

MODELING FOREST TRANSITION PATHWAYS FOR DECISION MAKING IN  
PRIVATE FORESTRY

---

A Thesis  
presented to  
the Faculty of the Graduate School  
University of Missouri-Columbia

---

In Partial Fulfillment  
of the Requirements for the Degree  
Master of Science

---

by  
CHAD LARSON  
Dr. David R. Larsen, Thesis Supervisor

DECEMBER 2004



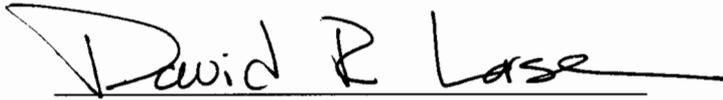
The undersigned, appointed by the Dean of the Graduate School, have examined the thesis entitled

MODELING FOREST TRANSITION PATHWAYS FOR DECISION MAKING IN  
PRIVATE FORESTRY

presented by Chad J. Larson

a candidate for the degree of Master of Science

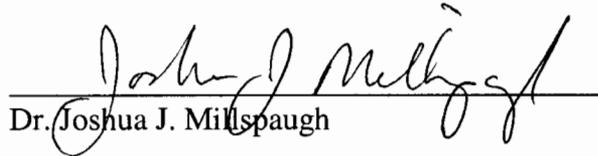
and hereby certify that in their opinion it is worthy of acceptance.



Dr. David R. Larsen



Dr. William B. Kurtz



Dr. Joshua J. Millsbaugh

## ACKNOWLEDGEMENTS

I would like to thank the Initiative for Future Agriculture and Food Services (IFAFS) for funding my project. I would also like to thank the rest of the IFAFS team at the University of Missouri for their support and assistance: Drs. Bill Kurtz, Dave Larsen, Rose-Marie Muzika, Gene Garrett, Hong He, Bernie Lewis, and Hank Stelzer; and fellow students Mark Yates, Julie Richter, Faren McCord, John Kluthe, Dong Ko, and David Shostak.

I would like to thank my committee for their guidance and patience from start to finish, without which I could not have completed my project and written my thesis. In addition, I would particularly like to thank Jim Lootens, Steve Shifley, Rose-Marie Muzika, Kevin Hosman, Gene Garrett, John Kluthe, and Jennifer Graham for their technical and professional assistance as I worked through the various stages of my project. And finally I would like to thank my undergraduate technicians, Kelly Mills and Jon Motsinger, for the long, monotonous hours they spent helping me run computer simulations during the data collection process.

## ABSTRACT

In the Central Hardwoods Region, 90% of forested lands are privately owned and the majority of harvested hardwoods come from non-industrial private forests. However, many landowners seek little professional advice when managing their forests and do not fully appreciate the resource potential of their forests. We developed a decision support tool summarizing a forest growth and yield model to explain forest stand dynamics in a simple fashion to private non-industrial forest landowners in the Ozark Highlands of Missouri.

To simplify forest growth modeling, we limited predictions to 20 years, which is long enough for potential forest change and short enough for landowners to have a vested interest in the land. Type-Size-Density classes were used to describe different forest structures. A set of Forest Inventory and Analysis (FIA) plots were grown in the Forest Vegetation Simulator (FVS); the initial and final Type-Size-Density classes were determined and simple transition probabilities calculated.

Various forest management options were employed (no treatment, thinning from below, and diameter limit cut) and a multitude of forest attributes were assigned relative values for all Type-Size-Density classes. The categories of forest attributes developed include commercial timber products, non-commercial timber products, wildlife habitat suitability, and risk susceptibility. A database was developed to guide users from initial Type-Size-Density to likely future Type-Size-Density classes dependent upon the management option selected. The database further provides a representative photograph

of each Type-Size-Density class along with scale bars indicating whether that class is good or poor at providing for each forest attribute.

## TABLE OF CONTENTS

ACKNOWLEDGEMENTS .....	ii
ABSTRACT .....	iii
LIST OF TABLES .....	vii
LIST OF FIGURES .....	viii
INTRODUCTION .....	1
Background .....	1
Purpose and Objectives .....	2
Modeling .....	4
Forest Growth Models .....	4
Forestry Decision Tools .....	6
METHODS .....	8
Study Area .....	8
Model Design .....	8
Data Sources .....	10
Forest Inventory and Analysis .....	10
Forest Vegetation Simulator .....	14
Model Development .....	15
Variables .....	15
Transition Pathways .....	17
Attributes .....	19
Model Testing .....	22

Decision Tool Development .....	23
Database .....	23
User Interface .....	23
RESULTS .....	26
Transition Pathway Model .....	26
Initial Classes .....	26
Transition Pathways .....	26
Forest Resource Attributes .....	36
Income Potential .....	36
Wildlife Habitat .....	38
Risk .....	38
Model Validation .....	41
Decision Tool .....	47
CONCLUSION .....	55
LITERATURE CITED .....	57
APPENDIX A .....	60
APPENDIX B .....	64
APPENDIX C .....	66

## LIST OF TABLES

Table 1. FIA data taken from the FIA database Plot, Condition, and Tree tables and used for input into FVS. ....	11
Table 2. The Type, Size, and Density variables defined by the categories for each variable and a brief description of each category. ....	16
Table 3. Combined Type-Size-Density classes. ....	18
Table 4. Developed forest attributes based on Type-Size-Density classes. ....	21
Table 5. The initial sample count of the Type-Size-Density classes occurring in the study area. Classes not occurring in the study area are not shown. Gray font indicates classes not used in the building of the transition pathway model. ....	28
Table 6. Transition pathway probabilities (in percent) for the White Oak category. ....	29
Table 7. Transition pathway probabilities (in percent) for the Red Oak category. ....	32
Table 8. Transition pathway probabilities (in percent) for the Pine category. ....	33
Table 9. Transition pathway probabilities (in percent) for the Other Hardwoods category. ....	34
Table 10. Transition probabilities (in percent) for the Mixed category. ....	35
Table 11. Relative attribute values assigned to the Income Potential categories. ....	37
Table 12. Relative attribute values assigned to the Wildlife Habitat categories. ....	39
Table 13. Relative attribute values assigned to the Risk categories. ....	40
Table 14. Results of the predicted White Oak transition pathway model chi-square tests. ....	42
Table 15. Results of the predicted Red Oak transition pathway model chi-square tests. .	43
Table 16. Results of the predicted Pine transition pathway model chi-square tests. ....	44
Table 17. Results of the predicted Other Hardwood transition pathway model chi-square test. ....	45
Table 18. Results of the predicted Mixed transition pathway model chi-square test. ....	46

## LIST OF FIGURES

Figure 1. The study area in southeastern Missouri as defined using USGS 8-digit hydrologic units (Seaber, et al. 1987). .....	9
Figure 2. The FIA plots selected using a 3-mile buffer around the combined watersheds. ....	13
Figure 3. Design of the user interface for the decision support tool.....	25
Figure 4. The FIA plots organized by Type category in the study area and the surrounding 3-mile buffer. ....	27
Figure 5. Transition pathway model for the White Oak Type category. ....	30
Figure 6. Screenshot of the introductory page of the decision support tool. ....	49
Figure 7. Screenshot of the page prompting the user to select the appropriate Type-Size-Density. ....	50
Figure 8. Screenshot of the page giving the user the option to select one of the three management options or to select the attributes for White Oak-Sapling-High. ....	51
Figure 9. Screenshot of the no treatment management option results for White Oak-Sapling-High. ....	52
Figure 10. Screenshot of the attribute switchboard giving the user the option to choose among the different attribute categories. ....	53
Figure 11. Screenshot of the risk attribute for White Oak-Sapling-High. The width of the bar indicates the degree of confidence, with High confidence being the narrowest bar. ....	54

## INTRODUCTION

### Background

The Central Hardwoods Region is a unique forest region in the United States. As defined by Parker (1993), the Central Hardwoods Region encompasses 340 million acres of land stretching from Pennsylvania to eastern Kansas and Wisconsin to northern Mississippi, of which 100 million acres are forested. The region contains one-fourth of the U.S. human population, with approximately 90% of the land in private ownership (Parker 1993). In general, private forested lands in the Central Hardwoods Region tend to be small, non-industrial forests with little to no forest management (Nyland 1992).

In 1997, 87% of the hardwood harvest in Indiana, Missouri and Tennessee came from non-industrial private forests (NIPF) (USDA Forest Service 1997). The tendency of these same NIPF landowners to eschew professional advice and guidance when managing and harvesting their forests is a cause for concern. The sustainability of the forests in the Central Hardwoods Region with regards to the economic, environmental and social benefits of forests may depend upon educating NIPF landowners and encouraging them to seek professional advice when managing their forests.

Since forests change so slowly, a historical misperception is that forests are nearly unchanging entities. The science of forestry, in particular the theories of succession and forest stand dynamics, views a forest as a constantly changing organism. A major stumbling block in educating landowners in managing their forest is that most landowners might not fully appreciate the many different potentials inherent in their

forest. Providing landowners with information demonstrating the effects that forest management have on a forest is one method to increase landowner knowledge. With increased knowledge and a greater appreciation of their forest, landowners may be more inclined to seek professional guidance and develop a management plan for their forest.

Private landowners as a group have many interests and goals pertaining to their lands. The NIPF landowner may be interested in increasing the value of timber produced, producing better wildlife habitat, or creating an aesthetically pleasing forest. In all cases, management options are available to the landowner to increase or decrease the inherent value of the forest relative to a particular goal. An efficient method for providing landowners access to information pertaining to forest management options is a decision support tool for private forest management in the form of a relatively simple forest growth model.

### Purpose and Objectives

The purpose of this research was to create a decision support tool designed to assist private landowners in identifying management goals based upon probable outcomes and impacts associated with forest management decisions. As a general rule, existing forest management tools are technical and complex. In designing a new tool for private landowners, we not only wanted to keep the tool relatively simple, we wanted to ensure compatibility with existing tools. To this end, a transition pathway model was developed using three traditional variables to describe the main characteristics of the structure of a forest stand: type, size, and density. The transition pathway model predicts

the probability of the current stand transitioning to a new Type-Size-Density class given various forest management treatments.

However, most people are not aware how Type-Size-Density variables relate to their management interests. Thus, several forest attributes were assigned to each Type-Size-Density class describing the suitability of that class for specific commodity and non-commodity use of resources. To prevent confusion arising from differing units and values for the attributes of interest, the attributes were defined using qualitative values. The assigned qualitative attributes were designed to give the landowner a greater appreciation for the different values potentially available from their forested land while describing likely structure change from different management decisions.

The specific objectives of this project were:

- to design a transition pathway model defined by Type-Size-Density classes that predicts forest change based on model output following a specific management treatment and produces the probability of a new Type-Size-Density classification;
- to assign qualitative values to each Type-Size-Density class regarding the suitability of each class for several forest resource attributes; and
- to develop software implementing a decision support tool based on the transition pathway model and forest resource attributes to provide landowners with information and facilitate landowner education.

## Modeling

### Forest Growth Models

The first modeling efforts aimed at describing forest change took place in the early 1970s and were based on the theories of succession and forest stand dynamics. These mathematical models were formulated at scales of stand, forest gap, and individual tree levels and were the antecedents to many forest modeling methods in use today (Mladenoff and Baker 1999). One of the first individual tree level models was the Prognosis Model conceived by Stage (1973). Since its first production version (Wykoff, et al. 1982), Prognosis has become the standard model used by various government agencies including the USDA Forest Service, USDI Bureau of Land Management, and USDI Bureau of Indian Affairs, as well as numerous state agencies, industry, educational institutions, and private landowners (Dixon 2003).

The USDA Forest Service funds and maintains the Prognosis Model and in the early 90s renamed it the Forest Vegetation Simulator (FVS). The FVS program is classified as an individual tree, distance-independent, forest growth and yield model and requires detailed forest inventory tree lists to run meaningful simulations. Using parameterized tree growth equations, FVS simulates the growth of the trees contained in the tree list. The user specifies the length of time, management activities, various output files, and selects from a variety of keywords used to further customize each FVS simulation. Forest managers have used FVS extensively to summarize current stand conditions, predict future stand conditions under various management alternatives, update

inventory statistics, and have also used FVS output as input to forest planning models and other analysis tools (Dixon 2003).

For many years, FVS required the user to possess sufficient computer skills to write programs utilizing files of FVS keywords in order to perform simulations. In 1997, a graphical user interface titled Suppose (Crookston 1997) was developed to facilitate the running of FVS. Suppose is an interface that includes the key element of allowing proposed management plans to be entered into the FVS system using methods much more directly related to forest management than the FVS keyword system alone. Also developed that year was another graphical user interface titled the Landscape Management System (LMS) (McCarter, et al. 1998). LMS coordinates the flow of information from FVS to computer visualization software and various additional analysis tools in a landscape management approach. Both interfaces allow multiple stand simulations to be run in FVS at the same time and substantially reduce the amount of computer skills required.

