To the Graduate Council:

I am submitting herewith a dissertation written by Xinyuan Wu entitled "Strategic planning models for wildlife habitat management and environmental assessment on forest landscapes". I have examined the final copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Ecology.

J. Frank McCormick, Major Professor

We have read this dissertation
and recommend its acceptance:

Accepted for the Council:

Associate Vice Chancellor
and Dean of The Graduate School

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Abstract

Two large-scale strategic planning models for wildlife habitat management and environmental assessment on forest dominated landscapes were developed with a specific application to wildlife habitat management at Land Between The Lakes (LBL) of Tennessee Valley Authority. A system of vegetation cover classes for LBL was developed to represent the structure and dynamics of managed forest and open land systems at LBL. Habitats for five evaluation wildlife species were evaluate using Habitat Suitability Index (HSI) models based on data from field sampling, the literature, and expert opinions. A system for evaluating management alternatives (SEMA) was developed in WingZ with an interactive user interface. SEMA simulates temporal vegetation changes in response to management activities; evaluates corresponding changes in habitats of evaluation species and provides detailed analysis of habitat changes; and evaluates corresponding changes in compositional landscape diversity. Simulation results are displayed in both graphical and tabular formats in a set of windows for the user to review. A system for exploring preferred solutions (SEPS) was developed in WingZ with a Robust Multiple Objective Linear Programming approach. SEPS enables the user to explore his or her preferred results in terms of HSI's for evaluation species at steady state. The results are achieved by identifying a satisfactory cover class distribution within a general management direction. These planning models are equally valuable for conducting environmental assessments and preparing associated Environmental Impact Statements (EIS).

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Chapter 1

Introduction

§1.1 Objective of the Study

The objective of this study is to develop large-scale strategic planning models for wildlife habitat management and environmental assessment on forest dominated landscapes, with a specific application on the wildlife habitat management at Land Between The Lakes (LBL) of Tennessee Valley Authority (TVA). This study was conducted in three parts:

1) To develop a system of vegetation cover classes for LBL; to establish methods for determining habitat suitability for a set of evaluation species based on the system of vegetation cover classes; and to determine habitat suitability for the evaluation species through field study and literature review.

2) To develop a system for evaluating management alternatives with an interactive user interface, which can simulate changes in vegetation, habitats of evaluation species and compositional landscape diversity.

3) To develop an interactive multiple objective programming (MOP) problem-solving system for exploring preferred management alternatives.

§1.2 Land Between The Lakes and Its Planning Needs

Land Between The Lakes (LBL) is a 170,000 acre (68,826 ha) national recreation demonstration area that extends from western Kentucky to midwestern Tennessee. LBL occupies a peninsula which is approximately 8 miles (13 km) wide and 38 miles (61 km) long. The peninsula separates TVA's Kentucky Lake impoundment from Lake Barkley

reservoir operated by the U.S. Army Corps of Engineers. The Barkley Canal connects the two reservoirs at the northernmost boundary, which gives LBL 300 miles (483 km) of undeveloped freshwater shoreline (Field et al. 1985, Thach et al. 1986). LBL is located in the Highland Rim of the Interior Low Plateau physiographic province (Smalley 1980). The land is highly dissected and the topography is hilly (Fralish and Crooks 1988). Elevation of LBL ranges from 360 to 590 feet (110 to 180 m). The average annual temperature of LBL is 58°F (14°C). Average annual precipitation is 46 inches (1178 mm), and cumulated rainfall during April to September averages 22 inches (560 mm). Summers are hot and humid. Soils are dry in summers resulting from high evaporation (Harris 1988). LBL has a forest dominated landscape (approximately 90% forest) with small agricultural fields along narrow creek drainages and maintained "woods openings" distributed throughout the land (Field et al. 1985). LBL occurs within the Western Mesophytic Forest Region and is a transitional area from mixed mesophytic hardwood forest to oak-hickory forests (Braun 1950). Today's forests at LBL are predominantly oak forests due to the high level of disturbances within the last two centuries (Franklin 1990, Fralish and Crooks 1988, 1989).

Land Between The Lakes was designated in 1963 by President John F. Kennedy as a national demonstration for outdoor recreation, environmental education, and resource management (Field et al. 1985). The multiple-use mission of LBL specifies: (1) to manage the resources for optimum yield of outdoor recreation and environmental education benefits for the American people; (2) to utilize TVA's demonstration assignment to research, test and implement innovative techniques and programs; (3) to help stimulate quality development of the surrounding region; and (4) to extend the beneficial results as widely as possible (Thach et al. 1986).

Wildlife habitat management (for upland vertebrates) is a key element of the natural resource management which underlies the multiple-use mission for LBL. Wildlife habitat

at LBL is managed through forest and open land management activities. Forest and open land management planning at LBL has been conducted at two levels. At the strategic planning level, the Natural Resource Management Plan for LBL specifies long range goals and operational guidelines for forest and open land management. It is reviewed and revised periodically to reflect changing needs and new technology (Thach et al. 1986). At the tactic planning level, specific forest and open land management plans are prepared and reviewed annually to implement the goals and operational guidelines set by the management plan.

LBL reviewed and revised the resource management plan in 1990-91 as directed by the 1985 revised resource management plan (TVA 1991, 1985). Along with this revision, LBL prepared its first Environmental Impact Statement (EIS) in accordance with the National Environmental Policy Act of 1969 (NEPA) to fully evaluate a range of resource management alternatives for LBL and to provide opportunities for public review and comment. A key component of an EIS is the analysis and documentation of short-term and long-term environmental consequences of the management alternatives. To conduct such complex analyses for the EIS, a strategic planning model is needed. This planning model needs to be able to simulate temporal changes in vegetation, habitats of evaluation wildlife species, and diversity of wildlife habitat under any management alternative. The structure, parameters, and resolution of this planning model must reflect those of the managed forest and open land systems at LBL. Given the interdisciplinary nature of LBL's planning process and EIS, this planning model should be user-friendly so that the resource managers from different disciplines can use the model to test alternatives of their interest, and communicate with each other using the model in a group decision-making environment.

Planning of habitat management for diverse wildlife species has to deal with conflicting objectives and their trade-offs. It is useful to have a planning model with a multiple objective programming approach, which enables resource managers to explore

preferred solutions at steady state under different general management directions. The use of this model can enhance resource manager's understanding of the managed system with multiple conflicting objectives and facilitate the formation of management alternatives.

§1.3 Wildlife Species-Habitat Relationship Models

Many wildlife species-habitat relationship models (habitat models) have been developed in the last two decades. Several types of habitat models have been widely used in studies of impact assessment, mitigation, and wildlife habitat management planning. Given the scope of this study, the following discussion is limited to habitat models for terrestrial vertebrate species within forest dominant systems.

Habitat Suitability Index (HSI) model

Habitat Suitability Index (HSI) is a dimensionless value bounded by 0.0 and 1.0 where 0.0 represents unsuitable habitat and 1.0 represents optimal habitat. It is assumed to be positively correlated to carrying capacity (U.S. Fish and Wildlife Service 1980, 1981). HSI models describe the functional relationship between HSI of a given species and physical habitat variables (environmental variables). HSI models for nearly 200 fish and wildlife species have been developed by U.S. Fish and Wildlife Service with similar standards (U.S. Fish and Wildlife Service 1981). They were developed originally as key elements of Habitat Evaluation Procedure (HEP) for use in impact assessment and project planning (Schamberger and Farmer 1978, Schamberger and Krohn 1982, U.S. Fish and Wildlife Service 1980); they have been also used in many projects using procedures different from HEP.

A HSI model includes several parts: information on habitat use; literature reviews; a model structure; documentation of model assumptions, application and related information;

and references. The structure of a HSI model can be divided into several components according to seasonal habitats, life requisites and cover types. There is a defined set of habitat variables which describes the resources needed for each life requisite in a certain cover type. The suitability of a habitat variable is described with a graph which displays the relationship between the variable and a suitability index ranging from 0.00 to 1.00. Suitability indices corresponding to habitat variables are aggregated in a single suitability index representing the suitability for the life requisite. The formulation of the aggregation is determined based on the relationship among the variables: limiting factors, cumulative, compensatory, or spatial relationships. Similar approaches are used to aggregate suitability indices for life requisites into the Habitat Suitability Index. HSI or suitability index for a life requisite over several cover types is the sum of the indices related to each cover type weighted by relative acreages* of the cover types.

A related measure, Habitat Unit (HU), is defined as the product of HSI for an evaluation species and the size of the area for which the HSI was calculated (U.S. Fish and Wildlife Service 1980). HU measures the equivalent amount of optimal habitat for the evaluation species.

Wildlife and Fish Habitat Relationships (WFHR) system

The USDA Forest Service initiated its Wildlife and Fish Habitat Relationship (WFHR) program in the early 1980's for integrating wildlife and fish information and assessment data into interdisciplinary land and resource management (Nelson and Salwasser 1982). A WFHR system was developed in each of the Forest Service's nine regions and two areas. The structure of a WFHR System can be illustrated with the Rocky

* The planning models developed in this project are for resource managers to use. Given the fact that the English system of units is used in the resource management in this country, the English system is used in the planning models of this study.

Mountain Region WFHR System (Sheppard et al. 1982). Based on a similar system in California (Hurley and Asrow 1980, Verner and Boss 1980), this system compiled information on 853 vertebrate animal species occurring in the Rocky Mountain Region. This information base consists of species narratives and two sets of computerized data matrices: status matrices and habitat relationship matrices. The narrative for each species includes information on legal and management status, distribution, habitat requirements for reproduction, food, territory/home range and special habitat requirements, and references. The status matrices contain information for each species on life form, Federal and State classification as threatened or endangered, protected or unprotected nongame, and hunted, trapped or fished.

Habitat relationship matrices are the core of this information base. The columns of these matrices are 24 vegetation types (10 forested, 14 nonforested) and 10 special habitat needs. The forested types are divided into five structural stages: grass/forb, shrub/seedling, young, mature, and old growth. Young and mature stages are each subdivided into three categories of canopy closure. Shrub types are divided into two structural stages: grass/forb and shrub/seedling. The rows of these matrix are arranged by names of the wildlife species. There are five rows associated with each species: three biological functions including breeding, feeding and resting/cover, season of use, and habitat capability coefficient (HCC). A habitat capability rating is assigned to each cell that corresponds to a particular structural stage of a vegetation type and a biological function of a given species (USDA Forest Service 1981a). The rating is an integer from 1 to 3, where 1 is optimal, 2 is acceptable, and 3 is marginal habitat for that biological function. A HCC is calculated for each structural stage of a vegetation type (USDA Forest Service 1981b). The HCC, ranging from 0.00 to 1.00, is an aggregated, weighted value based on habitat capability ratings for breeding, feeding, and resting.

A habitat capability index (HCI) can be used to evaluate habitat for a species in a planning area. HCI for a species is defined as the sum of HCC's of the stages of vegetation types occurring in the area weighted by the relative acreage of the stages:

$$HCI = \sum_i HCC_i \times A_i$$

where A_i is the percentage of acreage of vegetation type and stage i in total acreage of the planning area (Sheppard et al. 1982).

Pattern recognition (PATREC) model

A pattern recognition (PATREC) model was developed by Williams et al. (1978) based on Bayesian statistical inference. The "Bayesian theorem" used can be stated as: Given events $B_1,...,B_k$ such that

$$B_i \cap B_j = \varnothing \quad (i \neq j \text{ and } i,j \leq k)$$

$$P[\cup_i B_i]=1, \quad P[B_i]>0 \quad (i=1,...,k)$$

then for any event A with $P[A_i]>0$,

$$P[B_i|A]=P[B_i]P[A|B_i] / (P[B_1]P[A|B_1]+...+P[B_k]P[A|B_k]).$$

A simple example can illustrate the development and utilization of a PATREC model for an evaluation species. Suppose 3 independent habitat conditions important for the species (C_1, C_2 and C_3) and population density (d) for the species are sampled at a set of sample sites in a general area. Population density is divided into two levels, high (H) and low (L). The basic parameters of the PATREC model are then determined based on the sample data. Parameters include probabilities that a given site has high and low population densities (P[H], P[L]), conditional probabilities that a habitat condition is present in a site which has high and low population densities ($P[C_i|H]$, $P[C_i|L]$, i=1,2,3), and average population densities at sites with high and low population densities (E[d|H],E[d|L]).

A planning area, which is within or similar to the general area, is evaluated for habitat of the species using the following procedure. Sample the planning area for the three conditions. The results show, for example, C_1 and C_2 are present and C_3 is absent. The conditional probabilities that such a condition (C) exists in the planning area, given it has high and low population densities, can be calculated as

$$P[C|H]=P[C_1|H]\ P[C_2|H]\ (1-P[C_3|H])$$

and $$P[C|L]=P[C_1|L]\ P[C_2|L]\ (1-P[C_3|L]),$$

respectively. The conditional probabilities that the planning area has high and low population densities then are

$$P[H|C]=P[H]P[C|H]\ /\ (P[H]P[C|H]+P[L]P[C|L])$$

and $$P[L|C]=P[L]P[C|L]\ /\ (P[H]P[C|H]+P[L]P[C|L]),$$

respectively. A expected population density for the planning area can be determined

$$E[d|C]=E[d|H]\ P[H|C]\ +\ E[d|L]\ P[L|C].$$

PATREC is a regional model. It is appealing to many resource managers because it gives an estimate of population density (expected value) instead of a unitless index. PATREC models for several wildlife species have been used in solving multiresource forest management problems (Holthausen 1986, Kirkman et al. 1986).

Other habitat models

Habitat models for forest breeding birds were developed using a multivariate statistical method, discriminant function analysis (Conner and Adkisson 1976, Smith 1986, Smith et al. 1981a, 1981b). A discriminant function and a linear decision scale were used to determine whether a forest stand provided potential breeding habitat for a given bird species based on measures of stand vegetative structure.

A set of habitat models were developed by the Missouri Department of Conservation for wildlife habitat evaluation in Missouri (Urich et al. 1983). A habitat model was constructed as a worksheet with a list of habitat variables. These variables described resource needs of different life requisites and requirements for spatial arrangement. The suitability of each habitat variable was rated by the user. Quantitative but easy to use criteria for each rating were provided on the worksheet. The habitat suitability index was then the sum of the ratings divided by the potential maximum sum of the ratings. For a given wildlife species, different worksheets were developed for planning areas dominated by different vegetation cover types (Urich et al. 1983).

Some habitat models were developed in association with certain forest simulation models (Boyce 1977, Covington et al. 1988, Williamson 1983). Most of them had approaches similar to those of HSI and WFHR. Williamson (1983) developed several wildlife habitat models for use in a stand level multiresouce forest management decision support system (TIMPRO-FORMAN system) developed by TVA (Hendricks and Harrison 1985). These models produce a habitat index for each of the species based on stand level forest inventory data (Williamson 1983). In DYNAST (Dynamically Analytic Silviculture Technique), habitat models were structured to produce habitat indices based on relative acreages distributions of structural stages of forest cover types and sometimes opening sizes (Boyce 1977).

§1.4 Simulation Models for Forest Resource Planning

Evaluating effects of forest management for the purpose of wildlife habitat planning is dynamic in nature. Forest simulation models that can simulate temporal change of forest vegetation in response to management activities, and generate appropriate information for evaluating wildlife habitat are needed. Forest simulation models have been categorized in

two general types, "tree models" and "forest models" (Munro 1974, Shugart 1984, Shugart and Urban 1986). Tree models use individual trees as basic units of simulation, and forest models use developmental stages (in size or age) of the whole forest as basic units of simulation. Numerous simulation models of both types have been developed by foresters and ecologists (Shugart 1984). The following are some of the simulation models of both types which have been used, or are suitable for use, in evaluating dynamic effects of forest management on wildlife habitat.

Tree Models

Tree models project changes in forest stands by simulating growth of individual trees in a small area. Foresters and ecologists have developed hundreds of tree models. Two of them, TWIGS (The Woodsman's Ideal Growth Projection System) and FORET (an Appalachian deciduous forest stand simulator) serve as good examples. TWIGS is a data-rich, deterministic model based on regional species-specific regressions (Belcher 1982). Versions of TWIGS for several regions were developed and widely used in forestry (Miner et al. 1988, Bolton and Meldahl 1990a, 1990b). TWIGS was used in conjunction with HSI models and Geographical Information Systems (GIS) to simulate effects of management and natural succession on wildlife habitats (Brand et al. 1986, Yang and Sharpe 1991). FORET uses a very different structure than TWIGS. Growth, death and regeneration (birth and sprout) of individual trees are determined by a set of stochastic submodels which are based on easily obtained, species-specific silviculture data (Shugart and West 1977). FORHAB (deciduous forest habitat simulation model), a modified version of FORET, was developed to predict effects of forest management on habitats of nongame birds (Smith 1986, Smith et al. 1981).

Forest Models

Forest models include simulation models for large-scale strategic planning of forest management and some forest ecosystems models (Shugart and Urban 1986). DYNAST was developed for evaluating multiresource uses under different management alternatives (Boyce 1977, 1978, 1980). DYNAST simulates changes of a forest by moving acreages of successional stages within each forest type through time. The core model of DYNAST for succession and harvest consists of a set of negative feedback loops. The goal is to convert the current distribution of forest stages into a desired distribution and maintain it at a steady state. This is achieved by controlling the harvest rates which determine the amount of regeneration. The goals are established by assigning constants for the proportion and duration of old growth and mature timber habitats. DYNAST has been used in many studies for simulating wildlife responses to forest management alternatives, either using the habitat models in DYNAST or coupling DYNAST with other habitat models (Benson et al. 1986, Holthausen 1986, Kirkman et al. 1986). Strategic planning of multiresource forest management is non-site specific in nature. DYNAST and models of this type serve this type of planning well.

HABSIM, a habitat simulation procedure, is another model similar to DYNAST but with a different approach (Raedeke and Lehmkuhl 1986). The core model of HABSIM is a simple algorithm that creates an n×n matrix of forest age class rows and time interval columns based on information on the total area of the forest and harvest acreage in each time interval.

§1.5 Multiple Objective Programming for Forest Resource Planning

Multiple objective programming (MOP) methods have been used extensively in natural resource management planning in the past decades in response to needs for

multiresource management decision making (Cocklin 1989). A traditional multiple objective optimization problem can be described as follows: Given a feasible region X and a set of objective functions $f_i : X \rightarrow R$, i=1,...,k, find a $x \in X$ that yields a most preferred value of $\mathbf{f}(\mathbf{x})=(f_1(\mathbf{x}),...,f_k(\mathbf{x}))$.

A traditional approach for multiple objective problems is explicit utility maximization based on multi-attribute utility theory (Rosenthal 1985). In this approach, a utility function $U : R^k \rightarrow R$ is first specified such that $U(\mathbf{f}(\mathbf{y}))>U(\mathbf{f}(\mathbf{z}))$ if and only if $\mathbf{f}(\mathbf{y})$ is preferred to $\mathbf{f}(\mathbf{z})$; then solve

$$\max \ U(\mathbf{f}(\mathbf{x}))$$

$$\text{subject to } \mathbf{x} \in X.$$

The most popular approach of this type used in resource management, especially forest management, is goal programming (GP) approach (Arp 1982, Chang and Buongiorno 1981, Dyer et al. 1979, Field 1973, Field et al. 1980, Mendoza 1987, Rustagi 1985, Schuler and Meadows 1975, Schuler et al. 1977). A cardinally weighted GP with k objectives and n decision variables can be expressed as

$$\min \ \mathbf{w}^{-\prime}\mathbf{d}^{-} + \mathbf{w}^{+\prime}\mathbf{d}^{+}$$

subject to

$$\mathbf{C}\mathbf{x} + \mathbf{d}^{-} - \mathbf{d}^{+} = \mathbf{g}$$

$$\mathbf{A}\mathbf{x} \leq \mathbf{b}$$

$$\mathbf{x}, \mathbf{d}^{-}, \mathbf{d}^{+} \geq \mathbf{0}$$

$$\mathbf{d}^{-\prime}\mathbf{d}^{+} = 0$$

where $\mathbf{w}^{-}$ and $\mathbf{w}^{+}$ are vectors of k weights, $\mathbf{d}^{-}$ and $\mathbf{d}^{+}$ are vectors of k under- and over-achievements, $\mathbf{g}$ is a vector of k goal levels for the objectives, $\mathbf{x}$ is a vector of n decision variables, $\mathbf{C}$ is a $k \times n$ matrix relating $\mathbf{x}$ and $\mathbf{g}$, $\mathbf{A}$ is a $m \times n$ matrix of coefficients, $\mathbf{b}$ is a $m \times 1$ vector, and $\mathbf{A}\mathbf{x} \leq \mathbf{b}$ defines the feasible region of $\mathbf{x}$. GP can also be formulated with

ordinal weights or a combination of ordinal and cardinal weights. A GP with p priority levels can be solved by a series of p cardinally weighted GP's. Each of the GP depends on the solutions for those proceeding it.

Objectives in multiresource management problems are often incompatible. This makes GP an attractive approach because it can treat incompatible objectives well. When objectives in a multiple objective problem are measured by a common unit of measurement, a multiple objective linear programming MOLP can be used (Field et al. 1980). In MOLP, a weighted sum of values of the objectives is maximized:

$$\max \quad \mathbf{w'Cx}$$

subject to

$$\mathbf{Ax} \leq \mathbf{b}$$

$$\mathbf{x} \geq \mathbf{0}$$

where **w** is a vectors of k weights, **C**, **x**, **A** and **b** are the same as defined earlier.

It is often difficult for resource managers to specify explicitly the numerical weights, or even definite goal levels, for objectives *a priori*. Several interactive or implicit utility maximization approaches have been used to avoid this difficulty (Bare and Mendoza 1988b, 1990, Harrison and Rosenthal 1986, Rustagi and Bare 1987). These approaches use local preferences of the decision maker at each iteration to guide the solution process and finally arrive at the decision maker's preferred choice (maximum of an unspecified utility function).

Generation of efficient or noninferior solutions is another approach for solving multiple objective problems (Rosenthal 1985). A solution $\mathbf{x} \in X$ is noninferior if there exist no $\mathbf{x}' \in X$ such that $f_i(\mathbf{x}') \geq f_i(\mathbf{x})$ for any i and $f_i(\mathbf{x}') > f_i(\mathbf{x})$ for some i, i=1,...,k. Most multiresource management problems may be too large for generating all noninferior

solutions for evaluation by decision makers (Cocklin 1987a). Allen (1986) used the noninferior set estimation (NISE) method (Cohon et al. 1979) to generate an estimate of the true noninferior set with a known error in a multiple objective regional forest planning study. Several interactive approaches were used to generate a partial noninferior set (Gilbert et al. 1985, Ho 1981, Steuer 1977, Steuer and Schuler 1978, Steuer and Choo 1983). Theses approaches are related to implicit utility maximization approaches in that they are based on the decision maker's local preferences at each iteration to generate a different subset of noninferior solutions.

Given the complexity of multiresource management problems, they often can not be represented appropriately by a mathematical model. A optimal solution to the mathematical model may not represent the best solution to the real problem (Liebman 1976, Cocklin 1989b). For an incomplete MOP model, a preferred solution to the real problem may potentially be in the inferior region defined by the model (Brill 1979, Chang et al. 1982a). An approach with a different perspective from those of traditional MOP approaches, modeling to generate alternatives (MGA), has gained attention in multiresource management (Brill et al. 1982, Chang et al. 1982a, 1982b, Cocklin 1989b, Mendoza et al. 1987a, Mendoza 1988). The MGA approach generates distinctively different but satisfactory alternatives which may include inferior ones. One MGA approach is called Hop, Skip and Jump (HSJ) (Brill 1979, Brill et al. 1982). In HSJ, a initial solution is obtained by any method. Then an alternative solution is obtain by solving a linear program (LP):

$$\min \sum_{k \in K} x_k$$

subject to

$$f_i(\mathbf{x}) \leq T_i \text{ for any } i$$

$$\mathbf{x} \in X$$

where K is a set of indices of basic decision variables in the initial solution and T_i is the target specified for objective $f_i(x)$. Subsequent alternatives are generated by resolving the above LP where K includes indices of basic decision variables of all previous solutions.

In MOP studies of planning and evaluation of agroforestry systems, Mendoza et al. (1986, 1987b) employed and compared methods in four general MOP approaches mentioned above, noninteractive GP, interactive STEM (step method) (Benayoun et al. 1971), generating of noninferior set, and MGA.

Bare and Mendoza (1988, 1990) illustrated use of a *de novo* programming approach in multiple objective forest resource planning. Instead of simply optimizing a given system, an External Reconstruction Algorithm (ERA) was used to design an optimal system by determining the right hand side (RHS) of some constraints for given resource costs and limitations (Bare and Mendoza 1990, Zeleny 1986a, 1986b).

All approaches discussed above, except that of Harrison and Rosenthal (1986), use either an "analyst-machine" procedure (in non-interactive methods) or a "decision maker-analyst-machine" procedure (in interactive methods). A "decision maker-machine" procedure which lets the decision maker directly interact with the algorithm can make the decision process more convenient and effective in many decision processes for natural resource management planning. An implicit/explicit approach of Harrison and Rosenthal (1986) was used in a forest management activities scheduling system (FORMAN). FORMAN can be used by resource managers directly in scheduling multiple objective forest management activities in the non-industrial private forest sector (Hendricks and Harrison 1985). This approach articulates the decision makers preference through asking the user to select one or none of two solutions provided at each iteration of the solution process as the more preferred one.

Ho (1985) proposed a Robust Goal Programming (RGP) approach which provides the decision maker a semi-structured decision support environment with an underlying GP model for solving MOP problems. In each iteration of the solution process, the decision support environment can display results graphically for the user to review. It enables the user to alter goal levels or weights (as purely numerical parameters) interactively in order to drive the solution in the general direction of user preference, using what ever logic deemed appropriate. It then solves the underlying GP with modified parameters, and returns results for the next iteration. In this learning process, the user continually improves understanding of the system and ability to control it, until finds user preferred solutions. In this approach, the user does not respond to queries demanded by an algorithm and does not have to justify user actions (Ho 1985).

Wu and McCormick (1990) extended the RGP approach and used it in a MOP study for wildlife habitat management at TVA's Land Between The Lakes. In the extended RGP approach, goal levels, weights and RHS of non-fixed constraints can be altered interactively by the user. The decision support environment constructed in HyperCard (Apple Computer, Inc. 1989) can save a record of the solution at any iteration upon user request. The user can review the records at any time and can continue the solution process from any record when so desired.

Chapter 2

Evaluation of Wildlife Habitat in Vegetation Cover Classes

§2.1 Vegetation Cover Classes

In development of large-scale, long-term forest resource management plans (strategic planning), objectives are usually specified by the acreage distribution of vegetation cover types and their successional stages. Management parameters used usually are acreages of different treatments per year constrained by guidelines on size and spatial distribution of these treatments. Only in the process of implementing the forest management plan (tactic planning), will the scheduling of the treatments be site-specific. However, many habitat models, such as widely used HSI models, require site-specific information. In order to use habitat models such as HSI models in the strategic planning process to evaluate the impact of different forest resource management plans on wildlife habitat, one possible approach is to establish a system of vegetation cover classes for the entire planning area. The suitability index of the habitat or a habitat component for an evaluation species is then evaluated in each cover class, and thereafter it is considered a constant. The classification of cover classes is based on vegetation cover types and their successional stages. Additional cover classes outside main successional paths may also be recognized since some management practices may create distinct stand structure significantly different from structures in other cover classes.

A system of vegetation cover classes for LBL

A system of cover classes for forest and open land of LBL was constructed for the purpose of vegetation simulation and wildlife habitat evaluation (Table 2.1)*. The

* All tables and figures are displayed in Appendix A.

complexity of this system is limited by the resolution of silvicultural and open land management practices which are the means of habitat management at LBL. Within this limit, efforts have been made to have a classification detailed enough to reflect differences in wildlife habitats.

Approximately 9% of LBL land is maintained as open land. These lands can be divided into five management classes: cooperative farming land, contract farming land, open land maintained annually (road sides, pasture and gas line rights-of-ways), reverting fields maintained on a 4-year cycle with soil disturbance, and reverting fields maintained on a 4-year cycle without soil disturbance, plus power line rights-of-way (Table 2.2). These management classes are convenient for managers to use in their planning but are not suitable for the purposes of vegetation simulation and wildlife habitat evaluation. Therefore, four cover classes were defined for open land areas at LBL according to their vegetative composition and structure (Table 2.3). Cover class Crop Field (CF) include open lands for row crop farming only. The rest of open lands are classified into three cover classes, Grass Field (GF), Forb Field (FF) and Shrub Field (SF), according to the percent cover of the shrub layer and the proportion of the grass component in the percent cover of the herbaceous layer. A transformation matrix was built to define the relationship between management classes (and their successional stages) and cover classes (Table 2.4). The element of this matrix, $t_{i,j}$, represents the percentage of open land in the management class i that falls into cover class j. These elements were estimated based on planning records, field inspection, and expert opinions of resource managers directing open land management at LBL.

Hardwood forest is the dominant vegetation type at LBL and covers about 89% of the land base. Six cover classes of hardwood forest are recognized. Five of them are defined by stand age (in years): Young Growth (YG) (1-15 yr), Poletimber (PO) (16-50

yr), Small Sawtimber (SS) (51-80 yr), Large Sawtimber (LS) (81-150 yr), and Old Growth (OG) (>150 yr). The sixth cover class is called Shelterwood (SW). A stand is classified as a SW stand if it has had the first shelterwood cut within the last 35 years at a stand age greater than 80, but has not had the last shelterwood cut. SW is separated from either LS or OG because its distinct structure (considerably opened canopy and well developed understory) makes a significant difference in wildlife habitat.

Some silvicultural methods used in hardwood forest management at LBL may alter the classification of a stand when applied. Clear cut, salvage cutting, and final removal of shelterwood cutting will change the classification of a stand from cover class SS, LS, OG or SW to cover class YG. Thinnings are considered of low intensity and do not alter classification of a stand, except for the first shelterwood cut. The first shelterwood cut is considered to be heavy enough to alter canopy cover and understory structure significantly and will change a LS or OG stand to a SW stand.

Pine forest covers approximately 3% of the LBL land base. About half the pine forests are native shortleaf pine forests and the rest are plantations. Two cover classes are recognized for pine plantations based on stand age (in years): Young Pine Plantation (Yp) (1-15 yr) and Mature Pine Plantation (Mp) (>15 yr). Shortleaf pine stands in LBL are all mature stands and recognized as cover class Mature Shortleaf Pine (Ms).

Clearcutting and planting are used in the management of pine plantations at LBL. The former will change a Mp stand to a YG stand and the latter will change a YG stand to a Yp stand. For Ms stands, the only management activities employed are those to reduce hardwood competition.

§2.2 Measuring Wildlife Habitat

Five evaluation species were selected as representatives for evaluating the effect of different management alternatives on wildlife habitat at LBL. Habitat Suitability Index (HSI) and Habitat Units (HU) (U.S. Fish and Wildlife Service 1980) were used to measure the quality and quantity of habitat for evaluation species. HSI models are fairly simple and the outputs are easily understood (Schamberger and O'Neil 1986). There are many HSI models, developed with similar standards by U.S. Fish and Wildlife Service, available for species of interest. The fact that HSI models have been widely used may facilitate communication and comparison with other projects. Field samples (Appendix A) and the literature were used to estimate HSI for each evaluation species based on their HSI models.

Selection of evaluation species

Since upland hardwood forest and open land covered about 97% of LBL land, evaluation species were selected based on their dependency on successional stages of hardwood forest and maintained open land. Three major stages were used for this purpose:

1. Open land stage: Characterized by overdominance of the grass/forb component, which included cover classes CF, GF and FF.
2. Early successional stage: Characterized by overdominance of the shrub/sampling component, which included cover classes SF and YG.
3. Late successional stage: Characterized by overdominance of the mature tree component, which included cover classes SS, LS, SW and OG.

A "mid successional stage" could have been used, which included cover class PO. This stage is generally low in value for wildlife species because of low ground forage and

limited mast resulting from small tree size and high tree density. None of the upland wildlife species was considered dependent on this stage. Therefore, it was not used.

