To the Graduate Council:

I am submitting herewith a thesis written by Unsook Song entitled "Use of a Land Classification System in Growth and Yield Prediction on the Cumberland Plateau of Tennessee." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Forestry.

John C. Rennie, Major Professor

We have read this thesis
and recommend its acceptance:

Accepted for the Council:

Associate Vice Chancellor
and Dean of The Graduate School

USE OF A LAND CLASSIFICATION SYSTEM IN GROWTH AND YIELD PREDICTION ON THE CUMBERLAND PLATEAU OF TENNESSEE

A Thesis

Presented for the

Master of Science

Degree

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Unsook Song

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DEDICATION

I would like to dedicate this thesis

to my dear parents,

Mr. Baykhyun Song (성백현) and Mrs. Choonlay Kim (김춘례),

who have given me educational opportunities.

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ABSTRACT

Growth and yield predictors are a significant aid to foresters developing management plans. Stand level yield modeling has been well developed for even-aged stands of a single species. However, much planning for forest management is concerned with mixed species stands which may be even-aged or uneven-aged. Much of the Cumberland Plateau of Tennessee is in mixed hardwoods for which there are no applicable growth and yield predictors. Use of site index as a variable in growth and yield prediction models is limited in most stands because their history is not known and many may not be even-aged. Landtypes may offer an alternative to site index for these mixed stands because they were designed to include land of about equal productivity.

Data from 399 Forest Inventory and Analysis plots, collected by Southern Forest Experiment Station (SFES), Forest Service, USDA, were utilized in this study. To determine vegetation by landtype, dependency between landtype and detailed forest type was tested with Chi-square. Differences in productivity among landtypes was tested by employing regression analyses and analysis of variance (ANOVA). Basal area growth was fitted to the nonlinear models developed by Moser and Hall (1969). Basal area growth and volume growth

were also predicted as a function of initial total basal area and initial volume with linear regression by landtype and by landtype class. Differences in basal area growth and volume growth by landtype were tested with ANOVA. Dependency between site class and landtype was tested with Chi-square.

Vegetation types seem to be related to landtypes in the study area although the validity of the test is questionable because of a high proportion of sparsely occupied cells. No statistically significant differences in productivity among landtypes were found in this study. This may be because the data were from plots installed and maintained to monitor regional forest growth, or due to the absence of real differences. A study installed specifically to test for differences in productivity by landtype is recommended.

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CHAPTER 1

INTRODUCTION AND OBJECTIVES

Stand level yield modeling has been well developed for even-aged stands of a single species. However, much planning for forest management is concerned with mixed species stands which both even-aged and uneven-aged. Methods for predicting future yields in such stands should be developed to facilitate forest management planning (Lynch and Moser, 1986).

Much of the Cumberland Plateau of Tennessee supports mixed hardwoods for which there are no applicable growth and yield predictors. Use of site index as a variable in growth and yield prediction models is limited in most of these stands because their history is not known and many are uneven-aged. Landscape units may offer an alternative to site index for these stands because they are designed to include land of similar productivity.

Smalley (1982) delineated 20 landtypes on the Mid-Cumberland Plateau. A landtype is the smallest unit of the landscape recognized in a land classification system. He described the geology, soils, vegetation, productivity and management problems expected within each landtype. Productivity information was drawn from a variety of published material and, in some cases, was extrapolated from information applicable to adjacent areas.

The objectives of this study were:

1. to determine vegetation and productivity by landtypes.
2. to develop growth and yield predictors for mixed hardwoods on the Cumberland Plateau using landtype as a variable.

CHAPTER 2

LITERATURE REVIEW

In timber management, growth and yield predictors are basic tools used by foresters to predict stand volume and density (stems per acre), usually by diameter class, at various ages using initial or intermediate stocking, and site quality class. Mortality and volume growth for a five or ten year period can also be predicted from the same stand variables (Rennie, 1991).

Yield tables have been the primary method used by forest managers to forecast harvest volumes. Traditionally, yield tables have been prepared for even-aged stands of individual species or species groups. Yield tables can be classified into three types:

1. Normal yield tables have been developed to apply strictly to even-aged, fully-stocked stands. They use stand age and site index as independent variables. They have been considered as a guide to a life history of the ideal stand for a species or a species group.

2. Empirical yield tables are similar to the previous tables except they are based on plots of average stocking, not of full (normal) stocking.

3. Variable-density yield tables use a measure of density as an independent variable as well as stand age and site

index. The tables are usually presented as equations rather than in tabular form. They have greater flexibility for application to managed stands.

However, yield tables are merely a theoretical standard to which an actual forest stand may be compared. Consequently, several problems exist in their application. Other more effective means may be needed for future forest management tasks (Society of American Foresters, 1984).