While the Suppose and Landscape Management System graphical user interfaces have made simulations in FVS easier for the professional forester, the FVS program is still beyond the skills of the average private landowner to run unassisted. The decision support tool built for this project will be based on FVS simulations with the main purpose being to summarize FVS output for landowner education and information.

## Forestry Decision Tools

The next step beyond forest growth models is software that provides additional support in the forest management decision making process in the form of a decision tool. Two general categories of decision tools are prescriptive and option-based. An option-based decision tool provides the user with a series of options given the initial conditions, describes the options, and provides a number of metrics by which the user might rate the options against each other, but provides no recommendations to the user. A prescriptive decision tool on the other hand considers the initial conditions given by the user, weights the options available to the user by predetermined decision criteria, and then provides the user with a recommendation on which option best fits the data. The main forestry decision tools, SILVAH and the Northeast Decision Tool, currently fall more into the category of prescriptive than option-based.

SILVAH is a decision tool that takes as input a forest stand inventory of basic overstory, understory, and site factors that are summarized and analyzed to evaluate the stand's potential for growth and regeneration (Marquis and Ernst 1992). Decision tables are used to determine the proper prescription based on critical levels of the various site, overstory, and understory variables in combination with landowner objectives.

The Northeast Decision Tool (NED) is a collection of software tools created to help resource managers develop goals, assess current and future conditions, and produce management plans for forest properties (Twery 2000, Twery, et al. 2000). NED can incorporate management goals for multiple objectives, analyze current forest conditions,

recommend management alternatives, and predict future conditions under different alternatives.

NED and SILVAH both work best when the landowner can specifically state his/her goals. However, the most difficult part of the decision making process often lies in identifying and choosing a good set of goals. Since the purpose of modern forest management is to achieve diverse goals selected by the landowner, reasoned management cannot be practiced without those goals (Wang, et al. 2002).

The premise underlying the design of the decision tool portion of this project is that many landowners may have trouble stating specific goals for their land, making it difficult to proscribe an acceptable management plan (proscriptive decision tool); but, if presented with a number of options (option-based decision tool), these landowners would have little trouble choosing between them. The attributes assigned to each Type-Size-Density class provide the landowner with the means to evaluate management options by the criteria deemed most important by the landowner. Landowners may then proceed to existing forest growth models and forestry decision tools with a clear understanding of their own desires and goals, as well as knowledge of the effect professional management may have on their forest.

## METHODS

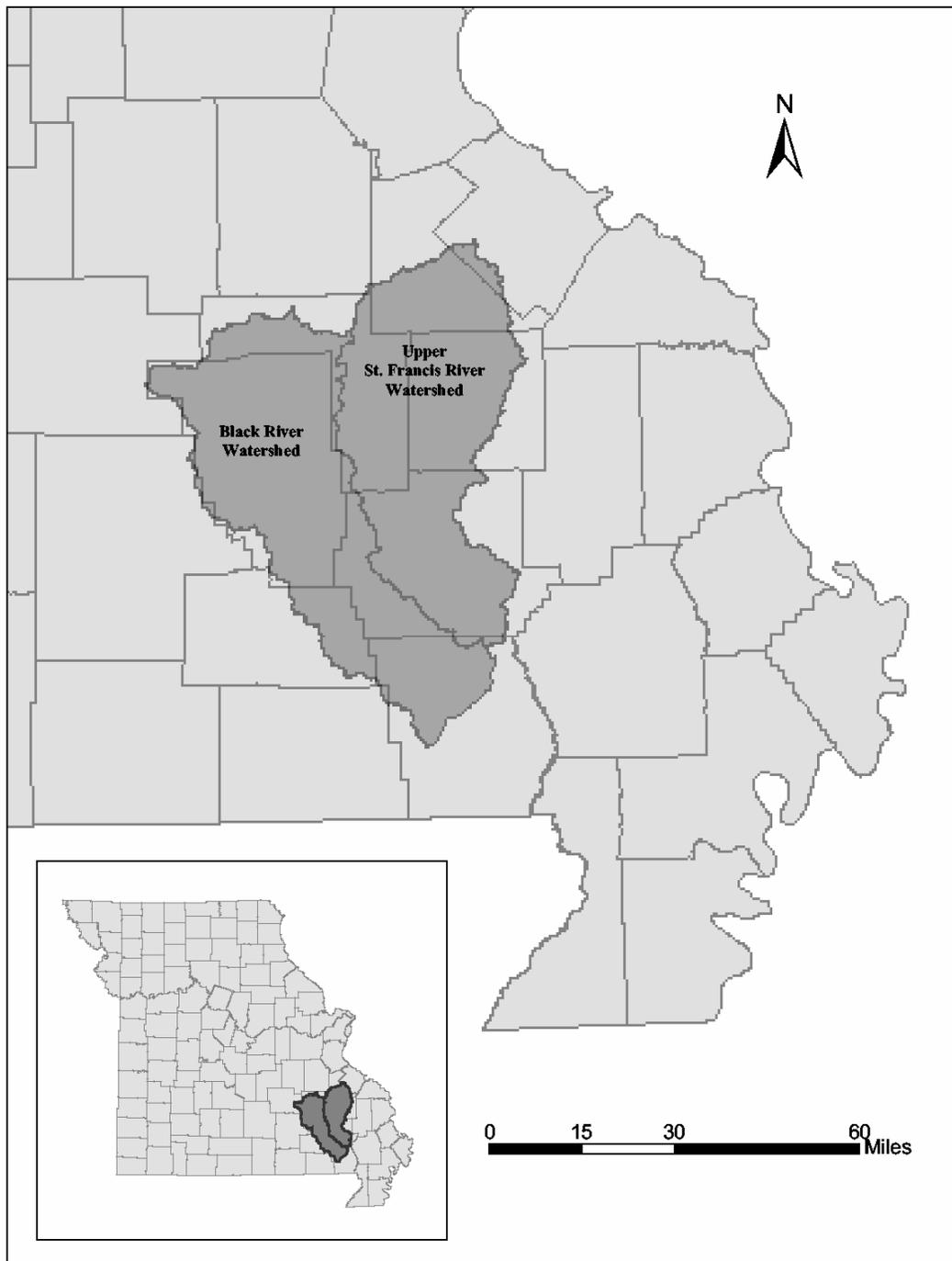
### Study Area

The study area consisted of the St. Francis River Watershed and the Black River Watershed located in southeastern Missouri. Both watersheds were chosen, in part, because over 90 percent of the land area is covered by forest. The combined watersheds encompass approximately 1.75 million acres and include portions of St. Francois, Madison, Iron, Reynolds, Wayne, Carter, Ripley and Butler counties (Figure 1).

### Model Design

The primary presupposition made in designing the decision support tool was that a simple model with easily defined variables was the best method for fulfilling the purpose of the study. However, in order to prevent placing unnecessary limits on the possible applications of the decision support tool, the underlying model was based on simulations run on the forest growth model FVS (Forest Vegetation Simulator). Summarizing output from the FVS model was intended to provide for the creation of a simple model whose predictions would remain consistent with the predictions of a more complex and proven model (FVS).

The model underlying the decision support tool was designed as a transition pathway model defined by the three variables Type, Size, and Density. The transition pathway model was built to predict the probability of an initial Type-Size-Density class transitioning to a new Type-Size-Density class. Simulations were run in FVS, the input



**Figure 1.** The study area in southeastern Missouri as defined using USGS 8-digit hydrologic units (Seaber, et al. 1987).

and output data were summarized into Type-Size-Density classes, and the transition probabilities were calculated. The data used as input came from inventory plots within the study area collected by Forest Inventory and Analysis, a program of the United States Forest Service.

To complete the design of the decision support tool, it was assumed that specific forest attributes can be defined as a function of Type-Size-Density and these attributes will be useful to landowners in understanding the resource potential of a forest. Each forest attribute was assigned a qualitative value for all Type-Size-Density classes in order to provide landowners with a general impression of forest potential.

## Data Sources

### Forest Inventory and Analysis

Forest Inventory and Analysis (FIA) is an endeavor mandated by Congress whose primary objective is to determine the extent, condition, volume, growth, and depletions of timber on the Nation's forest land (Hansen, et al. 1992, Woudenberg and Farrenkopf 1995, Miles, et al. 2001). The data collected by FIA is organized in a database comprised of nine tables (SURVEY, COUNTY, PLOT, SUBPLOT, COND, TREE, SEEDLING, SITETREE, and BOUNDARY). The FIA data fields required for running the FVS simulations used in building the transition pathway model are described in Table 1. FIA collected these data in 1987 and 1988. All counties comprising the study area were classified by FIA as being in the Eastern Ozarks Forest Survey Unit.

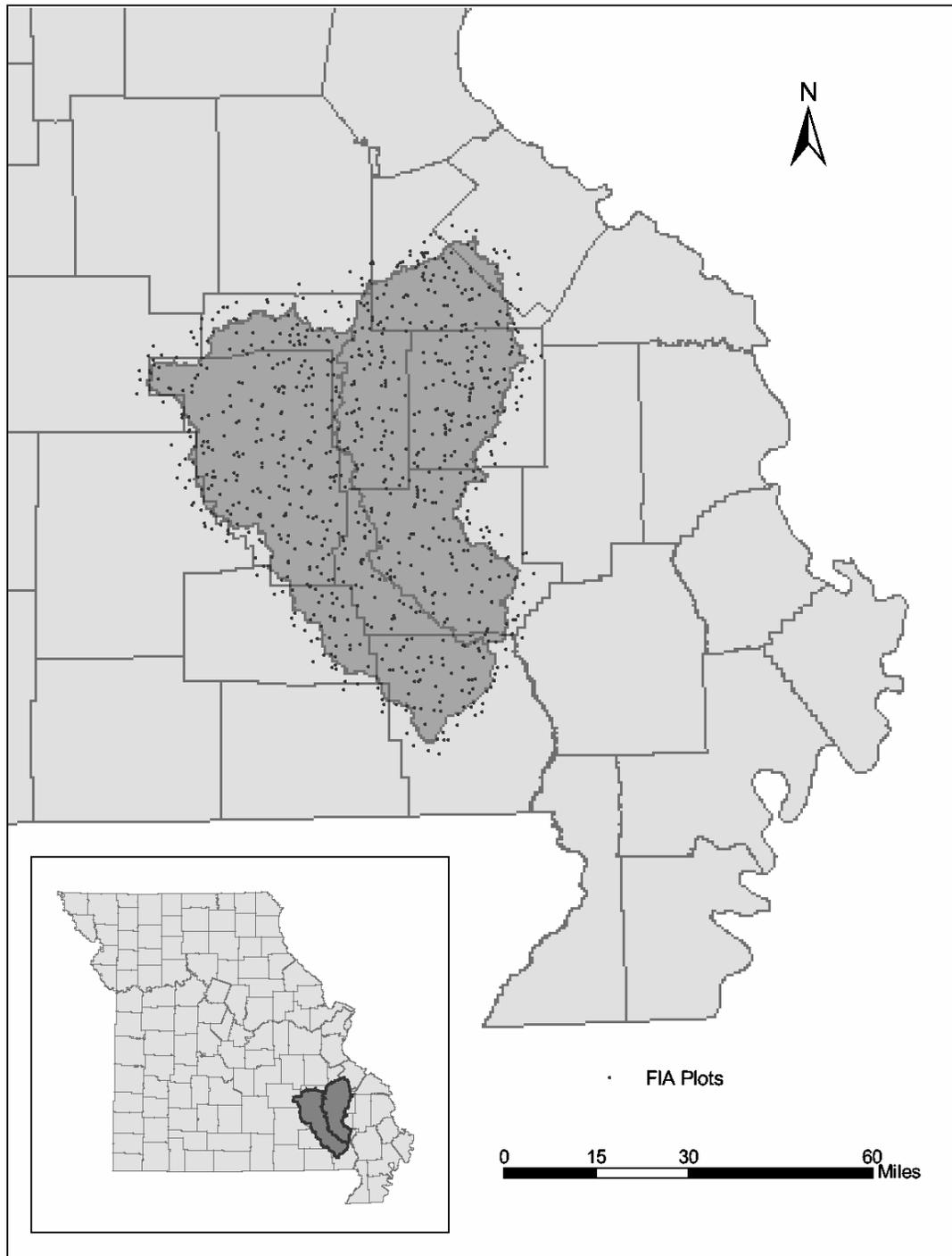
**Table 1.** FIA data taken from the FIA database Plot, Condition, and Tree tables and used for input into FVS.