Five evaluation species were selected to represent wildlife species depending on each of the stages or combinations of the stages, with consideration of model availability and coverage of both game and nongame species. Table 2.5 shows common and scientific names of evaluation species and citations to their HSI models. Eastern Meadowlark (*Sturnella magna*) was selected to represent species dependent on open land stage, especially cover classes GF and FF. Gray Squirrel (*Sciurus carolinensis*) and Pileated Woodpecker (*Dryocopus pileatus*) were selected to represent species dependent upon the late successional stage. Cover classes SS, LS and SW can be considered as the first substage of late successional stage, characterized by vigorous mature trees of diverse hard mast producing species. Gray Squirrel was selected to represent species sensitive to the abundance of this substage. Cover class OG can be considered as the second substage, characterized by larger and older trees, more snags and down logs, but less diverse hard mast producing tree species and lower hard mast production. Pileated Woodpecker was selected to represent species sensitive to the abundance of this substage. Eastern Wild Turkey (*Meleagris gallopavo sylvestris*) is dependent on more than one successional stage. The open land stage is essential for brood and summer food, and the late successional stage provides fall, winter and spring food and cover for Eastern Wild Turkey. White-tailed Deer (*Odocoileus virginianus*) is considered a generalist in habitat utilization. Quality of habitat for White-tailed Deer is most sensitive to the amount and distribution of the early successional stage and the first substage of late successional stage. All five evaluation species are important for recreation usesæconsumptional, nonconsumptional, or both.

Determination of HSI and HU

The average value for each habitat variable in each relevant cover class was estimated from field data, published literature or expert opinions. Except for Eastern Wild Turkey, a HSI value was calculated for every evaluation species in every cover class. This value was calculated based on the average values of habitat variables in the cover class. The overall HSI value for an evaluation species at LBL was a weighted sum of the HSI values for this species in each cover class, where the weights were the relative acreages of the cover classes. The HU for an evaluation species was then determined by multiplying its HSI and the total acreage of the planning area of LBL. The structure of HSI model for Eastern Wild Turkey is different from the others. Suitability indices (SI) for three habitat components in the whole planning area need to be determined first and the smallest of these indices represents the HSI for the species (Schroder 1985).

Data used to determine values of habitat variables include TVA's Continuous Forest Inventory (CFI) data and field data on habitat variables collected in 1988 and 1990. TVA's CFI data were collected from 150 permanent plots across LBL in 1966, 1976 and 1986. Information on the site and individual canopy and subcanopy trees in each 1/5 acre (809.4 m^2) plot was recorded. Information on forest understory vegetation was also recorded using a 50 foot (15.24 m) line transect at each of the permanent plots (Groton et al. 1988). Existing information is insufficient to support this study. Accordingly, field studies were conducted at LBL in 1988 and 1990 to supplement extensive CFI data. In September 1988, field data were collected on 35 open land units. Ocular estimations were made on shrub cover and its soft mast producing component, herbaceous cover, its average height, and its grass component. In October 1990, field data were collected on seventy-three 100 m line transects in 40 forest stands representing different cover classes. Data collected on each line transect include: overstory cover and its hard mast producing component, canopy

cover and its hard mast producing component, soft mast producing tree cover, shrub/sampling cover and its soft mast producing component, and average herbaceous height in 10 1×1m plots centered at each 10th meter of the transect. Twelve young growth stands were sampled. Ocular estimations were made on shrub/sampling cover and its soft mast producing component, herbaceous cover, its average height, and its grass component. Appendix A provides descriptions of methods and results of the field studies in 1988 and 1990.

A spatial factor is used in the HSI model for Wild Turkey. Since vegetation simulation is not site-specific, spatial factors can not be dealt with directly in the simulation. Suitabilities of herbaceous and shrub cover types for Wild Turkey are affected by the proximity of forest cover. In the HSI model for Wild Turkey, one habitat variable measures the distance from random points in a herbaceous or shrub cover type to the nearest edge of a forest or tree savanna cover type. The suitability index is 1.0 if this distance is less than or equal to 61 m and 100 m for herbaceous and shrub cover types, respectively (Schroder 1985a). Based on the fact that most open land units and young growth stands in LBL are either very small in size or long and irregular in shape, the value of the suitability index is assumed to be 1.0 for cover classes CF, GF, FF, SF, YG and Yp.

A modification was also made to the HSI model for Pileated Woodpecker. Habitat variable V_2 in the model is the number of trees greater than or equal to 20 inches dbh (dbh≥20") per acre. The suitability index is 0 when $V_2 \leq 3$, 1 when $V_2 \geq 30$ and increases linearly when $3 < V_2 < 30$. Few stands in LBL have 30 or more trees of dbh≥20" per acre because of relative low quality of the sites. Large sawtimber stands at LBL have only 5 trees of dbh≥20" per acre on the average and have a very low HSI value of 0.27. Small sawtimber stands at LBL have a HSI value of 0. Pileated Woodpecker is a common

species in LBL and its population level is considered fairly high (Sharp 1990 pers. comm.). Using the habitat variable V_2 and the suitability index curve may underestimate the habitat suitability for Pileated Woodpecker considerably. For the purpose of comparing the effect of different management alternatives on Pileated Woodpecker habitat, habitat variable V_2 was redefined as the number of trees of dbh≥15" per acre.

Chapter 3

A System for Evaluating Management Alternatives (SEMA)

SEMA, a system including a simulation model and a user interface was developed in WingZ© (Beil 1990) for evaluating management alternatives. SEMA can simulate vegetation changes under different management alternatives and evaluate effects on habitats for a set of evaluation wildlife species and landscape diversity. SEMA's user interface is robust in that it is uncomplicated and dependable as perceived by the user, although the underlying framework may be quite complex. The interface ensures that any parameter entered is witnin the valid range and updates related parameters automatically. Such a user interface makes SEMA efficient and user friendly.

§3.1. Simulation model of SEMA

There are three major components of the simulation modelæsimulation of vegetation, evaluation of wildlife habitat and evaluation of landscape diversity. The system of vegetation cover classes and their associated habitat coefficients described in Chapter 2 serve as a basis for this model. There are a variety of parameters in this model that enable the user to simulate different management alternatives effectively. In addition to management parameters and initial conditions, definitions of cover classes can also be changed interactively.

Simulation of Vegetation

Figure 3.1 is a general diagram of the open land and forest management system with cover classes as general components. Possible flows among components include those of natural succession and those caused by management activities.

State variables used in the simulation are defined based on stand age classes and are divided into four groups based on cover classes. The first group includes age classes in all hardwood forest cover classes except SW. Each stand age (yr) in cover classes YG, PO, SS and LS is an age class and all stand ages in cover class OG are an age class. A state variable in this group, X(i,t), is the acreage of the stands in age class i at year t. The second group includes age classes in cover class SW. Each "SW stand age", defined as number of years after the first SW cut, is an age class. Xs(i,t) denotes the acreage of the stands in age class i of the second group at year t. The third group includes all age classes in pine forest cover classes. Each stand age (yr) in cover classes Yp is an age class; all stand ages in cover class Mp and those in cover class Ms form two age classes, respectively. Xp(i,t) denotes the acreage of the stands in age class i of the third group at year t. The forth group includes age classes in open land cover classes. Each open land cover class is used as an age class. Xf(i,t) (i=1,2,3,4) denotes the acreages of open land in cover classes CF, GF, FF and SF at year t, respectively.

The initial condition, the current acreage for each age class, is needed for the simulation. Although it is often difficult to determine acreage of an one-year age class, the acreage in each cover class is usually available. If there are k one-year age classes in a cover class, it is assumed that the acreage in each age class is 1/k of the acreage in that cover class at t=0.

Current acreages of cover classes at LBL were estimated based on Geographic Information System (GIS) digital map estimation, LBL's forest inventory data and forest management records, TVA's Continuous Forest Inventory (CFI) data (Groton et al. 1988), and LBL's open land management planning records. Current acreages of cover classes YG, PO, OG and Yp were estimated with GIS from a digital stand map of LBL. Current acreages of all sawtimber stands, all mature pine stands, all open lands, and the total

manageable land base of LBL were also estimated using GIS. Acreage of sawtimber stands was subdivided into acreages of SS and LS using the SS/LS ratio calculated from CFI data. Acreage of SW was estimated by LBL foresters based on LBL's forest management records. Seventy percent of this acreage of SW was taken from the acreage of LS and the rest was taken from the acreage of SS. The acreage of all mature pine stands was subdivided into acreages of Mp and Ms based on LBL's forest inventory data. Acreage of all open lands was subdivided into acreages of open land management classes based on LBL's open land management records.

Two general assumptions were made for the forest simulation. It is assumed that, if i is not the oldest age class, X(i,t) is equal to X(i-1,t-1) minus the acreage in age class i-1 that has been harvested or reverted at year t-1, plus the inflow to age class i from other groups at year t-1. It is assumed that X(i,t) is not subject to harvest unless X(i+1,t)=0 or i is the oldest age class in the group. The same assumptions apply for Xs(i,t) and Xp(i,t).

Simulation of hardwood forest cover classes is controlled by growth and harvests. Following harvest, hardwood stands regenerate themselves from root sprouts and existing seedlings and saplings. Four management parameters related to harvest of hardwood forest stands were used. They are acreages of first shelterwood cut (First SW Cut), final shelterwood cut (Final SW Cut), clear cut of large sawtimber and surplus old growth (Clear Cut) and clear cut of small sawtimber (SS Clear Cut) per year. Two sets of these four parameters and a revision year, Tr ($1<Tr\leq100$), need be specified to conduct a "two phase" simulation. The first set of parameters is used during "phase I" ($t<Tr$) and the second set is used during "phase II" ($Tr\leq t\leq100$) of the simulation. In addition, a target acreage for preserved OG (OG Target) needs to be specified for the whole simulation.

First SW Cut moves acreage in the oldest age class(es) in OG and/or LS at year t to the youngest SW age class at year t+1, Xs(1,t+1). Final SW Cut moves acreage in the oldest SW age class(es) at year t to the youngest YG age class at year t+1, X(1,t+1). If a portion of the acreage in the oldest SW age class at year t is not consumed by the Final SW Cut, it will be evenly distributed into all LS age classes at year t+1. Clear Cut moves acreage in OG and/or the oldest LS age class(es) at year t to X(1,t+1). SS Clear Cut may also be used to move acreage in the oldest SS age class(es) at year t to X(1,t+1).

When OG acreage is greater than OG Target, surplus acreage is subject to harvest (First SW Cut and Clear Cut). When OG acreage at year t is less than OG Target, the oldest age classes of LS which have a total acreage equivalent to the deficit of OG will be reserved and not subject to harvest at year t. Acreage in age classes younger than those reserved will be subject to harvest.

Simulation of pine forest cover classes is controlled not only by growth and harvest, but also by controlled regeneration (pine planting) and reversion to hardwood forest. It is assumed that a native shortleaf pine stand can either be maintained as is or be left to revert to hardwood. Two management parameters related to harvest and planting are used in simulation of pine plantation, acreage of clear cut (Mp Clear Cut) and acreage of planting (Yp Planting) of pine plantation. These two parameters need to be specified for both "phase I" and "phase II" of the simulation. A target acreage for pine plantation (Pine Plantation Target) needs to be specified. Two logical parameters (1/0), Mp Reversion and Ms Reversion, indicate the occurrence of reversion of Mp and Ms.

Yp Planting moves acreage from X(1,t-1) to the youngest Yp age class, Xp(1,t). Mp Clear Cut moves acreage from Mp age class to X(1,t+1). Acreage of pine plantation (Yp and Mp) increases when it is less than Pine Plantation Target and specified acreage for

planting is greater than that for pine clear cut. When acreage of pine plantation reaches target level, acreage for the planting is set equal to that for pine clear cut. Similarly, acreage of pine plantation decreases when it is greater than Pine Plantation Target and specified acreage for pine clear cut is greater than that for planting. When pine plantation reaches target level, acreage for the pine clear cut is set equal to that for pine planting.

Based on estimates of LBL's foresters, it is assumed that significant reversion of pine plantation and shortleaf pine stands to hardwood stands should start in about 80 and 50 years, respectively, if these stands are left unmanaged. When pine plantation reversion is specified, a portion of the acreage in the Mp age class at year t will be removed and evenly distributed in to PO and SS age classes at year t+1. The proportion of Xp(i(Mp),t) reverted in year t is $r_{Mp}(t)=a^{(t/b)-1}$, where $t \leq b$. Parameters a and b are calibrated so that the significant decline of acreage in Mp will start in about 80 years. When shortleaf pine reversion is specified, a portion of the acreage in the Ms age class at year t will be removed and evenly distributed into SS and LS age classes at year t+1. The proportion of Xp(i(Ms),t) reverted in year t is $r_{Ms}(t)=c^{(t/d)-1}$, where $t \leq d$. Parameters c and d are calibrated so that the significant decline of acreage in Mp will start in about 50 years.

Simulation of open land cover classes is controlled by reversion (open land to YG) and conversion (YG to open land). Management parameters for open land management include a "target acreage" for each open land cover class, an annual reversion rate for each open land cover class, and maximum acreage for annual open land conversion. There is also a control parameter which defines the open land in the management class "Reverting field" to be managed in either a 4-year or a 3-year cycle. This parameter determines which transformation matrix will be used to transform acreages in management classes to acreages in open land cover classes.

When initial acreage of cover class i, Xf(i,0) is greater than the target acreage, target(i), surplus acreage is left alone to revert. It is assumed that the reversion (succession) has a single path from CF to GF, FF, SF and then to YG (Figure 3.1). The amount of reversion of cover class i at year t is assumed to be a fixed proportion of Xf(i,t)-target(i). The proportions or annual reversion rates for the four cover classes are defined by the user. Annual reversion rates used in this model for cover class CF, GF, FF are SF were 0.9, 0.8, 0.6 and 0.4, respectively. When initial acreage of cover class i, Xf(i,0) is less than target acreage, it is assumed that the deficit acreage is converted from YG to cover class i. The speed of this conversion is limited by the maximum acreage for annual open land conversion. A maximum of 200 acres of open land conversion per year at LBL is specified by LBL's open land managers. It is assumed that acreage of cover class CL, GF, FF or SF is maintained at its target level by open land management after it reaches the target level.

Evaluation of Wildlife Habitat

Based on cover class distributions resulting from vegetation simulation, Habitat Units (HU) for each of the evaluation species at every 10th year are calculated. HU's for evaluation species over time indicate the trend of change in average quality and quantity of wildlife habitat.

In certain cases, more detailed information is valuable for management decision-making but can not be provided by an average measure such as HU. Suppose that habitat of a species is evaluated in two separate tracks of land of the same size. Track 1 is homogeneous with average habitat quality for the species (HSI=0.5). Track 2 is heterogeneous. Cumulatively half of track 2 provides optimal habitat (HSI=1) and the rest

is not suitable for the species (HSI=0). These two tracks have the same HU for the species but they have very different values from a management perspective.

To provide more detailed information, a "profile", acreage distribution by habitat quality (HSI) class, for each of the evaluation species at each 10th year is determined. Six HSI classes, HSI=0, $0<HSI\leq0.2$, $0.2<HSI\leq0.4$, $0.4<HSI\leq0.6$, $0.6<HSI\leq0.8$, and $0.8<HSI\leq1$, were used. For a species at a given year, the acreage in a HSI class was the sum of the acreages of cover classes with HSI values within the range of the HSI class. For Eastern Wild Turkey, a profile for each of the three habitat components was determined due to the structure of the HSI model (Schroder 1985).

Evaluation of Landscape Diversity

There is often an interest in the diversity of the wildlife habitat. This diversity can be measured to some degree by indices of landscape diversity. Several indices of landscape diversity have been proposed to measure the composition or configuration of landscape elements or both (Romme 1982, O'Neill et al. 1988, Turner 1989). Landscape composition refers to both the number of landscape element types and the proportion of those types in a landscape. Landscape configuration refers to the spatial pattern of patches in landscape mosaics (Li 1990). Although measures of landscape configuration may be more important than measures of landscape composition in capturing the spatial patterns of landscape, only the latter can be used in this simulation due to its non-site-specific nature. Several landscape indices, Richness (Romme 1982), Evenness (Romme 1982) and Dominance (O'Neill et al. 1988) measure landscape composition in different aspects. However, to be simple and intuitive, a landscape diversity index was used to measure the richness and evenness of the landscape elements, cover classes, based on information theoretic measures (Shannon and Wiever 1962):

landscape diversity index = H/Hmax

where $H = - \sum_i p_i \log_2 p_i$,

$Hmax = \log_2 N$,

p_i = (acreage of cover class i) / (total acreage) ,

i = 1,2,...,N , and

N = possible number of cover classes in planning area.

This index was determined at each 10th year based on the acreage distribution of the cover classes in that year.

3.3. User Interface of SEMA

The user interface basically consists of four groups of windows. Three groups of windows are for editing cover class definition, initial cover class distribution and management parameters. The fourth group of windows is for viewing results of the simulation. There are three additional windows. Window "Main" displays a main menu of the system (Figure 3.2). Two other windows handle printing and editing of suitability indices.

Browsing and editing

A set of "buttons" (Informix Software, Inc. 1990a) can be used for browsing, i.e. moving from one window to another, in browsing mode (default mode). These buttons are labeled with appropriate destinations. The four buttons at the top of each window can be used to move to a window in one of the four groups. Some buttons at the bottom of the windows can be used to move from one window to another in the same group. Buttons for the current window are highlighted and no action will be taken when they are "clicked at" (Apple Computer, Inc. 1990) using the mouse.

To change the system from browsing mode to editing mode, click at the button "Editing" in an editing window. This button will change into an editing field, a highlighted "text field" (Informix Software, Inc. 1990a) with a flicking cursor. All buttons for browsing are disfunctional in editing mode.

To edit an entry in the window, enter a desired number through the key board. This number will appear in the editing field. Click at the entry, the content of which you want to replace with the number entered into the editing field. The replacement will occur if the number is within the valid range for that entry. When an invalid replace number is used or a non-editable entry/position is clicked at, no action will be taken. To edit another entry, repeat the above procedure by entering a number through the key board. If no new number is entered, the number entered last will be used to replace the content of the entry that is clicked at.

Either the button "Cancel" or the button "Save" can be used to change the system from editing mode to browsing mode. Click at button "Cancel" to cancel the changes made and restore previous parameter values. Click at button "Save" to save the changes made. Either action will change the editing field back to the button "Editing".

Editing simulation parameters

There are six windows which enable the user to review and edit interactively the cover class definition, initial cover class distribution, and management parameters.

Window "Cover Class Definition/Forest" displays the starting and ending stand age and duration of each forest cover class (Figure 3.3). The user can redefine a cover class other than SW by altering the ending stand age, which will trigger automatic updating of related starting stand age and durations. The definition of cover class SW can be changed

by altering its duration. The open land transformation matrix is displayed in window "Cover Class Definition/Open Land" and the user can change any element of the matrix (Figure 3.4). A column to the right of the matrix displays the row sums of the matrix which must all be 100% before an edited matrix can be saved.

Window "Cover Class Distribution/Forest" displays initial distribution of forest cover classes in both acreage and percentage (Figure 3.5). The user can edit acreages, and percentages will be updated accordingly. Window "Cover Class Distribution/Open Land" displays initial distribution of open land management classes and corresponding distribution of open land cover classes in both acreage and percentage (Figure 3.6). The user can edit acreage of any management class. Cover class distribution will be automatically updated using the transformation matrix defined in window "Cover Class Definition/Open Land".

Window "Management Parameters/Forest" displays all management parameters for forest management including cut/plant acreages, OG and pine plantation target levels and pine reversion controls (Figure 3.7). The user can edit each one of these. There are two sets of cut/plant parameters and a revision year (less or equal to 100), which enables the user to conduct a 100 year simulation with two distinct phases. Window "Management Parameters/Open Land" displays initial acreage, target acreage and the difference between the two for each of the open land management classes and cover classes (Figure 3.8). The user can edit target acreages for management classes. Acreages in cover classes will be automatically updated. The reversion rate for each open land cover class and the maximum acreage which can be converted to open land annually are also displayed and can be edited. The control parameter for "Reverting field" management cycle (3- or 4-year cycle) is displayed in a "pop-up menu" (Apple Computer, Inc. 1990) form.

Viewing simulation results

When the button "Simulation Results" is clicked at (after an editing session has been terminated with a "Save" button), a 100 year simulation is carried out. Results of the simulation can be viewed in eight windows in both graphical and tabular formats.

Window "Simulation Results/Vegetation/Chart" displays a combined bar chart showing changes in acreage over 100 years in 10-year intervals by vegetation cover class (Figure 3.9). The four open land cover classes are lumped together. Window "Simulation Results/Vegetation/Table" displays acreages of cover classes at present and at years 10, 50 and 100 in a table (Figure 3.10).

Window "Simulation Results/Habitat Units/Chart" displays a combined bar chart showing changes in Habitat Units over 100 years in 10-year intervals by evaluation species (Figure 3.11). Window "Simulation Results/Habitat Units/Table" displays Habitat Units of evaluation species at present and at years 10, 50 and 100 in a table (Figure 3.12).

Window "Simulation Results/HU profile/Chart" displays a combined bar chart showing changes in habitat quality distribution (acreages in HSI classes) of an evaluation species over 100 years in 10-year intervals (Figure 3.13). The name of the evaluation species is displayed in a box which is a pop-up menu. Habitat quality distribution of another evaluation species can be displayed by selecting the name of the species in the pop-up menu. Window "Simulation Results/HU profile/Table" displays habitat quality distribution of an evaluation species at present and at years 10, 50 and 100 in a table (Figure 3.14). There is also a pop-up menu showing the name of the species for which habitat quality distribution is being displayed. Using the pop-up menu to display habitat quality distribution of another species in this window will cause a corresponding change in "Simulation Results/HU profile/Chart" window, and vise versa.

Window "Simulation Results/Diversity/Chart" displays a bar chart showing change in the landscape diversity index over 100 years in 10-year intervals (Figure 3.15). Window "Simulation Results/Diversity/Table" displays the landscape diversity indices at present and at years 10, 50 and 100 in a table (Figure 3.16).

Pull-down menus and additional windows

Two "pull-down menus" (Apple Computer, Inc. 1990), "File" and "Go" are available in SEMA. There are three items, "Main", "Print..." and "Suitability Index" in the "Go" pull-down menu. Select "Main" in the "Go" menu to go to the main menu, window "Main" (Figure 3.2). Select "Print..." in the "Go" menu to go to the printing window. In the printing window, a list of check boxes (Informix Software, Inc. 1990b) for the windows can be used to select the windows to be printed. Three buttons, "Select all", "Default Selection" and "Clear All" can be used to facilitate selection. Once the selection is made, the button "Print" can be clicked at to start the printing (Figure 3.17). Select "Suitability Index" in the "Go" menu to go to window "Suitability Index". This window displays HSI values for an evaluation species or SI (suitability index) values for a habitat component of an evaluation species in every cover class (Figure 3.18). A "list box" (Informix Software, Inc. 1990b) shows names of evaluation species/components. The name of one species/component, the HSI/SI values of which is currently displayed, is highlighted. To display HSI values for another evaluation species/component, just select (click at) its name in the list box. The standard editing buttons "Editing", "Cancel", and "Save" are available for editing the HSI/SI values. There are six standard items in the "File" pull-down menu for file handling (Beil 1990). They include "New", "Open", "Close", "Save", "Revert to saved", and "Quit".

3.6. Applications of SEMA

As a tool for evaluating and comparing management alternatives with multiple objectives, SEMA can be used in many strategic planning processes such as development of resource management plans, Environmental Impact Statements (EIS) or Environmental Assessments (EA). SEMA may be used by resource management agencies for environmental education programs. It may serve as a tool for facilitating communication between resource management agencies and the concerned public. As a teaching model, it may also be used in classes of integrated resource management.

SEMA was used by TVA's Land Between The Lakes for preparation of an Environmental Impact Statement for LBL's Natural Resource Management Plan, in which six management alternatives were evaluated. To demonstrate the use of SEMA for EIS, two hypothetical management alternatives for LBL's wildlife habitat management are evaluated using SEMA. Cover class definition and initial acreage distribution are shown in Figures 3.3-3.6.

Evaluation of alternatives for EIS: an example

Management parameters for the two alternatives, alternative A and alternative B, are summarized in Table 3.1. Alternative A was similar to the current management plan. This alternative emphasized resource management with multiple objectives for outdoor recreation and environmental education that were demanded by different user groups. Under this alternative, there were 600 acres of first shelterwood cut and 600 acres of final shelterwood cut per year and no clear cut. The preserved old growth target was 30,000 acres. Fifty acres of pine were planted and 25 acres of mature pine plantation were harvested each year. Acreage of pine planting was reduced to 25 acres per year once the 2,400 acre pine

plantation target was reached. Acreages of open land cover classes were maintained at present level under this alternative (Table 3.1 and Figure 3.7 and 3.8).

Changes in vegetation cover classes over 100 years based on this simulation are shown in Figure 3.19. All cover classes except LS and OG stabilized at their steady state level. Most changes occurred in cover classes SS, LS and OG. The somewhat irregular transient behaviors of these cover classes were largely due to the very high initial acreage (per age class) in SS. Habitat units for the evaluation species changed little over the 100 years except that for Pileated Woodpecker which increased substantially (Figure 3.20). Changes in habitat quality distribution (profile) over 100 years for each of the evaluation species gave a more dynamic and interesting picture of habitat changes (Figure 3.21a-g). As expected, profiles for species more heavily dependent on early successional stages than late successional stages changed little. Woodpecker habitat was improved, a large amount of average habitat ($0.4<HSI\leq0.6$) became good habitat ($0.8<HSI\leq1.0$) with the increase of acreage in LS and OG cover classes (Figure 21g). For the fall, winter and spring food component of Wild Turkey habitat, a large amount of good habitat ($0.8<HSI\leq1.0$) became fair habitat ($0.6<HSI\leq0.8$) (Figure 3.21c). Although this change lowered the potential quality of Wild Turkey habitat, it was not reflected in the overall HSI or HU because the profile of the limiting component, summer food and brooding habitat, changed little (Figure 3.21b). Landscape diversity remained at about the same level (Figure 3.22).

Alternative B emphasized preservation of natural vegetation. This emphasis reflected the preference of certain users. This alternative reduced management activities to a minimum, primarily limited maintenance of access. Under this alternative, there was no timber harvest. Open land management was reduced to roadside, gas pipe rights-of-way and power line rights-of-way (Table 3.1).

Changes in vegetation cover classes over 100 years based on this simulation are shown in Figure 3.24. Most forest cover classes disappeared before the end of 100 years. Eventually, averages of all cover classes would go into OG except the small amount which remained in open land. Habitat units for all evaluation species except Deer changed considerably over the 100 years. Habitat units for Meadowlark and Wild Turkey were reduced greatly while those for Squirrel and Woodpecker were increased substantially (Figure 3.25). Again, changes in habitat quality distribution (profile) over 100 years for the evaluation species showed some interesting dynamics, especially those for Deer and Squirrel (Figure 3.26a-g). Although overall HU for Deer exhibited relatively little change, the profile showed that average habitat ($0.4<HSI\leq0.6$) increased at the expense of fair habitat ($0.6<HSI\leq0.8$) (Figure 3.26e). Overall HSI for Squirrel increased as a result of the increase of fair habitat ($0.6<HSI\leq0.8$) but good habitat ($0.8<HSI\leq1.0$) vanished (Figure 3.26f). Under this alternative, landscape diversity reduced substantially (Figure 3.23).

Chapter 4

A System for Exploring Preferred Solutions (SEPS)

SEPS consists of a multiple objective linear programming (MOLP) model, a linear programming (LP) solver and a user interface developed in WingZ. It enables users to explore preferred solutions in an interactive, semi-structured fashion. It is a useful tool for solving problems such as: given a set a general constraints in vegetation cover class distribution, what is the most preferred solution in terms of habitats of a set of evaluation species that can be achieved at steady state; and how can one achieve the preferred results in terms of vegetation cover class distribution.

§4.1 Model Approach of SEPS

Underlying MOLP model

There are seven objectives used in this MOLP model. They are measures of habitat suitability for the evaluation species. For Eastern Meadowlark, White-tailed Deer, Gray Squirrel and Pileated Woodpecker, the objectives are their HSI values. The structure of the HSI model for Eastern Wild Turkey (Schroder 1982) is quite different from those for the other four species. A suitability index is first determined for each of the three habitat components, brood, food and cover, throughout the entire planning area. The smallest of the three is then used as the overall HSI for Wild Turkey. Since the suitability indices of the three habitat components provide much more information in the interactive solution process than the overall HSI, they are used as three separate objectives in the model.

Decision variables of the MOLP model are the relative acreages of 10 of the 13 cover classes. Relative acreages of cover classes PO, SS and LS at steady state are strictly

dependent on durations of the cover classes and relative acreage of cover class YG. Therefore, they are not included in the decision variables. The contribution of cover classes PO, SS and LS to the HSI of a species is represented by a modified coefficient for YG. Let x, d and c denote the relative acreage, duration and suitability coefficient for a cover class, respectively. The modified coefficient for YG, c'_{YG} can be shown as follows:

$$x_{YG}c_{YG} + x_{PO}c_{PO} + x_{SS}c_{SS} + x_{LS}c_{LS}$$

$$= x_{YG}\,(c_{YG} + (d_{PO}/d_{YG})c_{PO} + (d_{SS}/d_{YG})c_{SS} + (d_{LS}/d_{YG})c_{LS})$$

$$= x_{YG}\,c'_{YG}\,.$$

The MOLP is as follows:

maximize $\mathbf{w}'\mathbf{y}$

subject to:

$$\mathbf{Cx} = \mathbf{y}$$

$$\mathbf{Ax} = \mathbf{b}$$

$$\mathbf{l} \le \mathbf{x} \le \mathbf{u}$$

where

$\mathbf{y}=(y_1, y_2,...,y_7)'$, y_j is the HSI for evaluation species j;

$\mathbf{w}=(w_1, w_2,...,w_7)'$, w_j is the weight for y_j;

$\mathbf{x}=(x_1, x_2,...,x_{10})'$, x_i is the relative acreage of cover class i;

$\mathbf{l}=(l_1, l_2,...,l_{10})'$, l_i is the lower bound of x_i;

$\mathbf{u}=(u_1, u_2,...,u_{10})'$, u_i is the upper bound of x_i;

A is a 2 by 10 coefficient matrix; and

C is a 7 by 10 coefficient matrix, $c_{j,i}$ $(i\neq5)$ is the suitability index for species j in cover class i, and $c_{j,5}$ is a weighted sum of the suitability indices of species j in cover classes YG, PO, SS and LS.

Ax=b includes two constraints on the relationship among x_i's. One constraint is that the relative acreages of all cover classes must sum to 1,

$$\Sigma_i x_i = 1.$$

The other constraint specifies an upper bound of the relative acreage of cover class SW, which is dependent on the relative acreage of cover class YG,

$$x_{SW}/d_{SW} \leq x_{YG}/d_{YG}.$$

Solution process

A Robust Multiple Objective Linear Programming (RMOLP) approach was used in SEPS. This approach is very similar to the extended Robust Goal Programing approach (Ho 1985, Wu and McCormick 1990) except a MOLP model is used as the underlying model instead of a Goal Programing model. This is because the objectives, HSI's of evaluation species, are unitless indices with the same scale. The use of a MOLP model simplifies the structure and hence makes the solution process easier for resource managers. Weights for objectives (**w**) and non-negative lower and upper bounds (**l** and **u**) for decision variables are treated purely as numerical parameters. In each iteration of the solution process, SEPS displays the solution and associated parameters (weights and bounds) from the last iteration and associated analyses (profiles) for the user to review. It enables the user to edit weights for the objectives and lower and upper bounds of the decision variables interactively in order to drive the solution in the general direction of user's preference. It then solves the underlying MOLP model and returns results with analyses for the next iteration. In such a learning process, the user improves understanding of the system and ability to control the direction of the solution using these parameters, until a preferred solution is found.

At any iteration, the user may save a copy of the solution that seems desirable before furthering the process in a different direction. The user can review and compare the set of records saved and delete any of them. When the user is dissatisfied with the direction of the current solution and would like to continue the solution process in the direction of one of the records, the user can "restore" the record to replace the current solution and continue the solution process.

The subroutine for solving the underlying MOLP is adapted from a LP solver written in HyperScript (Informix Software, Inc. 1990b) by Dr. Charles E. Noon, Management Science Program, the University of Tennessee, Knoxville.

Cover class definition and HSI coefficients

The user may be interested in altering the definition of forest cover classes, for example, to see the effect of a different rotation length. It is very likely that the user will want to modify HSI coefficients based on new estimates from the literature or field data. SEPS allows the user to change these parameters interactively in two windows. Since these changes will affect matrices **A** and **C** in the model, the MOLP formulation will be updated automatically after changes have been made.