Yield equations have replaced traditional yield tables. They are obtained from the mathematical integration of growth-rate equations, expressed primarily as a function of stand age (Clutter *et al.*, 1983).

The Chapman-Richards growth model (Richards, 1959; Chapman, 1961) has been used to model forest growth (Turnbull, 1963; Pienaar, 1965; Pienaar and Turnbull, 1973). The model is derived from basic biological principles and has proven to be very flexible in application. The standard formulation of the model conceptualizes the growth rate of an organism or a population as the resultant of an anabolic growth rate (constructive metabolism) and a catabolic growth rate (destructive metabolism). The anabolic rate is assumed to be proportional to the surface area of the organism, while the catabolic rate is assumed to be proportional to the volume of the biomass (Pienaar and Turnbull, 1973). Clutter *et al.* (1983) express these relationships symbolically as:

$$\frac{dY}{dt} = \alpha Y^{\beta} - \gamma Y \qquad (1)$$

where

Y = size of the organism

t = time

α, β, γ = constants ($\alpha>0, 0<\beta<1, \gamma>0$).

In uneven-aged stands, such as those on the Cumberland Plateau, stand age has obscure meaning which causes difficulty in applying yield functions. Moser and Hall (1969) developed a yield prediction model for uneven-aged mixed northern hardwood and oak-hickory stands in Wisconsin based on the Chapman-Richards function.

Examination of basal area growth-rate data resulted in selection of equation 2 from a derivative form of Von Bertalanffy's generalized growth-rate equation (Richards, 1959).

$$\frac{dB}{dt} = nB^{m} - kB \qquad (2)$$

where

B = initial basal area

t = time

n, m, k = constants

Equation 3 relates stand volume to basal area.

$$V = b_o B^{b_1} \tag{3}$$

where

V = initial net volume

b_0, b_1 = constants

Differentiating equation 3 with respect to time yields a relationship (equation 4) that represents stand volume growth rate.

$$\frac{dV}{dt} = (b_1 V B^{-1})\ (dB/dt) \tag{4}$$

Substituting equation 2 in equation 4 yields a predictor of stand volume growth in terms of initial volume and basal area (equation 5) (Moser and Hall, 1969).

$$\frac{dV}{dt} = b_1 V[nB^{(m-1)} - k] \tag{5}$$

Forest land classifications have been developed based on physical features alone, on vegetation features alone, or on a combination of physical and vegetation features. The approach using both physical and vegetation features has been called in several ways such as the "ecological", "ecosystem", "biophysical", or "biogeoclimatic" approach (Pierpoint, 1984). The holistic approach of integrating the pertinent ecosystem components into a classification system was initiated by Krauss and developed and expanded by Schlenker (1964) and others (Mühlhäusser *et al.*, 1983).

An ecological classification system provides a hierarchical organization for describing the forest. This system offers operational advantages for both the information users and the resource specialists who collect the data. It can be useful in a rapid and inexpensive land inventory, in interdiscipline communication, in providing a stable framework for monitoring, and in an overview of the landscape for information management (Nelson *et al.*, 1984). Ecological classification draws lines of differences and similarities between various geographic areas, thereby enhancing extrapability of research results (Russell and Jordan, 1991).

Smalley (1982; 1986; and 1991) adapted the Land System Inventory of Wertz and Arnold (1975) in developing a site classification system for the Interior Uplands. The system can be described as a process of successive landscape stratifications which were based on the author's knowledge of

the interaction and controlling influences of ecosystem components. Landtypes are the most detailed level of a 5-level hierarchy. They are visually identifiable areas that have resulted from similar climatic, geologic, and pedologic processes (Smalley, 1991). Each landtype is described in terms of nine elements: geographic setting, dominant soils, bedrock, depth to bedrock, texture, soil drainage, relative soil water supply, soil fertility, and vegetation. Also, forest management interpretations of productivity, management problems, and desirable species are included for each landtype.

CHAPTER 3

STUDY SITE DESCRIPTION

Climate

The weather of the Cumberland Plateau is influenced by cold, dry continental air masses from Canada and warm, moist air from the Gulf of Mexico (Smalley, 1982). The mean annual temperature of the Plateau is mostly in the range of 54 to 57° F (Springer and Elder, 1980). The temperature often falls below freezing at night from December to February. While air temperature does not vary much across the region, local temperatures vary considerably because of elevation, aspect, and cloud shade (Smalley, 1982). The Plateau has relatively cooler temperatures than the adjacent Ridge and Valley, and Eastern Highland Rim provinces with an approximately 3° F decrease for every 1,000 foot increase in elevation (Dickson, 1960).