FIA Table Name	Variable Name	Description
PLOT	COUNTYCD	Identification number for county
	PLOT	Unique plot number within county
	MEASYEAR	Measurement year
COND	COUNTYCD	Identification number for county
	PLOT	Unique plot number within county
	SICOND	Site index
	SIBASE	Site index base age
	SLOPE	Average percent slope within the condition
	ASPECT	The direction (in degrees) from magnetic north of drainage for most of the condition
TREE	COUNTYCD	Identification number for county
	PLOT	Unique plot number within county
	SUBP	Subplot number
	TREE	Tree number
	STATUSCD	Tree status code identifying if tree is alive, dead, or cut
	SPCD	Species code
	DIA	Current diameter
	CR	Compacted crown ratio

The inventory techniques used by FIA in 1987 and 1988 were designed to cover a 1-acre plot area using 10 sample points. At each sample point a variable radius sample was collected using a 37.5 Basal Area Factor (BAF) for trees greater than or equal to 5 inches DBH (diameter at breast height, or 4.5 feet), and a fixed area sample was collected using a 30<sup>th</sup> acre plot (in 1987) and a 100<sup>th</sup> acre plot (in 1988) for trees less than 5 inches DBH. The samples collected at all 10 sample points comprised one plot (Hansen, et al. 1992).

The FIA plots chosen for this project fell within the study area watersheds or within a 3-mile buffer surrounding the watersheds. The 3-mile buffer allowed for the inclusion of all FIA plots from the study area that might not have fallen within the boundaries of the watersheds due to the error added to the latitude and longitude coordinates of the FIA plots for privacy considerations. Additional FIA plots from outside the study area were captured by the latitude and longitude error and the 3-mile buffer; however, these plots were indistinguishable from study area plots and all plots were considered equal. The reported locations of the 582 selected plots are shown in Figure 2.

The selected FIA data were then formatted for input into FVS. Several assumptions were made when formatting the FIA data in the interests of consistency and simplicity: every live tree was considered to be a healthy, desirable tree regardless of its damage codes; every tree less than 5 inches DBH from 1987 received an expansion factor of 29.9989; every tree less than 5 inches DBH from 1988 received an expansion factor of 99.95; and the expansion factors of all other trees were calculated using a BAF of 37.5



**Figure 2.** The FIA plots selected using a 3-mile buffer around the combined watersheds.

and the following equation, where *DBH* is the diameter of the tree:

$$ExpansionFactor = \frac{37.5}{0.005454154(DBH)^2} \quad (\text{Husch, et al. 1993})$$

## Forest Vegetation Simulator

Once the FIA data were formatted, the plots were grown in FVS using the Suppose graphical user interface. Three types of files were required for Suppose FVS simulations: location files, stand list files, and tree list files. Tables of the variables and standard values used in these files may be found in Appendix A. The plots were grown for 20 years using the following management options: no treatment, thinning from below, and diameter limit cut. The time frame of 20 years was used in order to give the forest a long enough period of time in which to possibly change Type-Size-Density classes, while being a short enough length of time that a private landowner might retain a vested interest in the land.

The management option of No Treatment required simply running the FIA plots in FVS for 20 years. The Thinning From Below and Diameter Limit Cut management options required using FVS predefined management treatments. For the Thinning From Below management option, the traditional FVS thinning method of “Thinning from Below” to a basal area target of 55 ft<sup>2</sup>/acre was used. For the Diameter Limit Cut, the traditional FVS thinning method of “Thinning from Above” to a desired diameter of 10 inches DBH with 100 percent removal was used. All management options conducted the management prescription at year zero and then grew the sample plot for 20 years with no further management activity.

## Model Development

### Variables

The FIA sample plot data and the FVS simulation output from growing the FIA data were summarized into three variables (Type, Size, and Density) describing forest structure for transition pathway model development. The Type variable refers to the dominant tree species group in a stand; the Size variable refers to the average diameter of all the trees in a stand; and the Density variable refers to the number of trees per acre in a stand. The categories for each variable are listed and described in Table 2.

The species groups for Type were chosen based on the dominance of oak species in the study area and the economic importance of oak and pine species in Missouri. Categories for the Type variable species groups were White Oak, Red Oak, Pine, Other Hardwood, and Mixed species. A species group was considered dominant if the relative dominance by basal area was greater than 40 percent. The individual species making up each Type category can be found in Appendix B.

The average diameter for determining the Size category was calculated as a quadratic mean diameter (QMD). The QMD was calculated using the following equation, where  $n$  represents the total number of trees in the plot and  $DBH$  is the diameter of each tree in the plot:

$$QMD = \sqrt{\frac{\sum_{i=1}^n DBH^2}{n}} \quad (\text{Husch, et al. 1993})$$

**Table 2.** The Type, Size, and Density variables defined by the categories for each variable and a brief description of each category.

Variable	Category	Description
Type <sup>a,b</sup>	White Oak	White oak species group is dominant
	Red Oak	Red oak species group is dominant
	Pine	Pine species group is dominant
	Other Hardwood	All other species group is dominant
	Mixed	No species group is dominant
Size	Sapling	Less than 6 inches DBH
	Pole	6 to 10 inches DBH
	Sawlog	Greater than 10 inches DBH
Density	High	Greater than 750 trees per acre
	Medium	250 to 750 trees per acre
	Low	Less than 250 trees per acre

<sup>a</sup> The individual tree species associated with each Type category can be found in Appendix B.

<sup>b</sup> Species group dominance is defined as >40% relative dominance by basal area.

These quadratic mean diameters were then classified into three categories. The QMD breaks occurred at 6 and 10 inches, with the Sapling category less than 6 inches, the Pole category between 6 and 10 inches, and the Sawlog category greater than 10 inches. The Size categories were chosen based on industry standards and professional expertise.

Density, a measure of the number of individuals per unit area, was based on an estimate of trees per acre. This estimate was classified into three categories. The trees per acre (TPA) breaks for the density categories occurred at 250 and 750 TPA, with the Low density category less than 250 TPA, the Medium density category between 250 and 750 TPA, and the High density category greater than 750 TPA. The Density categories were chosen after initial analysis of the FIA data and the decision was based on professional expertise.

#### Transition Pathways

Based on categories defining the Type-Size-Density variables, all possible combinations of variables were developed (Table 3). Under the original concept of developing a full transition matrix, the large number of Type-Size-Density classes created an overly complex model. In addition, the amount of data did not support the development of a full transition matrix. Therefore, the problem was simplified by designing a series of transition pathways.

The design of the transition pathway model required making several assumptions. First, it was assumed that the dominant species group (Type) at year 0 would have a low probability of changing in only 20 years for the No Treatment option, thus all transitions

**Table 3.** Combined Type-Size-Density classes.

Class	Type	Size	Density
1	White Oak	Sapling	High
2	White Oak	Sapling	Med
3	White Oak	Sapling	Low
4	White Oak	Pole	High
5	White Oak	Pole	Med
6	White Oak	Pole	Low
7	White Oak	Sawlog	High
8	White Oak	Sawlog	Med
9	White Oak	Sawlog	Low
10	Red Oak	Sapling	High
11	Red Oak	Sapling	Med
12	Red Oak	Sapling	Low
13	Red Oak	Pole	High
14	Red Oak	Pole	Med
15	Red Oak	Pole	Low
16	Red Oak	Sawlog	High
17	Red Oak	Sawlog	Med
18	Red Oak	Sawlog	Low
19	Pine	Sapling	High
20	Pine	Sapling	Med
21	Pine	Sapling	Low
22	Pine	Pole	High
23	Pine	Pole	Med
24	Pine	Pole	Low
25	Pine	Sawlog	High
26	Pine	Sawlog	Med
27	Pine	Sawlog	Low
28	Other Hardwood	Sapling	High
29	Other Hardwood	Sapling	Med
30	Other Hardwood	Sapling	Low
31	Other Hardwood	Pole	High
32	Other Hardwood	Pole	Med
33	Other Hardwood	Pole	Low
34	Other Hardwood	Sawlog	High
35	Other Hardwood	Sawlog	Med
36	Other Hardwood	Sawlog	Low
37	Mixed	Sapling	High
38	Mixed	Sapling	Med
39	Mixed	Sapling	Low
40	Mixed	Pole	High
41	Mixed	Pole	Med
42	Mixed	Pole	Low
43	Mixed	Sawlog	High
44	Mixed	Sawlog	Med
45	Mixed	Sawlog	Low

to a different Type were combined into the same probability class of “other.” Second, it was assumed that Size and Density were negatively correlated, meaning that, for the No Treatment option, as the sample plots were grown for 20 years the plots would tend to grow larger in diameter (Size increases) while becoming smaller in density (Density decreases).

A matrix was created for each management option showing the initial classes (year 0) in rows and counts of the transition classes over a 20-year period in columns. Transition probabilities were calculated by dividing the count for each transition class by the total number of plots in the initial class. The transition pathways were then created by collating the initial classes by Type category, keeping intact all transition class probabilities of the initial Type, and combining all transition class probabilities to different Type categories (different from the initial class Type) into a new probability class called “other.”

#### Attributes

A forest attribute is a description of an inherent characteristic of a forest. The design of the transition pathway model and the definition of the variables dictated that the forest resource attribute assignments be qualitative. The complexity of analysis was limited by the simple model design and simple variables. However, the assumption previously stated regarding specific forest attributes being useful to landowners was based on the idea of providing landowners with general impressions of forest potential,

and for that purpose qualitative attribute values were defined as a function of Type-Size-Density.

Several attributes were developed for the main categories of income potential, wildlife habitat suitability, and risk susceptibility (Table 4). Income potential was represented by sawtimber (a commercial timber product) and floral greens (a non-commercial timber product) (Table 4). The sawtimber attribute was assigned qualitative values based on professional expertise and Missouri logging sale charts. Tree species and tree diameter influenced the attribute values. The floral greens attribute values were assigned based on the work of Kluthe (2004). Floral greens require a substantial amount of shade and thus were strongly influenced by the capacity of a stand for high shade production.

Wildlife habitat was represented by the two species, wild turkey (*Meleagris gallopavo sylvestris*) and gray squirrel (*Sciurus carolinensis*) (Table 4). Habitat suitability index (HSI) models from Larson, et al. (2003) were used in assigning attribute values. The wild turkey HSI model was concerned with the life requisites of nesting and brooding cover, adult cover, fall and winter food, and cover and food. The gray squirrel HSI model was concerned with winter food and cover.

Risk was represented by fire, wind, and insect/disease (Table 4). Professional opinion and the work of Oliver and Larson (1996), Barnes, et al. (1998), and Wargo, et al. (1983) were used in assigning values to the risk attributes. Fire risk was influenced by drought and stand density; wind risk was influenced by tree size; and insect/disease was influenced by stress from competition for resources.

**Table 4.** Developed forest attributes based on Type-Size-Density classes.

Main Category	Developed Attributes
Income potential	Commercial timber products: Sawtimber Noncommercial timber products: Floral greens
Wildlife habitat	Wild turkey ( <i>Meleagris gallopavo sylvestris</i> ) Gray squirrel ( <i>Sciurus carolinensis</i> )
Risk	Fire Wind Insect/Disease

The first step in assigning a qualitative attribute value to a Type-Size-Density class was to determine which variable(s) was the most influential for that attribute and then ranking all classes on a relative scale of 1 to 9. The second step was to indicate the degree of confidence in the assigned ranking for each class. The degree of confidence (high, medium, low) was a qualitative measure of the importance of outside factors not captured by Type-Size-Density in determining the suitability and potential of a particular forest for the attribute in question.

### Model Testing

After the transition pathway model was built the model required testing. Model testing consisted of verifying that the transition pathway model predictions were consistent with the FVS model being summarized. Test plots were selected from FIA plots outside the study area but within the Eastern Ozarks Forest Survey Unit. Ten test plots were chosen for each Type-Size-Density class using the random number generator in Microsoft Excel (an even distribution from 0 to 1), except in those classes with ten or fewer available samples from which to choose. The data were grown in FVS, the Type-Size-Density classes of the initial test data and of the resulting FVS output were calculated, and the results were compared to the predictions of the transition pathway model. The chi-square goodness of fit test (Zar 1999) was used to determine if a significant difference existed between the actual FVS output classes (*test*) and the predicted transition classes (*predicted*) at a 95 percent confidence level using the following equation, where  $n$  equals the number of test plots:

$$\chi^2 = \sum_{i=1}^n \left( \frac{[test_i - (predicted_i)(n)]^2}{(predicted_i)(n)} \right)$$

Two methods were used to determine if a significant difference existed between the FVS test results and the transition pathway model predictions. First, the chi-square value was compared to the appropriate critical value at a 95 percent confidence level. Second, the test plots used to calculate the chi-square value were analyzed to determine if any plots transitioned to a class (*test*) that was not predicted by the model (*predicted* = 0).

