

To the Graduate Council:

I am submitting herewith a dissertation written by Thomas A. Waldrop entitled "The Development of FORCAT: A Spatial Gap Model of Stand Dynamics for Forests of the Catoosa Wildlife Management Area." 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.

Edward R. Buckner
Edward R. Buckner, Major Professor

We have read this dissertation
and recommend its acceptance:

Boyd L. Seerde

H. H. Stutzant

Charles E. McGee

Robert A. McLean

Accepted for the Council:

C. W. Minkel
The Graduate School

THE DEVELOPMENT OF FORCAT: A SPATIAL GAP MODEL OF STAND DYNAMICS
FOR FORESTS OF THE CATOOSA WILDLIFE MANAGEMENT AREA

A Dissertation
Presented for the
Doctor of Philosophy
Degree
The University of Tennessee, Knoxville

Thomas A. Waldrop

December 1983

ACKNOWLEDGEMENTS

Even though only one name may appear on the title page, this dissertation represents the culmination of the efforts of many individuals. The author would like to acknowledge these people and express his gratitude.

Dr. Edward R. Buckner not only fulfilled the routine duties of major advisor to the author but also extended his friendship. He treated the author as a professional by allowing him to choose research methods and approaches on his own, with advice when requested. He also provided a challenge by asking difficult and often unanswerable questions. This was in an effort to teach the author to think, which may be the most important lesson in the career of a graduate student.

Special thanks are also given to other members of my committee, Drs. H. H. Shugart, C. E. McGee, B. L. Dearden, and R. A. Mclean who provided helpful suggestions and guidance as well as the critical reading of this document. Collection of field data was made considerably less difficult with the assistance of Amy Rowland McDonald and Vicki Jacobsen Woolley. Assistance with other field work was provided by P. Durr, E. Groton, R. Holtzclaw, P. Moditz, R. Little, A. Stone, G. Tanner, B. Trammel, and M. York. M. L. Tharp provided answers to computing problems when none appeared to be possible. Other assistance with computing was provided by Bruce Delaney, Alice Beauchene, and Melinda Pollard. Grateful appreciation is expressed to J. A. Muncy who provided suggestions for field work

based on experience, manpower for prescribed burns, and willing cooperation at every request.

This research was made possible by a grant from the USDA Forest Service Silviculture Laboratory at Sewanee, Tennessee. The Silviculture Laboratory also provided data for the validation of the model described here and manpower for conducting prescribed burns. The Tennessee Wildlife Resources Agency (TWRA) provided the land for study areas and equipment and manpower for conducting prescribed burns. Steve Patrick and Ken Arney, both of TWRA, provided information and guidance necessary to conduct field experiments. Steve Patrick also contributed many hours of labor to prepare for and conduct prescribed burns.

Most of all, I would like to express my love and appreciation to my wife, Gensie. She has provided support and understanding throughout my career as a graduate student which has been the majority of her married life. Without her, this dissertation would have been meaningless.

ABSTRACT

Low quality hardwood stands on the Catoosa Wildlife Management Area (CWMA) of the Cumberland Plateau of East Tennessee are often clearcut and burned 3 to 4 years later to maintain suitable habitat for several wildlife species. The long-term influences of these practices on stand structure and stand dynamics are poorly understood. The primary objective of this project was to develop a computer model that would predict from certain basic information the quantity and quality of vegetation that would occur on stands created by these management practices and enable the development of appropriate management strategies.

This project was the third phase in the development of a spatial gap model, FORCAT (FORests of the CAToosa), to simulate dynamics of stands on the CWMA. Phase I (Brandt et al., 1981) dealt with initial model selection and development. FORCAT was developed through revisions to the widely used FORET model (Shugart and West, 1977). Phase II (Muncy, 1980) included field studies on the effects of clearcutting of hardwood stands on the CWMA on the composition and structure of regeneration.

In the current study, Phase III, monitoring of the development of clearcuts was continued and the effects of browsing and prescribed burning on regeneration were studied. The data from this study and from Phase II were combined and used for model calibration and estimation of parameters. Major modifications to the initial version of FORCAT included the refinement of input parameters, beginning the

simulation with a mature stand rather than bare ground, refinements to the simulation of sprouting and to the calculation of growth rates, and the addition of three new subroutines, TEMPE, MOIST, and SEEDPR. TEMPE calculated the number of growing degree-days each year, MOIST introduced growth limitations due to droughty conditions, and SEEDPR limited seed availability. Modifications were also made to allow periodic clearcutting and prescribed burning.

Validation of FORCAT indicated model applicability for long-term projections of species composition, tree number, and basal area. Simulation of regeneration failed, however, as stems counts were under-estimated when seed for pioneer species was abundant. Even though further refinements are necessary, the current version was considered acceptable for use in making forest management decisions for some sites of the CWMA. Recommendations for further research included studies of seed availability, species- and site-specific growth rates, continued monitoring of stand dynamics in clearcuts, and further validation by application to other CWMA sites.

TABLE OF CONTENTS

CHAPTER	PAGE
I. INTRODUCTION	1
II. LITERATURE REVIEW	4
Nonspatial Forest Models	5
Nonspatial Tree Models	10
Spatial Tree Models	14
Gap Models	17
III. FIELD STUDIES	28
Study Area	28
Methods and Materials	34
Results and Discussion	39
Conclusions	57
IV. DESCRIPTION OF THE INITIAL MODEL	59
Subroutine INPUT	61
Subroutine PLOTIN	61
Subroutine GROW	65
Subroutine KILL	69
Subroutine BIRTH	70
Subroutine SPROUT	71
Other Subroutines and Functions	72
Model Output	72
V. THE SECOND VERSION OF FORCAT	75
Development of the Second Version of FORCAT	75
Model Output	86
Conclusions	93
VI. THE THIRD VERSION OF FORCAT	94
Development of the Third Version of FORCAT	94
Results and Discussion	107
Summary and Conclusions	116
VII. VALIDATION OF FORCAT	117
Description of the Validation Data	118
Changes in FORCAT to Simulate a New Land Type	120
Results and Discussion	123
Summary and Conclusions	132
VIII. CONCLUSIONS	135
Field Studies	135
Modeling of Forest Stands on the CWMA	136
Recommendations for the Application of FORCAT	137
Recommendations for Future Study	138

	PAGE
LITERATURE CITED	141
APPENDICES	155
APPENDIX A. PREHARVEST AND POST-HARVEST STAND CHARACTERISTICS	156
APPENDIX B. SCIENTIFIC NAMES	167
APPENDIX C. CORRESPONDENCE FOR THE DROUGHT TOLERANCE SURVEY	171
APPENDIX D. LISTING OF THE FORCAT MODEL	176
APPENDIX E. INSTRUCTIONS FOR THE EXECUTION OF THE FORCAT MODEL	203
VITA	207

LIST OF TABLES

TABLE	PAGE
1. Regeneration Three Years After Clearcutting (Both Cutting Treatments Combined)	42
2. Status of Residual Stems Three Years After Diameter Limit Clearcutting	45
3. Species Composition of Control Plots After Three Growing Seasons	46
4. Survival of Stumps in Burned Clearcuts Before and After Prescribed Fire (Both Cutting Treatments Combined)	49
5. Regeneration Four Years After Cutting (Both Treatments Combined) and One Year After Burning	51
6. Status of Residual Stems Four Years After Diameter Limit Clearcutting and One Year After Burning	54
7. Species Composition of Burned and Unburned Control Plots After Four Growing Seasons (One Growing Season After Burning)	56
8. Tree Species Included in the Initial Version of FORCAT . .	60
9. Summary of the Subroutines and Functions in the Initial Version of FORCAT	63
10. Input Parameters for the Initial Version of FORCAT	64
11. Comparison of Control Plot Data to Output from the Initial Version of FORCAT	73
12. Species Parameters Used in the Second Version of FORCAT	78
13. Comparison of the Average Observed Field Plot to the Average Plot Simulated by the Second Version of FORCAT . .	87
14. Revised Species Parameter Values Used in the Third Version of FORCAT	97
15. Results of Seedling Drought Tolerance Survey	101
16. Values for the Growth Constant G Used in the Third Version of FORCAT for Each Species and Land Type	109
17. Comparison of the Average Observed Field Plot to the Average Plot Simulated by the Third Version of FORCAT . .	112

TABLE	PAGE
18. Trees Harvested in a 68-Acre Clearcut Near Sewanee, Tennessee	119
19. Regeneration One Year After Clearcutting of a Hardwood Stand Near Sewanee, Tennessee	121
20. Regeneration One Year After Clearcutting for Simulated and Observed Plots	126
21. Species Composition for the Average Plot Predicted by FORCAT and the Average Preharvest Stand for the Sewanee Study Area	130
22. Analysis of Variance of Third Year Regeneration Characteristics in Clearcuts	157
23. T Test Results Between Complete and Diameter Limit Clearcut Treatments for Third Year Data	158
24. Status of all Trees Tallied in the Preharvest Inventory Three Years After Cutting (Both Cutting Treatments Combined)	159
25. Number of Sprouts and Height of Dominant Sprout on Cut Stems After Three Growing Seasons (Both Cutting Treatments Combined)	161
26. Mean Number of Sprouts per Cut Stem by Sprout Type After Three Growing Seasons (Both Cutting Treatments Combined) .	162
27. Analysis of Variance of Fourth Year Regeneration Characteristics in Clearcuts Using Only Burned Plot Data .	163
28. Status of all Cut Trees Tallied in the Preharvest Inventory after Four Years (One Year After Burning) for Both Cutting Treatments Combined	164
29. Number of Sprouts and Height of Dominant Sprout on Cut Stems (Both Cutting Treatments Combined) After Four Growing Seasons (One Year After Burning)	165
30. Number of Sprouts per Cut Stem (Both Cutting Treatments Combined) by Sprout Type Four Years After Cutting (One Year After Burning)	166
31. Common and Scientific Names of Tree Species	168
32. Common and Scientific Names of Birds and Mammals	170

LIST OF FIGURES

FIGURE	PAGE
1. Location of Catoosa Wildlife Management Area in Tennessee	29
2. Location of Study Area within the Catoosa Wildlife Management Area	30
3. Road Map to Study Areas	32
4. Map of Study Areas Showing Study Design	35
5. Location of Burned Plots	48
6. Flow Diagram of the Initial Version of FORCAT	62
7. The Evolution of the FORCAT Model	76
8. Species Composition for the Average of 100 Plots as Simulated by the Second Version of FORCAT	89
9. Flow Diagram for the Third Version of FORCAT	95
10. Species Composition for the Average of 100 Plots as Simulated by the Third Version of FORCAT	114
11. Species Composition for Land Type 16 as Simulated by the FORCAT Model	129

CHAPTER I

INTRODUCTION

Conflicting demands for resource use often result in multiple use management. A case in point was the desire to manage the forest stands of the Catoosa Wildlife Management Area (CWMA) on the Cumberland Plateau of East Tennessee primarily for high quality wildlife habitat and secondarily for timber production. The degree to which this goal can be accomplished will depend not only upon inherent species-site relationships in the area but also on the forest manager's understanding of how the use of available silvicultural tools will affect the species-site situations being managed and long term stand and wildlife population development.

The CWMA is a state-owned tract of land containing over 50,000 acres, it is managed by the Tennessee Wildlife Resources Agency (TWRA). TWRA has dealt with several problems in the implementation of timber management on the CWMA. This area is generally stocked with low quality hardwoods as a result of high-grading over the past 150 years (McGee, 1982). Repeated wildfires have contributed to maintaining this low quality. Site quality on the CWMA is adequate to produce merchantable timber with proper management.

Clearcutting and prescribed burning are techniques used on the CWMA to regenerate the forest and to maintain browse for white-tailed deer and suitable habitat for other wildlife species. Regrowth following clearcutting generally provides abundant deer browse for 3 to 4 years, after which stem terminals grow beyond the reach of deer.

At this time, prescribed fires have been used on some clearcuts to again regenerate a coppice stand, thus prolonging the period in which browse is available. Even though these burns may be repeated several times, the stand is eventually allowed to mature.

The short-term benefits of clearcutting hardwoods followed by prescribed burning are generally evident. However, the long term influence of these practices on stand structure and forest dynamics is poorly understood. The development of accurate simulation models would provide the information needed to evaluate the potential of the stands created and enable the development of appropriate management strategies. Such models are flexible in that new knowledge gained from field studies can be incorporated and then aid in assessing the impact of different silvicultural treatments on stand development.

This project was the third phase in the development of a forest stand model, FORCAT (FOREsts of the CAToosa), to simulate the stand dynamics of forests on the CWMA. Phase I (Brandt et al., 1981) dealt with the selection of an appropriate type of model and its initial development. FORCAT is a spatial gap model which was developed through modifications to the widely used FORET model (Shugart and West, 1977) which has general application for Appalachian deciduous forests.

Phase II (Muncy, 1980; Muncy and Buckner, 1981) was a field study designed to provide data for the verification of FORCAT. This study investigated the effects of complete and diameter limit clearcutting on the composition and structure of regeneration. Permanent sample

plots were established to provide data for continued refinement of FORCAT.

This study, Phase III, is a continuation of the studies established in Phase I and Phase II. The objectives of this study were:

1. to continue monitoring the effects of diameter limit and complete clearcutting on stand composition and structure;
2. to evaluate the effects of prescribed burning and browsing on regeneration and stand development of hardwoods;
3. to use the above information to refine and then verify FORCAT as an aid in making forest management decisions.

CHAPTER II

LITERATURE REVIEW

Modeling of forest stand dynamics has become common place, particularly with recent increases in computer capability and availability. Trimble and Shriner (1981) listed nearly 100 models available to the forest manager for a variety of forest types and management objectives. The forest stand models that are available today range from simple yield tables constructed over 50 years ago to complex computer simulators. Each of these has a common objective: to produce summary tables which indicate the state of a forest stand at some point or points in simulated time (Munro, 1974). Such statistics as volume, basal area, and number of stems per unit area are common forms of output.

A classification scheme for forest stand models based on three different modeling approaches was suggested by Munro (1974). These approaches were distinguished by whether individual trees or entire stands were the primary unit used in the calculations and whether the distance between the trees was considered. The approaches were called (i) whole stand/distance independent, (ii) single tree/distance independent, and (iii) single tree/distance dependent modeling. Shugart and West (1980) renamed these as (i) nonspatial forest, (ii) nonspatial tree, and (iii) spatial tree models, respectively. Also, categories were added for (iv) nonspatial gap models and (v) spatial gap models. Gap models simulate each tree on a relatively small plot, usually a sample quadrant or a gap in the forest canopy. The

categories in this second classification scheme were subdivided for models of mono-species or mixed-species stands as well as models of even-aged or mixed-aged stands. For the purpose of this review, however, these subdivisions will be combined in the discussion of each of the broader categories.

Nonspatial Forest Models

The primary unit for calculations in forest models is the stand. These models usually predict stand volume with variables such as age, site index, and basal area. Since information concerning individual trees is not necessary, the distance between trees is not considered. Therefore, such models are nonspatial. Four characterizations are commonly used in this type of modeling: conventional yield tables or equations, difference-differential equations, distributional methods, and stochastic processes (Ek and Monserud, 1975; vide Mitchell, 1980).

Conventional yield tables and equations. Conventional normal, empirical, and variable density yield tables are examples of the earliest attempts to quantify growth and yield (Husch et al., 1972). These were constructed to describe the undisturbed development of natural stands under stocking levels that were full, average, or variable, respectively. Yield tables are generally limited to even-aged forests of a single species.

The normal yield tables presented in the United States Forest Service Miscellaneous Publication No. 50 (Anonymous, 1929) were an early example of nonspatial forest modeling. These used a graphical relationship of site index and age to predict the volume and yield of

Southern pines. Schnur (1937) developed yield, volume, and stand tables for upland oak forests of Central and North Central U.S. which are widely used today.

MacKinney and Chaiken (1939) were among the first to use multiple regression along with variable densities in the development of yield tables. Since then, many others have used this technique to predict the yield of forest stands (Schumacher and Coile, 1960; Buckman, 1962; Brender and Clutter, 1970; Lenhart and Clutter, 1971; Burkhart et al., 1972; Murphy and Farrar, 1982).

Yield tables generally have limited use in making detailed management decisions. The small number of variables used in the predicting equations can rarely represent all possible combinations of site, age, and stand treatment. Curtis (1972) discussed yield table studies and problems in projecting stand development.

Difference-differential equations. Difference and differential equations have been used to model more complex systems or stand development processes than is possible using standard yield tables. Clutter (1963) differentiated yield models with respect to age to produce growth rate models for even-aged loblolly pine stands. This showed the mathematical dependency between growth and yield. Sullivan and Clutter (1972) later refined this method by accounting for correlated errors in remeasurement data and to insure that parameter estimates were numerically consistent. Beck and Della-Bianca (1972) used this system to predict growth and yield in thinned yellow-poplar stands in the Southern Appalachians.

Several approaches have been developed that give mathematical compatibility to models of unmanaged, even-aged stands of mixed and pure species composition (Turnbull, 1963; Pienaar, 1965; Pienaar and Turnbull, 1973; Moser, 1967; Moser and Hall, 1969). These have been based on a generalization of the von Bertalanffy (1957) growth model for animal physiology described by Richards (1959) and Chapman (1961; vide Stiff, 1979).

Shugart et al. (1973) used differential equations to model forest succession over large regions. Their model used cover states to define successional stages in the Great Lakes region of the United States. Linear differential equations determined the rate of change from one state to the next based on stand dynamic and silvical considerations. A similar technique was used by Johnson (1977) to model 12 stages of succession and land use in the Piedmont of North Carolina.

Ek (1974) and Adams and Ek (1974; vide Stiff, 1979) used non-linear difference equations to describe ingrowth, mortality, and growth of uneven-aged hardwood stands in northern Wisconsin. These equations were later used in SHAF (Adams et al., 1974), a program which simulated the development of uneven-aged hardwood stands in Wisconsin. Moser (1972) used a similar procedure to predict tree number and basal area in similar types of stands. Hann (1980) used difference equations to predict diameter distributions in the Ponderosa pine/Arizona fescue habitat type of the Southwestern United States. A complex simulator, RMYLD, to predict yield tables for even-aged and two-storied stands of Ponderosa pine or even-aged stands

of lodgepole pine was developed by Edminster (1978) using difference equations.

The use of difference and differential equations in the modeling of forest stands allows more detail than with yield tables and with relatively little computer time. Shugart et al. (1973) presented a more detailed discussion of this approach.

Distributional models. Models of diameter or other size class distributions have generally used probability functions in predicting the dynamics of forest stands. Several different distributions have been used in these models. Among these is the negative exponential distribution which was introduced to American literature by Meyer (1952). Further studies on this distribution were made by Leak (1964), Schmelz and Lindsey (1965), Goff and West (1975), Harcombe and Marks (1978), and Moser (1976).

Clutter and Bennett (1965) used the Beta density function for old-field slash pine stands. Burkhart (1971) found this to be an accurate method with large samples. This distribution has also been used for stands of yellow-poplar (McGee and Della-Bianca, 1967), old field loblolly pine (Lenhart and Clutter, 1971), and unthinned slash pine plantations (Bennett and Clutter, 1968).

The Weibull distribution has become popular in recent research efforts due to its flexibility and simplicity of mathematical derivation (Johnson and Kotz, 1970). Computer programs for quantifying diameter distributions with the Weibull function have been made available by Bailey (1974). This function was successfully

applied to stands of loblolly pine (Smalley and Bailey, 1974a; Schreuder and Swank, 1974; Feduccia et al., 1979), shortleaf pine (Smalley and Bailey, 1974b), white pine (Schreuder and Swank, 1974), slash pine (Schreuder et al., 1979; Clutter and Belcher, 1978; Dell et al., 1979; Nance et al., 1983), and longleaf pine (Lohrey and Bailey, 1976). Stiff (1979) used this approach to model natural hardwood stands in the Appalachian mountains of Virginia.

Distributional approaches represent a computationally efficient method for predicting not only stock and stand table information, but also point estimates of stand characteristics such as number of trees and basal area. The fundamental concepts of classical distribution models and problems occurring with them are discussed by Hyink (1980).

Stochastic processes. Many nonspatial forest models have used stochastically based processes to model stand development. This technique is also applicable to other modeling approaches.

Markov models have frequently been applied as forest stand projectors. Leak (1968) used this process to study the dynamics of birch regeneration. This model had 29 states beginning with the development of the flower and ending with stem formation. Hool (1966) used Markov theory to determine risk and dynamic programming to prescribe control activities in forest production. Williams (1978) discussed several problems with the use of Markov theory for stand predictions and gave several recommendations.

In another approach, Leak (1969) used a probabilistic death process to model northern hardwood forests. This method was used by

Leak (1970a) to predict numbers of trees by diameter class. Leak (1970b) later modeled succession in northern hardwood stands by birth and death simulation.

Nonspatial Tree Models

The basic unit for calculation in tree models is the individual tree rather than the entire stand. Therefore, detailed tree records can be provided and used for cumulative stand summaries. Nonspatial tree models use lists of tree diameters or diameter classes with no record of the relative position of each tree in the stand. Competition between trees is assumed to be highly correlated with tree or stand variables such as diameter and stand density. Applications and limitations of this approach were discussed by Shugart and West (1980).

Nonspatial tree models are commonly used to simulate growth and yield in pure even-aged plantations. Competition in mixed plantations established on a fixed spacing was estimated by stand density in models presented by Clutter (1963), Dress (1970), and Curtis (1967). Sullivan and Clutter (1972) recognized that yield and basal area were not independent. By deriving estimates of volume and basal area as functions of the number of trees and individual tree geometry, successful predictions were obtained of plantation yield at different site indices and stocking levels. Alder (1979) estimated the effects of competition on tree increment using basal area relative to a minimum basal area, diameter relative to a dominant diameter, and height as a site specific indicator of age. With this, yields from

plantations of three exotic conifers in East Africa were predicted in a wide variety of thinning regimes. Harms (1981) suggested that a two-term competition function is required to predict annual diameter increment in loblolly pine. These terms were measures of competition in the whole stand and the competitive advantage of individual trees. Other even-age, monospecies, nonspatial, tree models were presented by Goulding (1972) for Douglas-fir, Dale (1975) for white oak, Burkhart and Strub (1974) for loblolly pine, Clutter and Allison (1974) for Monterey pine, and Elfving (1974) for Scots pine.

A nonspatial tree model was developed by Soloman (1974) for even-aged mixed species stands of hardwood forests in the Northern United States. Stand development was predicted using a typical tree at different ages in a system with stocking guides of basal area and number of trees. Decreases in tree number were a function of the differences between the basal area of the simulated stand and the basal areas expected for full or minimal stocking (reviewed by Shugart and West, 1980).

Nonspatial tree models have also been developed for mixed-aged, single-species stands. Suzuki and Umemura (1974) attempted this by modeling changes in the shape of stand diameter distribution curves over time. The probability of a given tree growing to a specific diameter at specified time was determined as a function of its present diameter and the present time. Since age was not considered, this approach was applicable to both even-aged and mixed-aged stands. Other nonspatial tree models have been presented by Bosch (1971) and Nankoong and Roberts (1974) for redwood forests.

The dynamics of uneven aged, mixed-species stands are often modeled with Markov chains. Horn (1975) assumed that the probability of one species being replaced by a second species was a function of the number of seedlings of the second species in the understory. Acevedo (1981) introduced light gap opening rates to Horn's approach to evaluate the proportion of pioneers that can be maintained in a tropical forest. Culver (1981) successfully used Horn's approach to simulate succession in a spruce-fir forest in the Great Smoky Mountains National Park. Given sufficient time of simulation, each of these models exhibited stationary species composition allowing a check of the model against old forests. Peden (1973) and Bruner and Moser (1973) used the Markov approach to project diameter distributions over time. Cassel and Moser (1974) used Markov chains to model stand compositional changes in terms of shade tolerance classes. A detailed review of the use of Markov chains in forestry was given by Groton (1983).

Nonspatial tree models have also been established that are capable of modeling more than one mixture of species and age class. Stage (1973) presented a prognosis model that predicted stand development by a detailed interaction of growth factors rather than the growth rate of each individual tree.

The Forest Resources Evaluation Program (FREP) was begun in 1975 by the USDA Forest Service North Central Forest Experiment Station. (1979) to update, project, and analyze forest resource information in the North Central Region. A part of FREP was to create a generalized forest growth projection system for all forest types and species

mixtures, ages, sites, structures, and densities encountered in the Lake States. One of the many products of FREP was a nonspatial tree model called STEMS (Stand and Tree Evaluation and Modeling System - Belcher et al., 1982) which replaced the earlier models TRES and FREP78 described by the USDA Forest Service (1979). STEMS simulated the birth, growth, and death or harvest of individual trees within a stand. For each tree, projection equations predicted annual diameter growth, probability of mortality, and crown ratio. A subroutine handled management action to the stand according to management guides developed for Lake States conditions (Brand 1979, 1981a). A smaller model called GROW which contained only the growth and mortality parts of STEMS was developed by Brand (1981b). More detailed descriptions of the STEMS model were given by Holdaway and Brand (1983), Jakes and Smith (1980), Leary et al. (1979), and Belcher (1981).

Potter et al. (1979) developed the FORPLAN (Forest Planning Language and Simulator) model which was similar in scope to STEMS (Belcher et al., 1982). FORPLAN was designed to use data base modules for any vegetative cover type. It used the method developed by Noble and Slaytor (1977) of simulating forest succession on the basis of species-specific attributes such as mode of propagation at different life stages and longevity (described by Cattelino et al. 1979). Thirteen community types were identified for the Glacier National Park. Further uses and refinements of FORPLAN were discussed by Kessel and Potter (1980).

Meyers (1977) developed YLDTBL, a simulator to predict variable density yield tables for loblolly pine plantations. Separate

equations were used to predict basal area (Clutter, 1963), height of each tree in the stand (Farrar, 1973), and diameter of each tree (Smalley and Bailey, 1974a).

Spatial Tree Models

As with the previous category of models, the basic unit for calculations in spatial tree models is the individual tree. Models in this category, however, consider the distance between each tree in some measurement of competition. Because of the detailed data required to develop these models, most have dealt with single-species stands of commercially important species.

Newnham (1964) developed one of the first spatial tree models. He assumed that diameter growth in Douglas-fir plantations was equal to that of open grown Douglas-fir minus a measure of competition. This measure was the sum of the angles of intersection of the crowns of neighboring trees. Lee (1967) used this method for lodgepole pine.

Subsequent modelers have used the same theory of reducing diameter growth from that of open-grown trees by some measure of competition. The estimate of competition, however, has varied. Mitchell (1969) estimated competition in his simulation of white spruce stands by the amount of available space for tree crowns in several directions. Stem growth was then calculated as a function of crown size. Lin (1970) used a weighted sum of the largest angle of incidence from a stem in each quadrant surrounding a subject tree. Hatch (1971) considered the competitive ability of trees to receive light. Hatch used the proportion of the live crown surface area

exposed to direct sunlight per unit of height. Bella (1970) estimated the reduction of diameter growth due to competition in aspen stands by the ratio of total tree crown overlap from competing trees to the subject tree's crown area. Hegyi (1974) modeled jack pine stands by modifying Arney's (1972) model of Douglas-fir. Hegyi reduced diameter growth due to competition by a ratio of the diameter at breast height (dbh) of each competitor to that of the subject tree, weighted inversely by the corresponding distance between the two trees. These weighted ratios were then summed for all competing trees. This method was adapted by Daniels and Burkhardt (1975) for loblolly pine plantations.

The spatial tree models cited above have been used to simulate pure, even-aged stands. Mitchell (1975) and Arney (1974) developed models for mixed-aged stands of Douglas-fir. Equations were used by Mitchell (1975) to depict relations between age, site quality, and tree vigor. He used complex algorithms to calculate tree height, diameter at each node, and branch growth. Competition was estimated by branch pruning due to overlapping crowns. Tree growth was partially determined by the amount of foilage produced each year. Diameter growth for each node of each tree in Arney's (1974) model was reduced from that of open-grown Douglas-fir by the same crown-area overlap index as described by Bella (1970). Height growth was also restricted when the live crown ratio of a tree became less than 30 percent.

A model for uneven-aged mixed-species stands was developed by Ek and Monserud (1974a, 1974b) for the forests of Wisconsin. This model,

FOREST, estimated competition by weighting the overlap area for each competing tree by its ratio of crown radius times total height. Part of the detail in FOREST was the establishment of seedlings and sprouts based on the species, size, and age of overstory trees. The natural cycle of good, moderate, and poor seed years for each species was also considered. A further review of this model was provided by Shugart and West (1980).

Tree models tend to be more flexible than forest models because of the detail considered. Each tree can respond to silvicultural treatment, insects, disease, natural catastrophes, etc. (Munro, 1974). Therefore, these are the most commonly used models to evaluate forestry operations.

The detail achieved by these models is not without cost, however. Estimates of competition are difficult to calculate and require expensive computer time. Also, large amounts of storage space and computer time are required to simulate each individual tree which is particularly true for spatial tree models where the position of each tree must be cataloged. The detailed data required to develop one of these models is expensive to obtain and usually available only from intensively sampled permanent plots (Munro, 1974). Since spatial tree models were developed for commercial use, these models generally ignore invasion of seedlings from outside of the simulated stand. Therefore, these models tend to be inadequate for simulation of forest succession in many areas (Shugart and West, 1980). Other reviews of tree models were by Daniels and Burkhart (1975) and Mitchell (1980).

Gap Models

Gap models are similar to tree models in that the basic unit for calculation is an individual tree. However, gap models consider only the individual trees on relatively small land areas. These areas are usually the gap created by the death and removal of a canopy tree or a forest inventory quadrant (Shugart and West, 1980).

In developing a gap model, the choice of gap size is important. As plot size decreases, the amount of growth reduction due to competition between trees for root space is over-estimated relative to growth reductions due to competition for sunlight (Shugart and West, 1979). The result is that trees are prevented from reaching their maximum size. If plot size is too large, however, the effects of shading become more important than root competition and gap phase replacement does not occur. Even though it is partially dependent on tree size, Shugart and West (1979) recommended simulation of plots between 4/100 hectare and 8/100 hectare in size to give an even balance of tree growth and gap phase replacement. The concepts of forest gaps and gap modeling are discussed by Shugart (1984).

Gap models, like tree models, can be classified as either spatial or nonspatial. A nonspatial gap model was developed by Waggoner and Stephens (1970) to simulate succession in a northern hardwood forest. Both this model and Horn's (1975) model used the Markov approach. However, instead of using the probability of tree-by-tree replacement, Waggoner and Stephens considered the probability of changes to species composition on small tracts of land (1/100 hectare) during a 10 year period. Forty years of continuous inventory data from the Connecticut

Agricultural Experiment Station were used to establish and evaluate the model. This method was found to be accurate except for species changes due to unusual weather patterns and insect damage (Shugart, 1984).

Spatial gap models have been used for many applications in studies of forest succession. These models are spatial in the vertical sense rather than the horizontal as are spatial tree models. Instead of estimating competition as a function of the distance between trees, spatial gap models estimate competition by the degree of shading from neighbor trees. Therefore, this method is less expensive than spatial tree models because the detailed information on tree location is not required (Shugart and West, 1980).

Spatial gap models simulate yearly diameter increment of individual trees on a plot. Tree heights are then calculated as a function of diameter. New saplings are added to the plot in any year where conditions are adequate for germination or sprouting. Death is determined as a function of tree growth rates and age.

The data required for spatial gap models are general in nature relative to the data required for spatial tree models. These include such information as climatic data and species-specific information such as maximum age or shade tolerance (Mielke et al., 1978). Sufficient data for gap models can often be found in dendrology or silvics textbooks such as Fowells (1965) or Harlow and Harrar (1969) (Shugart and West, 1977).

Botkin et al. (1972a, 1972b) developed the first functional spatial gap model. This model, JABOWA, simulated stand dynamics for

13 tree species on a 1/100 hectare plot of a northern hardwood forest at the Hubbard Brook Experimental Forest. In an effort to use a minimal number of assumptions to find the simplest mathematical expression of each factor of stand dynamics, only nine variables were used to characterize tree species and seven to characterize the abiotic environment. Three main subroutines, GROW, BIRTH, and KILL, were used to project yearly stand dynamics.

The yearly diameter increment of each tree on the simulated plot was calculated in GROW. Separate equations were used to characterize the diameter growth of shade tolerant and shade intolerant species growing under optimal conditions. The shape of the growth curve for each species was modified by multiplying the growth equation by a constant G. The value of G was arbitrarily chosen so that the size of each tree would be $2/3$ of the record size for each species at $1/2$ of that species' record age. Diameter growth was reduced from that under optimum conditions by shading, climate, and soil quality. GROW also calculated tree height (as a function of diameter) and leaf biomass as a measure of the degree of shading on the plot.

In each simulated year, seedlings were established in the plot by subroutine BIRTH. The assumption was made that there was an available seed source for every species and in every year. BIRTH determined which species were eligible to germinate on the basis of relative shade tolerance and whether temperature and soil moisture conditions allowed growth of that species. Seedlings of eligible species were then stochastically added to the plot at a diameter of 1.27 centimeters.

Tree mortality was determined on an annual basis by subroutine KILL. Since tree mortality was more than an age-dependent process, the assumption was made that only 2 percent of actively growing trees would reach their maximum possible age. For trees that were not actively growing, there was a second mortality function. If a tree grew less than 1 millimeter per year, it was given only a 1 percent chance of surviving 10 years.

A fourth subroutine, SITE, was used to determine the values of two variables used in the above subroutines. Temperature was expressed as the number of growing degree-days in a growing season above a base of 40 degrees Fahrenheit. The number of growing degree-days was determined for each different elevation considered by JABOWA. Available water was calculated as a modified Thornthwaite balance (Sellers, 1965) by using soil depth and texture, percentage of rock in the soil mantle, and monthly precipitation means.

The model generally reached a steady stage of succession at 250 to 300 years. It was validated on its ability to predict the elevation of the transition from hardwood to coniferous forests in the Hubbard Brook forest.

JABOWA was modified by Shugart and West (1977) to simulate forest succession involving 33 species on a lower slope position in East Tennessee using a model called FORET (FOREsts of East Tennessee). Plot size was increased from 1/100 hectare to 1/12 hectare. This reduced the effect of root competition and allowed trees to grow to their maximum potential size. The SITE subroutine was replaced by GAUSS in which site factors were changed from constants to stochastic

variables. The base temperature for growing degree-days was raised to 42 degrees Fahrenheit to more closely simulate the growth habit of the more southern species. The probability of a tree reaching its maximum age was lowered to 1 percent. A subroutine, SPROUT, was added which allowed sprouting of eligible species. When trees died that were of appropriate age and species, then a number of sprouts of each eligible species was selected stochastically and added to the plot. Sprouts entered the plot at 1 millimeter in diameter. FORET was validated by accurately predicting species composition with and without American chestnut as compared to historical accounts of the forests of East Tennessee.

Mielke et al. (1978) used FORET as a starting point to produce FORAR, a simulator for 33 species on upland sites of Union County, Arkansas. The major modification in developing FORAR was the implementation of a moisture stress variable to reduce the growth rate of simulated trees. FORAR was validated by its accurate prediction of successional species replacement patterns when compared to USDA Forest Service Continuous Forest Inventory data from Union County, Arkansas.

FORAR was modified by Mann (vide Shugart, 1984) for use in loblolly pine plantations. The G constant in the growth equation was altered for each species so that the model could be validated against yield tables (Smalley and Bailey, 1974a). Tharp (1978) used FORAR to study the effects of fire. A subroutine, FIRE, was added to the model which altered tree growth and mortality on the basis of the fire tolerance of each species, fire intensity, and tree age.

The FORMIS model (Tharp, 1978) was also an adapted version of FORET. FORMIS simulated forests in the bottomlands and swamps of the Mississippi River Delta after flooding. The variable FLOOD was added to the list of parameters for the 32 species included in the model. This variable was the percentage of the growing season during which each species could tolerate flooded conditions. A subroutine, also called FLOOD, stochastically selected the percentage of the growing season with flooded conditions. If this was greater than the tolerance of a species, its diameter growth was reduced. The model was able to accurately predict species composition around oxbows, sloughs, and other standing water systems as they are found in the floodplain of the Mississippi River today (Shugart, 1984).

Another model based on FORET was BRIND (Shugart and Noble, 1981). This model simulated succession and fire influences in the high altitude Eucalyptus forest of the Brindabella Range near Canberra (Australian Capital Territory). BRIND simulated stand development for 19 species on a 1/12 hectare plot. The major modifications made to FORET to create BRIND were the inclusion of seed source, seed availability, and seed storage variables as well as the effects of fire on tree mortality, reproduction and growth. If a plot had a mature tree on it, then a seed source for that species was assumed to be present. If not, then availability was based on seed longevity, seed dispersal, and the effect of fire on seed germination. Tree mortality was increased for fire damaged trees in a subroutine called FIRE. Species with lignotubers were favored for sprouting in that they were given no lower diameter in the determination of sprouting

eligibility. After a fire, sprouting of 75 percent of the trees killed by the fire was allowed. Sprouts entered the plot at 2 centimeters rather than 1.27 centimeters as with seedlings because it was assumed that sprouts were more vigorous. The FIRE subroutine stochastically selected the occurrence of fires and determined fire intensity as a function of climatic conditions and fuel loading. Validation of BRIND was accomplished by comparison of experiments with different fire probabilities and at different altitudes to replacement patterns of vegetation in the Brindabella Range.

KIAMBRAM, another modification of FORET, was developed by Shugart et al. (1980) and Shugart et al. (1981) to simulate succession in a sub-tropical rain forest in Australia near the New South Wales/Queensland border. In addition to a large number of species (125) and a change in plot size (1/20 hectare), major modifications were the inclusion of strangler figs, the effects of treefall, and allowance of selective harvest of timber species. Strangler figs were stochastically added to the plot by subroutine STRGLE and host tree diameter growth was reduced. Subroutine CHABLI stochastically determined when a tree fell. Light levels were then increased for other trees and mortality of smaller trees was increased as if they had been hit by a falling tree. Subroutine LUMBER allowed tree harvest at specified intervals. Residual trees were given increased mortality rates to simulate logging damage. KIAMBRAM was validated by comparisons of the predicted successional dynamics to patterns observed in the field. Model output was also similar to mature stands in the area.

Doyle (1981) adapted FORET to produce FORICO which simulated gap succession in the lower montane rain forest of the Laquillo Experimental Forest in northern Puerto Rico. FORICO simulated 36 species on a 1/30 hectare tract. As with several of the previously discussed models, FORICO considered stand development after disturbance. A subroutine, HURCAN, was added to the model to stochastically predict hurricane occurrence. Hurricanes were given an average return frequency of 1 in every 9 years. In each hurricane, 0 to 10 percent of the stand biomass was removed. FORICO predicted tree diameter distributions which were not significantly different from actual field data.

FORNUT (Weinstein, 1982a, 1982b) has been the most sophisticated modification of FORET to date. In this model, the growth rates of each of 48 species in the Southern Appalachians were partially controlled by the nutrient demands of each tree. If a nutrient was limiting, tree diameter growth was reduced by an amount dependent upon the level of the nutrient present and the tolerance of the species to nutrient limitations. The demand of each tree for calcium, magnesium, potassium, phosphorus, and nitrogen was determined as a function of the current content of each of these elements in the trees' branches, stems, leaves, and three size classes of roots. As each tree grew, it was assumed that the new growth would contain the same concentration of each nutrient as before. Nutrient availability was determined by the decomposition of each of these tree parts and inputs to the system from precipitation, throughfall, and nutrients released by fire. The availability of these nutrients became limited by the simulation of

immobilization by soil microbial organisms. Tree growth and survival were also modified according to soil moisture availability. A subroutine, MOIST, stochastically determined the number of days in a year when soil moisture was insufficient for tree growth. Tree growth was reduced on dry days relative to species-specific drought tolerance. Drought tolerance was determined as a function of the number of dry days in a year that a species could tolerate at the western most extent of its range. Each species was classified into one of five categories in terms of the ability of its seedlings to survive droughts in May and June. Seedling establishment was either allowed or not allowed depending on rainfall patterns in each year.

Nutrient dynamics were also studied with a spatial gap model by Aber et al. (1979). The JABOWA model was modified to project levels of nitrogen availability after seven different harvesting regimes in northern hardwoods. Diameter growth of trees was reduced during periods of simulated nitrogen deficiency. Results indicated that production increased with longer rotations (90 years versus 30 and 45 years) and a larger percentage of net production was removed by whole tree harvesting and complete clearcutting than by diameter limit clearcutting.

FORET was modified by Smith et al. (1980) to produce FORHAB which simulated the forests of the Walker Branch Watershed near Oak Ridge, Tennessee. Subroutines HABIT and DISCRM were used as a two-group discriminant function to determine whether a simulated plot represented a possible breeding habitat for several species of nongame birds. Different forest management practices were introduced to the

simulated plot by subroutine CUT to determine cutting effects on breeding habitat. In an example using diameter limit cutting, there was a general increase in breeding habitat for ovenbird in managed stands over a 120 year simulation.

The SWAMP model was adapted from JABOWA by Phipps (1979) to model 25 species on 1/25 hectare plots in the wetland forests of the White River National Wildlife Refuge near DeWitt, Arkansas. Major modifications of JABOWA were the inclusions of subroutines CROWD, WATER, FLOOD, MAST, and NATS. CROWD calculated growth rate reductions on the basis of crowding, shading, and shade tolerance. Reductions of tree growth during periods of flooding were calculated in subroutine FLOOD. Species eligibility to germinate was affected by flood frequency. The FLOOD subroutine also determined when a flood occurred and compiled a list of species eligible to germinate. MAST calculated an estimate of the annual mast production. NATS regulated annual diameter growth by providing year to year variations in the climate. Unlike most spatial gap models, SWAMP began the simulation with a stand described by actual plot data. Most gap models have begun with bare ground in studies of succession.