Most of Tennessee, except the Cumberlands, Unakas, and northern part of the Ridge and Valley Region, receives 46 to 54 inches of annual precipitation (Springer and Elder, 1980). Average annual precipitation of the Cumberland Plateau is about 59 inches which is higher than in the Ridge and Valley Province (40 to 50 inches/year). Precipitation is well distributed throughout the growing season in most years.

Precipitation on the Plateau is greatest from December through March, and lowest from August through October. Another precipitation maximum on the Plateau occurs in the late spring and summer months as the result of convective shower and thunderstorm activity. Since the Plateau has orographic precipitation, the region sometimes receives more precipitation during dry-spells than adjacent physiographic provinces (Dickson, 1960).

Due to cooler temperatures, less potential evapotranspiration, and more precipitation, soil water deficits are much shorter and less frequent on the Cumberland Plateau and in the Unaka Mountains than in other parts of the State for soils with the same available capacity (Springer and Elder, 1980). However, tree growth on the Cumberland Plateau is reduced due to insufficient soil moisture for periods of several days up to six times each growing season (Smalley, 1982).

Physiography and Geology

The Cumberland Plateau is the southern portion of the Appalachian Plateau, which extends in a southwesterly direction from the southern New York to central Alabama where it disappears beneath coastal plain sediments. The Plateau covers an area of about 4,300 square miles in Tennessee - nearly one tenth of the state (Luther, 1977). The Plateau

rises 800 to 2,000 feet above the Ridge and Valley Province on the east and 800 to 1,000 feet above the Eastern Highland Rim on the west (Fullerton and Bernard, 1977). The Plateau gradually decreases in elevation from north to south (Miller, 1974). Elevation of the Plateau averages about 2,000 feet, with some peaks in the Cumberland Mountains exceeding 3,000 feet (Springer and Elder, 1980).

The Cumberland Plateau is capped by level-bedded, erosion-resistant Pennsylvanian sandstones, with more easily eroded Mississippian shales and limestones on lower slopes below the escarpment (Smalley, 1986). The Plateau has an undulating surface dissected by young valleys which become steeper and deeper toward the Plateau edges (Fenneman, 1938). The eastern boundary is a steep sandstone escarpment which is controlled by the direction of the folds formed by late Paleozoic mountain-building forces. It is only slightly dissected by streams; however, the western boundary is much more dissected, characterized by numerous deep, steep-walled gorges, spurs and outliers (Miller, 1974). The southern portion of the Plateau is less dissected than the northern (Fenneman, 1938).

The topography of the southern Appalachian Plateau is due to deformation occurring as early as Precambrian time, and as recent as the last major episode (Allegheny orogeny) occurring near the end of the Paleozoic Era. Sediments collected along the eastern edge of North America were buckled and fractured

into a long, high ranges of mountains (Miller, 1974). The western-most deformations associated with the Allegheny orogeny occurred as thrust faults and bedding plane faults along the eastern side of the mid-Cumberland Plateau. These various geologic events were responsible for the major structural features associated with the eastern Cumberland Plateau such as the Cumberland Plateau overthrust fault, Crab Orchard Mountains and Walden Ridge, Cumberland Block, Sequatchie and Elk Valley (Luther, 1977; Miller, 1974). Numerous outliers, formed by erosional dissection, occur in the Highland Rim, the largest being Short Mountain (Luther, 1977; Miller, 1974). Extensive coal beds in the Cumberland Mountains were derived from accumulation of plant material over many thousands of years, followed by deep burial, uplift, and erosion formed the mountains of today (Luther, 1977).

Soils

Soils of the Plateau formed either directly from Pennsylvanian-sandstones, siltstones, and shales, or from materials weathered from them (Springer and Elder, 1980). Sandstone outcrops are common on the slopes and cliffs. Much of the Plateau remains in forest (Francis and Loftus, 1977; Springer and Elder, 1980). The soils are for the most part highly leached Utilsols belonging to siliceous, mesic families (Francis and Loftus, 1977). Soils vary from deep to shallow;

however, most are about 2 to 4 feet deep to bed rock, and are generally well drained, loamy, strongly acid, and low in natural fertility (Springer and Elder, 1980). Shortages of nitrogen, phosphorous and calcium commonly limit tree growth (Francis and Loftus, 1977). Physical and chemical soil properties have been shown to vary along aspect and slope position gradients (Franzmeier *et al.*, 1969).

CHAPTER 4

METHODS AND MATERIALS

Data Collection

Tree and stand data used were provided by the Forest Inventory and Analysis Work Unit (FIA), Southern Forest Experiment Station (SFES), Forest Service, USDA. This unit is responsible for assessing the forest resources of over a hundred million acres of forest land in seven south central states (Alabama, Arkansas, Louisiana, Mississippi, Oklahoma, Tennessee, and Texas), and Puerto Rico (May, 1989). The data collection procedure used by USDA SFES FIA is as following:

Locating and establishing sample locations

Sample locations were at the intersections of a 3-mile grid. At this intensity, one sample location represents about 5,760 similar acres. A sample location is a cluster of points systematically located in the boundaries of an acre. The exact number of sample points is determined for a given unit or state by project scientists.