§4.2 User Interface of SEPS

The user interface basically consists of three groups of windows. Two groups of windows are for editing parameters in LP formulation, solving the LP and displaying the solution. The third group of windows is for handling and displaying records of solutions. There are three additional windows. Window "Main" displays a main menu of the system (Figure 4.1). Two other windows are for editing forest cover class definition and

suitability index values for evaluation species in the cover classes. Browsing and editing procedures are similar to those in SEMA, described in Chapter 3.

Solution process

There are six windows which enable the user to review a solution, record the solution if desired, review habitat quality distribution (profile), edit weights for objectives and ranges for cover classes, and solve the modified LP problem.

Window "HSI Value & Weight/Table" displays the resulting objective values, HSI values for evaluation species, and weights for the objectives in tabular form (Figure 4.2). The user can change the weight for any of the objectives. HSI values and weights are also displayed in window "HSI Value & Weight/Chart" with a combined bar chart (Figure 4.3). Values of weights in the chart remain unchanged. Window "HSI Value & Weight/Profile" displays habitat quality distribution (profile), relative acreages in each of the HSI classes, by evaluation species in a combined bar chart (Figure 4.4).

Window "Cover Class Dist. & Range/Table" displays the distribution of cover classes from the last solution in relative acreage and the lower and upper bounds of cover classes used in last solution iteration (Figure 4.5). The user can edit the lower and upper bound of any of the cover classes except PO, SS and LS which are determined by the bounds of YG. The upper bound of SW is also limited by that of YG. When an entered value for the upper bound of SW is too large, the largest possible value will be calculated and put into the entry. The same information is also displayed in window "Cover Class Dist. & Range/Chart" with a combined bar chart, where values of lower and upper bound remain unchanged (Figure 4.6). Window "Cover Class Dist. & Range/S. Index" displays a table showing suitability indices of cover classes for evaluation species (Figure 4.7).

There are three windows which enable the user to review records (recorded solutions) and delete or restore a record as desired. Windows "Record of Solution/HSI's" and "Record of Solution/Cover" display a record in tabular form which are basically the same as those in windows "HSI Value & Weight/Table" and "Cover Class Dist. & Range/Table", respectively (Figures 4.8 and 4.9). "Record of Solution/Charts" displays a record with two combined bar charts in forms similar to those in windows "HSI Value & Weight/Chart" and "Cover Class Dist. & Range/Chart" so that the user can review both the objectives and the decision variables of a solution at the same time (Figure 4.10).

There are four buttons and a pop-up menu for handling records in each of these three windows. The pop-up menu shows the current record number and can be used to select any record for display. Buttons "Previous" and "Next" can be used to display the previous and the next record, respectively. Button "Delete" can be used to delete the record currently being displayed. Records with record numbers greater than that of the deleted record are renumbered to maintain a continuous integer number series. Button "Restore" can be used to replace values of all entries in windows "HSI Value & Weight/Chart" and "Cover Class Dist. & Range/Chart" with the values in windows "Record of Solution/HSI's" and "Record of Solution/Cover", respectively. There are no editing buttons in these three windows.

Cover class definition and suitability index

There are two windows which enable the user to interactively review and edit cover class definitions and suitability indices for evaluation species. The MOLP formulation is automatically modified according to changed parameters. Window "Cover Class Definition/Forest" displays definitions of forest cover classes (Figure 4.11). Window "Suitability Index" displays HSI values for a species or SI (suitability index) values for a

habitat component of a species in every cover class (Figure 4.12). These two windows are similar to the windows "Cover Class Definition/Forest" and "Suitability Index" in SEMA, described in the last chapter, respectively (Figure 3.3, 3.18).

Pull-down menus

Two "pull-down" menus, "File" and "Go" are available in SEPS. There are six standard items in the "File" pull-down menu for file handling. They include "New", "Open", "Close", "Save", "Revert to saved" and "Quit". There are three items, "Main", "Process" and "Definition" in the "Go" pull-down menu.

Windows in groups "HSI Value & Weight", "Cover Class Dist. & Range" and "Record of Solution" are for the solution process and they share a set of browsing buttons on top of the windows. Windows "Cover Class Definition" and "Species HSI Coefficients" are for definitions and they share another set of browsing buttons on the bottom of the windows. Select "Process" in the "Go" menu to go to solution process windows and select "Definition" in the "Go" menu to go to definition windows. Select "Main" in the "Go" menu to go to the main menu, window "Main".

§4.3 Applications of SEPS

Similar to SEMA, SEPS can be used in many strategic planning processes such as development of a resource management plan and preparation of an EIS or EA. However, SEPS serves a different purpose than SEMA. Given a set of general constraints, the user can explore for a preferred result and the way to achieve it at steady state regardless of the initial condition. Results can serve as a basis for forming management alternatives, the transient behavior of which can then be simulated by SEMA based on the initial condition. Using SEPS also enhances the user's understanding of the system being managed.

Therefore, SEPS is a useful tool for environmental education and teaching related to integrated resource management.

In using SEPS, the user can start with the most relaxed constraints by specifying 0's for all lower bounds 1's for all upper bounds and then narrow the ranges as needed during the solution process. But in a practical setting, another approach may be more meaningful. It is often of interest to explore the preferred solutions in several general directions. A given general direction always dictates a set of constraints in terms of acceptable ranges for acreages of some of the vegetation cover classes and certain expectations for habitats of evaluation species. It may be more efficient to use SEPS to explore the most preferred solution in each of the general directions within constraint levels dictated by the general direction.

When using SEPS for a given system in a given general direction, a set of LP's can be solved first by specifying the weight for a species as 1, and those for other species as 0 (or a very small number such as 0.01). These single iteration solutions may provide valuable information for the user. An example of solutions of such a set of LP's with a general management direction similar to current management plan of LBL is shown in Figures 4.13.a-g and 4.14.a-g. These solutions reveal the highest HSI for each of the evaluation species that can be achieved under the set of constraints (Figures 4.13.a-g). Each of the solutions shows relative acreages for some cover classes are equal to their lower- or upper-bounds (Figures 4.14.a-g). This indicates parameters (lower- or upper-bounds) which can be altered to improved the highest achievable HSI for each of the evaluation species. Interesting insights on trade-off relationships may be revealed by these solutions. The solution for achieving highest HSI for Gray Squirrel, for example, assigns much more acreage to cover class OG than to cover classes SS, LS and SW (Figures 4.14.f). Although cover classes SS, LS and SW provide better habitat for Gray Squirrel

than cover class OG does (Figures 4.7), increases of relative acreage in cover classes SS, LS and SW are accompanied by increases in relative acreages of cover classes YG and PO which have no or low value habitat for Gray Squirrel. It is, therefore, beneficial for improving average habitat quality to allocate more acreage to cover class OG. One can also learn about tradeoff relationships among habitat requirements of evaluation species from these solutions.

Chapter 5

Discussion

§5.1 Model Validation

Validation of SEMA and SEPS was not conducted in this dissertation project. This does need to be done in the future. Validity of SEMA and SEPS is basically determined by the validity of the vegetative cover class based simulation model and HSI models. Suggestions for validation and improvement of these models are made in the following sections. SEMA and SEPS are structured in such a manner that updating, based on results of validation studies, can be made easily.

§5.2 Cover Classes and Simulation

System of vegetation cover classes

It is a reasonable assumption that composition and structure of stands in all cover classes except OG will remain unchanged over time. They are directly or indirectly maintained by management activities. In the absence of management, stands in these cover classes should all succeed into cover class OG, given time. However, composition and structure of stands in cover class OG may change over time due to natural succession. It has been suggested that the mixed oak forest at LBL occurring lower than elevation 150 m above sea level may succeed into beech-maple forest without heavy disturbances over a very long period of time (Fralish and Crooks 1988).

There are few if any very old stands (≥150 years) presently at LBL due to past land use prior to the establishment of LBL. The majority of the stands currently in cover class OG are large sawtimber stands, or small sawtimber stands in some cases, which have been

assigned into cover class OG and let grow into old growth stands. Cover class OG was not sampled in the 1990 field sampling (Appendix A) due to limits on time. There was also a lack of information on old growth stands in TVA's CFI data (Groton et al. 1988). Average values of habitat variables in cover class OG were estimated by resource managers at LBL referencing average values of habitat variables in cover classes SS, LS and SW. It was assumed that these values would not change over time. This was because the scope of the EIS analysis for which SEMA was used was the next 50 years. In 50 years, the amount of successional change is very limited given the relative young stand ages of the stands in cover class OG. A better inventory of stands in cover class OG is very much needed. Also more research is needed on direction and pace of the succession from mixed oak to beech-maple forest at low elevation sites.

In future improvement of SEMA and SEPS for LBL, an expansion of the system of cover classes is needed. Hardwood forest at LBL can be divided into two groups. One include stands on dry south and southwest slopes and ridges with poor soils. The other includes stands on more mesic sites. These two groups have parallel cover classes from YG to OG and SW but the definition of the cover classes in the two groups in terms of stand age should be different. Cover classes in the first group have longer durations than those in the second group since growth rates are lower in poor sites. Cover class LS may even be eliminated in the first group because of relatively small tree sizes in mature stands. Stands in the cover class OG of the first group have stable compositions and structures which change little over time. Different management activities can be prescribed for forests in the two groups. This expanded system of cover classes may lead to more realistic simulations of vegetation and more accurate evaluations of wildlife habitat. In order to utilize this expanded system of cover classes for SEMA and SEPS, sufficient data provided by an adequate inventory system or additional field studies are needed.

Simulation models

A simulation model (referred to as "cover class model") less complex than the simulation model described in Chapter 3 (referred to as "age class model") was used in an earlier version of SEMA. The "cover class model" had 13 state variables which were acreages of each of the cover classes. Age distribution (in one-year intervals) in each class is assumed to be a uniform distribution because current age distribution within each cover class is not available. For cover class i with d one-year age classes, it is assumed that output acreage from cover class i to cover class i+1 at year t is 1/d of the acreage of cover class i at year t-1 . It is also assumed that the difference between input acreage from cover class i-1 at year t and 1/d of the acreage of cover class i at year t-1 will be evenly distributed into the d one-year age classes.

These assumptions for the "cover class model" are the same as those made in DYNAST (Boyce 1980), although the model structures are not the same. Sweeney (1986) indicated two problems with these assumptions when there was an empty (zero acreage) cover class and made refinements of DYNAST to solve these problems. The first problem was that an empty cover class i which received input at year t would start output at year t+1. The second was that a non-empty cover class i with d one-year age classes would not be empty after not receiving any input for d years (the preceding cover class was empty).

There is a third problem associated with the assumptions that can not be solved by Sweeney's refinements. Due to large-scale natural or human disturbances, it is not unusual that one cover class has a per one-year age class acreage much higher than those of other cover classes of the same cover type. With the above assumptions, the simulation will flatten the acreage "pulse" by distributing it into following cover classes and as a consequence give misleading results. The "age class model" in this study solves all three

problems by using the acreage of each one-year age class as a state variable, except for cover classes at the end of (within cover type) successional paths. Cover classes at the end of successional paths do not contribute to the problems based on the model structure. Defining acreage of each of these cover classes as a state variable can reduce the computation considerably because these cover classes usually have long durations.

Comparisons of the simulation results of the "cover class model" to the simulation results of the more realistic "age class model" were conducted for alternatives A and B described in Chapter 3 (Figures 5.1, 5.2). For alternative A with no empty cover class, "cover class model" overestimated acreages for cover class SS and underestimated acreages for cover classes LS and OG significantly in some periods of the simulation. The largest discrepancy exceeded 19,000 acres. Trends of change in several cover classes, especially in SS, were also misrepresented in the simulation result of "cover class model" (Figure 5.1). For alternative B, "cover class model" had both the second and the third problems associated with its assumptions. Decrease in acreages of cover classes YG, PO, SW and Yp was delayed significantly in the simulation result of "cover class model". Acreages in cover classes LS and OG were underestimated with the largest discrepancy exceeding 26,000 acres. The trend of change in cover classes SS was misrepresented in the simulation results of "cover class model" (Figure 5.2).

§5.3 Evaluation of Wildlife Habitat

Habitat models

HSI models have been developed for large geographical areas. Testing and modifying for local conditions, "localization", of HSI models are needed. These exercises are usually limited by time and budget. A project testing the HSI model for Gray Squirrel

at LBL is currently being conducted by Rice and Fieldhammer of Southern Illinois University (Rice, personal comm.).

Improvements in selection of habitat variables for HSI models are needed. HSI models have been developed based on wildlife literature and expert opinions of wildlife biologists. Most habitat variables used are relatively easy to sample. But they are very different from variables used in typical ecological surveys and forest inventories. This is not a problem in the traditional use of HSI models such as land development assessment and mitigation projects. It, however, hinders the wide use of HSI models in the planning of multiresource management by other agencies and private companies. It would be very helpful to use, or have options to use, more standard forest inventory variables such as basal areas and densities instead of canopy covers of different forest components.

Spatial factors

Spatial interspersion of cover classes is an important factor in determining habitat quality for species dependent on more than one cover class. Given the non-site-specific nature of this level of planning, spatial factors can not be dealt with directly or explicitly in the simulation. However, some spatial factors can be taken into account in the simulation indirectly based on the existing condition of the planning area and management guidelines regarding spatial distribution of cover classes for site-specific scheduling. In addition to the example of evaluating Wild Turkey habitat described in Chapter 2, the following is another example.

An extended version of SEMA used for LBL's revised EIS included three more evaluation species, Bobcat (*Felis rufus*), Northern Bobwhite (*Colinus virginianus*) and Bared Owl (*Strix varia*). Interspersion or spatial distribution of cover types affects the suitability of the habitat for Northern Bobwhite. All open land units and YG and Yp stands

in LBL are considered small and widely dispersed. But some mature forest stands may be too far away from any open land or young growth openings and therefore have little value for Bobwhite. In the HSI model for Bobwhite, interspersion is measured by an interspersion index based on distance between cover types, which requires site-specific spatial information (Schroder 1985b). Due to the non-site-specific nature of the simulation, a different approach was taken which determines "useable" acreages in mature forest cover classes and uses these acreages in calculating HSI and HU for Bobwhite.

It is assumed that forest land within 100 m from the edge of an open land unit or a young growth stand is "usable" by Bobwhites. All open land units in 15 systematically selected work areas (416 units total) were studied on 1:20,000 aerial photographs. For each unit, the shape and the percent of its perimeter that adjoined forest land were determined. The size of each of these units was obtained from LBL's open land inventory data. A ratio of the acreage of "usable" forest land to the acreage of the open land unit (F/O ratio) was then determined.

A ratio of the acreage of "usable" forest land to the acreage of each of the 837 YG and 77 Yp stands in LBL (F/Y ratio) was also determined based on the acreage of the stand, as obtained from forest inventory data. YG and Yp stands are more regular in shape than open land units are, and the majority of them are surrounded by forest. It was assumed that on the average a YG or Yp stand has a rectangular shape (length is twice of the width) with 95% of its perimeter adjoining forest land.

Using average values of F/O and F/Y ratios, "usable" acreages in cover classes PO, SS, LS, OG, Mp and Ms at a given year can be determined based on their acreages and the acreages of cover classes CF, GF, FF, SF, YG and Yp in the same year. All acreages in cover class SW are considered "usable" because of the open nature of SW stands.

Multiresource inventory database

A multiresource inventory database is essential to the development of a planning model for multiresource management and validation and improvement of such a model. Most resource inventory systems were originally designed for single resource management goals and served their original purposes well. However, they need to be improved or redesigned for multiresource management.

Tree species groupings currently used in LBL's forest inventory data base and sampling regime serve well for purpose of timber sales. This inventory, however, can not generate some of the species groupings frequently used by wildlife habitat models such as group of hard mast producing species and group of soft mast producing species. Individual tree information needed to determine some habitat variables, such as density of trees of certain size class and species group, is not maintained in the data base. Some coarse measures or visual estimation of variables regarding coverages of certain species groups in shrub layer and herbaceous layer would also be valuable for assessing wildlife habitat.

Development of an information base similar to the Wildlife and Fish Habitat Relationship (WFHR) system for LBL will substantially improve the ability of resource managers for wildlife habitat management planning.

§5.4 RMOLP Approach

Similar to the implicit/explicit approach (Harrison and Rosenthal 1986), RGP and RMOLP approaches use a "decision maker-machine" procedure. Different from traditional "analyst-machine" procedures and "decision maker-analyst-machine" procedures, it enables decision makers to directly use the MOP model to explore their preferred solutions and

communicate with other decision makers in a group decision making environment. In the implicit/explicit approach, an algorithm controls the direction of the solution process based on user responses. RGP and RMOLP approaches however, let the user be in control. The user can influence direction of solution by altering weights for the objectives and/or restructure the problem by altering constraints in the case of RMOLP. A robust and user friendly user interface or decision support environment, which makes viewing and editing easy and efficient, is essential for such approaches.

In addition to enabling the user to alter weights in the objective function as in RGP approach, RMOLP approach enables the user to alter the right hand side (RHS) of some constraints as well. This ability to manipulate the RHS values, which are the lower and upper bounds of relative acreages of cover classes in the model, may be very useful in exploring preferred solutions. The range of relative acreages of a cover class can be reduced in either direction to influence achievements in certain objectives, when altering weights is not effective or is causing undesirable changes in other objectives. The range can also be relaxed to a degree in either direction when needed since it is a general but not definite range for a given general direction. SEPS displays these RHS values as lower and upper bounds for a set of variables instead of in a LP format. This makes them intuitive and easy to understand by resource managers. Criteria embedded in the interface prevent these RHS values from being altered in such ways that make the altered problem infeasible.

Given the nature of the RMOLP approach, the solution process can explore in many directions before the user reaches a conclusion. The feature that allows the user to save a record of any solution for any reason and to restore any saved record and continue the solution process from that solution, adds considerably to the efficiency of SEPS.

The LP solver written in HyperScript (Informix Software, Inc. 1990b) currently used in SEPS is slow for an interactive system. A commercial LP solver, LINDO© for Macintosh (Schrage 1991), is going to be linked to SEPS to replace the current LP solver. This replacement will improve the speed of solution and hence the efficiency of SEPS substantially. Large problems with more objectives and more constraints can be treated efficiently. There are also commercial nonlinear programming solvers such as GINO© (Liebman et al. 1986), although they are expensive. With the linkage of GINO to SEPS, more general MOP problems including nonlinear constraints can be solved using SEPS. HSI for Northern Bobwhite determined with nonlinear formulations, for example, can be included as an objective in the model.

§5.5 Generality of Planning Models

Generality and Usefulness of planning models

The usefulness of a planning model can be measured by its effectiveness and efficiency in the planning process(es) at the planning area(s) that this model is developed for. To be useful in a planning process in a given planning area, a planning model must be able to address the array of questions to the levels of detail required by the planning process. The model is less effective if it can not address the questions or can not address them to the required levels of detail. The model is less efficient if it addresses additional questions not required, or addresses questions to levels of detail finer than required, at the expense of greater effort in data collection or greater difficulty in understanding and using the model (due to increased model complexity, decreased speed or robustness of the interface). To be useful in a planning process, a planning model should be robust and user friendly enough that resource managers in all areas involved in this planning process can use it on their own. They should be able to use the model to test any relevant scenario they

are interested in and communicate with other mangers using the model. It is less efficient, and more importantly less effective, if a "decision maker-analyst-machine" system has to be used. With such a system, resource managers have to rely totally or partially on an analyst to make use of the model.

There are two likely approaches to make a planning model more general, i.e. to make it applicable for many planning areas which have different settings. One approach is to ignore differences by making stronger assumptions. This often is not a satisfactory solution because it may greatly reduce the effectiveness of a model. The resulting model is developed for use at many planning areas but serves none satisfactorily. Another approach is to include more options in the model which cover all or most of the possible situations in all planning areas under consideration. This may not be feasible. Given the different settings of natural resources and the different legislative regulations and public demands, different planning areas have different questions which need to be addressed. They may also have some of the same questions which need to be addressed in different ways. The requirements on the computer facility at each of the planning areas for a more complex model may also limit feasibility. Assuming this approach is feasible, it may not be efficient. Non-necessary options and more complex procedures may be a burden to the user. It may prevent resource managers from using the model directly.

A "general structure and interface, specific model" approach

A "general structure and interface, specific model" approach, may serve better in developing effective and efficient planning models. In this approach, a general structure and interface is designed for a planning process but is implemented with detailed structures and parameters specific for a given planning area. A parameter or a detailed structure is included in the specific model for planning area A, for example, if and only if it is required

by the planning process at planning area A. A specific model for the same planning process at another planning area, e.g. planning area B, can be developed by modifying the specific model. An effective and efficient planning model for planning area B thus can be built with only a moderate amount of effort since there should be very limited change in the general structure and interface. Also, there may not be a great deal of change in detailed structures and parameters. A specific model developed using this approach, in a sense, is general because it can be relatively easily modified to form other specific models which can be used for the same planning process at other planning areas.

SEMA was developed with the "general structure and interface, specific model" approach. It was built to evaluate management alternatives in strategic planning of forest and open land management for wildlife habitat improvement at LBL. The interface design of SEMA is, however, useful for a variety of planning models and can be fairly easily adapted. The basic structure of SEMA (i.e., stand age based cover class definition, age class based forest simulation, evaluation of wildlife habitat using HSI and simulated cover class distribution, and evaluation of landscape diversity based on simulated cover class distribution) can serve well for this type of planning at other planning areas with forest dominated vegetation. Most of these management parameters are used in standard forest management.

SEPS was developed with the same approach. It uses stand age based cover class definition and evaluates wildlife habitat using HSI based on steady state cover class distribution. SEPS's interface design is actually more general in nature. It can be easily modified for solving other multiple objective linear programming problems, not limited to resource management problems, using Robust MOLP approach.

Modifying SEMA and SEPS for use in other places

SEMA can be modified to develop a planning model for other planning areas, for example national or state forests and wildlife management areas. Resource managers at a planning area need to develop a system of vegetative cover classes for their planning area, describe the management activity used and the effect of a management activity on a stand in a given cover class, select evaluation wildlife species, and determine the suitability indices of cover classes for evaluation species using HSI or other habitat models. This may appear to be a major undertaking. But in any planning area, there is very likely a classification system of cover types and their successional stages (cover classes) already established for management purposes. Effects of management activities on a stand (changing the cover class classification of a stand) are usually known. Evaluation species can be selected based on management objectives and habitat model availability. There may be some difficulties in determining suitability indices for evaluation species in the cover classes when the information from inventory data bases and previous studies at the site is not sufficient for determining values of habitat variables used in the habitat models. In this case, additional field sampling will be needed, as in this study. If this is not feasible in terms of time and budget, an adaptive management approach (Walters 1986) may be taken. Estimates of values of habitat variables made by a team of experts can be used and can later be updated based on field study. Once information is obtained, it may take one to three weeks for a programmer to modify SEMA with this information and build a new specific planning model for that planning area.

Modification of SEPS for use in other places can be done in a similar manner. Information used for modifying SEMA is more than sufficient for modifying SEPS because SEPS only deals with steady state distribution of cover classes and corresponding HSI of evaluation species.

§5.6 Implementation of Resource Management Plans

Tactic planning - site specific scheduling

Implementation of a strategic resource management plan is accomplished by tactical planning, i.e., site specific scheduling of management activities. Objectives for acreage distribution of cover classes and acreages for various management activities determined by the management plan need to be implemented, as well as guidelines and criteria for spatial distributions of cover classes. Site specific scheduling is a planning process involving an interdisciplinary team of resource managers from areas such as forestry, wildlife, recreation, water quality and archaeology. In such a process, there are always site specific problems or factors which can not be incorporated into the scheduling model for use in all sites. Recognition and solution of these problems depend upon the expertise, experiences, and judgement of resource managers. To be effective, this scheduling process must have efficient ways of allowing for active interventions of resource managers.

Various multiple objective programming (MOP) models and approaches have been developed for "site-specific" planning of multiresource forest management (Arp and Lavigne 1982, Bare and Mendoza 1990, 1988, Leuschner et al. 1975, Mendoza 1988, Mendoza et al. 1987, Schuler and Meadows 1975, Steuer and Schuler 1978). These approaches are used to allocate areas within homogeneous management units to various management regimes. A management regime is defined as a combination of management activities at fixed points of time within a given planning period. This type of allocation is not quite site-specific because it only assigns a certain acreage within a management unit to a management regime without specifying spatial location of the acreage in the unit. It is possible to modify most of these approaches to allocate a management regime to each individual stand in the management unit. Given the model structures of these approaches

however, it is difficult to capture and use explicit spatial information in evaluating some of the objectives such as wildlife habitat. Using either "analyst-machine" or "decision maker-analyst-machine" procedures, these approaches are not efficient for active interventions of resource managers. Covington et al. (1988) developed TEAMS (Terrestrial Ecosystem Analysis and Modeling System), a decision support system to aid forest managers in developing site specific management schedules over a fixed planning period (Covington et al. 1988, Wood et al. 1989). TEAMS is a synthesized system composed of commercially available software (relational data base and query system, geographic information system, multiresource forest management simulation system, linear programming package, graphics package) and internally developed interfacing modules. TEAMS is an interactive tool that provides managers with rapid feedback on the consequences of management alternatives. It ultimately depends on human judgement and expertise for a final decision (Covington et al. 1988). TEAMS is currently operational for southwestern ponderosa pine forest in the southwestern U.S..

Scheduling of management activities at LBL has been conducted by resource managers manually without computerized tools. It has been relatively effective due to the design of the scheduling scheme. LBL is divided in to 65 work areas for forest management. These work areas are divided into seven groups, each of which includes nine or ten work areas. Groups are formed in such a way that work areas within a group are spatially separated and well distributed across LBL. Each year, only one of the groups is scheduled for forest management. Each group is therefore scheduled for forest management in a 7-year cycle. The scheduling is done at the work area level. Implementing some of the criteria for spatial distribution bsed on human judgment is feasible because of the limited number of stands in a work area (50-100). The effectiveness of this scheduling process, however, is limited. It is difficult for resource

managers to experiment with alternative schedules due to the level of efficiency. There is also a lack of effective means for evaluating the effect of a schedule on wildlife habitat.

A proposed scheduling system for LBL (SSLBL)

A scheduling system for LBL (SSLBL) is proposed in this section. Hopefully, a prototype of SSLBL will be developed in the near future. The proposed SSLBL can aid resource managers at LBL in scheduling forest management activities with an emphasis on spatial arrangement of stands of different cover classes and effects on wildlife habitats. For each work area, a "scheduling unit" is defined as the area including all stands in the work area and stands outside but within a certain distance of the boundary of this work area. Total acreage for each management activity is distributed into work areas in the group due for scheduling each year according to relative size of the work areas. This distribution can be adjusted to a degree by resource managers to accommodate other considerations.

A spatial data base can be constructed for each scheduling unit. It contains information on physical attributes (size, shape, slope, aspect, soil type, etc.) of the stands and their dynamic vegetative status (cover type, stand age, basal areas, volume, etc.). It also contains information on spatial relationships (distance, adjacency, amount of common boundary with a given immediate neighbor, etc.) among stands. This data base is linked to LBL's forest inventory data base and the GIS data base. It can retrieve information from the two data bases and update the two data bases.

A set of scheduling rules will be assembled which impose both spatial and temporal constraints on scheduling. There are global and local rules. Global rules apply to all scheduling units and local rules apply only to the target scheduling unit. Users can modify, delete or add rules. Some possible rules may be as follows. Stands other than LS and surplus OG are not eligible for clear cut or first shelterwood cut. A stand adjacent to a

stand which has been harvested during last two cycles is not eligible for harvesting. Stands within a certain distance from legal roads, streams and recreation facilities are not eligible for clear cut or shelterwood cut.

In SSLBL, scheduling is conducted on a map of the scheduling unit. The map shows the spatial distribution and classifications of stands within the scheduling unit. Stands are shaded with different patterns according to their cover class classifications.

Upon user request, SSLBL can display (highlight) stands eligible for a given management activity based on relevant rules. Information related to these stands, such as total acreage, distributions of stand acreage, stand age, and basal area, is also displayed or available for request. These attributes can be displayed in various forms, graphs or tables that can be sorted by any of the attributes.

When the total acreage of eligible stands is greater than the acreage planned for that management activity in this scheduling unit, a subset of the eligible stands needs to be selected to meet the acreage goals. The selection of such a subset of eligible stands for the management activity for the current management cycle, i.e. scheduling, is based on different conditions of these stands and their spatial distribution.

Scheduling can be done automatically. Several scheduling algorithms such as select older stands first, select larger stands first, select for maximum interspersion, or select randomly are available for the user to choose. Scheduling can be done manually in a graphical fashion. The user can select a stand and reverse the selection on the displayed map interactively using the "mouse". Together with the acreage planned, the acreage that has been scheduled is displayed and updated with each selection and reversion of a selection. Information on attributes of stands and some specified rules on spatial distribution can be used to facilated the scheduling. What is very important is that in

manual scheduling, the judgments of resource managers, which are based on experience and consideration of many possible factors not explicitly specified in the model, can be used in the scheduling process. A combination of automatic scheduling and manual scheduling may be most effective.

At any point during the scheduling process, evaluations of scheduling can be carried out upon user request. The acreage distribution of cover class, habitat suitability of evaluation wildlife species and indices of the landscape after the management activity can be calculated and displayed. These conditions can also be compared with those before the management activity and those established in the management plan. At the level of scheduling, habitat suitability of a stand for evaluation species requiring interspersed habitat such as Wild Turkey and Bobwhite, is evaluated with explicit spatial measures. Estimates of volumes of timber harvested from these stands can also be made. When scheduling is finished, a set of pre-designed tables and figures can be generated for use in the scheduling report.

§5.7 Summary

Two large-scale strategic planning models for wildlife habitat management and environmental assessment on forest dominated landscapes were developed with a specific application to wildlife habitat management at TVA's Land Between The Lakes (LBL).

A system of vegetation cover classes for LBL was developed. It represents the structure and dynamics of managed forest and open land systems at LBL. HSI models of selected evaluation species were used to evaluate habitat suitability based on the system of vegetation cover classes. Suitability indices of cover classes for evaluation species were determined based on data from field sampling, the literature, and expert opinions.

A system for evaluating management alternatives (SEMA) was developed in WingZ with a robust user interface. SEMA lets the user edit cover class definitions, initial conditions and management parameters interactively and efficiently. SEMA simulates vegetation changes in response to management activities over 100 years; evaluates corresponding changes in habitats of evaluation species and provides detailed analysis of habitat changes; and evaluates corresponding changes in compositional landscape diversity. Simulation results are displayed in both graphical and tabular formats in a set of windows for the user to review. Any of the windows can be printed out upon user request.

A system for exploring preferred solutions (SEPS) was developed in WingZ with a robust multiple objective linear programming (RMOLP) approach. SEPS enables the user to explore user preferred results in terms of HSI's of evaluation species at steady state. The results are achieved by identifying a satisfactory cover class distribution within a general management direction.

Applications of these models include both integrated resource management and environmental assessment. SEMA has been used by LBL to prepare the Environmental Impact Statement (EIS) of natural resource management at LBL.

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Appendices

Appendix A

Tables and Figures

Table 2.1. Vegetation Cover Classes at LBL

	Vegetation Cover Class	Stand Age (yr)
Open Land:	1. Crop Field (CF)	
	2. Grass Field (GF)	
	3. Forb Field (FF)	
	4. Shrub Field (SF)	
Hardwood Forest:	5. Young Growth (YG)	1-15
	6. Poletimber (PO)	16-50
	7. Small Sawtimber (SS)	51-80
	8. Large Sawtimber (LS)	81-150
	9. Old Growth (OG)	>150
	10. Shelterwood (SW)	>80
Pine Forest:	11. Young Pine Plantation (Yp)	1-15
	12. Mature Pine Plantation (Mp)	>15
	13. Mature Shortleaf Pine (Ms)	>15

Table 2.2. Description of Open Land Management Classes at LBL

Management Class	Description
Cooperative farming	Open land farmed by cooperative farmers annually. Up to 20 percent of the crops are left unharvested for wildlife consumption.
Contract farming (Food plots)	Open land farmed by contractors on a 2-year cycle. All crops are left unharvested for wildlife consumption.
Pasture, roadsides, etc.	Open land treated annually, including buffalo pasture, roadsides, prairie and scenic vista areas, and gas pipeline rights-of-way.
Reverting field (soil disturb.)	Open land treated in a 4-year cycle with soil disturbance (mowing, disking and sowing).
Reverting field (no soil dist.) & power line r.o.w	Open land treated in a 4-year cycle without soil disturbance (mowing/burning), plus power line rights-of-way which is bushhogged in about a 4-year cycle.