Gap models appear to be among the most useful of the several types of forest stand models discussed. The detail of tree models is included without as much expense for computer time, computer storage, and data collection. Gap models also appear to be very versatile. As shown here, these models have been used for many different forest systems over the world as well as for studies of the effects of natural perturbations and forest management on stand development. Use

of gap models has generally been limited, however, to ecological studies. These models remain relatively untested for the short term projections (one rotation and less) of species composition and volume needed for forest management decisions. As stated earlier, one objective of this study is to develop a spatial gap model for forest management applications.

CHAPTER III

FIELD STUDIES

Similar data for the verification of FORCAT were obtained from permanent sample plots on the Catoosa Wildlife Management Area (CWMA). These plots were established in a study of the effects of two harvesting techniques (complete and diameter limit clearcutting) and animal browse (white-tailed deer and small mammals) on the composition and quantity of regeneration (Phase II) (Muncy, 1980). This study provided data for a mature stand prior to harvest and a one-year-old stand on the same site after harvest. Data for the third and fourth years after harvest were collected as a part of the present study (Phase III). The effects of prescribed fire on the quantity and composition of regeneration were also a part of this study.

The methods and materials of this study were largely those described by Muncy (1980). Therefore, relevant sections of Muncy's study will be summarized in this discussion.

Study Area

Location. The CWMA is located on the Cumberland Plateau of East Tennessee (Figure 1), approximately 10 miles north of Crossville, Tennessee and in the northeast corner of Cumberland County. Two adjacent areas were selected for this study which are located in the northwest corner of the CWMA (Figure 2). Area I is located in compartment 6 and Area II is in compartment 8. They are accessible from Crossville by Genesis Road, to Myatt Creek Road, to Turner Road.

CATOOSA WILDLIFE MANAGEMENT AREA

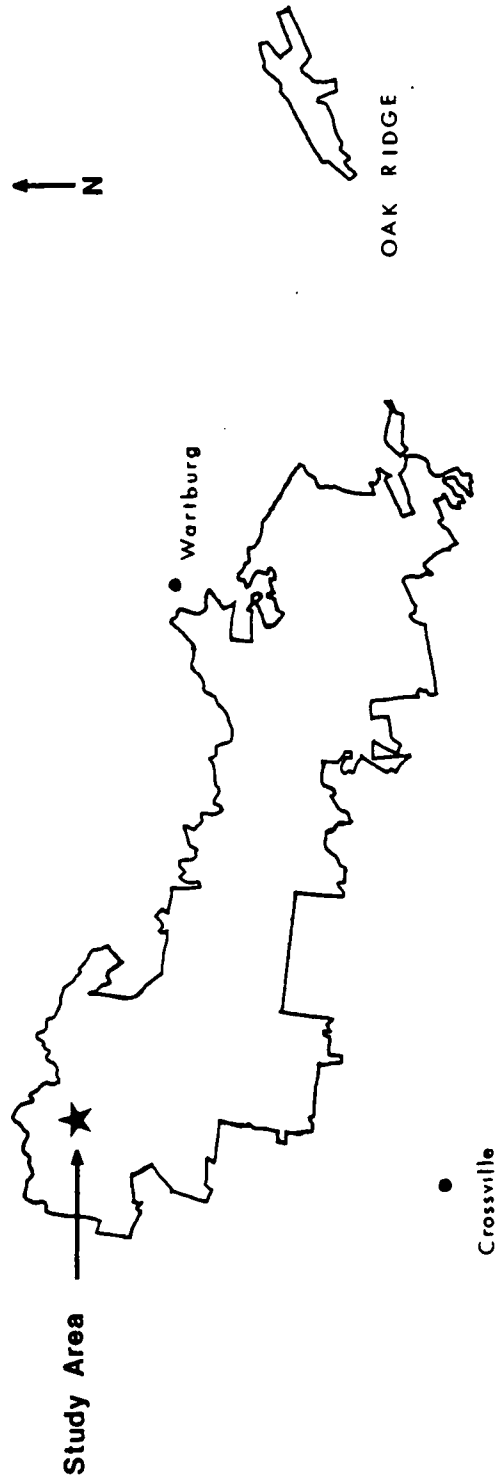


Figure 2. Location of study area within the Catoosa Wildlife Management Area.

Area I is located due east of Pigeon Lot and Area II is at the junction of Turner Road and Sally Robbins Place Trail (Figure 3).

Climate. The climate of the area is characterized by long, moderately hot summers and short, mild winters (Smalley, 1982). Daily and seasonal weather is controlled by continental air masses from Canada and by moist air from the Gulf of Mexico. Mean monthly temperatures range from 35 degrees (Fahrenheit) in January to 73 degrees in July (USDC, 1977) with an average growing season of 179 days (USDA Soil Conservation Service, 1950). Rainfall averages 57 inches per year with extremes of 3 inches in October and 6 inches in January (USDC, 1977). Droughts of sufficient intensity to limit tree growth are most likely to occur in July, August, and October (Smalley, 1982).

Topography. The two study areas are classified as landtype 1 under Smalley's (1982) classification of forest sites on the Mid-Cumberland Plateau. These areas are gently undulating to slightly rolling with slopes of less than 10 percent. Slopes of greater than 6 percent are uncommon so that aspect is not a dominant factor controlling species occurrences. Elevation ranges from 1,700 to 1,760 feet.

Soils. Soils of the Hartsells and Lonewood series are dominant in both study areas. Hartsells were formed in loamy residuum from sandstone or from interbedded sandstone and shale. Lonewood soils were derived from the incorporation of the underlying residuum of

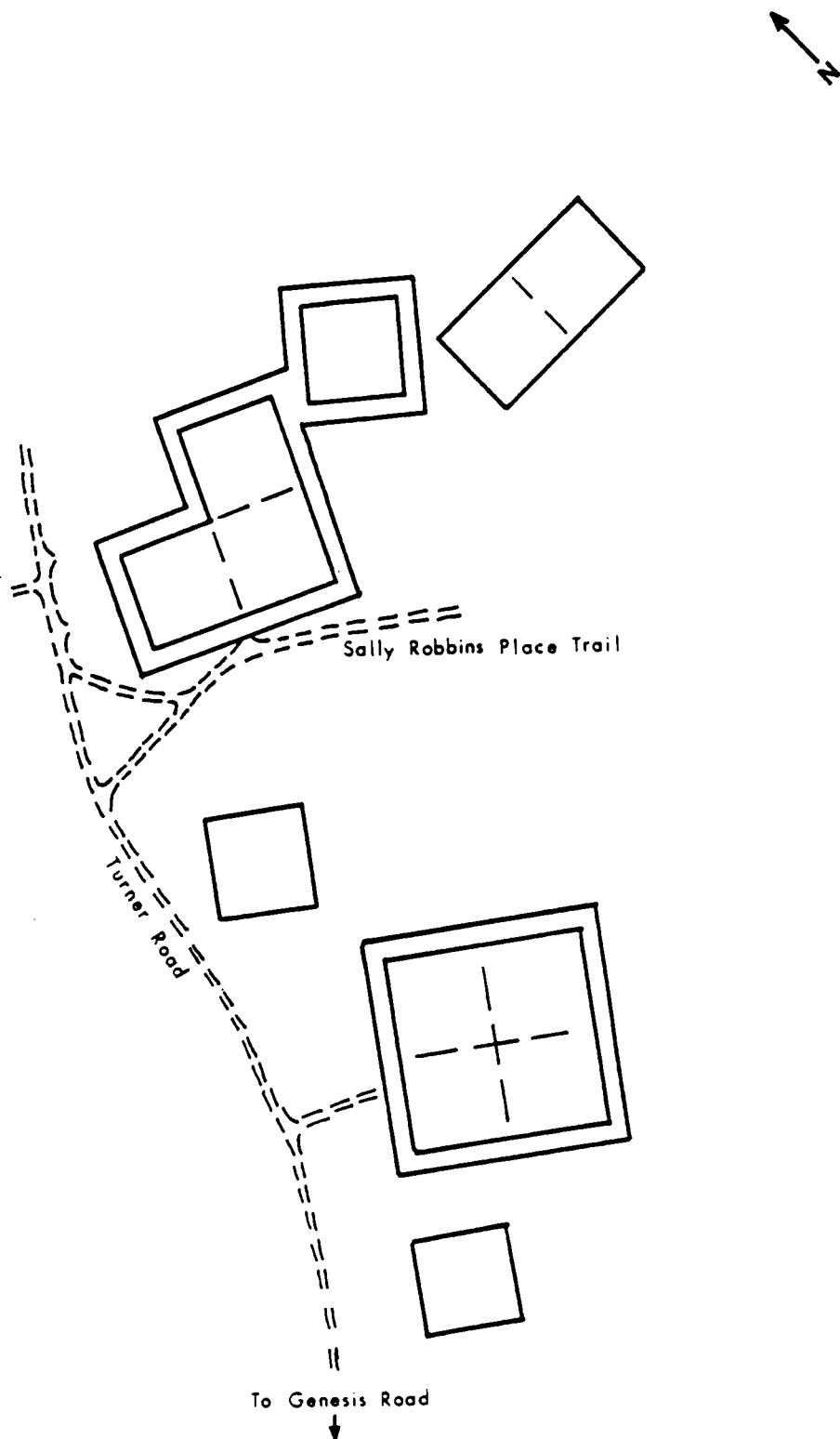


Figure 3. Road map to study areas.

shale and sandstone with silty mantle material (presumably loess) 2 to 3 feet thick. Depth to bedrock is 20 to 40 inches with Hartsells series soils and 40 to 65 inches with Lonewood series soils (USDA, 1974 and 1975). Both soils are strongly acidic, moderately well drained, and of moderately low fertility (Smalley, 1982).

Vegetation. Both study areas best fit the Society of American Foresters (SAF, 1964) type 41 scarlet oak group which is within the Oak-Hickory Type Group. Mature forest stands on both study areas are dominated by scarlet oak and post oak with Southern red oak and black oak as common associates. Pignut hickory, mockernut hickory, Virginia pine, eastern white pine, white oak, blackjack oak, blackgum, red maple, and chestnut oak frequently occur in the overstory. Common tree species found in the understory are sourwood, sassafras, dogwood, persimmon, serviceberry, sumac, and American holly.

Wildlife. The increase of wildlife populations for hunting is the primary objective in forest management on the CWMA. Since white-tailed deer is the most commonly hunted wildlife species on the CWMA, forest management activities are largely for improved deer production. Management goals are to provide suitable habitat to support one deer on every 30 acres (Arney and Pough, 1983). Turkey are also popular game animals on the CWMA. CWMA forest management goals include providing habitat capable of supporting one turkey on every 80 acres. Other species hunted on the CWMA (by decreasing order of popularity) include raccoon, eastern gray squirrel, ruffed grouse, bobwhite quail, mourning dove, eastern cottontail rabbit, and American

woodcock (Muncy, 1980). Management guidelines are to improve the quality and quantity of habitat for these species when compatible to deer and turkey needs (Arney and Pough, 1983).

Methods and Materials

Study design. The study was established as a split-plot randomized complete block design to study the effects of two harvesting techniques, prescribed fire, and animal browse on the composition and quantity of regeneration. Each of three replications was divided into two 10-acre plots for the main treatments (Figure 4). These included (i) diameter limit clearcutting, (ii) complete clearcutting, and (iii) uncut controls. Each main treatment plot was split into two 5-acre subplots, one of which would be burned when regeneration grew out of reach for deer browsing. Nine permanent sampling points were established in each subplot. Each of these points represented the center of four concentric sampling plots (1/5, 1/20, 1/40, and 1/100 acre) for each of four tree size classes (sawtimber, pulpwood, sapling, and regeneration).

Animal exclosures, 1/40 acre in size, were constructed around two randomly selected points of each group of nine sampling points. By using different sized fencing, these exclosures were constructed so that deer were excluded from the entire fenced-in area and rabbits and other small mammals were excluded from one-half of the area.

A buffer strip 100 feet wide was cut around both the commercial and silvicultural clearcut plots to eliminate any edge effect in the measurement plots. A total of 30 acres was clearcut in the first

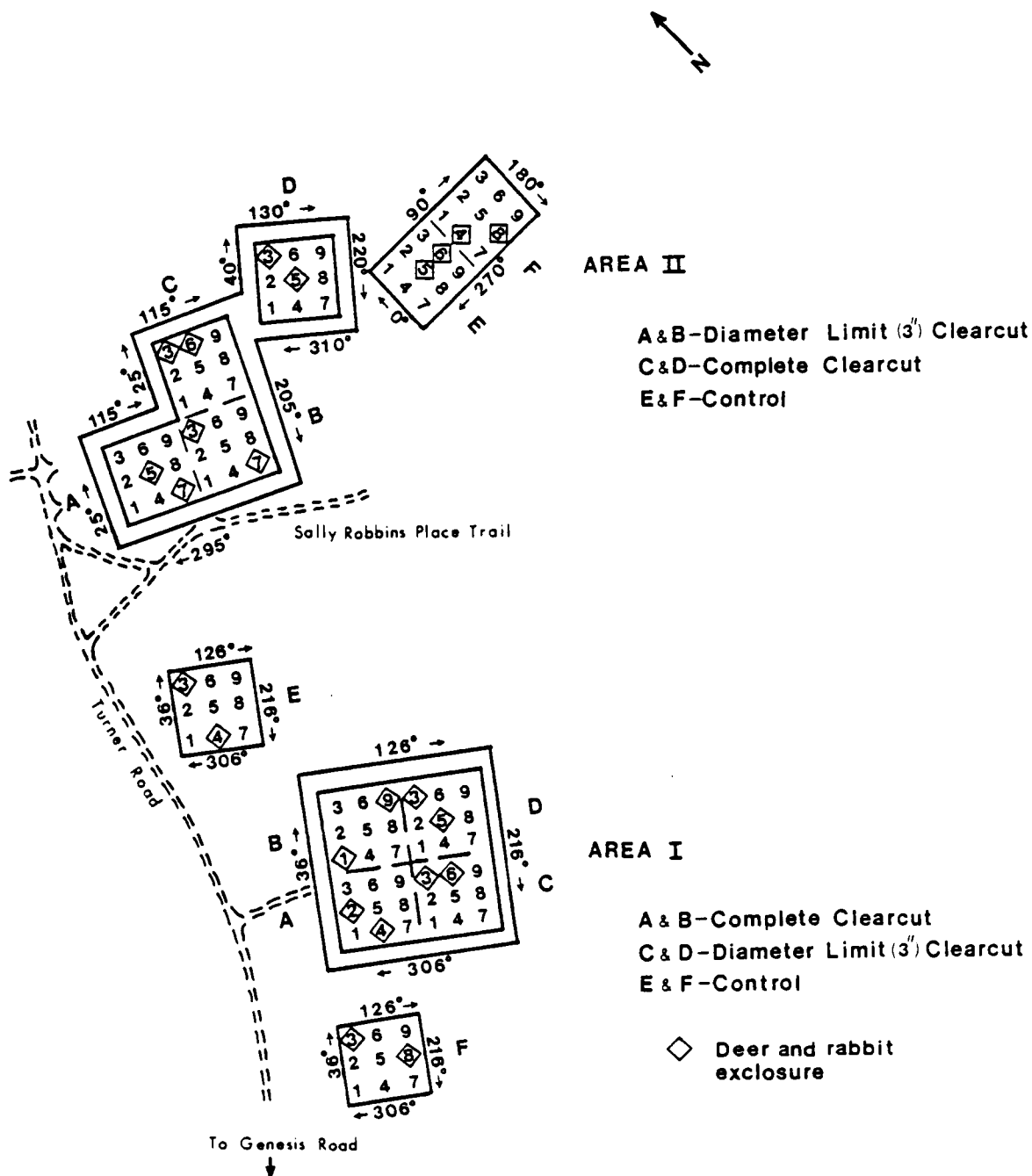


Figure 4. Map of study areas showing study design.

replication (Area I) and 35 acres in the second (Area II). Uncut control plots were located near cut areas but away from any influence of logging operations. Each sampling point was marked with either a 5/8 inch or a 1/2 inch steel rod.

Treatments. Diameter limit and complete clearcut harvesting were completed by the early summer of 1979. The diameter limit cut was defined as the cutting of all stems over 3 inches dbh. This conforms to Tennessee Wildlife Resources Agency policy and was stipulated in contractual agreements with loggers. The complete clearcut was defined as the removal of all stems over 6 feet in height. The removal of stems between 6 feet in height and 3 inches dbh was accomplished after the commercial logging operation had been completed.

Control plots were established to provide a comparison for treatment plots. These areas were chosen as representative of the cut areas and were left virtually undisturbed.

Prescribed fires were conducted in each replication between the third and fourth growing seasons after harvest (early spring 1982). Young clearcuts on the CWMA are often burned at or near this age to improve deer browse. This technique slows stand development and keeps regeneration within the reach of deer for longer periods of time. Burns were conducted on April 12, April 14, and May 2, 1982. Each day had gusty winds from 10 to 30 miles per hour and low relative humidities of approximately 40 percent. Rain had not fallen on the study areas for 4 days and 6 days, respectively for the first two burn

dates. Rain had not fallen for 7 days prior to the third burn date. For all three burn dates, fire danger was rated as class 5 and the fire spread index was rated as class 7. Fire lines were plowed around each plot to be burned with an International tractor and a 2-disk plow. All fires were set with standard drip torches using an equal mixture of gasoline and diesel fuel. Due to the gusty winds and high fire spread indices, all fires were set to burn into the wind (backing fire). Fires were started at 1:00 pm (Central Standard Time), 10:00 am, and 11:00 am, respectively for the three burn dates.

Data collection. Detailed maps of the location of all trees recorded in a preharvest inventory were provided by Muncy (1980). Each sawtimber sized tree (11 inches dbh and over) located on each 1/5 acre subplot was mapped in relation to the plot center, measured for height and dbh, and recorded by species. The same was done for each pulpwood sized tree (3 to 10.9 inches dbh) on 1/20 acre plots and each sapling sized tree (6 feet in height to 2.9 inches dbh) on 1/40 acre plots. Regeneration sized trees (under 6 feet in height) on 1/100 acre plots were not mapped or measured but were tallied by species and by the presence or absence of browse on each tree.

Muncy (1980) completed a similar inventory at the end of the first growing season after cutting. Each mapped tree in the uncut control areas was located and tallied as either alive or dead. Uncut trees in clearcut areas were located and measured for height and dbh. If a tree had been cut, its stump was located and the number of basal sprouts, stump sprouts, and/or root sprouts produced by that stump was

recorded. The height of the dominant sprout was recorded for each stump and sprout type. The number of sprouts from each stump showing evidence of animal browse was also recorded. Regeneration was again tallied by the number of trees of each species found on 1/100 acre plots in cut and control areas. The occurrence of animal browse was also recorded for these trees.

Successive inventories of all plots were completed at the end of the third (1981) and fourth (1982) growing seasons after harvest. Identical methods to those used by Muncy (1980) and described above were used for these data collection periods.

Data analysis. Raw field data were transcribed onto 80 column computer sheets to be keypunched onto computer cards. Card images were then placed on CMS (Conversational Monitoring System) disk files for editing of errors.

Data were analyzed on the University of Tennessee IBM 3031 computer using the general linear models (GLM) and TTEST procedures of the Statistical Analysis System (SAS) (Barr, et al. 1979). SAS procedures were also used to compile, merge, and summarize the data. Storage, editing, and remote job entry to the IBM 3031 computer were accomplished using CMS.

A factorial arrangement of the analysis of variance was used to test for differences in the number of stems for each of three factors. These factors included two methods of clearcutting (diameter limit and complete), 10 species, and two classes of saplings (seedlings and sprouts). T-tests were used to compare the sprouting characteristics

observed in each type of clearcut. Test results showing differences at the 95 percent level of confidence were considered significant. Differences at the 99 percent level of confidence were considered highly significant.

Results and Discussion

Browsing. The incidence of browsing in clearcut and control areas was minimal. During data collection at the end of the fourth growing season (1982), over 7,000 regeneration sized trees were observed. Of these, only 93 showed evidence of browse. This number was even smaller during data collection at the end of the third growing season (1981). Therefore, it was assumed that browsing had no affect on the number of stems or the average height of stems in clearcut and control areas. Animal exclosure effects were not included in statistical comparisons of regeneration characteristics.

Muncy (1980) noted that browsing occurred most often along haul roads and skid trails. This trend was repeated during the third and fourth growing seasons. Heavy deer browse of trees was also observed in areas where deer had bedded and in areas adjacent to highly preferred plants, particularly pokeweed.

Browsing was most common on sassafras and blackgum sprouts. Blackgum is listed as a preferred species for deer browse in Tennessee while sassafras is listed as a common food (Hurd, 1980). Occasional browsing of black oak, pignut hickory, and red maple was also observed.

The location of sampling points within clearcut areas may offer an explanation for the small number of browsed stems observed. Sampling points were located near the center of nearly square shaped 30 and 35 acre clearcuts. Buffer strips, 100 feet wide, were cut around study plots further isolating points near the center of large cuttings. Browsing was observed to be heavier in this buffer strip than within sampling plots. This may have been due to the proximity of the buffer strips to the cover provided by the forest edge. The buffer strips were large enough and contained sufficient browse that deer likely remained near the forest edge which would account for the low browsing intensity in sample plots.

Observations of browsing may be more valuable in the future as stands close and much of the regeneration in the buffer areas is shaded out. Under these conditions, browsing animals will have to cover a larger area to obtain food, possibly causing an impact on species composition and tree growth rates in study plots.

Third year regeneration. The results of regeneration counts following the third growing season agreed with those reported by Muncy (1980) for the 1-year-old stand. No significant differences were detected between stem numbers in areas harvested by complete and diameter limit clearcutting methods (Table 22 Appendix A). Also, significant differences were not detected between the numbers of seedlings and sprouts in clearcut areas. Significant differences were detected, however, between the numbers of stems of the 10 species tested.

Table 1 characterizes regeneration after 3 growing seasons for both cutting treatments combined. The total number of stems per acre was 6,168, an increase of 1,223 stems over the 1-year-old stand. Of these, 2,374.6 (38 percent) were classified as seedlings and 3,794.4 (62 percent) were classified as sprouts. The oak group composed 24 percent of the total regeneration. Other potential overstory hardwoods (including the hickories) made up 38 percent of the regeneration. Thirty-seven percent of the regeneration consisted of several understory hardwood species while 2 percent consisted of pines.

Scarlet oak was the most abundant oak species in the regeneration with 651 seedlings and sprouts per acre. Black oak, Southern red oak, post oak, and white oak were also abundant with 343, 189, 151, and 111 stems per acre, respectively.

Two species, blackgum and red maple, predominated in the category of other potential overstory hardwoods. Blackgum was the most abundant of all species observed with 1,115 stems per acre. Red maple had 988 stems per acre of which 832 (84 percent) were classified as sprouts. Other species in this category, in decreasing order of abundance, were pignut hickory, black locust, persimmon, and mockernut hickory.

Sassafras regeneration was the most abundant of the understory hardwoods category with 1,875 stems per acre. The majority (94 percent) was of sprout origin. Dogwood and sourwood seedlings and sprouts were common and American holly seedlings were observed

TABLE 1
REGENERATION THREE YEARS AFTER CLEARCUTTING
(BOTH CUTTING TREATMENTS COMBINED)

Species	Seedlings	Sprouts	Total
	----- Mean Number Per Acre (Percent) -----		
Oaks			
Blackjack	20.8 (0.9)	2.8 (0.1)	23.6 (0.4)
Scarlet	588.9 (24.8)	62.5 (1.6)	651.4 (10.6)
Black	255.6 (10.8)	87.5 (2.3)	343.1 (5.6)
Southern Red	116.7 (4.9)	72.2 (1.9)	188.9 (3.1)
Post	94.4 (4.0)	59.7 (1.6)	154.1 (2.5)
White	84.7 (3.6)	26.4 (0.7)	111.1 (1.8)
Hickories			
Pignut	59.7 (2.5)	88.9 (2.3)	148.6 (2.4)
Mockernut	11.1 (0.5)	9.7 (0.3)	20.8 (0.3)
Other Potential			
Overstory Hardwoods			
Blackgum	594.4 (25.0)	520.8 (13.7)	1115.2 (18.1)
Red Maple	155.6 (6.6)	831.9 (21.9)	987.5 (16.0)
Persimmon	31.9 (1.3)	6.9 (0.2)	38.8 (0.6)
Black Locust	41.7 (1.8)	- (-)	41.7 (0.7)
Understory Hardwoods			
Sassafras	111.1 (4.7)	1763.9 (46.5)	1875.0 (30.4)
Dogwood	63.9 (2.7)	165.3 (4.4)	229.2 (3.7)
Sourwood	30.6 (1.3)	77.8 (2.1)	108.4 (1.8)
Serviceberry	54.2 (2.3)	1.4 (0.1)	55.6 (0.9)
Am. Holly	9.7 (0.4)	1.4 (0.1)	11.1 (0.2)
Am. Chestnut	- (-)	15.3 (0.4)	15.3 (0.2)
Pines			
Virginia	45.8 (1.9)	- (-)	45.8 (0.7)
White	2.8 (0.1)	- (-)	2.8 (0.1)
Totals	2373.6 (100)	3794.4 (100)	6168.0 (100)

occasionally. Sprouts of American chestnut were present but infrequent.

The pine component in study plots was smaller than had been expected. Virginia pine seedlings composed .7 percent of the total regeneration (46 seedlings per acre) while white pine accounted for only .1 percent (3 per acre). Since larger proportions of pine regeneration were observed in the buffer areas around study plots, the distance from a seed source to study plots may partially account for the lack of pine regeneration.

Sprouting remained the most common form of regeneration through the third growing season. No significant differences were detected between diameter limit and complete clearcuts in the number of sprouts per cut tree or in the height of the dominant sprout from each stump (Table 23 Appendix A). There were differences, however, between size classes and species of cut trees. Seventy-seven percent of the stumps from sapling sized trees had live sprouts after 3 years (Table 24 Appendix A). Thirty-nine percent of the stumps from pulpwood sized trees had live sprouts while only 4 percent of the stumps from sawtimber sized trees had live sprouts. Red maple was the most prolific sprout producer with 6.2 and 14.8 sprouts per cut stem for sapling and pulpwood sized trees, respectively (Table 25 Appendix A). Oaks as a group had an average of 3 sprouts per cut stem for sapling sized trees and 4 sprouts per cut pulpwood sized tree. For most species, basal sprouts were the most abundant of the three types of sprouts observed (stump, basal, and root sprouts) (Table 26 Appendix A). However, this may not be true for species such as red maple and

blackgum which are known to be prolific root sprouters. Many root sprouts of these species which were located away from a cut stem may have been incorrectly classified as seedlings.

Uncut trees after 3 years. The majority of the sapling and pulpwood sized trees that were not cut in the diameter limit clearcuts survived the first three growing seasons (Table 2). Sixty-five percent of all uncut sapling sized trees survived even though 41 percent of the total had been damaged by logging operations. Sixty-six percent of all pulpwood sized trees survived after 36 percent of all uncut trees in this size class were damaged. These trees were generally of poor form and did not respond to release. Crowns of uncut trees remained undeveloped and, therefore, represented very little competition for sunlight to the regeneration.

Control plots after 3 years. There was very little change in the composition and characteristics of the control plots between measurements. They were still dominated by the oaks after 3 years (Table 3). Post oak was the most abundant of all species with 31 percent of the total basal area. Other predominant oaks were Southern red oak with 18.5 percent of the total basal area, black oak with 15.9 percent, and scarlet oak with 14.7 percent. Virginia pine was the most common species, other than the oaks, with 7.3 percent of the total basal area. Of the understory hardwoods, sourwood was the most abundant with 3.9 percent of the total basal area. These means are slightly different from those of the preharvest stand described by Muncy (1980). Those stands had a larger proportion of scarlet oak

TABLE 2

STATUS OF RESIDUAL STEMS THREE YEARS AFTER DIAMETER LIMIT CLEARCUTTING

Species	Sapling 6'High-2.9"dbh			Pulpwood 3.0-10.9"dbh		
	No. left uncut	No. * damaged	No. alive after 3 years	No. left uncut	No. * damaged	No. alive after 3 years
Oaks	----- Mean Number Per Acre (Percent) -----					
Southern Red	16	6 (36)	12 (78)	1	.5 (50)	.5 (50)
Black	11	2 (20)	7 (60)	1	0 (0)	.5 (50)
Post	4	2 (50)	4 (100)	3	1 (33)	3 (100)
White	3	0 (0)	2 (67)	2	2 (100)	2 (100)
Scarlet	2	2 (100)	2 (100)	3	1 (33)	2 (67)
Hickories						
Pignut	22	12 (55)	12 (55)	1	1 (100)	0 (0)
Mockernut	11	6 (50)	11 (100)	1	0 (0)	0 (0)
Other Potential Overstory Species						
Blackgum	32	14 (45)	18 (55)	2	1 (50)	1 (50)
Red Maple	-	- (-)	- (-)	1	0 (0)	1 (100)
Understory Hardwoods						
Sassafras	32	10 (31)	21 (65)	.2	0 (0)	0 (0)
Sourwood	15	6 (39)	10 (69)	2	1 (50)	1 (50)
Dogwood	13	4 (33)	3 (25)	5	2 (34)	4 (80)
Pines						
Virginia	16	4 (25)	9 (57)	2	1 (50)	1 (50)
Totals	174	64 (37)	111 (64)	24	8 (33)	16 (67)

* Trees damaged during logging operations.

TABLE 3

SPECIES COMPOSITION OF CONTROL PLOTS AFTER THREE GROWING SEASONS

Species	Sawtimber (11.0" dbh and over)			Pulpwood (3.0"-10.9" dbh)			Percent of Total Basal Area
	No. stems per acre	Mean dbh (inches)	Basal area (ft ² /acre)	No. stems per acre	Mean dbh (inches)	Basal area (ft ² /acre)	
Oaks							
Scarlet	7.0	15.1	8.7	12.0	6.2	2.5	14.7
Post	14.0	12.9	12.7	42.0	6.9	10.9	31.0
Southern Red	5.0	14.7	5.9	58.0	5.1	8.2	18.5
Black	5.5	14.8	6.6	32.0	5.6	5.5	15.9
White	0.5	15.6	0.7	8.0	4.3	0.8	2.0
Blackjack	0.5	13.4	0.5	0.6	8.3	0.2	0.9
Hickories							
Pignut	1.0	17.1	1.6	4.0	3.8	0.3	2.5
Mockernut	0.2	13.6	0.2	3.4	6.4	0.8	1.3
Other Potential							
Overstory Hardwoods							
Blackgum	1.0	13.2	1.0	2.0	4.9	0.3	1.7
Red Maple	-	-	-	1.6	3.5	0.1	0.1
Understory Hardwoods							
Sourwood	0.2	12.9	0.2	36.0	3.8	2.8	3.9
Dogwood	-	-	-	0.6	4.3	0.1	0.1
Pines							
Virginia	0.5	13.1	0.5	28.0	5.8	5.1	7.3
Totals	35.4	-	38.6	228.2	-	37.6	100.0

(17.5 percent) and a smaller proportion of black oak (8.9 percent). Both species are well adapted to these sites and each has the potential to dominate.

Fourth year regeneration. One of the prescribed fires conducted prior to the fourth growing season (May 2) was blown across plowed fire lines by gusty winds into clearcut areas that were not intended to be burned. As a result, all study plots in the clearcuts of Area I were burned (Figure 5). Since this left no replication of burned plots, no statistical tests of the effects of prescribed burning were possible. Many effects were obvious, however, and will be discussed. Means of burned and unburned plots were tabulated separately (Table 4).

The majority of the stumps that had live sprouts at the end of the third growing season still had live sprouts one year after burning. This varied somewhat by species and diameter class. Seventy-nine percent of the stumps from sapling sized trees that were alive just prior to burning survived the fire. Survival rates of oaks in this size class were generally above 60 percent. Black oak, white oak, and Southern red oak had survival rates of 95, 83, and 88 percent, respectively. Several other species in the sapling size class had excellent survival rates. These included mockernut hickory (89 percent), pignut hickory (82 percent), blackgum (76 percent), red maple (71 percent), sassafras (81 percent), and sourwood (75 percent). Of the survivors in the pulpwood size class, the oaks were most abundant. Black oak had the best survival rate of all species

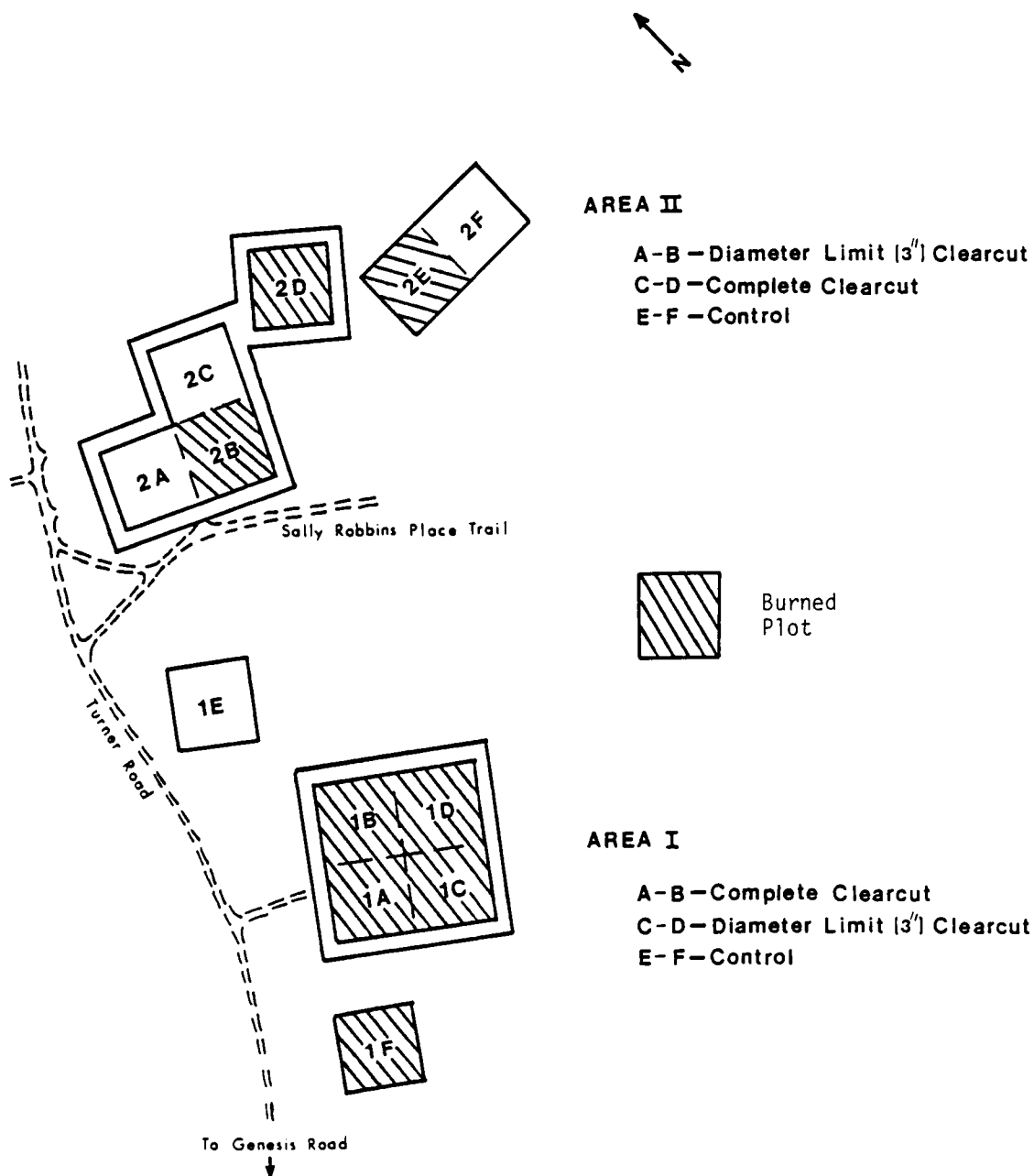


Figure 5. Location of burned plots.

TABLE 4

SURVIVAL OF STUMPS IN BURNED CLEARCUTS BEFORE AND AFTER PRESCRIBED FIRE
(BOTH CUTTING TREATMENTS COMBINED)

Species	Sapling (6' High-2.9" dbh)		Pulpwood (3.0"-10.9" dbh)		Sawtimber (11.0" dbh and over)	
	No. alive before burning	No. alive after burning	No. alive before burning	No. alive after burning	No. alive before burning	No. alive after burning
Oaks	2	0 (0)	2	0 (0)	-	- (-)
Blackjack	14	8 (57)	36	25 (69)	7	5 (71)
Scarlet	56	53 (95)	18	15 (83)	-	- (-)
Black	24	20 (83)	26	15 (58)	-	- (-)
White	33	29 (88)	23	15 (65)	-	- (-)
Southern Red	22	14 (64)	14	10 (71)	3	1 (33)
Post						
Hickories						
Mockernut	9	8 (89)	3	3 (100)	-	- (-)
Pignut	50	41 (82)	-	- (-)	3	2 (67)
Other Potential						
Overstory Hardwoods						
Blackgum	79	60 (76)	-	- (-)	1	0 (0)
Red Maple	7	5 (71)	2	0 (0)	-	- (-)
Understory Hardwoods						
Am. Chestnut	2	0 (0)	-	- (-)	-	- (-)
Am. Holly	2	2 (100)	-	- (-)	-	- (-)
Serviceberry	1	0 (0)	-	- (-)	-	- (-)
Sassafras	83	67 (81)	-	- (-)	-	- (-)
Sourwood	20	15 (75)	65	41 (63)	-	- (-)
Dogwood	16	10 (63)	7	4 (57)	-	- (-)
Totals	420	332 (79)	196	128 (65)	11	8 (72)

observed in this size class (83 percent). Very few sawtimber sized stumps had sprouts after the third growing season. Of those that did, stumps of scarlet oak and pignut hickory had excellent survival rates after the fires.

An analysis of variance was conducted to test for differences in stem numbers between the two treatments, 10 species, and the two size classes of saplings by considering only burned plots (Table 27 Appendix A). The results were nearly identical to those of the third year regeneration. There was no significant difference between the number of stems in complete and diameter limit clearcut plots. Also, there was no significant difference between the number of seedlings and sprouts. Highly significant differences were detected, however, between the stem numbers for each species.

Regeneration after the fourth growing season had a large component of oaks in both burned and control plots (Table 5). In both areas, stems of black oak and scarlet oak were the most abundant of the oaks. The oaks as a group made up 22.6 percent of the stem count in unburned plots and 18.7 percent in burned plots. This difference may be due to the sprouting characteristics of sassafras and blackgum. These species are prolific sprouters and resprouted vigorously after burning (Table 4). Burning may have stimulated the sprouting of sassafras and blackgum as shown by the large increase in the stem numbers of these species in burned plots (Table 5). Sassafras had almost 2,200 stems per acre in unburned plots and over 4,000 stems per acre in burned plots. Blackgum had only 750 stems per acre in unburned plots as compared to over 2,600 stems per acre in burned

TABLE 5

REGENERATION FOUR YEARS AFTER CUTTING (BOTH TREATMENTS COMBINED)
AND ONE YEAR AFTER BURNING

Species	Burned	Unburned
	-- Mean Number of Stems Per Acre (Percent)--	
Oaks		
Scarlet	779.6 (7.5)	500.1 (7.0)
Black	453.7 (4.4)	716.7 (10.0)
Southern Red	359.3 (3.5)	161.1 (2.2)
Post	209.3 (2.0)	138.9 (1.9)
White	138.9 (1.3)	105.6 (1.5)
Chestnut	3.7 (0.1)	- (-)
Hickories		
Pignut	112.0 (1.1)	249.9 (3.5)
Mockernut	22.2 (0.2)	39.0 (0.5)
Other Potential Overstory Hardwoods		
Blackgum	2631.5 (23.5)	750.0 (10.4)
Red Maple	296.3 (2.9)	1105.5 (15.4)
Persimmon	14.9 (0.1)	55.5 (0.8)
Black Locust	270.4 (2.6)	166.8 (2.3)
Black Cherry	1.9 (0.1)	5.7 (0.1)
Yellow-poplar	- (-)	11.1 (0.2)
Understory Hardwoods		
Sassafras	4050.0 (39.2)	2177.7 (30.3)
Dogwood	187.0 (1.8)	183.3 (2.6)
Sourwood	446.3 (4.3)	583.2 (8.1)
Serviceberry	5.6 (0.1)	50.1 (0.7)
Am. Holly	11.1 (0.1)	16.8 (0.2)
Am. Chestnut	5.6 (0.1)	111.1 (1.5)
Hawthorn	1.9 (0.1)	- (-)
Winged Sumac	357.4 (3.5)	5.7 (0.1)
Pines		
Virginia	7.4 (0.1)	44.7 (0.6)
Totals	10,339.0 (100.0)	7178.4 (100.0)

plots. These two species combined had over 6,600 stems per acre in burned plots which was almost equal to the total number of stems of all species in unburned plots (7,178). The numbers of oak stems remained relatively unchanged after burning. However, with the large increase in the numbers of blackgum and sassafras stems, oak percentages decreased.

An opposite trend after burning was observed with red maple. Even though red maple was a prolific sprouter and had good survival rates after burning, the average number of stems per acre was much smaller in burned plots (296.3) than in unburned plots (1105.5). This may be due to the distribution of this species through the plots rather than to burning, however. Before the fires were conducted, red maple distribution was observed to be patchy. Stems of this species appeared to be more abundant in plots that were to be left unburned. Had red maple been more uniformly distributed over burned and unburned plots, it may have shown a different response to fire.