Establishment of sample locations

Starting Point -- A landmark was selected that was readily identifiable on the ground and on an aerial photo, and

as close to the sample location as possible. The starting point was used to accurately locate the sample location on the ground.

Point Cluster -- After point one was established, and providing it was in commercial forest land, the other points were located and marked. An objective of the grid pattern of sample points was to have an even distribution over about one acre with points far enough apart to be independent. The spacing and orientation of the sample points resulted in equilateral triangles with sides of 66 feet. Substitute points were located in an objective manner if any point falls on, or within 33 feet of nonforest land (USDA Forest Service, 1985).

Plot size and tree tally

At each point, data were recorded on all live trees 5.0 inches D.B.H. and larger whose center at D.B.H. falls within the horizontal limiting distance of a 37.5 (sq.ft./acre) basal area factor prism. Data were recorded for all live trees 1.0 to 4.9 inches D.B.H. on a 7.1 foot radius plot (about 1/275 acre) at points 1, 2, and 3 (USDA Forest Service, 1985).

Description of Data

This study utilized two levels of data which were routinely collected by SFES FIA personnel. One is tree level

data (Appendix B) which consists of individual tree measurements. The other is plot (sample location) level data (Appendix C) which contains plot description variables and data from the tree level preprocessed up to a "per acre" basis for each sample location (May, 1989). These two data sets were obtained for the same sample locations for 1980 and 1989.

One plot level variable, site class, described below, was used in the statistical analysis. Site class is based on potential yield in cubic feet per acre at culmination of mean annual growth in fully stocked natural stands. It is assigned based on the following criteria (Todd, 1990):

Class 1 - 225 cubic feet/acre/year (cf/ac/yr) or more timber growth.
Class 2 - 165-224 (cf/ac/yr) timber growth.
Class 3 - 120-164 (cf/ac/yr) timber growth.
Class 4 - 85-119 (cf/ac/yr) timber growth.
Class 5 - 50- 84 (cf/ac/yr) timber growth.
Class 6 - 20- 49 (cf/ac/yr) timber growth.
Class 7 - less than 20 (cf/ac/yr) timber growth.

For this study, FIA personnel also determined landtype (Smalley, 1982) (Table 1) for each point at sample locations on the Cumberland Plateau (Figure 1). When the first landtype code was followed by number 89, the sample location had a single landtype. The code 99 was assigned when a point was disturbed by a strip mine, stream, road, etc. When a sample location did not have a single landtype, it needed at least 6 points out of 10 with same landtype to be assigned a dominant landtype. In summarizing the landtype data for analysis, number 99 also designated that a particular sample location

Table 1. Summary of landtypes and landtype codes (LT) (Smalley, 1982)

Landtype summary	LT
Broad undulating sandstone uplands	1
Broad sandstone ridges - north aspect	2
Broad sandstone ridges - south aspect	3
Narrow sandstone ridges and convex upper slopes	4
North sandstone slopes	5
South sandstone slopes	6
Sandstone outcrops and shallow soils	7
Broad shale ridges - north aspect	8
Broad shale ridges - south aspect	9
Upper shale slopes - north aspect	10
Upper shale slopes - south aspect	11
Lower shale slopes - north aspect	12
Lower shale slopes - south aspect	13
Footslopes, terraces, and streambottoms with good drainage	14
Terrace, streambottoms, and depressions with poor drainage	15
Plateau escarpment and upper sandstone slopes and benches - north aspect	16
Plateau escarpment and upper sandstone slopes and benches - south aspect	17
Lower limestone slopes, benches, and spur ridges - north aspect	18
Lower limestone slopes, benches, and spur ridges - south aspect	19
Limestone outcrops and shallow soils	20

County code	Plot No.	LT code by sample point within plot									
		1	2	3	4	5	6	7	8	9	10
007	001	06	04	04	04	06	06	06	06	04	04
007	003	04	04	04	05	05	04	04	06	06	06
007	005	17	17	17	17	17	16	16	17	17	17
007	006	01	14	14	14	01	01	01	01	01	14
007	007	02	89								
007	011	03	89								
007	012	02	02	99	03	14	14	02	02	02	02
007	016	14	05	05	05	05	05	05	14	05	05
007	018	05	14	14	05	05	05	05	14	06	06
007	019	02	89								
007	021	17	89								
007	025	01	89								
007	027	01	89								
007	028	01	89								
007	029	19	14	19	19	14	14	19	19	19	19
007	030	19	89								
007	031	18	89								
007	032	19	89								
007	033	02	06	06	05	05	02	06	06	05	02
007	034	03	89								
007	035	03	89								
007	038	16	16	16	16	16	16	16	17	17	17
007	039	01	89								
007	040	01	89								
007	041	01	89								
007	042	04	89								
007	044	03	89								
007	045	02	89								
007	046	01	89								
049	001	16	89								
049	002	06	06	06	06	06	06	07	07	06	06
049	003	14	89								
049	004	06	89								
049	005	05	07	14	14	14	07	05	05	05	05