Table 2.3. Definition of Open Land Cover Classes at LBL

	Value of Defining Variable		
Cover Class	Percent canopy cover of shrub	Proportion of herbaceous cover that is grass	Average spring height of herbaceous canopy
Crop Field *			
Grass Field	< 35 %	>50 %	≤40 cm
Forb Field	< 35 %	≤50 %	>40 cm
Shrub Field	≥35 %		

* Open land used for growing row crops.

Table 2.4. Relationship between Management Class and Cover Class at LBL

Management Class		Cover Class			
		Crop Field	Grass Field	Forb Field	Shrub Field
Cooperative farming		70 %	30 %		
Contract farming	yr 1 & 2	100 %			
Pasture, roadsides, etc.			100 %		
Reverting field (soil dist.)	yr 1		100 %		
	yr 2		40 %	60 %	
	yr 3		10 %	75 %	15 %
	yr 4			80 %	20 %
Reverting field (no soil d.)	yr 1		20 %	20 %	60 %
& power line r.o.w	yr 2			30 %	70 %
	yr 3			20 %	80 %
	yr 4			10 %	90 %

Table 2.5. Evaluation Species and Citation of the HSI Models

Evaluation Species		Citation of HSI models
Eastern Meadowlark	*Sturnella magna*	Schroeder and Sousa 1982
Eastern Wild Turkey	*Meleagris gallopavo sylvestris*	Schroeder 1985b
White-tailed Deer	*Odocoileus virginianus*	Urich et al. 1983
Gray Squirrel	*Sciurus carolinensis*	Allen 1987
Pileated Woodpecker	*Dryocopus pileatus*	Schroeder 1983

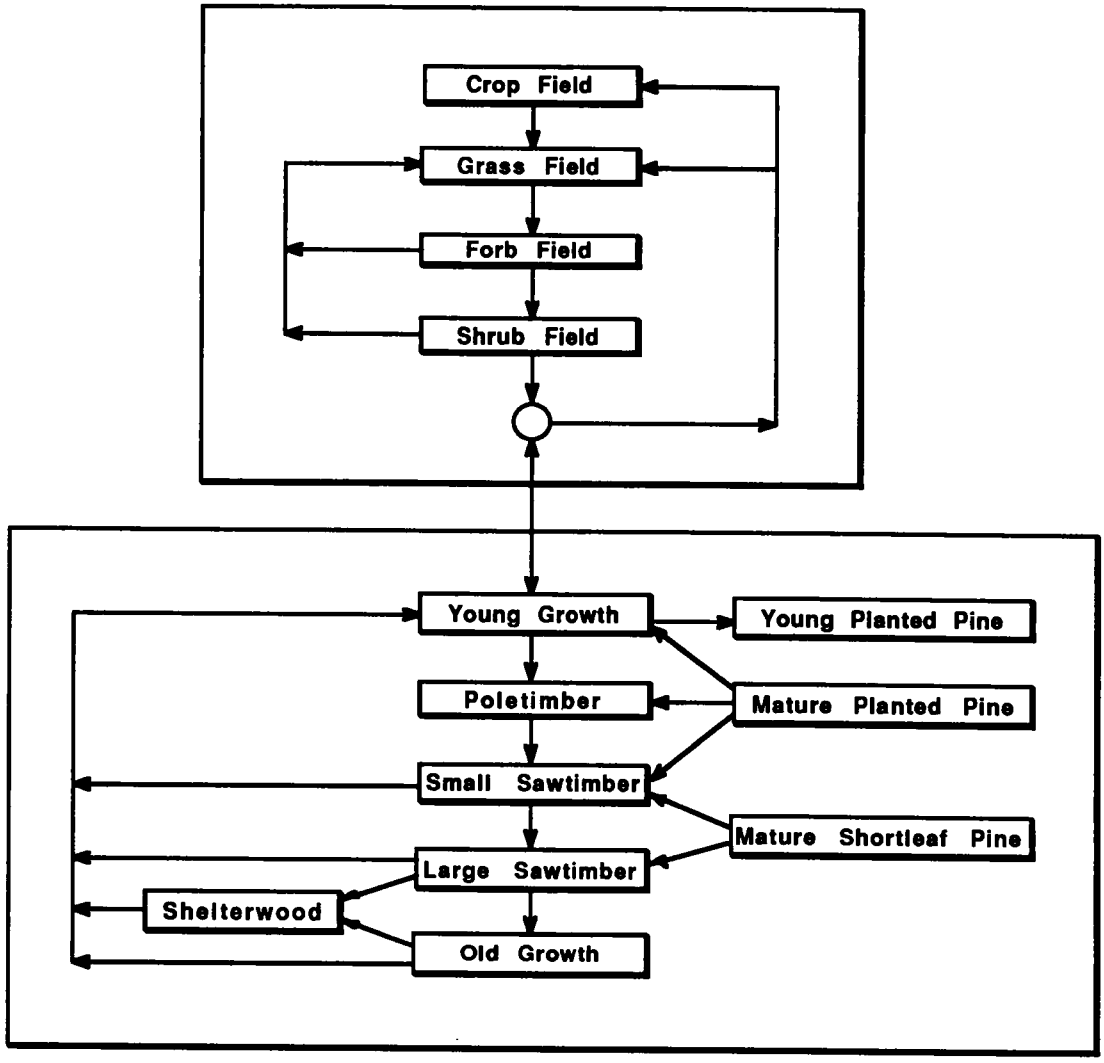


Figure 3.1. Diagram of the Vegetation Cover Class System for LBL

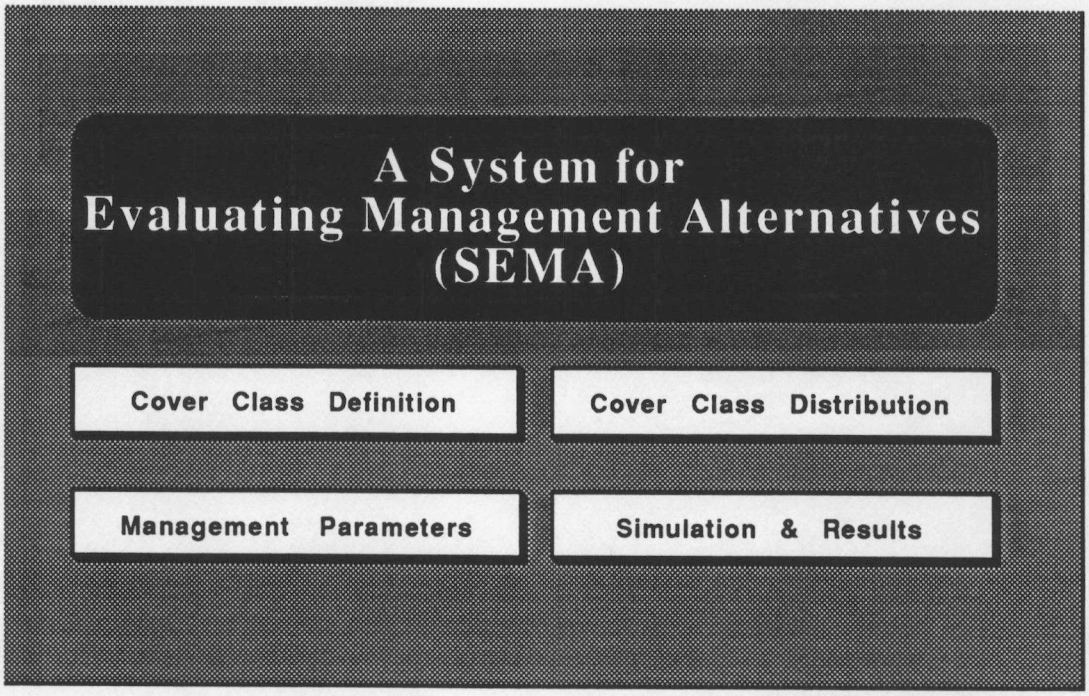


Figure 3.2. Window "Main", showing title and main menu of SEMA.

LANCASTER BOND

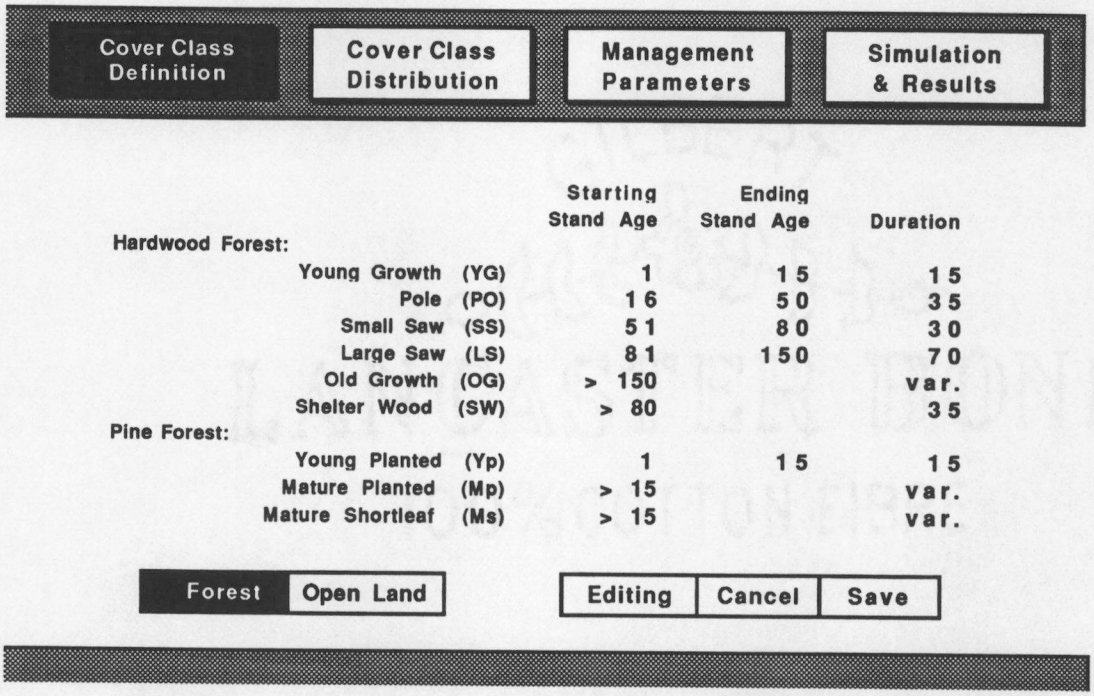


Figure 3.3. Window "Cover Class Definition/Forest"

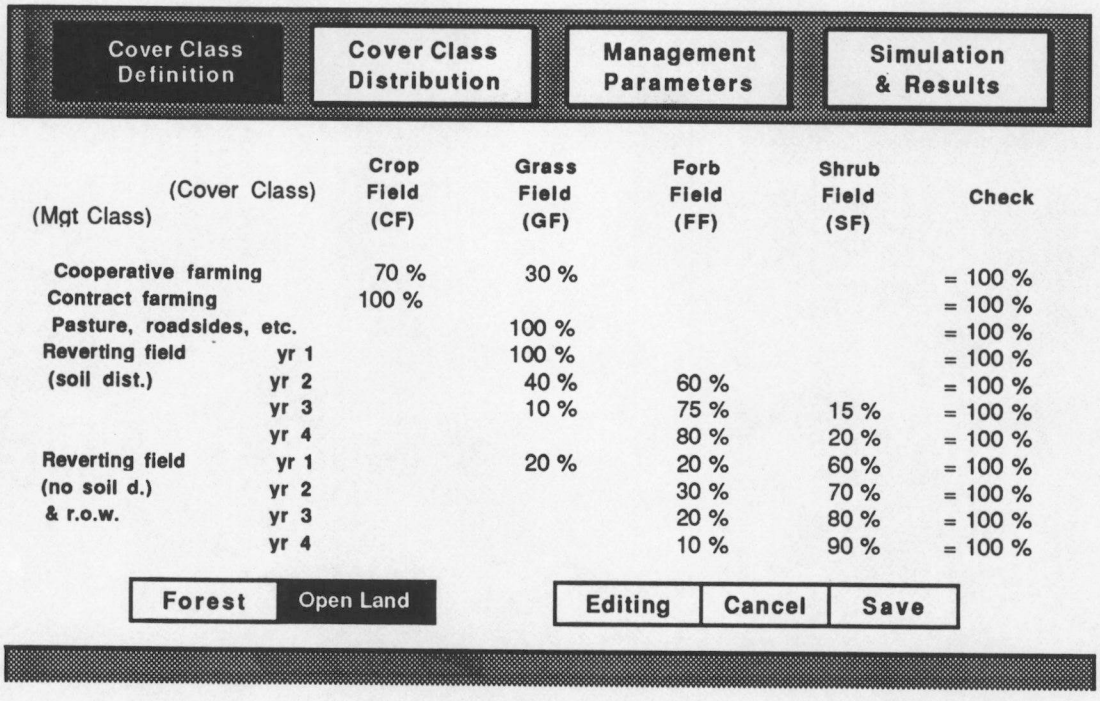


Figure 3.4. Window "Cover Class Definition/Open Land".

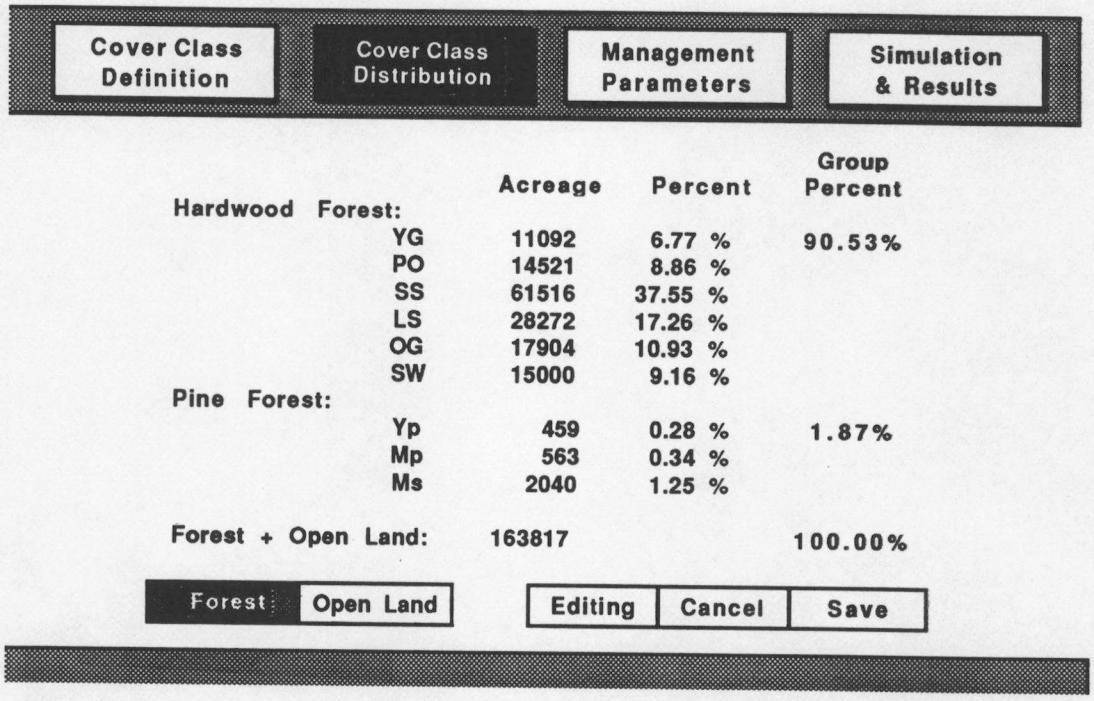


Figure 3.5. Window "Cover Class Distribution/Forest".

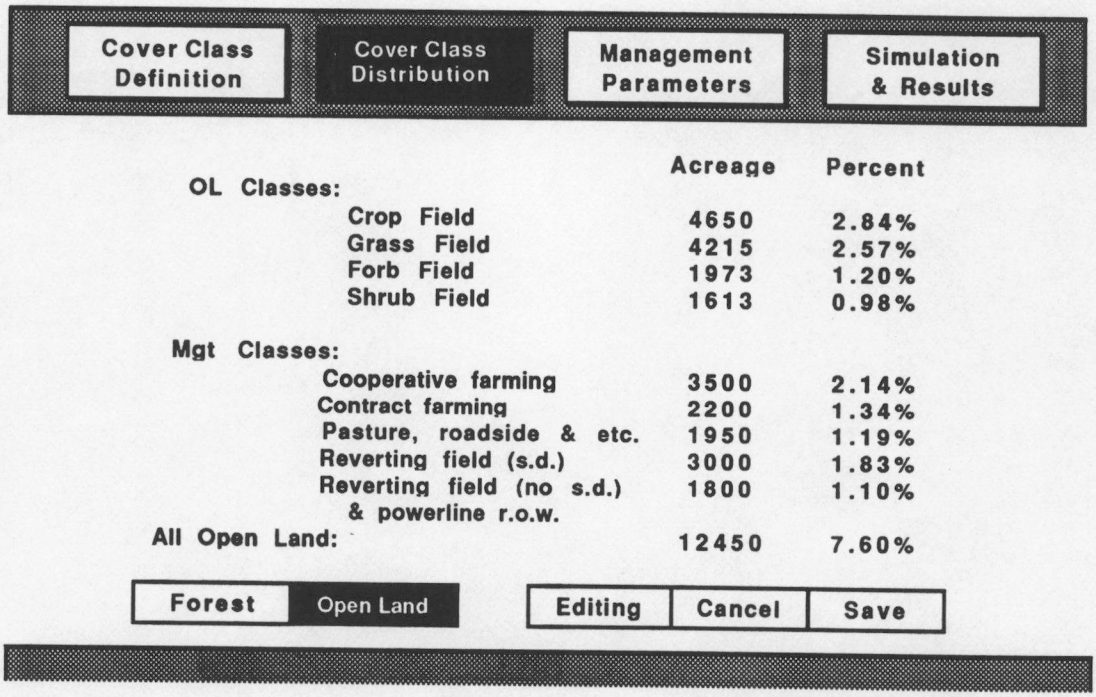


Figure 3.6. Window "Cover Class Distribution/Open Land".

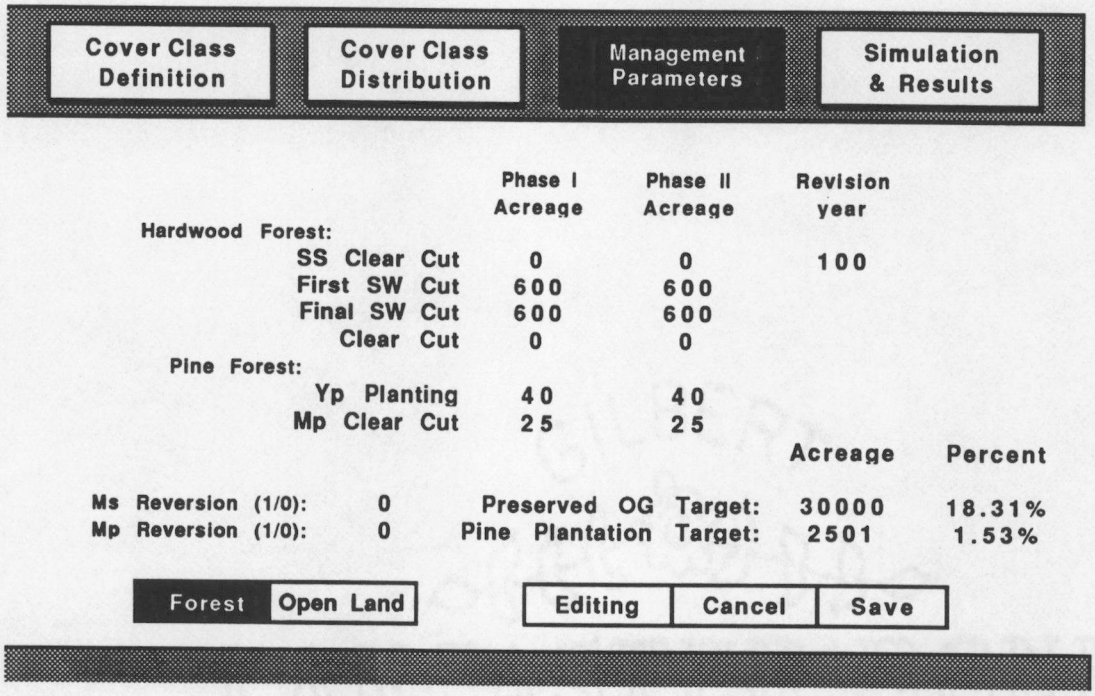


Figure 3.7. Window "Management Parameters/Forest".

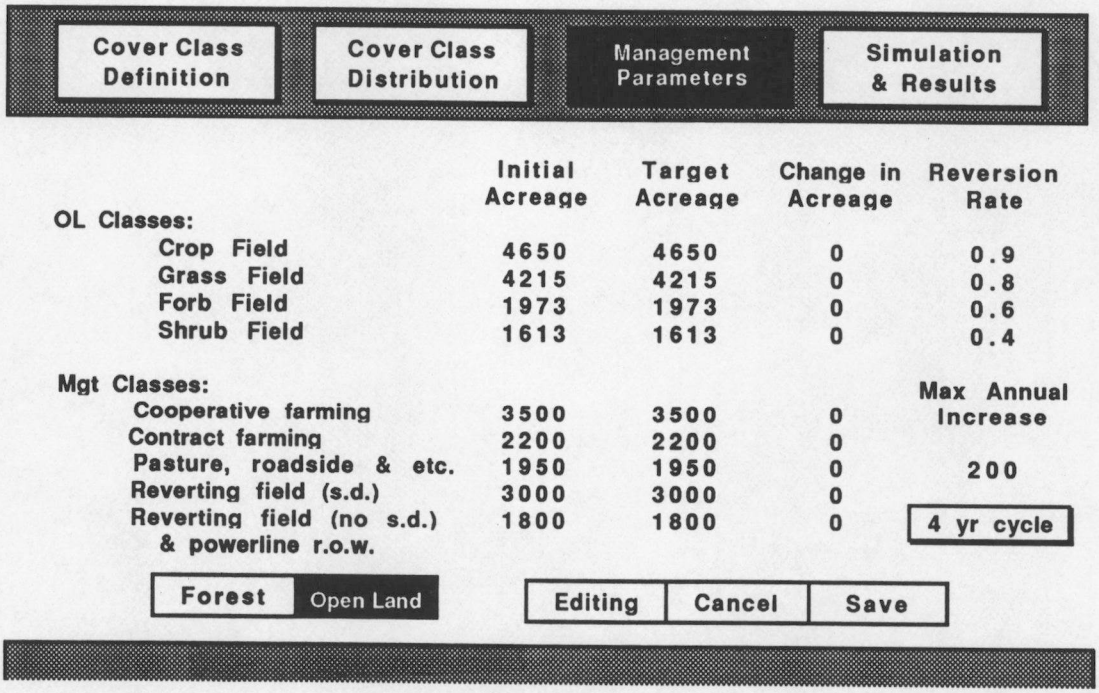


Figure 3.8. Window "Management Parameters/Open Land".

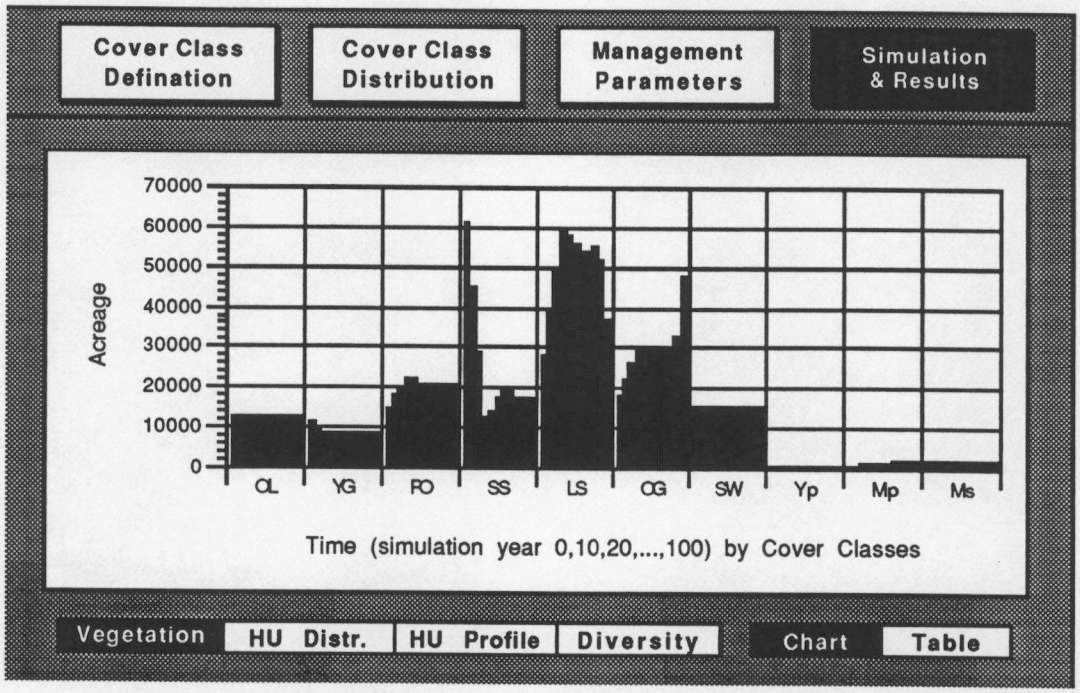
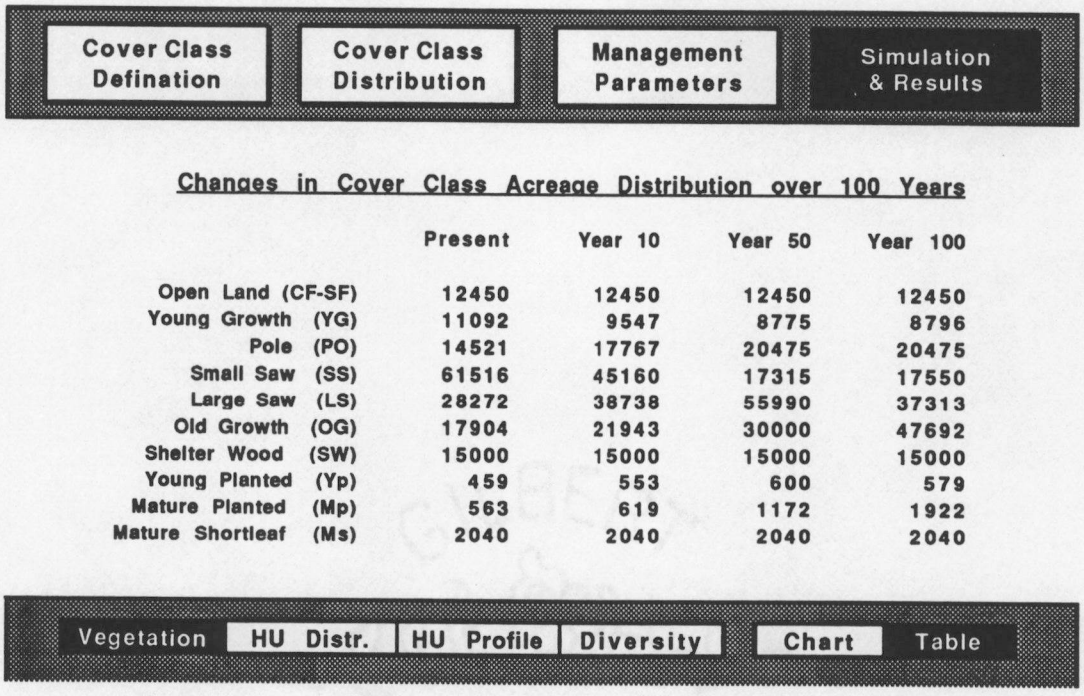


Figure 3.9. Window "Simulation Results/Vegetation/Chart".



Changes in Cover Class Acreage Distribution over 100 Years

	Present	Year 10	Year 50	Year 100
Open Land (CF-SF)	12450	12450	12450	12450
Young Growth (YG)	11092	9547	8775	8796
Pole (PO)	14521	17767	20475	20475
Small Saw (SS)	61516	45160	17315	17550
Large Saw (LS)	28272	38738	55990	37313
Old Growth (OG)	17904	21943	30000	47692
Shelter Wood (SW)	15000	15000	15000	15000
Young Planted (Yp)	459	553	600	579
Mature Planted (Mp)	563	619	1172	1922
Mature Shortleaf (Ms)	2040	2040	2040	2040

Figure 3.10. Window "Simulation Results/Vegetation/Table".

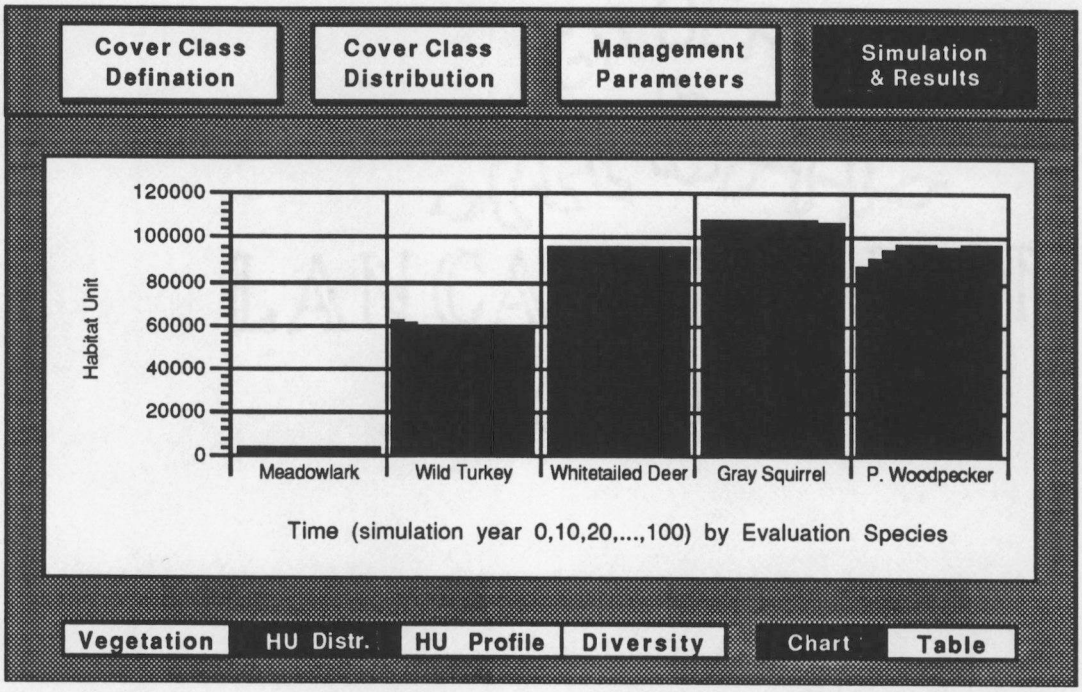


Figure 3.11. Window "Simulation Results/Habitat Units/Chart".

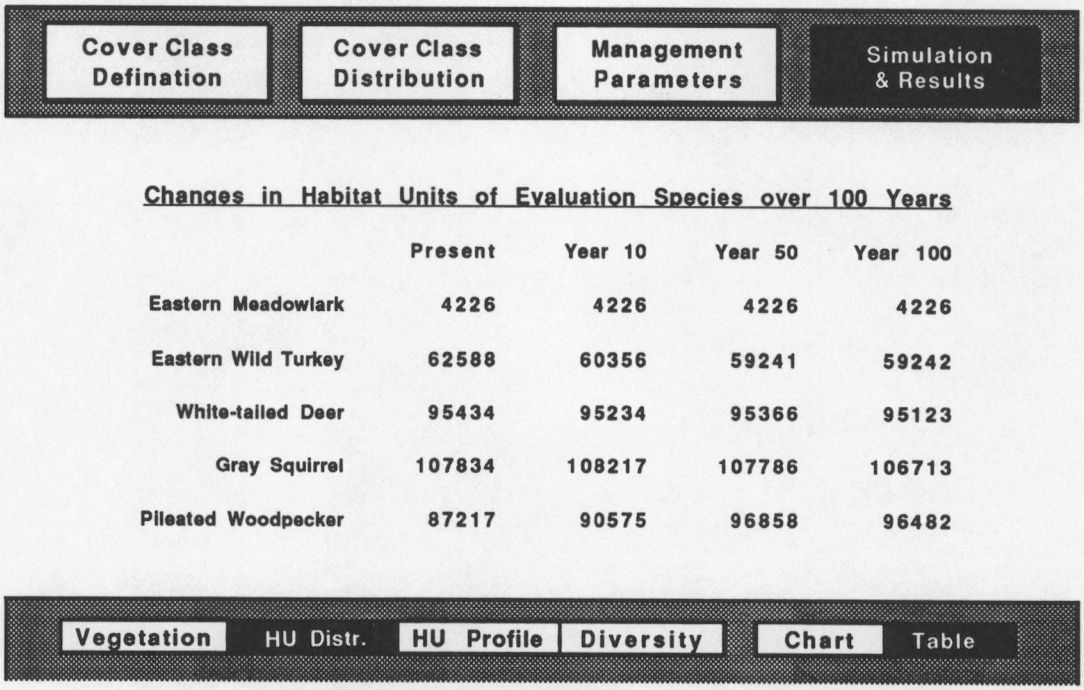


Figure 3.12. Window "Simulation Results/Habitat Units/Table".

