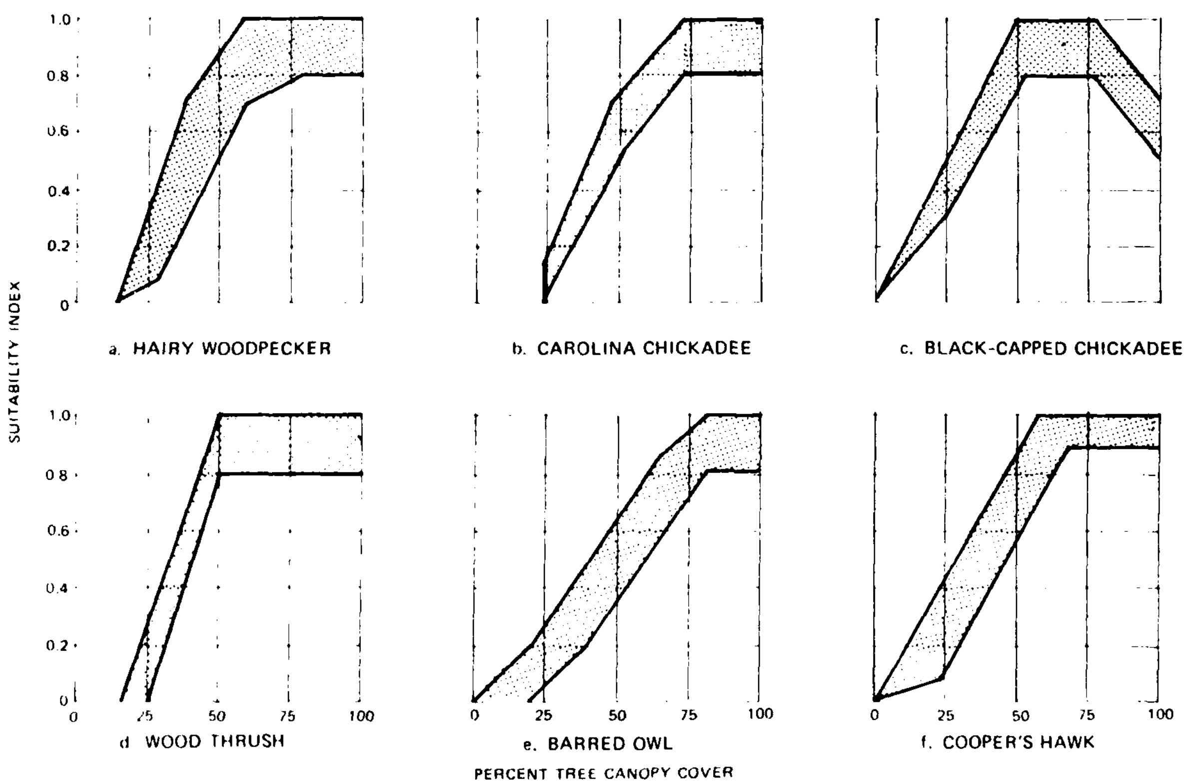

Figure 13. Effect of cover by forest overstory trees on the food value component of the HSI model (adapted from USFWS 1980b, c, and d)

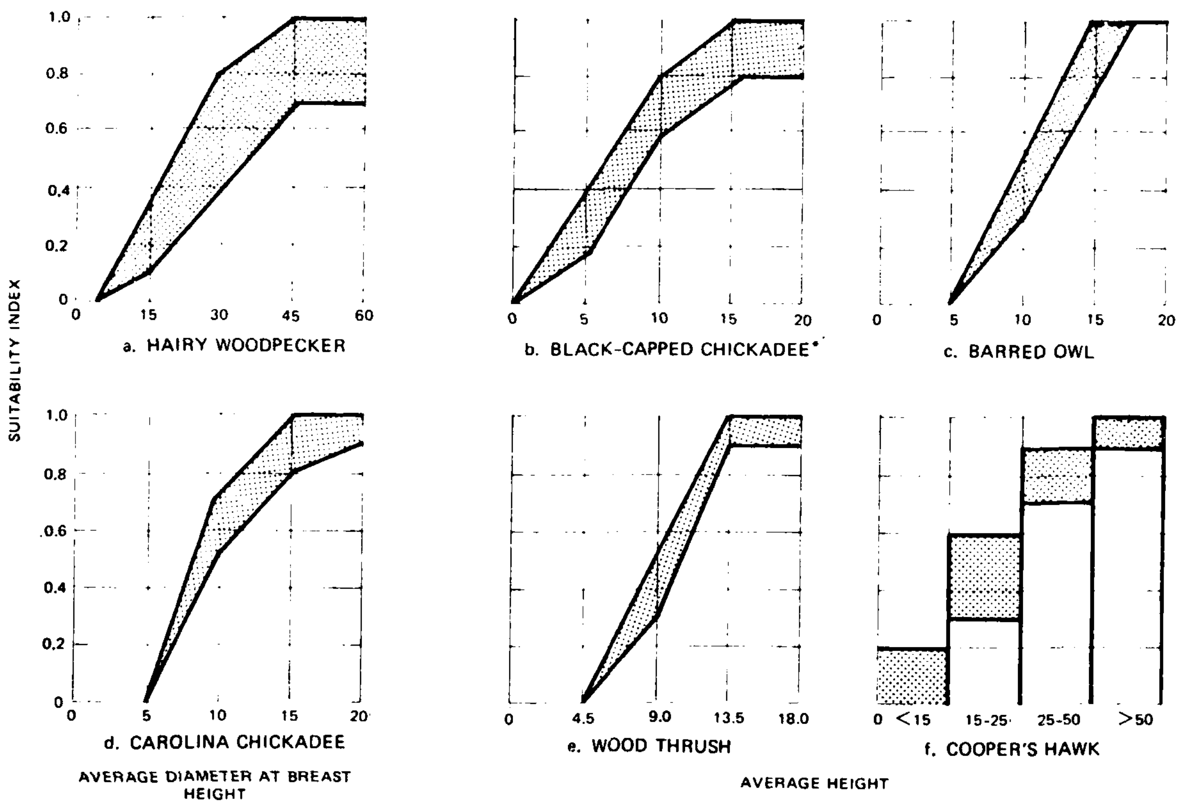

Figure 14. Effect of size of forest overstory trees on the food value component of the HSI model (adapted from USFWS 1980b, c, and d)