The frequency of pines and other pioneer species remained low in burned and control plots through the fourth growing season after cutting. Virginia pine was the only pine species observed, although shortleaf pine and Eastern white pine are native in the region. The average number of Virginia pine seedlings per acre was 44.7 in unburned plots and 7.4 in burned plots. Yellow-poplar was observed in unburned plots at the rate of only 11.1 seedlings per acre. No seedlings or sprouts of this species were found in burned plots.

Stems of sprout origin composed a large portion of the fourth year regeneration. The majority of stumps from sapling sized trees

had live sprouts after this period of time (Table 28 Appendix A). This was consistent for both burned and unburned plots. The oaks were the most abundant group of sprouts from sapling sized stumps. Pignut hickory, blackgum, and sassafras were also common species in this size class. Sprouts from stumps of pulpwood sized trees were less common but were also dominated by the oaks. Sourwood was a common understory species in the pulpwood size class. Sprouting from sawtimber sized trees was uncommon. The only species in this size class that had live sprouts after four growing seasons were scarlet oak, post oak, pignut hickory, and sourwood.

Red maple was the most prolific sprout producing species after four growing seasons with almost 18 sprouts per cut stem in the pulpwood size class (Table 29 Appendix A). Sourwood and dogwood stumps were also prolific sprout producers. This did not seem to vary between burned and unburned plots.

As was noted for the previous year, basal sprouts were the most common form of sprouts for most species after four growing seasons (Table 30 Appendix A). This was true for both burned and unburned plots. A few root sprouts were observed near stumps of pignut hickory, blackgum, and sassafras. Several stumps of scarlet oak and dogwood had stump sprouts.

Uncut trees after 4 years. The survival of uncut sapling and pulpwood sized trees in unburned diameter limit clearcuts was essentially unchanged between the third and fourth years after cutting (Table 6). Every black oak, post oak, and sourwood tree that was left

TABLE 6

STATUS OF RESIDUAL STEMS FOUR YEARS AFTER DIAMETER LIMIT CLEARCUTTING
AND ONE YEAR AFTER BURNING

Species	Burned		Unburned	
	No. left after cutting	No. alive after 4 years	No. left after cutting	No. alive after 4 years
Oaks	-----	Mean Number Per Acre (Percent)	-----	-----
Southern Red	14.1	0 (0)	26.7	8.9 (33)
Black	16.3	0 (0)	8.9	8.9 (100)
Post	6.7	1.5 (22)	8.9	8.9 (100)
White	7.5	0 (0)	-	- (-)
Scarlet	5.9	0 (0)	8.9	4.4 (50)
Hickories				
Pignut	24.4	0 (0)	17.8	13.3 (75)
Mockernut	1.5	0 (0)	44.4	35.6 (80)
Other Potential Overstory Hardwoods				
Blackgum	32.5	1.5 (5)	37.8	22.2 (59)
Red Maple	-	- (-)	15.6	2.2 (14)
Understory Hardwoods				
Sassafras	35.6	0 (0)	22.2	0 (0)
Sourwood	21.5	0 (0)	4.4	4.4 (100)
Dogwood	19.2	0 (0)	24.4	8.9 (36)
Pines				
Virginia	23.7	1.5 (6)	2.2	0 (0)
Totals	208.8	4.5 (2)	222.2	117.7 (53)

uncut in unburned plots was still alive at the last remeasurement. Southern red oak was the only species that showed a large drop in survival rate. Of the 22.2 trees per acre of this species that were alive the previous year, only 8.9 were alive at the end of the fourth growing season (Table 2). Growth and crown development of these trees remained minimal during the fourth growing season.

Survival rates of uncut sapling and pulpwood sized trees in burned, diameter limit clearcuts were very low. After the third year, there were almost 125 trees per acre left in these areas. Of these, only 4.5 survived through the fourth year. These included 1.5 trees per acre of post oak, blackgum, and Virginia pine.

Control plots after 4 years. Prescribed burning in unharvested control plots resulted in the mortality of many trees, particularly in the pulpwood size class (Table 7). Burned plots had an average of 133.3 trees per acre of this size class with 23.6 square feet of basal area. In unburned plots, the pulpwood sized class averaged 207.7 trees per acre with 37.7 square feet of basal area. This difference was not as pronounced with sawtimber sized trees, however. This size class had 29.3 trees and 31.7 square feet of basal area per acre in burned plots. Unburned plots had 37.4 trees per acre with 35.2 square feet of basal area. Tree death in burned plots did not appear to be species-specific. Most species had lower basal areas in burned plots than in unburned plots, while the relative abundance of each species showed little change. The oaks predominated the canopy with scarlet oak, post oak, black oak, and Southern red oak being the most

TABLE 7

SPECIES COMPOSITION OF BURNED AND UNBURNED CONTROL PLOTS AFTER FOUR GROWING SEASONS
(ONE GROWING SEASON AFTER BURNING)

Species	Sawtimber (11.0 in. dbh and over)				Pulpwood (3.0 to 10.9 in. dbh)			
	Burned		Unburned		Burned		Unburned	
	Mean No. Per Acre (ft.2/Acre)	Mean BA (ft.2/Acre)	Mean No. Per Acre (ft.2/Acre)	Mean BA (ft.2/Acre)	Mean No. Per Acre (ft.2/Acre)	Mean BA (ft.2/Acre)	Mean No. Per Acre (ft.2/Acre)	Mean BA (ft.2/Acre)
Oaks								
Scarlet	3.9	5.1	7.5	8.7	-	-	15.6	4.4
Post	15.3	14.3	10.0	8.7	23.3	6.2	41.1	10.4
Southern Red	2.2	3.3	9.4	6.5	10.0	2.2	55.6	9.5
Black	3.3	4.5	6.7	7.2	8.9	1.7	41.1	7.8
White	0.6	0.7	0.6	0.2	7.8	0.8	1.1	0.3
Blackjack	0.6	0.5	0.6	0.8	-	-	-	-
Hickories								
Pignut	0.6	0.8	1.4	2.2	3.3	0.2	3.3	0.3
Mockernut	-	-	0.3	0.3	-	-	4.4	1.0
Other Potential								
Overstory Hardwoods								
Blackgum	1.4	1.2	0.6	0.3	-	-	1.1	0.3
Red Maple	-	-	-	-	-	-	2.2	0.1
Understory Hardwoods								
Sourwood	0.3	0.3	-	-	36.7	3.4	28.9	2.0
Dogwood	-	-	-	-	2.2	0.2	5.6	0.6
Pines								
Virginia	1.1	1.0	0.3	0.3	41.1	8.9	7.7	1.0
Totals	29.3	31.7	37.4	35.2	133.3	23.6	207.7	37.7

abundant. Understory species were predominated by sourwood and dogwood.

Conclusions

Several conclusions pertinent to forest stand modeling of the CWMA may be drawn from the results of these field studies. The species composition of regeneration in young clearcuts was largely a function of sapling and pulpwood sized trees harvested. Sprouts from cut stems of these size classes composed a large portion of the regenerated stand. In addition, species that were prolific sprouters tended to dominate the regeneration. The seedlings that were a component of the regeneration tended to be of the same species as the harvested trees suggesting that root suckering may be more important than casual observation would indicate. Pioneer species were generally absent from the clearcut study areas. Seedlings of Virginia pine and yellow-poplar were present but only in small numbers.

Regeneration and stand development was relatively unaffected by the choice of either diameter limit or complete clearcutting methods. Species composition and stem numbers tended to be the same with both methods. The uncut sapling and pulp sized trees in diameter limit cuts generally did not respond to release. Therefore, these trees competed very little with the regeneration.

Browsing in large, nearly square clearcuts had no apparent affect on the development of young stands. Even though certain species preferences were noted, vegetation was abundant and only a small

portion was browsed. This proportion was too small to cause differences in mean growth rates or in numbers of individuals.

Prescribed burning of young clearcuts affected the rate of stand development but had little affect on species composition.

Regeneration observed 1 year after burning was very similar to that observed the first year after cutting. Species composition was very similar in burned and unburned plots, both being dominated by oaks. The most obvious differences between burned and unburned plots were the sizes and ages of the regeneration. Burned clearcuts had small, 1-year-old seedlings and sprouts while unburned clearcuts had larger, 4-year-old seedlings and sprouts. In terms of modeling, prescribed fire in young clearcuts should produce results similar to clearcutting.

CHAPTER IV

DESCRIPTION OF THE INITIAL MODEL

The selection of an appropriate model to simulate stands on the Catoosa Wildlife Management Area (CWMA) and its initial development (Phase I) was conducted by Brandt et al. (1981). Simultaneously, an independent field study (Phase II) was being conducted by Muncy (1980) to provide verification information. This model, FORCAT (FOREsts of the CAToosa), was a spatial gap model (Shugart and West, 1980) that was patterned after the FORET model of Shugart and West (1977) and the JABOWA model of Botkin et al. (1972a and 1972b). The major modification of FORET to produce the initial version of FORCAT was the change of species and appropriate growth parameters to those typical of the CWMA. This version of FORCAT considered the 31 species listed in Table 8. Other changes to FORET were mainly in the formatting of input and output. Therefore, much of the following description of the initial version of FORCAT also applies to its predecessor, FORET.

FORCAT was designed to simulate stand development on a $1/5$ acre ($1/12$ hectare) plot beginning with bare ground in the first simulated year and continuing for a user-specified number of years. The model also had the flexibility to be run for any number of plots and to graphically display the species composition of the average plot. For each simulated year, the model computed the numbers of individuals and biomass of each species on the plot as well as the dbh of each tree. Annual diameter growth was calculated as a function of species, present tree size, available light, climate, and competition with

TABLE 8

TREE SPECIES INCLUDED IN THE INITIAL VERSION OF FORCAT

Red Maple	Shortleaf Pine
Sugar Maple	Eastern White Pine
Bitternut Hickory	Virginia Pine
Pignut Hickory	Black Cherry
Shagbark Hickory	White Oak
Mockernut Hickory	Scarlet Oak
Dogwood	Southern Red Oak
Persimmon	Blackjack Oak
White Ash	Chestnut Oak
American Holly	Post Oak
Black Walnut	Black Oak
Eastern Redcedar	Black Locust
Sweetgum	Sassafras
Yellow-poplar	Eastern Hemlock
Blackgum	Winged Elm
Sourwood	

nearby trees. Tree birth and death were determined stochastically on a yearly basis.

The initial version of FORCAT was written in Fortran IV and implemented on the University of Tennessee's IBM Series 3031 computer. This version had 13 subroutines and functions (Figure 6) in addition to the main driving program. Many of these were used to input data and to print results at an interval of any desired number of years during the simulation. In terms of computations, subroutines BIRTH, SPROUT, KILL, and GROW were the major components of the model. Table 9 summarizes the main operations of each subroutine and function of the initial version of FORCAT.

Subroutine INPUT

The INPUT subroutine was designed to read species parameters from data cards at the end of the program. One card containing values for each of 18 parameters was provided for each species. Most of these parameters were used in the determination of annual diameter growth for each tree or for the determination of the probability of the birth or death of trees of each species in each year. These parameters have been summarized in Table 10 and will be presented in greater detail in the discussion of appropriate subroutines.

Subroutine PLOTIN

The PLOTIN subroutine was developed to allow the input of the characteristics of any forest stand. The simulation could, therefore, begin at any point in time and with any type of stand. PLOTIN was set

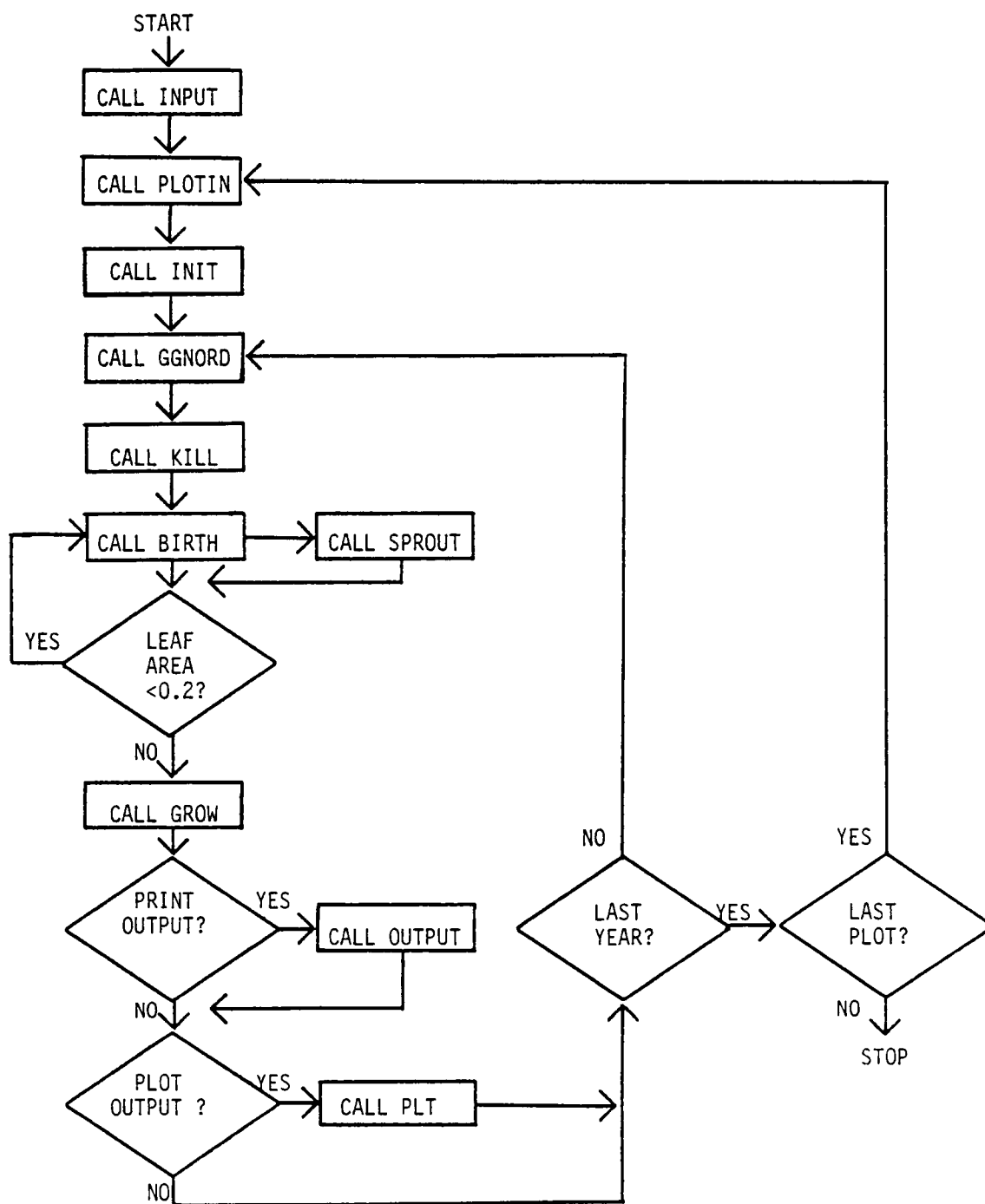


Figure 6. Flow diagram of the initial version of FORCAT.

TABLE 9

SUMMARY OF THE SUBROUTINES AND FUNCTIONS
IN THE INITIAL VERSION OF FORCAT*

Subroutine	Operations Performed
INPUT	Read in and listed species parameters
PLOTIN	Initialized plot to desired stand characteristics
INIT	Initialized all other arrays not handled by PLOTIN
RANDOM	Called the RANDU function
KILL	Stochastically killed trees
GROW	Calculated yearly growth for each tree
BIRTH	Added new seedlings to the plot and called the SPROUT subroutine
SPROUT	Determined which species were eligible to sprout and added sprouts to the plot
OUTPUT	Printed dbh of each tree and other summary statistics
ERR	Printed error message when tree number was over 700
GGNORD	Drew a number from a normal distribution
PLT	Plotted output
<u>Function</u>	<u>Operations Performed</u>
RANDU	Uniform random number generator

* Reprinted from Brandt and Dearden (1980).

TABLE 10

INPUT PARAMETERS FOR THE INITIAL VERSION OF FORCAT*

Parameter Name	Meaning
AAA	Species name
DMAX	Maximum degree-days for species range
DMIN	Minimum degree-days for species range
b3	Species specific growth parameter
b2	Species specific growth parameter
ITOL	Shade tolerance 1 = tolerant 2 = intolerant
AGEMX	Maximum age recorded for species
G	Species specific growth constant
CURVE	Choice of empirical curve for biomass calculation 1 = deciduous trees other than yellow poplar 2 = conifers 3 = yellow poplar
SPRTND	Sprouting tendency 0 = no sprouting 3 = high sprouting tendency
SPRTMN	Minimum dbh of tree which will sprout
SPRTMX	Maximum dbh of tree which will sprout
SWITCH(1)	Does the seed require a litter layer to germinate? T or F
SWITCH(2)	Does the seed require mineral soil to germinate? T or F
SWITCH(3)	Is the seedling susceptible to hot years? T or F
SWITCH(4)	Is the seedling a preferred wildlife food? T or F
SWITCH(5)	Does the species produce mast which is eaten by wildlife? T or F
KTIME	Seed source limitation for old-field successional species

*Reprinted from Brandt and Dearden (1980).

to give values of zero to the age and size of all trees, thus simulating stand development beginning with bare ground.

Subroutine GROW

The GROW subroutine calculated the annual diameter growth of each tree on the simulated plot. The growth equation for trees growing under optimal conditions was,

$$\frac{dD}{dt} = \frac{GD(1 - DH/D_{MAX} * H_{MAX})}{(274 + 3b_2D - 4b_3(D*D))} \quad (1)$$

where: D = present dbh,

H = present tree height,

D_{MAX} = record dbh attained for each species,

H_{MAX} = record height attained for each species,

b₂ = a constant derived from D_{MAX},

b₃ = a constant derived from H_{MAX}, and

G = a constant derived from D_{MAX} and the record age
of each species.

This equation was developed by Botkin et al. (1972b) under the assumptions that (i) annual diameter growth in trees was proportional to the amount of sunlight received by the tree and (ii) growth rates were reduced as the tree reached its maximum size. The first assumption took into account the increase in leaf area attained as trees grew. The second assumption accounted for the energy required to maintain the living tissue in older trees. Detailed descriptions

of the development of this equation were given by Botkin et al. (1972b) and Shugart and West (1977).

The values for the variables in this growth equation were relatively easy to obtain. DMAX and HMAX were listed in either dendrology (Harlow and Harrar, 1969) or silvics (Fowells, 1965) textbooks. These values were then used to determine the constants b_2 and b_3 with the following equations:

$$b_2 = 2(HMAX - 137)/DMAX \quad (2)$$

$$b_3 = (HMAX - 137)/(DMAX*DMAX). \quad (3)$$

These equations were developed by Botkin et al. (1972b) from Ker and Smith's (1955) height equation,

$$H = 137 + b_2D - b_3(D*D) \quad (4)$$

by choosing b_2 and b_3 so that H equals $HMAX$ and dH/dD equals zero when D equals $DMAX$. By using the calculated values for b_2 and b_3 as constants in equation (1), the species-specific values of the constant G were determined. A value of this constant was selected so that the cumulative results of the growth equation (1) would equal two-thirds of the maximum diameter ($DMAX$) at one-half of the maximum age ($AGEMX$) for each species. Without adjustments for climate and competition, equation (1) was capable of simulating trees of record size. Trees of this size were rarely observed in model output, however, since these growth limiting factors and other mortality rates were considered in the model.

Competition between individual trees in the simulated plot was partially described in the vertical sense by the assumption that all trees taller than a given tree would cast shade on that tree. This

assumption is unique to gap models since the area over which a single tree can cast shade is relatively small. The height of each tree on the simulated plot was calculated by equation (4). For any given tree, the leaf areas of all taller trees on the simulated plot were calculated by using,

$$L = (aD)\exp(b) \quad (5)$$

where L is the leaf area of a tree at diameter, D , while a and b are constants with values of 0.1193 and 2.939, respectively (Sollins et al., 1973; vide Shugart and West, 1977). Light extinction was calculated as a function of the sum of the leaf areas above each tree on the plot. Methods and equations for this function were described by Botkin et al. (1972b) and Shugart and West (1977). Available light was denoted by the variable AL and growth reduction by shading was denoted by $r(AL)$.

FORCAT used separate equations for shade tolerant and shade intolerant species to determine the reduction of growth rates due to shading. These equations were:

$$r(AL) = 1 - \exp(-4.64(AL-0.05)) \quad (6)$$

for shade tolerant species and:

$$r(AL) = 2.24(1 - \exp(-1.136(AL - 0.08))) \quad (7)$$

for shade intolerant species. These two functions were scaled to yield results from zero to one for conditions of complete darkness to complete sunlight and gave reasonable results when compared to measured photosynthesis curves (Kramer and Kozlowski, 1960). Each of the species in the initial version of FORCAT were classified as either shade tolerant or shade intolerant based on species descriptions given

by Fowells (1965) and Harlow and Harrar (1969) or by the previous modeling studies of Shugart and West (1977) and Mielke et al. (1978). The growth rates of species of intermediate shade tolerance were assumed to equal those of tolerant species.

Botkin et al. (1972b) assumed that each species had an optimal temperature for photosynthesis and that net photosynthesis decreased as temperatures varied above or below this optimum. To estimate the effects of this on growth rates they first calculated the number of growing degree-days (DEGD) for a site above a base of 40 degrees F. Then they calculated the parabolic function,

$$T(\text{DEGD}) = \frac{4(\text{DEGD} - \text{DDMIN})(\text{DDMAX} - \text{DEGD})}{(\text{DDMAX} - \text{DDMIN})(\text{DDMAX} - \text{DDMIN})} \quad (8)$$

where DDMAX and DDMIN are the maximum and minimum growing degree-days calculated from mean temperatures from the southern and northern extremes of each species' native range. This function had a value of one at median temperatures and zero at DDMAX and at DDMIN. This approach was adapted to FORCAT using DDMAX and DDMIN values determined by Shugart and West (1977) and Mielke (1978) and by using a growing degree-day base of 42 degrees F.

Growth reduction in the horizontal sense (due to crowding or root competition) was estimated by the function,

$$S(\text{BAR}) = 1 - \text{BAR}/\text{SOILQ}, \quad (9)$$

where BAR was the biomass of the simulated stand and SOILQ was the maximum biomass recorded for the forests of the area. The value of S(BAR) varied from one in open stands (no growth reduction from competition) to zero in dense stands.

The results of equation (8) for temperature effects and equation (9) for stand density, as well as the appropriate results of either equation (6) or (7) for shade tolerance, were multiplied by the result of the optimal growth equation (1) to determine annual diameter increment. These equations do not consider the effects of soil moisture as Botkin et al. (1972b) described for JABOWA. Therefore, the use of these equations was restricted to lower slope sites (Shugart and West, 1977).

Subroutine KILL

The probability of the death of individual trees in each simulated year was determined as a function of the present age of each tree. Botkin et al. (1972b) assumed that for actively growing trees, no more than 2 percent of of all saplings would reach the maximum age (AGEMX) recorded for that species. This probability was changed to 1 percent for FORET (Shugart and West, 1977) and was used for the initial version of FORCAT. Slow growing trees were subjected to a second death mechanism. Trees that grew less than 0.04 inches (1 millimeter) per year were given a 1 percent chance of surviving for 10

years (36.8 percent each year). A detailed description of the equations used in KILL was given by Botkin et al. (1972b).

Subroutine BIRTH

For each simulated year, the BIRTH subroutine compiled a list of species which were eligible to enter the plot. A seed source for all species was assumed to be present, however, eligibility for germination was potentially limited by any of five comparisons of environmental conditions to the silvical requirements of each species. The environmental conditions were estimated by the model and included the presence of mineral soil, the presence of a litter layer, mean ambient temperature for the growing season, wildlife predation of seeds, and wildlife browsing of young trees.

The requirements of each species for mineral soil or leaf litter for germination as well as species sensitivity to hot conditions were the same as used in FORET (Shugart and West, 1977) and FORAR (Mielke et al., 1978) and originally obtained from Fowells (1965). Preferred browse species for saplings and seed were also those used in FORET and FORAR. The original sources for this information were Fowells (1965), Harlow and Harrar (1969), and Halls and Alcaniz (1972). Mineral soil was assumed to be present on the 1/5 acre (1/12 hectare) plot until stand biomass reached 0.2 metric tons (179 pounds). A greater stand biomass was assumed to produce a litter layer. The temperature for each growing season was determined from a random selection from a group of numbers with a mean and standard deviation appropriate to the temperature of a weather station near the CWMA and Crossville,

Tennessee. Germination was reduced in years having a temperature greater than the mean. Consumption by wildlife was assumed to cause a major reduction in seed availability for preferred species in half of the simulated years. Heavy browsing of preferred species which eliminated species from the plot was also assumed to occur in half of the simulated years.

Once the list of species eligible to germinate was compiled, the BIRTH subroutine randomly selected each species from one to three times and added from zero to seven seedlings of that species to the simulated plot. Seedlings entered the plot at an average of 0.5 inch (1.27 centimeters) dbh. BIRTH was repeated several times during the first year of simulation until the plot had an appropriate number of trees (approximately 700).

Subroutine SPROUT

The SPROUT subroutine used similar methodology to BIRTH for selecting species of sprouts to add to the simulated plot. A list of eligible species was compiled and either one, two, or three sprouts of these species were added to the plot depending on the value of the species-specific variable SPRTND. This variable was a measure of the average number of sprouts produced per tree. SPRTND had a value of zero for species that do not sprout and three for species that are prolific sprout producers. Sprouts entered the plot at an average dbh of 0.04 inch (1 millimeter).

Species eligibility to sprout was determined by the death of a tree in subroutine KILL and whether the tree was of appropriate size.

Trees that were larger than a specified maximum diameter (SPRTMX) or smaller than a specified minimum diameter (SPRTMN) were not allowed to sprout.

Other Subroutines and Functions

Subroutine INIT was used to initialize all arrays that were not handled by PLOTIN. The ERR subroutine printed an error message when the number of trees exceeded 700. Function RANDU and subroutine RANDOM were used together to select random numbers. The GGNORD subroutine drew a number from a normal distribution which was used to determine the growing degree-days for each simulated year. Subroutine OUTPUT printed the dbh of each tree on the plot at desired intervals. Summary statistics were also printed by this subroutine. The PLT subroutine was written for FORET (Shugart and West, 1977) to provide a graphical summary of species composition for the mean of all simulated plots. Although incorporated into the initial version of FORCAT, PLT was not adapted for use with the University of Tennessee computing system and therefore, was not used.

Model Output

The initial version of FORCAT was provided by Brandt, et al. (1981) (Phase I) for evaluation and refinement as a part of the current study (Phase III). The model was run for a simulated period of 100 years and output was averaged for 100 simulated plots. Table 11 compares the percentage of the total basal area represented by each species as predicted by the model for years 50 and 100 to control plot data from study areas on the CWMA (Table 3). The mean age of control

TABLE 11
COMPARISON OF CONTROL PLOT DATA TO OUTPUT FROM THE
INITIAL VERSION OF FORCAT

Species	Predicted at 50 Years	Predicted at 100 Years	Observed in Control Plots
----- Percentage of Total Stand Basal Area -----			
Oaks			
Scarlet	0	0	14.7
Post	0	0	31.0
Southern Red	0	0	18.5
Black	15.8	28.2	15.9
White	0	0	2.0
Blackjack	0	0	0.9
Chestnut	1.7	1.0	0
Hickories			
Bitternut	0.9	2.0	0
Pignut	0	0	2.5
Mockernut	0	0	1.3
Other Potential Overstory Hardwoods			
Blackgum	0	0	1.7
Red Maple	13.9	6.5	0.1
White Ash	3.0	4.1	0
Black Walnut	12.5	11.3	0
Yellow-poplar	30.4	38.5	0
Black Cherry	3.8	0.8	0
Understory Hardwoods			
Sourwood	0.8	0.1	3.9
Dogwood	0	0	0.1
Sassafras	10.0	4.2	0
Conifers			
Virginia Pine	0	0	7.3
Eastern Redcedar	4.1	3.1	0

plots was not determined but it was assumed to be between 50 and 100 years.

With the exception of black oak, model output had no similarity to species composition observed on the CWMA. Yellow-poplar was the dominant species simulated by the initial version of FORCAT at 50 and 100 years. Secondary species on simulated plots were black oak and black walnut. Observed control plots were predominated by mixtures of post oak, scarlet oak, Southern red oak, and black oak.

These results indicate a lack of site-specific considerations for growth and establishment rates of individual species in this version of the model. Dry upland sites such as those on the study areas of the CWMA cannot support moisture demanding species such as yellow-poplar and black walnut. Modeling can often be a trial and error process where different methods are used until acceptable results are obtained. One of the stated objectives of the current study was to develop FORCAT into a model usable for making forest management decisions. Since the first version of FORCAT was considered unacceptable for this purpose, the development and trial of new versions was required.

CHAPTER V

THE SECOND VERSION OF FORCAT

In addition to the first version of FORCAT, several other spatial gap models for various types of forests were developed by modifications to FORET (Shugart and West, 1977) (Figure 7). Among the modifications in these models was the implementation of several modeling techniques to control simulated stand development on the basis of site-specific variables. The general procedure for the development of a second version of FORCAT has been to update the model in terms of current modeling technology by incorporating these new modeling techniques where the needed species-site relationships are known. Results of field studies on the CWMA provided that information for the development of the second version of FORCAT.

Development of the Second Version of FORCAT

The second version of FORCAT was developed by making several changes to subroutines and input parameters and by the addition of two new subroutines. These changes are as follows:

Changes to input parameters. Each of the 18 input parameters for each species which were a part of the initial version of FORCAT (Table 10) was checked for accuracy. Minor changes were required for the growth constants b2 and b3. These differences were attributed to rounding errors. The variable AGEMX, the record age for each species, was changed for several species to reflect more reliable data. The same sources were used as before (Fowells, 1965 and Harlow and Harrar,

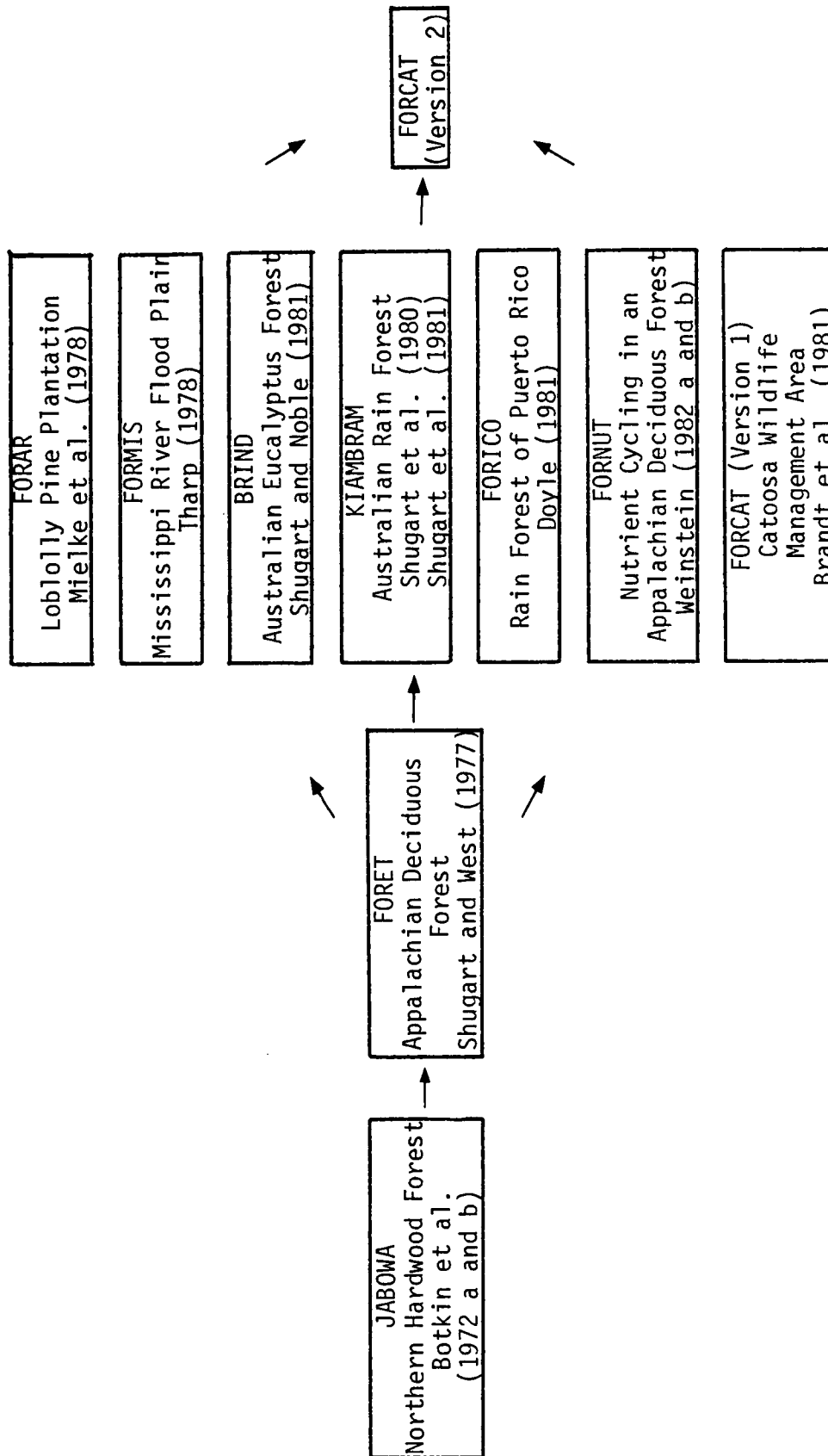


Figure 7. The evolution of the FORCAT model.

1969), however, these sources did not agree for several species and the lesser of the two had been used previously. The variables DMAX and DMIN were changed from a base of 42 degrees (F.) to a base of 5.83 degrees (C.). This was done so that all measurements in FORCAT would be metric. Input parameters for each species in the second version of FORCAT are listed in Table 12.

Parameters which dealt with sprouting were also changed. In the first version of FORCAT, the variable SPRTND, the mean number of sprouts produced by stumps of each species, was assigned a value from zero to three. Therefore, the most prolific sprouting species yielded a mean of only three sprouts per stump. This was much lower than observed by Muncy (1980) and during field observations in the current study on plots of the CWMA. New values were assigned to SPRTND equal to the mean number of sprouts from all cut trees of each species which were observed during the first year after clearcutting. These values ranged from zero for species that do not sprout to 14 for red maple and sourwood (Table 12). SPRTND was not changed for species which were absent from CWMA study plots.

The parameter SPRTMN, the dbh below which each species did not sprout, was eliminated from the model. Repeated field observations indicated that small trees were the most likely to sprout. The majority of the values of SPRTMN used in the first version of FORCAT were either 2.4 or 4.7 inches (6 or 12 centimeters). Many trees smaller than this were cut in study plots and most sprouted during the first growing season. While it is likely that there is a diameter

TABLE 12

SPECIES PARAMETERS USED IN THE SECOND VERSION OF FORCAT

Species	DMAX	DMIN	b3	b2	ITOL	AGENX	G	SPRTND	SPRTMX	SWITCH	KTIME	D3	NUM
Red Maple	7439	1278	.1725	52.60	2	150.	141.0	14.	200.	FTTTF	9999	210.	1
Sugar Maple	5000	889	.0773	33.00	1	125	259.0	1.	50.	FFTF	9999	180.	2
Serviceberry	6023	1930	.5174	46.92	2	100.	42.0	3.	10.	FFFTF	9999	250.	3
Bitternut Hickory	5094	1928	.3412	83.25	4	300.	149.0	1.	200.	TFTFF	30	210.	4
Pignut Hickory	6978	1928	.2879	70.25	4	300.	127.0	6.	200.	TFTFF	30	250.	5
Shagbark Hickory	6978	2056	.2573	62.75	4	275.	125.0	1.	200.	TFTFF	9999	220.	6
Mockernut Hickory	6011	1928	.3916	23.10	4	300.	99.0	5.	200.	TFTFF	9999	280.	7
Dogwood	6011	1928	.5174	47.34	1	100.	115.0	12.	200.	FFTTF	9999	270.	8
Persimmon	7439	2678	.0840	35.86	2	150.	232.0	6.	200.	FFTTF	30	160.	9
White Ash	6011	1417	.0806	34.43	3	300.	112.0	2.	20.	FTTTF	9999	220.	10
American Holly	6011	2678	.1957	47.75	1	200.	135.0	6.	40.	TFTFF	9999	280.	11
Black Walnut	4589	1928	.0745	36.37	4	250.	160.0	1.	20.	TFTFF	20	220.	12
Eastern Redcedar	5556	1739	.2367	57.75	4	300.	107.0	0.	0.	FTFFF	20	220.	13
Sweetgum	6011	2678	.1908	58.20	4	250.	152.0	2.	80.	FFFTF	9999	220.	14
Yellow-poplar	6011	1928	.0441	32.25	4	300.	174.0	2.	200.	FTTTF	9999	200.	15
Blackgum	6978	1928	.1646	50.20	2	300.	115.0	7.	200.	FTTTF	9999	300.	16
Sourwood	4589	2678	.7828	95.51	4	100.	259.0	14.	200.	FFFTF	9999	200.	17
Shortleaf Pine	5094	2678	.2900	70.75	3	400.	96.0	1.	20.	FTFFF	9999	240.	18
Eastern White Pine	3183	878	.1963	71.84	3	450.	127.0	0.	0.	FTTTF	9999	170.	19
Virginia Pine	3689	2678	.4208	77.00	4	300.	106.0	0.	0.	FTFFF	20	170.	20
Black Cherry	6011	2150	.0833	35.57	4	200.	173.0	3.	200.	FFFTF	9999	200.	21
White Oak	5556	1739	.0745	36.38	3	400.	100.0	8.	40.	TFFFF	9999	280.	22
Scarlet Oak	4589	2056	.1279	39.00	2	400.	69.0	6.	80.	TFTTF	9999	185.	23
Southern Red Oak	6011	2678	.0786	33.57	4	400.	82.0	6.	30.	TFTTF	9999	220.	24
Blackjack Oak	5556	2511	.1658	30.34	4	400.	36.0	6.	40.	FFFFF	9999	320.	25
Chestnut Oak	4128	1928	.0639	27.29	2	267.	102.0	2.	40.	TFFFF	9999	175.	26
Post Oak	5094	1828	.0974	41.57	4	400.	68.0	5.	30.	TFFFF	9999	310.	27
Black Oak	5094	1828	.0974	41.57	4	300.	133.0	5.	40.	FTFFF	9999	290.	28
Winged Sumac	6011	2768	.2021	43.15	2	100.	37.0	1.	110.	FFFFF	9999	220.	29
Black Locust	3689	2678	.1253	38.20	5	200.	136.0	3.	80.	FTFFF	20	185.	30
Sassafras	6011	1928	.2021	43.15	4	100.	174.0	7.	200.	TFTTF	20	210.	31
Eastern Hemlock	3644	1342	.1041	44.43	1	999.	42.0	0.	0.	TFTTF	9999	160.	32
Winged Elm	6011	2768	.2021	43.15	2	125.	176.0	1.	110.	FFFFF	9999	210.	33

below which sprouting is less frequent for most species, this diameter was below that recommended for cutting during Phase II.

The parameter ITOL, species tolerance to shade, was assigned a value of either 1 for tolerant species or 2 for intolerant species in the first version of FORCAT. Separate equations to reduce diameter growth rates from those of optimal conditions were used for species of each tolerance category. Three categories of shade tolerance were added to the second version of the model for species of intermediate tolerance. Each species was classified as either very tolerant, tolerant, intermediate, intolerant, or very intolerant as reported by Daniel et al. (1979) (Table 12). Diameter growth reductions of very tolerant species were calculated with the same equation as was used for tolerant species in the first version of the model. The equation for intolerant species was used for species of the new category of very intolerants. Reductions in diameter growth for the three intermediate classes were calculated as weighted averages of the results of these two equations. Growth reductions for species of the tolerant category were calculated as 75 percent of the result of the equation for very tolerant species plus 25 percent of the result of the equation for very intolerant species. Intermediate species were given growth rate reductions of 50 percent of the results of each of these two equations. Intolerant species had a growth rate reduction of 25 percent of the result of the equation for very tolerant species plus 75 percent of the result of the equation for very intolerant species.

The values for the parameter for species browsing preferences, SWITCH(4), were changed for several species. In the first version of FORCAT, these values were based on published lists of species preferences. For the second version, however, patterns of browsing observed on study plots of the CWMA were considered. Only those species on which browsing was commonly observed were considered as preferred. These included scarlet oak, southern red oak, blackgum, red maple, persimmon, sassafras, and sourwood. The value of SWITCH(4) was not changed for the species included in the model that were not found on study plots.

A variable for the relative drought tolerance of each species, D3, was added to the list of species parameters (Table 12). This variable was used in a new subroutine added to the second version of FORCAT and will be discussed with that subroutine. Parameters not mentioned in this discussion were left unchanged from the initial version of the model.

Winged sumac and serviceberry were commonly observed on study plots of the CWMA but were not included in the first version of FORCAT. Values for each of the species parameters were added to model input for these, which brought the total number to 33. Parameter values were determined by similar methods as for the species already included.

Additional subroutines. Two additional subroutines, TEMPE and MOIST, were added for the second version of FORCAT. These had

previously been developed for FORNUT by Weinstein (1982a and 1982b) and were adapted from that model.

TEMPE calculated the growing degree-days for each simulated year above a base of 5.83 degrees (C.) (42 degrees F.). This calculation was based on a random selection of mean monthly temperatures from a distribution of temperatures with a mean and standard deviation equal to that observed near Crossville, Tennessee from 1950 through 1979 (USDC, 1950-1979). A similar method for calculating growing degree-days was used in the initial version of FORCAT. However, this was done in the main program and was based on yearly rather than monthly means.