### Decision Tool Development

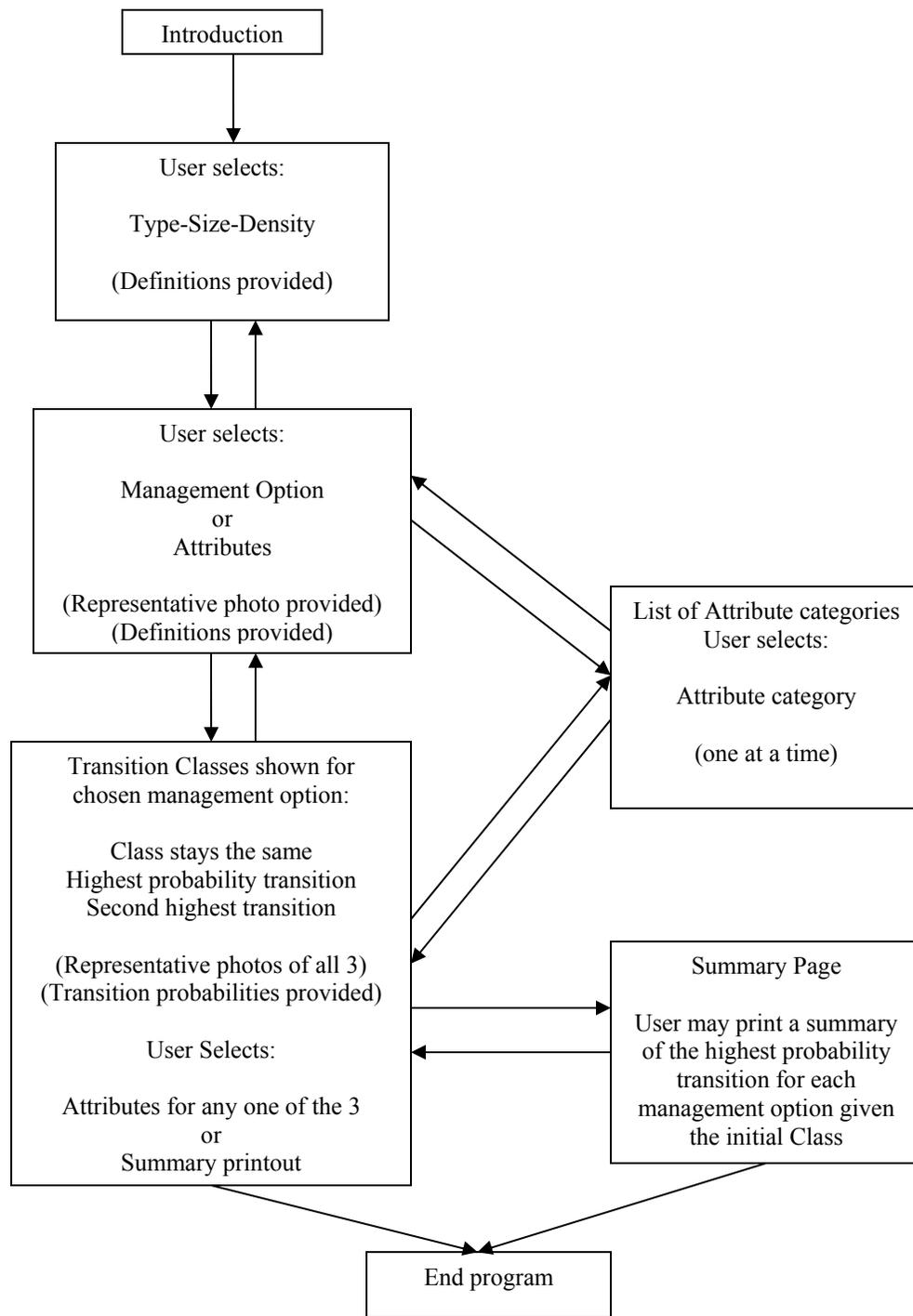
#### Database

The predictions and attributes developed in the transition pathway model were organized in a Microsoft Access database (Appendix C). A transition table was created for each management option containing the two largest transition probabilities for each initial class along with the probability of that class staying the same. The attribute tables in the database consisted of the classes, the relative ranking, and the degree of confidence. A table consisting of representative photographs of each class was added to the database for additional landowner edification.

#### User Interface

The user interface was built in the same Microsoft Access database using a series of forms, command buttons, and macros, and was designed to provide landowners with a series of screens giving them the ability to choose the Type-Size-Density class of their

forest from drop down menus, select management options, view attributes, and maneuver back and forth through the screens (Appendix C). A flowchart demonstrating the user interface logic is shown in Figure 3.



**Figure 3.** Design of the user interface for the decision support tool.

## RESULTS

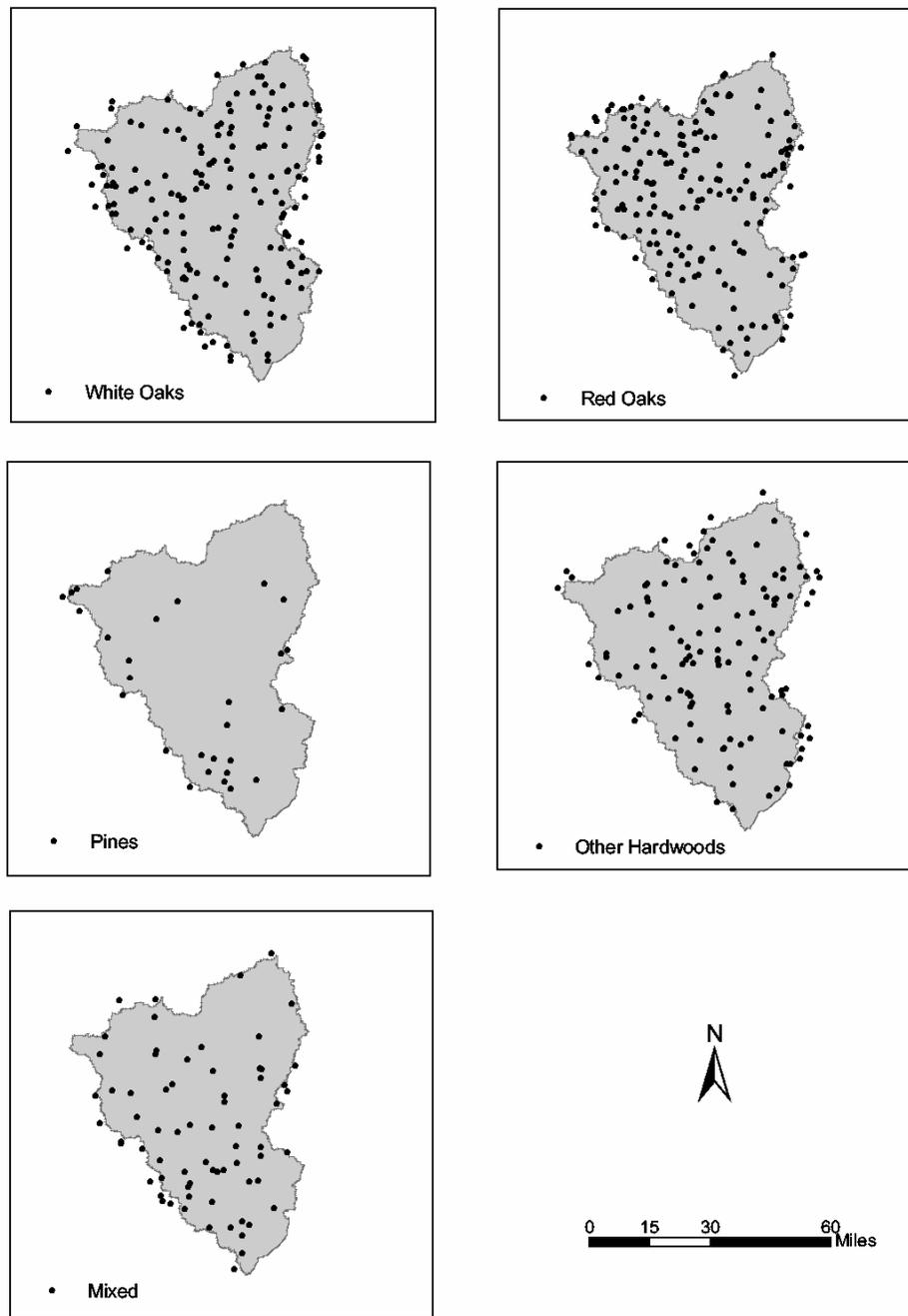
### Transition Pathway Model

#### Initial Classes

Type-Size-Density initial classes were calculated for the 582 study area FIA data plots and the spatial distributions were mapped by Type (Figure 4). Analysis of initial sample counts prompted the removal of all Size-Density combinations of Sapling-Low and Pole-High classes from the database due to small sample size. In addition, Sawlog classes and plots containing no live trees were removed. The 546 remaining FIA data plots constituted the sample size for the building of the transition pathway model predictions (Table 5).

#### Transition Pathways

The White Oak category included 166 sample plots. The transition pathway probabilities (Table 6) affirmed the assumptions made for the No Treatment management option; the White Oak, No Treatment management option demonstrated that Size and Density were negatively correlated and the Type at year 0 had a low probability of changing in 20 years. The largest sample size for White Oak, White Oak-Sapling-Medium (class 2), was 94 plots and only 7.4 percent of the plots changed Type, while 78.7 percent changed Size to White Oak-Pole-Medium (class 5). The No Treatment transition pathway is illustrated in Figure 5.



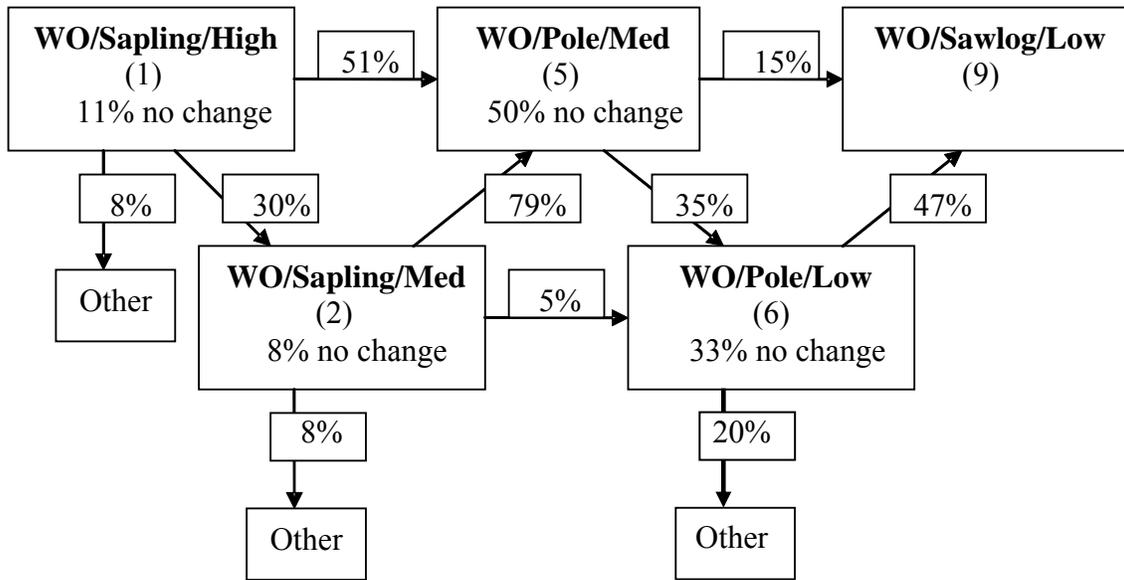
**Figure 4.** The FIA plots organized by Type category in the study area and the surrounding 3-mile buffer.

**Table 5.** The initial sample count of the Type-Size-Density classes occurring in the study area. Classes not occurring in the study area are not shown. Gray font indicates classes not used in the building of the transition pathway model.