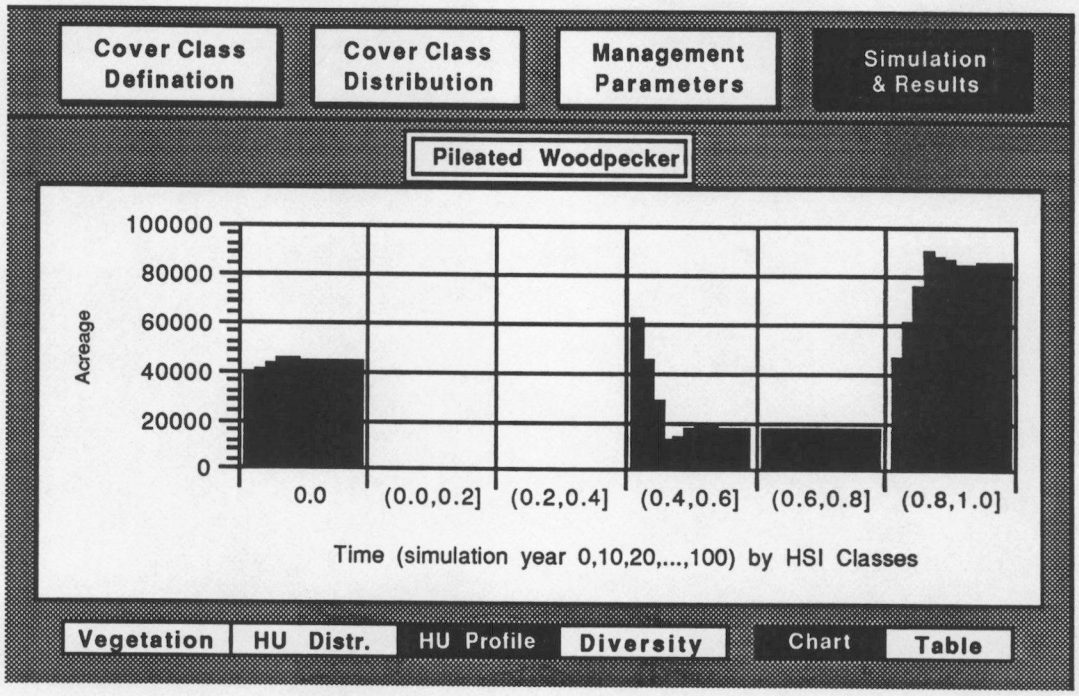


Figure 3.13. Window "Simulation Results/HU profile/Chart".

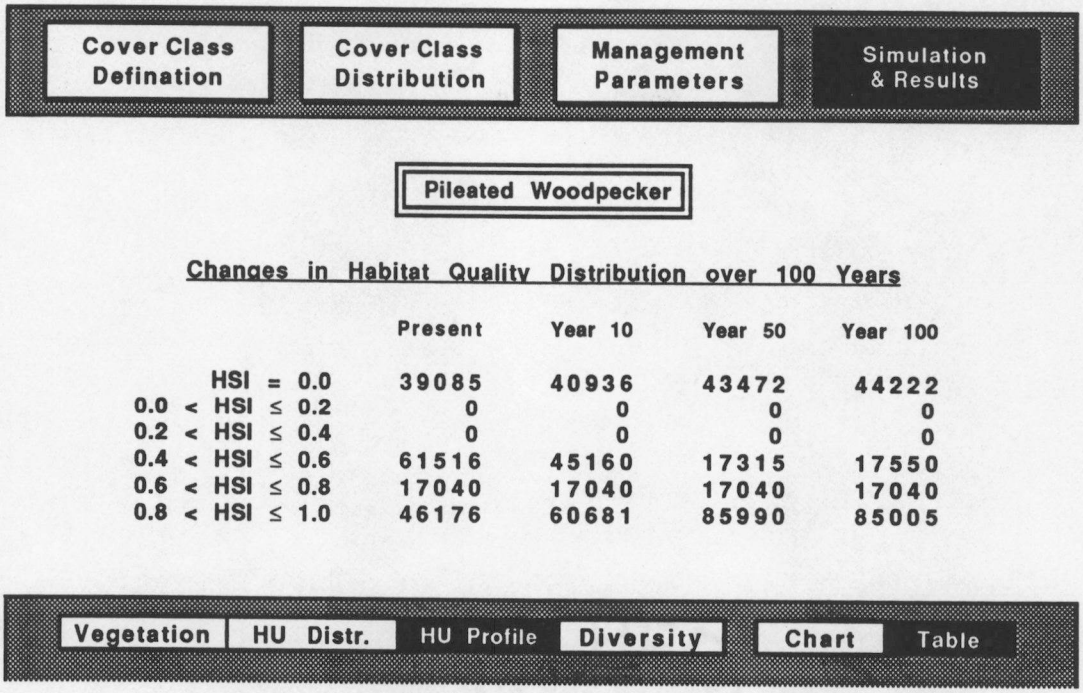


Figure 3.14. Window "Simulation Results/HU profile/Table".

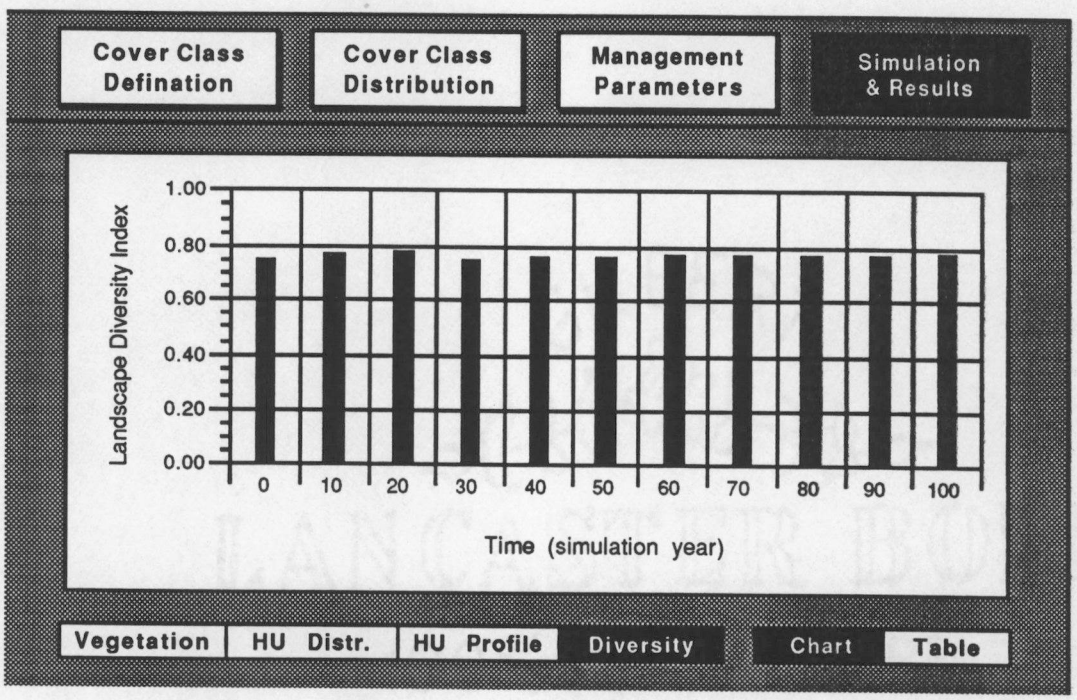


Figure 3.15. Window "Simulation Results/Diversity/Chart".

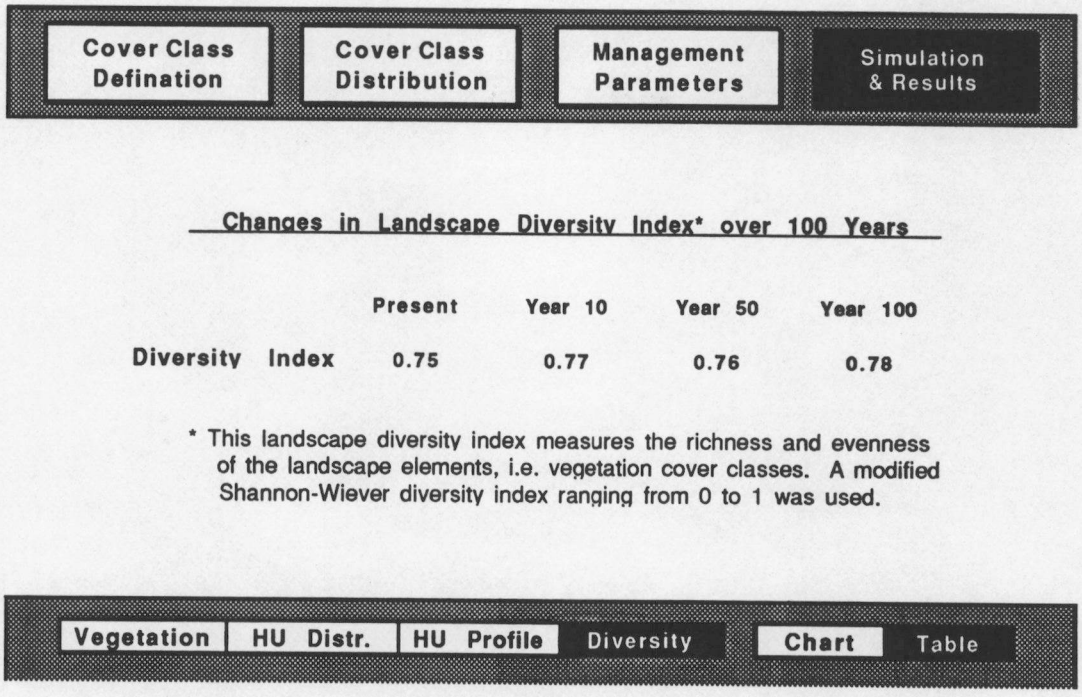


Figure 3.16. Window "Simulation Results/Diversity/Table".

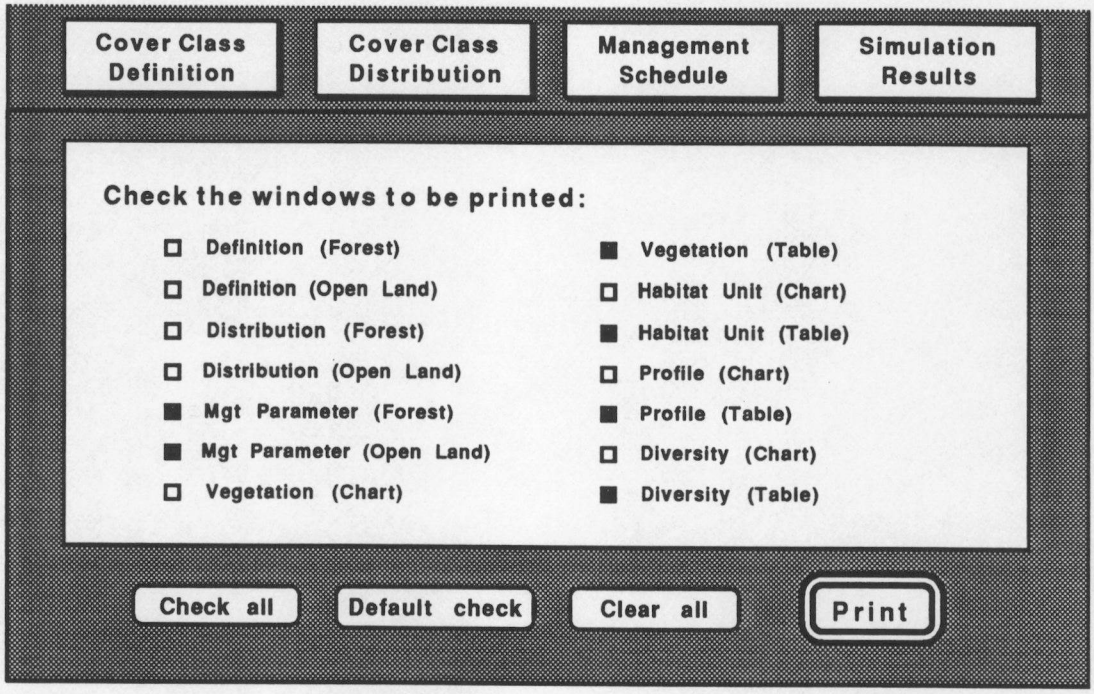


Figure 3.17. Window "Print...".

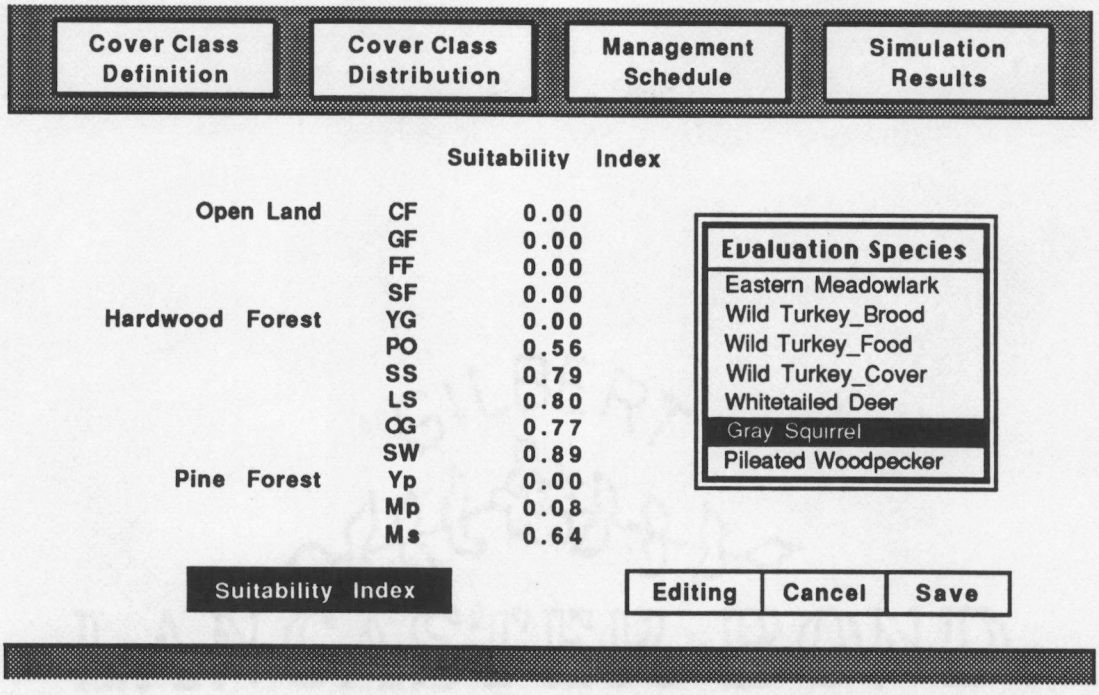


Figure 3.18. Window "Suitability Index".

Table 3.1. Management Parameters for Alternative A and Alternative B.

	Management Parameter	Alternative A	Alternative B
Hardwood Forest			
	SS Clear Cut (acre/yr)	0	0
	First SW Cut (acre/yr)	600	0
	Final SW Cut (acre/yr)	600	0
	LS Clear Cut (acre/yr)	0	0
	Preserved OG Target (acre)	30000	n/a
Pine Forest			
	Yp Planting (acre/yr)	40	0
	Mp Clear Cut (acre/yr)	25	0
	Pine Plantation Target (acre)	2500	n/a
	Ms Reversion (1/0)	0	1
	Mp Reversion (1/0)	0	1
Open Land			
	CF Target (acre)	4650	0
	GF Target (acre)	4215	1340
	FF Target (acre)	1973	160
	SF Target (acre)	1613	600

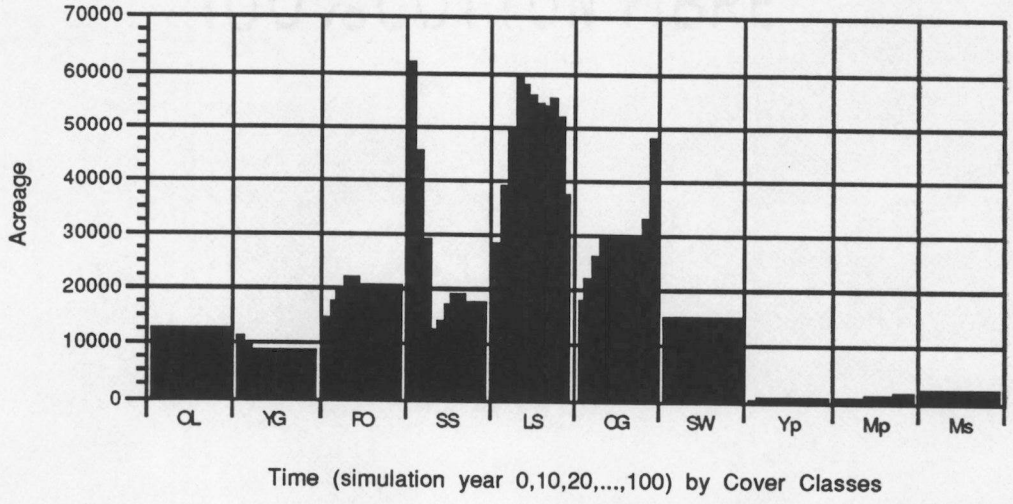


Figure 3.19. Projected changes in acreages of cover classes over time under alternative A.

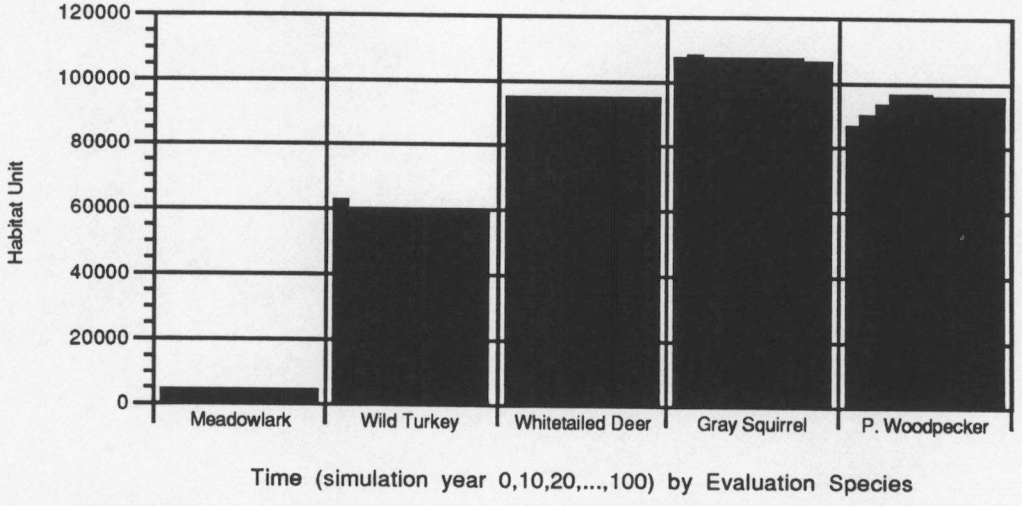
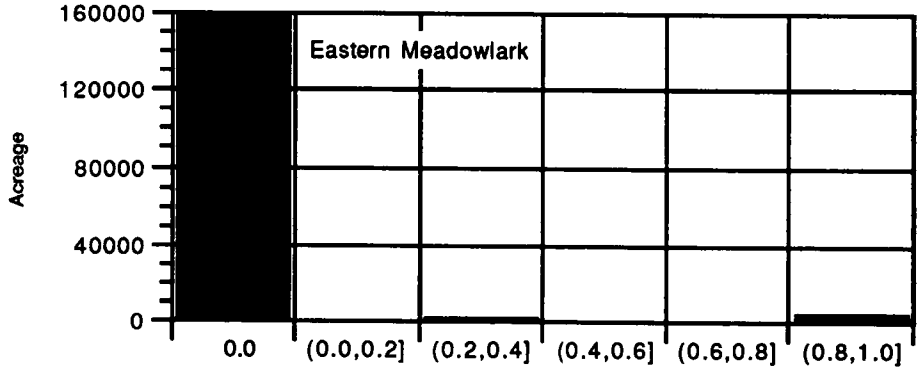
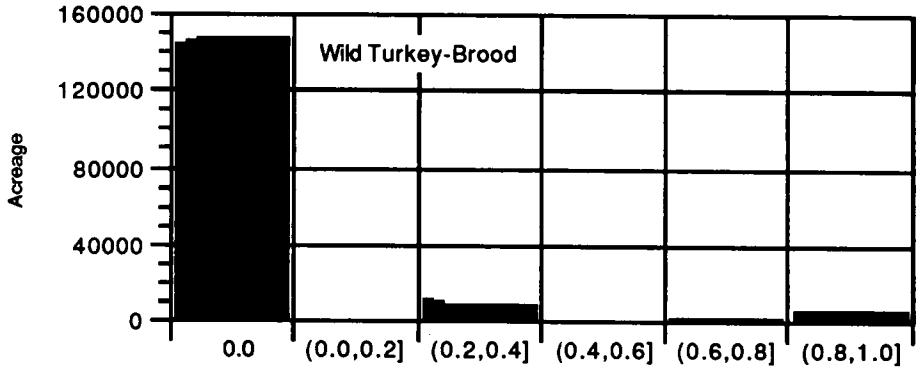


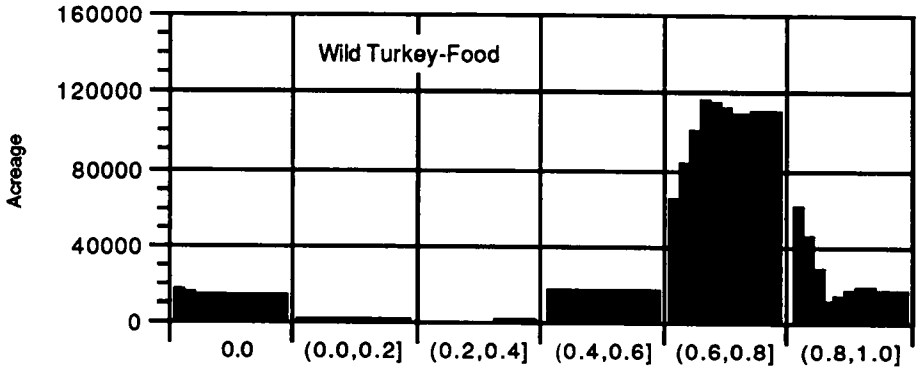
Figure 3.20. Projected changes in habitat units for evaluation species over time under alternative A.


Eastern Meadowlark
Acreage
160000
120000
80000
40000
0
0.0
(0.0,0.2]
(0.2,0.4]
(0.4,0.6]
(0.6,0.8]
(0.8,1.0]

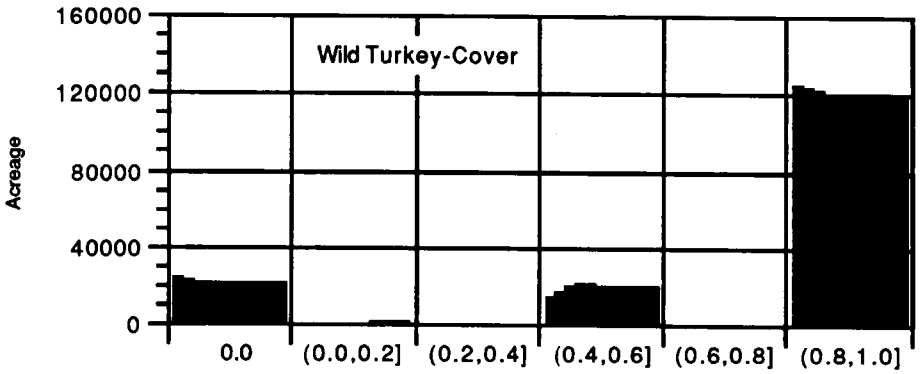
a.


Wild Turkey-Brood
Acreage
160000
120000
80000
40000
0
0.0
(0.0,0.2]
(0.2,0.4]
(0.4,0.6]
(0.6,0.8]
(0.8,1.0]

b.


Wild Turkey-Food
Acreage
160000
120000
80000
40000
0
0.0
(0.0,0.2]
(0.2,0.4]
(0.4,0.6]
(0.6,0.8]
(0.8,1.0]

c.


Wild Turkey-Cover
Acreage
160000
120000
80000
40000
0
0.0
(0.0,0.2]
(0.2,0.4]
(0.4,0.6]
(0.6,0.8]
(0.8,1.0]

d.

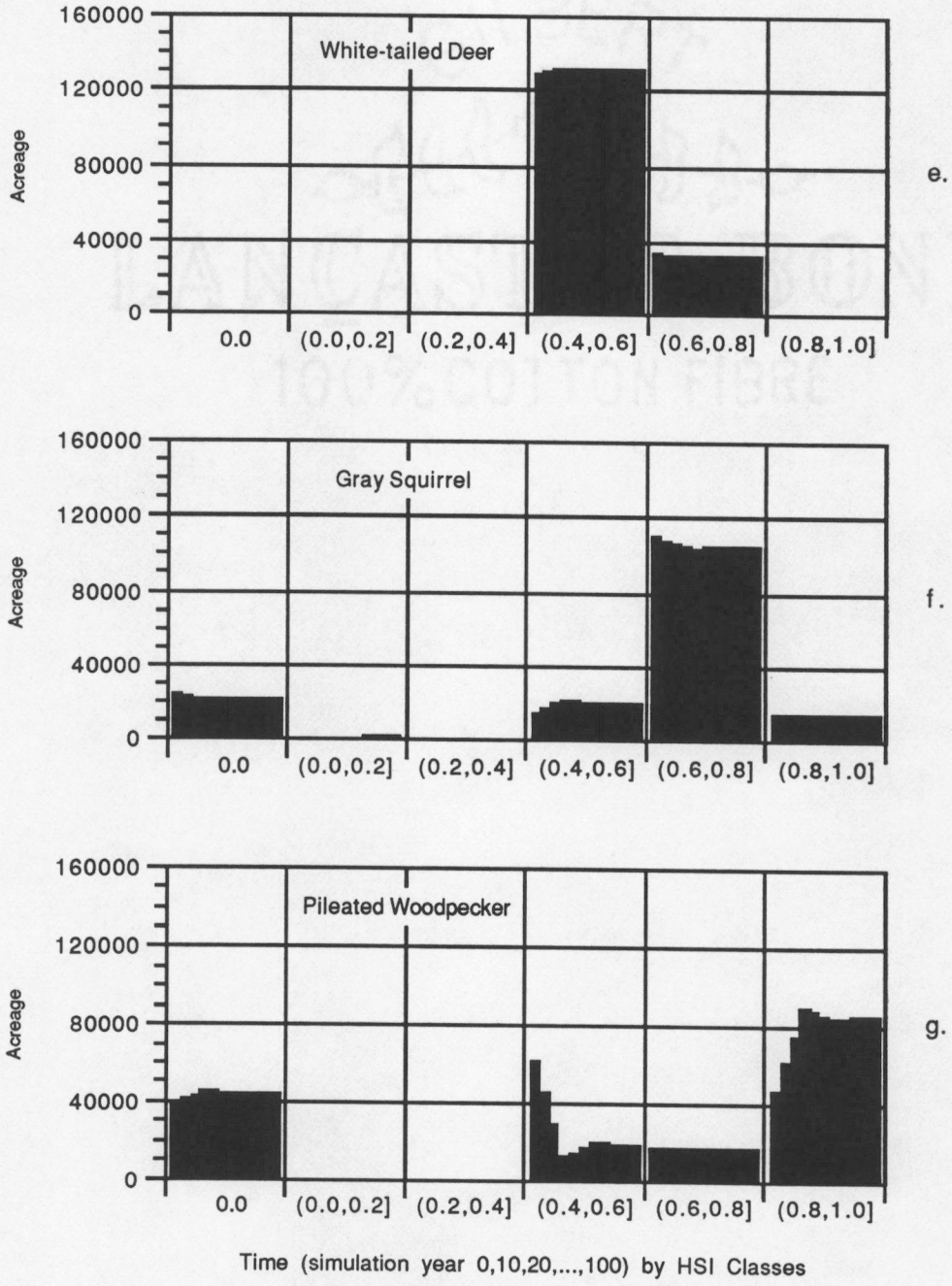


Figure 3.21. Projected changes in habitat quality distribution (profile) for evaluation species over 100 years under alternative A.

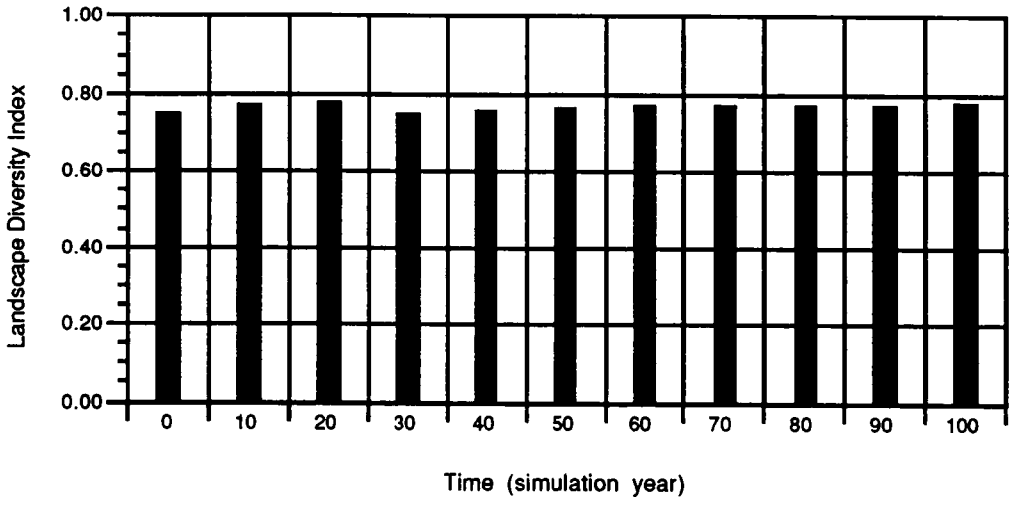


Figure 3.22. Projected changes in compositional landscape diversity over 100 years under alternative A.

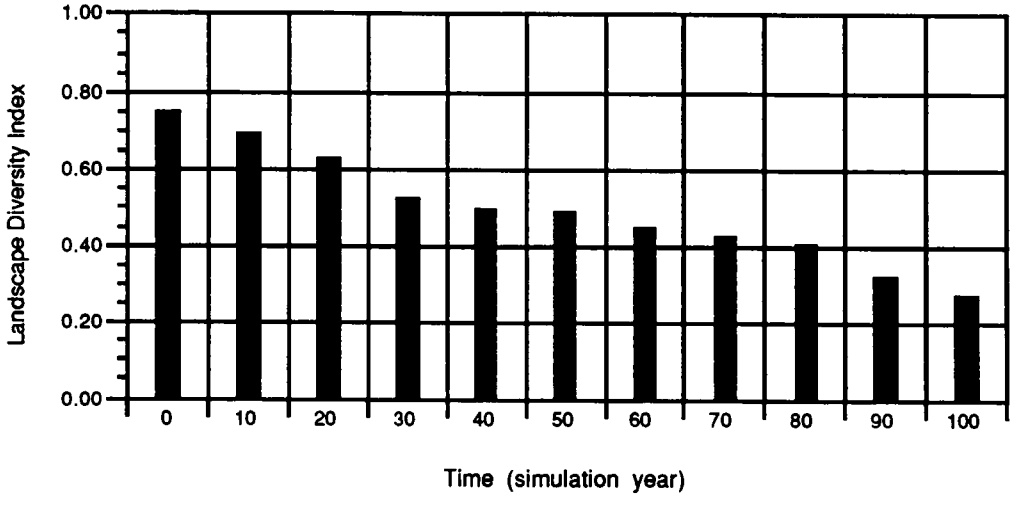


Figure 3.23. Projected changes in compositional landscape diversity over 100 years under alternative B.