The MOIST subroutine determined the number of days in the growing season in which soil moisture was too low to support tree growth. MOIST was based on Bassett's (1964) assumption that yearly diameter growth is proportional to the number of days in a growing season with adequate soil water availability. Bassett calculated the amount of available water in the root zone using the Thornthwaite (1948) method, and then converted it to soil water potential in bars for every day of the growing season. MOIST used this technique and then summed the number of days in which water potential was below permanent wilting point (PWP). The PWP for trees was defined as 4 atmospheres.

Data required for MOIST included the 30-year temperature and precipitation means and the standard deviations used in TEMPE. Other data required were the latitude of the simulated plot (36.01 degrees, USDC, 1979), mean beginning and ending dates of the growing season (April 18 and October 14, USDA-SCS, 1950), and the centimeters of

water present in the soil of the simulated plot at field capacity (13.1) and at PWP (7.7). Water levels at field capacity and at PWP were based on a 20 inch soil of medium to coarse texture as reported by Muncy (1980) for the soils of study plots on the CWMA.

The number of days with moisture tension in excess of 4 atmospheres as calculated by MOIST were compared to D3 in the GROW subroutine to determine the percentage of growth reduction for each species on the simulated plot. As mentioned before, D3 was a species-specific constant giving an expression of drought tolerance. This variable was assigned values equal to the maximum number of days in a year that each species could survive droughty conditions. This was determined as the average number of days in which soil water availability was below that found at 4 atmospheres at the western-most extent of the range of each species. It was assumed that at this point on an east-west gradient, species were prevented from living further west by an insufficient number of days in which available water was adequate to maintain tree growth (Weinstein, 1982b). The number of days without sufficient water calculated by MOIST in each year was subtracted from D3 and this difference was divided by D3 to determine the percentage reduction of annual diameter increment due to droughty conditions. A further discussion of MOIST and associated calculations was given by Weinstein (1982a, 1982b).

Changes made to existing subroutines. Changes were made to several existing subroutines of the first version of FORCAT. Among these was a change in the starting point for simulation of stand

development. Rather than beginning with bare ground, as was done previously, the second version of the model began with a mature stand. Variables related to the size, age, and species of each tree on an average plot of the CWMA study areas prior to clearcutting were included in the INPUT subroutine. Statements were added to the KILL subroutine to remove each tree at the end of the first simulated year. This technique simulated the forest management method of clearcutting mature stands followed by natural regeneration (seeding and coppice).

Sprouting was allowed for each species in the first version of FORCAT when any tree of appropriate species and of appropriate size 'died' in subroutine KILL. Since this was done on a species by species basis rather than by individual trees, only the number of sprouts equal to the value of SPRTND for each species was added to the plot in the SPROUT subroutine. When more than one tree of each species died, or was removed as was the case with a simulated clearcut, the number of sprouts established was far too small. Weinstein (1982a) changed this approach in FORNUT so that each tree that died was allowed to sprout. This approach was adopted in the second version of FORCAT with several modifications.

Sprouting of each tree that 'died' in the KILL subroutine resulted in an unrealistically large number of trees on the simulated plot, particularly in the first few years of simulation. During this period, mortality of seedlings and sprouts was high which closely resembled natural stand development. However, each of these small trees was allowed to sprout and, therefore, replaced on the simulated plot by an average of up to 14 sprouts, as was the case for red maple

and sourwood. The problem was solved by a change in one of the assumptions used in SPROUT. Rather than each dead tree, only trees that were harvested were allowed to sprout. The assumption was made that when a tree died, regardless of age, its root system also died and it could not produce sprouts. This new theory may be inaccurate occasionally. For example, trees blown down by wind should be eligible to sprout. This occurrence was assumed to be relatively rare and was not included in FORCAT.

A second change in SPROUT involved the average size of sprouts entering the plot. The previous version of FORCAT assigned an average value of 0.04 inch (1 millimeter) as the dbh of each new sprout as compared to 0.5 inch (1.27 centimeters) for seedlings. Observations on study plots of the CWMA indicated that sprouts were no smaller than seedlings. Therefore, sprouts were given an average dbh equal to that of seedlings in the second version of the model.

In the first version of FORCAT, the total number of trees on a 1/5 acre plot was assumed to never exceed 700. However, Muncy (1980) observed nearly 1,000 stems per plot during the first year after clearcutting. To increase this total in this version of the model, two changes were required. First, all arrays that recorded information about each tree on the simulated plot (dbh, height, age, and etc.) had been dimensioned at 700. These were redimensioned at 1200 for the new version of the model. Second, tree number was controlled by a test in the BIRTH subroutine. When total plot biomass was less than 0.22 tons (0.2 metric tons) additional trees were added to the plot by recalling BIRTH and SPROUT until this value was

exceeded. This gave a total of almost 700 trees. The biomass observed on study plots during the first year after clearcutting was equal to 0.35 tons (0.317 metric tons). The biomass test was changed to this larger value to give a larger number of trees on the simulated plot. The result was a total of almost 1,000 trees per plot during the first year after the simulated clearcut which more closely agreed with Muncy's (1980) observations.

Total plot biomass was calculated at the beginning of the BIRTH subroutine for each year. The biomass test for total tree number, however, was not conducted until the end of BIRTH. Therefore, the biomass represented by new seedlings and sprouts created in each pass through BIRTH and SPROUT was not included in the test. Statements were added to BIRTH and SPROUT to include the biomass of these new trees in the test. This should eliminate unnecessary passes through the BIRTH and SPROUT subroutines by detecting adequate biomass and tree numbers earlier.

The PLT subroutine was included in the first version of FORCAT but was never used. It was implemented to graphically display simulated plot characteristics at any chosen interval of years. This was changed in the second version of the model to produce a graph of stand characteristics over the entire period of simulation and for the average of any number of simulated plots.

PLT was originally written to be compatible with software conventions of the computing facilities of the Oak Ridge National Laboratory. The graphics programming of this subroutine was rewritten to be compatible with the University of Tennessee's system and to

produce CalComp plotter output (California Computer Products, Inc., 1983).

Model Output

The second version of FORCAT was tested by averaging the values from 100 simulated plots and for a 100-year period. Species composition for the average of these simulated plots is summarized and compared to field data in Table 13. The second version of FORCAT appeared to be an improvement over the first, particularly during the first few years of the stand development. Simulated regeneration was dominated by species that were present in the stand before clearcutting especially those that were prolific sprout producers. These species included red maple, pignut and mockernut hickories, dogwood, blackgum, sourwood, sassafras, and most of the oaks included in the simulation which was very similar to species composition observed in study plots (Table 13). Both simulated and observed plots were dominated by those preharvest species that were prolific sprout producers.

There were some differences, however, between model output and observed stands. Red maple was more common on study plots (13 percent) than was predicted by FORCAT (2.8 percent) during the first year after clearcutting. Dogwood, on the other hand, composed only 4 percent of the first year regeneration while the model predicted it to have 10.7 percent. The seven oak species, taken as a group, were very similar in their actual and simulated roles in stand regeneration. The model predicted that 34 percent of the first year regeneration

TABLE 13

COMPARISON OF THE AVERAGE OBSERVED FIELD PLOT TO THE AVERAGE PLOT
SIMULATED BY THE SECOND VERSION OF FORCAT

Species	Simulated Year 1	Observed Year 1	Simulated Year 50	Simulated Year 100	Observed Controls
----- Percent of the Total Basal Area -----					
Oaks					
Scarlet	4.1	20.0	0.3	0.01	14.7
Post	5.9	2.0	0.8	0.1	31.0
Southern Red	6.9	4.0	0.02	0.01	18.5
Black	11.9	8.0	46.4	72.4	15.9
White	4.5	1.0	3.5	0.4	2.0
Blackjack	0.6	0	0.03	0.01	0.9
Chestnut	0.1	0	0.6	0.3	0
Hickories					
Bitternut	0.2	0	0.6	1.2	0
Pignut	7.3	3.0	0.01	0	2.5
Mockernut	2.5	0.5	0.2	0.1	0
Other Overstory					
Hardwoods					
Red Maple	2.8	13.0	9.4	6.5	0.1
Sugar Maple	1.1	0	17.1	5.6	0
Black Walnut	0.2	0	4.5	8.3	0
Blackgum	11.3	16.0	0.1	0	1.7
Understory Hardwoods					
Sassafras					
Dogwood	10.7	4.0	0.01	0.01	0
Sourwood	12.6	1.0	0.02	0.01	0
Pines					
Virginia	0.1	0.4	0	0	7.3

would be oak seedlings and sprouts while the observed value was 35 percent. On a species basis, however, the comparison was not as close. In field plots, the oak regeneration was dominated by scarlet oak (20 percent of the total) and black oak (8 percent). Simulated oak regeneration was dominated by black oak (11.9 percent) and a fairly even mixture of white oak (4.5 percent), scarlet oak (4.1 percent), Southern red oak (6.9 percent), and post oak (5.9 percent).

The results from the first few years of simulation indicated the importance of beginning the simulation with the harvest of a mature stand as well as the importance of the changes made to the SPROUT subroutine. The composition of regeneration on the average simulated plot, even though not in perfect agreement with observed plots, was dominated by the same species as the preharvest stand. This trend was identical to that observed on the study plots of the CWMA. Due to the stochastic nature of the model and the infinite number of unmeasured variables controlling regeneration of study plots, general patterns or trends, such as this, are more important in simulations than predicting the precise percentage of each species found on a plot. The majority of the species found in the regeneration of observed study plots was also present in the regeneration simulated by the second version of FORCAT. This indicated that the model had a good starting point from which to simulate longer periods of stand dynamics.

Species composition of the average of 100 simulated plots is summarized in Figure 8 for a 100 year simulation period. In this figure, the distance between any two lines and at any point along the

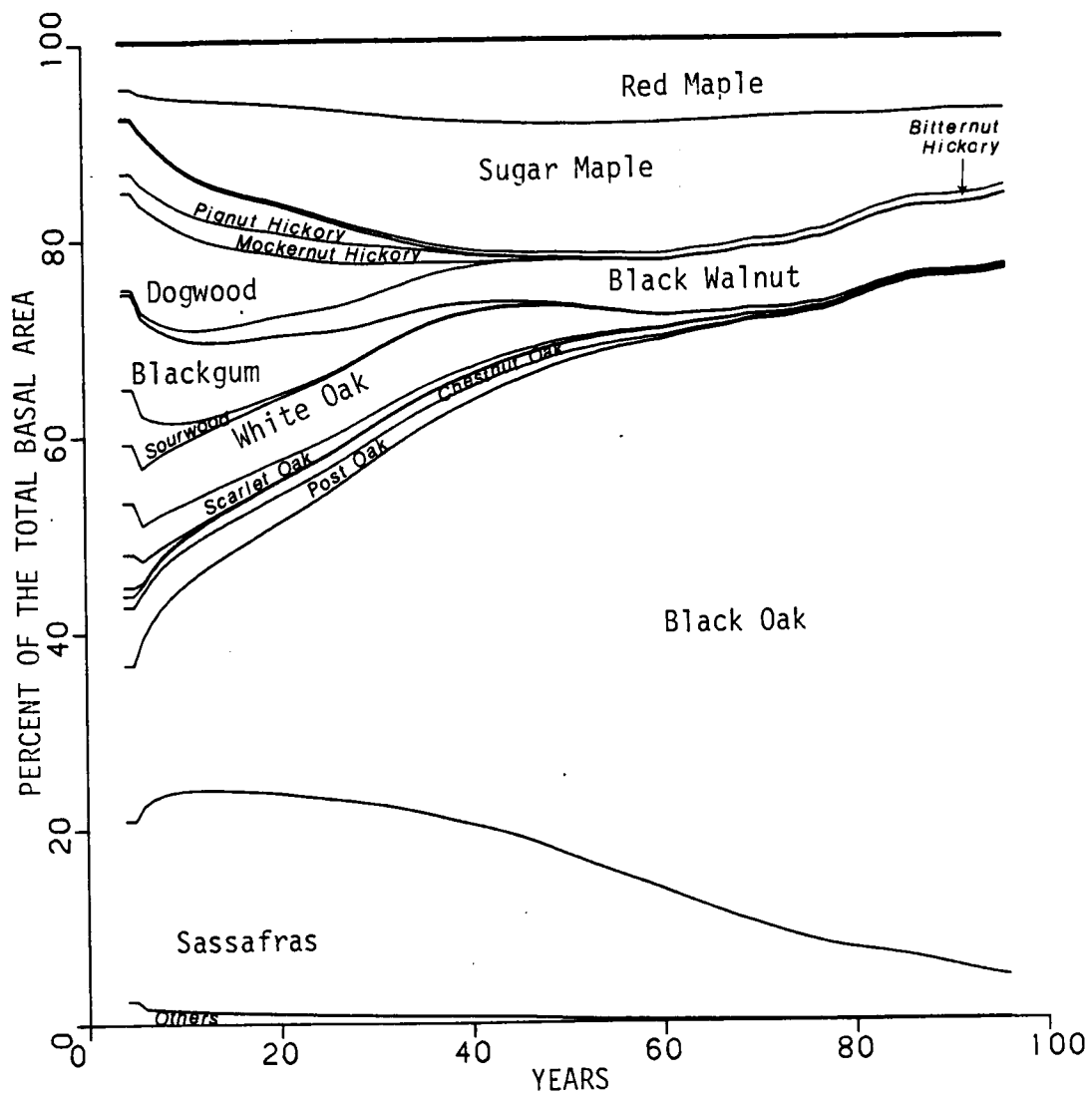


Figure 8. Species composition for the average of 100 plots as simulated by the second version of FORCAT.

X-axis represents the percentage of the total basal area represented by that species. The greater this distance, the greater the importance of the species to total plot basal area.

Black oak was the most abundant species throughout the simulation (Figure 8) with 46 percent of the total basal area at year 50 and 72 percent at year 100 (Table 13). Even though the simulation began with a mixture of species, black oak was the best competitor and increased in relative importance throughout the simulation. This species was common on control plots (15.9 percent - Table 13), however, scarlet oak (14.7 percent), post oak (31 percent), and Southern red oak (18.5 percent) were also important.

Possible causes for the dominance of black oak on the simulated plots were combinations of three factors. These included the growth rate, drought tolerance, and establishment rate of this species. Black oak was assigned a fast growth rate with a value for the growth constant G of 133 (Table 12). This fast growth rate was reduced very little by the MOIST subroutine relative to other species. The value of $D3$ for each species in Table 12 represents the relative drought tolerance between species. Larger numbers represented higher drought tolerance and lower reductions in growth rates due to drought. Even though black oak had a lower $D3$ value (290) than blackjack oak (320) and post oak (310) it was among the most drought tolerant species. As stated earlier, black oak was the most common of the oaks during the first year after clearcutting (11.9 percent). This coupled with fast growth rates and small growth reductions due to droughts may have caused the dominance of this species on the simulated plot.

Four other species, red maple, sugar maple, black walnut, and sassafras were also common on the average simulated plot throughout the 100-year simulation (Figure 8). Red maple and sassafras were prolific sprout producing species and, therefore, were abundant among regeneration of both observed and predicted plots. These species were less common, however, in the mature stands of the observed control plots. This trend was predicted fairly well by FORCAT as the relative importance of both of these species decreased at the end of the simulated period.

Sugar maple and black walnut were not components of the preharvest stand and, therefore, seedlings of these species were of relatively minor importance in the simulated regeneration (Figure 8). They increased as a percentage of the basal area on the simulated plots, however, through the first 50 years. This was in direct contrast to observed study plots where these species were totally absent. Sugar maple and black walnut are generally considered as moist site species. When seeds of these species germinate on dry sites, such as those of the CWMA study plots, survival is generally poor.

The presence of sugar maple and black walnut indicated that the MOIST subroutine was inadequate for removing moist site species from the simulated plots. An inspection of the D3 values for each species (Table 12) suggested that the problem may have been with the method of determining the relative drought tolerance of each species. For example, black walnut was assigned a D3 value of 220 which indicated a species of intermediate drought tolerance. Virginia pine, a typically

dry site species, was assigned a value of 170 which indicated a species of low drought tolerance. These were among several errors in the classification of species as to drought tolerance which indicated the need for reconsidering this method for arriving at that classification.

In addition to problems with the MOIST subroutine, the presence of black walnut in large numbers on the simulated plot indicated a problem with an underlying assumption of the model. FORCAT was developed under the assumption that a seed source was available for all species at the beginning of the simulation. For many heavy seeded species, such as black walnut, this assumption was incorrect. With no black walnut trees in the preharvest stand, regeneration of this species could only occur through seed germination. In nature, seeds could only enter the study plots by being carried in either by animals or by gravity (rolling downhill). Since the probability of this is relatively small, the necessity for a revision of the seed source assumption was indicated.

An explanation for the abundance of sugar maple on the simulated plot may be similar to that of black oak. Even though sugar maple was considered one of the most drought intolerant species with a D3 value of 180 (Table 12), it had a high growth rate with a G value of 259. This rapid growth rate may have negated any effect that MOIST had on the growth and survival of this species. If so, the assumption that all species reach $2/3$ of their maximum size at $1/2$ of their maximum age may be incorrect, particularly for moisture demanding species on

dry sites. The value of G would then have to be changed on the basis of more site specific data.

Conclusions

The second version of FORCAT showed several improvements over the first. Predicted species composition of regeneration was close to that of observed study plots and yellow-poplar was no longer a component of the simulated plot. Problems were detected, however, with the method for determining relative species drought tolerance, with growth rates of off-site species, and with the assumption that a seed source existed for all species. The over-abundance of black oak in simulated plots as well as the presence of sugar maple and black walnut caused the second version of FORCAT to be considered unacceptable as a tool for forest management. Even though the second version had incorporated all of the appropriate and current improvements to FORET, a third version with additional improvements was considered necessary.

CHAPTER VI

THE THIRD VERSION OF FORCAT

Development of the Third Version of FORCAT

Problems associated with several assumptions used in the first two versions of FORCAT were identified in Chapter V. These included errors in the determination of relative species drought tolerance (D3) and species growth rates (G) as well as the need for a more realistic control over seed availability. The general procedure for the development of the third version of FORCAT was to try new approaches for determining D3 and G and to include seed source limitations. Changes were also implemented in this version that allowed the model to be used for different sites on the CWMA and for the simulation of prescribed burning and clearcutting at specified intervals. Model changes required to develop the third version of FORCAT included the addition of one subroutine and many changes to existing parameters and subroutines.

Seed source subroutine. A new subroutine, SEEDPR, was added to FORCAT making a total of 16 subroutines and functions (Figure 9). SEEDPR determined the probability of the seed of each species entering from outside of the simulated plot based on three assumptions. These assumptions were: (i) the probability of seeds entering the plot was inversely proportional to the weight of the seed, (ii) a seed source was available for all species in the model from adjacent areas, and

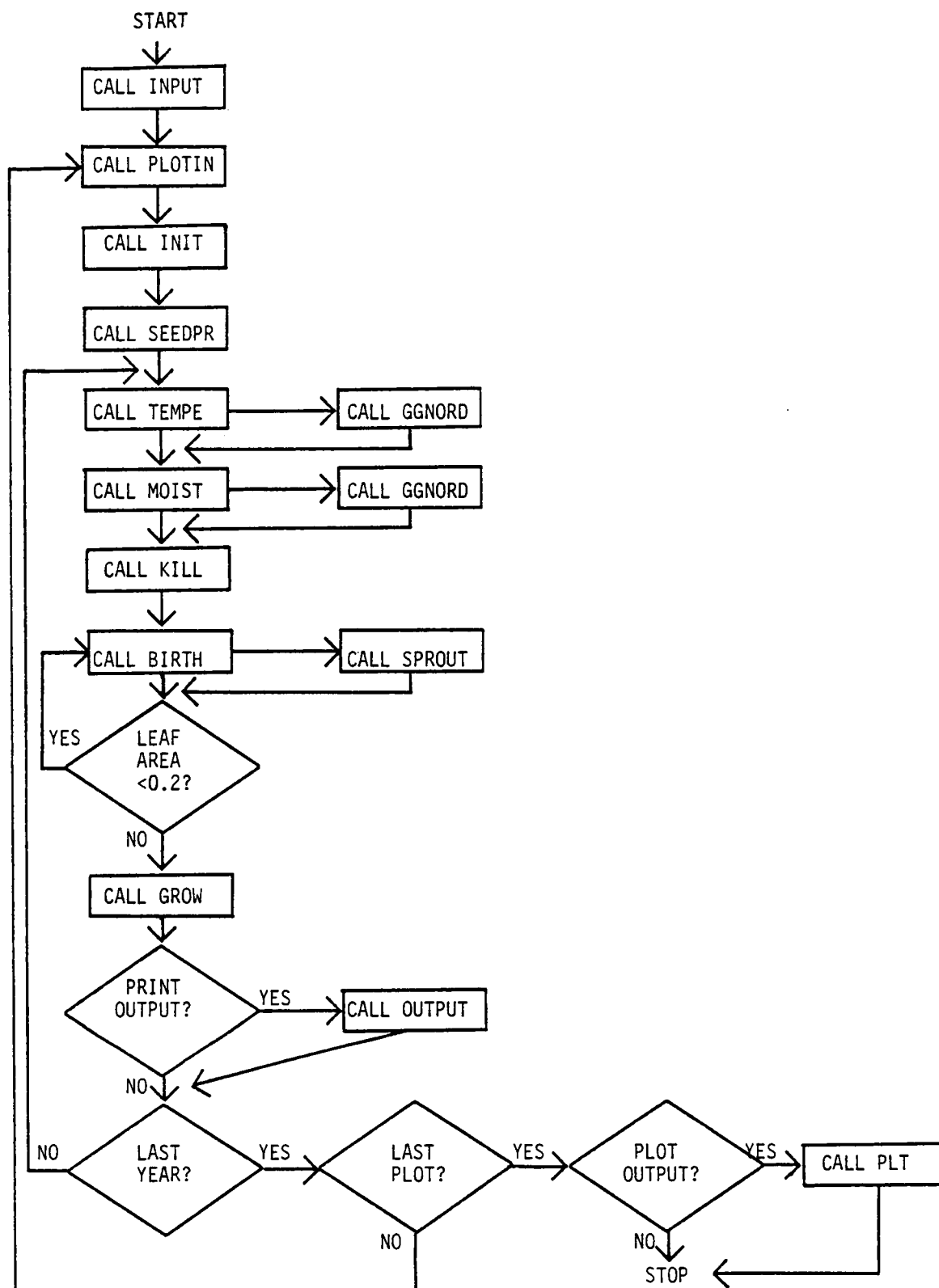


Figure 9. Flow diagram for the third version of FORCAT.

and (iii) a seed source was available for species already on the simulated plot.

Values for a new parameter, SDSPLB, which represented the average number of seeds per pound for each species (USDA Forest Service, 1948) were input into the model (Table 14). These values were converted to the mean weight (in grams) of one seed of each species by the SEEDPR subroutine.

After seed weights were calculated, SEEDPR determined which species had the heaviest seed and assigned a probability of 5 percent of seeds for that species entering the simulated plot. Other species were assigned probability values proportional to their seed weights and relative to the heaviest seed. This was accomplished by dividing the mean weight of the seed of each species by a predetermined constant which gave a result of 5 percent for the heaviest seeded species and larger values for lighter seeded species. A second parameter, WING, was also added to species input parameters (Table 14). This parameter was assigned a value of 1 for species without winged seeds and 2 for those with winged seeds. The probability of winged seeded species reaching the simulated plot as determined by the above procedure was doubled. The final probabilities of the 33 species included in FORCAT ranged from 5 percent for black walnut to nearly 100 percent for sourwood. In each simulated year, the BIRTH subroutine determined whether each species was present on the plot the previous year. Species that were present were assigned a probability of 100 percent of having seed on the plot. A random number from zero to one was selected and compared to the probability of each species

TABLE 14

REVISED SPECIES PARAMETER VALUES USED IN THE THIRD VERSION OF FORCAT

Species	D3	TINC (cm)	SDSPLB (# per lb)	WING
Red Maple	2	0.15	22,860	2
Sugar Maple	4	0.20	7,030	2
Serviceberry	3	0.20	80,000	1
Bitternut Hickory	3	0.10	156	1
Pignut Hickory	2	0.10	200	1
Shagbark Hickory	3	0.10	100	1
Mockernut Hickory	2	0.10	90	1
Dogwood	2	0.10	34,567	1
Persimmon	2	0.10	1,200	1
White Ash	4	0.20	8,470	2
American Holly	3	0.10	28,430	1
Black Walnut	4	0.15	40	1
Eastern Redcedar	2	0.10	43,600	1
Sweetgum	4	0.10	82,000	2
Yellow-poplar	4	0.30	18,680	2
Blackgum	2	0.10	3,380	1
Sourwood	2	0.20	3,675,000	1
Shortleaf Pine	1	0.15	46,300	2
Eastern White Pine	3	0.15	26,500	2
Virginia Pine	1	0.15	55,400	2
Black Cherry	3	0.10	4,240	1
White Oak	2	0.10	120	1
Scarlet Oak	2	0.10	235	1
Southern Red Oak	2	0.11	540	1
Blackjack Oak	1	0.10	250	1
Chestnut Oak	2	0.10	100	1
Post Oak	1	0.05	380	1
Black Oak	3	0.10	245	1
Winged Sumac	2	0.20	57,000	1
Black Locust	3	0.20	24,000	1
Sassafras	2	0.08	5,800	1
Eastern Hemlock	5	0.10	187,000	2
Winged Elm	2	0.10	111,500	2

entering the plot. If the random number was larger, the species was not allowed to germinate that year. The result was that the heaviest seeded species could only germinate in 5 percent of the years in which it was not already on the simulated plot.

Many limitations and oversights are recognized with this subroutine. In nature, the probability of a particular seed reaching a particular point is determined by many factors other than seed weight. Among these are the height and age of parent trees, distance from a seed source, different seed dispersal mechanisms, feeding habits of animals, wind speed and direction, periodicity of abundant seed crops, weather patterns, and numerous other variables. Although several of these variables were included in the BRIND model (Shugart and Noble, 1981), appropriate data was unavailable and too difficult to obtain within the scope of the current study. The approach used in this study was, first, to recognize that seed source limitations were required for species not on the simulated plot and, second, to reflect at least one factor observed in nature in the determination of this limitation, that being the relationship between seed dispersal and seed weight.

Growth reductions due to droughty conditions. Problems with the growth reductions of trees growing under droughty conditions were discussed in Chapter V. Since the MOIST subroutine appeared to correctly predict the number of days in a growing season in which soil water potential was below PWP, changes to this subroutine were not considered necessary. Changes were required, however, in several

input parameters and for the actual calculation of growth reductions. The values of two variables input into MOIST were changed to take advantage of the best available published information. In previous versions of FORCAT, these variables, which were measures of the amount of available water (in centimeters) at field capacity and at PWP, were calculated with the assumption that soil texture was uniform throughout the depth of the soil. Longwell et al. (1963) published a list of the percentages of water in the different horizons at various levels of tension for 78 soils in East Tennessee. Since many tree species are deep rooted, they are able to obtain water from several horizons having different soil textures. Therefore, values were assigned to the soil moisture variables based on the average amount of available water for soils of the CWMA study plots at field capacity and PWP as reported by Longwell et al. (1963) weighted by the thickness of each soil horizon. The new values used for the third version of FORCAT were 6.4 inches (16.3 centimeters) of water at field capacity and 3.0 inches (7.6 centimeters) at PWP.

Relative species drought tolerance was determined in previous versions of FORCAT as a function of soil moisture characteristics at the western most extent of the range of each species. Since this produced several errors in classifying species, a new approach was attempted. Each species in FORCAT was placed in one of five tolerance categories in terms of seedling survival in droughty conditions. These included very tolerant, tolerant, intermediate, intolerant, and very intolerant. Since this information was unavailable in published literature for all of the 33 species, classification was accomplished

by a survey of 18 scientists and field foresters (Appendix C). Each of these professionals was asked to place each species into one of the five tolerance categories, based on personal knowledge and experience and by assuming that all possible variables were equal for all species. Survey results were tallied (Table 15) and the category number with the largest number of votes was chosen for the new D3 value of each species (Table 14). For species in which there was not a clear consensus, the mean category number was used as D3.

The new D3 values were used in the GROW subroutine to calculate growth reductions for seedlings due to drought. Following the theory of Bassett (1964) this reduction was proportional to the percentage of drought days in a growing season. The reduction was calculated by:

$$SMGF(I) = \frac{179 - ((FJ * D3) / 2)}{179} \quad (10)$$

where:

SMGF(I) = soil moisture growth factor for species number I,

D3 = species drought tolerance category number, and

FJ = number of drought days in a year as calculated by MOIST.

The constant 179 was the number of days in the growing season at the CWMA study areas (USDA, 1950). The constant 2 was used as a modification to reduce the amount of growth reduction. Trials of the model without this modification yielded stands that were composed of species that were classified as very tolerant to drought. Growth reductions were too large for seedlings of other species to survive. Trials using constants larger than 2 resulted in growth reductions

TABLE 15
RESULTS OF SEEDLING DROUGHT TOLERANCE SURVEY

Species	Very Tolerant	Tolerant	Intermediate	Intolerant	Very Intolerant
	Number of Votes				
Red Maple	--	11	5	2	--
Sugar Maple	--	--	6	9	1
Serviceberry	--	6	5	6	--
Bitternut Hickory	1	5	8	1	1
Pignut Hickory	3	10	3	--	--
Shagbark Hickory	1	4	12	--	--
Mockernut Hickory	4	9	4	--	--
Dogwood	--	10	6	1	1
Persimmon	2	7	5	3	--
White Ash	--	--	5	11	--
American Holly	--	2	11	4	--
Black Walnut	--	--	3	13	2
Eastern Redcedar	9	9	--	--	--
Sweetgum	--	2	4	9	3
Yellow-poplar	--	--	4	9	5
Blackgum	3	10	3	1	--
Sourwood	4	9	4	--	--
Shortleaf Pine	12	3	3	--	--
Eastern White Pine	--	2	14	2	--
Virginia Pine	14	4	--	--	--
Black Cherry	--	2	8	8	--
White Oak	--	13	4	1	--
Scarlet Oak	7	9	1	--	--
Southern Red Oak	1	15	1	--	--
Blackjack Oak	16	1	--	--	--
Chestnut Oak	7	10	--	--	--
Post Oak	10	6	--	--	--
Black Oak	1	4	11	1	--
Winged Sumac	2	9	7	--	--
Black Locust	--	5	11	2	--
Sassafras	1	11	5	1	--
Eastern Hemlock	--	--	1	5	10
Winged Elm	6	4	5	1	--

that were too small to eliminate seedlings of intolerant and very intolerant species from simulated plots. The result of equation (10) was a value between zero and one which was multiplied by the result of the diameter growth equation in the GROW subroutine.

Equation (10) was also used to calculate growth reductions for sprouts and established trees. It was assumed that young trees of sprout origin and trees of seed origin over 10 years in age could obtain water through established root systems and would be less affected by drought than seedlings. Therefore, a D3 value of 1 was assigned to all trees of this type. This allowed growth rate reductions during droughts without resulting in the death of sprouts and older seedlings. This was a change from the procedure used in the second version of FORCAT. Previously, all trees were assigned growth rate reductions on the basis of species, regardless of age or origin.

Growth parameters. The growth parameters, b2 and b3, for the first two versions of FORCAT were developed to simulate the growth of a tree under optimal conditions assuming that this growth rate was equal to that of the largest tree of each species recorded. A value for the constant G was then selected for each species that gave each tree a size equal to two-thirds of the record size at one-half of the record age. Results of the first two versions of FORCAT indicated that these assumptions may not be valid for sites such as those of the CWMA study plots. The thin, rocky soils of these areas are of low fertility and generally support stands of lower stocking and timber quality than have been simulated by other models derived from FORET

(Shugart and West, 1977). Tree growth rates, particularly for species demanding moist and fertile sites, were unrealistically high in the previous versions of FORCAT.

An attempt was made to determine new values of b_2 , b_3 , and G that would be more site specific. Growth rates were based on the largest tree of each species found on CWMA study plots, rather than the largest tree ever recorded. These trees were located and increment cores were extracted. Increment cores from species included in FORCAT but absent from CWMA study areas were obtained from adjacent stands. The width of each growth ring from all extracted cores was measured to provide growth rate data. Computer programs were executed using the unmodified diameter equation (1) for FORCAT and different combinations for trial values of b_2 , b_3 , and G . Two sets of values were used for b_2 and b_3 . These included the values used in the previous versions of the model and values calculated from measured trees. Integers ranging from 10 to 400 were used as trial values of G . The calculated values were compared to increment core data to determine the best combination.

The results of these trials indicated that the original values of b_2 and b_3 were better than those based on trees from CWMA study areas. Tree growth predicted by the new values matched that of observed trees for the first 5 to 10 years of simulation. Beyond this point, however, predicted tree size was unrealistically small. Even though the original b_2 and b_3 values tended to underestimate the growth of young trees, particularly among the oak species, simulated trees were allowed to grow to their genetic potential.

Variations in the values of G showed little change in the upper limit of tree size but affected the rate at which each species obtained that size. New values of G were selected that best matched the growth rates of trees observed on the CWMA. For most species, these values were smaller than those used in previous versions of FORCAT. This reflected the lower site quality of study plots as compared to previously modeled sites where the assumption of 2/3 of the record tree size attained by 1/2 of the record age was valid.

Tree mortality. The KILL subroutine determined tree mortality rates as a function of tree age and growth rate. Mortality rates were increased for trees of any species which grew less than 0.04 inch (1 millimeter) per year. Increment cores from trees on the CWMA indicated some variability among species in the ability to tolerate extremely slow growth. A variable, TINC, was added to the species input parameters (Table 14) which was a measure of the slowest allowable growth rate for each species. This was determined by the width of the smallest growth ring observed on each increment core. TINC ranged in value from 0.02 inch (0.5 millimeter) for post oak to 0.12 inch (3 millimeters) for yellow-poplar. Several changes were made to the KILL subroutine to allow the calculation of mortality rates of slow growing trees to be made on a species-specific basis.

Simulation of clearcutting. Even though the second version of FORCAT contained statements that allowed clearcutting of stands, this could only be done during the first year of simulation. Changes were made to the MAIN program as well as to the KILL and BIRTH subroutines

to allow clearcutting at any specified interval of years. A value for a new variable, CUTYR, was specified in the MAIN program to indicate the desired number of years between clearcuts. A value for another new variable, DIALIM, was also specified in MAIN. This was the lower diameter of trees, in centimeters, which were to be removed during a simulated harvest. Smaller trees remained on the simulated plot.

A word of caution about clearcutting is necessary. FORCAT was designed to accommodate the clearcutting of merchantable sized timber. If a clearcut in a young stand (less than 10 years) is specified, numerous small trees would become eligible to sprout. In this case, the total tree number on the plot could exceed 1200. This would overload arrays and cause the simulation to cease. If clearcutting in young stands is desired, arrays containing dbh and height information should be dimensioned to a value larger than 1200.

Prescribed fire simulation. Changes were made to KILL, BIRTH, SPROUT, and MAIN to allow the simulation of a prescribed fire during a specified year after a clearcut. This was intended to simulate a burn in young stands for the purpose of maintaining browse within the reach of wildlife for longer periods of time. An assumption made in the execution of this function was that the fire would be hot enough and that the trees were young enough that all trees would be killed. Records for stumps of each tree harvested from the simulated plot were updated each year by the model until the time of burning. If a stump had live sprouts, it became eligible to sprout after burning. Stumps without sprouts were assumed to be dead and were not eligible.

The assumption that all trees die during a prescribed fire was valid for burns conducted in 3-year-old stands on the study plots of the CWMA. In older stands, however, larger trees may be better protected from fire and some may survive. Therefore, the prescribed fire function was written so that it can only be used during the first 10 years after clearcutting. If a fire is specified in a simulated stand older than 10 years, the simulation will continue for the specified number of years but the prescribed fire will not be conducted. This 10 year period should be sufficient to simulate prescribed fires for wildlife purposes without violating the assumption of 100 percent mortality.

Simulation of different land types. The third version of FORCAT was changed to allow future improvements for the purpose of simulating any of the 20 land types found on the mid-section of the Cumberland Plateau as described by Smalley (1982). Each land type represents a different site in terms of forest productivity and species composition. An array containing a value for the growth constant G for each species and land type was added to the model. An integer from 1 to 20 was selected in the MAIN program which indicated the desired land type to be simulated. The model then selected the G value for each species which corresponded to the chosen land type.

Data was collected to determine G values for only one land type (land type 1). Values for the remaining 19 were estimated by site indices and descriptions of species composition for each land type as

reported by Smalley (1982). These values were not tested and may need to be adjusted as the model is used and more data becomes available.

Results and Discussion

The SEEDPR subroutine. The use of seed weight in the SEEDPR subroutine to prevent species not present in the preharvest stand from entering the simulated plot was effective for several species. The calculated probabilities of seed entering the simulated plot were small for all species of oak and hickory and for black walnut. Since all of the oak species plus pignut and mockernut hickories were components of the preharvest stand, they were not prevented from germinating in the post-harvest stand. Black walnut, bitternut hickory, and shagbark hickory were not components of the preharvest stand and were rarely observed among regeneration.

Growth reductions due to droughty conditions. The new methods used to simulated tree growth and survival in droughty conditions appeared to be more effective than the previous approach. Seedlings of species classified as intermediate, tolerant, and very tolerant to droughty conditions generally became established on the simulated plot. The intolerant and very intolerant species rarely survived for more than a few years. Sugar maple and black walnut, which were components of the plots simulated by the second version of FORCAT (Figure 8), were absent from the output of the third version.

Values for G. Trial runs of FORCAT using the new values for the growth constant G showed improvements over previous attempts. Species

composition was similar to that of observed control plots. Changes to these values were required, however, as several species were either over- or under-abundant. Scarlet oak and black oak represented a portion of the total basal area that was too large while Southern red oak and blackgum were observed only as small trees. A trial and error approach was used to determine the values of G that would yield appropriate growth rates and species composition. These values are given in Table 16 for each of 20 land types found on the mid-section of the Cumberland Plateau. Only the G values for land type 1 were tested. As before, others were estimated on the basis of these values and site indices and descriptions of species composition given by Smalley (1982).

Several species required large increases of G to produce reasonable growth rates. These included Southern red oak, blackjack oak, sourwood, shortleaf pine, and Virginia pine. An inspection of the values of $DMIN$ (Table 12) used in the model gave a possible explanation for this. Each of these species was assigned one of the largest $DMIN$ values used in FORCAT, which indicated that their native range did not extend as far north as other species. Since CWMA study plots were close to the northern boundary of the native range for these species, growth rates were reduced to a value of near zero by equation (8) for the variable $TEGD$. To compensate for this over-reduction of growth rates, large G values were required.

TABLE 16

VALUES FOR THE GROWTH CONSTANT G USED IN THE THIRD VERSION OF FORCAT FOR EACH SPECIES AND LAND TYPE

Species	Land Type Number																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Red Maple	50	50	45	40	50	50	40	45	50	50	45	60	50	60	65	45	50	50	50	40
Sugar Maple	24	24	20	20	80	24	24	45	24	80	24	70	24	45	70	68	70	65	24	24
Serviceberry	42	42	42	42	42	42	42	42	42	34	42	42	42	50	40	42	42	42	42	30
Bitternut Hickory	49	49	49	49	40	49	40	49	49	49	49	49	49	40	40	115	49	49	49	49
Pignut Hickory	88	88	88	88	80	88	80	88	88	88	88	88	88	80	80	88	88	88	88	88
Shagbark Hickory	50	50	50	50	40	50	40	50	50	50	50	50	50	40	40	90	50	50	50	50
Mockernut Hickory	49	49	49	49	40	49	40	49	49	49	49	49	49	40	40	40	40	40	40	40
Dogwood	53	53	53	53	53	53	53	53	53	55	55	55	53	55	55	55	53	53	53	45
Persimmon	29	29	29	29	49	29	29	29	49	49	39	39	29	29	39	40	29	29	29	29
White Ash	37	37	37	37	85	37	37	37	37	55	37	55	37	50	55	55	50	37	37	55
American Holly	14	14	14	14	20	14	14	14	14	14	14	14	14	25	25	20	14	14	14	14
Black Walnut	34	34	34	34	64	34	34	50	55	34	34	50	34	55	70	100	70	34	34	50
Eastern Redcedar	74	84	74	69	74	74	69	74	74	74	74	74	74	74	74	74	74	74	74	88
Sweetgum	50	50	50	50	80	50	40	80	70	70	50	80	55	90	90	50	50	70	50	40
Yellow-poplar	35	45	35	35	95	35	35	90	80	95	35	100	60	100	90	80	80	85	35	35
Blackgum	60	60	50	50	60	60	60	60	50	60	60	65	60	60	70	65	60	55	55	60
Sourwood	259	259	259	259	259	259	259	259	259	259	259	259	259	270	259	259	259	200	200	200
Shortleaf Pine	146	146	120	130	146	146	146	146	146	150	146	155	146	150	146	150	146	146	140	146
E. White Pine	166	166	140	150	166	166	166	166	180	180	166	180	166	180	180	172	166	166	160	166
Virginia Pine	326	326	300	310	326	326	326	326	326	350	326	350	326	350	326	340	326	326	310	326
Black Cherry	35	35	35	35	85	35	30	45	50	50	35	50	40	85	95	95	50	35	35	35

TABLE 16

(CONTINUED)

Species	Land Type Number																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
White Oak	42	42	42	43	47	47	42	42	42	43	42	44	42	44	46	56	44	43	42	41
Scarlet Oak	43	43	43	44	41	43	43	43	43	43	43	43	43	45	43	35	43	43	43	42
Southern Red Oak	340	340	340	350	300	340	340	300	300	300	340	340	340	340	300	200	350	345	340	330
Blackjack Oak	137	137	137	141	100	120	137	137	110	110	137	110	137	137	100	100	137	137	137	130
Chestnut Oak	35	35	35	39	30	35	35	35	35	37	35	35	35	39	50	42	37	37	35	35
Post Oak	42	42	42	43	35	42	42	42	40	40	42	40	42	48	39	30	42	41	42	41
Black Oak	46	46	46	47	40	46	46	46	46	48	46	48	46	46	42	50	46	46	46	45
Winged Sumac	37	37	37	37	37	37	37	37	37	30	37	37	37	37	30	30	37	37	37	37
Black Locust	84	84	84	84	70	84	84	84	84	88	88	88	88	88	84	90	88	84	88	75
Sassafras	57	57	57	57	57	57	57	57	57	63	63	60	57	60	57	57	50	50	50	50
Eastern Hemlock	19	19	19	19	40	19	19	19	19	40	19	50	19	40	50	50	25	19	19	19
Winged Elm	33	33	33	33	33	33	33	33	33	30	33	35	33	40	44	44	40	37	40	40

Prescribed fire simulation. Trials of FORCAT using prescribed fire in the first 4 years of simulation showed only small changes in species composition between pre-burn and post-burn stands. As with clearcutting, the same species were present on simulated plots before and after burning. Some increase was observed in the numbers of individuals of species that were prolific sprouters. The results of a simulated burn agreed with those of field plot studies. Post-burn species composition was largely a function of the species present before burning. Rather than species composition changes, the most apparent difference between pre-burn and post-burn stand characteristics was stand age in both simulated and observed plots.