to evaluate the food value of an area. If, like the other five species models, the cover requirements of the black-capped chickadee are considered equal to food requirements, then average height of overstory trees is in fact related to habitat quality in a fashion essentially identical to all five other models (see Figure 11c versus a, b, d, e, and f).

77. Thus, based on the observed HSI model similarities, all six species could be considered members of a single general guild; all are species that feed most effectively in tall and nearly fully closed-canopy forests. Described this way, this guild is simply a slightly more elaborate description of the deciduous forest cover type. (A forest cover type can, according to FWS guidance, have from 25 to 100 percent tree canopy closure. A deciduous forest has a deciduous to evergreen canopy closure ratio greater than one.) Recall that using the FWS guilding framework (Figure 12), the most general guild cell containing all six species was identified as "terrestrial

carnivores." Clearly, this guild definition bears no direct relationship to the similarities that can be recognized among the six HSI models. This is not to say the six birds are not terrestrial carnivores--in the main, they are. Rather, identifying them as terrestrial carnivores does not provide straightforward assurance that an evaluation (for feeding requirements only, in this example) of a deciduous forest using the Carolina chickadee model is likely to yield a result more correlated to the result that would have been observed using another terrestrial carnivore such as the hairy woodpecker, as opposed to a terrestrial omnivore such as the gray squirrel. As long as the terrestrial omnivore shared a preference for tall, closed-canopy forests, separate evaluation of the omnivore and carnivore could yield similar conclusions.

78. At the next level of specificity in defining guilds, the remaining habitat variables and their relationships to feeding requirements included in the six models are no more meaningfully related to the guild definitions. At this second level, each of the six birds predominantly occupies one or more of the following feeding guilds (see Figure 12):

a. Invertebrate carnivores that use tree canopies.

b. Invertebrate carnivores that use tree boles.

c. Invertebrate carnivores that use shrubs.

d. Invertebrate carnivores that use the ground surface.

e. Vertebrate carnivores that feed on the ground.

79. The model for the hairy woodpecker (now in guilds a and b above) includes the number of snags greater than 25 cm dbh per acre and the size of the continuous forested stand as variables coequal to overstory tree size and percent canopy closure in determining the food value of a deciduous forest. In comparison, the model for the Carolina chickadee (in guilds a, b, and c, as well as being marginally herbivorous) suggests that percent canopy closure of deciduous trees in a stand is coequal to overstory tree size and percent canopy closure in determining the food value of a deciduous forest. These differences between the woodpecker and chickadee models are not clearly aligned to the chickadee's partial herbivory and shrub-layer insectivory as opposed to the woodpecker's restricted insectivory on tree boles and in tree canopies. This is but one example. If any other pair of the six species models were similarly compared, the same disparity between guild definitions and model contents would be found.

80. In summary, at level 1 specificity, the similarities that exist

among species models are not related to guild definitions. At level 2, a common choice based on the demonstration studies and intuition (level 2 is an intermediate level that presumably makes a trade-off between HEP implementation cost and evaluation accuracy), the models become increasingly unrelated to guild definitions. Thus, remarkably, expenditure of additional resources to increase the level of detail does not improve the confidence level of the HEP application. In fact, the perspective actually provided becomes increasingly misleading. This criticism is not of HEP in theory, but rather of HEP as so far available for implementation. The current disparity of the guilding and HSI modeling procedures accounts for a shortcoming of HEP in providing a defensible and clearly understandable broad ecological perspective.

81. To maintain ecological validity and provide a reconstructible and readily interpretable logic for HEP implementation, the guild definitions must be similar to the species-specific HSI models. If the HSI species models are recognized as already simplified attempts to define a species' niche (conclusion f, paragraph 68), all species included within any guild must share a virtually common model. Otherwise, guilding of species serves no ecologically defensible purpose.

Immediate Needs

82. Thus far, more technical attention has been paid by both the FWS and the CE to developing valid species-specific HSI models than to developing methods of defining guilds that provide a sound mechanism for scaling HEP implementation efforts as well as a clear ecological perspective. One reasonable suggestion is to scrutinize the existing HSI models for categorical similarities of habitat variable-to-suitability relationships. Recognizable common features in several models provide a logical basis for developing a procedure for constructing guilds that will enhance a defensible and understandable broad ecological perspective while minimizing the number of evaluation species that must be used in a HEP effort.

Identifying similarities among models

83. As shown in Tables 5-8, variables from existing models can be roughly arranged into groups that measure distinct aspects of the landscape. That is, there are variables that measure aspects of forests and trees, shrublands and shrubs, herbaceous vegetation and the ground surface, and

waterbodies and wetland. Furthermore, within these general groups, variables can be arranged according to what type of and how specific a characterization of the landscape is provided by measurement of each variable. For example, among variables that measure cover or density of trees (shown in Table 5), percent tree canopy closure is less specific than percent canopy closure of mast-producing trees, which is in turn less specific than the number of snags per acre that are greater than 25 cm dbh. As already discussed, a few variables that are differently named in different species' HSI models actually measure essentially identical landscape characteristics. These variables, such as average dbh and height of overstory trees (both measures of the size or age of the forest overstory) should be considered as a single variable. Then, the number of common features that are potentially recognizable among the HSI models is increased.