Class	Type	Size	Density	Count
1	White Oak	Sapling	High	37
2	White Oak	Sapling	Med	94
3	White Oak	Sapling	Low	3
5	White Oak	Pole	Med	20
6	White Oak	Pole	Low	15
9	White Oak	Sawlog	Low	5
10	Red Oak	Sapling	High	31
11	Red Oak	Sapling	Med	99
12	Red Oak	Sapling	Low	1
14	Red Oak	Pole	Med	31
15	Red Oak	Pole	Low	8
18	Red Oak	Sawlog	Low	5
19	Pine	Sapling	High	11
20	Pine	Sapling	Med	9
21	Pine	Sapling	Low	1
23	Pine	Pole	Med	3
24	Pine	Pole	Low	3
27	Pine	Sawlog	Low	1
28	Other Hardwood	Sapling	High	35
29	Other Hardwood	Sapling	Med	69
30	Other Hardwood	Sapling	Low	5
32	Other Hardwood	Pole	Med	8
33	Other Hardwood	Pole	Low	4
36	Other Hardwood	Sawlog	Low	2
37	Mixed	Sapling	High	21
38	Mixed	Sapling	Med	36
39	Mixed	Sapling	Low	1
41	Mixed	Pole	Med	7
42	Mixed	Pole	Low	5

**Table 6.** Transition pathway probabilities (in percent) for the White Oak category.

Management Treatment	Initial Class	Transition Class (percent)						
		1	2	3	5	6	9	Other
No Treatment	1	10.8	29.7	0.0	51.4	0.0	0.0	8.1
	2	0.0	8.5	1.1	78.7	4.3	0.0	7.4
	5	0.0	0.0	0.0	50.0	35.0	15.0	0.0
	6	0.0	0.0	0.0	0.0	33.3	46.7	20.0
Thinning from Below	1	0.0	13.5	0.0	10.8	5.4	40.5	29.7
	2	0.0	7.4	1.1	17.0	14.9	48.9	10.6
	5	0.0	0.0	0.0	0.0	10.0	65.0	25.0
	6	0.0	0.0	0.0	0.0	13.3	66.7	20.0
Diameter Limit Cut	1	8.1	45.9	0.0	21.6	0.0	0.0	24.3
	2	0.0	26.6	2.1	44.7	3.2	0.0	23.4
	5	0.0	0.0	5.0	20.0	30.0	0.0	45.0
	6	0.0	0.0	0.0	0.0	40.0	6.7	53.3



**Figure 5.** Transition pathway model for the White Oak Type category.

The No Treatment management options for Red Oak, Pine, and Other Hardwood (Tables 7-9) followed similar patterns as White Oak and further affirmed the assumptions made in the design of the transition pathways; the Sapling classes showed strong probabilities to increase in either Size, Density, or both, while showing low probabilities of changing Type. However, the Mixed category (Table 10) averaged more than a 30 percent probability of changing Type. This tendency was expected due to the characteristic of the Mixed category (no dominant species group) and is consistent with forest stand dynamics theory, as competition for resources allows tree species with a competitive edge to achieve dominance over time.

The Thinning From Below management option generally showed a stronger tendency for classes to change Type than the No Treatment option (Tables 6-10), with the exception of the Red Oak category. Thinning proscriptions were carried out in FVS with no regard to tree species; thus, the dominance of tree species groups (Type) was potentially shifted at year zero. Any shifts were then exaggerated over the 20 year simulation, resulting in a stronger tendency to change Type.

The Diameter Limit Cut management option generally showed an even stronger tendency for classes to change Type than the Thinning From Below option (Tables 6-10), with the exception of the Other Hardwood category. Harvesting the largest trees in a stand at year 0 has an even greater potential to shift tree species group dominance than thinning.

**Table 7.** Transition pathway probabilities (in percent) for the Red Oak category.

Management Treatment	Initial Class	Transition Class (percent)							
		10	11	12	14	15	17	18	Other
No Treatment									
	10	9.7	16.1	0.0	71.0	0.0	0.0	0.0	3.2
	11	0.0	1.0	0.0	89.9	5.1	0.0	0.0	4.0
	14	0.0	0.0	0.0	51.6	38.7	3.2	3.2	3.2
	15	0.0	0.0	0.0	0.0	50.0	0.0	37.5	12.5
Thinning from Below									
	10	0.0	6.5	0.0	3.2	19.4	0.0	71.0	0.0
	11	0.0	1.0	0.0	17.2	11.1	0.0	65.7	5.1
	14	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0
	15	0.0	0.0	0.0	0.0	50.0	0.0	50.0	0.0
Diameter Limit Cut									
	10	9.7	25.8	0.0	25.8	0.0	0.0	0.0	38.7
	11	0.0	6.1	2.0	47.5	2.0	0.0	0.0	42.4
	14	0.0	0.0	0.0	32.3	22.6	0.0	0.0	45.2
	15	0.0	0.0	0.0	0.0	25.0	0.0	12.5	62.5

**Table 8.** Transition pathway probabilities (in percent) for the Pine category.

Management Treatment	Initial Class	Transition Class (percent)					
		20	22	23	24	27	Other
No Treatment							
	19	9.1	9.1	81.8	0.0	0.0	0.0
	20	0.0	0.0	88.9	11.1	0.0	0.0
	23	0.0	0.0	66.7	0.0	33.3	0.0
	24	0.0	0.0	0.0	0.0	100.0	0.0
Thinning from Below							
	19	0.0	0.0	0.0	0.0	100.0	0.0
	20	0.0	0.0	0.0	22.2	66.7	11.1
	23	0.0	0.0	0.0	0.0	33.3	66.7
	24	0.0	0.0	0.0	0.0	100.0	0.0
Diameter Limit Cut							
	19	18.2	9.1	45.5	0.0	0.0	27.3
	20	0.0	0.0	44.4	0.0	0.0	55.6
	23	0.0	0.0	33.3	33.3	0.0	33.3
	24	0.0	0.0	0.0	0.0	66.7	33.3

**Table 9.** Transition pathway probabilities (in percent) for the Other Hardwoods category.

Management Treatment	Initial Class	Transition Class (percent)						
		28	29	30	32	33	36	Other
No Treatment								
	28	5.7	51.4	0.0	31.4	0.0	0.0	11.4
	29	0.0	15.9	1.4	63.8	4.3	0.0	14.5
	32	0.0	0.0	0.0	25.0	62.5	12.5	0.0
	33	0.0	0.0	0.0	0.0	25.0	75.0	0.0
Thinning from Below								
	28	2.9	17.1	0.0	11.4	20.0	14.3	34.3
	29	0.0	14.5	1.4	15.9	17.4	21.7	29.0
	32	0.0	0.0	0.0	0.0	12.5	62.5	25.0
	33	0.0	0.0	0.0	0.0	25.0	50.0	25.0
Diameter Limit Cut								
	28	2.9	82.9	0.0	8.6	0.0	0.0	5.7
	29	0.0	49.3	2.9	33.3	5.8	0.0	8.7
	32	0.0	0.0	0.0	12.5	87.5	0.0	0.0
	33	0.0	0.0	0.0	0.0	100.0	0.0	0.0

**Table 10.** Transition probabilities (in percent) for the Mixed category.

Management Treatment	Initial Class	Transition Class (percent)					Other
		37	38	41	42	45	
No Treatment	37	4.8	9.5	52.4	0.0	0.0	33.3
	38	0.0	2.8	52.8	2.8	0.0	41.7
	41	0.0	0.0	57.1	14.3	0.0	28.6
	42	0.0	0.0	0.0	40.0	20.0	40.0
Thinning from Below	37	0.0	0.0	9.5	19.0	19.0	52.4
	38	0.0	2.8	8.3	0.0	13.9	75.0
	41	0.0	0.0	0.0	0.0	14.3	85.7
	42	0.0	0.0	0.0	20.0	40.0	40.0
Diameter Limit Cut	37	0.0	9.5	14.3	0.0	0.0	76.2
	38	0.0	0.0	19.4	0.0	0.0	80.6
	41	0.0	0.0	0.0	0.0	0.0	100.0
	42	0.0	0.0	0.0	0.0	0.0	100.0

## Forest Resource Attributes

### Income Potential

The most influential variable for sawtimber was Size, with the Sawlog category receiving the highest ranking (Table 11). The highest value sawtimber species in Missouri are oaks and pines, and thus the Sawlog classes for White Oak, Red Oak, and Pine received the highest ranking of 9. However, the confidence for the ranking of 9 was assigned as Low due to the Type-Size-Density variables being unable to take into account the quality and grade of lumber from the stands. The classes for Other Hardwood and Mixed were ranked slightly lower than the White Oak, Red Oak, and Pine across all classes.

Since floral greens require a substantial amount of shade, the Density variable was deemed the most influential (Table 11). However, due to the relative nature of assigning rankings, Size and Type were also taken into account due to the larger the trees the more potential for shade and the tendency of oaks and pines to produce leaf litter adding to the acidity of the soil. The Pine classes received slightly lower rankings due to lower shade production. The confidence levels assigned to White Oak, Red Oak, and Pine classes were Low due to the effect of landscape position and aspect on moisture availability.

**Table 11.** Relative attribute values assigned to the Income Potential categories.

Class	Sawtimber		Floral Greens	
	Rank	Confidence	Rank	Confidence
1	1	High	6	Low
2	1	High	5	Low
5	4	Med	7	Low
6	4	Med	6	Low
9	9	Low	7	Low
10	1	High	6	Low
11	1	High	5	Low
14	4	Med	7	Low
15	4	Med	6	Low
18	9	Low	7	Low
19	1	High	5	Low
20	1	High	4	Low
23	4	Med	6	Low
24	4	Med	5	Low
27	9	Low	6	Low
28	1	High	4	Med
29	1	High	3	Med
32	3	Med	5	Med
33	3	Med	4	Med
36	8	Low	5	Med
37	1	High	4	Med
38	1	High	3	Med
41	3	Med	5	Med
42	3	Med	4	Med
45	7	Low	5	Med

## Wildlife Habitat

The most influential variable for both wild turkey and gray squirrel species was Size, as related to forage for wild turkey (fall and winter), and forage and nesting for gray squirrel (Table 12). Hard mast production and gray squirrel nesting were considered highest in the Sawlog classes, particularly for White Oak and Red Oak. High density was considered important for creating nesting and brood rearing habitat in summer for wild turkey in the form of visual obstruction, best provided by the Sapling classes. Due to seasonal variations in the habitat demands of wild turkey, the majority of confidence values were Low. The confidence values for the best gray squirrel habitats were High due to nesting and forage requirements being met by the same classes of forest.

## Risk

The most important factor in fire risk is drought, which cannot be captured by Type-Size-Density; thus, the confidence for all rankings was Low (Table 13). The most influential variable was Density, with Size as a contributing variable. Sapling classes and High density classes were assigned the highest rankings.

The most influential variable contributing to wind risk was Size, with Sawlogs being the most susceptible to windthrow (Table 13). Most classes received confidences of Low due to the importance of landscape position and soil depth on susceptibility.

The most influential variable contributing to insect/disease risk was determined to be Density combined with Size (Table 13). The competition for moisture and nutrients

**Table 12.** Relative attribute values assigned to the Wildlife Habitat categories.

Class	Wild Turkey		Gray Squirrel	
	Rank	Confidence	Rank	Confidence
1	4	Low	1	High
2	4	Low	1	High
5	2	Med	6	Med
6	3	Low	6	Med
9	8	Med	9	High
10	4	Low	1	High
11	4	Low	1	High
14	2	Med	6	Med
15	3	Low	6	Med
18	8	Med	9	High
19	6	Low	1	High
20	6	Low	1	High
23	3	Low	4	Med
24	3	Low	4	Med
27	8	Med	6	Med
28	4	Low	1	High
29	4	Low	1	High
32	2	Med	4	Low
33	3	Low	4	Low
36	7	Low	6	Low
37	4	Low	1	High
38	4	Low	1	High
41	2	Med	3	Low
42	3	Low	4	Low
45	6	Low	6	Low

**Table 13.** Relative attribute values assigned to the Risk categories.

Class	Fire		Wind		Insect/Disease	
	Rank	Confidence	Rank	Confidence	Rank	Confidence
1	5	Low	1	Med	1	High
2	5	Low	1	Low	1	High
5	4	Low	3	Med	4	Low
6	4	Low	4	Low	3	Med
9	3	Low	5	Low	4	Med
10	5	Low	1	Med	2	High
11	5	Low	1	Low	2	High
14	4	Low	3	Med	5	Low
15	4	Low	4	Low	4	Med
18	3	Low	5	Low	6	Low
19	5	Low	1	Med	1	High
20	5	Low	1	Low	1	High
23	4	Low	4	Med	4	High
24	4	Low	5	Low	3	High
27	3	Low	6	Low	5	Med
28	5	Low	1	Med	1	Med
29	5	Low	1	Low	1	Med
32	4	Low	3	Med	5	Low
33	4	Low	4	Low	4	Low
36	3	Low	5	Low	5	Low
37	5	Low	1	Med	1	High
38	5	Low	1	Low	1	High
41	4	Low	3	Med	3	Med
42	4	Low	4	Low	3	Med
45	3	Low	5	Low	4	Med

(Note: higher rankings indicate the class is at greater risk.)

among the trees in a forest was the main factor increasing susceptibility to insect/disease. The confidence levels assigned were Low to Medium due to the importance of landscape position, frost injury, and drought.