Figure 1. An example of landtype (LT) data

was unclassified because it did not have a dominant landtype.

Statistical Analyses

Subsetting of the data

FIA provided 1980 and 1989 data for 399 sample locations in 16 Cumberland Plateau counties (Table 2).

Sample locations classified as having significant cutting or other disturbances or lacking a dominant landtype (landtype 99) were removed from the data set. Only 329 sample locations had a single or dominant landtype and entered step 1 of the statistical analysis.

In subset 2, sample locations with less than 70% of the 1980 basal area in trees surviving from 1980 to 1989 were dropped (Table 2). Tree history categories are shown in table 3.

To reduce variability among sample locations, only those with an initial basal area of 50 sq.ft./acre were included in subset 3.

Subsets 4a, 4b, and 4c (Table 2) each started with sample locations included in subset 2. Landtypes having 16 or more sample locations were included in subset 4a. Sixteen was considered the minimum number of plots necessary to represent general dominant landtypes over the Cumberland Plateau.

Similar landtypes were grouped into landtype classes (LTCL).

Table 2. Sample location distribution by county for each subset of analyses

CT	CO	number of sample locations by subset									
		OD	1	2	3	4a	4b	4c	5a	5b	5c
BL	7	29	24	16	6	13	16	16	19	23	21
CU	35	55	40	28	19	26	27	28	36	39	33
FE	49	42	27	21	11	13	17	19	16	22	19
FR	51	22	22	15	9	10	15	15	15	22	19
GR	61	29	26	17	11	13	15	17	20	22	21
HA	65	10	8	7	4	6	6	7	7	7	5
MA	115	40	36	26	14	17	18	23	27	28	21
MO	129	41	34	32	16	17	30	31	19	32	24
OV	133	17	14	11	8	4	8	10	5	11	8
PI	137	6	5	4	3	4	4	4	5	5	3
PU	141	12	11	9	7	4	7	7	4	9	9
SC	151	30	24	20	16	10	17	19	12	20	15
SE	153	24	21	18	10	12	13	17	15	16	16
VB	175	24	21	13	7	11	13	13	15	19	18
WA	177	6	6	5	4	3	4	5	4	5	5
WH	185	12	10	7	5	7	7	7	10	10	10
Total		399	329	249	150	170	217	238	229	290	247

Abbreviations - CT: county [BL: Bledsoe, CU: Cumberland, FE: Fentress, FR:Franklin, GR: Grundy, HA: Hamilton, MA: Marion, MO: Morgan, OV: Overton, PI: Pickett, PT: Putnam, SC: Scott, SE: Sequatchie, VB: Van Buren, WA: Warren, WH: White], CO: county code, OD: original data.

Table 3. Categories of Tree History

Category	Tree History (THIS)	
	Code	Description
Survivors	11	survivor live tree recorded in past
	12	missed survivor live tree
	15	two trees in past; one tree now (forked trees)
Mortality	21	nonsalvable dead (>=5.0" dbh) live in prior survey
	22	salvable dead recorded live in prior survey (>=5.0" dbh)
	23	salvable dead not recorded live in prior survey (>=5.0" dbh)
	24	nonsalvable dead not recorded not recorded in prior (>=5.0" dbh)
Cut	31	stump of prior survey live tree (cut and used)
	32	live in prior survey - killed by logging; not utilized
	33	live in prior survey - killed by cultural treatment
	34	stump of dead tree that was live in prior survey

LTCL 1 - sandstone uplands (LT 1).
LTCL 2 - sandstone ridges (LT 2 and 3).
LTCL 3 - north sandstone slopes (LT 5).
LTCL 4 - south sandstone slopes (LT 6).
LTCL 5 - shale (LT 8, 9, 10, 11, 12, and 13).
LTCL 6 - escarpment and upper sandstone slopes and benches (LT 16 and 17).
LTCL 7 - limestone (LT 18, 19, and 20).

Those sample locations in landtype classes with 16 or more sample locations were retained in subset 4b.

In subset 4c, sample locations were grouped into broad categories for contrasts in analysis of variance.