Relations to guild use

84. For any variable that is shared by several HSI species models, careful inspection of the variable's relationship to the HSI in each model should yield useful suggestions for guild definitions. For example, when all models that include the variable "percent canopy closure by trees" are reviewed, the conclusion is that two guilds of animals have been modeled that use forests: species that prefer closed versus open-canopied forest. Likewise for the variable size of forest overstory trees, at least two guilds are suggested--species that prefer tall, mature woodlands as opposed to species preferring shorter, younger woodlands. Thus, four potential general guilds are suggested: species preferring tall closed-canopy forests; tall open-canopy forests; short closed-canopy forests; and short open-canopy forests.

85. As mentioned, most of the variables that are shared in several models are general characteristics of the landscape, such as percent tree canopy coverage, average size of overstory trees, percent shrub crown closure, percent herbaceous canopy cover, and coverage height of herbaceous vegetation. More specific variables, like percent canopy coverage of mast-producing trees $\geq$ 20 cm dbh, percent canopy coverage by preferred shrubs (fruit and seed producers such as blackberry, maple, and wax myrtle), and percent canopy coverage by herbaceous vegetation $\geq$ 20 cm tall, are usually unique to one or a few models. Also, these more specific variables suggest more specific guild definitions: species that rely on acorns or certain seeds and fruits as a critical component of their diet or ground-nesting species that prefer tall but

herbaceous cover. At this level of habitat description, often not enough species models are available to reveal much intermodel commonality. That is, the species involved are the only members of these specific guilds that have been considered thus far by modelers. Also, at this level of specificity, modelers may be more likely to err by overemphasizing the importance of specific habitat characteristics. Certainly, at this level, the selection of each new required model input must be well founded. The negative effect each detailed and species-unique variable has on the operational utility of HEP is overwhelming, since the number of species that must be evaluated to represent the broadest ecological perspective can grow exponentially with the addition of each new and more specific level of guild definitions.

86. The presence of detailed variables within some models may indeed be well founded. If such variables prove to be necessary in a number of models, the array of possible guilds will become so large that the broadest ecological perspective cannot be provided by a HEP analysis because of cost constraints. Especially then, the relationship between the more general guilds and all of the species-specific models must be clear. This will allow judicious selection of fewer evaluation species without losing sight of what portion of the analysis sheds light on other species versus what portion does not. For example, if the hairy woodpecker is selected for use in analyzing a deciduous forest, the data generated on percent tree canopy closure and overstory size will be directly applicable to a partial interpretation of how valuable the same forest might be for the black-capped and Carolina chickadees, wood thrush, barred owl, and Cooper's hawk, since all of these species share the woodpecker's preference for tall closed forests. Of equal importance, the remaining doubt about how well these five species are represented by the woodpecker can be focused on the nature of the guild definitions at the level of detail at which the six birds no longer all fall into a single guild. This degree of understanding of the interspecific applicability of HSI evaluations cannot be obtained using the current HEP guild procedures.

Relation to airborne-sensor applications

87. Habitat variables in most of the existing HSI models are intended to be measured using on-site methods. None of the existing models have been constructed with the intent of using airborne sensors to delineate all variables. If airborne sensors are to be used effectively, then existing models must be translated. Many of the variables in Tables 5-8 must be renamed or

correlated to other variables before they can be aerially delineated. The original variable's relationship to habitat suitability must be considered during these changes, as should the potential for maximizing intermodel similarities so that fewer representative models must be translated and tested by the research community. A foundation for developing a useful guild procedure can be laid as models are being translated.

88. As shown in Part III for the white-tailed deer, models can be translated in two ways. The existing model can be translated without significant change by carefully correlating the present variables to ones more amenable to aerial detection without substantially altering the original habitat variable-to-suitability index relationship. In comparison, models can be generalized by casting aside variables that are either correlated to other variables in the same model or given low weighting in the aggregation functions. To further generalize the models, HSI values can be assigned to slightly detailed cover type descriptions that would usually be associated with particular ranges of habitat variable values. Both of the latter modifications can be used to reduce HEP data acquisition costs while still retaining a habitat-based evaluation model that has most of its original meaning. Information in Tables 6-9 suggests that detailed habitat variables are often highly species-specific and potentially correlated to less detailed variables included in a single HSI model. Unless species-specific glimpses of habitat quality are desired, then a compelling reason for applying many of the HSI models exactly as they are written does not exist. In fact, until guild definitions that directly relate to model contents are developed for use (and this will undoubtedly invoke modifications to many models), applying generalized versions of existing HSI models represents state-of-the-science use of HEP if a broad ecological perspective is purported. Generalized versions should provide models that have substantial similarity to at least a few other species models. Preliminary review of existing models suggests that to provide such intermodel relationships, only slightly detailed descriptions of cover types need to be included in many HSI models.

89. Virtually direct translation of existing ground version HSI models into versions more amenable to airborne sensor applications will provide an opportunity for critical review of models with the intent of streamlining them without sacrificing the detail at which species-to-habitat relationships are modeled. However, if detail must be sacrificed in order to allow airborne

sensor use, the detail lost may often be mitigated by the greater ease of assessment and greater coverage afforded by airborne sensor techniques. Since the detailed habitat variables are often unique to one or very few species models, measurement of these variables does little to provide a defensible broad ecological perspective. Simplification of already simple models may often be necessary because of the diminished returns, as ecological insights, provided by increased investments in acquiring and analyzing detailed habitat data.