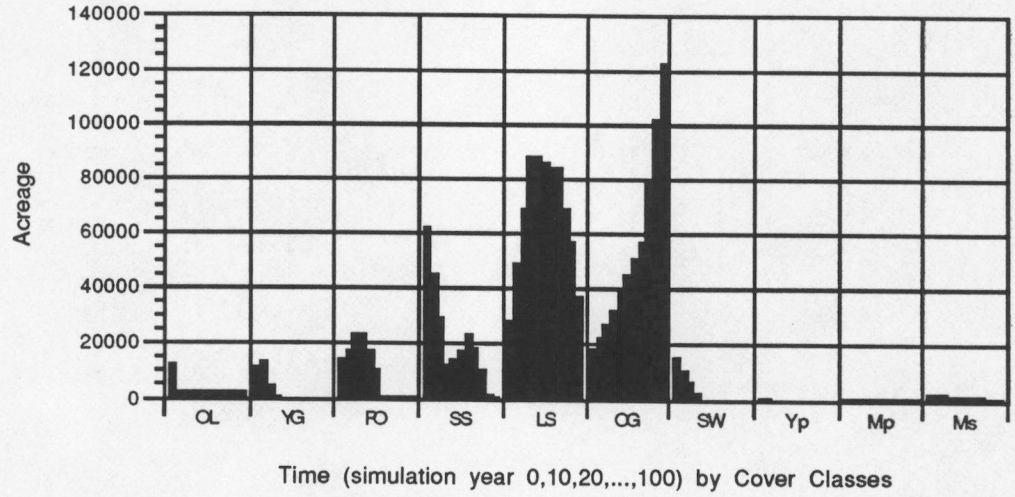


Figure 3.24. Projected changes in acreages of cover classes over 100 years under alternative B.

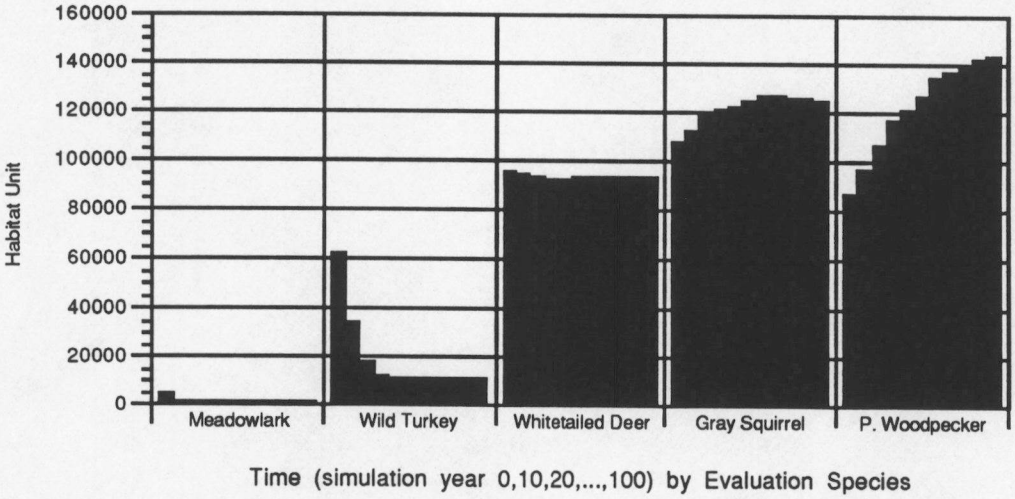
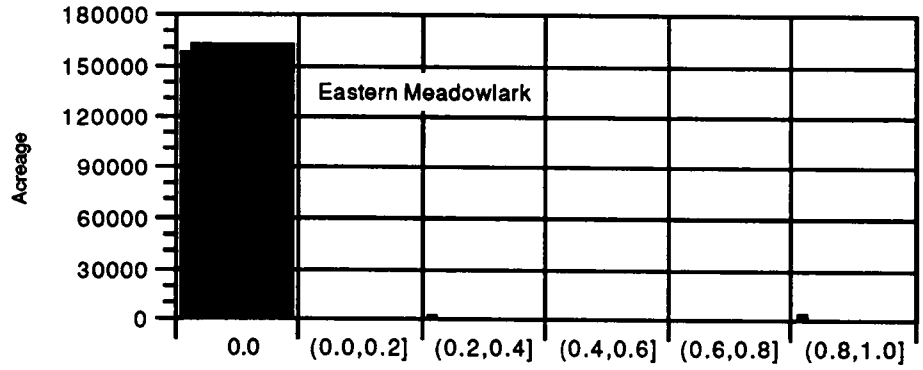
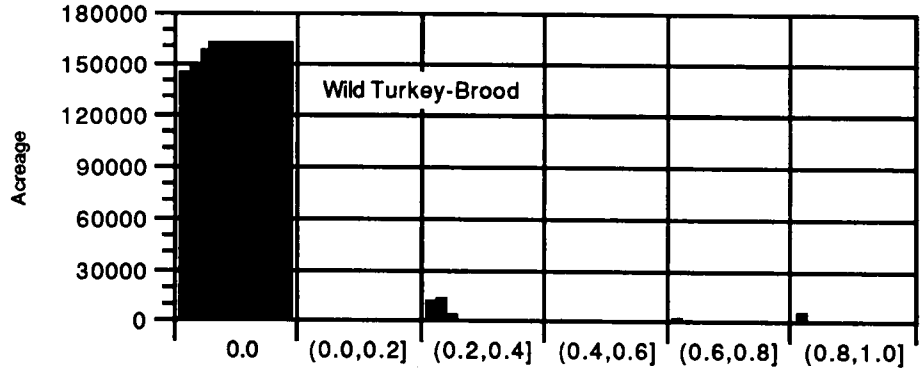


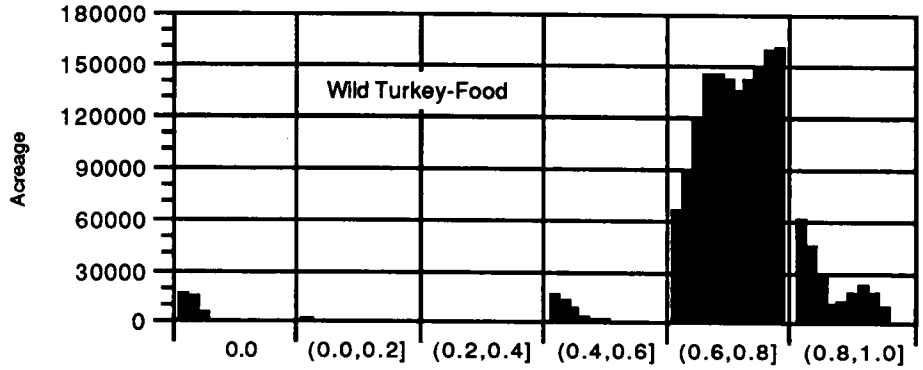
Figure 3.25. Projected changes in habitat units for evaluation species over 100 years under alternative B.


Eastern Meadowlark
Acreage
180000
150000
120000
90000
60000
30000
0
0.0
(0.0,0.2]
(0.2,0.4]
(0.4,0.6]
(0.6,0.8]
(0.8,1.0]

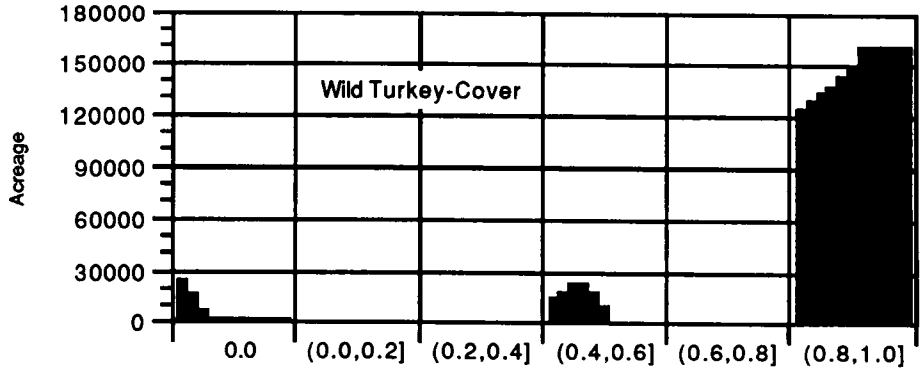
a.


Wild Turkey-Brood
Acreage
180000
150000
120000
90000
60000
30000
0
0.0
(0.0,0.2]
(0.2,0.4]
(0.4,0.6]
(0.6,0.8]
(0.8,1.0]

b.


Wild Turkey-Food
Acreage
180000
150000
120000
90000
60000
30000
0
0.0
(0.0,0.2]
(0.2,0.4]
(0.4,0.6]
(0.6,0.8]
(0.8,1.0]

c.


Wild Turkey-Cover
Acreage
180000
150000
120000
90000
60000
30000
0
0.0
(0.0,0.2]
(0.2,0.4]
(0.4,0.6]
(0.6,0.8]
(0.8,1.0]

d.

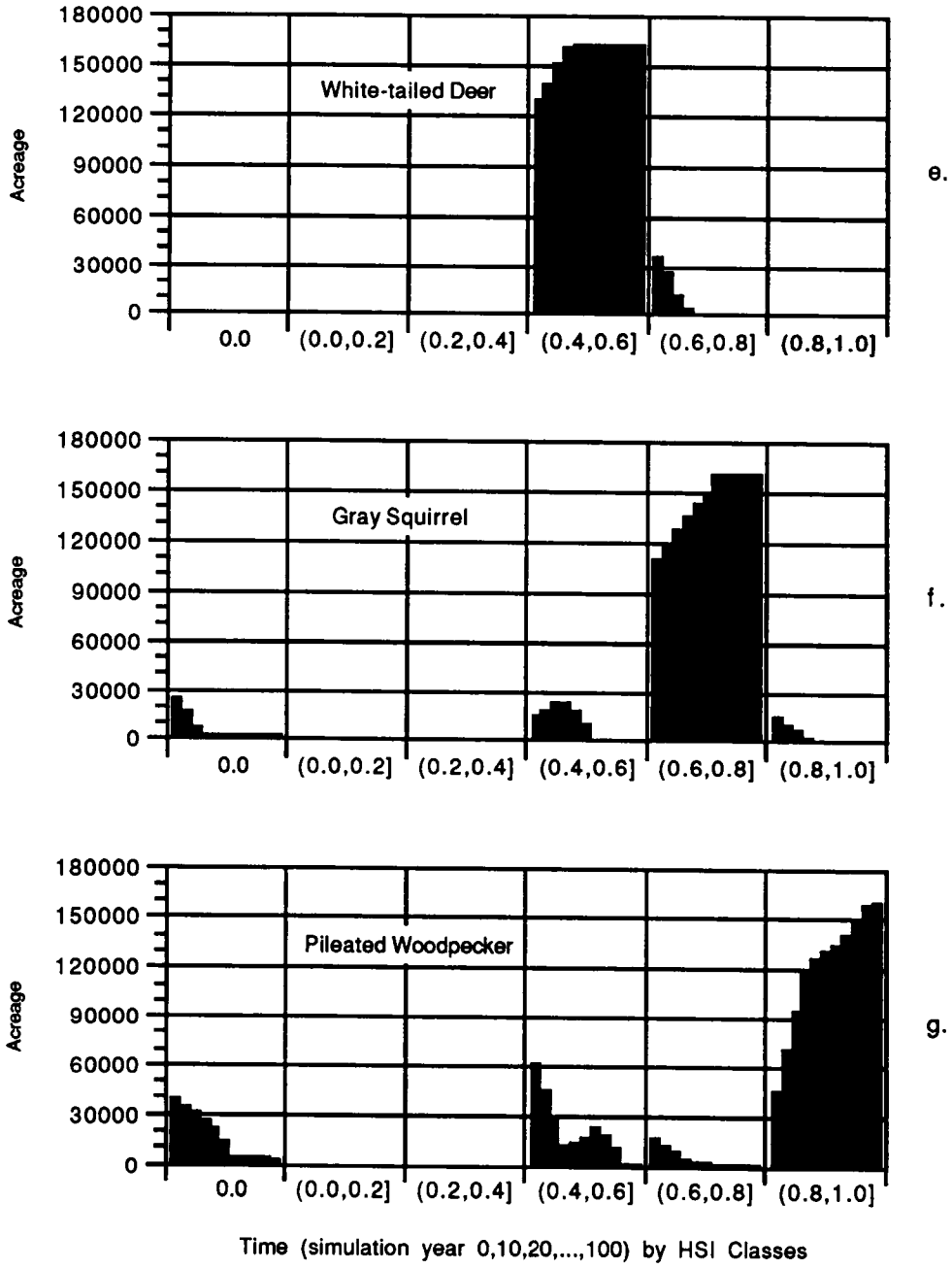


Figure 3.26. Projected changes in habitat quality distribution (profile) for evaluation species over 100 years under alternative B.

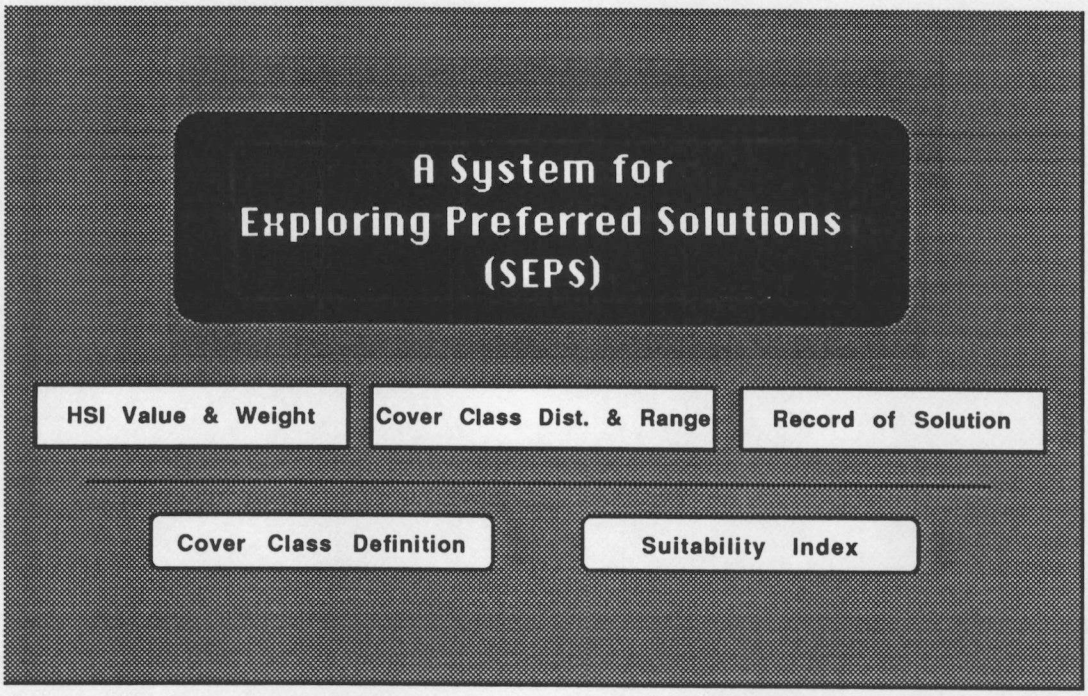


Figure 4.1. Window "Main", showing title and main menu of SEPS.

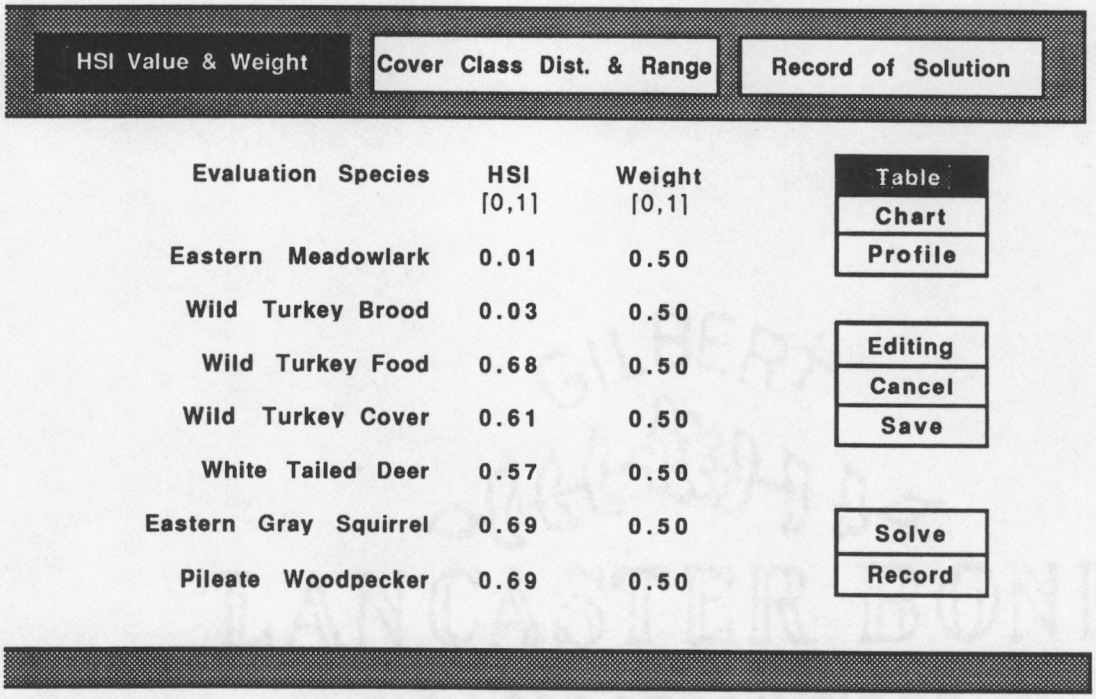


Figure 4.2. Window "HSI Value & Weight/Table".

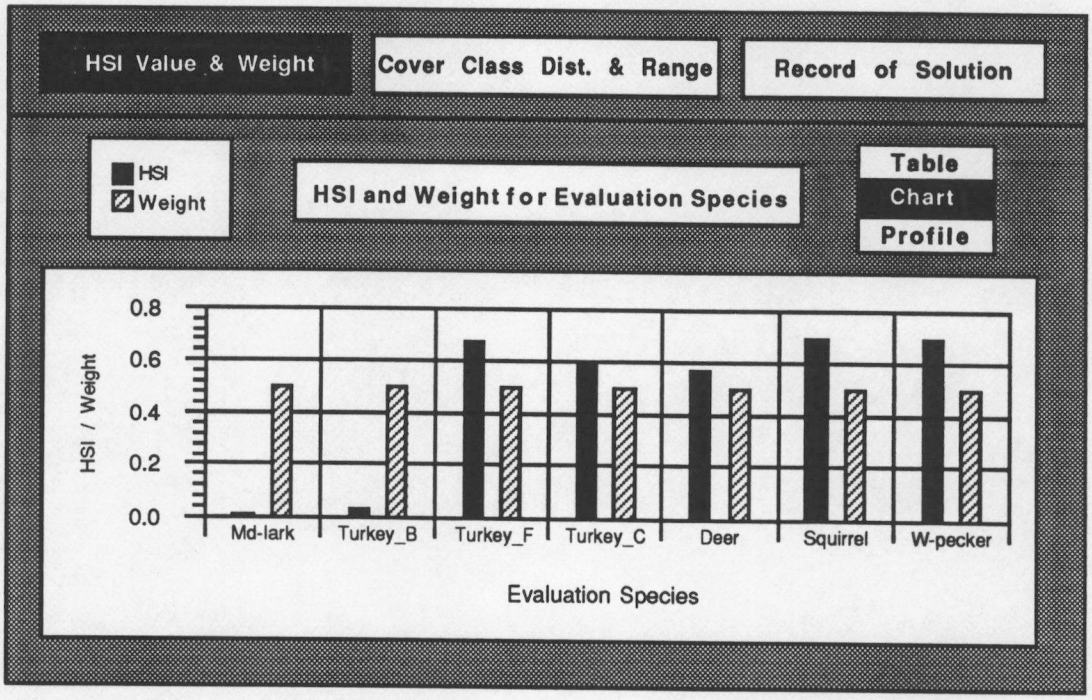


Figure 4.3. Window "HSI Value & Weight/Chart".

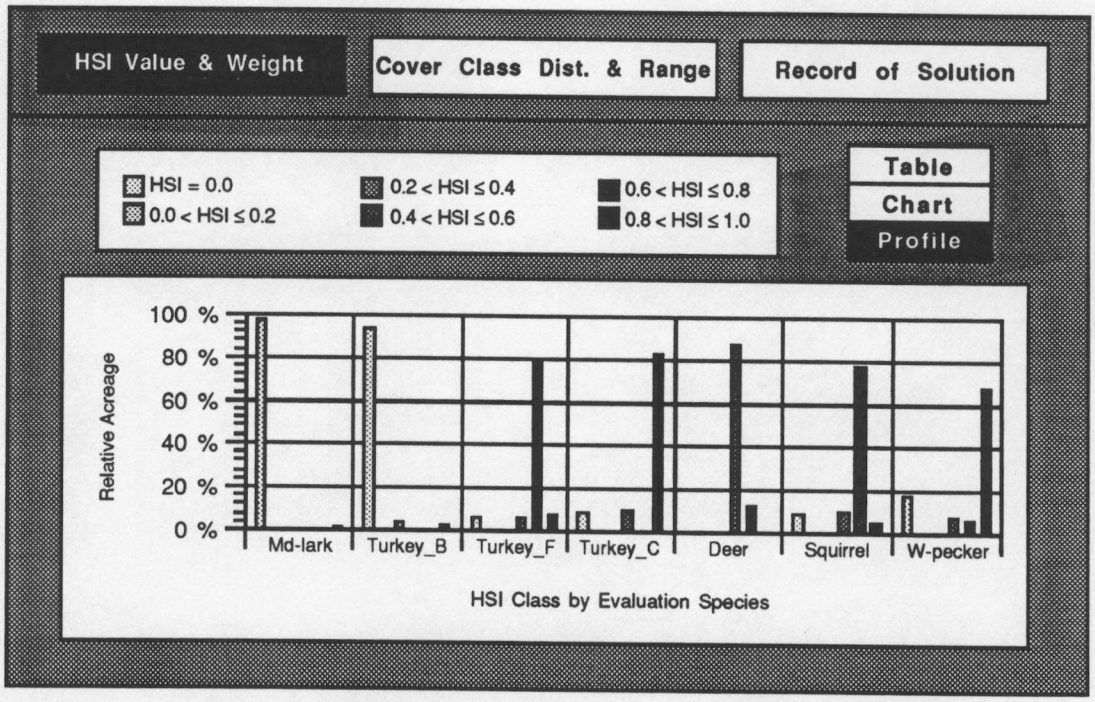


Figure 4.4. Window "HSI Value & Weight/Profile".

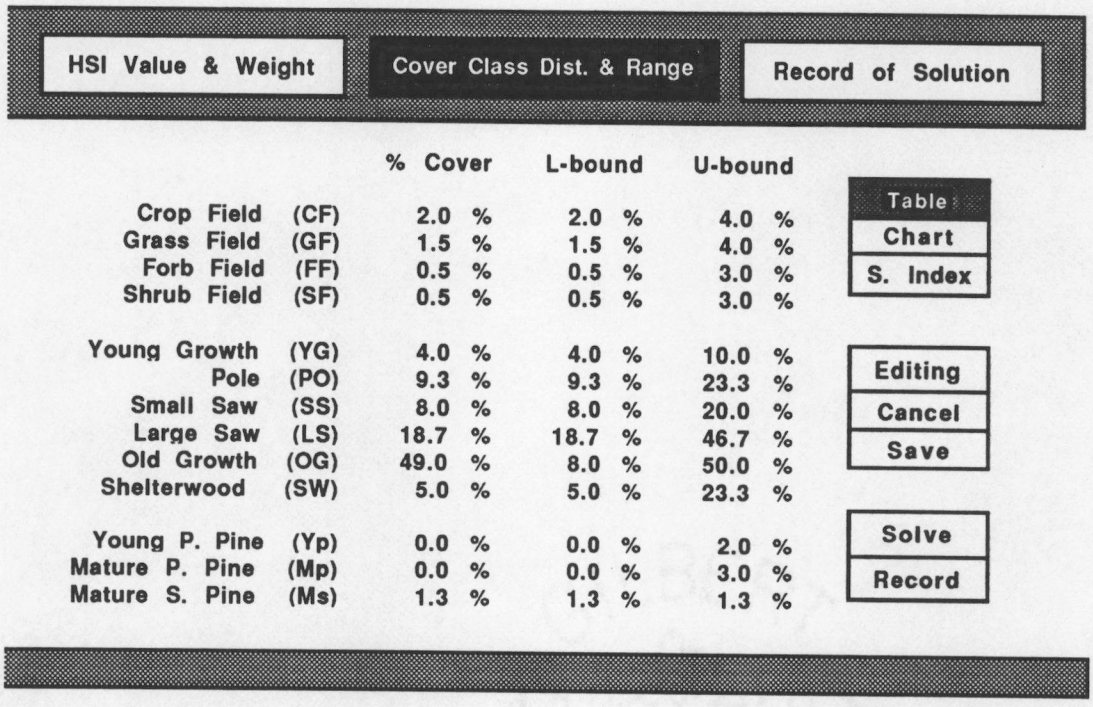


Figure 4.5. Window "Cover Class Dist. & Range/Table".

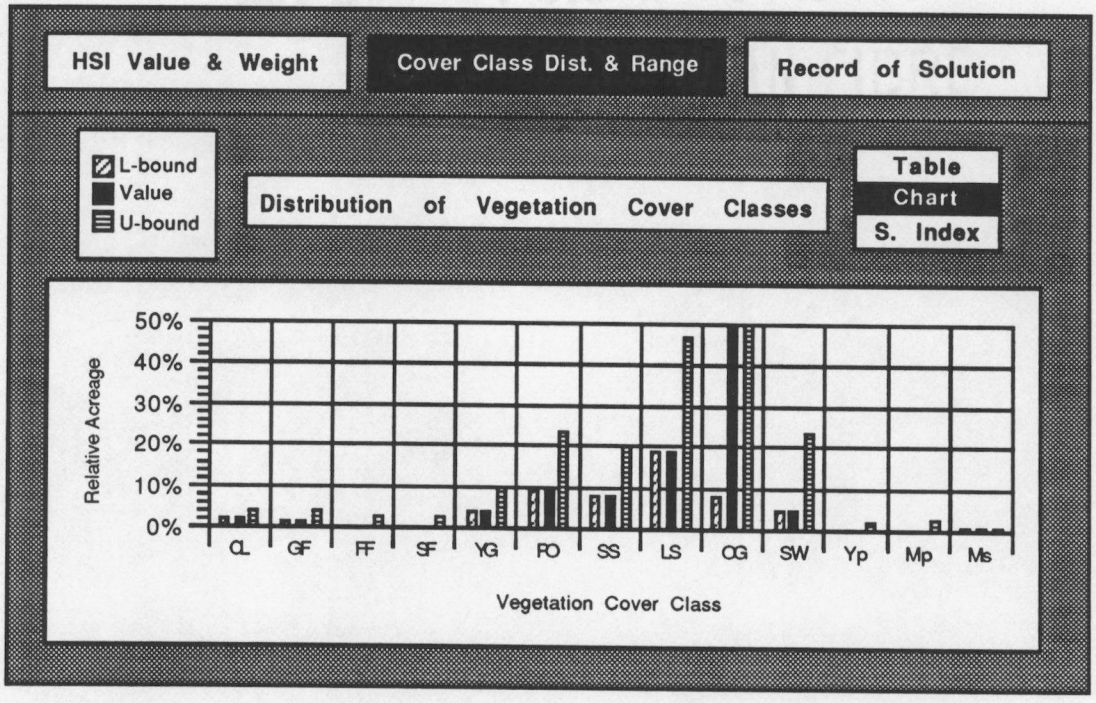


Figure 4.6. Window "Cover Class Dist. & Range/Chart".

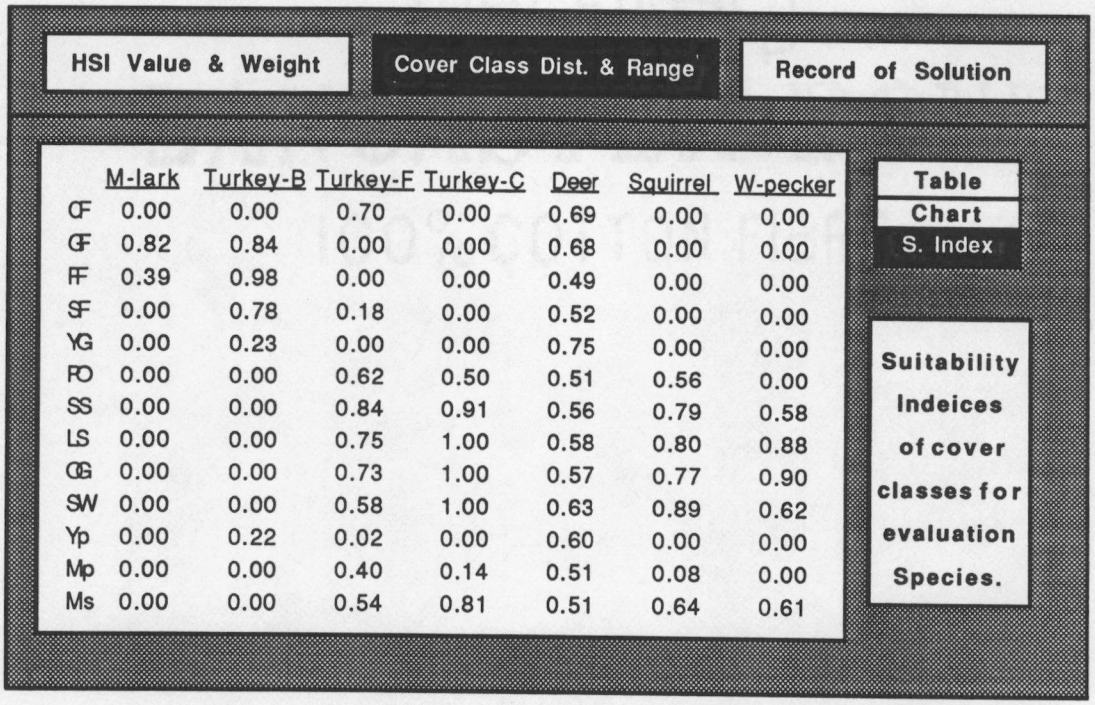


Figure 4.7. Window "Cover Class Dist. & Range/S. Index".

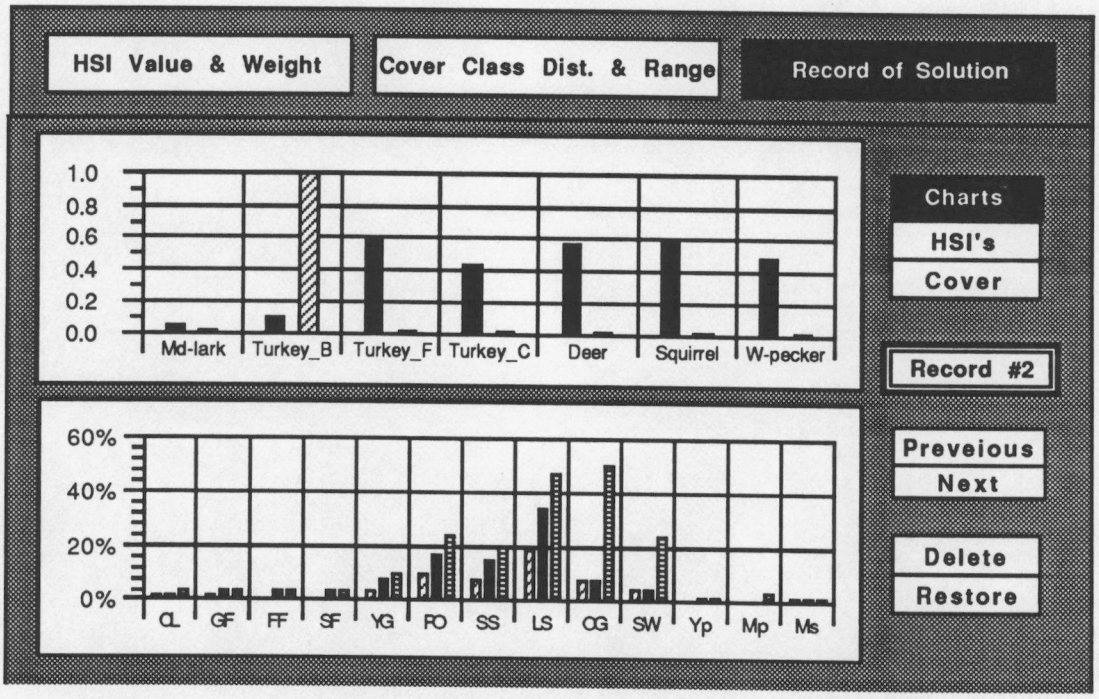


Figure 4.8. Windows "Record of Solution/Table".