Sandstone	- LT 1, 2, 3, 4, 5, 6, 7, 16, and 17.
Limestone	- LT 18, 19, and 20.
Shale	- LT 8, 9, 10, 11, 12, and 13.
Outcrops	- LT 7 and 20.
Ridges	- LT 1, 2, 3, 4, 8, and 9.
North aspect	- LT 5, 10, 12, 16, and 18.
South aspect	- LT 6, 11, 13, 17, and 19.

Sample locations in landtypes 14 and 15 were removed since they did not fall in any of the contrast groups.

For analyses of site class and of detailed forest type, tree category (cutting, mortality and other causes) was not important because site class and detailed forest type are plot level variables. Thus, 329 sample locations were again considered for subsets 5a, 5b, and 5c. In subset 5a, sample locations were excluded when the number of 1989 sample locations in a landtype was 16 or less. In subset 5b, sample locations were removed when number of 1989 sample locations in a landtype class was less than 16. To reduce variability among detailed forest types (FTYPEX), sample locations were

dropped from 329 to 247 in subset 5c. In this subset, FTYPEX not appearing more than 19 times in a landtype were excluded. Nineteen was selected because it was considered to be the minimum number that was large enough to cover general dominant forest types in the study area. Seven forest type classes (FTCL) were grouped.

All statistical tests in this study were tested on probability level 95% ($\alpha = 0.05$).

Regression of growth on initial value

Equations 2 and 5 were fitted using PROC NLIN (SAS, 1988) for basal area growth and volume growth over 329 sample locations (subset 2). These models were selected because of their biological basis and Moser and Hall's (1969) success in similar stands. Linear regression of basal area growth and volume growth on initial basal area and initial volume, respectively, was run using PROC GLM (SAS, 1988) by both landtype and landtype class because of poor results obtained with equation 2.

Tests for homogeneity of regression coefficients with covariance

Homogeneity of regression coefficients (Steel and Torrie, 1960) was tested using covariance analysis. Regression coefficients were calculated for each landtype (subset 4a) and for each landtype class (subset 4b). Overall regression

coefficients were calculated with PROC GLM (SAS, 1988), and the estimates of SSmodel, SSerror, SStotal, and df were obtained from the regressions by both landtype and landtype class.

Estimate of maximum R^2

Variability among sample locations was high. Sample locations were grouped into 20 sq.ft./acre classes (basal area class) in landtype (from data set 4a) and in landtype class (subset 4b). Within-class corrected sums of squares (CSS) were calculated. These were summed and subtracted from the overall CSS. The difference was divided by the overall CSS and multiplied by 100 to estimate the coefficients of determination for a perfect fit, i.e., a model passing through each class mean.

Analyses of variance

ANOVAs were run to test for differences in basal area growth and volume growth (subset 4c) between logical groups of landtypes. Contrasts used were (1) parent material: sandstone, limestone, and shale, and (2) aspect: ridge, north facing, and south facing slopes.

Contingency tables

Differences in productivity by landtype result in different distributions of sample locations over site class

(SITEC) among landtypes (LT) or over SITEC among landtype classes (LTCL). Contingency tables were constructed with LT and SITEC (subset 5a), and with LTCL and SITEC (subset 5b) for 1989 data. Independence was tested with Chi-square.

To determine whether there were positive relationships between LT and detailed forest type (FTYPEX) and between LTCL and forest type class (FTCL), two independence tests of 1989 data: (1) LT and FTYPEX (subset 1) and (2) LTCL and FTCL (subset 5c) were tested with Chi-square.

CHAPTER 5

RESULTS

Nonlinear and Linear Regressions

Nonlinear regression of basal area growth using all 329 sample locations

Fitting the Chapman-Richards model (Equation 2) to predict basal area growth from basal area resulted in a small coefficient of determination (R^2) and standard errors 5 to 12 times the coefficients (Table 4, run 1). Also, correlations among regression coefficients were high with n having a 0.9997 correlation with k.

In an attempt to reduce the variability, plots with an initial basal area of 50 sq.ft. per acre or less were dropped. Coefficients were estimated starting with values based on Moser and Hall's (1969) results (Table 4, run 2). A second set of regression coefficients was estimated starting with an initial range for each coefficient that included the initial values used in run 2 (Table 4, run 3). Although the residual sums of squares were very similar for these two sums, the estimates of coefficients n and k were quite different. As with run 1, the standard errors of the coefficients were much larger than the coefficients and the intercoefficient correlations were all 0.9999. To get R^2 (Table 4), predicted

Table 4. Results of nonlinear regression to predict basal area growth from initial basal area with the Chapman-Richards model