PART V: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

90. From the brief review of HEP and HEP-related research and the exemplary translations of white-tailed deer model, five main conclusions were drawn:

- a. Existing HSI models have been developed with the intent of measuring most, and many times all, habitat variables using on-site and sometimes detailed procedures. At least two categories of variables may prevent cost-effective use of airborne sensors to delineate and map these variables. First, some variables are simply hidden from vertical view (such as forest mid- and understory features) (paragraph 68). Other variables, especially those estimates of openland habitat features, may be difficult to resolve in aerial imagery.
- b. Generally, existing HSI models must be translated to provide versions amenable to cost-effective use of airborne sensors (paragraph 87). The white-tailed deer translations showed that two variables hidden from vertical view (tree diameter and the abundance of evergreen foliage) were probably related to two forest canopy features that can be detected in a vertical view (tree canopy diameter and percent canopy closure). Two other variables (species richness of oaks and soil phosphorus) were shown to be not clearly important and thus were eliminated from the general aerial version of the deer model (paragraph 53).
- c. A general aerial version of the white-tailed deer model was provided that has a direct relationship to the original model and can be applied using medium-scale (1:24,000) aerial photography guided by virtually no on-site investigation (paragraph 44). This general model was based solely on the distribution of cover types rather than estimates of detailed habitat variables. Thus, great potential exists for using these cover type-to-habitat quality relationships to develop new guild definitions, once similar versions of other models are produced.
- d. Guild definitions that have been proposed for use with HEP appear to have no direct relationship to the contents of evaluation species' HSI models (paragraphs 85-86). Thus, HEP presently offers little more than a catalog of species-specific models for evaluating habitat quality. HEP could be improved by having it reflect the commonality of species life requisites within the respective guilds.
- e. Common features (and categorical differences) occur among HSI models and can be used to begin developing new guild procedures that relate directly to HSI model contents (paragraph 87). Such changes will improve HEP as an environmental analysis tool yielding a sound and clear ecological perspective broader than species-specific.

Recommendations

91. To guide airborne sensor applications to HEP, the following recommendations are made:

a. Immediately, guilding procedures must be developed that are directly related to the contents of HSI models. This will require revision of many existing models to clarify categorical interspecific similarities and differences in species-to-habitat relationships that are already suggested in the models.

b. Until such guilding procedures are provided, only generalized versions of many of the existing models merit application. Increased investments in acquisition of detailed habitat data that are required by full application of many of the models are not balanced by increased returns in sound and broadly applicable ecological insights.

c. Direct translation followed by general translation of existing ground versions to aerial versions of models is recommended. Models will be provided that bear a direct relationship to the original version and can be applied using virtually no on-site measurement of variables. As importantly, these general aerial models will themselves provide a set of cover type-to-habitat quality relationships that will suggest new guild definitions.

d. Species models must be strategically selected for translation so that a cross section of models (and habitats) is represented. A few examples must be provided for each group of models dominated by variables characteristic of either forests, shrublands or openlands, or waterbodies and wetlands. Also, models with a greater than average number of variables should be translated first so that relatively unimportant variables can be eliminated quickly.

e. Once translated, the general and direct aerial models as well as the original ground version must be simultaneously evaluated during field trials designed to compare accuracy and to determine optimum airborne sensors and their altitudes as well as to determine appropriate photointerpretation techniques.

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Table 1

Acorn Life Requisite SIs Associated with 36 Mature Forest or Savannah Cover Types

Canopy Closure (Percent Tree Canopy Closure)	Tree Canopy Description: Deciduousness (Percent Canopy Closure by Deciduous Trees as a Percent of Canopy Closure)	Tree Canopy Description: Oak Presence Among Deciduous Overstory (Percent Canopy Closure by Oaks as a Percent of Deciduousness)	Predicted SI: Minimum	Predicted SI: Maximum	Predicted SI: Median
Closed Forest (>75)	Deciduous (D) (>75)	Oak Dominant (OD) (>75)	1.0	1.0	1.00
		Oak Common (OC) (25-75)	0.6	1.0	1.00
		Oak Rare (OR) (<25)	0.0	1.0	0.50
	Mixed (M) (25-75)	OD	0.6	1.0	0.80
		OC	0.2	1.0	0.60
		OR	0.0	0.6	0.30
	Piney (P) (<25)	OD	0.0	1.0	0.50
		OC	0.0	0.5	0.25
		OR	0.0	0.2	0.10
Moderately Closed Forest (>50-75)	D	OD	1.0	1.0	1.00
		OC	0.4	1.0	0.70
		OR	0.0	0.8	0.40
	M	OD	0.4	1.0	0.70
		OC	0.1	1.0	0.55
		OR	0.0	0.2	0.10
	P	OD	0.0	0.8	0.40
		OC	0.0	0.6	0.30
		OR	0.0	0.2	0.10
Open Forest (25-50)	D	OD	0.6	1.0	0.80
		OC	0.2	1.0	0.60
		OR	0.0	0.5	0.25

(Continued)

Table 1 (Concluded)

Canopy Closure (Percent Tree Canopy Closure)	Tree Canopy Description: Deciduousness (Percent Canopy Closure by Deciduous Trees as a Percent of Canopy Closure)	Tree Canopy Description: Oak Presence Among Deciduous Overstory (Percent Canopy Closure by Oaks as a Percent of Deciduousness)	Predicted SI: Minimum	Predicted SI: Maximum	Predicted SI: Median
Open Forest (25-50) (Cont'd)	M	OD	0.2	1.0	0.60
		OC	0.1	1.0	0.55
		OR	0.0	0.4	0.20
	P	OD	0.0	0.5	0.25
		OC	0.0	0.4	0.20
		OR	0.0	0.2	0.10
	D	OD	0.0	1.0	0.50
		OC	0.0	0.8	0.40
		OR	0.0	0.2	0.10
Savannah (<25)	M	OD	0.0	0.8	0.40
		OC	0.0	0.6	0.30
		OR	0.0	0.2	0.10
	P	OD	0.0	0.2	0.10
		OC	0.0	0.2	0.10
		OR	0.0	0.1	0.05