### Model Validation

The chi-square goodness of fit test was conducted 84 times and used 255 test plots. The White Oak and Red Oak classes were tested twice each with replacement. In total, 31 of the 84 tests (37 percent) were significantly different from the transition pathway model predictions (Tables 14-18). Each management option had 28 tests, with all three options showing less than a 40 percent significant difference. Of the 31 tests that showed a significant difference, 23 were significantly different due to one or more test plot transitions having a predicted transition probability of zero, while only 8 (10 percent of the total) were significantly different due to the chi-square value being greater than the critical value.

The sample sizes for the tests were not all equal to 10. However, removing the 12 tests containing less than 10 samples did not substantially change the statistics, with 39 percent being significantly different (compared to 37 percent). In addition, the initial sample counts (Table 5) used to build the transition pathway model did not all contain 10 or more samples. Removing the 27 tests run on Type-Size-Density classes containing less than 10 samples also produced no substantial change, with 33 percent being significantly different.

**Table 14.** Results of the predicted White Oak transition pathway model chi-square tests.

Management Treatment	Class <sup>a</sup>	n	$\chi^2$ Test 1	$\chi^2$ Test 2	Critical Value
No Treatment					
	1	10	2.721	0.061	7.815
	2	10	1.503	0.601	7.815
	5	10	*	*	5.991
	6	10	0.046	3.153	5.991
Thinning from Below					
	1	10	2.297	4.232	9.488
	2	10	1.276	3.440	11.07
	5	10	1.138	1.138	5.991
	6	10	0.450	2.796	5.991
Diameter Limit Cut					
	1	10	1.003	<b>8.207</b>	7.815
	2	10	0.950	1.994	9.488
	5	10	1.500	4.222	7.815
	6	10	*	2.019	5.991

<sup>a</sup> The Type-Size-Density classes are: 1-White Oak-Sapling-High, 2-White Oak-Sapling-Medium, 5-White Oak-Pole-Medium, 6-White Oak-Pole-Low.

\* - Indicates one or more observed test plots transitioned to a Class that was not predicted in the study area.

**Table 15.** Results of the predicted Red Oak transition pathway model chi-square tests.

Management Treatment	Class <sup>a</sup>	n	$\chi^2$ Test 1	$\chi^2$ Test 2	Critical Value
No Treatment					
	10	10	2.735	6.854	7.815
	11	10	5.111	<b>9.111</b>	7.815
	14	10	<b>25.769</b>	<b>10.833</b>	7.815
	15	10	1.411	2.674	5.991
Thinning from Below					
	10	10	*	*	7.815
	11	10	1.444	<b>10.333</b>	9.488
	14	10	*	*	0
	15	10	0.400	*	3.841
Diameter Limit Cut					
	10	10	0.291	1.984	7.815
	11	10	8.571	<b>15.446</b>	9.488
	14	10	*	0.295	5.991
	15	10	*	*	5.991

<sup>a</sup> The Type-Size-Density classes are: 10-Red Oak-Sapling-High, 11-Red Oak-Sapling-Medium, 14-Red Oak-Pole-Medium, 15-Red Oak-Pole-Low.

\* - Indicates one or more observed test plots transitioned to a Class that was not predicted in the study area.

**Table 16.** Results of the predicted Pine transition pathway model chi-square tests.

Management Treatment	Class <sup>a</sup>	n	$\chi^2$ Test	Critical Value
No Treatment				
	19	10	*	5.991
	20	10	*	3.841
	23	4	0.116	3.841
	24	1	0	0
Thinning from Below				
	19	10	*	0
	20	10	*	5.991
	23	4	<b>8.121</b>	3.841
	24	1	0	0
Diameter Limit Cut				
	19	10	*	9.488
	20	10	1.039	3.841
	23	4	0.501	5.991
	24	1	*	3.841

<sup>a</sup> The Type-Size-Density classes are: 19-Pine-Sapling-High, 20-Pine-Sapling-Medium, 23-Pine-Pole-Medium, 24-Pine-Pole-Low.

\* - Indicates one or more observed test plots transitioned to a Class that was not predicted in the study area.

**Table 17.** Results of the predicted Other Hardwood transition pathway model chi-square test.

Management Treatment	Class <sup>a</sup>	n	$\chi^2$ Test	Critical Value
No Treatment	28	10	3.264	7.815
	29	10	<b>9.531</b>	9.488
	32	10	*	5.991
	33	10	*	3.841
Thinning from Below	28	10	2.445	11.070
	29	10	5.023	11.070
	32	10	1.202	5.991
	33	10	3.400	5.991
Diameter Limit Cut	28	10	2.348	7.815
	29	10	3.559	11.070
	32	10	*	3.841
	33	10	*	0

<sup>a</sup> The Type-Size-Density classes are: 28-Other Hardwood-Sapling-High, 29-Other Hardwood-Sapling-Medium, 32-Other Hardwood-Pole-Medium, 33-Other Hardwood-Pole-Low.

\* - Indicates one or more observed test plots transitioned to a Class that was not predicted in the study area.

**Table 18.** Results of the predicted Mixed transition pathway model chi-square test.

Management Treatment	Class <sup>a</sup>	n	$\chi^2$ Test	Critical Value
No Treatment	37	10	0.656	7.815
	38	10	4.462	7.815
	41	7	4.932	5.991
	42	3	4.500	5.991
Thinning from Below	37	10	4.160	7.815
	38	10	*	7.815
	41	7	1.234	3.841
	42	3	0.333	5.991
Diameter Limit Cut	37	10	1.278	5.991
	38	10	0.006	3.841
	41	7	*	0
	42	3	0	0

<sup>a</sup> The Type-Size-Density classes are: 37-Mixed-Sapling-High, 38-Mixed-Sapling-Medium, 41-Mixed-Pole-Medium, 42-Mixed-Pole-Low.

\* - Indicates one or more observed test plots transitioned to a Class that was not predicted in the study area.

Finally, analyzing the chi-square tests by Type shows that Pine and Red Oak transition pathways were the weakest with 58 percent and 54 percent significantly different, respectively. The White Oak and Mixed transition pathways were the best with both having only 17 percent significantly different.

### Decision Tool

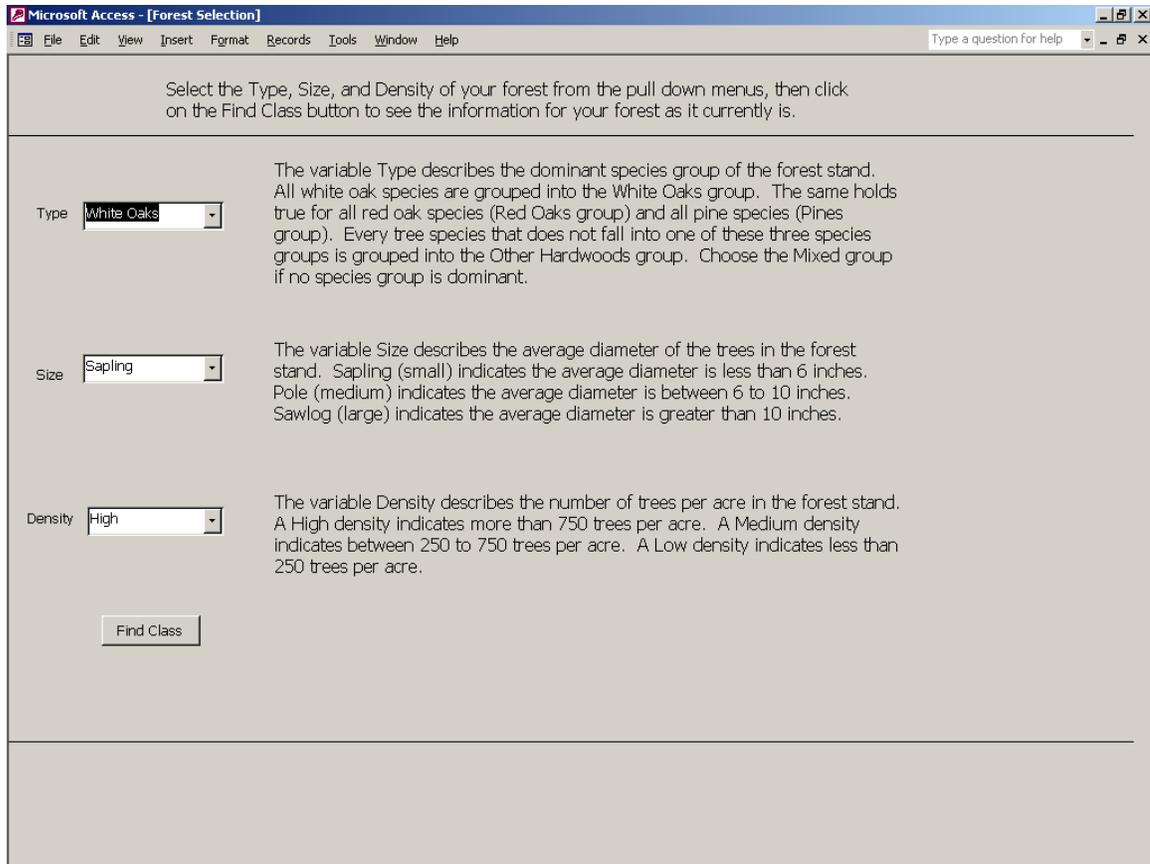
The database structure was built using the class numbers defined in Table 3 to link together the transition probability, forest resource attribute, and representative photograph tables. One form was designed for each block in the flowchart shown in Figure 3. Command buttons and macros provided for maneuvering through the forms, while queries were used to load the appropriate data into the forms depending upon the user's selections. For example, a landowner might do the following:

- select Start on the introductory form (Figure 6);
- the user is prompted to select the appropriate Type-Size-Density (Figure 7);
- if the user selects White Oak-Sapling-High, the next form appears showing a representative photograph, the three management options, and an opportunity to view attributes for that forest class (Figure 8);
- selecting the No Treatment management option causes the next form to appear showing the representative photographs and probabilities for the class staying the same and the two most likely transition classes (Figure 9);

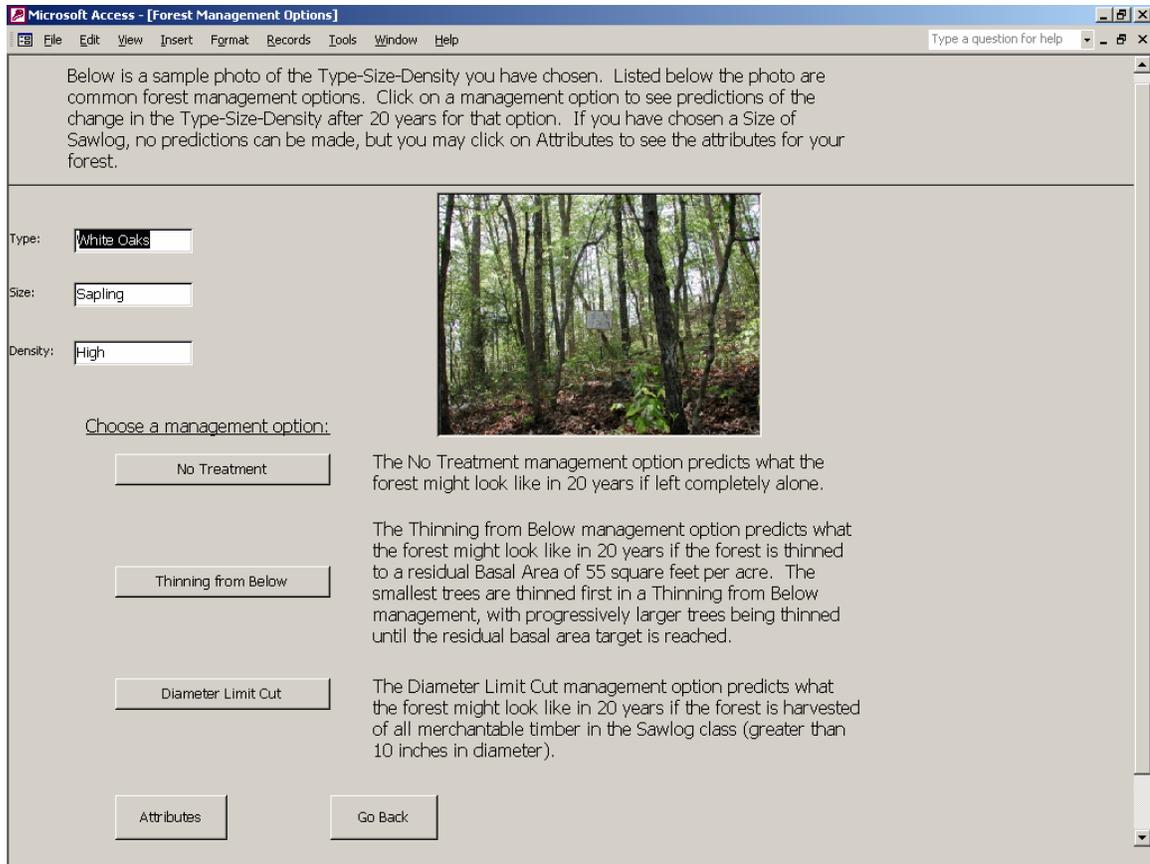
- clicking on the Attributes command button for any of the three classes in Figure 9, or the Attribute command button in Figure 8, takes the user to the attribute switchboard (Figure 10); and
- if the user clicks on the Attributes command button for White Oak-Sapling-High from either Figure 8 or 9, then selecting the Risk attributes in Figure 10 shows the fire, wind, and insect/disease risks for White Oak-Sapling-High (Figure 11).