Run	Number of sample locations	Initial Conditions	Estimated Coefficient	Asymptotic standard error	Residual sum of squares	R^2 (%)
1	249	n=-0.8 to -0.1 by 0.1 m=0.75 to 1.15 by 0.1 k=-1.2 to -0.3 by 0.1	-0.587 1.118 -1.211	7.483 0.653 7.934	8192.970	26.6
2	150	n=-0.5 m= 1.0 k=-0.5	-0.318 1.088 -0.692	28.735 5.751 30.457	4521.938	20.8
3	150	n=-0.8 to -0.1 by 0.1 m=0.75 to 1.15 by 0.1 k=-1.2 to -0.3 by 0.1	-0.747 1.049 -1.150	99.925 5.218 101.856	4572.530	20.7

value (e.g., DB) for each plot (location) was calculated. Deviations of predicted and observed value were squared and added (residual SS). Finally, residual SS was subtracted from corrected SS (CSS), and this value was divided by CSS, and multiplied by 100. Because of the very poor results with basal area growth, no results are reported for volume growth.

Linear regression of basal area growth and volume growth by landtype

Basal area growth (DB) was predicted as a function of initial total basal area (TPBAPA) with a simple linear model (equation 6) and also with a model having a linear, quadratic, and cubic term (equation 7). These models were fitted with data in step 4a (Table 2) to evaluate the strength of the relationship between basal area growth and landtype.

$$DB = 5.1281 + 0.1654(TPBAPA) \quad (6)$$

$$DB = 4.0295 + 0.2680(TPBAPA) - 0.0023(TPBAPA)^2 + 0.00002(TPBAPA)^3 \quad (7)$$

The simple linear model itself (p-value = 0.0001), intercept (p-value = 0.0001), and TPBAPA (p-value = 0.0001) were significant. R^2 was 0.3000. None of coefficients of the cubic model were significant [intercept: p-value = 0.2344; TPBAPA: p-value = 0.1685; $(TPBAPA)^2$: p-value = 0.5025;

$(TPBAPA)^3$: p-value = 0.4408].

Similarly, volume growth (DV) was predicted as a function of a linear term of initial total net volume (TPNVPA) (equation 8) and as a function with a linear, quadratic, and cubic term (equation 9).

$$DV = 139.3446 + 0.2934(TPNVPA) \quad (8)$$

$$DV = 221.2055 - 0.2115\ (TPNVPA) + 2.6878 \times 10^{-4} (TPNVPA)^2 - 0.0669 \times 10^{-8} (TPNVPA)^3 \quad (9)$$

The linear model itself (p-value = 0.0001), intercept (p-value = 0.0006), and TPNVPA (p-value = 0.0001) were all significant. R^2 was 0.3091. None of coefficients of the cubic model were significant except intercept (p-value = 0.02) [TPNVPA: p-value = 0.9940; $(TPNVPA)^2$: p-value = 0.2539; $(TPNVPA)^3$: p-value = 0.2440].

Linear regression of basal area growth and volume growth by landtype class

The same procedure used for the landtype was applied to landtype class. Basal area growth (DB) was predicted as a function of initial total basal area (TPBAPA) with a simple linear model (equation 10) and also with a model having a linear, quadratic, and cubic term (equation 11). These models

were fitted with data in subset 4b (Table 2) to evaluate strength of the relationship between basal area growth and landtype class.

$$DB = 5.2958 + 0.1625(TPBAPA) \quad (10)$$

$$DB = 3.7303 + 0.2976(TPBAPA) - 0.0029(TPBAPA)^2 + 0.00002(TPBAPA)^3 \quad (11)$$

The linear model itself (p-value = 0.0001), intercept (p-value = 0.0001), and TPBAPA (p-value = 0.0001) were significant. R^2 was 0.2923. The cubic model (p-value = 0.0001) was significant. TPBAPA (p-value = 0.0843) was almost significant. The other two independent variables were insignificant [intercept: p-value = 0.2020; $(TPBAPA)^2$: p-value = 0.3462; $(TPBAPA)^3$: p-value = 0.2966]. R^2 was 0.2966.

Volume growth (DV) was predicted as a function of a linear term of initial total net volume (TPNVPA) (equation 12) and as a function with a linear, quadratic, and cubic term (equation 13).

$$DV = 154.2930 + 0.2919(TPNVPA) \quad (12)$$

$$DV = 190.9391 + 12.5429(TPNVPA) + 1.7560 \times 10^{-4} (TPNVPA)^2 - 0.0486 \times 10^{-8} (TPNVPA)^3 \quad (13)$$

The linear model itself (p-value = 0.0001), intercept (p-value = 0.0001), and TPNVPA (p-value = 0.0001) were significant. R^2 was 0.3080. The cubic model (p-value = 0.0001) was significant. The intercept (p-value = 0.0254) was significant. The rest of the independent variables were not significant [TPNVPA: p-value = 0.6119; $(TPNVPA)^2$: p-value = 0.4031; $(TPNVPA)^3$: p-value = 0.3492]. R^2 was 0.3114.