Table 2

Acorn Life Requisite SIs Associated with 45 Mature Forest or Savannah Cover Types

Canopy Closure (Percent Tree Canopy Closure)	Tree Canopy Description: Deciduousness (Percent Canopy Closure by Deciduous Trees as a Percent of Canopy Closure)	Tree Canopy Description: Oak Presence Among Deciduous Overstory (Percent Canopy Closure by Oaks as a Percent of Deciduousness)	Predicted SI: Minimum	Predicted SI: Maximum	Predicted SI: Median
Closed Forest (>75)	Deciduous (D) (>75)	Oak Dominant (OD) (>75)	1.0	1.0	1.00
		Oak Common (OC) (25-75)	0.6	1.0	1.00
		Oak Rare (OR) (<25)	0.0	1.0	0.50
	Mixed (M) (25-75)	OD	0.6	1.0	0.80
		OC	0.2	1.0	0.60
		OR	0.0	0.6	0.30
	Piney (P) (<25)	OD	0.0	1.0	0.50
		OC	0.0	0.5	0.25
		OR	0.0	0.2	0.10
Moderately Closed Forest (>60-75)	D	OD	1.0	1.0	1.00
		OC	0.4	1.0	0.70
		OR	0.0	0.8	0.40
	M	OD	0.4	1.0	0.70
		OC	0.2	1.0	0.60
		OR	0.0	0.2	0.10
	P	OD	0.0	0.8	0.40
		OC	0.0	0.6	0.30
		OR	0.0	0.2	0.10
Moderately Open Forest (>50-60)	D	OD	1.0	1.0	1.00
		OC	0.4	1.0	0.70
		OR	0.0	0.6	0.30

(Continued)

Table 2 (Continued)

Canopy Closure (Percent Tree Canopy Closure)	Tree Canopy Description: Deciduousness (Percent Canopy Closure by Deciduous Trees as a Percent of Canopy Closure)	Tree Canopy Description: Oak Presence Among Deciduous Overstory (Percent Canopy Closure by Oaks as a Percent of Deciduousness)	Predicted SI: Minimum	Predicted SI: Maximum	Predicted SI: Median
Moderately Open Forest (>50-60) (Cont'd)	M	OD	0.4	1.0	0.70
		OC	0.2	1.0	0.60
		OR	0.0	0.4	0.20
	P	OD	0.0	0.6	0.30
		OC	0.0	0.4	0.20
		OR	0.0	0.2	0.10
Open Forest (25-50)	D	OD	0.6	1.0	0.80
		OC	0.2	1.0	0.60
		OR	0.0	0.5	0.25
	M	OD	0.2	1.0	0.60
		OC	0.1	1.0	0.55
		OR	0.0	0.4	0.20
	P	OD	0.0	0.5	0.25
		OC	0.0	0.4	0.20
		OR	0.0	0.2	0.10
Savannah (<25)	D	OD	0.0	1.0	0.50
		OC	0.0	0.8	0.40
		OR	0.0	0.2	0.10

(Continued)

Table 2 (Concluded)

Canopy Closure (Percent Tree Canopy Closure)	Tree Canopy Description: Deciduousness (Percent Canopy Closure by Deciduous Trees as a Percent of Canopy Closure)	Tree Canopy Description: Oak Presence Among Deciduous Overstory (Percent Canopy Closure by Oaks as a Percent of Deciduousness)	Predicted SI: Minimum	Predicted SI: Maximum	Predicted SI: Median
Savannah (<25) (Cont'd)	M	OD	0.0	0.8	0.40
		OC	0.0	0.6	0.30
		OR	0.0	0.2	0.10
	P	OD	0.0	0.2	0.10
		OC	0.0	0.2	0.10
		OR	0.0	0.1	0.05

Table 3

Vegetation Life Requisite SIs Associated with Three Terrestrial Cover Types Based Solely on Percent Tree Canopy Closure

Cover Type (Percent Tree Canopy Closure)	Predicted SI Minimum	Predicted SI Maximum	Predicted SI Median
Open (0-50)	1.0	1.0	1.00
Moderately Closed (>50-60)	0.6	1.0	0.80
Closed (>60)	0.4	0.6	0.50

Table 4

Crop Residue Life Requisite SIs Associated with Nine Terrestrial Cover Types

SI_5				SI_6				$SI_5 \times SI_6$		
Percent Agricultural Land	Predicted SI			Average Distance to Ecotone yd	Predicted SI			Crop Residue Life Requisite SI		
	Minimum	Maximum	Median		Minimum	Maximum	Median	Minimum	Maximum	Median
High (>35)	0.65	1.00	0.83	Short (<500)	0.65	1.00	0.83	0.42	1.00	0.71
				Medium (500-660)	0.35	0.65	0.50	0.23	0.65	0.44
				Long (>660)	0.00	0.35	0.18	0.00	0.35	0.18
Medium (20-35)	0.35	0.65	0.50	Short	0.65	1.00	0.83	0.23	0.65	0.44
				Medium	0.35	0.65	0.50	0.12	0.42	0.27
				Long	0.00	0.35	0.18	0.00	0.23	0.12
Low (<20)	0.00	0.35	0.18	Short	0.65	1.00	0.83	0.00	0.35	0.18
				Medium	0.35	0.65	0.50	0.00	0.23	0.12
				Long	0.00	0.35	0.18	0.00	0.12	0.06