Model output. The third version of FORCAT was run to simulate 100 plots for a 100-year period. Species composition for the average simulated plot is summarized and compared to field observations in Table 17. Species composition among predicted first year regeneration was similar to that predicted by the second version of the model. The most abundant species were those that were present in the preharvest stand. There was a fairly even mixture of the oak species which, again, contrasted to field plot data. Regeneration in field plots was dominated by scarlet oak with 20 percent of the total basal area as compared to only 4.5 percent on the simulated plot. Values lower than field plot observations were also predicted for red maple, blackgum, and sassafras. These differences were not considered serious, however, since there were sufficient numbers of trees of all species, except

TABLE 17

COMPARISON OF THE AVERAGE OBSERVED FIELD PLOT TO THE AVERAGE PLOT
SIMULATED BY THE THIRD VERSION OF FORCAT

Species	Simulated Year 1	Observed Year 1	Simulated Year 50	Simulated Year 100	Observed Controls
----- Percent of the Total Basal Area -----					
Oaks					
Scarlet	4.5	20.0	11.2	24.0	14.7
Post	6.5	2.0	11.5	21.3	31.0
Southern Red	8.6	4.0	11.1	1.6	18.5
Black	7.6	8.0	10.3	13.3	15.9
White	5.7	1.0	9.0	4.7	2.0
Blackjack	3.1	0.1	8.1	4.4	0.9
Chestnut	2.5	0.1	4.4	3.2	0.1
Hickories					
Pignut	8.0	3.0	7.7	8.3	2.5
Mockernut	3.8	0.5	4.6	0.8	0.1
Other Overstory					
Hardwoods					
Red Maple	2.3	13.0	2.5	2.4	0.1
Blackgum	7.9	16.0	9.0	9.6	1.7
Understory Hardwoods					
Sassafras	9.7	24.0	3.4	1.1	0.1
Dogwood	9.8	4.0	4.9	1.5	0.1
Sourwood	10.6	1.0	0.3	0.1	0.1
Pines					
Eastern White	0.2	0.1	1.5	2.9	0.1
Virginia	0.1	0.4	-	-	7.3

those eliminated by SEEDPR, in the predicted regeneration to serve as a basis for the simulation of longer term stand development.

Therefore, further changes to subroutines and statements controlling regeneration were considered unnecessary.

Species composition for the average of 100 simulated plots and over a 100-year period as predicted by the third version of FORCAT is summarized in Figure 10. No single species dominated the simulated plot as was the case with black oak in the second version of the model. Pignut hickory, blackgum, and all of the oak species were abundant. Scarlet oak and post oak were the most common species, particularly at the end of the simulation period. Scarlet oak represented 11.2 percent of the total plot basal area at year 50 (Table 17) and 24.0 percent at year 100. Corresponding values for post oak were 11.5 percent at year 50 and 21.3 percent at year 100. Occasional individuals of red maple, mockernut hickory, and white pine were observed in the overstory of simulated plots. Major simulated understory species were dogwood, sourwood, and sassafras. These understory species remained a component of the simulated plots throughout the 100-year period but their relative importance decreased as overstory species became larger.

The average plot predicted by the third version of FORCAT had many similarities to observed control plots. All overstory species, with the exception of Virginia pine, that were present on control plots were also present on the average simulated plot. Off-site species such as sugar maple, black walnut, and yellow-poplar, which were present in previous simulations, were absent from simulated

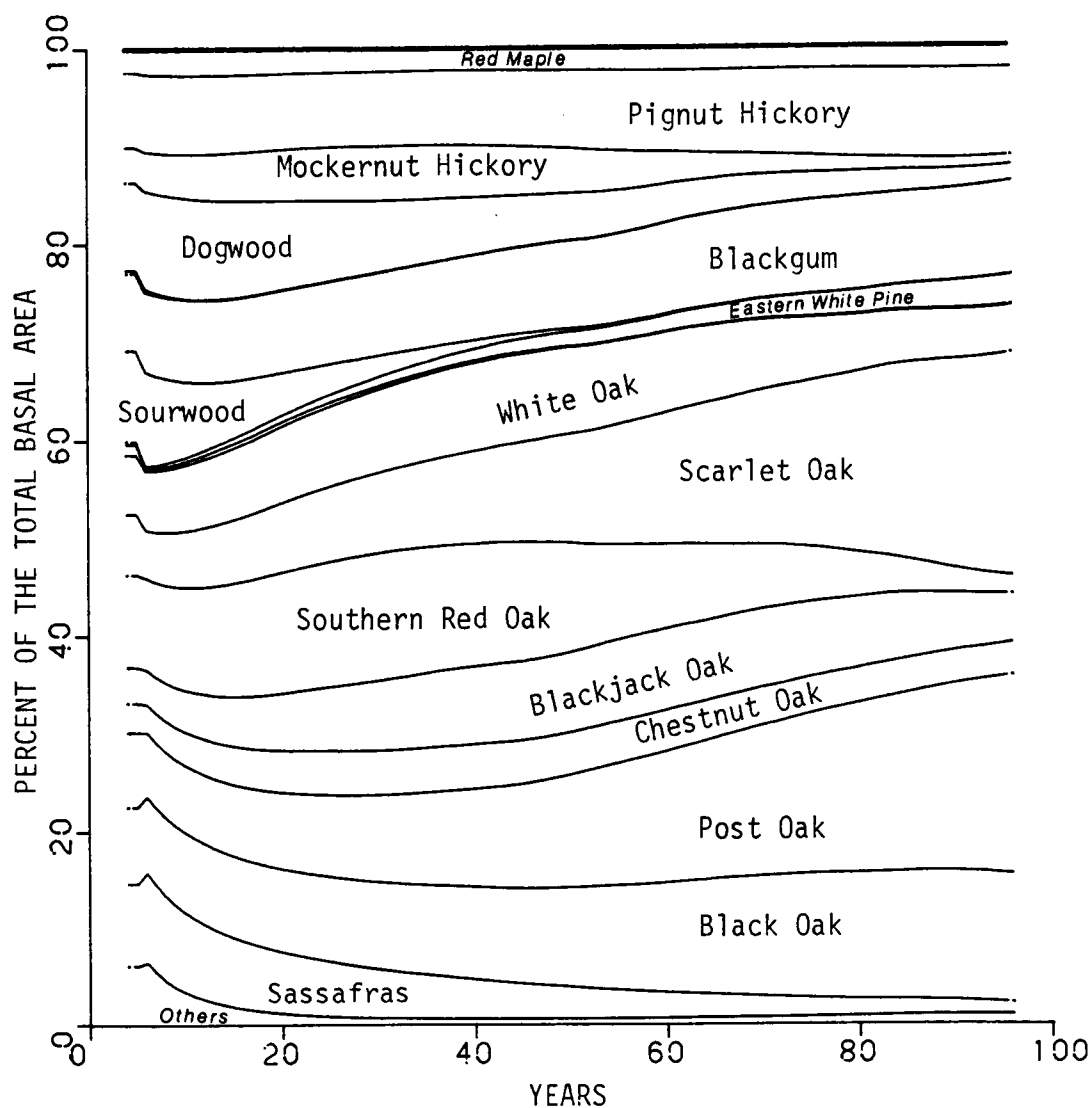


Figure 10. Species composition for the average of 100 plots as simulated by the third version of FORCAT.

plots. Control plots were dominated by post oak, Southern red oak, scarlet oak, and black oak. At times through the simulation, each of these species were also major components of the simulated plot. Understory species were also correctly simulated by the model. Dogwood, sourwood, and sassafras were the most common of these in both simulated and observed plots.

Other similarities between observed and simulated plots included tree number and total plot basal area. The third version of FORCAT simulated an average of 939 stems per plot during the first year after clearcutting as compared to an average of 988 stems observed in CWMA study plots. There was a total of 70 sawtimber and pulpwood sized trees on the average simulated plot at year 100 while 73 were observed in control plots of the CWMA. Basal area simulated by the model was 84.1 square feet per acre (19.3 square meters per hectare) at year 50 and 69.3 square feet per acre (15.9 square meters per hectare) at year 100. The basal area observed in control plots was 76.2 square feet per acre (17.5 square meters per hectare). The reduction of simulated basal area between years 50 and 100 was attributed to the death of several large trees near the end of the simulation period.

The control plots in field studies represented only a small portion of the total land area of Smalley's (1982) land type number 1 on the CWMA. Since the ages and past histories of present stands on this small area are unknown, direct comparisons of precise percentages between simulated and observed plots would be meaningless. The ability of the model to correctly simulate which species are present or absent from plots and to simulate the relative abundance of

each species is more important in terms of evaluating the model. The third version of FORCAT appeared to accurately simulate species composition of sites of land type 1 on the CWMA. Therefore, further revisions were considered unnecessary.

Summary and Conclusions

The third version of FORCAT showed many improvements over the second. The combination of changes in the calculation of growth rates, reductions of growth due to droughty conditions, and mortality of slow growing trees resulted in simulated plots with species composition similar to that of observed control plots. Simulated regeneration species composition was slightly improved by the addition of the SEEDPR subroutine. The model was made more versatile in terms of its use for forest management decisions by changes to allow periodic clearcutting and prescribed burning.

Due to the similarities between simulated and observed plots, further refinements of FORCAT were considered unnecessary. Using the terminology of Shugart (1984), FORCAT was verified against the data set which was used for its development. The validation of this model will not be complete, however, until its output is compared to a second and independent data set. Chapter VII will deal with the validation of FORCAT and evaluation of this model for use as a forest management tool.

CHAPTER VII

VALIDATION OF FORCAT

Even though forest stand models may never perfectly represent the real system (Buchman and Shifley, 1983), these models should be tested to determine how well they simulate ecosystem attributes. Shugart (1984) described a three part procedure for such tests including: (i) verification procedures, (ii) validation procedures, and (iii) application procedures. Verification procedures include the testing of a model to determine whether it can be made consistent with some set of observations. Adjustments to the model are sometimes required to make the model agree with observations. Validation procedures include a comparison of model output to a second set of observations. This new data set should be completely independent of the data used for verification and should not be used for model development. Application procedures include the evaluation of the model through extended use of the purpose for which it was developed.

Chapters IV, V, AND VI dealt with the development and verification of FORCAT. The model was repeatedly changed until output resembled data collected on CWMA study plots. This chapter deals with the validation of FORCAT. A data set similar to that collected on the CWMA, but independent of model development, was used for validation procedures. Model output was compared to this new data set to determine model validity. Application procedures cannot be completed until FORCAT is tested through future use for aid in making forest management decisions.

Description of the Validation Data

Data for the validation of FORCAT was provided by Dr. C. E. McGee, with the USDA Forest Service Silviculture Laboratory of Sewanee, Tennessee. A 68 acre (27.5 hectare) study area, which was part of the Domain of the University of the South, was harvested by complete clearcutting methods during the summer of 1978. All stems over 8 inches (20.3 centimeters) were harvested. Inventories were conducted prior to and for each of 5 years after clearcutting.

The study area was on the escarpment of the Cumberland Plateau near Sewanee, Tennessee. The site is generally described as land type 16 (plateau escarpment and upper sandstone slopes and benches with a north aspect) in Smalley's (1982) classification for forest sites on the mid-section of the plateau. Soils of this land type are generally of the Grimsley, Jefferson, Ramsey, and Zenith series. These soils have a gravelly loam, cobbly loam, silt loam, sandy clay loam, or clay loam texture and are well drained despite a relatively high water supply from subsurface flow and seepage. Aspect was predominantly to the north while slopes ranged from almost flat along benches to very steep between benches (McGee, 1978). Site index for yellow-poplar at 50 years averaged 101.

Overstory species of preharvest stands included chestnut oak (25 percent of the total number of harvested stems), the hickories as a group (25 percent), white oak (15 percent), northern red oak (14 percent), and yellow-poplar (10 percent) (Table 18). Other overstory species included black oak (3 percent), white ash (4 percent), black

TABLE 18
TREES HARVESTED IN A 68-ACRE CLEARCUT
NEAR SEWANEE, TENNESSEE

Species	Number	Percent
Chestnut Oak	716	25.3
Hickories	713	25.2
White Oak	431	15.3
Northern Red Oak	390	13.8
Yellow-poplar	276	9.8
White Ash	99	3.5
Black Oak	72	2.5
Sugar Maple	38	1.3
Black Walnut	29	1.0
Blackgum	18	0.6
Black Cherry	10	0.4
Other	35	1.2

walnut (1 percent), sugar maple (1 percent), and blackgum (1 percent). Species included in advance regeneration were all of the above plus dogwood, winged elm, sourwood, and black cherry.

Stem counts of post-harvest regeneration for each species were conducted on 46 sample plots located throughout the clearcut area. Each stem was classified as either above or below 4.5 feet (1.37 meters) in height. The number of stems per acre observed for each tree species during the first year after clearcutting is presented in Table 19. The most common species among all regeneration were yellow-poplar (24 percent of the total number of stems) and black locust (12 percent). The oaks composed 18 percent of the total stem count with chestnut oak (8 percent) and northern red oak (6 percent) being common. Other potential overstory species included the hickories (5 percent), white ash (5 percent), blackgum (3 percent), red maple (3 percent), and sugar maple (3 percent). Common understory species included dogwood (9 percent), sassafras (9 percent), and winged elm (7 percent). Of the 13,039 stems per acre observed in study plots, 97 percent were less than 4.5 feet in height.

Changes in FORCAT to Simulate a New Land Type

Several changes to FORCAT were required to simulate stand development for the new stand and land type described above. Most of these changes dealt with the input of site-specific data that are required to adapt the model to any new land type.

Data required for the MOIST subroutine. Changes in values for three variables were required for the MOIST subroutine. The values

TABLE 19

REGENERATION ONE YEAR AFTER CLEARCUTTING OF A HARDWOOD STAND
NEAR SEWANEE, TENNESSEE

Species	Under 4.5 feet in height	Over 4.5 feet in height	Total
	----- Number per Acre (Percent) -----		
Oaks			
Northern Red	783 (6)	2 (1)	785 (6)
Scarlet	65 (1)	- (-)	65 (1)
Black	130 (1)	11 (3)	141 (1)
White	326 (3)	6 (2)	332 (2)
Chestnut	1,000 (8)	4 (1)	1,004 (8)
Other Potential Overstory Species			
Hickories	587 (5)	35 (10)	622 (5)
Yellow-poplar	3,109 (25)	43 (12)	3,152 (24)
Black Cherry	152 (1)	- (-)	152 (1)
White Ash	696 (5)	13 (4)	709 (5)
Black Walnut	22 (.2)	2 (1)	24 (.2)
Blackgum	283 (2)	67 (18)	350 (3)
Red Maple	326 (3)	9 (2)	335 (3)
Sugar Maple	348 (3)	24 (7)	372 (3)
Black Locust	1,456 (11)	106 (29)	1,562 (12)
Understory Species			
Sourwood	87 (1)	6 (2)	93 (1)
Dogwood	1,152 (9)	33 (9)	1,185 (9)
Sassafras	1,174 (9)	- (-)	1,174 (9)
Am. Chestnut	22 (.2)	- (-)	22 (.2)
Winged Elm	956 (8)	4 (1)	960 (7)
Totals	12,674	365	13,039

for FC and DRY, which represented the amount of water present in the soil at field capacity and at PWP, were determined from descriptions of soil depth and texture for land type 16 given by Smalley (1982). These values were 8.3 inches (21.1 centimeters) at field capacity and 5.0 inches (12.7 centimeters) at PWP. The variable PLAT was changed to the latitude of the weather station closest to the new study area at Monteagle, Tennessee. This value was 35.15 degrees (USDC, 1979). Values for BGS and EGS were not changed from those used earlier. These variables were used to determine the length of the growing season for simulated plots. Since the new study area was relatively close to the CWMA, the length of the growing season was assumed to be equal for both areas.

Additional species. One species, northern red oak, was common at the second study area but had not been included in FORCAT. Species parameters for northern red oak were determined by the methods described earlier and added to FORCAT input.

Changes to the PLOTIN subroutine. The PLOTIN subroutine was used in FORCAT to begin the simulation with a mature stand of trees rather than bare ground. The number of trees of each species harvested from the average 1/5 acre (1/12 hectare) plot at the new study area was included in PLOTIN. Stem counts of advanced regeneration were also included in this subroutine for each species and for two size classes, greater than or less than 4.5 (1.4 meters) in height. Understory trees were not removed from the plot by the simulated clearcut.

G values. A trial run of the validation model using values for the growth rate constant G which were estimated from site indices and descriptions of species composition for land type 16 (Smalley, 1982) yielded an average plot simulation with the same overstory species as were found in the preharvest stand. Minor changes in G values were required, however, for several species. The growth rates of yellow-poplar, chestnut oak, and northern red oak were slightly over-estimated while those of bitternut hickory, black oak, and white oak were under-estimated. A trial and error approach was used to determine the best G value for each of these species for land type 16.

Results and Discussion

Determination of G values. Botkin et al. (1972b) found that the calculation of G values based on the assumption that each species reaches $2/3$ of its record diameter at $1/2$ of its record age gave unreasonable growth rates for some species and, therefore, they altered G values for those species. They suggested that a better method would be to determine G values from field observations. The determination of these values from the largest tree of each species found in plots of the CWMA was an attempt to follow that suggestion. Even though FORCAT accurately simulated the species present on plots with the new values of G, alterations were required as growth rates were too high for some species and too low for others. Only minor changes were required, however, since the species for which problems were detected in the calculation of TDEGD (growth reduction due to the proximity of a species to the boundary of its native range) were

absent from the preharvest stands of the Sewanee study area. Even though changes were small, the necessity for them indicated that errors existed with the new method of determining G values.

A possible cause for errors in growth rates is sample size. Study plots of the CWMA consisted of only 21.6 acres (8.7 hectares), which was only a small portion of the area of land type 1 on the CWMA. The tree selected as the largest of each species may not have accurately represented the growth potential for that species on land type 1. If the selected tree was considerably smaller than the largest possible tree, the value for G would be under-estimated.

Over-estimation of G values occurred only among the oaks. Growth rates of oaks tended to be under-estimated during the first 50 to 100 years of simulation when a value of G was selected that gave reasonable results for trees older than 100 years. Since FORCAT was developed for forest management purposes, accuracy beyond the length of one rotation (60 to 100 years) was not required. Therefore, G values for oaks were selected that best simulated the growth of measured trees during this period. Since the growth curves calculated by the equations of FORCAT did not exactly parallel the curves of measured oaks, a certain amount of error was unavoidable. Depending on the choice of G value, growth rates of oaks were either under-estimated for young trees (under 50 years) or over-estimated for older trees (over 50 years). In a first estimation of G values for oaks, preference was given to accuracy of growth rates during the first 50 years of simulation. However, the over-estimation of the growth of older oaks was too great so G was reduced by trial and error

until an acceptable estimate of growth over the entire 100 year simulation period was obtained.

First year regeneration. The average of 100 simulated plots on land type 16 provided the data used for validation comparisons. The simulated regeneration during the first year after clearcutting is summarized and compared to field observations in Table 20. The total number of stems less than 4.5 feet in height on the average simulated plot (4,108 per acre) was considerably lower than the number observed in study plots (12,674 per acre). Even though the model under-estimated the numbers of most species, the largest errors were for yellow-poplar, black locust, dogwood, sassafras, and chestnut oak.

With the exception of scarlet oak, errors of this magnitude were not observed for any species simulated by the third version of FORCAT. The model generated a large number of stems for species that were present before clearcutting and were prolific sprout producers. After a simulated clearcut, sprouts were added to the simulated plot first and then relatively equal numbers of seedlings of all species were added until the total reached approximately 5,000 stems per acre (12,000 per hectare). This number was selected on the basis of the numbers of stems observed on study areas of the CWMA. The SEEDPR subroutine functioned only to eliminate heavy seeded species from the simulated plot without favoring the very light seeded or pioneer species such as yellow-poplar and black locust. This technique was adequate for the simulation of CWMA study plots where a seed source for yellow-poplar and black locust was essentially absent.

TABLE 20

REGENERATION ONE YEAR AFTER CLEARCUTTING FOR
SIMULATED AND OBSERVED PLOTS

Species	Under 4.5 Feet in Height		Over 4.5 Feet in Height	
	Simulated	Observed	Simulated	Observed
	----- Number Per Acre (Percent) -----			
Oaks				
Northern Red	318 (8)	783 (6)	1 (1)	2 (1)
Scarlet	109 (3)	65 (1)	5 (3)	- (-)
Black	12 (.3)	130 (1)	8 (4)	11 (3)
White	420 (10)	326 (3)	12 (6)	6 (2)
Chestnut	109 (3)	1,000 (8)	5 (3)	4 (1)
Blackjack	105 (3)	- (-)	- (-)	- (-)
Post	112 (3)	- (-)	- (-)	- (-)
Southern Red	25 (1)	- (-)	- (-)	- (-)
Other Potential Overstory Species				
Hickories	691 (17)	587 (5)	54 (28)	35 (10)
Yellow-poplar	66 (2)	3,109 (25)	18 (9)	43 (12)
Black Cherry	132 (3)	152 (1)	3 (2)	- (-)
White Ash	505 (12)	696 (5)	21 (11)	13 (4)
Black Walnut	12 (.3)	22 (.2)	- (-)	2 (1)
Blackgum	357 (9)	282 (2)	20 (10)	67 (18)
Red Maple	46 (1)	326 (2)	3 (2)	9 (2)
Sugar Maple	190 (5)	348 (3)	12 (6)	24 (7)
Black Locust	- (-)	1,456 (11)	- (-)	106 (29)
Understory Species				
Sourwood	28 (1)	87 (1)	3 (2)	6 (2)
Dogwood	274 (7)	1,152 (9)	14 (7)	33 (9)
Sassafras	40 (1)	1,174 (9)	- (-)	- (-)
Am. Holly	101 (2)	- (-)	- (-)	- (-)
Am. Chestnut	- (-)	22 (.2)	- (-)	- (-)
Winged Elm	456 (11)	956 (8)	16 (8)	4 (1)
Totals	4,108	12,674	195	365

The inability of FORCAT to estimate the numbers of dogwood, sassafras, and chestnut oak stems was partially due to a difference in harvesting methods used at the CWMA and at Sewanee. The smallest tree cut in the clearcut near Sewanee was 8 inches dbh (20.3 centimeters). Since this diameter was specified in FORCAT during the validation test, few dogwood, sassafras, and chestnut oak stems were harvested and the simulated number of sprouts was small. Simulated regeneration of these species test was almost entirely composed of seedlings.

All stems above 3 inches (7.6 centimeters) dbh, regardless of species, were felled in CWMA study areas. The result of using this diameter during simulation of CWMA plots was the simulated harvest of many dogwood, sassafras, and chestnut oak stems. Therefore, many sprouts of these species were included among simulated regeneration. The under-estimation of numbers of seedlings was not detected during the development of FORCAT because of the large number of sprouts it simulated.

The occurrence of species in the regeneration simulated in the validation test, without considering relative numbers, was similar to that of study plots (Table 20). Only two species, black locust and American chestnut, were present in field plots but absent from simulated plots. American chestnut was observed in small numbers in both CWMA and Sewanee plots and was not included as model input. The absence of black locust can only be explained by the apparent errors in simulating seedling establishment discussed above. Blackjack oak, post oak, Southern red oak, and American holly were included in simulated regeneration but were absent from observed plots. Since no

trees of these species were present in the preharvest stand, all of the simulated regeneration was of seed origin. The numbers of seedlings of these species were relatively small which should help prevent them from becoming a major component of older simulated stands.

Stand development for 100 years. Although FORCAT did not simulate regeneration accurately, this did not appear to affect the prediction of species composition through the 100 year simulation period. Species composition for the average of 100 simulated plots during the validation test is summarized in Figure 11. The distance between any two lines represents the percentage of the total biomass on the average simulated plot for the indicated species. Chestnut oak was the dominant species on simulated plots with white oak and northern red oak also major components. Sugar maple, white ash, yellow-poplar, and the hickories were common. Black walnut, eastern redcedar, black cherry, and black oak were occasionally observed in the overstory of simulated plots.

Simulated species composition at selected stages of development in the validation test is compared to the species composition of harvested trees in Table 21. Even though the values for model output at years 50 and 100 were based on total plot biomass and the values for harvested trees were based on volume (International 1/4 rule), the expression of these as percentages should give a comparison of species composition. Three species, white oak, chestnut oak, and northern red oak were dominant in the simulated and harvested stands.

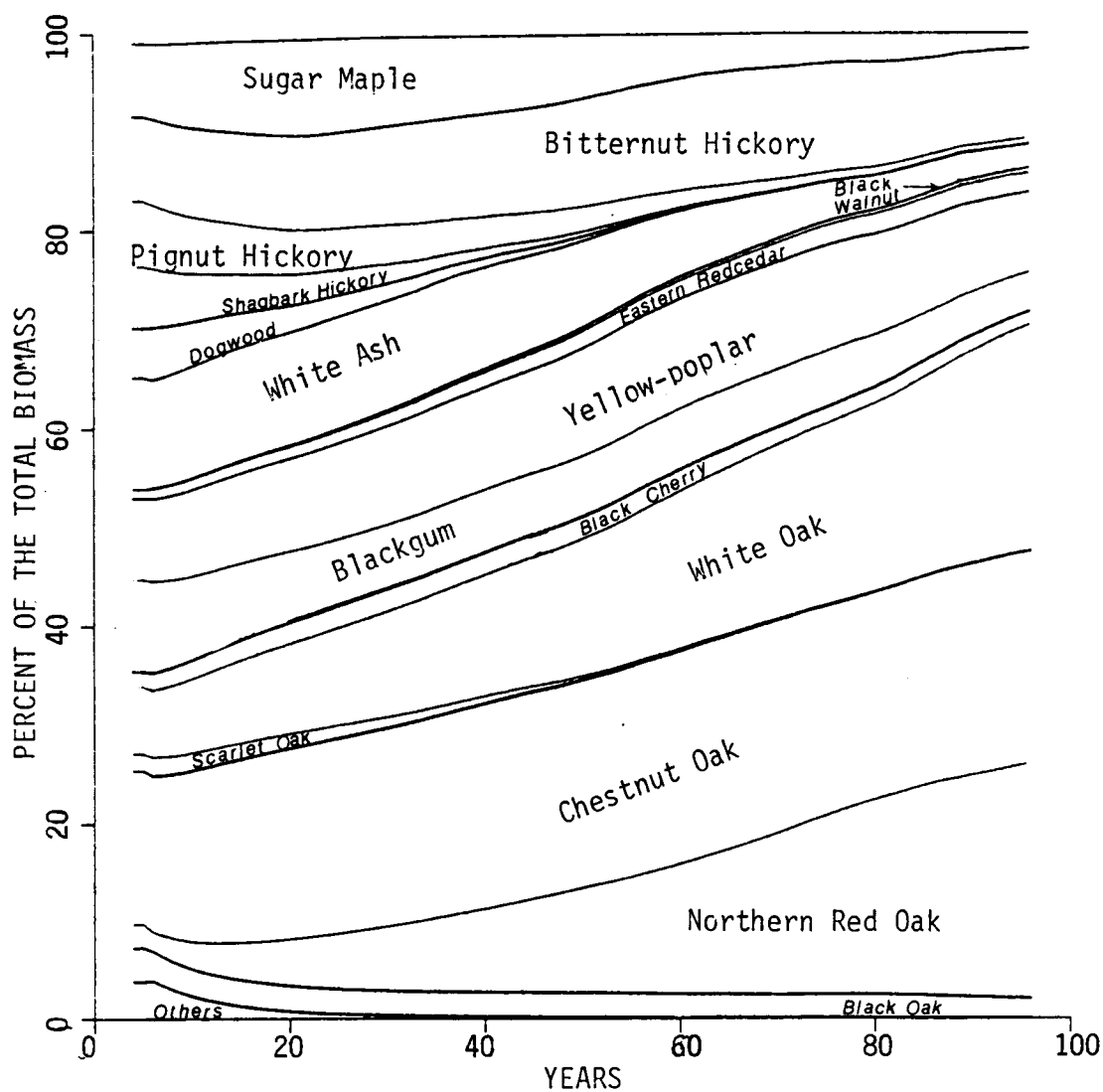


Figure 11. Species composition for land type 16 as simulated by the FORCAT model.

TABLE 21

SPECIES COMPOSITION FOR THE AVERAGE PLOT PREDICTED BY FORCAT
AND THE AVERAGE PREHARVEST STAND FOR THE SEWANEE STUDY AREA

Species	Simulated at Year 50	Simulated at Year 100	Observed
	--Percent of the Total Biomass--		Percent of the -Total Volume-
Oaks			
White	13.9	23.7	22.1
Chestnut	21.4	21.1	24.6
Northern Red	10.7	25.0	18.6
Black	1.0	1.9	4.5
Other Overstory Species			
Hickories	14.9	9.1	11.8
Yellow-poplar	11.0	7.7	11.6
Black Cherry	2.3	1.3	0.2
White Ash	8.8	2.4	3.9
Black Walnut	0.4	0.4	0.9
Blackgum	6.1	3.8	0.7
Sugar Maple	6.7	1.5	0.8
Eastern Redcedar	1.7	2.1	-
Understory Species			
Dogwood	0.5	-	-

Yellow-poplar, white ash, sugar maple, and the hickories were secondary species in both simulated and harvested stands. Among the less common species, FORCAT tended to over-estimate the abundance of eastern redcedar, sugar maple, black cherry, and blackgum and under-estimate the presence of black oak. As with previous versions of the model, the prediction of exact percentages are less important than the prediction of general trends such as relative species abundance. In this sense, the validation version of FORCAT adequately predicted species composition.

Other similarities between observed and simulated plots occurred with basal area and the number of merchantable trees (8 inches and over) (20.3 centimeters). The average basal area for preharvest plots on the Sewanee study area was 90.6 square feet per acre (20.8 square meters per hectare) as compared to 86.3 square feet per acre (19.8 square meters per hectare) in the average simulated plot at year 100. FORCAT predicted a total of 22.8 merchantable trees (11.0 inches dbh and larger) per acre (56.3 per hectare) at year 100 while an average of 24.6 per acre (60.8 per hectare) were harvested from Sewanee study plots. The total number of stems at year 100 per simulated plot was not as accurate, however. Study plots had an average of 1,535 stems per acre (3,791 per hectare) while the model simulated an average of only 583 stems per acre (1,440 per hectare). This difference was attributed to problems associated with simulating regeneration as discussed earlier.

Summary and Conclusions

Validation of the FORCAT model was attempted by the simulation of stand dynamics for a different land type from that on which the model was developed. Comparisons were made of model output to a second and independent data set from this new area. Simulation of the new land type required the addition of parameters for northern red oak, estimation of new G values for each species, the input of new values for site-specific variables used by the MOIST subroutine, and the input of a description of the new preharvest stand.

Output of the validation model indicated that problems existed with the simulation of regeneration after clearcutting. The total number of stems on plots near Sewanee, Tennessee 1 year after clearcutting was considerably larger than on plots of the CWMA or on plots simulated by FORCAT. Most of the simulated regeneration was composed of sprouts from stumps of harvested trees with the remainder being composed of relatively equal numbers of seedlings of all species. With this technique, none of the species were favored in terms of numbers of seedlings regardless of seed weight, dispersal mechanisms, or abundance of seed.

The under-estimation of stem numbers of regeneration had no adverse effects on the simulation of longer term stand dynamics, however. The average of 100 plots simulated by FORCAT had similar species composition to the preharvest stands of the Sewanee study area. Both were dominated by white oak, chestnut oak, and northern red oak with yellow-poplar, white ash, sugar maple, and the hickories occurring as secondary species. Even though the numbers of several of

these species were under-estimated in the regeneration, an adequate number must have been included on the simulated plot to allow their development as dominants in the developing stand. Other similarities between field plots and model output included the number of merchantable trees and the total plot basal area.

The comparison of model output to data from a very different land type from which the model was developed was perhaps the most rigorous validation test possible. However, FORCAT accurately simulated species composition, tree number, and basal area of mature stands on this new land type. The ability of FORCAT to make these accurate simulations should its use for making long term forest management decisions. The current version of the model can be easily altered to simulate different intervals of clearcutting to different minimum diameters and to simulate prescribed burning of young stands. Continued testing where data is available would be the best means of validation.

The current version of FORCAT may not be as useful for short term simulations of regeneration. Continued improvements in this aspect of the model are needed if, for example, the model is to be used to predict the number of stems of each species available for browsing after clearcutting. The necessary improvements may prove to be too expensive, however. Regeneration of tree species in study plots near Sewanee, Tennessee numbered over 13,000 stems per acre (32,110 per hectare) while the current version of FORCAT can simulate no more than 6,000 stems per acre (14,820 per hectare). The added information gained by such improvements may not be worth the expense of the extra

computer time and storage space required to simulate the growth of each of these additional trees.

CHAPTER VIII

CONCLUSIONS

Field Studies

Phase III field studies generally agreed with those of Phase II (Muncy, 1980). There were no significant differences in species composition between complete and diameter limit clearcuts after three and four growing seasons. Species composition was largely controlled by the sapling and pulpwood sized trees harvested. Basal and stump sprouts from cut trees of these size classes composed most of the regeneration. Other regeneration was composed of seedlings of the same species present before harvesting and small numbers of pioneer species.

The continued monitoring of stand development in the two types of clearcuts clarified the role of trees greater than 6 feet (1.8 meters) in height and less than 3 inches dbh (7.6 centimeters) which were not cut in diameter limit clearcuts. These trees did not respond to release and, therefore, did not compete significantly with regeneration as was previously hypothesized.

Prescribed burning of 3-year-old clearcuts had little effect on species composition. Regeneration 1 year after burning was similar to regeneration 1 year after clearcutting being composed largely of seedlings and sprouts of oaks. As was the case following cutting, pioneer species did not become established. The only obvious differences between burned and unburned clearcuts were the sizes and ages of the regeneration. Sprouts and seedlings in burned clearcuts

were 3 years younger than in unburned clearcuts and, therefore, were considerably smaller.

Browsing of regeneration in study plots was minimal with less than 1 percent of all stems affected. Since study plots were located in the center of large clearcuts, they were too far from protective cover for deer to utilize. Browsing of stems was so light that there was no measurable effect on growth rates or stem numbers among species. Another study design using narrow or small clearcuts in which experimental units were exposed to browsing would likely result in other inferences about browsing effects. Also, future browsing may cause measurable effects in CWMA clearcuts as trees become large enough to provide cover for deer or if food shortages due to unfavorable weather conditions occur.

Modeling of Forest Stands of the CWMA

FORCAT was considered acceptable for use as an aid in making long-term forest management decisions on areas of land type 1 and 16. Refinements to the model based on data collected in Phase II and Phase III resulted in an adequate simulation of species composition, basal area, and tree number on field plots. Continued testing where appropriate stand data is available would be the best means of validation.

FORCAT may not be as useful for short-term simulation of regeneration. Numbers of seedlings were under-estimated, particularly when a seed source for pioneer species was present. For certain objectives, the added computer costs of simulating the growth of

additional seedlings may be worthwhile. This would require research on seed availability and viability and further refinements to the simulation of seed germination.

Recommendations for the Application of FORCAT

The current version of FORCAT has several possible applications for both forest managers and reseachers involved with the CWMA. The accurate simulation of species composition, basal area, and tree number provided by the model should enable managers to project the future value of stands of land types 1 and 16 in terms of both wildlife habitat and merchantable timber. FORCAT was designed to provide this type of information to evaluate various cultural practices. For example, the best rotation for hardwood stands may be determined by the simulation of different intervals between clearcuts. The simulated effects of prescribed burning can be used to determine, first, whether a burn is desirable and, second, during which year after clearcutting the burn would produce the best results. Even though small trees are expensive to cut and are of little commercial value, this practice may be justified by an increase in sprouting. Output from simulations using different diameter limits of trees to be harvested can be compared to determine which lower limit would be the most economical and yield adequate sprouting for browse and stand development. In addition, FORCAT can be used to evaluate the results of any combination of rotation length, lower diameter limit for tree harvest, and presence or absence of prescribed fire in young stands.

Recommendations for Future Study

The need for further refinements to the FORCAT model was discussed in the previous two chapters and additional studies on several aspects of FORCAT were recommended. Among these was a study of seed availability and viability after clearcutting hardwood stands. This type of information is particularly needed for pioneer species such as yellow-poplar and black locust.

An alternative to the above would be to begin the simulation during the first year after clearcutting rather than with a preharvest stand. Stem counts of seedlings and sprouts of all species in clearcut areas could be used as input to the PLOTIN subroutine. This method would eliminate the need to simulate the germination rates of pioneer species, however, it would not allow forest and wildlife managers to evaluate different harvesting techniques in terms of the quantity and quality of vegetation produced.

Even though trial and error process of determining G values resulted in simulations of correct species composition, the need for a better method was apparent. An evaluation of the assumption that trees reach $2/3$ of their record diameter at $1/2$ of their record age seems to be in order. The fractions used in this assumption were shown by Botkin (1972b) to vary by species. Results of this study indicate that they may also vary for different site conditions. Alterations of the fractions in this assumption based on both species-specific and site-specific information on the growth habit of trees may lead to more accurate and biologically sound G values.

The necessity for large increases in G values for species with the southern-most native ranges indicated that growth rate reductions for trees growing near the boundary of their native range were too large. This reduction was calculated as a parabolic function where growth was not reduced for trees at the mid-point of their native range but reductions increased to nearly 100 percent for trees at their southern and northern boundaries. Even though growth rates for many species are reduced at these boundaries, the reductions are not as large as simulated by FORCAT. In addition, many species have excellent growth rates outside of their native range. Research is needed to determine the actual amount of growth reduction for each species that can be attributed to the proximity of a tree to the boundary of its native range. With this information, site-specific values calculated for G would give a more accurate simulation of tree growth.

While the third version of FORCAT was considered to be acceptable for use as a tool for making forest management decisions on areas of land types 1 and 16 on the CWMA, the accuracy of this conclusion should be tested by application of the model to other areas of these land types for which management plans call for clearcutting. Descriptions of other preharvest stands should be included in the PLOTIN subroutine and model output compared to post-harvest regeneration. Even though the problems encountered in simulating regeneration on land type 16 may also occur with the simulation of new areas of land type 1, the simulation of longer term stand dynamics should continue to be accurate.

Continued monitoring of stand dynamics on study plots of the CWMA may prove valuable for future refinements to FORCAT. The evaluation of simulated species composition was based on the assumption that clearcut areas would be similar to surrounding unharvested stands after crown closure. Clearcutting by either complete or diameter limit methods and prescribed burning of young stands may have long term effects on stand dynamics that are not apparent at present. Browsing may also affect stand dynamics as crown closure limits the abundance of regeneration and the proportion of browsed to unbrowsed stems increases.

Study plots of the CWMA were designed to allow continued monitoring of stand dynamics for an indefinite period of time. The center of each plot was marked with an iron rod making relocation of these plots relatively easy. Also, the position of each tree harvested from study plots was mapped to allow continued monitoring of sprouting from each stump. Animal exclosures were constructed with materials of sufficient quality to remain standing for many years. The presence of relatively permanent sampling plots and animal exclosures as well as the abundance of data collected from them as part of the Phase II and Phase III studies, represent an economical starting point for a study of long term stand dynamics for future refinements to FORCAT. These plots should not be limited to studies related to the FORCAT model, however, as they could also provide an economical source of data for studies in the fields of Ecology, Silviculture, and Wildlife Management.