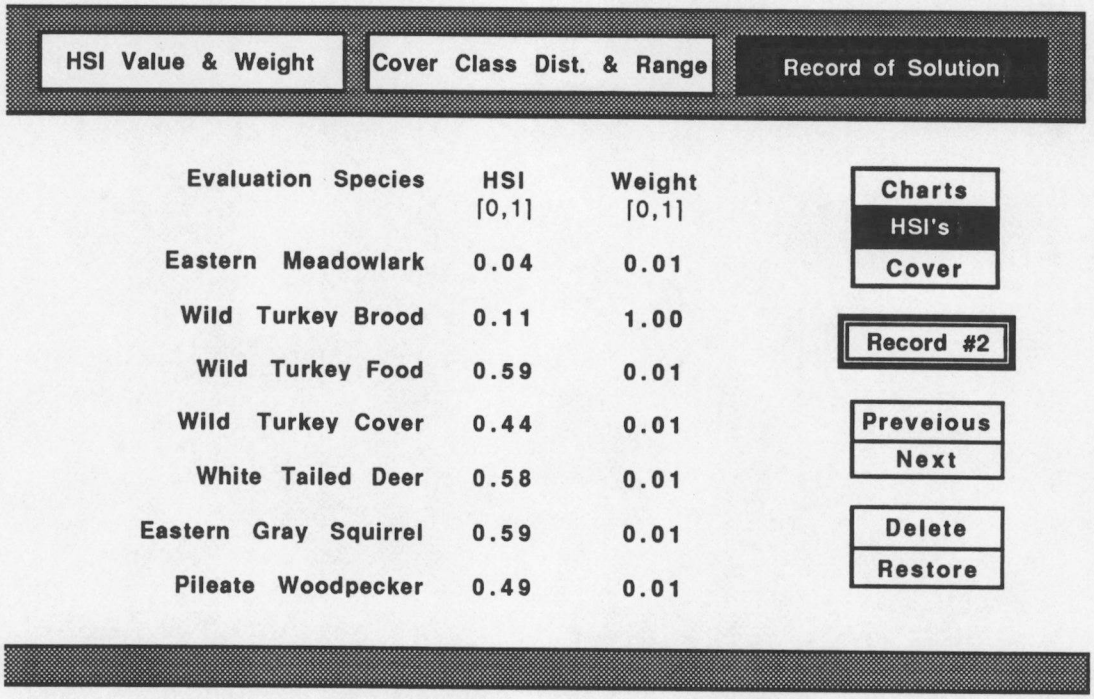


Figure 4.9. Windows "Record of Solution/HSI's".

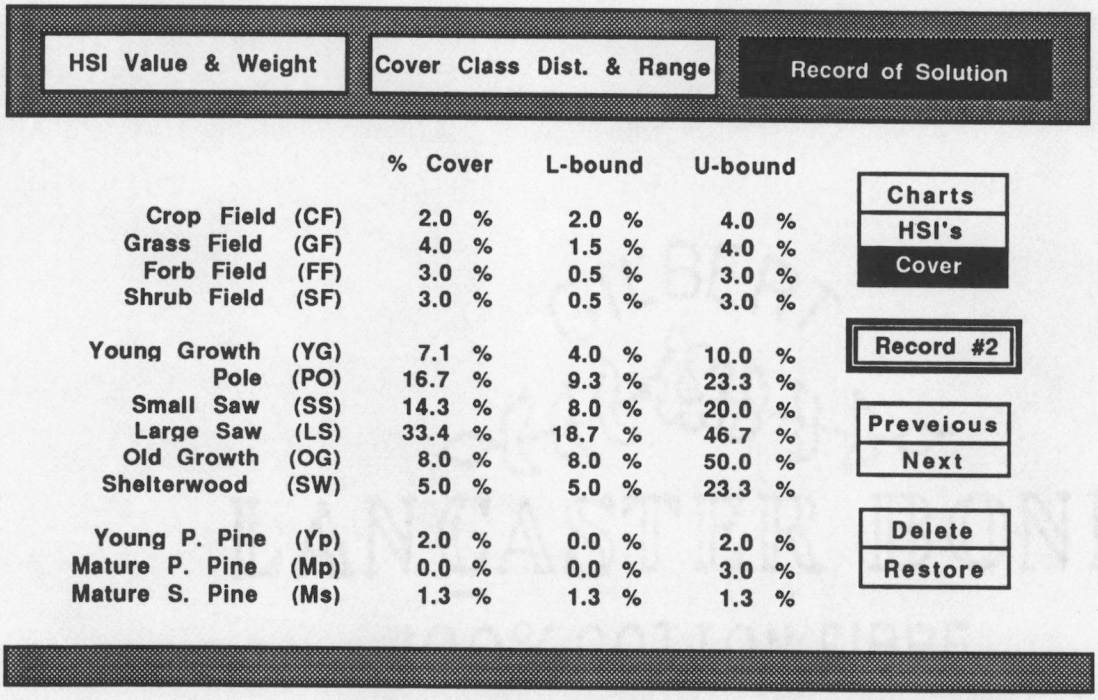


Figure 4.10. Windows "Record of Solution/Cover".

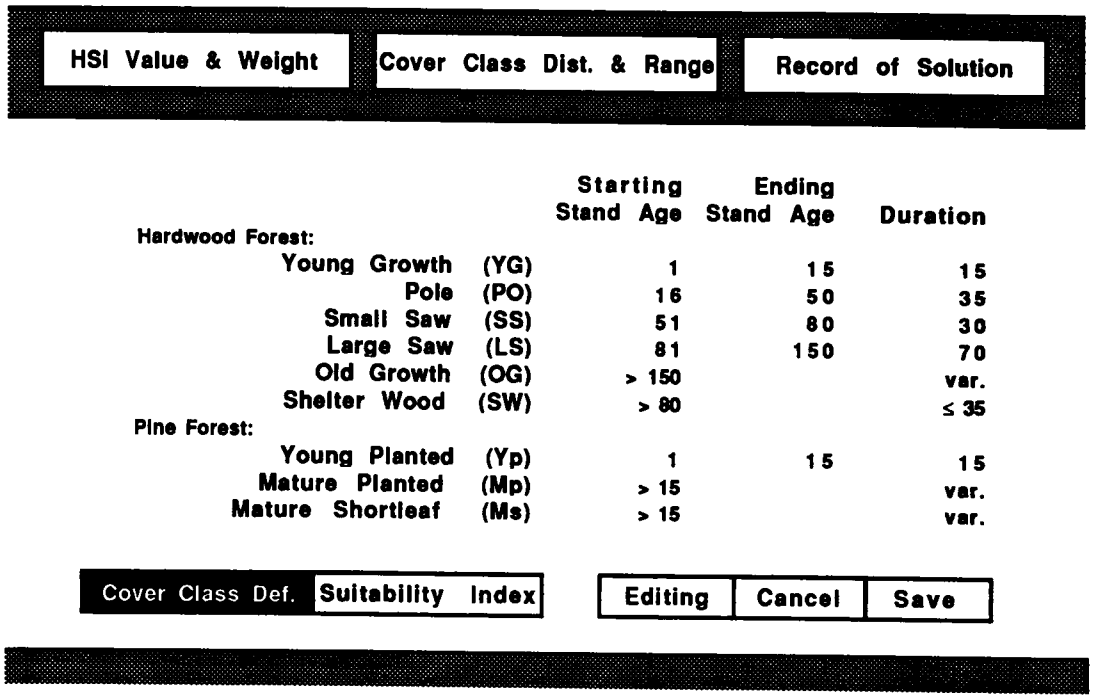


Figure 4.11. Window "HSI Value & Weight/Distr.".

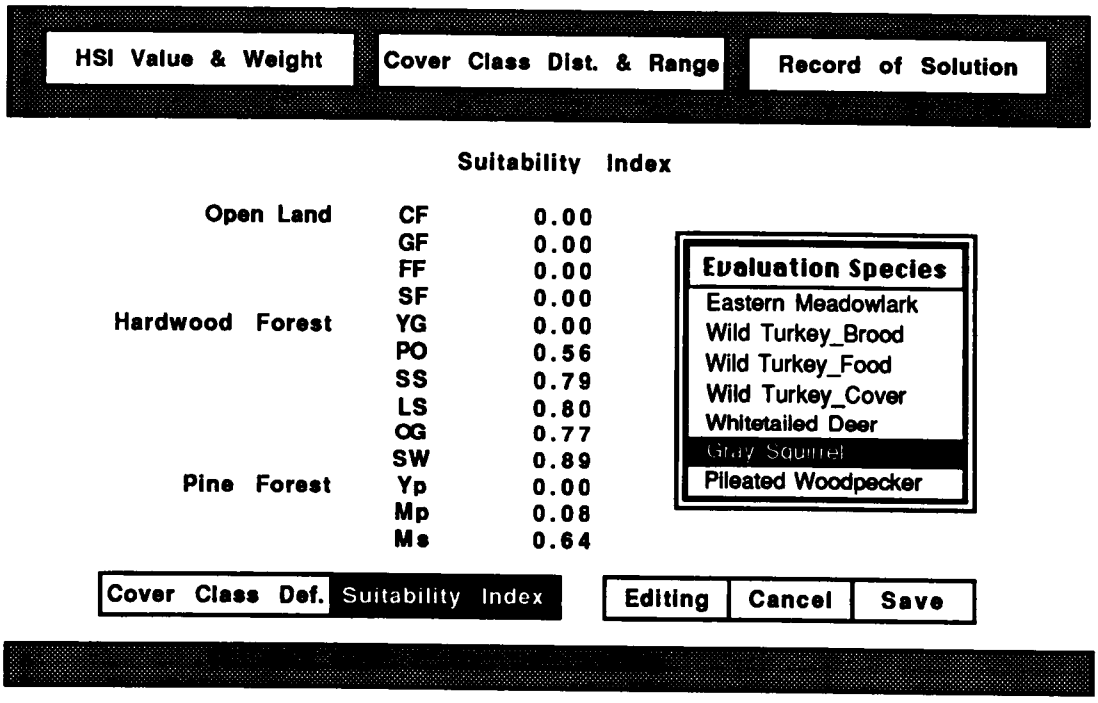
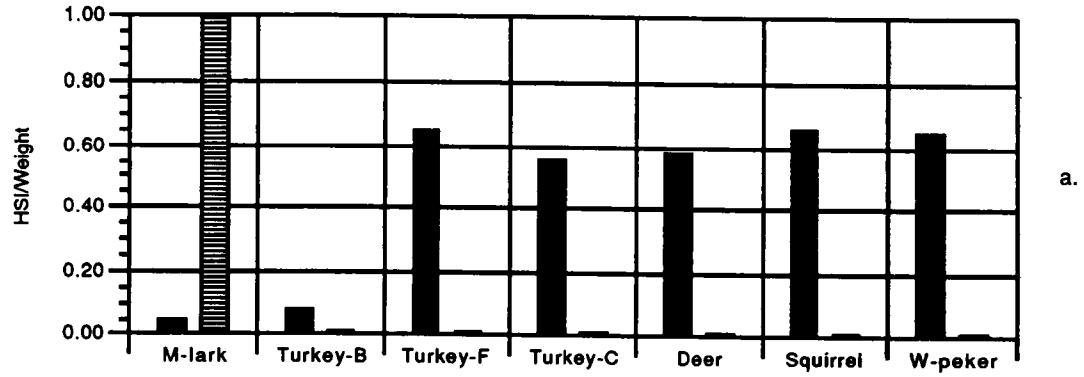
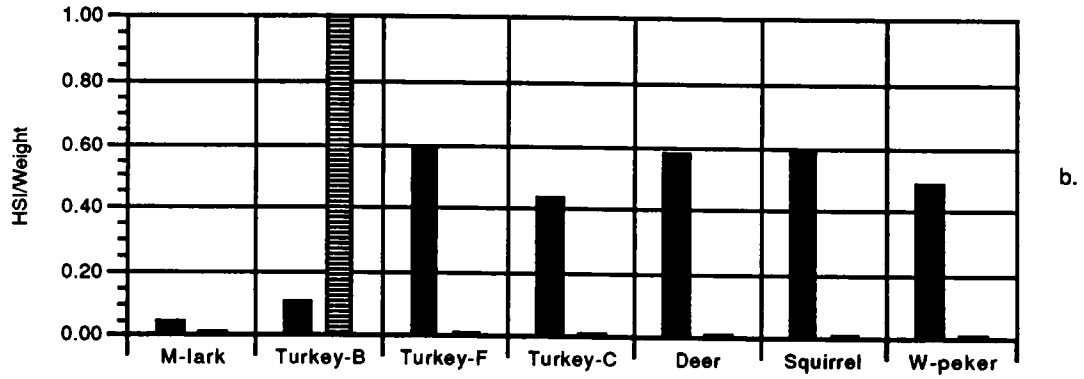


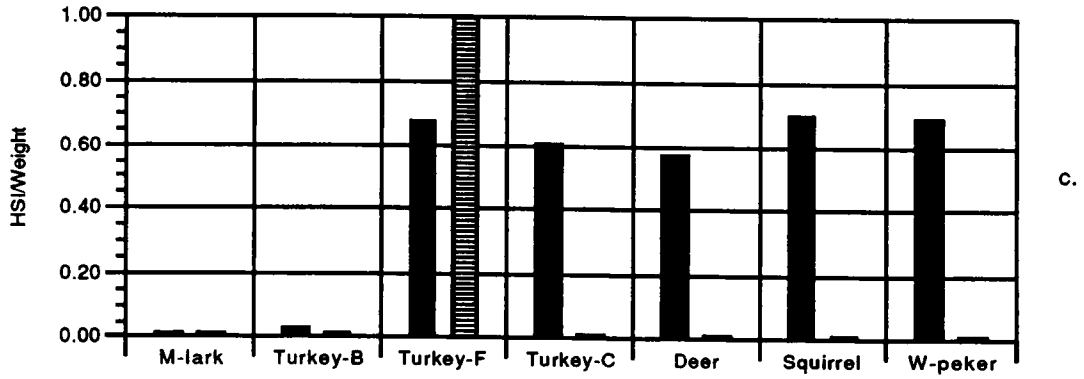
Figure 4.12. Window "Suitability Index" .


HSI/Weight
1.00
0.80
0.60
0.40
0.20
0.00
M-lark
Turkey-B
Turkey-F
Turkey-C
Deer
Squirrel
W-peker

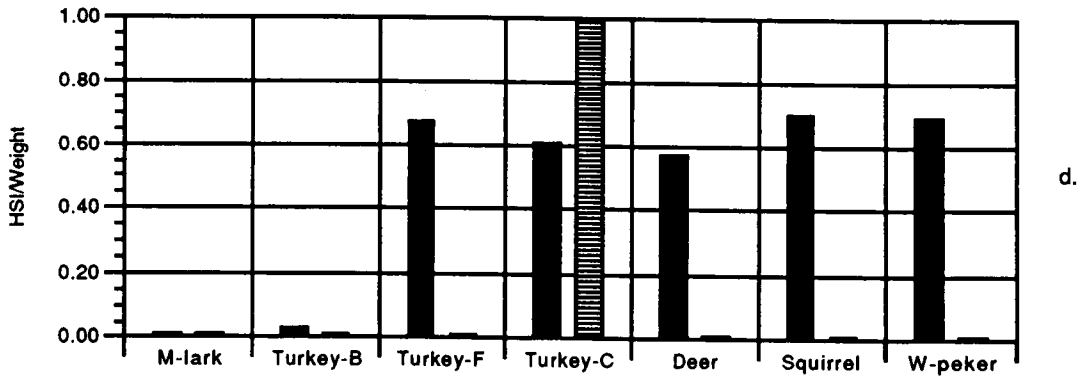
a.


HSI/Weight
1.00
0.80
0.60
0.40
0.20
0.00
M-lark
Turkey-B
Turkey-F
Turkey-C
Deer
Squirrel
W-peker

b.


HSI/Weight
1.00
0.80
0.60
0.40
0.20
0.00
M-lark
Turkey-B
Turkey-F
Turkey-C
Deer
Squirrel
W-peker

c.


HSI/Weight
1.00
0.80
0.60
0.40
0.20
0.00
M-lark
Turkey-B
Turkey-F
Turkey-C
Deer
Squirrel
W-peker

d.

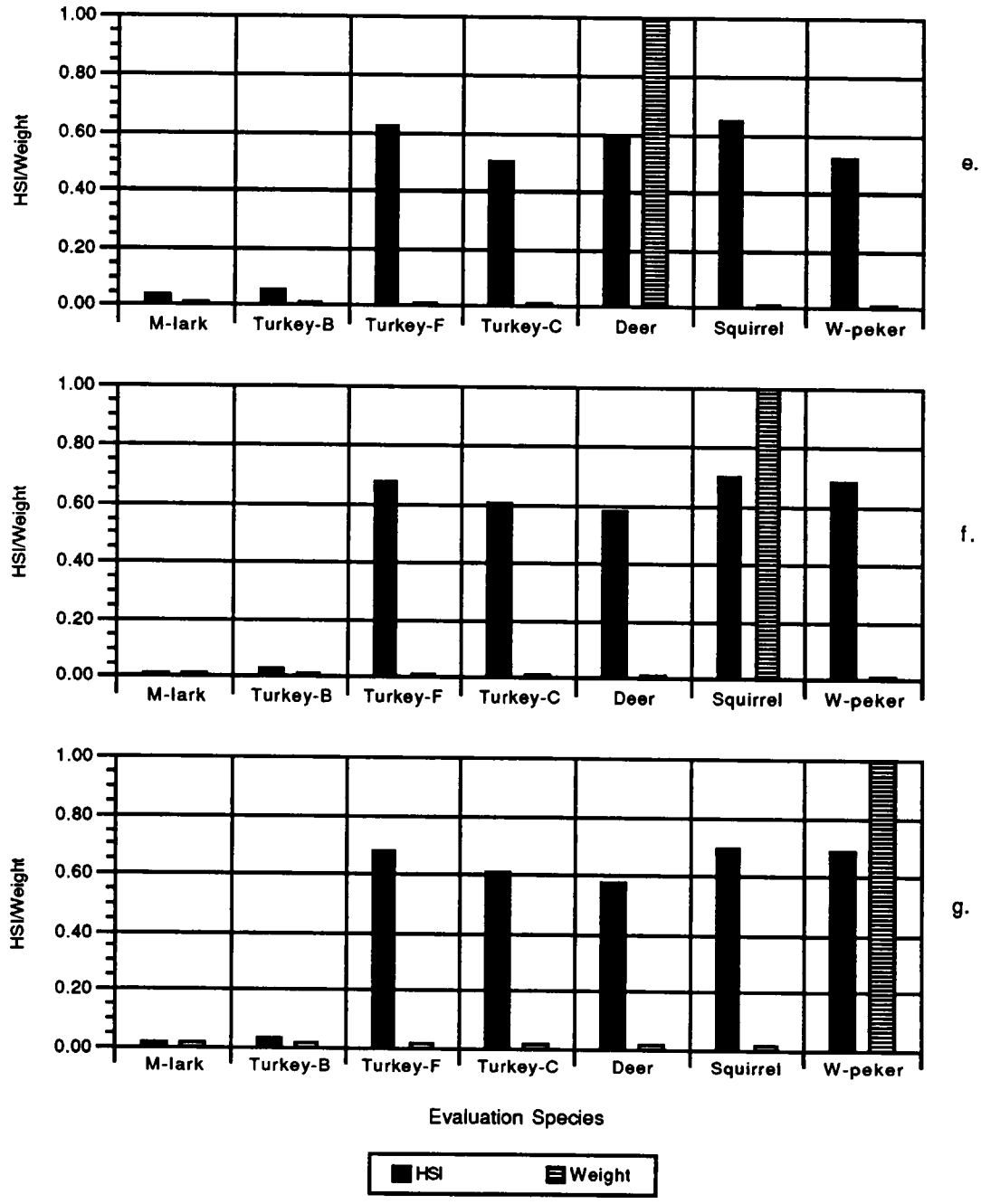
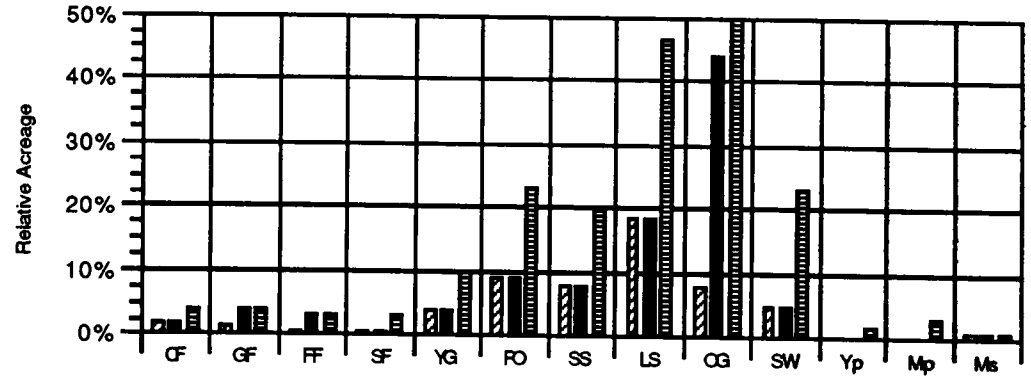
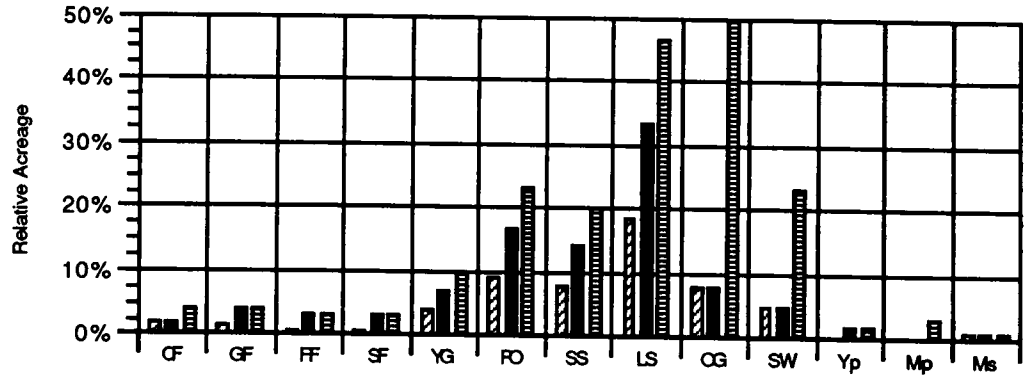


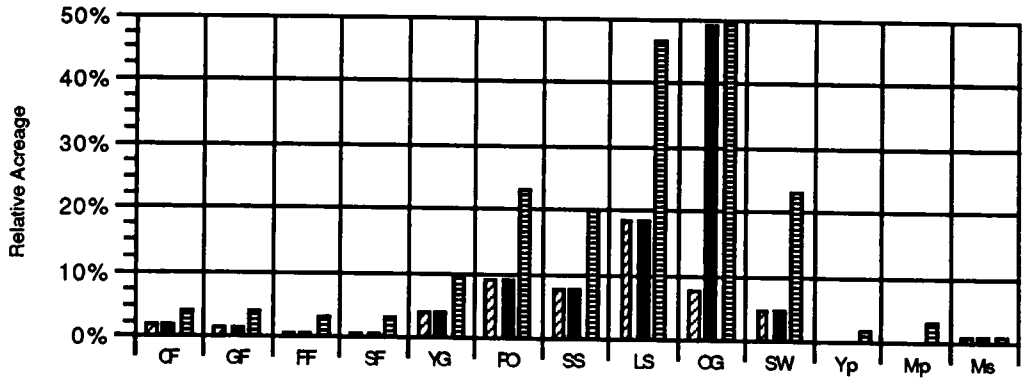
Figure 4.13. HSI's (objective values) of the solutions when assigning weight 1 for one objective and weight 0.01 for the other objectives.


50%
40%
30%
20%
10%
0%
Relative Acreage
CF
GF
FF
SF
YG
FO
SS
LS
OG
SW
Yp
Mp
Ms

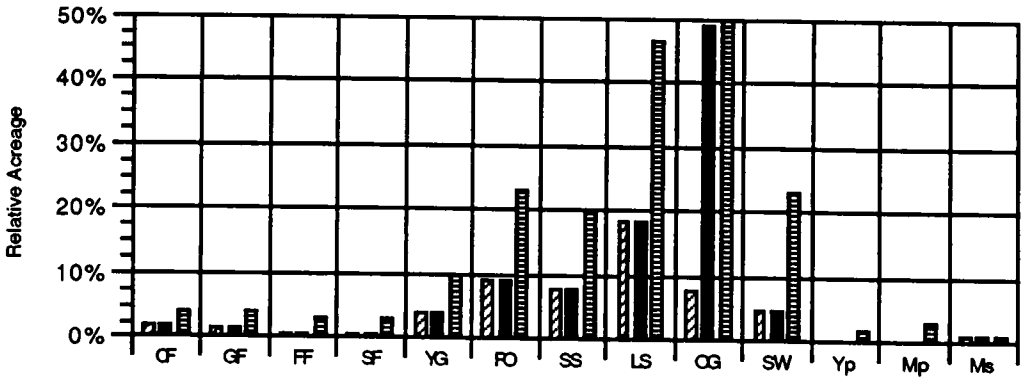
a.


50%
40%
30%
20%
10%
0%
Relative Acreage
CF
GF
FF
SF
YG
FO
SS
LS
OG
SW
Yp
Mp
Ms

b.


50%
40%
30%
20%
10%
0%
Relative Acreage
CF
GF
FF
SF
YG
FO
SS
LS
OG
SW
Yp
Mp
Ms

c.


50%
40%
30%
20%
10%
0%
Relative Acreage
CF
GF
FF
SF
YG
FO
SS
LS
OG
SW
Yp
Mp
Ms

d.

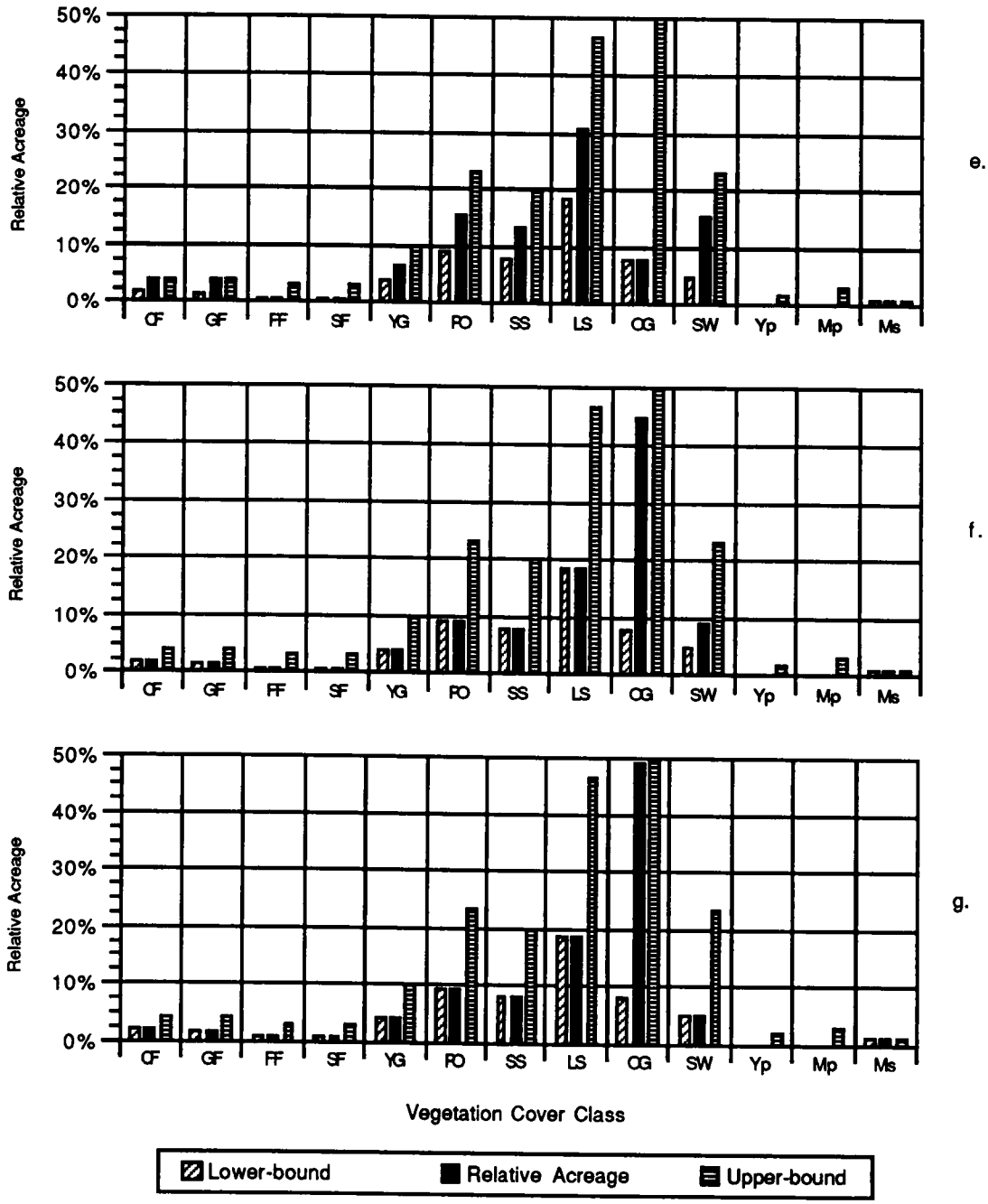
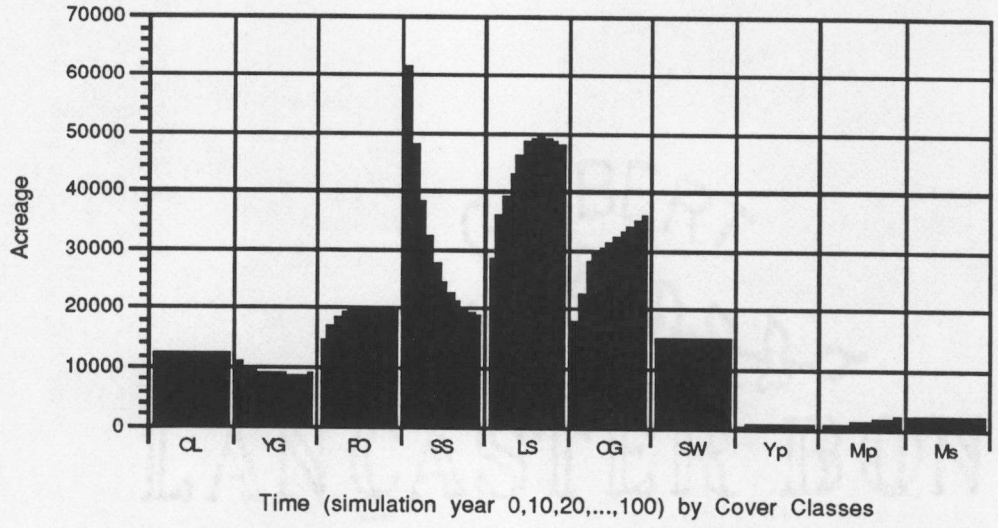
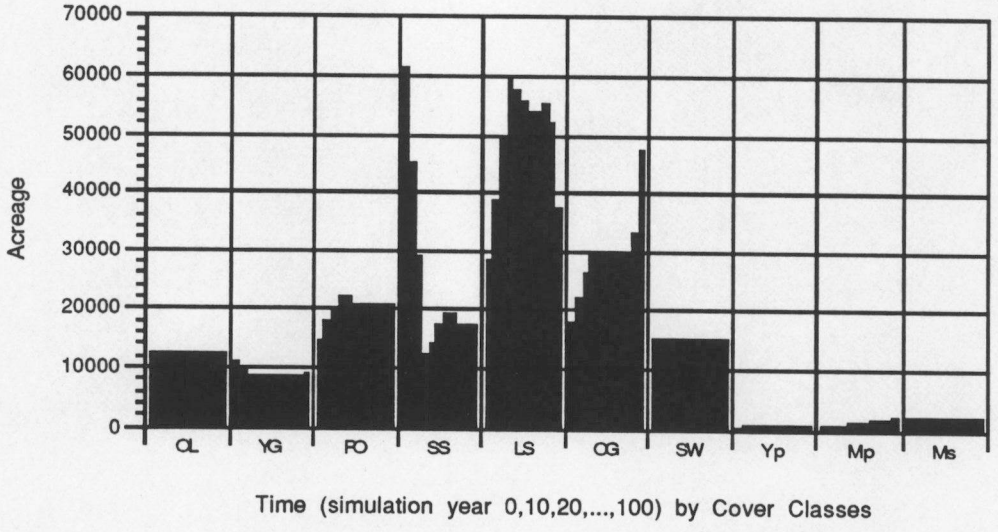


Figure 4.14. Relative acreage (decision variable) distribution of the solutions when assigning weight 1 for one objective and weight 0.01 for the other objectives. The weight 1 is assigned to Meadowlark, Turkey-Brood, Turkey-Food, Turkey-Cover, White-tailed Deer, Gray Squirrel and Pileated Woodpecker in a, b, c, d, e, f and g, respectively.