Table 5

Matrix of Evaluation Species and Forest and Tree Variables in HSI Models*

Forest and Tree Variables in HSI Models	Hairy woodpecker	Carolina chickadee	Gray squirrel	Black-capped chickadee	Cooper's hawk	Fox squirrel	Turkey	American woodcock	Red-tailed hawk	American kestrel	Wood thrush	Barred owl	Pine warbler	Great-horned owl	Scissor-tailed flycatcher	Central newt	Green heron	White-tailed deer	Common flicker	Bobwhite quail	Mourning dove	Wood duck	Raccoon	Eastern box turtle	Eastern wood rat	Indigo bunting	Eastern cottontail	Field sparrow	White-footed mouse	Meadow vole	Racer	Belted kingfisher	Mink	Muskrat	Blue-winged teal	Snapping turtle	Long-billed marsh wren	Red-winged blackbird	Yellow warbler	Bullfrog
Average size of trees in forest:																																								
Average ht. of overstory trees (ft)		•		•							•	•																												
Average dbh of overstory trees (in.)	•		•			•																																		
Forest overstory size class (in. or ft)					•			•		•			•	•									•																	
Cover provided by or density of trees:																																								
Size of continuous forested stand	•						•							•																										
Percent tree canopy closure	•	•	•	•	•	•					•	•				•																								
Percent tree and shrub canopy closure								•																																
Percent canopy closure of overstory trees								•	•																															
Percent canopy closure of deciduous trees		•														•																								
Number of deciduous trees per acre															•																									
Percent canopy closure of evergreens					•		•																																	
Number of trees >20 in. dbh per acre									•																															
Number of large lone trees ≥12 in. dbh or groves ≤1 acre in size containing large trees within a diameter of 1 mile										•											•																			
Percent canopy closure of mast-producing trees >10 in dbh per acre						•												•		•																				
Percent canopy closure of pines													•																											
Percent canopy closure of nut, seed, or fruit producing trees							•																																	
Number of snags >10 in. dbh per 1 acre	•		•	•															•																					

(Continued)

* Adapted from USFWS 1980b, c, and d.

Table 5. (Concluded)

Forest and Tree Variables in HSI Models	Hairy woodpecker	Carolina chickadee	Gray squirrel	Black-capped chickadee	Cooper's hawk	Fox squirrel	Turkey	American woodcock	Red-tailed hawk	American kestrel	Wood thrush	Barred owl	Pine warbler	Great-horned owl	Scissor-tailed flycatcher	Central newt	Green heron	White-tailed deer	Common flicker	Bobwhite quail	Mourning dove	Wood duck	Raccoon	Eastern box turtle	Eastern wood rat	Indigo bunting	Eastern cottontail	Field sparrow	White-footed mouse	Meadow vole	Racer	Belted kingfisher	Mink	Muskrat	Blue-winged teal	Snapping turtle	Long-billed marsh wren	Red-winged blackbird	Yellow warbler	Bullfrog
Number of woody stems ≥3.3 ft tall per acre									•																															
Number of snags <10 in. dbh per 1 acre		•																																						
Number of potential nest cavities at least 14 in. dbh in live trees per acre																						•																		
Distance to trees or *forests:*																																								
Forested wetland or deciduous shrub wetland (mi)																	•																							
Distance to nearest trees, forest edge, fence post, or utility poles and lines (mi)										•																														
Distance to nearest deciduous shrubs and trees (clumps of shrubs and trees, forest edge, windbreaks, isolated trees)(ft)															•		•																							
Total number of forest or tree variables in model		4					3							2						1													0							

Table 6

Matrix of Evaluation Species and Shrub Variables in HSI Models*

Shrub Variables In HSI Model	Wood thrush	American woodcock	White-tailed deer	Turkey	Indigo bunting	Eastern cottontail	Bobwhite quail	Barred owl	Fox squirrel	Common flicker	Red-tailed hawk	Great horned owl	Eastern woodrat	Eastern box turtle	Mourning dove	Eastern meadowlark	Field sparrow	Racer	White-footed mouse	Yellow warbler	Hairy woodpecker	Gray squirrel	Carolina chickadee	Black-capped chickadee	Cooper's hawk	Pine warbler	American kestrel	Scissor-tailed flycatcher	Meadow vole	Raccoon	Green heron	Wood duck	Red-winged blackbird	Belted kingfisher	Long-billed marsh wren	Central newt	Muskrat	Mink	Blue-winged teal	Common snapping turtle	Bullfrog
Average height of shrubs:																																									
Average height of shrub canopy					•																																				
Cover provided by shrubs:																																									
Percent shrub canopy coverage		•			•	•	•	•	•	•	•	•	•			•	•																								
Percent shrub or tree canopy coverage		•																																							
Percent deciduous shrub canopy coverage																			•																						
Percent evergreen shrub canopy coverage	•																																								
Percent canopy coverage by shrubs <5 ft in height			•			•								•																											
Percent canopy coverage by evergreen broad-leaf or deciduous shrubs 5 ft in height																																									
Percent canopy coverage by shrubs <1.5 m 5 ft in height			•																	•																					
Percent canopy coverage by deciduous shrubs >5 ft in height	•																																								
Percent canopy coverage by preferred shrubs (fruit-producers like blackberry, maple, and wax myrtle)							•																																		
Percent canopy coverage by fruit-producing shrubs				•																																					
Distance to shrubs or shrublands:																																									
Distance to shrubby edge or shrub thickets (ft)																		•																							

(Continued)

* Adapted from USFWS 1980b, c, and d.