LITERATURE CITED

LITERATURE CITED

- Aber, J.D., D.B. Botkin, and J.M. Melillo. 1979. Predicting the effects of different harvesting regimes on productivity and yield in northern hardwoods. *Can. J. For. Res.* 9:10-14.
- Adams, D.M., N.L. Dennis, and J.B. Schmechel. 1974. Program SHAF for simulating the harvest of uneven-aged stands of northern hardwoods. Univ. of Wis., Dept. of For., Staff Paper Series 1, 8pp.
- Acevedo, M.F. 1981. On Horn's Markovian model of forest dynamics with particular reference to tropical forests. *Theoretical Population Biology.* 19:230-250.
- Adams, D.M. and A.R. Ek, 1974. Optimizing the management of uneven-aged forest stands. *Can. J. For. Res.* 4:274-287.
- Alder, D. 1979. A distance-independent tree model for exotic conifer plantations in East Africa. *For. Sci.* 25(1):59-71.
- Anonymous. 1929. Volume, yield, and stand tables for second growth Southern pines. U.S. Forest Service, Misc. Pub. 50, 202pp.
- Arney, J.D. 1972. Computer simulation of Douglas-fir tree and stand growth. Unpublished Ph.D. Dissertation. Oregon State Univ. 79pp. (University Microfilms Disser. Abstr. 33/01-B p. 8).
- Arney, J.D. 1974. An individual tree model for stand simulation in Douglas-fir. IN: *Growth Models for Tree and Stand Simulation*, J. Fries, ed.). Royal College of Forestry, Stockholm. p. 38-46.
- Arney, K. and B. Pough. 1983. Showcase for wildlife: Catoosa. *Tennessee Wildlife.* 6(5):20-25.
- Bailey, R.L. 1974. Announcement: Computer programs for quantifying diameter distributions with the Weibull function. *For. Sci.* 20:229.
- Barr, A.J., J.H. Goodnight, J.P. Sall, W.H. Blair, D.M. Chilko, J.T. Helwig, and J.A. Council. 1979. *SAS User's Guide*. SAS Institute, Inc. Raleigh, NC. 494 pp.
- Bassett, J.W. 1964. Tree growth as affected by soil moisture availability. *Soil Sci. Soc. Am. Proc.* 28:436-438.
- Beck, D.E. and L. Della-Bianca. 1972. Growth and yield of thinned yellow-poplar. USDA For. Serv. Research Paper SE-101, 20pp.

- Belcher, D.M. 1981. User's Guide to STEMS, the Stand and Tree Evaluation and Modeling System. Gen. Tech. Rep. NC-70. USDA Forest Service, North Central For. Exp. Sta. 49pp.
- Belcher, D.M., M.R. Holdaway, and G.J. Brand. 1982. A description of STEMS - the stand and tree evaluation and modeling system. USDA For. Serv. Gen. Tech. Report NC-79, 18pp.
- Bella, I.E. 1970. Simulation of growth, yield, and management of aspen. Unpublished Ph.D. Dissertation, Univ. of British Columbia, Vancouver. 190pp. (University Microfilms Disser. Abstr. 31/12-B p. 7019).
- Bennett, F.A. and J.L. Clutter. 1969. Multiple product yield estimates for unthinned slash pine plantations -- pulpwood, sawtimber, gum. USDA For. Serv. Research Paper SE-35, 21pp.
- Bertalanffy, L. von. 1957. Quantitative laws in metabolism and growth. The Quart. Rev. of Biol. 32:217-231.
- Bosch, C.A. 1971. Redwoods: A population model. Science 162:345-349.
- Botkin, D.B., J.F. Janak, and J.R. Wallis. 1972a. Rationale, limitations, and assumptions of a northeastern forest growth simulator. IBM J. Res. Develop. 16:101-116.
- Botkin, D.B., J.F. Janak, and J.R. Wallis. 1972b. Some ecological consequences of a computer model of forest growth. J. Ecology 60:849-873.
- Brand, G.J. 1979. Timber management guides and marketing rules. IN: A generalized forest growth projection system applied to the Lake States region. USDA For. Serv. Gen. Tech. Report NC-49. p. 56-60.
- Brand, G.J. 1981a. Simulating timber management in Lake States Forests. USDA For. Serv. Gen. Tech. Report NC-69, 25pp.
- Brand, G.J. 1981b. GROW - A computer subroutine that projects the growth of trees in the Lake States' forests. USDA For. Serv. Research Paper NC-207. 11pp.
- Brandt, C.C. and B.L. Dearden. 1980. User's guide for FORCAT, a forest stand simulator for the Catoosa Wildlife Management Area. Unpublished manuscript. Univ. of Tennessee, Dept. of For., Wildl., and Fisher., Knoxville. 41pp.
- Brandt, C.C., H.H. Shugart, and B.L. Dearden. 1981. Forest stand simulation model for the Catoosa Wildlife Management Area (FORCAT). IN: Proc. of the First Biennial Southern Silvicultural Research Conference (J.P. Barnett ed.). USDA For. Serv. Gen. Tech. Rep. SO-34. p. 362-365.

- Brender, E.V. and J.L. Clutter. 1970. Yield of even-aged natural stands of loblolly pine. Ga. Forest Res. Council, Report No. 23, 7pp.
- Bruner, H.D. and J.W. Moser. 1973. A Markov chain approach to the prediction of diameter distributions in uneven-aged forest stands. Can. J. For. Res. 3:409-417.
- Buckman, R.E. 1962. Growth and yield of red pine in Minnesota. USFS Tech. Bull. No. 1272, 50pp.
- Burkhart, H.E. 1971. Slash pine plantation yield estimates based on diameter distribution: An evaluation. For. Sci. 17:452-453.
- Burkhart, H.E., R.C. Parker, and R.G. Oderwald. 1972. Yields of natural stands of loblolly pine. Div. of For. and Wildl. Res., VPI & SU, FWS-2-72, 63pp.
- Burkhart, H.E. and M.R. Strub. 1974. A model for simulation of planted loblolly pine stands. IN: Growth models for tree and stand simulation (J. Fries, ed.). Royal College of Forestry, Stockholm, p. 128-135.
- California Computer Products, Inc. 1983. Programming calcomp electromechanical plotters. Anaheim. 32pp.
- Cassel, R.F. and J.W. Moser, Jr. 1974. A programmed Markov model for predicting diameter distribution and species composition in uneven-aged forests. Indiana Ag. Exp. Sta. Bull. No. 915, 43pp.
- Cattelino, P.J., I.R. Noble, R.O. Slatyer, and S.R. Kessel. 1979. Predicting the multiple pathways of plant succession. Environmental Management. 3:41-50.
- Chapman, D.G. 1961. Statistical problems in population dynamics. Proc Fourth Berkeley Symp. Math. Stat. and Prob., Univ. of Calif. Press, Berkeley and Los Angeles, p. 153-163.
- Clutter, J.L. 1963. Compatible growth and yield models for loblolly pine. For. Sci. 9:354-371.
- Clutter, J.L. and B.J. Allison. 1974. A growth and yield model for Pinus radiata in New Zealand. IN: Growth models for tree and stand simulation (J. Fries, ed.), Royal College of Forestry, Stockholm, p. 136-160.
- Clutter, J.L. and D.M. Belcher. 1978. Yield of site-prepared slash pine plantations in the lower Coastal Plain of Georgia and Florida. IN: Growth models for long term forecasting of timber yields (J. Fries, H.E. Burkhart, and T.A. Max, ed.) VPI & SU, Blacksburg, VA, FWS-1-78, p. 53-70.

- Clutter, J.L. and F.A. Bennett. 1965. Diameter distributions in old-field slash pine plantations. Ga. For. Res. Council Rep. No. 13, 9pp.
- Culver, D.C. 1981. On using Horn's Markov succession model. American Naturalist. 17:572-574.
- Curtis, R.O. 1967. A method for estimation of gross yield of Douglas-fir. For. Sci. Monog. 13:1-24.
- Curtis, R.O. 1972. Yield tables past and present. J. For. 70:28-32.
- Dale, M.E. 1975. Individual tree growth and simulation of stand development of an 80-year-old white oak stand. IN: Forest modeling and inventory (A.R. Ek, J.W. Balsiger, and L.C. Promnitz, eds.), Dept. of For., Univ. of Wis., p. 49-63.
- Daniel, T.W., J.A. Helms, F.S. Baker. 1979. Principles of Silviculture Second Edition. McGraw-Hill Book Company, New York. 500pp.
- Daniels, R.F. and H.E. Burkhart. 1975. Simulation of individual tree growth and stand development in managed loblolly pine plantations. Div. of For. and Wildl. Res., FWS-5-75, VPI & SU, 69pp.
- Dell, T.R., D.P. Feduccia, T.E. Campbell, W.F. Mann, Jr., and B.H. Polmer. 1979. Yields of unthinned slash pine plantations on cut-over sites in the West Gulf region. USDA For. Serv. Research Paper SO-147, 84pp.
- Doyle, T.W. 1981. The role of disturbance in the gap dynamics of a Montane rain forest: An application of a tropical forest succession model. IN: Forest Succession: Concepts and Application. (D.C. West, H.H. Shugart, and D.B. Botkin, eds.). Springer-Verlag, New York. p. 56-73.
- Dress, P.E. 1970. A system for the stochastic simulation of even-aged forest stands of pure species composition. Unpublished Ph.D. Dissertation, Purdue Univ., West Lafayette, IN. (University Microfilms Disser. Abstr. 31/08-B p. 4424).
- Edminster, C.B. 1978. RMYLD: Computation of yield tables for even-aged and two-storied stands. USDA For. Serv. Research Paper RM-199. 26pp.
- Ek, A.R. 1974. Nonlinear models for stand table projection in Northern hardwood stands. Can. J. For. Res. 4:23-27.

- Ek, A.R. and R.A. Monserud. 1974a. Trials with program FOREST: Growth and reproduction simulation for mixed species forest stands. IN: Growth models for tree and stand simulation (J. Fries, ed.). Royal College of Forestry, Stockholm. p. 56-73.
- Ek, A.R. and R.A. Monserud. 1974b. FOREST: A computer model for simulating the growth and reproduction of mixed forest stands. Research Report A2635, College of Ag. and Life Sci., Univ. of Wis., 17pp.
- Ek, A.R. and R.A. Monserud. 1975. Methodology for modeling forest stand dynamics. Univ. Wisconsin, Coll. of Agr. and Life Science, Staff Paper Series 2, 30 p.
- Elfving, B. 1974. A model for the description of the structure in unthinned stands of Scots pine. IN: Growth models for tree and stand simulation (J. Fries, ed.), Royal College of Forestry, Stockholm. p. 161-179.
- Farrar, R.M., Jr. 1973. Southern pine site index equations. J. For. 71:696-697.
- Feduccia, D.P., T.R. Dell, W.F. Mann, Jr., T.E. Campbell, and B.H. Polmer. 1979. Yields of unthinned loblolly pine plantations on cutover sites in the West Gulf region. USDA For. Serv. Research Paper SO-148, 88pp.
- Fowells, H.A. 1965. Silvics of Forest Trees of the United States. USDA For. Serv. Handbook No. 271. 762pp.
- Goff, F.G. and D. West. 1975. Canopy-understory interaction effects on forest population structure. For. Sci. 21:98-108.
- Goulding, C.J. 1972. Simulation techniques for a stochastic model of the growth of Douglas-fir. Unpublished Ph.D. Dissertation, Univ. of British Columbia, Vancouver. (University Microfilms Diss. Abstr. 33/12-B p. 5599).
- Groton, E.S. 1983. An evaluation of Markov chains for projecting diameter distributions. Unpublished M.S. Thesis. Univ. of Tennessee. 131pp.
- Halls, L.K. and R. Alcaniz. 1972. Growth patterns of deer browse plants in southern forests. USDA For. Serv. Research Paper, SO-75, 14pp.
- Hann, D.W. 1980. Development and evaluation of even- and uneven-aged Ponderosa pine/Arizona fescue stand simulator. USDA For. Serv. Research Paper INT-267. 95pp.

- Harcombe, P.A. and P.L. Marks. 1978. Tree diameter distributions and replacement in Southeast Texas forests. *For. Sci.* 24:153-166.
- Harlow, W.M. and E.S. Harrar. 1969. Textbook of Dendrology. McGraw-Hill Book Co., New York. 512pp.
- Harms, W.R. 1981. A competition function for tree and stand growth models. IN: Proceedings of First Biennial Southern Silvicultural Research Conference (J.P. Barnett, ed.) USDA For. Serv. Gen Tech. Report SO-34, p. 179-183.
- Hatch, C.R. 1971. Simulation of an even-aged red pine stand in northern Minnesota. Unpublished Ph.D. Dissertation, Univ. Minn., 120pp. (University Microfilms Diss. Abstr. 32/11-B p. 6148).
- Hegyi, F. 1974. Forest stand modeling experience in Canada. IN: Forest Modeling and Inventory (A.R. Ek, J.W. Balsiger, and L.C. Promnitz, eds.) Dept. of For., Univ. of Wisconsin. p. 15-19.
- Holdaway, M.R. and G.J. Brand. 1983. An evaluation of the STEMS tree growth projection system. USDA For. Serv. Research Paper NC-234. (In press).
- Hool, J.N. 1966. A dynamic programming - Markov chain approach to forest production control. *For. Sci. Monog.* No. 12, 26 pp.
- Horn, H.S. 1975. Forest succession. *Scientific American*, May, 1975. p. 90-98.
- Hurd, D. 1980. Browsing around. *Tennessee Wildlife*. 3:10-12.
- Husch, B., C.I. Miller, and T.W. Beers. 1972. Forest Mensuration (Second Edition). Ronald Press Co., New York, 410pp.
- Hyink, D.M. 1980. Diameter distribution approaches to growth and yield modeling. IN: Forecasting Stand Dynamics, Workshop - Lakehead Univ., Thunder Bay, Ont. p. 138-160.
- Isebrands, J.G., A.R. Ek, and R.S. Meldahl. 1982. Comparison of growth model and harvest yields of short rotation intensively cultured Populus: A case study. *Can. J. For. Res.* 12:58-63
- Jakes, P.J. and W.B. Smith. 1980. Predicted yields from selected cutting prescriptions in Northern Minnesota. USDA For. Serv. Research Paper NC-188, 29pp.
- Johnson, N.L. and S. Kotz. 1970. Continuous Univariate Distributions. John Wiley and Sons, Inc. New York, 300pp.

- Johnson, W.C. 1977. A mathematical model of forest succession and land use for the North Carolina Piedmont. Bull. of the Torrey Botanical Club. 104(4):334-336.
- Kessel, S.R. and M.W. Potter. 1980. A quantitative succession model for nine Montana forest communities. Environmental Management. 4(3):227-240.
- Ker, J.W. and J.H. Smith. 1955. Advantages of parabolic expression of height-diameter relationships. For. Chron. 31:235-246.
- Kramer, P.J. and T.T. Kozlowski. 1960. Physiology of Trees. McGraw-Hill, New York. 642pp.
- Leak, W.B. 1964. An expression of diameter distribution for unbalanced, uneven-aged stands and forests. For. Sci. 10:39-50.
- Leak, W.B. 1968. Birch regeneration: A stochastic model. USDA For. Serv. Research Note NE-85, 7pp.
- Leak, W.B. 1969. Stocking of northern hardwood regeneration based on experimental dropout rate. Forestry Chron. 45:344-347.
- Leak, W.B. 1970a. Sapling stand development: A compound exponential process. For. Sci. 16:177-180.
- Leak, W.B. 1970b. Successional change in northern hardwoods predicted by birth and death simulation. Ecology 51:794-801.
- Leary, R.A., J.T. Hahn, and R.G. Buchman. 1979. Tests. IN: A Generalized Forest Growth Projection System Applied to the Lake States Region. USDA For. Serv. Gen. Tech. Rep. NC-49, p. 79-89.
- Lee, Y. 1967. Stand models for lodgepole pine and limits to their application. Unpublished Ph.D. Dissertation. Univ. of British Columbia, Vancouver. 322pp. (University Microfilms Disser. Abstr. 29/03-B p. 829).
- Lenhart, J.D. and J.L. Clutter. 1971. Cubic-foot yield tables for old-field loblolly pine plantations in the Georgia Piedmont. Ga. Forest Res. Council, Report 22 - Series 3, 12pp.
- Lin, J.Y. 1970. Growing space index and stand simulation of young western hemlock in Oregon. Unpublished D.F. Thesis, Duke Univ., Durham, N.C. 193pp. (University Microfilms Disser. Abstr. 31/04-B p. 2397).
- Lohrey, R.E. and R.L. Bailey. 1977. Yield tables and stand structure for unthinned longleaf pine plantations in Louisiana and Texas. USDA For. Serv. Research Paper SO-133, 53pp.

- Longwell, T.J., W.L. Parks, and M.E. Springer. 1963. Moisture characteristics of Tennessee soils. Univ. of Tenn. Ag. Exp. Sta. Bull. 367. 46pp.
- MacKinney, A.L. and L.E. Chaiken. 1939. Volume, yield, and growth of loblolly pine in the Mid-Atlantic Coastal Region. USFS Tech. Note 30, 30pp.
- McGee, C.E. 1978. Predicting successional development following harvest on a high quality hardwood site on the Cumberland Plateau. Unpublished study plan. USDA Forest Service FS-SO-1105-1.40. 15pp.
- McGee, C.E. 1982. Low-quality hardwood stands - opportunities for management of the interior uplands. USDA For. Serv. Gen. Tech. Rep. SO-40. 22pp.
- McGee, C.E. and L. Della-Bianca. 1967. Diameter distributions in natural yellow-poplar stands. USDA For. Serv., Research Paper SE-25, 7pp.
- Meyer, H.A. 1952. Structure, growth, and drain in balanced uneven-aged forests. J. For. 50:85-92.
- Meyers, C.A. 1977. A computer program for variable density yield tables for loblolly pine plantations. USDA For. Serv. Gen. Tech. Report SO-11, 31pp.
- Mielke, D.L., H.H. Shugart, and D.C. West. 1978. A stand model for upland forests of southern Arkansas. ORNL/TM-6225. Oak Ridge National Laboratory, Oak Ridge, TN. 87pp.
- Mitchell, K.J. 1969. Simulation of growth of even-aged stands of white spruce. Yale Univ. Sch. For. Bull. 75:1-48.
- Mitchell, K.J. 1975. Dynamics and simulated yield of Douglas-fir. Forest Sci. Monog. 17:1-39.
- Mitchell, K.J. 1980. Distance dependent individual tree stand models: Concepts and applications. IN: Forecasting forest stand dynamics, Workshop - Lakehead Univ., Thunder bay, Ont. p. 100-137.
- Moser, J.W., Jr. 1967. Growth and yield models for un-even aged forest stands. Unpublished Ph.D. Dissertation, Purdue Univ., 149pp. (University Microfilms Disser. Abstr. 28/07-B p. 2679).
- Moser, J.W. 1972. Dynamics of an uneven-aged hardwood stand. For. Sci. 18:184-191.
- Moser, J.W., Jr. 1976. Specification of density for the inverse J-shaped diameter distribution For. Sci. 22:177-180.

- Moser, J.W. and O.F. Hall. 1969. Deriving growth and yield functions for uneven-aged forest stands. *For. Sci.* 15:183-188.
- Muncy, J.A. 1980. Stand development following two intensities of clearcutting for deer and timber production on the Catoosa Wildlife Management Area. Unpublished M.S. Thesis. University of Tennessee, Knoxville. 102pp.
- Muncy, J.A. and E.R. Buckner. 1981. Stand development after two types of clearcutting for deer and timber production. IN: *Proc. First Biennial Southern Silvicultural Research Conference* (J.P. Barnett, ed.). USDA For. Serv. Gen. Tech. Rep. SO-34. p. 269-273.
- Munro, D.D. 1974. Forest Growth Models -- A Prognosis. IN: *Growth Models for Tree and Stand Simulation* (J. Fries, ed.). Royal College of Forestry, Stockholm. p. 7-21.
- Murphy, P.A. and R.M. Farrar. 1983. Sawtimber volume predictions for uneven-aged loblolly-shortleaf pine stands on average sites. *Sou. J. Appl. For.* 7(1):45-50.
- Namkoong, G., and J.H. Roberts. 1974. Extinction probabilities and the changing age structure of redwood forests. *Am. Nat.* 108:355-368.
- Nance, W.L., R.C. Froelich, T.R. Dell, and E. Shoulders. 1983. A growth and yield model for unthinned slash pine plantations infected with fusiform rust. IN: *Proceedings of the Second Biennial Southern Silvicultural Research Conference* (E.P. Jones, ed.). USDA For. Serv. Gen. Tech. Rep. SE-24. p. 275-282.
- Newnham, R.M. 1964. The development of a stand model for Douglas-fir. Unpublished Ph.D. Dissertation, Univ. of British Columbia, Vancouver, 210pp. (University Microfilms Disser. Abstr. 26/07 p. 3567).
- Noble, I.R. and R.O. Slayter. 1977. Post-fire succession of plants in Mediterranean ecosystems. IN: *Proc. of the Symp. of the Environmental Consequences of Fire and Fuel Management in Mediterranean Climate Ecosystems* (H.A. Mooney and C.E. Conrad, eds.). USDA For. Serv. Gen. Tech. Report WO-3, p. 27-36.
- Peden, L.M., J.S. Williams, and W.E. Frayer. 1973. A Markov model for stand projection. *For. Sci.* 19:303-314.
- Phipps, R.L. 1979. Simulation of wetlands forest vegetation dynamics. *Ecological Modeling* 7(4):257-288.
- Pienaar, L.V. 1965. Quantitative theory of forest growth. Unpublished Ph.D. Dissertation, Univ. of Wash., Seattle, 176pp. (University Microfilms Disser. Abstr. 26/05 p. 2403).

- Pienaar, L.V. and K.J. Turnbull. 1973. The Chapman-Richards generalization of von Bertalanffy's growth model for basal area growth and yield in even-aged stands. *For. Sci.* 19:2-22.
- Potter, M.W., S.R. Kessel, and P.J. Kessel. 1979. FORPLAN: A FOREst Planning LANGUAGE and simulator. *Envir. Mgmt.* 3(1):59-72.
- Richards, F.J. 1959. A flexible growth function for empirical use. *J. Exp. Bot.* 10:290-300.
- Schmelz, D.V. and A.A. Lindsey. 1965. Size class structure of old-growth forests in Indiana. *For. Sci.* 11:258-264.
- Schreuder, H.T., W.L. Hafley, and F.A. Bennett. 1979. Yield prediction for unthinned natural slash pine stands. *For. Sci.* 25:25-30.
- Schreuder, H.T. and W.T. Swank. 1974. Coniferous stands characterized with the Weibull distribution. *Can. J. For. Res.* 4:518-523.
- Schnur, G.L. 1937. Yield, stand, and volume tables for even-aged upland oak forests. USDA For. Serv., Tech. Bull. No. 560, Alleghany For. Exp. Sta., 86pp.
- Schumacher, F.X. and T.S. Coile. 1960. Growth and yield of natural stands of the Southern pines. T.S. Coile, Inc., 115pp.
- Sellers, W.D. 1965. Physical Climatology. University of Chicago Press, Chicago. 367pp.
- Shugart, H.H. 1984. A Theory of Forest Dynamics. Unpublished manuscript. Springer-Verlag, New York. (In process).
- Shugart, H.H., T.R. Crow, and J.M. Hett. 1973. Forest succession models: A rationale and methodology for modeling forest succession over large regions. *For. Sci.* 19:203-212.
- Shugart, H.H., M.S. Hopkins, L.P. Burgess, and A.T. Mortlock. 1980. The development of a succession model for subtropical rain forest and its application to assess the effects of timber harvest at Wiangaree State Forest, New South Wales. *J. Envir. Management.* 11:243-265.
- Shugart, H.H. and J.R. Noble. A computer model of succession and fire response on the high-altitude Eucalyptus forest of the Brindabella Range, Australian Capital Territory. 1981. *Aust. J. Ecol.* 6:149-164.
- Shugart, H.H. and D.C. West. 1977. Development of an Appalachian deciduous forest succession model and its application to assessment of the impact of the chestnut blight. *J. Environ. Management.* 5:161-179.

- Shugart, H.H. and D.C. West. 1979. Size and pattern of simulated forest stands. *For. Sci.* 25(1):120-122.
- Shugart, H.H., and D.C. West. 1980. Forest succession models. *Bioscience* 30(5):308-313.
- Shugart, H.H., D.C. West, and W.R. Emanuel. 1981. Patterns and dynamics of forests: An application and simulation. IN: Forest Succession: Concepts and Application (D.C. West, H.H. Shugart, and D.B. Botkin, eds.). Springer-Verlag, New York. p. 74-94.
- Smalley, G.W. and R.L. Bailey. 1974a. Yield tables and stand structure for loblolly pine plantations in Tennessee, Alabama, and Georgia Highlands. USDA For. Serv. Research Paper SO-96, 81pp.
- Smalley, G.W. and R.L. Bailey. 1974b. Yield tables and stand structure for shortleaf pine plantations in Tennessee, Alabama, and Georgia Highlands. USDA For. Serv. Research Paper SO-97, 57pp.
- Smalley, G.W. 1982. Classification and evaluation of forest sites on the Mid-Cumberland Plateau. USDA For. Serv. Gen. Tech. Rep. SO-38, 58pp.
- Smith, T.M., H.H. Shugart, and D.C. West. 1980. FORHAB: A forest simulation model to predict habitat structure for nongame bird species. IN: *The use of multivariate statistics in studies of wildlife habitat: a workshop.* p. 114-123.
- Society of American Foresters. 1964. Forest cover types of North America. Soc. Amer. For., Washington. 67pp.
- Soloman, D.S. 1974. Simulation of the development of natural and silviculturally treated stands of even-aged Northern Hardwoods. IN: *Growth models for tree and stand simulation* (J. Fries, ed.), Royal College of Forestry, Stockholm. p. 327-352.
- Sollins, P., D.E. Reichle, and J.S. Olson. 1973. Organic budget and model for a southern Appalachian Liriodendron forest. EDFB/IBP-73/2. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 73pp.
- Stage, A.R. 1973. A prognosis model for stand development. USDA For. Serv. Research Paper INT-137, 32pp.
- Stiff, C.T. 1979. Modeling the growth dynamics of natural mixed-species Appalachian hardwood stands. Unpublished Ph.D. Dissertation. Virginia Polytechnic and State University, Blacksburg. 206pp.
- Sullivan, A.D. and J.L. Clutter. 1972. A simultaneous growth and yield model for loblolly pine. *For. Sci.* 18:76-86.

- Suzuki, T. and T. Umemura. 1974. Forest transition as a stochastic process - II. IN: Growth models for tree and stand simulation (J. Fries, ed.). Royal College of Forestry, Stockholm. p. 358-379.
- Tharp, M.L. 1978. Modeling major perturbations on a forest ecosystem. Unpublished M.S. Thesis. Univ. of Tennessee, Knoxville. 52pp.
- Thorntwaite, C.W. 1948. An approach toward a rational classification of climate. *Geograph. Rev.* 38(1):55-94.
- Trimble, J.L., and C.R. Shriner. 1981. Inventory of United States Growth models. Environmental Sci. Div. Oak Ridge Natl. Lab., ORNL/Sub-80/13819/1. 133p.
- Turnbull, K.J. 1963. Population dynamics of mixed forest stands. A system of mathematical models of mixed stand growth and structure. Unpublished Ph.D. Dissertation, Univ. of Wash., Seattle, 186pp. (University Microfilms Disser. Abstr. 24/07 p. 2642).
- USDA Forest Service. 1948. Woody Plant Seed Manual. Misc. Publication 654. 763pp.
- USDA Forest Service. 1979. A generalized forest growth projection system applied to the Lake States region. USDA For. Serv. Gen. Tech. Report NC-49, 96pp.
- USDA Soil Conservation Service. 1950. Soil Survey: Cumberland County, Tennessee. Series 1928, No. 25. 107pp.
- USDA Soil Conservation Service. 1974. Hartsells soil series. U.S. Government Printing Office, Washington. 4pp.
- USDA Soil Conservation Service. 1975. Lonewood soil series. U.S. Government Printing Office, Washington, 4pp.
- United States Department of Commerce, National Oceanic and Atmospheric Administration. 1950-1979. Climatological data: Tennessee annual summary. National Climatic Center, Asheville, NC. 82(13).
- Waggoner, P.E. and G.R. Stephens. 1970. Transition probabilities for a forest. *Nature* 225:1160-1161.
- Weinstein, D.A. 1982a. The long-term nutrient retention properties of forest ecosystems: A simulation investigation. Unpublished Ph.D. Dissertation. Univ. of Tennessee, Knoxville. 175pp.
- Weinstein, D.A. 1982. A user's guide to FORNUT: a simulation model of forest dynamics and nutrient cycling during succession. Unpublished Manuscript. Available from Oak Ridge National Laboratory, Environmental Sciences Division, Oak Ridge, TN. 32pp. + appendix.

Williams, J.S. 1978. Markov models for stand projection. IN: Growth models for long term forecasting of timber yields (J. Fries, H.E. Burkhart, and T.A. Max, eds.), VPI & SU, Blacksburg, VA, p. 243-249.

APPENDICES

APPENDIX A

PREHARVEST AND POST-HARVEST STAND CHARACTERISTICS

TABLE 22
ANALYSIS OF VARIANCE OF THIRD YEAR REGENERATION
CHARACTERISTICS IN CLEARCUTS

Source	Sum of Squares	Mean Squares	F	Prob.>F
<u>Main Effects</u>				
Treatments	768	768	34.87 ^{ns}	0.1068
Replications x Treatments	22	22		
Species	204,262	22,696	8.89**	0.0016
Replications x Species	22,982	2,554		
Sapling Classes	64,638	64,638	42.96 ^{ns}	0.0967
Replications x Classes	1,514	1,514		
<u>Interactions</u>				
Species x Treatments	15,676	15,676	2.72 ^{ns}	0.0761
Replications x Species x Treatments	5,764	640		
Treatments x Classes	18	18	0.01 ^{ns}	0.9409
Replications x Treatments x Classes	2,081	2,081		
Species x Classes	162,783	18,087	7.80*	0.0026
Replications x Species x Classes	20,868	2,319		

^{ns} No significant differences between means.

* Significant differences between means at the 95% level of confidence.

** Significant differences between means at the 99% level of confidence.

TABLE 23

T TEST RESULTS BETWEEN COMPLETE AND DIAMETER LIMIT CLEARCUT
TREATMENTS FOR THIRD YEAR DATA

Source	<u>T</u> Value	Prob. > <u>T</u>
No. sprouts/cut stem		
Sapling size class	0.3031 ^{ns}	0.7644
Pulpwood size class	0.4094 ^{ns}	0.6287
No. sprouts/cut stem by sprout type		
Sapling size class		
Stump sprouts	0.9623 ^{ns}	0.3526
Basal sprouts	0.2087 ^{ns}	0.8364
Pulpwood size class		
Stump sprouts	0.4284 ^{ns}	0.6725
Basal sprouts	0.7284 ^{ns}	0.4740
Height of dominant sprout/cut stem		
Sapling size class	0.2158 ^{ns}	0.8311
Pulpwood size class	0.4856 ^{ns}	0.6328

^{ns} No significant differences between means.

TABLE 24

STATUS OF ALL TREES TALLIED IN THE PREHARVEST INVENTORY THREE YEARS AFTER CUTTING
(BOTH CUTTING TREATMENTS COMBINED)

Species	Sapling (6ft. high to 2.9 in. dbh)			Pulpwood (3.0 in. to 10.9 in. dbh)			Sawtimber (11.0 in. and over)		
	No. of			No. of			No. of		
	Stems Cut	Sprouted	No.	Stems Cut	Sprouted	No.	Stems Cut	Sprouted	No.
----- Number Per Acre (Percent) -----									
Oaks									
Blackjack	4	3 (75)		5	1 (20)		6	0 (0)	
Scarlet	17	15 (88)		51	27 (53)		188	8 (4)	
Black	93	78 (84)		56	27 (48)		36	0 (0)	
White	54	46 (85)		44	18 (41)		6	0 (0)	
Southern Red	-	- (-)		75	29 (39)		49	0 (0)	
Post	26	17 (65)		125	14 (11)		69	1 (1)	
Chestnut	-	- (-)		-	- (-)		1	0 (0)	
Hickories									
Mockernut	24	20 (83)		3	3 (100)		4	0 (0)	
Pignut	71	56 (79)		10	7 (70)		16	3 (19)	
Other Potential Overstory Hardwoods									
Persimmon	1	1 (100)		-	- (-)		-	- (-)	
Blackgum	87	73 (84)		3	1 (33)		3	1 (33)	
Red Maple	22	10 (45)		7	5 (71)		-	- (-)	

TABLE 24

(CONTINUED)

Species	(6ft. high to 2.9 in. dbh)		(3.0 in. to 10.9 in. dbh)		(11.0 in. and over)	
	No. of Stems Cut	No. Sprouted	No. of Stems Cut	No. Sprouted	No. of Stems Cut	No. Sprouted
----- Number Per Acre (Percent) -----						
Understory Hardwoods						
Am. Chestnut	4	2 (50)	-	- (-)	-	- (-)
Am. Holly	2	2 (100)	-	- (-)	-	- (-)
Serviceberry	1	1 (100)	1	1 (100)	-	- (-)
Sassafras	115	95 (83)	-	- (-)	-	- (-)
Sourwood	36	30 (92)	63	62 (98)	2	2 (100)
Dogwood	25	23 (92)	6	6 (100)	-	- (-)
Pines						
Virginia	33	0 (0)	63	0 (0)	15	0 (0)
White	1	0 (0)	-	- (-)	-	- (-)
Totals	616	472 (77)	522	201 (39)	395	15 (4)

TABLE 25

NUMBER OF SPROUTS AND HEIGHT OF DOMINANT SPROUT ON CUT STEMS AFTER
THREE GROWING SEASONS (BOTH CUTTING TREATMENTS COMBINED)

Species	Sapling (6 ft. high to 2.9 in. dbh)	Pulpwood (3.0 to 10.9 in. dbh)	Sawtimber (11.0 in. dbh and over)
	-----Number Per Stump (feet)-----		
Oaks			
White	3.0 (4.4)	5.1 (5.9)	- (-)
Southern Red	3.1 (4.4)	3.7 (4.9)	- (-)
Scarlet	3.0 (4.7)	4.6 (7.3)	3.6 (5.9)
Post	3.0 (4.5)	3.6 (4.9)	3.0* (5.0)
Black	3.1 (4.6)	3.7 (5.9)	- (-)
Blackjack	3.0 (3.3)	3.0 (5.0)	- (-)
Hickories			
Pignut	4.5 (4.4)	3.7 (4.4)	4.0 (5.2)
Mockernut	3.0 (3.7)	3.0 (4.3)	- (-)
Other Potential Overstory Hardwoods			
Red Maple	6.2 (6.6)	14.8 (11.1)	- (-)
Blackgum	3.5 (5.0)	3.0 (5.0)	8.0* (9.0)
Persimmon	3.0*(3.5)	- (-)	- (-)
Understory Hardwoods			
Serviceberry	3.0*(5.0)	8.0*(5.0)	- (-)
Sourwood	6.2 (5.2)	9.6 (8.5)	15.0 (7.0)
Dogwood	6.7 (5.9)	9.8 (6.8)	- (-)
Am. Holly	3.0 (3.8)	- (-)	- (-)
Am. Chestnut	3.0 (3.3)	- (-)	- (-)
Sassafras	3.1 (4.4)	- (-)	- (-)

* Based on one observation.

TABLE 26

MEAN NUMBER OF SPROUTS PER CUT STEM BY SPROUT TYPE AFTER THREE GROWING SEASONS
(BOTH CUTTING TREATMENTS COMBINED)

Species	Sapling (6 ft. high to 2.9 in. dbh)		Pulpwood (3.0 to 10.9 in. dbh)		Sawtimber (11.0 in. dbh and >)	
	Stump	Basal Root	Stump	Basal Root	Stump	Basal Root
Oaks						
Scarlet	0	3.0	3.0	4.7	3.0	3.7
White	0	3.0	0	5.1	-	-
Southern Red	0	3.1	0	3.7	-	-
Post	0	3.0	0	3.7	0	3.0*
Black	0	3.1	0	3.8	-	-
Blackjack	0	3.0	3.0*	0	-	-
Hickories						
Pignut	3.0	4.6	0	3.7	0	3.0
Mockernut	0	3.0	0	3.0	-	-
Other Potential						
Overstory Hardwoods.						
Blackgum	3.0	3.4	0	3.0*	0	8.0
Red Maple	0	6.2	3.0	19.3	-	-
Understory Hardwoods						
Sourwood	15.0	5.9	0	9.8	0	15.0
Dogwood	3.0	7.4	0	9.8	-	-
Sassafras	3.0	3.2	0	-	-	-
Am. Chestnut	0	3.0	0	-	-	-
Am. Holly	0	3.0	0	-	-	-

* Based on one observation.

TABLE 27

ANALYSIS OF VARIANCE OF FOURTH YEAR REGENERATION CHARACTERISTICS
IN CLEARCUTS USING ONLY BURNED PLOT DATA

Source	Sum of Squares	Mean Squares	F	Prob. > F
<u>Main Effects</u>				
Treatments	262	262	0.19 ^{ns}	0.7399
Replications x Treatments	1,396	1,396		
Species	551,877	61,320	30.42**	0.0001
Replications x Species	18,142	2,016		
Sapling Classes	343,740	343,740	41.02 ^{ns}	0.0986
Replications x Classes	8,379	8,379		
<u>Interactions</u>				
Species x Treatments	2,516	280	0.82 ^{ns}	0.6137
Replications x Species x Treatments	2,717	340		
Treatments x Classes	262	262	0.19 ^{ns}	0.7399
Replications x Treatments x Classes	1,396	1,396		
Species x Classes	551,877	61,320	30.42**	0.0001
Replications x Species x Classes	18,142	2,016		

^{ns} No significant differences between means.

** Significant differences between means at the 99% level of confidence.

TABLE 28
STATUS OF ALL CUT TREES TALLIED IN THE PRE-HARVEST INVENTORY AFTER FOUR
YEARS (ONE YEAR AFTER BURNING) FOR BOTH CUTTING TREATMENTS COMBINED

Species	Saplings (6 ft. high to 2.9 in. dbh)			Pulpwood (3.0 to 10.9 in. dbh)			Sawtimber (11.0 in. dbh and >)					
	Burned			Unburned			Burned					
	No. cut	No. sprouted	No. cut No. sprouted	No. cut	No. sprouted	No. cut No. sprouted	No. cut	No. sprouted	No. cut No. sprouted			
-----Stems Per Acre (Percent)-----												
Oaks	3	0 (0)	1	1 (100)	5	0 (0)	-	2 (25)	5	0 (0)	1	0 (0)
Blackjack	11	8 (73)	6	6 (100)	43	25 (58)	8	11 (46)	137	5 (4)	51	2 (4)
Scarlet	65	53 (81)	28	25 (89)	32	15 (47)	24	3 (30)	18	0 (0)	18	0 (0)
Black	23	20 (87)	-	-	34	15 (44)	10	3 (26)	3	0 (0)	3	0 (0)
White	33	29 (88)	21	18 (86)	41	15 (37)	34	9 (22)	23	0 (0)	26	0 (0)
Southern Red	26	14 (54)	-	-	70	10 (14)	55	3 (5)	43	1 (2)	26	0 (0)
Post	-	-	-	-	-	-	-	-	1	0 (0)	-	-
Chestnut	-	-	-	-	-	-	-	-	-	-	-	-
Hickories	9	8 (89)	15	11 (73)	3	3 (100)	4	2 (50)	3	0 (0)	1	0 (0)
Mockernut	56	41 (73)	15	11 (73)	-	-	6	5 (83)	13	2 (15)	3	0 (0)
Pignut	-	-	-	-	-	-	-	-	-	-	-	-
Other Potential	-	-	-	-	-	-	-	-	-	-	-	-
Overstory Hardwoods	74	60 (81)	13	9 (69)	2	0 (0)	1	1 (100)	2	0 (0)	1	0 (0)
Persimmon	9	5 (56)	13	4 (31)	3	0 (0)	4	3 (75)	-	-	-	-
Blackgum	-	-	-	-	-	-	-	-	-	-	-	-
Red Maple	-	-	-	-	-	-	-	-	-	-	-	-
Understory Hardwoods	1	0 (0)	3	2 (67)	-	-	-	-	-	-	-	-
Am. Chestnut	2	2 (100)	-	-	-	-	-	1 (100)	-	-	-	-
Am. Holly	1	0 (0)	-	-	-	-	-	-	-	-	-	-
Serviceberry	83	67 (81)	32	29 (91)	-	-	-	-	-	-	-	-
Sassafras	18	15 (83)	18	15 (83)	45	41 (91)	18	18 (100)	-	-	2	2 (100)
Sourwood	13	10 (77)	12	11 (92)	4	4 (100)	2	2 (100)	-	-	-	-
Dogwood	-	-	-	-	-	-	-	-	-	-	-	-
Pines	16	0 (0)	1	0 (0)	41	0 (0)	6	0 (0)	8	0 (0)	4	0 (0)
Virginia	-	-	-	-	-	-	-	-	-	-	-	-
Totals	443	332 (75)	179	142 (79)	323	128 (40)	173	60 (35)	256	8 (3)	136	4 (3)

TABLE 29

NUMBER OF SPROUTS AND HEIGHT OF DOMINANT SPROUT ON CUT STEMS (BOTH CUTTING TREATMENTS COMBINED)
AFTER FOUR GROWING SEASONS (ONE YEAR AFTER BURNING)

Species	Sapling (6 ft. high to 2.9 in. dbh)		Pulpwood (3.0 to 10.9 in. dbh)		Sawtimber (11.0 in. dbh and >)	
	Burned	Unburned	Burned	Unburned	Burned	Unburned
Oaks						
White	5.0 (3.8)	-	6.3 (4.2)	8.7 (7.3)	-	-
Southern Red	4.1 (3.4)	3.0 (5.4)	4.7 (4.2)	3.0 (6.0)	-	-
Scarlet	3.0 (5.1)	3.0 (6.9)	7.5 (5.3)	3.0 (7.3)	4.0 (4.8)	3.0 (9.0)
Post	3.7 (2.4)	-	6.0 (3.5)	3.0 (5.8)	3.0*(6.0)	-
Black	3.1 (3.9)	3.0 (5.9)	3.0 (3.9)	3.9 (7.1)	-	-
Blackjack	-	3.0* (4.5)	-	-	-	-
Hickories						
Pignut	5.5 (3.4)	3.5 (3.5)	5.5 (3.0)	4.0 (5.5)	5.5 (3.3)	0 (0)
Mockernut	3.0 (5.1)	3.0 (5.0)	-	3.0 (5.5)	-	-
Other Potential						
Overstory Hardwoods						
Red Maple	7.0 (3.6)	6.0 (13.2)	-	17.7 (6.8)	-	-
Blackgum	5.2 (3.3)	5.8 (6.1)	-	3.0 (7.0)	-	-
Understory Hardwoods						
Sourwood	6.8 (5.0)	4.0 (6.6)	12.0 (7.4)	9.8 (9.1)	-	15.0(13.0)
Dogwood	6.0 (3.4)	7.9 (6.7)	13.3 (4.8)	9.0 (5.8)	-	-
Am. Holly	3.0 (3.5)	-	-	-	-	-
Am. Chestnut	-	3.0 (4.8)	-	-	-	-
Sassafras	7.4 (4.0)	6.5 (5.1)	-	-	-	-

* Based on one observation

TABLE 30

NUMBER OF SPROUTS PER CUT STEM (BOTH CUTTING TREATMENTS COMBINED)
BY SPROUT TYPE FOUR YEARS AFTER CUTTING (ONE YEAR AFTER BURNING)

Species	Burned			Unburned		
	Stump	Basal	Root	Stump	Basal	Root
Oaks						
Scarlet	3.0	6.2	0	0	3.0	0
White	0	5.6	0	0	8.7	0
Southern Red	0	4.3	0	0	3.0	0
Post	0	4.6	0	0	3.0	0
Black	0	3.1	0	0	3.3	0
Blackjack	-	-	-	0*	3.0*	0*
Hickories						
Pignut	0	5.2	11.5	0	3.3	8.0
Mockernut	0	3.0	0	0	3.0	0
Other Potential						
Overstory Hardwoods						
Blackgum	0	4.2	10.3	0	3.6	11.5
Red Maple	0	7.0	0	0	11.0	0
Understory Hardwoods						
Sourwood	0	10.6	0	0	7.6	0
Dogwood	0	8.1	0	3.0	8.5	0
Sassafras	0	4.7	9.5	0	3.2	8.2
Am. Holly	0	3.0	0	-	-	-

* Based on one observation.