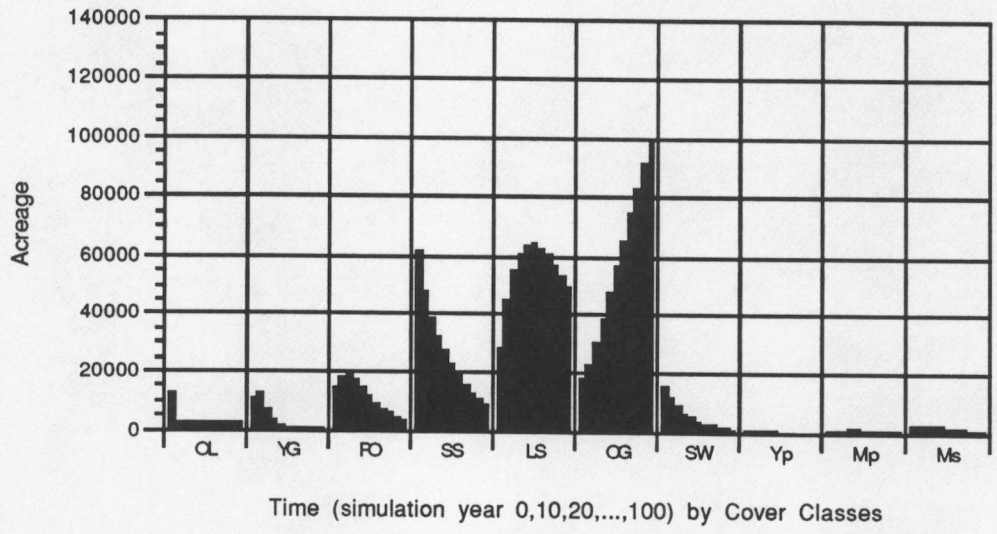


(a)

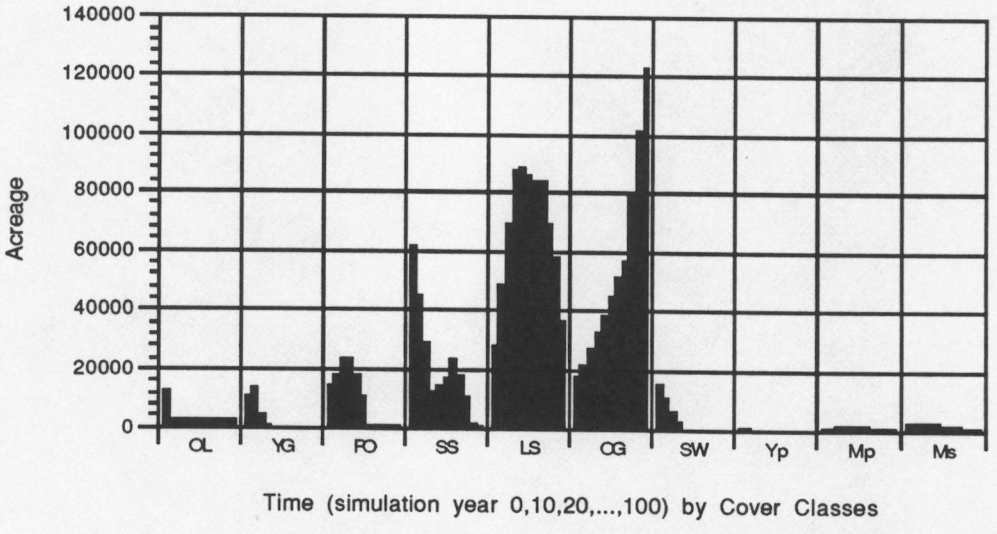


(b)

Figure 5.1. Simulation results of (a) "cover class model" and (b) "age class model" for alternative A described in Chapter 3.



(a)



(b)

Figure 5.2. Simulation results of (a) "cover class model" and (b) "age class model" for alternative B described in Chapter 3.

Appendix B

Description of Field Studies

Field Studies in 1988

An early version of the proposal for this study proposed to build a planning model with stand level simulation for LBL's Hunt Compartment 3 which include work areas 12, 13 and 19. Field work was conducted in work areas 12, 13 and 19 in May and July of 1988. Data were collected for determining habitat variables in 15 HSI models available for upland wildlife species present at LBL. Eight hardwood forest stands and one pine plantation stand were sampled with eighteen 10×50 m transects. Three young growth (YG) stands and 35 open land units were sampled with ocular estimates.

In each 10x50 m transect, species name and diameter at breast height (dbh) of all trees with height of 5 m or greater were recorded. Two 50 m line transect (Hays et al. 1981), as the two boundary lines of each 10x50 m transect, were conducted to sample the percent cover of shrub layer and its soft mast producing component. In each mature and young growth forest stand, ocular estimations were made for variables of coverages of forest canopy, herbaceous layer and their components. All 35 open land units in the work areas 12, 13 and 19 were sampled. Ocular estimates were made for the following variables: percent canopy cover of shrub layer, percent canopy cover of herbaceous layer, proportion of herbaceous layer that was grass, and average height of herbaceous layer.

In late 1989, the proposal for the study was revised according to the planning needs of LBL. It was then proposed to develop interactive planning models for the entire area of LBL based on a system of vegetation cover classes. Only data on open land sampled in 1988 were finally used for this study due to this change in project direction. The 35 open

land units were classified into cover classes GF, FF and SF based on their structures. The average values and standard deviations of 4 variables in each cover class were then calculated (Table B.1).

Field Sampling in 1990

In October 1990, more field work was conducted after the system of vegetation cover classes was established. Due to the time constraints, this field work focused on collecting data in stands of eight cover classes for determining the habitat variables used in HSI models of eight potential evaluation species.

Forty mature forest stands (PO, SS, LS, SW, Ms or Mp) were sampled in 15 work areas located throughout LBL (Table B.2). Stands were selected by foresters at LBL based on silvicultural definitions of the cover classes (Groton et al. 1988)) and LBL's forest inventory data.

Seventy three 100 m line transects were conducted to sample the coverage of defined layers (Table B.2). Two line transects were conducted in each of the mature hardwood (PO, SS, LS or SW) stand, except in one small homogeneous SW stand where only one transect was conducted. In each of the pine (Mp or Ms) stands, only one transect was conducted because of relatively homogeneous structures in those stands. Line transects were laid out along the environmental gradient in each stand.

In each line transect, lengths of the segments which are under the vertical projections of defined layers were recorded for determining seven habitat variables. The seven habitat variables were: percent canopy cover of overstory trees (height≥80% of the height of the tallest tree in the stand); percent canopy cover of hard mast producing overstory trees; percent canopy cover of canopy trees (height≥5 m); percent canopy cover

of hard mast producing overstory trees; percent canopy cover of soft mast producing overstory trees; percent canopy cover of shrub layer (woody vegetation ≤ 5 m in height); and percent canopy cover of soft mast producing shrub layer. Average height of herbaceous layer (non-woody vegetation) in 10 1x1 m plots centered at each 10th meter of the transect were sampled.

A 10×100 m transect associated with each line transect was conducted for sampling densities of snags and fallen logs. Each 10×100 m transect was formed by using the line transect as the central line and extending five meters to both side of the central line. Number of fallen logs with diameter of six inches (15 cm) or greater in each transect was recorded. DBH's of all snag trees with dbh of six inches (15 cm) or greater within the transect were recorded.

Twelve young growth stands (8 YG and 4 Yp) were sampled and ocular estimates were made for percent canopy cover of shrub layer; percent canopy cover of soft mast producing shrub layer, percent canopy cover of herbaceous layer, proportion of herbaceous layer that was grass, and average height of herbaceous layer.

Table B.3 shows the average values and standard deviations of the variables sampled in mature forest stands. All stands except shelterwood stands had high values of tree canopy coverage. The hard mast producing tree component occupied a very large proportion in both overstory and canopy layers of all hardwood stands. More than half of canopy cover in both overstory and canopy layers of shortleaf pine stands were made by hard mast producing trees. However, hard mast producing trees were missing in the overstory and canopy layers of plantation pine stands. Small sawtimber stands had the most soft mast producing tree cover. Shelterwood stands had the most shrub layer and soft mast producing shrub covers. The number of fallen logs and snags were the most in

plantation pine stands and shelterwood stands (Table B.3). The average values and standard deviations of the variables sampled in young forest (YG and Yp) stands were displayed in Table B.4. Hardwood young growth stands had more shrub cover and less herbaceous cover than young pine plantation stands. There was little soft mast producing shrubs in young pine plantation stands (Table B.4).

Table B.1. Average values and standard deviations (in parentheses) of the variables sampled in open land (GF, FF and SF) units

Variable	GF	FF	SF
Percent cover of herbaceous layer (%)	87.57	81.38	44.56
	(8.41)	(15.04)	(14.74)
Average height of herbaceous layer (inch)	22.05	23.62	22.53
	(7.48)	(5.39)	(6.70)
Proportion of grass in herbaceous cover (%)	76.47	38.33	66.16
	(13.11)	(6.64)	(15.27)
Percent cover of shrub layer (%)	9.21	9.00	53.33
	(8.62)	(9.71)	(14.91)

Table B.2. Summary of number of work areas, stands and 100 m line transects sampled in October 1990

Cover class	Number of work areas sampled in	Number of forest stands sampled	Number of transects sampled
Poletimber (PO)	4	8	16
Small Sawtimber (SS)	4	8	16
Large Sawtimber (LS)	4	8	16
Shelterwood (SW)	8	10	19
Mature Shortleaf Pine (Ms)	2	2	2
Mature Pine Plantation (Mp)	4	4	4

Table B.3. Average values and standard deviations (in parentheses) of the variables sampled in 100 m line transects and 10×100 m transect in mature forest stands

	PO	SS	LS	SW	Ms	Mp
Percent cover of overstory trees (%)	86.33 (7.35)	91.76 (4.05)	88.72 (4.56)	58.51 (6.83)	90.25 (3.85)	95.43 (3.43)
Percent cover of hardmast producing overstory trees (%)	83.86 (8.57)	91.76 (4.05)	87.76 (4.30)	55.79 (11.06)	51.45 (3.45)	0.00 (0.00)
Percent cover of canopy trees (%)	94.32 (3.08)	96.00 (2.93)	95.54 (1.69)	68.77 (7.82)	95.25 (3.85)	97.07 (1.14)
Percent cover of hardmast producing canopy trees (%)	88.99 (4.92)	91.93 (6.59)	89.63 (4.85)	59.37 (13.29)	53.25 (3.85)	0.00 (0.00)
Percent cover of soft mast producing trees (%)	22.76 (11.51)	33.42 (22.89)	24.89 (8.12)	21.87 (13.71)	19.68 (12.37)	15.98 (3.96)
Percent cover of shrubs (%)	33.84 (10.91)	38.71 (6.86)	40.04 (12.41)	46.07 (18.32)	25.98 (6.22)	44.07 (9.10)
Percent cover of soft mast producing shrubs (%)	8.06 (3.67)	8.24 (5.02)	9.55 (3.47)	12.44 (9.63)	3.25 (3.25)	8.45 (7.64)
Average height of herbaceous layer (inch)	8.67 (2.13)	8.47 (2.04)	7.86 (1.67)	8.55 (2.50)	6.46 (1.79)	7.12 (2.44)
Number of logs/snags (d≥6") per acre	28.08 (18.37)	36.68 (30.81)	46.03 (26.71)	113.32 (44.85)	68.80 (20.23)	118.71 (65.62)
Average dbh of snags (dbh≥6") (inch)	12.22 (3.73)	11.61 (3.27)	11.79 (1.98)	14.98 (5.72)	15.75 (3.25)	7.33 (0.33)

Table B.4. Average values and standard deviations (in parentheses) of the variables sampled in YG and Yp stands

Variable	YG	Yp
Percent cover of herbaceous layer (%)	13.56	22.00
	(16.90)	(6.98)
Average height of herbaceous layer (inch)	35.70	28.00
	(7.98)	(14.97)
Percent cover of shrub layer (%)	86.44	76.00
	(16.90)	(5.35)
Proportion of shrub cover that is made of soft mast producing shrubs (%)	23.33	0.67
	(18.41)	(0.94)

Appendix C

List of Acronyms

Acronym	Definition	Page #
CF	Crop Field	18
CFI	Continuous Forest Inventory	22
DBH	Diameter at breast height	116
DYNAST	Dynamically Analytic Silviculture Technique	9
EA	Environmental Assessment	37
EIS	Environmental Impact Statement	3
ERA	External Reconstruction Algorithm	15
FF	Forb Field	18
FORHAB	Deciduous forest habitat simulation model	10
FORMAN	A forest management activities scheduling system	10
FORET	An Appalachian deciduous forest stand simulator	15
GF	Grass Field	18
GINO©	General Interactive Optimizer	57
GIS	Geographical Information System	10
GP	Goal Programming	12
HABSIM	A habitat simulation procedure	11
HCC	Habitat capability coefficient	6
HCI	Habitat capability index	7
HEP	Habitat Evaluation Procedure	4
HSI	Habitat Suitability Index	4
HSJ	Hop, Skip and Jump	14
HU	Habitat Unit	5
LBL	Land Between The Lakes	1
LINDO©	Linear, Interactive, and Discrete Optimizer	57
LP	Linear Programming	14
LS	Large Sawtimber	19
MGA	Modeling to Generate Alternatives	14
MOLP	Multiple Objective Linear Programming	13

MOP	Multiple Objective Programming	1
Mp	Mature Pine Plantation	19
Ms	Mature Shortleaf Pine	19
NEPA	National Environmental Policy Act	3
NISE	Noninferior set estimation method	14
OG	Old Growth	19
PATREC	Pattern recognition	7
PO	Poletimber	18
RGP	Robust Goal Programming	16
RHS	Right hand side (of a constraint)	15
RMOLP	Robust Multiple Objective Linear Programming	42
SEMA	System for Evaluating Management Alternatives	25
SEPS	System for Exploring Preferred Solutions	40
SF	Shrub Field	18
SI	Suitability Index	22
SS	Small Sawtimber	19
SSLBL	A scheduling system for LBL	63
STEM	Step method	15
SW	Shelterwood	19
TEAMS	Terrestrial Ecosystem Analysis and Modeling System	62
TIMPRO-FORMAN	A stand level multiresouce forest management decision support system	9
TVA	Tennessee Valley Authority	1
TWIGS	The Woodsman's Ideal Growth Projection System	10
WFHR	Wildlife and Fish Habitat Relationship	5
YG	Young Growth	18
Yp	Young Pine Plantation	19

Appendix D

HyperScript Subroutines for Simulation in SEMA

```
function simu()

 define Yr, i, j, k, jv, iv, jx, jxp, jxs, temp, add
 define SScut, SW1cut, SWfcut, Ccut, Pcut, Pplant, OGtarget, Ptarget
 define LScut, OGdebt, Ptrend
  define SScut_t, SWfcut_t, Pcut_t, Pplant_t
  define SWrvt, Msrvt, Mprvt, OLrvt, OLcvt, maxInc, totInc
 define dYG, dPO, dSS, dLS, dSW, dYp
 define CL, GF, FF, SF, YG, PO, SS, LS, SW, OG, Mp, Yp, Ms
 define CLg, GFg, FFg, SFg, CLd, GFd, FFd, SFd, rCL, rGF, rFF, rSF

 {============================================== set initial condition }

   {------------------------------------ array locations }
{..... hardwood (X) }
  jx = colof(range("X"))
{..... shelterwood (Xs) }
  jxs = colof(range("Xs"))
{..... pine (Xp) }
  jxp = colof(range("Xp"))
{..... result (SimuVeg_1) }
  jv = colof(range("SimuVeg_1"))
  iv = rowof(range("SimuVeg_1"))

     {------------------------------------ initial acreage }
  CL = index(range("SimuVeg_1"),0,0)
  GF = index(range("SimuVeg_1"),0,1)
  FF = index(range("SimuVeg_1"),0,2)
  SF = index(range("SimuVeg_1"),0,3)
  YG = index(range("SimuVeg_1"),0,4)
  PO = index(range("SimuVeg_1"),0,5)
  SS = index(range("SimuVeg_1"),0,6)
  LS = index(range("SimuVeg_1"),0,7)
  OG = index(range("SimuVeg_1"),0,8)
  SW = index(range("SimuVeg_1"),0,9)
  Yp = index(range("SimuVeg_1"),0,10)
  Mp = index(range("SimuVeg_1"),0,11)
  MS = index(range("SimuVeg_1"),0,12)

  {------------------------------ end year of the classes }
  dYG = index(range("DEFfor"),1,0)
  dPO = index(range("DEFfor"),1,1)
  dSS = index(range("DEFfor"),1,2)
  dLS = index(range("DEFfor"),1,3)
```

```
  dSW = index(range("DEFfor"),2,5)
  dYp = index(range("DEFfor"),1,7)

 {------------------- write to X, Xs & Xp (acreage distr by age) }
{..................................................... write to X (YG,PO,SS,LS) }
 put YG/dYG into makerange(jx,1,jx,dYG)
 put PO/(dPO-dYG) into makerange(jx,dYG+1,jx,dPO)
 put SS/(dSS-dPO) into makerange(jx,dPO+1,jx,dSS)
 put LS/(dLS-dSS) into makerange(jx,dSS+1,jx,dLS)
 {..................................................... write to Xs (SW) }
 put SW/dSW into makerange(jxs,1,jxs,dSW)
 {..................................................... write to Xp (Yp) }
 put Yp/dYp into makerange(jxp,1,jxp,dYp)

  {------------------------------- 1st phase management }
 SScut = index(range("CUT"),0,0)
 SW1cut = index(range("CUT"),0,1)
 SWfcut = index(range("CUT"),0,2)
 Ccut = index(range("CUT"),0,3)
 Pplant = index(range("CUT"),0,5)
 Pcut = index(range("CUT"),0,6)

{---------------------------------- OG and Mp targets }
 OGtarget = index(range("TARGET"),0,0)
 Ptarget = index(range("TARGET"),0,1)

  {------------------------------------ open land mgt }
{..................................................... target levels }
 CLg = index(range("MGTol"),1,0)
 GFg = index(range("MGTol"),1,1)
 FFg = index(range("MGTol"),1,2)
 SFg = index(range("MGTol"),1,3)
{..................................................... totle changes }
 CLd = index(range("MGTol"),2,0)
 GFd = index(range("MGTol"),2,1)
 FFd = index(range("MGTol"),2,2)
 SFd = index(range("MGTol"),2,3)
{..................................................... reversion rates }
 rCL = index(range("MGTol"),3,0)
 rGF = index(range("MGTol"),3,1)
 rFF = index(range("MGTol"),3,2)
 rSF = index(range("MGTol"),3,3)
{..................................................... max annual increase }
 maxInc = index(range("MGTol"),3,8)

  {------------------------- set parameter raleted to pine }
{..................................................... set pine rvt acreage to 0 }
 Msrvt = 0
 Mprvt = 0
{..................................................... determine Ptrend }
 if Mp<Ptarget and Pplant>Pcut
   Ptrend = 1
```

```
 elseif Mp>Ptarget and Pplant<Pcut
   Ptrend = -1
 else
   Ptrend = 0
 end if

{================================================== simulation }
for Yr=1 to 100 step 1

   {---------------------------------------- open land }
  totInc = if(CLd>0,CLd,0)+if(GFd>0,GFd,0)+if(FFd>0,FFd,0)+if(SFd>0,SFd,0)
 OLrvt = 0
 OLcvt = 0
 {..... shruby field }
if SFd<>0
  if SFd<0
     OLrvt = -SFd*rSF
      SFd = if(SFd<-0.001, SFd - SFd*rSF + if(FFd<0,FFd*rFF,0), 0)
   SF = SFg - SFd
   else
     temp = min( SFd, maxInc*SFd/totInc )
    SF = SF + temp
    OLcvt = OLcvt + temp
    SFd = SFd - temp
  end if
 end if
 {..... forb field }
if FFd<>0
  if FFd<0
      FFd = if(FFd<-0.001, FFd - FFd*rFF + if(GFd<0,GFd*rGF,0), 0)
   FF = FFg - FFd
  else
     temp = min( FFd, maxInc*FFd/totInc )
    FF = FF + temp
    OLcvt = OLcvt + temp
    FFd = FFd - temp
  end if
 end if
 {..... grass field }
if GFd<>0
  if GFd<0
     GFd = if(GFd<-0.001, GFd - GFd*rGF + if(CLd<0,CLd*rCL,0), 0)
   GF = GFg - GFd
   else
     temp = min( GFd, maxInc*GFd/totInc )
    GF = GF + temp
    OLcvt = OLcvt + temp
    GFd = GFd - temp
  end if
 end if
 {..... cropland }
if CLd<>0
```

```
  if CLd<0
     CLd = if(CLd<-0.001, CLd - CLd*rCL, 0)
    CL = CLg - CLd
   else
     temp = min( CLd, maxInc*CLd/totInc )
    CL = CL + temp
    OLcvt = OLcvt + temp
    CLd = CLd - temp
  end if
 end if

{------------------------------ simulation of pine forest }
 {..... pine conversions }
  if index(range("CNVT"),0,1)
   temp = spA^(Yr/spB) / spA
   Msrvt = Ms*temp
 end if
  if index(range("CNVT"),0,2)
   temp = ppA^(Yr/ppB) / ppA
   Mprvt = Mp*temp
 end if
 {..... pine cut/plant }
  Pcut_t = min(Pcut, Mp)
 if Ptrend = 0
   Pplant_t = Pplant
 elseif Ptrend = 1
    temp = Ptarget-(Yp+Mp)
  if temp>0
     Pplant_t = min( Pplant, temp+Pcut_t )
  else
    Pplant_t = Pcut_t
  end if
 elseif Ptrend = -1
    temp = Ptarget-(Yp+Mp)
  if temp<0
     Pcut_t = min( Pcut_t, Pplant-temp )
  else
    Pcut_t = Pplant_t
  end if
 end if
 {..... shortleaf pine }
  Ms = Ms - Msrvt
 {..... mature planted pine }
  temp = index(range("Xp"),0,dYp-1)
 Mp = Mp - Pcut_t + temp
 if Mprvt>0
   Mp = Mp - Mprvt
  if Mp<0
   Mp = 0
    Mprvt = Mprvt + Mp
  end if
 end if
```

```
{..... young planted pine }
 Yp = 0
 for k = dYp-1 to 1 step -1
     put index(range("Xp"),0,k-1) into makecell(jxp,k+1)
    Yp = Yp + index(range("Xp"),0,k)
 end for
  put Pplant_t into makecell(jxp,1)
  Yp = Yp + index(range("Xp"),0,0)

  {------------------------- simulation of hardwood forest }
{..... SW }
  temp = index(range("Xs"),0,dSW-1)
  SWrvt = max(temp-SWfcut, 0)
  SWfcut_t = max(SWfcut-temp,0)
 for k = dSW-1 to 1 step -1
     temp = index(range("Xs"),0,k-1)
     put max(temp-SWfcut_t,0) into makecell(jxs,k+1)
    SWfcut_t = max(SWfcut_t-temp,0)
 end for
  put SW1cut into makecell(jxs,1)
{..... OG }
 LScut = Ccut+SW1cut
OGdebt = OGtarget-OG
  temp = index(range("X"),0,dLS-1)
if OGdebt>0
  OG = OG + min(temp,OGdebt)
   LScut = LScut - max(temp-OGdebt,0)
  OGdebt = max(OGdebt-temp,0)
else
  OG = OG - min(LScut,-OGdebt)
   LScut = LScut - min(LScut,-OGdebt)
  OG = OG + max(temp-LScut,0)
   LScut = max(LScut-temp,0)
 end if
{..... LS }
{... save for OGdebt before cut }
 add = SWrvt/(dLS-dSS)
 for k = dLS-1 to dSS+1 step -1
     temp = index(range("X"),0,k-1)
  if OGdebt>0
     put temp + add into makecell(jx,k+1)
    OGdebt = max(OGdebt-(temp+add),0)
   else
      put max(temp-LScut,0) + add into makecell(jx,k+1)
     LScut = max(LScut-temp,0)
  end if
 end for
  temp = index(range("X"),0,dSS-1)
  put max(temp-SScut,0) + add into makecell(jx,dSS+1)
{..... SS }
  add = (Msrvt + Mprvt)/(2*(dSS-dPO))
  SScut_t = max(SScut-temp,0)
```

```
 for k = dSS-1 to dPO+1 step -1
     temp = index(range("X"),0,k-1)
     put max(temp-SScut_t,0) + add into makecell(jx,k+1)
    SScut_t = max(SScut_t-temp,0)
 end for
  temp = index(range("X"),0,dPO-1)
 put temp + add into makecell(jx,dPO+1)
{..... PO }
  add = (Msrvt + Mprvt)/(2*(dPO-dYG))
 for k = dPO-1 to dYG step -1
     put index(range("X"),0,k-1) + add into makecell(jx,k+1)
 end for
{..... YG }
 for k = dYG-1 to 1 step -1
      put index(range("X"),0,k-1) into makecell(jx,k+1)
 end for
  put (SScut+Ccut+SWfcut) + (Pcut_t-Pplant_t) + OLrvt-OLcvt into makecell(jx,1)
  {::: assume (SScut+Ccut+SWfcut)>=(Pplant-Pcut) }
{::: assume OLrvt ≥ 0; SScut ≤ SS          }

   {---------------------------------  output  results  }
  if Yr*0.1 = int(Yr*0.1)
   temp = Yr*0.1
    YG = sum(range(makerange(jx,1,jx,dYG)))
    PO = sum(range(makerange(jx,dYG+1,jx,dPO)))
    SS = sum(range(makerange(jx,dPO+1,jx,dSS)))
    LS = sum(range(makerange(jx,dSS+1,jx,dLS)))
    SW = sum(range(makerange(jxs,1,jxs,dSW)))
    Yp = sum(range(makerange(jxp,1,jxp,dYp)))
    put CL into makecell (jv+temp,iv+0)
    put GF into makecell (jv+temp,iv+1)
    put FF into makecell (jv+temp,iv+2)
    put SF into makecell (jv+temp,iv+3)
    put YG into makecell (jv+temp,iv+4)
    put PO into makecell (jv+temp,iv+5)
    put SS into makecell (jv+temp,iv+6)
    put LS into makecell (jv+temp,iv+7)
    put OG into makecell (jv+temp,iv+8)
    put SW into makecell (jv+temp,iv+9)
    put Yp into makecell (jv+temp,iv+10)
    put Mp into makecell (jv+temp,iv+11)
    put MS into makecell (jv+temp,iv+12)
 end if

{---------------------- change of management (2nd phase) }
  if Yr = int(turnYr)
    SScut = index(range("CUT"),1,0)
    SW1cut = index(range("CUT"),1,1)
    SWfcut = index(range("CUT"),1,2)
    Ccut = index(range("CUT"),1,3)
    Pplant = index(range("CUT"),1,5)
    Pcut = index(range("CUT"),1,6)
```

```
 end if
end for

{================================================ HSI's simulation }

{-------------------------- calculate HSI's from SIMUveg }
 select range "HSIcoef_1"
 select more range "SIMUveg_1"
 select more range "HSIval_1"
  multiply
 recalc range Q_factor
 recalc range SIMUveg_2
 select range "HSIcoef_2"
 select more range "SIMUveg_2"
 select more range "HSIval_2"
  multiply

{-------------------------------------- recalculation }
 recalc range VegChart
 recalc range VegTable
 recalc range HSIval_3
 recalc range HsiChart
 recalc range HsiTable
 recalc range Diversity
 recalc range DivChart
 recalc range DivTable
 call sema.wkz:profile(0)
 unselect
end function


function profile(pWindow)

  define yr, cc, dj, di, temp, acre, cumu, coef, Veg, sp, sumacre
   pWindow = int(pWindow)
  if pWindow < 0 or pWindow >2
    message "Wrong parameter for Profile."
    exit function
  end if

      {-------------------------------- update both windows }
  if pWindow <= 1
     select object "profilePm1"
      sp = ctvalue(number(),0)
     select object "profilePm2"
  else
     select object "profilePm2"
      sp = ctvalue(number(),0)
     select object "profilePm1"
  end if
  select control item sp
```

```
unselect

    {--------------------------------  update  range  Distr  }
if sp<=9
  coef = "HSIcoef_1"
  Veg = "SimuVeg_1"
else
  sp = sp-9
  coef = "HSIcoef_2"
  Veg = "SimuVeg_2"
end if
select range HUdistr
dj = col()
di = row()
clear
format custom "0"
unselect
for yr=0 to 10
 sumacre = 0
  for cc=0 to 12
     temp = index(range(coef),cc,sp-1)
     acre = index(range(Veg),yr,cc)
   sumacre = sumacre + acre
    if temp<0.0001
       cumu = index(range("HUdistr"),yr,0)
      put cumu + acre into makecell(dj+yr,di+0)
    elseif temp<=0.2
       cumu = index(range("HUdistr"),yr,1)
      put cumu + acre into makecell(dj+yr,di+1)
    elseif temp<=0.4
       cumu = index(range("HUdistr"),yr,2)
      put cumu + acre into makecell(dj+yr,di+2)
    elseif temp<=0.6
       cumu = index(range("HUdistr"),yr,3)
      put cumu + acre into makecell(dj+yr,di+3)
    elseif temp<=0.8
       cumu = index(range("HUdistr"),yr,4)
      put cumu + acre into makecell(dj+yr,di+4)
   else
       cumu = index(range("HUdistr"),yr,5)
      put cumu + acre into makecell(dj+yr,di+5)
   end if
 end for
 if totAcre>sumacre
       cumu = index(range("HUdistr"),yr,0)
       put cumu + (totAcre-sumacre) into makecell(dj+yr,di+0)
 end if
end for

   {-------------------------update  &  repaint  the  chart/table  }
recalc range HUdistrTable
if pWindow=1
```

```
    call sema.wkz:window(1,7,0)
   select object "profileCh1"
    repaint object number()
  elseif pWindow=2
    call sema.wkz:window(2,7,0)
   repaint range HUdistrTable
 end if
 unselect
end function
```

Vita

Xinyuan Wu (Bin Yan) was born in Tangshan, China on September 23, 1956. He attended primary school in Lanzhou, China and graduated from the High School of Lanzhou Railway Institute in January, 1974. After working in the Orchestra of Lanzhou Ensemble for three years as a violist, he entered Lanzhou University in January 1978 and received a B.S. degree in Botany/Plant Ecology in January 1982. Offered a teaching position upon graduation, he worked in the Department of Biology, Lanzhou University for three years.

He entered the Graduate School at the University of Tennessee in January, 1985, received his first M.S. degree in Ecology in March, 1988 and his second M.S. degree in Management Science in August, 1990. He is receiving his Ph. D. degree in Ecology in December, 1991. During May 1989 and November 1991, he also worked for Tennessee Valley Authority at Forest Resource Development, Norris, TN and Land Between The Lakes, Golden Pond, KY.