Table 6. (Concluded)

Shrub Variables In HSI Model	Wood thrush	American woodcock	White-tailed deer	Turkey	Indigo bunting	Eastern cottontail	Bobwhite quail	Barred owl	Fox squirrel	Common flicker	Red-tailed hawk	Great horned owl	Eastern woodrat	Eastern box turtle	Mourning dove	Eastern meadowlark	Field sparrow	Racer	White-footed mouse	Yellow warbler	Hairy woodpecker	Gray squirrel	Carolina chickadee	Black-capped chickadee	Cooper's hawk	Pine warbler	American kestrel	Scissor-tailed flycatcher	Meadow vole	Raccoon	Green heron	Wood duck	Red-winged blackbird	Belted kingfisher	Long-billed marsh wren	Central newt	Muskrat	Mink	Blue-winged teal	Common snapping turtle	Bullfrog
Distance to shrubs or shrublands: (con't)																																								
Distance to forest or shrub cover type, or travel lane of shrubs or trees connected to forest of shrub cover types				•											•																									
Total number of shrub variables in HSI model				2									1										0																	

Table 7

Matrix of Evaluation Species and Herbaceous Vegetation and Ground Surface Variables in HSI Models*

Herbaceous Vegetation or Ground Surface Variables in HSI Model	American woodcock	Turkey	Great horned owl	Eastern cottontail	American kestrel	Bobwhite quail	White-tailed deer	Red-tailed hawk	Eastern meadowlark	Mourning dove	Red-winged blackbird	Eastern box turtle	White-footed mouse	Meadow vole	Racer	Long-billed marsh wren	Blue-winged teal	Eastern woodrat	Scissor-tailed flycatcher	Field sparrow	Raccoon	Central newt	Belted kingfisher	Barred owl	Cooper's hawk	Carolina chickadee	Black-capped chickadee	Wood thrush	Pine warbler	Gray squirrel	Fox squirrel	Hairy woodpecker	Common flicker	Indigo bunting	Yellow warbler	Wood duck	Green heron	Mink	Muskrat	Common snapping turtle	Bullfrog
Height of herbaceous vegetation:																																									
Average height of herbaceous vegetation						•					•			•																											
Average height of herbaceous canopy	•	•	•																																						
Average height of herbaceous canopy in summer									•						•				•																						
Type of pasture/hayland management			•																																						
Cover provided by or density of herbaceous vegetation:																																									
Percent canopy coverage by herbaceous vegetation	•	•	•	•	•	•		•	•	•	•	•	•	•	•	•																									
Percent canopy coverage by forbs							•																																		
Percent canopy coverage of vegetation remaining green in winter months		•																																							
Percent herbaceous canopy coverage >8 in tall																	•																								
Percent herbaceous canopy coverage ≥12 in. tall																				•																					
Percent herbaceous canopy coverage <12 in. tall					•																																				
Percent herbaceous canopy coverage by herbs 6-24 in. tall								•																																	
Availability of fence rows, roadside ditches, and grassy uncultivated areas				•	•	•											•																								
Number of refuge sites per acre				•								•	•					•			•																				

(Continued)

* Adapted from USFWS 1980b, c, and d.

Table 7. (Concluded)

Herbaceous Vegetation or Ground Surface Variables in HSI Model	American woodcock	Turkey	Great horned owl	Eastern cottontail	American kestrel	Bobwhite quail	White-tailed deer	Red-tailed hawk	Eastern meadowlark	Mourning dove	Red-winged blackbird	Eastern box turtle	White-footed mouse	Meadow vole	Racer	Long-billed marsh wren	*Blue-winged teal*	Eastern woodrat	Scissor-tailed flycatcher	Field sparrow	Raccoon	Central newt	Belted kingfisher	Barred owl	Cooper's hawk	Carolina chickadee	Black-capped chickadee	Wood thrush	Pine warbler	Gray squirrel	Fox squirrel	Hairy woodpecker	Common flicker	Indigo bunting	Yellow warbler	Wood duck	Green heron	Mink	Muskrat	Common snapping turtle	Bullfrog
Cover provided by or density of herbaceous vegetation: (con't)																																									
Availability of weed, grass, and/or grain seed						•			•																																
Overwinter crop management and grain availability		•	•	•			•	•		•																															
Percent coverage of ground by litter	•																																								
Composition of the cover type									•																																
Percent composition of broadleafed herbaceous vegetation											•					•																									
Species richness of herbaceous vegetation:																																									
Type of crop present		•					•			•																															
Diversity of forbs							•	•																																	
Soil characteristics:																																									
Soil texture	•																					•																			
Soil moisture	•																																								
Soil compaction	•																																								
Distance to vertical relief features:																																									
Distance to cliffs, ledges, earth banks, or old abandoned buildings within 1 mi					•																																				
Distance to a bare, steep, dirt, or gravel bank >4 ft in height (m:)																							•																		
Total number of herbaceous vegetation or ground surface variables in HSI model	6	5			4					3				2						1												0									

Table 8

Matrix of Evaluation Species and Waterbody-Related Variables in HSI Models*

Waterbody-Related Variables in HSI Models	Belted kingfisher	Green heron	Wood duck	Muskrat	Blue-winged teal	Mink	Central newt	Snapping turtle	Bullfrog	Raccoon	American kestrel	Red-winged blackbird	Long-billed marsh wren	Eastern box turtle	Barred owl	Wood thrush	American woodcock	White-tailed deer	Meadow vole	Fox squirrel	Eastern cottontail	Bobwhite quail	Common flicker	Black-capped chickadee	Yellow warbler	Indigo bunting	Eastern woodrat	Gray squirrel	Red-tailed hawk	Hairy woodpecker	Scissor-tailed flycatcher	Carolina chickadee	Eastern meadowlark	Racer	White-footed mouse	Cooper's hawk	Turkey	Mourning dove	Great horned owl	Pine warbler	Field sparrow
Type or configuration of waterbody:																																									
Water body type						•																																			
Size of waterbody					•		•																																		
Shoreline configuration	•					•																																			
Average width of stream, river, or creek	•																																								
Permanence of water:																																									
Water regime	•			•	•	•	•	•	•	•	•					•																									
Water regime (average summer conditions)		•																																							
Permanence of standing water in wetland			•			•																																			
Percent of wetland area covered by standing water during average April to September conditions							•						•																												
Depth distribution, water quality, and substrate composition:																																									
Percent of water area 6 ft deep (average summer conditions			•		•																																				
Percent of water area <10 in. deep (average summer conditions)		•																																							
Average water depth beneath emergent herbaceous vegetation												•																													
Water current	•	•	•	•	•			•	•																																
Water turbidity	•																																								
Aquatic substrate composition in littoral zone								•																																	
Aquatic substrate composition in littoral zone (average summer conditions)		•																																							

(Continued)

* Adapted from USFWS 1980b, c, and d.