APPENDIX B

SCIENTIFIC NAMES

TABLE 31

COMMON AND SCIENTIFIC NAMES OF TREE SPECIES

Common Name	Scientific Name
Red Maple	<i>Acer rubrum</i> L.
Sugar Maple	<i>Acer saccharum</i> Marsh.
Serviceberry	<i>Amelanchier arborea</i> var. <i>laevis</i> Wieg.
Birch	<i>Betula</i> sp.
American Chestnut	<i>Castanea dentata</i> Marsh.
Bitternut Hickory	<i>Carya cordiformis</i> (Wangenh.) K. Koch
Pignut Hickory	<i>Carya glabra</i> Mill.
Shagbark Hickory	<i>Carya ovata</i> (Mill.) K. Koch
Mockernut Hickory	<i>Carya tomentosa</i> Nutt.
Dogwood	<i>Cornus florida</i> L.
Persimmon	<i>Diospyros virginiana</i> L.
Strangler Fig	<i>Ficus</i> sp.
White Ash	<i>Fraxinus americana</i> L.
American Holly	<i>Ilex opaca</i> Ait.
Black Walnut	<i>Juglans nigra</i> L.
Eastern Redcedar	<i>Juniperus virginiana</i> L.
Sweetgum	<i>Liquidambar styraciflua</i> L.
Yellow-poplar	<i>Liriodendron tulipifera</i> L.
Blackgum	<i>Nyssa sylvatica</i> Marsh.
Sourwood	<i>Oxydendron arboreum</i> L.
White Spruce	<i>Picea glauca</i> (Moench) Voss
Lodgepole Pine	<i>Pinus contorta</i> Dougl.
Shortleaf Pine	<i>Pinus echinata</i> Mill.
Slash Pine	<i>Pinus elliottii</i> Engelm.
Longleaf Pine	<i>Pinus palustris</i> Mill.
Ponderosa Pine	<i>Pinus ponderosa</i> Laws.
Monterey Pine	<i>Pinus radiata</i> D. Don
Eastern White Pine	<i>Pinus strobus</i> L.
Scots Pine	<i>Pinus sylvestris</i> L.
Loblolly Pine	<i>Pinus taeda</i> L.
Virginia Pine	<i>Pinus virginiana</i> Mill.
Black Cherry	<i>Prunus serotina</i> Ehrh.
Douglas Fir	<i>Pseudotsuga menziesii</i> (Mirb.) Franco

TABLE 31
(CONTINUED)

Common Name	Scientific Name
White Oak	<i>Quercus alba</i> L.
Scarlet Oak	<i>Quercus coccinea</i> Muenchh.
Southern Red Oak	<i>Quercus falcata</i> Michx.
Blackjack Oak	<i>Quercus marilandica</i> Muenchh.
Chestnut Oak	<i>Quercus prinus</i> L.
Northern Red Oak	<i>Quercus rubra</i> L.
Post Oak	<i>Quercus stellata</i> Wangenh.
Black Oak	<i>Quercus velutina</i> Lam.
Winged Sumac	<i>Rhus copallina</i> L.
Black Locust	<i>Robinia pseudoacacia</i> L.
Sassafras	<i>Sassafras albidum</i> Nutt.
Redwood	<i>Sequoia sempervirens</i> (D. Don) Endl.
Eastern Hemlock	<i>Tsuga canadensis</i> (L.) Carr.
Winged Elm	<i>Ulmus alata</i> Michx.

TABLE 32

COMMON AND SCIENTIFIC NAMES OF BIRDS AND MAMMALS

Species Common Name	Scientific Name
<u>Birds</u>	
Ruffed Grouse	<i>Bonasa umbellus</i>
Bobwhite Quail	<i>Colinus virginianus</i>
Turkey	<i>Meleagris gallopavo</i>
American Woodcock	<i>Philohela minor</i>
Ovenbird	<i>Seiurus aurocapillus</i>
Mourning Dove	<i>Zenaidura macroura</i>
<u>Mammals</u>	
White-tailed Deer	<i>Odocoileus virginianus</i>
Raccoon	<i>Procyon lotor</i>
Eastern Gray Squirrel	<i>Sciurus carolinensis</i>
European Wild Hog	<i>Sus scrofa</i>
Eastern Cottontail Rabbit	<i>Sylvilagus floridanus</i>

APPENDIX C

CORRESPONDENCE FOR THE DROUGHT TOLERANCE SURVEY

August 3, 1983

Dr. Edward R. Buckner
University of Tennessee
Department of Forestry,
Wildlife, and Fisheries
P.O. Box 1071
Knoxville, TN 37901

Dear Sir,

I am a Ph.D. candidate in Forest Ecology at the University of Tennessee working with Drs. Edward Buckner and H.H. Shugart. My dissertation topic involves the development of a computer model (FORCAT) to simulate forest stand dynamics for mixed pine and hardwood stands on the Cumberland Plateau of East Tennessee. One of the many variables considered in FORCAT is the relative ability of seedlings of 33 species to survive droughty conditions. Several attempts have been made to quantify the relative drought tolerance of each species by other students working with similar models. Since past attempts have shown little success, I would like to try a different approach. To accomplish this, I am requesting your assistance.

The FORCAT model reduces seedling survival during periods of moisture stress by a subroutine called MOIST. In this, many variables dealing with soil characteristics, weather patterns, and vegetational characteristics are considered. All of these appear to be working accurately with the exception of the relative ability of each species to survive periods of moisture stress.

My approach to this problem is to place each species into a drought tolerance category and adjust seedling survival rates on that basis. This is where I need your help. Please take a few minutes to place each of the species in the enclosed list into one of the 5 drought tolerance categories indicated. I am asking the same assistance from several other scientists and field foresters experienced in this area. In summarizing these, I hope to reach a general consensus on the expected response of seedlings of each species to moisture stress.

Even though it may happen only rarely, please assume the following:

- 1) Seedlings of all species are standing together on the same site and that all possible variables are equal for all species.
- 2) Each seedling is free to grow without competition.
- 3) The only limiting factor for the survival of each seedling is moisture.

4) Periods of moisture stress occur often enough and/or are of sufficient intensity (i.e. duration) to eliminate those species intolerant of drought. The survival rates of drought tolerant species, however, would not change significantly while that of intermediate species would be variable.

Based on your knowledge of each species, please place each one into a category in terms of how periods of moisture stress would effect it's ability to become established on the site. These categories include very tolerant, tolerant, intermediate, intolerant, and very intolerant. A very tolerant species would generally survive while a very intolerant one would become eliminated.

I greatly appreciate your help with this problem. Any questions or comments would certainly be welcome.

Sincerely,

Thomas A. Waldrop

Drought Tolerance Survey for Seedlings of the Tree Species in the
FORCAT Model

CATEGORIES*

1	2	3	4	5	
()	()	()	()	()	-Red Maple (<u>Acer rubrum</u>)
()	()	()	()	()	-Sugar Maple (<u>A. saccharum</u>)
()	()	()	()	()	-Serviceberry (<u>Amelanchier laevis</u>)
()	()	()	()	()	-Bitternut Hickory (<u>Carya cordiformis</u>)
()	()	()	()	()	-Pignut Hickory (<u>C. glabra</u>)
()	()	()	()	()	-Shagbark Hickory (<u>C. ovata</u>)
()	()	()	()	()	-Mockernut Hickory (<u>C. tomentosa</u>)
()	()	()	()	()	-Dogwood (<u>Cornus florida</u>)
()	()	()	()	()	-Persimmon (<u>Diospyros virginiana</u>)
()	()	()	()	()	-White Ash (<u>Fraxinus americana</u>)
()	()	()	()	()	-American Holly (<u>Ilex opaca</u>)
()	()	()	()	()	-Black Walnut (<u>Juglans nigra</u>)
()	()	()	()	()	-Eastern Redcedar (<u>Juniperus virginiana</u>)
()	()	()	()	()	-Sweetgum (<u>Liquidambar styraciflua</u>)
()	()	()	()	()	-Yellow Poplar (<u>Liriodendron tulipifera</u>)
()	()	()	()	()	-Blackgum (<u>Nyssa sylvatica</u>)
()	()	()	()	()	-Sourwood (<u>Oxydendron arboreum</u>)
()	()	()	()	()	-Shortleaf Pine (<u>Pinus echinata</u>)
()	()	()	()	()	-Eastern White Pine (<u>P. strobus</u>)
()	()	()	()	()	-Virginia Pine (<u>P. virginiana</u>)
()	()	()	()	()	-Black Cherry (<u>Prunus serotina</u>)
()	()	()	()	()	-White Oak (<u>Quercus alba</u>)
()	()	()	()	()	-Scarlet Oak (<u>Q. coccinea</u>)
()	()	()	()	()	-Southern Red Oak (<u>Q. falcata</u>)
()	()	()	()	()	-Blackjack Oak (<u>Q. marilandica</u>)
()	()	()	()	()	-Chestnut Oak (<u>Q. prinus</u>)
()	()	()	()	()	-Post Oak (<u>Q. stellata</u>)
()	()	()	()	()	-Black Oak (<u>Q. velutina</u>)
()	()	()	()	()	-Winged Sumac (<u>Rhus copallina</u>)
()	()	()	()	()	-Black Locust (<u>Robinia pseudoacacia</u>)
()	()	()	()	()	-Sassafras (<u>Sassafras albidum</u>)
()	()	()	()	()	-Eastern Hemlock (<u>Tsuga canadensis</u>)
()	()	()	()	()	-Winged Elm (<u>Ulmus alata</u>)

* Categories for the drought tolerance of seedlings:

- 1 = Very tolerant
- 2 = Tolerant
- 3 = Intermediate
- 4 = Intolerant
- 5 = Very intolerant

August 31, 1983

Dr. Edward R. Buckner
University of Tennessee
Department of Forestry, Wildlife, and Fisheries
P.O. Box 1071
Knoxville, TN 37901

Dear Dr. Buckner,

I would like to express my appreciation for your help in classifying the species of the FORCAT model into drought tolerance categories. Enclosed, are the results of this survey. The number of votes received for each category of drought tolerance and for each species is indicated. A total of 18 scientists and field foresters cooperated in this survey. Their names are listed below for your information. In some cases, individuals were not familiar with certain species and did not put them into a category. Therefore, there is not a total of 18 votes for all species. Again, I would like to express my appreciation for your efforts.

Sincerely,

Thomas A. Waldrop

D.E. Beck - USDA Forest Service, Asheville, NC
D. Bivens - USDA Forest Service, Sewanee, TN
E.R. Buckner - University of Tennessee, Knoxville, TN
E. Clebsch - University of Tennessee, Knoxville, TN
J.K. Francis - USDA Forest Service, Stoneville, MS
J. Hodges - Mississippi State University, Mississippi State, MS
D.L. Loftis - USDA Forest Service, Asheville, NC
C.E. McGee - USDA Forest Service, Sewanee, TN
H. McNab - USDA Forest Service, Asheville, NC
W.F. Miller - Mississippi State University, Mississippi State, MS
K. Pierce - USDA Forest Service, Sewanee, TN
J.G. Schroeder - USDA Forest Service, Asheville, NC
R.E. Schoenike - Clemson University, Clemson, SC
G.W. Smalley - USDA Forest Service, Sewanee, TN
D.W. Smith - VPI & SU, Blacksburg, VA
K. Steinbeck - University of Georgia, Athens, GA
D.H. Van Lear - Clemson University, Clemson, SC
R. Zahner - Clemson University, Clemson, SC

APPENDIX D

LISTING OF THE FORCAT MODEL

```

//FORCAT JOB ,WALDROP,GROUP=J10262,USER=P74958,
//      PASSWORD=BASSET,TIME=300
/*JOBPARM      LINES=200
/*ROUTE      CMSRJO USERID=PA74958
/*ROUTE      PRINT RMT17
// EXEC FORTGCLG,GOREG=448K
//FORT.SYSIN DD *
C.....
C.....CATOOSA FOREST SUCCESSION MODEL
C.....
COMMON/WATER/T(12),VT(12),RT(12),R(12),VR(12),FC,DRY,
1BGS,EGS,PLAT,FJ
COMMON/FOREST/NTREES(100),DBH(1200),IAGE(1200),KSPRT(100),
1NEWTR(100),SUMLA(1200),NEW(100),SWTCH(5)
COMMON/PARAM/AAA(100,6),DMAX(100),DMIN(100),B3(100),
1B2(100),(ITOL(100),AGEMX(100),CURVE(100),G(100,20),
2SPRTND(100),WING(100),SPRTMX(100),SWITCH(100,5),
3KTIME(100),D3(100),TINC(100),SDSPLB(100)
COMMON/CONST/NSPEC,SOILQ,DEGD,DIALIM,SDPR(100),KPRNT
COMMON/RAN/YFL
COMMON NSELCT(100)
COMMON/OUTPT/IO1,IO2,PLOT,PRINT,LIST
COMMON/PAREA/HTREE(1200)
COMMON/MARK/NOGRO(1200),NFLAG(1200)
COMMON/COUNT/NTOT,NYEAR
COMMON/TEMP/DTEMP(1200),ITEMP(1200),NFTEMP(1200)
COMMON/PASSX/A(1001,50)
COMMON/SEED/USEED(16)
DIMENSION Z(2)
INTEGER USEED,CUTYR,FYR
LOGICAL SWITCH,SWTCH,PLOT,PRINT,LIST
DATA NCT/0/
C.....
C.....*****
C.....ARRAYS USED IN THE MODEL
C.....A - PERCENT BIOMASS OF EACH SPECIES ON THE PLOT
C.....    FOR EACH SIMULATED YEAR
C.....AAA - NAMES OF EACH OF THE SPECIES
C.....AGEMX - MAXIMUM AGE RECORDED FOR EACH SPECIES
C.....B2 - SPECIES SPECIFIC GROWTH CONSTANTS
C.....B3 - SPECIES SPECIFIC GROWTH CONSTANTS
C.....CURVE - USED IN PLT SUBROUTINE
C.....    WITH THE SHAPE OF THE GROWTH CURVE
C.....D3 - RELATIVE DROUGHT TOLERANCE OF EACH SPECIES
C.....DBH - DIAMETER AT BREAST HEIGHT FOR EACH TREE
C.....DMAX - UPPER TEMPERATURE LIMIT OF EACH SPECIES
C.....DMIN - LOWER TEMPERATURE LIMIT OF EACH SPECIES
C.....DTEMP - TEMPORARY STORAGE FOR DBH
C.....G - GROWTH PARAMETER FOR EACH SPECIES DEALING
C.....HTREE - HEIGHT OF EACH TREE ON THE PLOT
C.....IAGE - THE AGE OF EACH TREE

```

C.....ITEMP - TEMPORARY STORAGE FOR TREE AGES
 C.....ITOL - SHADE TOLERANCE OF EACH SPECIES
 C.....KSPRT - TREES THAT CAN SPROUT
 C.....KTIME - UPPER AGE AT WHICH EACH SPECIES PRODUCES SEED
 CONTINUE
 C.....NEW - SPECIES ELIGIBLE TO SPROUT
 C.....NEWTR - NEW TREES WHICH ARE ADDED TO PLOT
 C.....NFLAG - FLAGS SPROUTS AFTER EACH CLEARCUT TO DETERMINE
 C.....WHICH STUMPS ARE ALIVE DURING A BURN YEAR
 C.....NFTEMP - TEMPORARY STORAGE FOR THE NFLAG ARRAY
 C.....NOGRO - TREES THAT DON'T GROW
 C.....NSELCT - NUMBERS OF SPECIES TO BE INCLUDED IN ANY RUN
 C.....NTREES - NUMBER OF TREES FOR EACH SPECIES
 C.....R - MEAN MONTHLY RAINFALL FOR THE CROSSVILLE EXP. STATION
 C.....RT - MEAN MONTHLY TEMPERATURE AS STOCHASTICALLY DETERMINED
 C.....BY THE MODEL
 C.....SDPB - PROBABILITY OF SEEDS OF EACH SPECIES COMING INTO
 C.....THE SIMULATED PLOT
 C.....SDSPLB - NUMBER OF SEEDS PER POUND OF CLEANED SEED
 C.....SPRTMX - MAXIMUM DIAMETER AT WHICH EACH SPECIES SPROUT
 C.....SPRTND - SPROUTING TENDENCY OF EACH SPECIES
 C.....SUMLA - LEAF AREA OF EACH TREE
 C.....SWITCH - SPECIES SPECIFIC LIMITATIONS TO GERMINATION
 C.....SWTCH - SWITCHES DETERMINED BY THE MODEL TO COMPARE WITH
 C.....THOSE IN THE ABOVE ARRAY TO SEE IF SEEDING IS ALLOWED
 C.....T - MEAN MONTHLY TEMP. FOR THE CROSSVILLE EXP. STATION
 C.....TINC - YEARLY DIAMETER INCREMENT BELOW WHICH EACH
 C.....SPECIES HAS A HIGHER MORTALITY RATE
 C.....USEED - SEEDS FOR RANDOM NUMBER GENERATORS
 C.....VR - STD. DEV. OF MONTHLY RAINFALL AT CROSSVILLE EXP. STA.
 C.....VT - STD. DEV. OF MONTHLY TEMP. AT CROSSVILLE EXP. STA.
 C.....WING - INDICATES SPECIES WITH WINGED SEEDS
 C.....*****
 CONTINUE
 C.....
 C.....REFERENCE FOR RANDOM NUMBER GENERATOR - DESIGN AND
 C.....USE OF COMPUTER SIMULATION MODELS - EMSHOFF AND SISSON -
 C.....THE MACMILLAN COMPANY
 C.....USEED(1) - KILL: TEST MAXIMUM AGE FOR EACH TREE
 C.....USEED(2) - KILL: TEST GT .368 FOR TREE TO DIE
 C.....USEED(3)-SPROUT: SELECT SPECIES TO SPROUT: NOT USED
 C.....USEED(4)-SPROUT: SELECT NUMBER OF TREES TO SPROUT
 C.....USEED(5) - SPROUT: USED TO CALCULATE DBH FOR SPROUTS
 C.....USEED(6) - BIRTH: SELECT A SPECIES FROM 1 TO 3 TIMES
 C.....USEED(7) - BIRTH: USED IN SMALL MAMMAL SWITCH
 C.....USEED(8) - BIRTH: USED IN SEEDING RATE SWITCH
 C.....USEED(9) -BIRTH: DETERMINES THE NUM. OF SEEDLINGS TO PLANT
 C.....USEED(10) - BIRTH: SELECT SEEDLINGS (PARTICULAR SPECIES)
 C.....USEED(11) - BIRTH: USED TO CALCULATE DBH FOR SEEDLINGS
 C.....USEED(12) - TEMPE: USED TO SELECT YEARLY TEMP.E EXTREME
 C.....USEED(13) - TEMPE: USED TO SELECT YEARLY TEMP. EXTREME

```

C.....USEED(14) - MOIST: USED TO SELECT RAINFALL EXTREMES
C.....USEED(15) - MOIST: USED TO SELECT RAINFALL EXTREMES
C.....USEED(16) - BIRTH: USED TO DETERMINE PROBABILITY OF SEED
C.....      REACHING THE SIMULATED PLOT
C.....      CONTINUE
C.....
C.....INITIAL SEEDS FOR SUBROUTINE RANDOM
C.....
C.....      USEED(1) = 13284
C.....      USEED(2) = 21224
C.....      USEED(3) = 99052
C.....      USEED(4) = 00199
C.....      USEED(5) = 60578
C.....      USEED(6) = 74976
C.....      USEED(7) = 35553
C.....      USEED(8) = 74815
C.....      USEED(9) = 50899
C.....      USEED(10) = 48396
C.....      USEED(11) = 22951
C.....      USEED(12) = 15688
C.....      USEED(13) = 36926
C.....      USEED(14) = 22972
C.....      USEED(15) = 62823
C.....      USEED(16) = 31687
C.....
C.....INITIAL SEEDS FOR SUBROUTINE GGNORD
C.....
C.....      NSEED1 = 86899
C.....      NSEED2 = 99221
C.....
C.....SELECT OUTPUT MODE
C.....
C.....      PLOT = .TRUE.
C.....      PRINT = .TRUE.
C.....      LIST = .TRUE.
C.....
C.....SET DEVICE SWITCHES
C.....
C.....SWITCH      IBM DEVICE #
C.....  I01      5 (CARDS)
C.....  I02      6 (PRINTER)
C.....  I03      4 (TAPE)
C.....
C.....      I01 = 5
C.....      I02 = 6
C.....      I03 = 4
C.....
C.....SET SIMULATION PARAMETERS
C.....
C.....KTIMES - NUMBER OF RUNS

```

```

C.....NYEAR - LENGTH OF RUN (YEARS)
C.....KPRNT - PRINT INTERVAL (YEARS)
C.....CUTYR - INTERVAL BETWEEN CLEARCUTS
C.....DIALIM - LOWER LIMIT TO CUT A TREE (CM)
C.....LT - LAND TYPE TO BE SIMULATED (REF:SMALLEY)
C.....CAUTION -IF A CLEARCUT IS CONDUCTED EARLY IN THE ROTATION
C.....      (<10 YEARS), SPROUT WILL PUT IN AN UNREALISTICALLY
C.....      LARGE NUMBER OF TREES. THIS MAY OVERLOAD THE ARRAYS.
      KTIMES = 100
      NYEAR = 100
      KPRNT = 50
      LT = 1
      CUTYR = 1001
      FYR = 11
      DIALIM = 7.6
      CALL INPUT(LT)
      IF(.NOT.PLOT)      GO TO 10
      M3 = NSPEC+3
      DO 100 IVA = 1,NYEAR
      DO 100 IVS = 1,M3
      A(IVA,IVS) = 0.
100 CONTINUE
C.....
C.....SOILQ - THE MAX. BIOMASS RECORDED FOR FORESTS IN THE AREA
C.....
      10 SOILQ = 25416.
      IPLOT = 0
      KYR = 0
      NYSCC = 0
      DO 200 JJ = 1,KTIMES
      CALL PLOTIN(IPLOT)
      WRITE(IO2,2201) IPLOT
2201 FORMAT('1',58X,'PLOT NUMBER ',I4)
      CALL INIT
      CALL SEEDPR
      DO 250 I = 1,NYEAR
      KYR = I
      CALL TEMPE(DEGD,KYR)
      CALL MOIST(KYR)
      CALL KILL(KYR,CUTYR,FYR,NYSCC)
      CALL BIRTH(KYR,CUTYR,FYR,NYSCC)
      CALL GROW(LT,NYSCC)
      CALL OUTPUT(KYR,IPLOT)
250 CONTINUE
200 CONTINUE
      IF(.NOT.PLOT)      STOP
      ZNYR = IPLOT
      NYR1 = NYEAR+1
      DO 300 IV1 = 1,NYR1
      TIMEX = IV1-1

```

```

C      WRITE(4,2010) TIMEX
2010  FORMAT(' ',E10.3)
      DO 350 IV2 = 1,M3
      A(IV1,IV2) = A(IV1,IV2)/ZNYR
C      WRITE(4,2020)A(IV1,IV2)
2020  FORMAT(2E10.3)
      350 CONTINUE
      300 CONTINUE
      CALL PLT
      STOP
      END

C.....
C.....
C.....
      SUBROUTINE TEMPE(DEGD,KYR)
      COMMON/WATER/T(12),VT(12),RT(12),R(12),VR(12),FC,DRY,
1BGS,EGS,PLAT,FJ
      COMMON/SEED/USEED(16)
      COMMON/OUTPT/IO1,IO2,PLOT,PRINT,LIST
      DIMENSION DAYS(12),Z(2)
      INTEGER USEED
      DATA NCT/0/
      DATA DAYS/31.,28.,31.,30.,31.,30.,31.,31.,30.,31.,30.,31./
      YR = KYR
      DDBASE = 5.83
      DEGD = 0.
      DO 3 I=1,12
3      RT(I) = 0.
      DO 1 I=1,12
      NCT = NCT+1
      IF(NCT .EQ. 2) GO TO 36
      CALL GGNORD(USEED(12),USEED(13),Z)
      GO TO 38
36     Z(1) = Z(2)
      NCT = 0
38     CONTINUE
C      WRITE(IO2,2201) I,T(I),VT(I)
2201  FORMAT(' TEMP =',I10,2E16.8)
      RT(I) = T(I)+VT(I)*Z(1)
      IF(RT(I) .LE. DDBASE) GO TO 1
      DEGD = DEGD+(RT(I)-DDBASE)*DAYS(I)
1      CONTINUE
      RETURN
      END

C.....
C.....
C.....
      SUBROUTINE INPUT(LT)
      COMMON/WATER/T(12),VT(12),RT(12),R(12),VR(12),FC,DRY,
1BGS,EGS,PLAT,FJ

```

```

COMMON NSELCT(100)
COMMON/OUTPT/IO1,IO2,PLOT,PRINT,LIST
COMMON/PARAM/AAA(100,6),DMAX(100),DMIN(100),B3(100),
1B2(100),ITOL(100),AGEMX(100),CURVE(100),G(100,20),
2SPRTND(100),WING(100),SPRTMX(100),SWITCH(100,5),
3KTIME(100),D3(100),TINC(100),SDSPLB(100)
COMMON/CONST/NSPEC,SOILQ,DEGD,DIALIM,SDPR(100),KPRNT
INTEGER SENSIT
LOGICAL LIST
C.....
C.....READ PARAMETERS FOR MOIST SUBROUTINE
C.....
    READ(IO1,1020) PLAT,BGS,EGS,FC,DRY
1020 FORMAT(F5.2,3F5.1,F4.1)
    READ(IO1,1035)(T(I),I=1,12)
    READ(IO1,1035)(VT(I),I=1,12)
    READ(IO1,1035)(R(I),I=1,12)
    READ(IO1,1035)(VR(I),I=1,12)
1035 FORMAT(5X,12F5.2)
    WRITE(IO2,1025) PLAT,BGS,EGS
1025 FORMAT(' LATITUDE=',F5.2,' GROWING SEASON: BEGINS DAY ',
1F5.1,' ENDS DAY ',F5.1)
    WRITE(IO2,1027) FC,DRY
1027 FORMAT(' FIELD CAPACITY (CM) = ',F5.1,
1' WILTING POINT (CM) = ',F5.1)
    WRITE(IO2,1029) LT
1029 FORMAT(' THE LAND TYPE IS NUMBER ',I2)
C.....
C.....SUBROUTINE INPUT READS IN SPECIES PARAMETERS
C.....
    READ(IO1,2201) NSPEC,(NSELCT(I),I=1,NSPEC)
2201 FORMAT(40I2)
    J = 1
    IF (.NOT.LIST) GO TO 10
    WRITE(IO2,1101)
1101 FORMAT('1',56X,'SPECIES PARAMETERS')
    WRITE(IO2,2010)
2010 FORMAT('0SPECIES',18X,'DMAX',3X,'DMIN',4X,'B3',3X,'B2',
13X,'ITOL',2X,'AGEMX',5X,'G',4X,'SPRTND',2X,
2'SPRTMX',2X,'SWITCH',2X,'KTIME',3X,'D3',2X,'TINC',2X,
3'SEEDS/LB',2X,'WING',2X,'NUM')
    WRITE(IO2,2020)
2020 FORMAT(1X,'-----',18X,'----',3X,'----',4X,'---',3X,'---',
13X,'----',2X,'-----',5X,'-',4X,'-----',2X,
2'-----',2X,'-----',2X,'-----',3X,'---',2X,'-----',2X,
3'-----',2X,'-----',2X,'----')
    DO 107 I=1,NSPEC
    READ(IO1,3011) (G(I,L),L=1,20)
3011 FORMAT(14F5.1,/6F5.1)
107 CONTINUE
    L = NSPEC + 1

```

```

DO 108 I = L,100
DO 109 N = 1,20
G(I,N) = 0.
109 CONTINUE
108 CONTINUE
10 DO 100 K=1,100
  READ(IO1,1010) (AAA(J,I),I=1,6),DMAX(J),DMIN(J),B3(J),
  1B2(J),ITOL(J),AGEMX(J),CURVE(J),SPRTND(J),
  2SPRTMX(J),(SWITCH(J,I),I=1,5),KTIME(J),
  3D3(J),NUM,TINC(J),SDSPLB(100),WING(J)
1010 FORMAT(5A4,A3,F6.0,F5.0,F4.4,F5.2,I1,F4.0,F2.0,F3.0,
  1F4.0,5L1,I4,F2.0,I2,/F3.2,F9.1,I1)
  IF(NSELCT(J) .NE. NUM) GO TO 100
  IF(.NOT.LIST) GO TO 20
  WRITE(IO2,2030)(AAA(J,I),I=1,6),DMAX(J),DMIN(J),B3(J),
  1B2(J),ITOL(J),AGEMX(J),G(J,LT),SPRTND(J),SPRTMX(J),
  2(SWITCH(J,I),I=1,5),KTIME(J),D3(J),TINC(J),SDSPLB(J),
  3WING(J),NUM
2030 FORMAT(1X,6A4,F6.0,2X,F5.0,1X,F5.4,1X,F5.2,3X,I1,
  14X,F4.0,3X,F5.1,4X,F3.0,5X,F4.0,3X,5L1,3X,I4,3X,
  2F2.0,3X,F3.2,1X,F9.1,4X,I1,4X,I2)
  20 IF(NUM .EQ. NSELCT(NSPEC)) RETURN
  J = J+1
100 CONTINUE
  RETURN
  END
C.....
C.....
C.....
  SUBROUTINE PLOTIN(IPL0T)
  COMMON/FOREST/NTREES(100),DBH(1200),IAGE(1200),KSPRT(100),
  1NEWTR(100),SUMLA(1200),NEW(100),SWTCH(5)
  COMMON/CONST/NSPEC,SOILQ,DEGD,DIALIM,SDPR(100),KPRNT
  COMMON/OUTPT/IO1,IO2,PLOT,PRINT,LIST
C.....
C.....PLOTIN BEGINS THE SIMULATION WITH A PREHARVEST STAND
C.....FOUND ON THE CATOOSA. NTREES IS THE NUMBER OF TREES
C.....FOR EACH SPECIES. DBH IS THE ARRAY OF DIAMETERS FOR EACH
C.....INDIVIDUAL TREE ON THE 1/20TH HECTERE PLOT. IAGE IS
C.....THE ARRAY OF TREE AGES. IAGE IS BASED ON FABRICATED
C.....DATA SINCE ALL OF THE TREES WILL BE CUT
C.....BEFORE THE FIRST YEAR OF SIMULATION
  IPL0T = IPL0T+1
  NSP1 = NSPEC + 1
  READ(IO1,1234) (NTREES(I),I=1,33)
1234 FORMAT(24I3,/9I3)
  DO 12 J=34,100
  12 NTREES(J) = 0
  READ(IO1,1200) (DBH(K), K=1,250)
1200 FORMAT(14F5.1,/14F5.1,/14F5.1,/14F5.1,/14F5.1,/14F5.1,/
  214F5.1,/14F5.1,/14F5.1,/14F5.1,/14F5.1,/14F5.1,/

```

```

314F5.1,/14F5.1,/14F5.1,/14F5.1,/12F5.1)
DO 14 I=251,1200
14 DBH(I) = 0.
DO 121 I=1,1200
IF(DBH(I) .EQ. 4.4) IAGE(I) = 15
IF(DBH(I) .EQ. 17.8) IAGE(I) = 50
IF(DBH(I) .EQ. 40.1) IAGE(I) = 99
121 CONTINUE
RETURN
END
C.....
C.....
C.....
SUBROUTINE INIT
COMMON/FOREST/NTREES(100),DBH(1200),IAGE(1200),KSPRT(100),
1NEWTR(100),SUMLA(1200),NEW(100),SWTCH(5)
COMMON/CONST/NSPEC,SOILQ,DEGD,DIALIM,SDPR(100),KPRNT
COMMON/MARK/NOGRO(1200),NFLAG(1200)
DO 100 I=1,NSPEC
NOGRO(I) = 0
NFLAG(I) = 0
KSPRT(I) = 1
100 CONTINUE
NSPE1 = NSPEC+1
DO 200 I=NSPE1,1200
NOGRO(I) = 0
NFLAG(I) = 0
200 CONTINUE
RETURN
END
C.....
C.....
C.....
SUBROUTINE SEEDPR
COMMON/PARAM/AAA(100,6),DMAX(100),DMIN(100),B3(100),
1B2(100),ITOL(100),AGEMX(100),CURVE(100),G(100,20),
2SPRTND(100),WING(100),SPRTMX(100),SWITCH(100,5),
3KTIME(100),D3(100),TINC(100),SDSPLB(100)
COMMON/CONST/NSPEC,SOILQ,DEGD,DIALIM,SDPR(100),KPRNT
DIMENSION WEIGHT(100)
HEAVY = 0.
C.....CONVERT SEEDS PER POUND TO WEIGHT PER SEED IN GRAMS.
DO 101 I = 1,NSPEC
A = 1./SDSPLB(I)
WEIGHT(I) = A * 453.59237
C.....FIND THE HEAVIEST SEED
IF(WEIGHT(I).GT.HEAVY) HEAVY = WEIGHT(I)
101 CONTINUE
C.....DEFINE THE PROB. OF THE SEEDS OF A SPECIES BEING FOUND ON
C.....THE PLOT AS A FUNCTION OF THE WEIGHT OF THE SEED OF EACH
C.....SPECIES, ASSUMING THAT THE HEAVIEST SEED HAS A 5% CHANCE

```

```

C.....INCREASE PROB. OF A WINGED SEED REACHING THE PLOT BY 2
      B = HEAVY/0.95
      DO 103 I=1,NSPEC
      IF(WING(I).EQ.2) WEIGHT(I) = WEIGHT(I)/2.
      SDPR(I) = WEIGHT(I)/B
103  CONTINUE
      RETURN
      END

C.....
C.....
C.....
      SUBROUTINE RANDOM(NSEED)
      COMMON/RAN/YFL
      YFL = RANDU(NSEED)
      RETURN
      END

C.....
C.....
C.....
      SUBROUTINE KILL(KYR,CUTYR,FYR,NYSCC)
      COMMON/FOREST/NTREES(100),DBH(1200),IAGE(1200),KSPRT(100),
1NEWTR(100),SUMLA(1200),NEW(100),SWTCH(5)
      COMMON/PARAM/AAA(100,6),DMAX(100),DMIN(100),B3(100),
1B2(100)ITOL(100),AGEMX(100),CURVE(100),G(100,20),
2SPRTND(100),WING(100),SPRTMX(100),SWITCH(100,5),
3KTIME(100),D3(100),TINC(100),SDSPLB(100)
      COMMON/CONST/NSPEC,SOILQ,DEGD,DIALIM,SDPR(100),KPRNT
      COMMON/RAN/YFL
      COMMON/MARK/NOGRO(1200),NFLAG(1200)
      COMMON/COUNT/NTOT,NYEAR
      COMMON/TEMP/DTEMP(1200),ITEMP(1200),NFTEMP(1200)
      COMMON/SEED/USEED(16)
      INTEGER USEED,STNO
      LOGICAL SWITCH,SWTCH
      INTEGER CUTYR,FYR
      NG = 1
      STNO = 0
      KNT = 0
      IF((((KYR/CUTYR)*CUTYR).NE.KYR).AND.(KYR.NE.2)) GO TO 14
      NYSCC = 0
      WRITE(6,7654) KYR
7654  FORMAT(' THE PLOT WAS CLEARCUT PRIOR TO YEAR',1X,I3)
      14  CONTINUE
      IF((NYSCC.GT.10).OR.(NYSCC.NE.FYR)) GO TO 12
      WRITE(6,7655) KYR
7655  FORMAT(' A PRESCRIBED FIRE WAS CONDUCTED IN YEAR',1X,I3)
      12  DO 100 I=1,NSPEC
      IF(NTREES(I) .EQ. 0) GO TO 100
      NL = KNT+1
      NU = NTREES(I)+KNT
      DO 150 K=NL,NU

```

```

      IF(KYR.EQ.2) GO TO 10
      IF((((KYR/CUTYR)*CUTYR).EQ.KYR).AND.(DBH(K).GT.DIALIM))
1GO TO 10
      IF((NYSCC.LE.10).AND.(NYSCC.EQ.FYR)) GO TO 10
      CALL RANDOM(USEED(1))
      YFLA = YFL
      IF(YFLA .LE. (4.605/AGEMX(I)))      GO TO 10
C.....
C.....CHECK IF THERE WAS ANY GROWTH FOR TREE
C.....
      IF(NOGRO(NG) .NE. K) GO TO 150
      NG = NG+1
      CALL RANDOM(USEED(2))
      IF(YFL .GT. 0.368) GO TO 150
10 NTREES(I) = NTREES(I)-1
      IF(NYSCC.EQ.FYR) GO TO 87
C.....
C.....CHECK IF DEAD TREE CAN SPROUT. INCREMENT KSPRT BY -1
C.....FOR EACH TREE THAT CAN SPROUT.
C.....
      IF(NOGRO(NG) .EQ. K+1) GO TO 87
      IF(YFLA .LE. (4.605/AGEMX(I))) GO TO 87
      IF(DBH(K) .GE. SPRTMX(I)) GO TO 87
      KSPRT(I) = KSPRT(I) - 1
87 CONTINUE
C.....
C.....DURING BURN YEARS, INCREMENT KSPRT(I) BY -1 FOR EACH
C.....STUMP THAT IS STILL ALIVE.
C.....
      IF(NYSCC.NE.FYR) GO TO 89
      IF(STNO.EQ.NFLAG(K)) GO TO 89
      IF(NFLAG(K).LE.0) GO TO 89
      STNO = NFLAG(K)
      KSPRT(I) = KSPRT(I) - 1
89 CONTINUE
C.....
C.....FLAG DEAD TREES
C.....
      DBH(K) = -1.0
150 CONTINUE
      KNT = NU
100 CONTINUE
C.....NYSCC - NUMBER OF YEARS SINCE CLEARCUTTING
      NYSCC = NYSCC + 1
C.....
C.....ELIMINATE DEAD TREES FROM DBH AND IAGE ARRAYS
C.....
      K = 0
      DO 200 I=1,1200
      IF(DBH(I) .EQ. 0.) GO TO 20
      IF(DBH(I) .LT. 0.) GO TO 200

```

```

      K = K+1
      DTEMP(K) = DBH(I)
      ITEMP(K) = IAGE(I)
      NFTEMP(K) = NFLAG(I)
200  CONTINUE
      20  NTOT = K
      IF(NTOT .EQ. 0) RETURN
      DO 300 I=1,K
      DBH(I) = DTEMP(I)
      IAGE(I) = ITEMP(I)
      NFLAG(I) = NFTEMP(I)
300  CONTINUE
      NTOT1 = K+1
      DO 400 I=NTOT1,NU
      DBH(I) = 0.
      IAGE(I) = 0
400  CONTINUE
      RETURN
      END
C.....
C.....
C.....
      SUBROUTINE SPROUT(BIOM,KYR,CUTYR,FYR)
      COMMON/FOREST/NTREES(100),DBH(1200),IAGE(1200),KSPRT(100),
1NEWTR(100),SUMLA(1200),NEW(100),SWTCH(5)
      COMMON/PARAM/AAA(100,6),DMAX(100),DMIN(100),B3(100),
1B2(100),ITOL(100),AGEMX(100),CURVE(100),G(100,20),
2SPRTND(100),WING(100),SPRTMX(100),SWITCH(100,5),
3KTIME(100),D3(100),TINC(100),SDSPLB(100)
      COMMON/CONST/NSPEC,SOILQ,DEGD,DIALIM,SDPR(100),KPRNT
      COMMON/OUTPT/IO1,IO2,PLOT,PRINT,LIST
      COMMON/RAN/YFL
      COMMON/MARK/NOGRO(1200),NFLAG(1200)
      COMMON/COUNT/NTOT,NYEAR
      COMMON/TEMP/DTEMP(1200),ITEMP(1200),NFTEMP(1200)
      COMMON/SEED/USEED(16)
      INTEGER USEED,CUTYR,FYR,KYR
      LOGICAL SWITCH,SWTCH
      NSTMP = 0
C.....
C.....SMALLEST AVERAGE STUMP SPROUT IS 1.27 CM
C.....THIS IS EQUAL TO 1/2 OF AN INCH
C.....
      SIZE = 1.27
      IF(NTOT .EQ. 0) RETURN
C.....
C.....DETERMINE WHICH SPECIES CAN SPROUT
C.....
      NW = 0
      DO 20 I=1,NSPEC
      IF(SPRTND(I) .LE. 0.) GO TO 20

```

```

        IF(KSPRT(I) .GE. 0)          GO TO 20
        NW = NW+1
        NEW(NW) = I
20    CONTINUE
C.....
C.....CHECK FOR SPROUTS
C.....
        IF(NW .EQ. 0) GO TO 72
        DO 25 J=1,NTOT
        ITEMP(J) = IAGE(J)
        DTEMP(J) = DBH(J)
25    CONTINUE
C.....
C.....SPRTND IS THE TENDENCY FOR THE ITH SPECIES TO STUMP OR
C.....ROOT SPROUT. THE VALUE OF SPRTND IS THE AVERAGE NUMBER
C.....OF SPROUTS THAT MIGHT OCCUR WITH A TREE DEATH
C.....
C.....RANDOMLY SELECT NUMBER OF TREES TO SPROUT AND PLACE
C.....DIAMETERS AND AGES OF NEW SPROUTS INTO ARRAYS
C.....
        NL = 1
        L=1
        NU=0
        ICNT=1
        DO 30 I=1,NSPEC
        IF(NTREES(I) .EQ. 0 .AND. KSPRT(I) .GE. 0) GO TO 30
        IF(NTREES(I) .EQ. 0) GO TO 24
        NU = NL + NTREES(I) - 1
        DO 22 K=NL,NU
        DBH(K) = DTEMP(L)
        IAGE(K) = ITEMP(L)
        L=L+1
22    CONTINUE
        NL=NU+1
24    IF(NEW(ICNT).NE.I) GO TO 30
        ICNT=ICNT+1
        IK1 = -(KSPRT(I))
        DO 26 J=1,IK1
        CALL RANDOM(USEED(4))
        NSPRT = YFL*SPRTND(I)+1
        IF((((KYR/CUTYR)*CUTYR).NE.KYR).AND.(KYR.NE.2)) GO TO 37
        NSTMP = NSTMP + 1
37    CONTINUE
        DO 19 IX=1,NSPRT
        NTREES(I)=NTREES(I)+1
        NTOT = NTOT+1
        IF(NTOT .GT. 1200) GO TO 90
        CALL RANDOM(USEED(5))
        DBH(NL) = SIZE + .1*(1.0-YFL)**3
        BIOM = BIOM + 1.9283295E-4*DBH(NL)**2.129

```

```

      IAGE(NL) = 0
C.....FLAG SPROUTS WITH THE NUMBER OF THE STUMP IT COMES FROM
      IF((((KYR/CUTYR)*CUTYR).NE.KYR).AND.(KYR.NE.2)) GO TO 38
      NFLAG(NL) = NSTMP
      38 CONTINUE
      IF((((KYR/CUTYR)*CUTYR).EQ.KYR).OR.(KYR.EQ.2)) GO TO 39
      NFLAG(NL) = 0
      39 CONTINUE
      NL=NL+1
      19 CONTINUE
      26 CONTINUE
      30 CONTINUE
C.....
C.....REINITIALIZE SPROUT SWITCH FOR EACH SPECIES
C.....
      90 DO 100 I=1,NSPEC
      100 KSPRT(I) = 0
      72 CONTINUE
      RETURN
      END
C.....
C.....
C.....
      SUBROUTINE GROW(LT,NYSCC)
      COMMON/WATER/T(12),VT(12),RT(12),R(12),VR(12),FC,DRY,
      1BGS,EGS,PLAT,FJ
      COMMON/FOREST/NTREES(100),DBH(1200),IAGE(1200),KSPRT(100),
      1NEWTR(100),SUMLA(1200),NEW(100),SWTCH(5)
      COMMON/PARAM/AAA(100,6),DMAX(100),DMIN(100),B3(100),
      1B2(100),ITOL(100),AGEMX(100),CURVE(100),G(100,20),
      2SPRTND(100),WING(100),SPRTMX(100),SWITCH(100,5),
      3KTIME(100),D3(100),TINC(100),SDSPLB(100)
      COMMON/CONST/NSPEC,SOILQ,DEGD,DIALIM,SDPR(100),KPRNT
      COMMON/PAREA/HTREE(1200)
      COMMON/MARK/NOGRO(1200),NFLAG(1200)
      COMMON/COUNT/NTOT,NYEAR
      COMMON/TEMP/DTEMP(1200),ITEMP(1200),NFTEMP(1200)
      DIMENSION SMGF(100)
      LOGICAL SWITCH,SWTCH
      DO 100 I=1,1200
      NOGRO(I) = 0
      SUMLA(I) = 0.
      100 CONTINUE
C.....
C.....TINC - MINIMUM INCREMENT OF DBH GROWTH PER YEAR (CM)
C.....PHI - ANNUAL INSOLATION
C.....
      PHI = 1.
C.....
C.....CALCULATE TOTAL NUMBER OF TREES
C.....