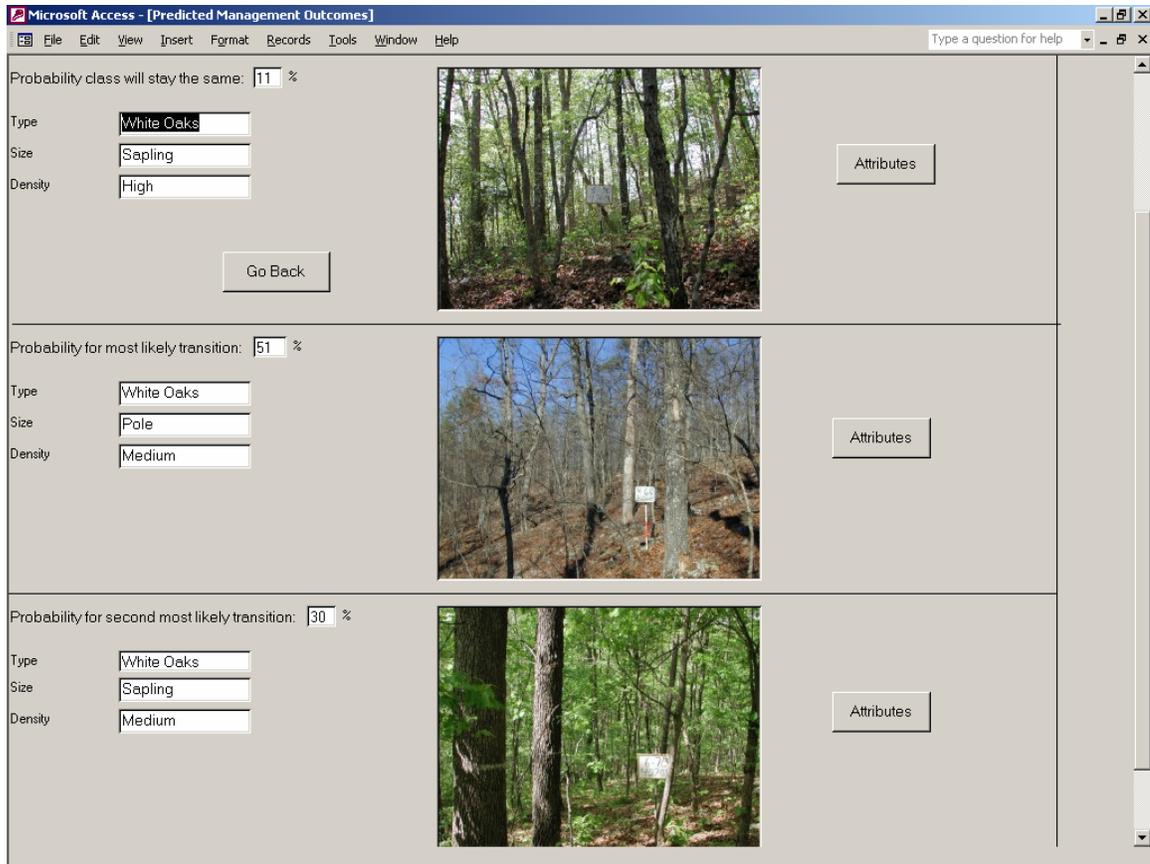
**Figure 6.** Screenshot of the introductory page of the decision support tool.



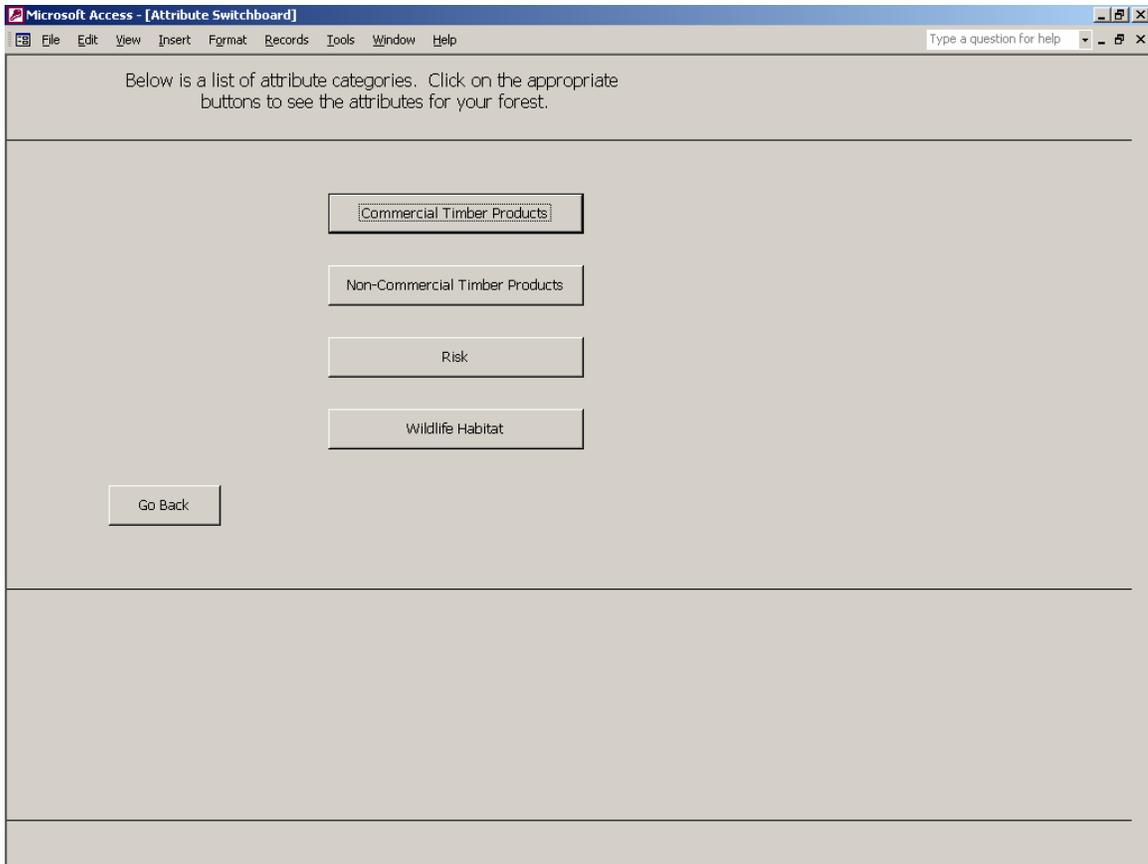
**Figure 7.** Screenshot of the page prompting the user to select the appropriate Type-Size-Density.



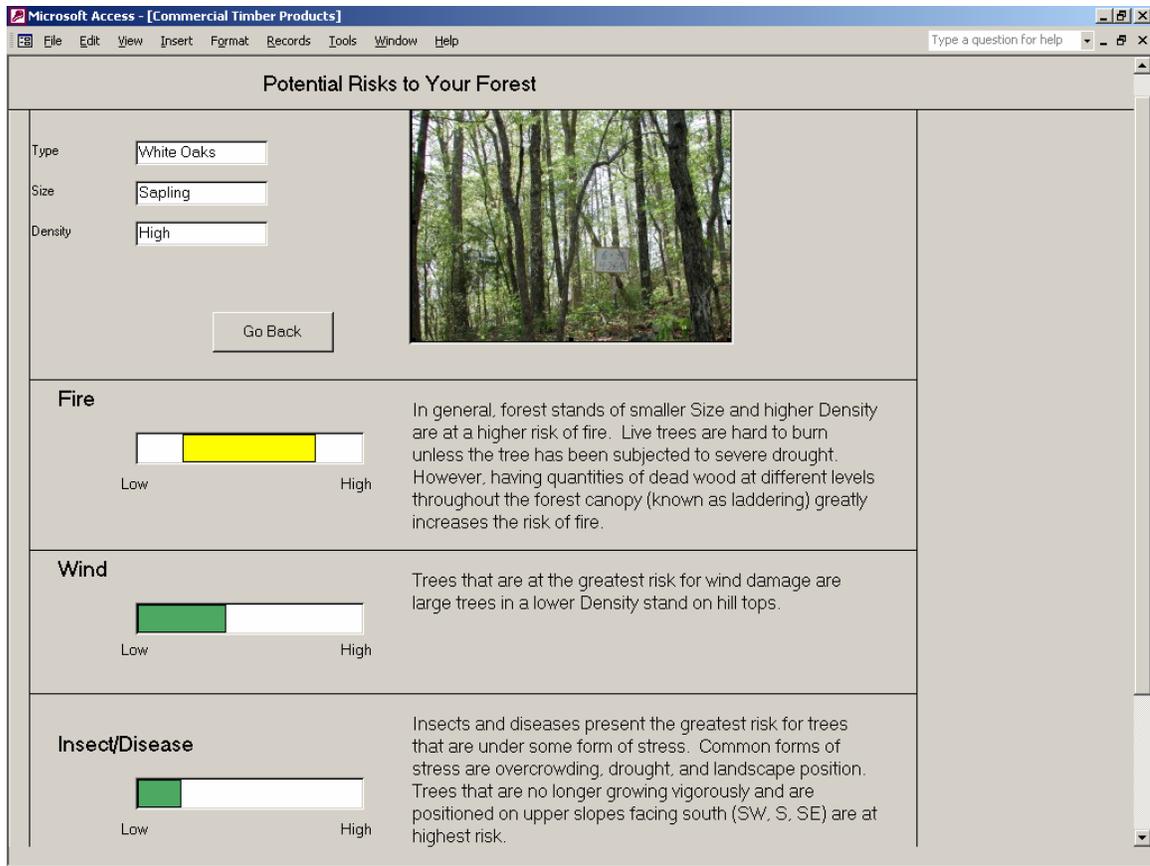
**Figure 8.** Screenshot of the page giving the user the option to select one of the three management options or to select the attributes for White Oak-Sapling-High.



**Figure 9.** Screenshot of the no treatment management option results for White Oak-Sapling-High.



**Figure 10.** Screenshot of the attribute switchboard giving the user the option to choose among the different attribute categories.



**Figure 11.** Screenshot of the risk attribute for White Oak-Sapling-High. The width of the bar indicates the degree of confidence, with High confidence being the narrowest bar.

## CONCLUSION

The decision support tool is based on the idea of producing a simple forest growth model capable of predicting forest change while providing descriptive forest resource attributes to assist forest landowners in developing management goals. The additional goal, to maintain compatibility between the developed simple forest growth model and existing models, was a major design consideration. A transition pathway model utilizing the three traditional variables, Type, Size, and Density, was designed and tested for compatibility against the FVS model on which it was based.

The management treatments used (No Treatment, Thinning From Below, and Diameter Limit Cut) all produced differing transition pathways (Tables 6-10) showing that the model design was capable of capturing select effects of forest management. The No Treatment scenario shows that as trees grow larger in size, stand density goes down, and the dominant tree species group (Type), once established, is unlikely to change in 20 years. The Thinning From Below scenario demonstrated that trees grow larger more rapidly when competition for resources is eased. The Diameter Limit Cut scenario demonstrated that the forest stand will continue to grow and transition after management actions have been taken. However, the Diameter Limit Cut scenario also demonstrated that removing the largest trees in a forest stand does not guarantee those trees will be replaced by similar species.

The transition pathway model tested reasonably compatible with the FVS model. Over 60 percent of all chi-square tests conducted showed no significant difference from the model predictions at a 95 percent confidence level (Tables 14-18). Of the 31 tests

showing a significant difference, 23 were due to one or more test plots transitioning to a Type-Size-Density class that was not predicted by the transition pathway model (prediction = 0.0%). However, no model can predict all transitions for every possible forest combination.