Table 8. (Concluded)

Evaluation Species

Waterbody-Related Variables in HSI Models	Belted kingfisher	Green heron	Wood duck	Muskrat	Blue-winged teal	Mink	Central newt	Snapping turtle	Bullfrog	Raccoon	American kestrel	Red-winged blackbird	Long-billed marsh wren	Eastern box turtle	Barred owl	Wood thrush	American woodcock
Vegetative cover in and near waterbody:																	
Percent aquatic vegetative cover in littoral zone							•	•									
Percent emergent herbaceous canopy coverage in littoral zone (average summer conditions)		•	•	•	•				•								
Percent of water's surface covered by logs, trees, or woody vegetation (consider material projecting from water plus overhanging material with 1 m of water surface)	•	•	•	•													
Percent herbaceous canopy coverage within 68.5 ft of water's edge				•													
Percent of ground surface within 333 ft of water's edge covered by woody vegetation, downfall, brush piles, and/or boulders						•											
Availability of suitable perch sites (including trees, leafless branches, snags, powerlines, etc.)	•																
Distance to water:																	
Distance to water (mi)										•				•			•
Distance to permanent waterbody >1 acre in size (mi)															•		
Total number of waterbody-related variables in HSI models	7	6			5		4		3	2				1			

Waterbody-Related Variables in HSI Models	White-tailed deer	Meadow vole	Fox squirrel	Eastern cottontail	Bobwhite quail	Common flicker	Black-capped chickadee	Yellow warbler	Indigo bun ng	Eastern woodrat	Gray squirrel	Red-tailed hawk	Hairy woodpecker	Scissor-tailed flycatcher	Carolina chickadee	Eastern meadowlark	Racer	White-footed mouse	Cooper's hawk	Turkey	Mourning dove	Great horned owl	Pine warbler	Field sparrow
Vegetative cover in and near waterbody:																								
Percent aquatic vegetative cover in littoral zone																								
Percent emergent herbaceous canopy coverage in littoral zone (average summer conditions)																								
Percent of water's surface covered by logs, trees, or woody vegetation (consider material projecting from water plus overhanging material with 1 m of water surface)																								
Percent herbaceous canopy coverage within 68.5 ft of water's edge																								
Percent of ground surface within 333 ft of water's edge covered by woody vegetation, downfall, brush piles, and/or boulders																								
Availability of suitable perch sites (including trees, leafless branches, snags, powerlines, etc.)																								
Distance to water:																								
Distance to water (mi)																								
Distance to permanent waterbody >1 acre in size (mi)																								
Total number of waterbody-related variables in HSI models												0												

Table 9

Distribution of Four Major Types of Habitat Variables Among 41 HSI Models*

	Percent Contribution** to HSI Model of Variables that Characterize:												
	I			II			III			IV			
	Trees (Forests)			Shrubs (Shrublands)			Grasses, Forbs, or Ground Surfaces (Openlands)			Water (Waterbodies or Wetlands)			Total No. of Variables in HSI Model
Evaluation Species	≥0.67	≥0.33	<0.33	≥0.67	≥0.33	<0.33	≥0.67	≥0.33	<0.33	≥0.67	≥0.33	<0.33	
Hairy woodpecker	1.00												4
Carolina chickadee	1.00												4
Black-capped chickadee	1.00												3
Cooper's hawk	1.00												3
Gray squirrel	1.00												3
Pine warbler	1.00												2
Scissor-tailed flycatcher	0.67				0.33								3
Fox squirrel		0.60			0.40								5
Barred owl		0.50				0.25						0.25	4
Common flicker		0.33		0.67									3
Wood thrush		0.40			0.40							0.20	5
American kestrel		0.37						0.50				0.13	8
Red-tailed hawk		0.37				0.13		0.50					8
Turkey			0.30			0.20		0.50					10
Great horned owl			0.29			0.14		0.57					7
Central newt			0.25						0.13		0.63		8
Raccoon			0.25						0.25		0.50		4
Green heron			0.14							0.86			7
American woodcock			0.27			0.09		0.55				0.09	11
Mourning dove			0.20			0.20		0.60					5
Wood duck			0.17							0.83			6
Bobwhite quail			0.14			0.29		0.57					7
White-tailed deer			0.14			0.29		0.57					7
Indigo bunting				1.00									2
Yellow warbler				1.00									1
Eastern woodrat					0.50			0.50					2
Field sparrow					0.50			0.50					2
Eastern cottontail					0.33		0.67						6
White-footed mouse					0.33		0.67						3
Racer					0.33		0.67						3
Eastern box turtle						0.25		0.50				0.25	4
Meadow vole							1.00						2
Red-winged blackbird							0.75					0.25	4
Long-billed marsh wren							0.67				0.33		3
Eastern meadowlark						0.20	0.80						5
Blue-winged teal									0.29	0.71			7
Belted kingfisher									0.13	0.87			8
Bullfrog										1.00			3
Snapping turtle										1.00			4
Mink										1.00			5
Muskrat										1.00			6

* Compiled from USFWS 1980b, c, and d.

** Percent contribution equals the number of variables in column I, II, III, or IV divided by the total number of variables in the model.

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