```

```

      NTOT = 0
      DO 200 I=1,NSPEC
      NTOT = NTOT+NTREES(I)
200  CONTINUE
      IF(NTOT .EQ. 0) RETURN
      NL = 1
      SBIO = 0.
      DO 300 J=1,NSPEC
      IF(NTREES(J) .EQ. 0) GO TO 300
      NU = NL+NTREES(J) -1
      DO 350 K=NL,NU
C.....
C.....CALCULATE STAND BIOMASS
C.....
      SBIO = SBIO+.1193*DBH(K)**2.393
C.....
C.....CALCULATE HEIGHT PROFILE (.1 METER UNITS)
C.....
      IHT = (B2(J)*DBH(K)-B3(J)*DBH(K)**2)/10.+1.
      IF(IHT .GT. 1200) GO TO 20
      SUMLA(IHT) = SUMLA(IHT)+1.9283295E-4*DBH(K)**2.129
350  CONTINUE
      NL = NL+NTREES(J)
300  CONTINUE
      DO 400 J=1,1199
      J1 = 1200-J
      SUMLA(J1) = SUMLA(J1)+SUMLA(J1+1)
400  CONTINUE
C.....
C.....CALCULATE MOISTURE GROWTH FACTOR
C.....
      GSDAYS = EGS - BGS
      DO 55 I=1,NSPEC
      SMGF(I) = (GSDAYS - (FJ * (D3(I)/2.0))) / GSDAYS
      IF(SMGF(I) .LT. 0.) SMGF(I) = 0.
55  CONTINUE
C.....CALCULATE SMGF FOR SPROUTS
C.....PLACE ALL SPROUTS INTO THE VERY TOLERANT CATEGORY
      SPRTGF = (GSDAYS - (FJ/2.0)) / GSDAYS
      IF(SPRTGF .LT. 0.) SPRTGF = 0.
C.....
C.....CALCULATE AMOUNT OF GROWTH FOR EACH TREE
C.....
      NL = 1
      NG = 1
      DO 500 I=1,NSPEC
      IF(NTREES(I) .EQ. 0) GO TO 500
      NU = NL+NTREES(I)-1
      DO 550 J=NL,NU
      HT = B2(I)*DBH(J)-B3(I)*DBH(J)**2

```

```

IHT = HT/10.+2.
HTREE(J) = IHT
SLAR = SUMLA(IHT)
AL = PHI*EXP(-SLAR*.25)
GR = (137.+25*B2(I)**2/B3(I))*(0.5*B2(I)/B3(I))
DNC = G(I,LT)*DBH(J)*(1.0-(137.*DBH(J)+B2(I)*DBH(J)**2
1-B3(I)*DBH(J)**3)/GR)/(274.+3.0*B2(I)*DBH(J)-4.0*B3(I)*
2DBH(J)**2)*(1.0-SBIO/SOILQ)*4.0*(DEGD-DMIN(I))*
3(DMAX(I)-DEGD)/(DMAX(I)-DMIN(I))**2
IF((NFLAG(J).LE.0) .OR. (NYSCC.GT.10)) GO TO 44
DNC = DNC*SPRTGF
GO TO 33
44 CONTINUE
DNC = DNC*SMGF(I)
33 DINCT = 2.24*(1.-EXP(-1.136*(AL-.08)))*DNC
DINCI = (1.0-EXP(-4.64*(AL-.05)))*DNC
C.....
C.....ADJUST DINC BASED ON SHADE TOLERANCE OF EACH SPECIES
C.....
IF(ITOL(I).EQ.1) DINC=DINCT
IF(ITOL(I).EQ.2) DINC=(3.0*DINCT+DINCI)/4.0
IF(ITOL(I).EQ.3) DINC=(DINCI+DINCT)/2.0
IF(ITOL(I).EQ.4) DINC=(3.0*DINCI+DINCT)/4.0
IF(ITOL(I).EQ.5) DINC=DINCI
C.....
C.....FLAG TREES GROWING LESS THAN THE REQUIRED INCREMENT
C.....
IF(DINC .LT. TINC(NSPEC)) DINC = 0.0
IF(DINC .NE. 0.) GO TO 10
NOGRO(NG) = J
NG = NG+1
10 DBH(J) = DBH(J)+DINC
550 CONTINUE
NL = NL+NTREES(I)
500 CONTINUE
RETURN
20 WRITE(IO2,2000)
2000 FORMAT('1 IHT EXCEEDED 1200')
STOP
END
C.....
C.....
C.....
SUBROUTINE BIRTH(KYR,CUTYR,FYR,NYSCC)
COMMON/FOREST/NTREES(100),DBH(1200),IAGE(1200),KSPRT(100),
1NEWTR(100),SUMLA(1200),NEW(100),SWTCH(5)
COMMON/PARAM/AAA(100,6),DMAX(100),DMIN(100),B3(100),
1B2(100),ITOL(100),AGEMX(100),CURVE(100),G(100,20),
2SPRTND(100),WING(100),SPRTMX(100),SWITCH(100,5),
3KTIME(100),D3(100),TINC(100),SDSPLB(100)
COMMON/CONST/NSPEC,SOILQ,DEGD,DIALIM,SDPR(100),KPRNT

```

```

COMMON/RAN/YFL
COMMON/MARK/NOGRO(1200),NFLAG(1200)
COMMON/COUNT/NTOT,NYEAR
COMMON/TEMP/DTEMP(1200),ITEMP(1200),NFTEMP(1200)
COMMON/SEED/USEED(16)
INTEGER USEED,CUTYR,FYR
LOGICAL SWITCH,SWTCH
DIMENSION SDTMP(100)
ICOUNT = 0
C.....
C.....SAPLINGS ENTER THE PLOT AT AVERAGE SIZE OF 1.27 CM DBH
C.....
      SIZE = 1.27
C.....
C.....SELECT A SPECIES FROM 1 TO 3 TIMES
C.....
      CALL RANDOM(USEED(6))
      NPLANT = 3.*YFL+1.
C.....
C..... RAT  RANDOM NUMBER IS FIXED FOR YEAR - USED IN SWITCH 4
C.....
      CALL RANDOM(USEED(7))
      RAT = YFL
      DO 100 JK=1,NPLANT
10  BIOM = 0.
      NL = 1
C.....
C.....CALCULATE BIOMASS (LEAF MASS) FOR EACH SPECIES
C.....
      DO 110 J=1,NSPEC
      IF(NTREES(J) .EQ. 0) GO TO 110
      NU = NL+NTREES(J)-1
      DO 115 K=NL,NU
      BIOM = BIOM+1.9283295E-4*DBH(K)**2.129
115  CONTINUE
      NL = NL+NTREES(J)
110  CONTINUE
      NTOT = NL-1
C.....
C.....SWITCH 1 IS TRUE IF THE SPECIES REQUIRES LEAF LITTER FOR
C.....SUCCESSFUL RECRUITMENT
C.....SWITCH 2 IS TRUE IF THE SPECIES REQUIRES MINERAL SOIL
C.....SWITCH 3 IS TRUE IF GERMINATION IS REDUCED IN HOT YEAR
C.....SWITCH 4 IS TRUE IF THE SPECIES IS A PREFERRED FOOD OF
C.....DEER OR SMALL MAMMALS
C.....SWITCH 5 REDUCES SEEDING RATE OF DESIRABLE MAST
C.....
      DO 120 J=1,5
      SWTCH(J) = .TRUE.
120  CONTINUE

```

```

C.....
C.....SET SWITCHES BASED ON BIOMASS, DEGD, AND RANDOM NUMBER
C.....
      IF(BIOM .GE. .1) SWTCH(1) = .FALSE.
      IF(BIOM .LE. .2) SWTCH(2) = .FALSE.
      IF(DEGD .LE. 3264.34) SWTCH(3) = .FALSE.
      IF(RAT .GT. .5) SWTCH(4) = .FALSE.
      CALL RANDOM(USEED(8))
      IF(YFL .GE. .5) SWTCH(5) = .FALSE.
C.....
C.....IF A SPECIES IS PRESENT ON THE SIMULATED PLOT, THE
C.....PROBABILITY OF SEED OF THAT SPECIES BEING PRESENT ON THE
C.....PLOT IS SET EQUAL TO 100 PERCENT, OTHERWISE IT IS SET
C.....TO THE PROBABILITY DETERMINED BY THE SEEDPR SUBROUTINE.
C.....
      DO 101 I=1,NSPEC
      IF(NTREES(I).EQ.0) GO TO 102
      SDTMP(I) = 0.0
      GO TO 101
102 SDTMP(I) = SDPR(I)
101 CONTINUE
      CALL RANDOM(USEED(16))
C.....
C.....CHECK SWITCHES AND PROBABILITY OF SEED BEING PRESENT TO
C.....DETERMINE IF SEED GERMINATION IS ALLOWED
C.....
      NW = 0
      DO 130 J=1,NSPEC
      DO 135 K=1,5
      IF(SWITCH(J,K) .AND. SWTCH(K)) GO TO 130
135 CONTINUE
      IF(KYR .GT. KTIME(J) .AND. NTREES(J) .LE. 0) GO TO 130
      IF(YFL.LT.SDTMP(J)) GO TO 130
      NW = NW+1
      NEWTR(NW) = J
130 CONTINUE
C.....
C.....CHECK TO SEE IF THERE ARE ANY NEW TREES
C.....
      IF(NW .EQ. 0) GO TO 30
C.....
C.....CALCULATE AGE AND DIAMETER FOR NEW TREES
C.....
      DO 140 I=1,NTOT
      ITEMP(I) = IAGE(I)
      DTEMP(I) = DBH(I)
      NFTEMP(I) = NFLAG(I)
140 CONTINUE
C.....
C.....DETERMINE THE NUMBER OF SEEDLINGS TO PLANT (0 TO 8)

```

```

C.....
    CALL RANDOM(USEED(9))
    MPLANT = 8.*YFL
C.....
C.....SELECT SPECIES OF SEEDLINGS
C.....
    CALL RANDOM(USEED(10))
    NW = NW*YFL+1.0
    NSP = NEWTR(NW)
    NSUM = 0
    DO 150 I=1,NSP
        NSUM = NSUM+NTREES(I)
150 CONTINUE
C.....
C.....PLANT RANDOM NUMBER OF SEEDLINGS
C.....
    NL = NSUM+1
    NUP = NTOT
    DO 160 J=1,MPLANT
        NTOT = NTOT+1
        IF(NTOT .GT. 1200) CALL ERR
        NSUM = NSUM+1
        NTREES(NSP) = NTREES(NSP)+1
        ITEMP(NSUM) = 0
C.....
C.....CALCULATE DBH FOR SEEDLINGS
C.....
    CALL RANDOM(USEED(11))
    DTEMP(NSUM) = SIZE+.3*(1.0-YFL)**3
    BIOM = BIOM + 1.9283295E-4*DTEMP(NSUM)**2.129
160 CONTINUE
    IF(NL .GT. NUP) GO TO 20
    N1 = NSUM+1
    DO 170 L=N1,NUP
        DTEMP(N1) = DBH(L)
        ITEMP(N1) = IAGE(L)
        NFTEMP(N1) = NFLAG(L)
        N1 = N1+1
170 CONTINUE
C.....
C.....WRITE DIAMETERS AND AGES OF SEEDLINGS INTO ARRAYS
C.....
20 DO 180 I=1,NTOT
    IAGE(I) = ITEMP(I)
    DBH(I) = DTEMP(I)
    NFLAG(I) = NFTEMP(I)
180 CONTINUE
    IF((((KYR/CUTYR)*CUTYR).EQ.KYR).AND.(ICOUNT.GE.1))
1GO TO 11
    IF((KYR.EQ.2).AND.(ICOUNT.GE.1)) GO TO 11
    IF((NYSCC.EQ.FYR).AND.(ICOUNT.GE.1)) GO TO 11

```

```

30 CALL SPROUT(BIOM,KYR,CUTYR,FYR)
   ICOUNT = ICOUNT + 1
11 CONTINUE
   IF(BIOM .LT. 0.32) GO TO 10
100 CONTINUE
C.....
C.....INCREMENT AGES
C.....
   DO 200 I=1,NTOT
     IAGE(I) = IAGE(I)+1
200 CONTINUE
   RETURN
   END
C.....
C.....
C.....
   SUBROUTINE OUTPUT(KYR,IPLLOT)
   COMMON/WATER/T(12),VT(12),RT(12),R(12),VR(12),FC,DRY,
1BGS,EGS,PLAT,FJ
   COMMON/FOREST/NTREES(100),DBH(1200),IAGE(1200),KSPRT(100),
1NEWTR(100),SUMLA(1200),NEW(100),SWTCH(5)
   COMMON NSELCT(100)
   COMMON/OUTPT/IO1,IO2,PLOT,PRINT,LIST
   COMMON/PARAM/AAA(100,6),DMAX(100),DMIN(100),B3(100),
1B2(100),ITOL(100),AGEMX(100),CURVE(100),G(100,20),
2SPRTND(100),WING(100),SPRTMX(100),SWITCH(100,5),
3KTIME(100),D3(100),TINC(100),SDSPLB(100)
   COMMON/PASSX/A(1001,50)
   COMMON/COUNT/NTOT,NYEAR
   COMMON/CONST/NSPEC,SOILQ,DEGD,DIALIM,SDPR(100),KPRNT
   DIMENSION BAR(100)
   LOGICAL PRINT,PLOT
   KYR1 = KYR+1
   N=1
   AREA=0.0
   TBAR=0.0
   TOBAR=0.0
   NTOT = 0
   DO 100 I=1,NSPEC
     BAR(I)=0.0
     IF(NTREES(I).EQ.0) GO TO 100
     NN=N+NTREES(I) - 1
     DO 150 J =N,NN
C.....
C.....TOBAR - TOTAL BASAL AREA ON PLOT
C.....TBAR - TOTAL BIOMASS ON PLOT
C.....BAR(I) - BIOMASS OF SPECIES I
C.....
       TOBAR=TOBAR+0.7854*(DBH(J)*DBH(J))
       AREA=AREA+1.9283295E-4*DBH(J)**2.129
       BAR(I)=BAR(I)+.1193*DBH(J)**2.393

```

```

150 CONTINUE
    TBAR=TBAR+BAR(I)
    NTOT=NTOT+NTREES(I)
    N=N+NTREES(I)
100 CONTINUE
    IF(KYR.LE.2) GO TO 308
C    IF(KYR.EQ.4) GO TO 308
C    IF(KYR.EQ.5) GO TO 308
    IF((((KYR/KPRNT)*KPRNT).NE.KYR) GO TO 307
308 CONTINUE
    IF (PRINT) WRITE(IO2,2000) KYR
2000 FORMAT('OYEAR',I5)
    IF (PRINT) WRITE(IO2,2010)
2010 FORMAT('OSPECIES',20X,'STEMS',5X,'BIOMASS',8X,'PERCENT',
138X,'DBH')
    N=1
    DO 200 I =1,NSPEC
        IF(NTREES(I).EQ.0) GO TO 200
        PER=(BAR(I)/TBAR)*100.
        NN=N+NTREES(I) - 1
        NLINES=((NTREES(I)-1)/8)+1
        NLINES=NLINE-1
        IF (NLINES.EQ.0) GO TO 10
        L1=N+7
        IF (PRINT) WRITE(IO2,2020)(AAA(I,J),J=1,6),NTREES(I),
1BAR(I),PER,(DBH(II),II=N,L1)
2020 FORMAT('O',6A4,4X,I3,4X,E9.3,6X,F8.2,8X,8(F6.1,2X))
        DO 250 J=1,NLINES
            L2=L1+1
            L1=L1+8
            IF (J.EQ.NLINES) L1=NN
            IF (PRINT) WRITE(IO2,2030)(DBH(II),II=L2,L1)
2030 FORMAT(67X,8(F6.1,2X))
        250 CONTINUE
        GO TO 20
    10 IF (PRINT) WRITE(IO2,2040)(AAA(I,J),J=1,6),NTREES(I),
1BAR(I),PER,(DBH(II),II=N,NN)
2040 FORMAT('O',6A4,4X,I3,4X,E9.3,6X,F8.2,8X,8(F6.1,2X))
    20 N=N+NTREES(I)
    200 CONTINUE
        TOBAR=TOBAR*0.0012
        IF(PRINT) WRITE(IO2,2050) NTOT,TBAR
2050 FORMAT('O TOTAL NUMBER=',I5,5X,'TOTAL BIOM.=',E12.3)
    307 CONTINUE
        IF(.NOT.PLOT) RETURN
        DO 300 IV1 = 1,NSPEC
            A(KYR1,IV1)=A(KYR1,IV1)+BAR(IV1)*.012
    300 CONTINUE
        ATOT=NTOT
        N1 = NSPEC+1

```

```

      N2 = N1+1
      N3 = N2+1
      A(KYR1,N1)=A(KYR1,N1) + (TBAR*.012)
      A(KYR1,N2)=A(KYR1,N2) + ATOT
      A(KYR1,N3)=A(KYR1,N3) + AREA
      RETURN
      END
C.....
C.....
C.....
      SUBROUTINE ERR
      WRITE(IO2,2000)
2000  FORMAT('1 THE NUMBER OF TREES HAS EXCEEDED 1200')
      STOP
      END
C.....
C.....
C.....
      SUBROUTINE GGNORD(NSEED1,NSEED2,Z)
      DIMENSION Z(1)
      DATA PI2/0.62831853E01/
C.....
C.....GAUSSIAN RANDOM NUMBER GENERATOR
C.....
      K = 0
      A1 = RANDU(NSEED1)
      A2 = RANDU(NSEED2)
      K = K+1
      Z(K) = SQRT(-.2E01*ALOG(A1))*SIN(PI2*A2)
      K = K+1
      Z(K) = SQRT(-0.2E01*ALOG(A1))*COS(PI2*A2)
      RETURN
      END
C.....
C.....
C.....
      FUNCTION RANDU(SEED)
      REAL*4 RNEW
      INTEGER PLUS/Z1000000/,IBIT/Z40000000/,HEX/Z10003/
      INTEGER OLD,NEW,SEED
      EQUIVALENCE(NEW,RNEW)
C.....
C.....UNIFORM RANDOM NUMBER GENERATOR
C.....
      OLD=HEX*SEED
      SEED = IABS(OLD)
      NEW=OLD/256
      IF(NEW.LE.0) NEW=NEW+PLUS
      NEW=NEW+IBIT
      RANDU = RNEW+0.0

```

```

      RETURN
      END
C.....
C.....
C.....
      SUBROUTINE PLT
      COMMON/CONST/NSPEC,SOILQ,DEGD,DIALIM,SDPR(100),KPRNT
      COMMON/COUNT/NTOT,NYEAR
      COMMON/OUTPT/IO1,IO2,PLOTX,PRINT,LIST
      COMMON/PASSX/A(1001,50)
      DIMENSION X(1001),Y(1001),IYVAR(100)
      LOGICAL PLOTX,PRINT,LIST
      YR = NYEAR
      NYEAR = NYEAR+1
      NU = NYEAR-4
      NPTS = NYEAR-8
      READ(IO1,6666) NN,(IYVAR(I),I=1,NN)
6666  FORMAT(36I2)
      M1 = NSPEC+1
      DO 200 IQ = 2,NYEAR
      A(IQ,IYVAR(1)) = 100.*(1.-A(IQ,IYVAR(1)))/A(IQ,M1))
200  CONTINUE
      DO 300 IQ = 2,NYEAR
      DO 300 IR = 2,NN
      IB = IR-1
      A(IQ,IYVAR(IR)) = A(IQ,IYVAR(IB))-100.*A(IQ,IYVAR(IR))
      1/A(IQ,M1)
      KYR=IQ-1
      IF((KYR.GT.5).AND.(KYR.NE.50).AND.(KYR.NE.100)) GO TO 77
      WRITE(6,2374) KYR,IB,A(IQ,IYVAR(IR))
2374  FORMAT(' YEAR = ',I4,' SPECIES = ',I3,' % OF BA = ',E10.5)
      77 CONTINUE
      300 CONTINUE
C1    CALL CALCMP
C1    CALL BGNPL(-1)
C1    CALL PAGE(14.,11.)
C1    CALL TITLE(' ',1,'YRS',5,'PERCENT OF BIOM',100,9.,10.)
C1    CALL FRAME
C1    CALL GRAF(0.,'SCALE',YR,0.,'SCALE',100.)
      CALL PLOTS(0,0,20)
      CALL PLOT(0.0,1.5,-3)
      CALL IAXIS(0.0,0.0,' ',2,5.0,90.0,0.0,20.0,-1)
      X(1) = 4.0
      X(2) = YR/2.0
      X(3) = YR
      CALL SCALE(X,8.0,3,1)
      FIRSTV = X(4)
      DELTAV = X(5)
      CALL IAXIS(0.0,0.0,' ',-2,5.0,0.0,0.0,20.0,-1)
      DO 400 II = 1,NN
      DO 450 IJK = 5,NU

```

```

      IJK1 = IJK-4
      IJK9 = IJK+4
      X(IJK1) = IJK-1
      SUM = 0.
      DO 475 MMM = IJK1,IJK9
      SUM = SUM+A(MMM,IYVAR(II))
475  CONTINUE
      Y(IJK1) = SUM/9.
450  CONTINUE
      Y(1) = Y(2)
C1   CALL CURVE(X,Y,NPTS,0)
      X(NPTS+1)=FIRSTV
      X(NPTS+2)=DELTAV
      Y(NPTS+1)=0.0
      Y(NPTS+2)=20.0
      CALL LINE(X,Y,NPTS,1,0,0)
400  CONTINUE
C1   CALL ENDPL(1)
C1   CALL DONEPL
      CALL PLOT(0.0,0.0,999)
      STOP
      END
C.....
C.....
C.....
      SUBROUTINE MOIST(KYR)
C.....
C.....SUBROUTINE FOR CALCULATING THE FRACTION OF THE
C.....GROWING SEASON WITH FAVORABLE SOIL MIOSTURE FOR GROWTH
C.....
      COMMON/WATER/T(12),VT(12),RT(12),R(12),VR(12),FC,DRY,
1BGS,EGS,PLAT,FJ
      COMMON/COUNT/NTOT,NYEAR
      COMMON/CONST/NSPEC,SOILQ,DEGD,DIALIM,SDPR(100),KPRNT
      COMMON/SEED/USEED(16)
C.....
C.....DATA REQUIRED FOR THE OPERATION OF THIS SUBROUTINE:
C....  T = AVERAGE MONTHLY TEMPERATURES (JAN-DEC)  CENTIGRADE
C....  R = AVERAGE MONTHLY RAINFALL (JAN-DEC)  CENTIMETERS
C....  VR = STANDARD DEVIATION OF AVERAGE MONTHLY RAINFALL
C.....FC = CENTIMETERS OF WATER AT FIELD CAPACITY
C.....DRY = CENTIMETERS OF WATER BELOW WHICHRS)
C.....  TREE GROWTH STOPS (<5 BARS)
C.....BGS = YEAR DAY ON WHICH THE GROWING SEASON BEGINS
C.....EGS = YEAR DAY ON WHICH THE GROWING SEASON ENDS
C.....PLAT = LATITUDE OF PLOT (DEGREES NORTH)
C.....
      DIMENSION Z(2)
      DIMENSION C(12,26),D(12,6),DAYS(12)
      INTEGER USEED
      EQUIVALENCE (C(1,21),D(1,1))

```

```

C...MONTHLY CORRECTION FACTORS FOR 25-50 DEGREES LATITUDE NORTH
  DATA C/.93,.89,1.03,1.06,1.15,1.14,1.17,1.12,1.02,.99,.91,
    1.91,
    6.92,.88,1.03,1.06,1.15,1.15,1.17,1.12,1.02,.99,.91,.91,
    7.92,.88,1.03,1.07,1.16,1.15,1.18,1.13,1.02,.99,.90,.90,
    8.91,.88,1.03,1.07,1.16,1.16,1.18,1.13,1.02,.8,.90,.0,
    9.91,.87,1.03,1.07,1.17,1.16,1.19,1.13,1.03,.98,.90,.89,
    *.90,.87,1.03,1.08,1.18,1.17,1.20,1.14,1.03,.98,.89,.88,
    1.90,.87,1.03,1.08,1.18,1.18,1.20,1.14,1.03,.98,.89,.88,
    2.89,.86,1.03,1.08,1.19,1.19,1.21,1.15,1.03,.98,.88,.87,
    3.88,.86,1.03,1.09,1.19,1.20,1.22,1.15,1.03,.97,.88,.86,
    4.88,.85,1.03,1.09,1.20,1.20,1.22,1.16,1.03,.97,.87,.86,
    5.87,.85,1.03,1.09,1.21,1.21,1.23,1.16,1.03,.97,.86,.85,
    6.87,.85,1.03,1.10,1.21,1.22,1.24,1.16,1.03,.97,.86,.84,
    7.86,.84,1.03,1.10,1.22,1.23,1.25,1.17,1.03,.97,.85,.83,
    8.85,.84,1.03,1.10,1.23,1.24,1.25,1.17,1.04,.96,.84,.83,
    9.85,.84,1.03,1.11,1.23,1.24,1.26,1.18,1.04,.96,.84,.82,
    *.84,.83,1.03,1.11,1.24,1.25,1.27,1.18,1.04,.96,.83,.81,
    1.83,.83,1.03,1.11,1.25,1.26,1.27,1.19,1.04,.96,.82,.80,
    2.82,.83,1.03,1.12,1.26,1.27,1.28,1.19,1.04,.95,.82,.79,
    3.81,.82,1.02,1.12,1.26,1.28,1.29,1.20,1.04,.95,.81,.77,
    4.81,.82,1.02,1.13,1.27,1.29,1.30,1.20,1.04,.95,.80,.76,
    *72*0./
  DATA D/.80,.81,1.02,1.13,1.28,1.29,1.31,1.21,1.04,.94,
    *.79,.75,
    6.79,.81,1.02,1.13,1.29,1.31,1.32,1.22,1.04,.94,.79,.74,
    7.77,.80,1.02,1.14,1.30,1.32,1.32,1.22,1.04,.93,.78,.73,
    8.76,.80,1.02,1.14,1.31,1.33,1.34,1.23,1.05,.93,.77,.72,
    9.75,.79,1.02,1.14,1.32,1.34,1.35,1.24,1.05,.93,.76,.71,
    *.74,.78,1.02,1.15,1.33,1.36,1.37,1.25,1.06,.92,.76,.70/
C....DAYS(K) = NUMBER OF DAYS BETWEEN MID-MONTH K-1 AND K
  DATA DAYS/31.,28.,31.,30.,31.,30.,31.,31.,30.,31.,30.,30./
  DATA NCT/0/
  IF(KYR .EQ.1) TFJ = 0
C.....
C.....ADJUST LATITUDE POINTER
C.....
  LAT=(PLAT+.5)-24
C.....
C.....INITIALIZE WATER CONTENT OF SOIL IN JANUARY OF THE
C.....INITIAL YEAR OF SIMULATION
C.....
  WATER=FC
C.....
C.....INITIALIZE THORNTHWAITE PARAMETERS
C.....TE = TEMPERATURE EFFICIENCY
C.....A = EXPONENT OF EVAPTRANSPIRATION FUNCTION
C.....
  TE=0.
  DO 10 K=1,12

```

```

        IF(RT(K) .LT. 0.0) RT(K) = 0.0
        TE=TE+(.2*RT(K))**1.514
10      CONTINUE
        A=.675*TE**3-77.1*TE**2+17920.0*TE+492390.0
        A=.000001*A
C.....
C.....INITIALIZE THE NUMBER OF DRY DAYS (DD),
C..... AND CURRENT DAY OF YEAR (CDAY)
C.....
        DD=0.0
        CDAY=15.0
C.....
C.....COMPUTE MONTHLY WATER BALANCE
C.....LOOP FOR YEARLY WATER BALANCE CALCULATION BY MONTH
C.....
        DO 50 K=1,12
C.....
C.....COMPUTE EVAPOTRANSPIRATION
C.....
        TTMP=T(K)
        IF(TTMP.LT.0.0) TTMP=0.0
        U=1.6*((10.0*TTMP/TE)**A)*C(K,LAT)
        U=1.2*U*WATER/FC
C.....
C.....UPDATE WATER BALANCE, CURRENT DAY OF YEAR
C.....
        OWATER=WATER
        NCT = NCT+1
        IF(NCT .EQ. 2) GO TO 36
        CALL GGNORD(USEED(14),USEED(15),Z)
        GO TO 38
36      Z(1) = Z(2)
        NCT = 0
38      RAIN = R(K)+VR(K)*Z(1)
C.    38 RAIN=R(K)
        IF(RAIN .LT. 0.0) RAIN = 0.0
        RAIN = AMAX1(0.0,RAIN)
        WATER=WATER-U+RAIN
C.....TRUNCATE IF NECESSARY
        WATER=AMIN1(FC,WATER)
        WATER=AMAX1(0.0,WATER)
        OCDAY=CDAY
        CDAY=CDAY+DAYS(K)
        DDI=0.0
C.....
C.....INCREMENT THE NUMBER OF DRY DAYS, INTERPOLATING
C.....IF NECESSARY, TRUNCATE AT ENDS OF GROWING SEASON
C.....
        IF(CDAY .LE. BGS) GO TO 49
        IF(OCDAY .GE. EGS) GO TO 49

```

```

        IF(OWATER .GE. DRY .AND. WATER .GE. DRY) GO TO 49
        IF(OWATER .GT. DRY .AND. WATER .LT. DRY) GO TO 20
        IF(OWATER .LT. DRY .AND. WATER .GT. DRY) GO TO 30
        DDI=DAYS(K)
        IF(OCDAY .LT. BGS .AND. CDAY .GT. BGS) DDI=CDAY-BGS
        IF(OCDAY .LT. EGS .AND. CDAY .GT. EGS) DDI=EGS-OCDAY
        GO TO 40
20      DDI=DAYS(K)*(DRY-WATER)/(OWATER-WATER)
        IF(OCDAY .LT. BGS .AND. CDAY .GT. BGS) DDI=AMIN1(DDI,CDAY
1-BGS)
        IF(OCDAY .LT. EGS .AND. CDAY .GT. EGS) DDI=EGS-CDAY+DDI
        IF(DDI .LT. 0.0) DDI=0.0
        GO TO 40
30      DDI=DAYS(K)*(DRY-OWATER)/(WATER-OWATER)
        IF(OCDAY .LT. BGS .AND. CDAY .GT. BGS) DDI=OCDAY+DDI-BGS
        IF(DDI .LT. 0.0) DDI=0.0
        IF(OCDAY .LT. EGS .AND. CDAY .GT. EGS) DDI=AMIN1(DDI,EGS
1-OCDAY)
40      DD=DD+DDI
49      CONTINUE
50      CONTINUE
C.....
C.....SAVE TOTAL NUMBER OF DRY DAYS FOR YEAR
C.....
        FJ=DD
C        WRITE(6,2001)KYR,FJ,DEGD
2001  FORMAT(' ','YEAR=',I5,' FJ=',E16.8,' DEGD=',E16.8)
        TFJ=TFJ+FJ
        IF(KYR.EQ.NYEAR)TFJ=TFJ/NYEAR
        IF(KYR.EQ.NYEAR)WRITE(6,2002)TFJ
2002  FORMAT(' ','AVERAGE # DRY DAYS = ',F16.8)
        RETURN
        END
//GO.SYSIN DD *
DATA CARDS GO HERE
//GO.FT20F001 DD DSN=J10262.TWELVEA,
//          DISP=(,CATLG),UNIT=ONLINE,
//          SPACE=(3204,(100,50),RLSE),
//          DCB=(RECFM=VBS,LRECL=136,BLKSIZE=3024)

```

APPENDIX E

INSTRUCTIONS FOR THE EXECUTION OF THE FORCAT MODEL

FORCAT was written in Fortran IV and may be implemented on any computing system which supports this programming language. The model was developed on the University of Tennessee's IBM 3071 series computer using the MVS job control language (jcl). To execute this program for 100 plots and for a 100 year simulation period, a region of at least 356K and an execution time of at least 60 minutes should be requested. The listing of FORCAT in Appendix D includes appropriate jcl to provide plotted output and should be changed if this is not desired.

The values for several variables in the MAIN program should be selected prior to model execution. These variables include:

- KTIMES - the number of 1/5 acre plots to be simulated,
- NYEAR - the number of years to be simulated,
- KPRNT - the interval of years for which output is desired,
- LT - the land type (1 - 20) to be simulated,
- CUTYR - the interval of years between clearcuts,
- FYR - the number of years after clearcutting in which
a prescribed fire is to be conducted,
- DIALIM - the lower dbh (in centimeters) of trees that are to
be harvested during a simulated clearcut,
- PLOT - set to 'true' if plotted output is desired,
- PRINT - set to 'true' if printed output is desired.

The value for CUTYR should be set to a value greater than the value of NYEAR if clearcutting is not desired. A clearcut will be conducted during the first year of simulation regardless of the selected value

of CUTYR. FYR should be set to a value less than or equal to 10 or a fire will not be conducted. If a simulation of the area where study plots of the CWMA is desired, no further changes are required.

Simulation of other areas, however, requires several changes to the PLOTIN subroutine and to input parameters. Descriptions of preharvest stands are included in the PLOTIN subroutine. Values of several variables are required and include:

NTREES(J) - the total number of trees of species number J on
an average 1/5 acre (1/12 hectare) plot,

DBH(I) - the dbh of tree number I (input in order
of species beginning with species 1),

IAGE(I) - the age of tree number I.

One value of NTREE(J) should be supplied for each of the 33 species included in FORCAT. A value of DBH(I) and IAGE(I) should also be included for every tree on the average 1/5 acre plot of the preharvest stand.

A total of 161 data cards are included at the end of the Fortran program. All but 27 of these include species parameters and do not require changes when the simulation of a new site is desired. The first data card in the deck contains values for five variables, all of which require changes. A value for PLAT is recorded in columns 1 through 5. This is the latitude of the simulated plot and should be given the format of F5.2. The Julian dates for the beginning of the growing season and the end of the growing season are recorded in columns 6 through 15 using the format 2F5.1. The centimeters of water

present at field capacity and at PWP for the soils of the simulated plot are given in columns 17 through 24 with a format of 2F4.1.

The second data card contains the mean monthly temperature in Centigrade for the desired plot in columns 6 through 65. The required format is 12F5.2. Data card number 3 contains the standard deviation of monthly temperatures in columns 6 through 65 with a format of 12F5.2. Mean monthly precipitation in centimeters and associated standard deviations are included in data cards 4 and 5, respectively. This data is recorded in the same columns and by the same format as data cards 2 and 3.

The number of species to be simulated and the assigned number for each desired species are recorded in columns 1 through 68 on data card number 6 using the format of I2,33I2. The last data card (number 161) is used to indicate the number of species to be plotted and to indicate which particular species are desired. The same columns and format are used as for data card number 6.

Data cards 141 through 160 are used to input data to the PLOTIN subroutine for up to 33 species and 250 trees of a measured 1/5 acre plot. The number of trees for each species are included on cards 141 and 142 using the format of 24I3,/9I3. The dbh for each of 14 trees are recorded on cards 143 through 159 using the format of 14F5.1 for each card. Card 160 contains the dbh of the last 12 trees using a format of 12F5.1. The dbh of all trees should be recorded in centimeters.

VITA

Thomas A. Waldrop was born on July 17, 1956 in Asheville, North Carolina, the son of Thomas J. and Lois B. Waldrop. In 1962 his family moved to Charleston, South Carolina where he attended public schools. He was graduated from Hanahan High School in 1974. That same year he entered Clemson University at Clemson, South Carolina. He received a Bachelor of Science degree in forest management in May, 1978. Work experience during this period included summer internships with the USDA Forest Service and Westvaco Timberlands. He was married to the former Virginia Puckett Cheatham on August 5, 1978. During that same month, he accepted a graduate research assistantship to study forest protection at Clemson University. In August of 1980, he graduated with a Master of Forestry degree and moved to Knoxville, Tennessee. There he began study toward a Doctor of Philosophy degree in forest ecology at The University of Tennessee, Knoxville. He received this degree in December of 1983. He is a member of the Society of American Foresters, Xi Sigma Pi, Alpha Zeta, and Gamma Sigma Delta.