The forest resource attributes captured the general aspects of forest potential. The simple model design limited the amount of information that could be shown using attributes. However, when taken with the descriptive explanations in the decision tool, landowners have access to knowledge of forest potential that is capable of aiding in the development of management goals.

The decision support tool software, as currently developed, will provide landowners with the means to predict forest change, analyze forest resource potential, and aid in the development of management goals. Overall, the decision support tool is designed largely as an education and information tool. Future developments will seek to produce an internet based version, apply the methodology to data sets from different geographical regions, and distribute the software to federal and state agencies for use with landowner consultations.

## LITERATURE CITED

- Barnes, B. V., D. R. Zak, S. R. Denton, and S. H. Spurr. 1998. Forest Ecology, 4th edition. John Wiley & Sons, Inc., New York. 774 p.
- Crookston, N. L. 1997. Suppose: an interface to the Forest Vegetation Simulator. pp. 7-14. *in* R. Teck, M. Moeur, and J. Adams, compilers. Proceedings: Forest Vegetation Simulator conference, 1997 February 3-7, Fort Collins, CO.
- Dixon, G. E. 2003. Essential FVS: a user's guide to the Forest Vegetation Simulator. Internal Rep. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Forest Management Service Center. 193 p.
- Hansen, M. H., T. Frieswyk, J. F. Glover, and J. F. Kelly. 1992. The Eastwide forest inventory database: user's manual. Gen. Tech. Rep. NC-151. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 48 p.
- Husch, B., C. I. Miller, and T. W. Beers. 1993. Forest mensuration, 3rd edition. Krieger Publishing Company, Malabar, FL. 402 p.
- Kluthe, J., L. D. Godsey, and H. E. Garrett. 2004. Forest farming: ferns as a companion crop. 5 p. *in* Proceedings of the 8th North American Agroforestry Conference, June 2003, Corvallis, OR.
- Larson, M. A., W. D. Dijak, F. R. Thompson, and J. J. Millsaugh. 2003. Landscape-level habitat suitability models for twelve wildlife species in southern missouri. Gen. Tech. Rep. NC-233. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station. 51 p.
- Marquis, D. A., and R. L. Ernst. 1992. User's guide to SILVAH: stand analysis, prescription, and management simulator program for hardwood stands of the Alleghenies. Gen. Tech. Rep. NE-162. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 124 p.
- McCarter, J. B., J. S. Wilson, P. J. Baker, J. L. Moffett, and C. D. Oliver. 1998. Landscape management through integration of existing tools and emerging technologies. *Journal of Forestry*. 96(6) 17-23.
- Miles, P. D., G. J. Brand, C. L. Alerich, L. F. Bednar, S. W. Woudenberg, J. F. Glover, and E. N. Ezzell. 2001. The Forest Inventory and Analysis database: database description and user's manual version 1, revision 8.  
[http://www.ncrs2.fs.fed.us/4801/FIADB/fiadb\\_documentation/FIADB\\_DOCUMENTATION.htm](http://www.ncrs2.fs.fed.us/4801/FIADB/fiadb_documentation/FIADB_DOCUMENTATION.htm).

- Mladenoff, D. J., and W. L. Baker. 1999. Development of forest and landscape modeling approaches. pp. 1-13. *in* D. J. Mladenoff and W. L. Baker, editors. *Advances in spatial modeling of forest landscape change: approaches and applications*. Cambridge University Press, Cambridge, UK.
- Nyland, R. D. 1992. Exploitation and greed in eastern hardwood forests. *Journal of Forestry*. 90 33-37.
- Oliver, C. D., and B. C. Larson. 1996. *Forest Stand Dynamics*, Update edition. John Wiley & Sons, Inc., New York. 520 p.
- Parker, G. R. 1993. Limitations on ecosystem management in the Central Hardwood Region. pp. 202-216. *in* G. H. Aplet, N. Johnson, J. T. Olson, and V. A. Sample, editors. *Defining Sustainable Forestry*. Island Press, Washington, D.C.
- Seaber, P. R., F. P. Kapinos, and G. L. Knapp. 1987. Hydrologic unit maps. Washington, D.C.: U.S. Geological Survey Water-Supply Paper 2294. 63 p.
- Stage, A. R. 1973. Prognosis model for stand development. Res. Paper INT-137. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 20 p.
- Twery, M. J. 2000. NED: a set of tools for managing nonindustrial private forests in the east. <http://www.fs.fed.us/ne/burlington/ned/pub1.htm>.
- Twery, M. J., H. M. Rauscher, D. J. Bennett, S. A. Thomasma, S. L. Stout, J. F. Palmer, R. E. Hoffman, D. S. DeCalesta, E. Gustafson, H. Cleveland, J. M. Grove, D. Nute, G. Kim, and R. P. Kollasch. 2000. NED-1: integrated analyses for forest stewardship decisions. *Computers and Electronics in Agriculture*. 27(1-3) 167-193.
- Wang, J., W. D. Potter, D. Nute, F. Maier, H. M. Rauscher, M. J. Twery, S. Thomasma, and P. Knopp. 2002. An intelligent information system for forest management: NED/FVS integration. *in* N. L. Crookston and R. N. Havis, compilers. *Second Forest Vegetation Simulator Conference, 2002 February 12-14, Fort Collins, CO*.
- Wargo, P. M., D. R. Houston, and L. A. LaMadeleine. 1983. Oak Decline. *Forest Insect & Disease Leaflet 165*. U.S. Department of Agriculture, Forest Service. p.
- Woudenberg, S. W., and T. O. Farrenkopf. 1995. *The Westwide forest inventory database: user's manual*. Gen. Tech. Rep. INT-GTR-317. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 67 p.

Wykoff, W. R., N. L. Crookston, and A. R. Stage. 1982. User's guide to the Stand Prognosis Model. Gen. Tech. Rep. INT-133. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 112 p.

Zar, J. H. 1999. Biostatistical analysis, 4th edition. Prentice-Hall, Inc., Upper Sadler River, NJ. 931 p.

## APPENDIX A

Standard values and FIA variables used in FVS simulation files:

Location File

Stand List File

Tree List File

Location File			
Field	Name	Example	FIA Variable Name
1	Record Type	A	
2	Location Name	cnty17 plot1	COUNTYCD, PLOT
3	SLF Access Method	Suppose	
4	SLF File Name	(file path)	
5	Mapfile Type	@	
6	Mapfile Name	@	

Stand List File			
Field	Name (Record Type A)	Example	FIA Variable Name
1	Record Type	A	
2	Stand Identification Code	17001	COUNTYCD + PLOT
3	FVS Tree Data File	(file name)	
4	Sample Point Sight Data	NoPointData	
5	Variant	cs	
Field	Name (Record Type B)	Example	FIA Variable Name
1	Record Type	B	
2	Stand Identification Code	17001	COUNTYCD + PLOT
3	Inventory Year	1990	
4	Latitude	@	
5	Longitude	@	
6	Location Code	@	
7	Habitat Type	@	
8	Stand Origin Year	@	
9	Aspect	305	ASPECT
10	Slope	1	SLOPE
11	Elevation	@	
12	Basal Area Factor	37.5	
13	Inverse of Fixed Plot Size	999.5	
14	Breakpoint DBH	5	
15	Number of Plots	10	
16	Number of Nonstockable Plots	@	
17	Stand Sampling Weight	@	
18	Stockable Percent	@	
19	Diameter Growth Translation Code	@	
20	Diameter Growth Measurement Period	@	
21	Height Growth Translation Code	@	
22	Height growth Measurement Period	@	
23	Mortality Measurement Period	@	
24	Maximum Basal Area	140	
25	Maximum Stand Density Index	230	
26	Site Species	50	
27	Site Index	77	SICOND
28	Model Type Code	@	
29	Physiographic Region Code	@	
30	Forest Type Code	@	

Tree Data (per tree) in Tree List File		
Field Name	Example	FIA Variable Name
Plot ID	1	SUBP
Tree ID	11	SUBP + TREE
Tree Count	1 (all)	
Tree History	1 (all)	
Species	BO	SPCD
DBH	10.1	DIA
DBH Growth	0	
Height	0	
Height to Topkill	0	
Height Growth	0	
Crown Ratio	5	CR
Damage Code 1	0	
Severity 1	0	
Damage Code 2	0	
Severity 2	0	
Damage Code 3	0	
Severity 3	0	
Tree Value Class	1 (all)	
Prescription Code	0	
Plot Slope	0	
Plot Aspect	0	
Plot Habitat	0	
Plot Topo Code	0	
Plot Site Prep	0	

## APPENDIX B

Individual tree species making up each  
Type category

Type Category	Individual Species	
	Common Name	Scientific Name
White Oak	Bur oak	<i>Quercus macrocarpa</i>
	Chestnut oak	<i>Quercus prinus</i>
	Chinkapin oak	<i>Quercus muehlenbergii</i>
	Delta post oak	<i>Quercus stellata</i> var. <i>mississippiensis</i>
	Overcup oak	<i>Quercus lyrata</i>
	Post oak	<i>Quercus stellata</i>
	Swamp chestnut oak	<i>Quercus michauxii</i>
	Swamp white oak	<i>Quercus bicolor</i>
	White oak	<i>Quercus alba</i>
	Red Oak	Black oak
Blackjack oak		<i>Quercus marilandica</i>
Cherrybark oak		<i>Quercus pagodifolia</i>
Northern red oak		<i>Quercus rubra</i>
Nuttall oak		<i>Quercus texana</i>
Pin oak		<i>Quercus palustris</i>
Scarlet oak		<i>Quercus coccinea</i>
Shingle oak		<i>Quercus imbricaria</i>
Shumard oak		<i>Quercus shumardii</i>
Southern red oak		<i>Quercus falcata</i>
Water oak		<i>Quercus nigra</i>
Willow oak		<i>Quercus phellos</i>
Pine	Eastern white pine	<i>Pinus strobos</i>
	Loblolly pine	<i>Pinus taeda</i>
	Shortleaf pine	<i>Pinus echinata</i>
	Virginia pine	<i>Pinus virginiana</i>
Other Hardwood	all other species	

## APPENDIX C

Summary of steps to produce a new  
decision support tool

- Create transition pathways
  1. Format forest inventory data for FVS simulations (Appendix A)
  2. Run management option simulations in FVS
  3. Perform calculations on FVS output to determine Type-Size-Density classes (Table 2)
  4. Calculate transition pathway probabilities for each management option (Tables 6 – 10)
  
- Create transition pathway database
  1. Enter all possible Type-Size-Density classes into a table, with the Class number defined as the primary key (Table 3)
  2. Create transition pathway probability tables for each management option using the defined Class numbers (Table 3) for a primary key with the following fields: Initial Class, Probability Initial Class Stays the Same, Most Likely Transition Class, Most Likely Transition Probability, Second Likely Transition Class, Second Likely Transition Probability
  3. Create table of representative photographs for each Type-Size-Density class using the defined Class numbers as a primary key
  4. Create a table for each forest resource attribute using the defined Class numbers as a primary key
  5. Create a table of scale bars graphically representing all possible combinations of the forest resource attribute rankings and confidences

- Create user interface forms for the transition pathway database (Figure 3)
  1. Introductory Form (Figure 6): introductory remarks and a Start command button to open the Type-Size-Density Selection Form
  2. Type-Size-Density Selection Form (Figure 7): three drop-down menus allowing the user to select the appropriate Type, Size, and Density for their forest stand; descriptive paragraphs providing the category definitions for Type-Size-Density; a Find Class command button to open the Management Option Form and query for the Class number associated with the chosen Type-Size-Density
  3. Management Option Form (Figure 8): Type-Size-Density text boxes and a representative photograph, initialized upon opening the form using the Class number returned by the Find Class query; Management Option command buttons for each management option to open the Transition Pathway Prediction Form and query for the transition pathway information, including transition classes, transition probabilities, and representative photographs; descriptive paragraphs for each management option; an Attributes command button to open the Attribute Switchboard Form
  4. Transition Pathway Prediction Form (Figure 9): Type-Size-Density text boxes and representative photographs for the initial class, the most likely transition class, and the second most likely transition class; the

- probabilities associated with each class; an Attributes command button for each Type-Size-Density to open the Attribute Switchboard Form
5. Attribute Switchboard Form (Figure 10): command buttons for each category of attributes to open the respective Forest Resource Attributes Form and query for the Class number associated with the chosen Type-Size-Density used to open the Attribute Switchboard Form
  6. Forest Resource Attributes Form (Figure 11): Type-Size-Density text boxes and a representative photograph; forest resource attributes with descriptive paragraphs and scale bars graphically representing the attribute ranks and confidences for the chosen Type-Size-Density