Test for Homogeneity of Regression Coefficient Using Covariance

Simple linear regressions of basal area growth as a function of initial total basal area and volume growth as a function of initial total volume were run by landtype and landtype class. Regression coefficients for basal area growth and for volume growth among landtypes and among landtype classes were homogeneous based on covariance analysis (Table 5).

Table 5. Adjusted degrees of freedom (df), reduced sums of squares (SS), and F value (F) from test for homogeneity of regression coefficient using covariance analysis by landtype (LT) or landtype class (LTCL).

	Adjusted df	Reduced SS	F
LT on basal area growth	6	141.55	0.7334
LT on volume growth	6	477464.95	1.2485
LTCL on basal area growth	6	135.59	0.6966
LTCL on volume growth	6	438311.94	1.1271

Estimate of Maximum R^2

The coefficients of determination for "perfect" fit are presented in table 6. The R^2 values from linear regression were 55% to 70% of the R^2 expected with a "perfect" fit (table 6).

Table 6. Comparison of coefficients of determination (R^2) for "perfect" fit with R^2 of simple linear regression

	LT ("perfect" R^2 : simple linear regression R^2)	LTCL ("perfect" R^2 : simple linear regression R^2)
Basal area growth	50.37% : 30.00%	44.95% : 29.23%
Volume growth	55.97% : 30.91%	48.19% : 30.80%

ANOVA of Basal Area and Volume Growth

There were no statistical differences among sandstone, limestone, and shale, or among outcrops, ridges, and slopes for either basal area growth or volume growth (Table 7).

Contingency Tables

Chi-square test of landtype (LT) and site class (SITEC)

Because Chi-square p-value was 0.05, the null hypothesis that LT and SITEC were independent was rejected. Dependency suggests that potential yield of stands on the Cumberland

Table 7. P-values of contrasts on basal area growth and volume growth.

Contrast	P-value	
	basal area growth	volume growth
Sandstone vs Limestone and Shale	0.4991	0.8405
Limestone vs Shale	0.1668	0.1670
Outcrops vs Ridges and Slopes	0.4370	0.1496
Ridges vs Slopes	0.1751	0.1337
North aspect vs South aspect	0.1626	0.2497

Plateau is related to landtypes. However, validity of this test was questionable since high proportion (49%) of the cells had expected counts less than 5.

Chi-square test of landtype class (LTCL) and site class (SITEC)

Since Chi-square p-value was 0.147, the null hypothesis that LTCL and SITEC were independent could not be rejected. They were independent, i.e., when landtypes were grouped into landtype classes, the relationship between potential yield and landtypes was weak. Again, validity was questionable because 50 percent of the cells had expected counts less than 5.

Chi-square test of landtype (LT) and detailed forest type (FTYPEX)

The Chi-square test of landtype (LT) and detailed forest type (FTYPEX) indicated that landtype and forest type were

dependent (p-value < 0.000). This suggested that specific vegetation types occur on specific landtypes. However, 97% of the cells had expected counts less than 5 which raised questions about the validity of this test.

Chi-square test of landtype class (LTCL) and forest type class (FTCL)

To reduce variability among the detailed forest types, those with less than 19 sample locations were dropped. The remaining sample locations with dominant forest types were assigned values of 1 to 7 for forest type classes (FTCL). A Chi-square test of landtype class (LTCL) and FTCL rejected the hypothesis that LTCL and FTCL are independent (p-value < 0.000). Therefore, forest type classes were related to landtype classes (Table 8). Again, validity was still questionable since 86% of the cells had expected counts less than 5.

Table 8. Number of sample locations by landtype class (LTCL) and forest type class (FTCL)

LTCL \ FTCL	1	2	3	4	5	6	7	total
1	6	8	7	2	26	0	0	49
2	5	1	5	0	22	2	0	35
3	3	2	4	0	20	0	1	30
4	4	3	3	2	15	3	1	31
5	0	1	0	1	11	0	1	14
6	1	3	1	7	23	6	6	47
7	0	1	2	6	19	5	8	41
total	19	19	22	18	136	16	17	247

CHAPTER 6

DISCUSSION

Since landtypes and detailed forest types are dependent, forest types can be predicted by landtype on the Cumberland Plateau in Tennessee. Also, landtype classes and forest type classes are dependent. However, both have so many cells with 5 or fewer observation that the tests are of questionable validity.

The Chapman-Richards model to predict basal area growth from initial basal area was selected for this study because of its sound biological basis and because of the Moser and Hall's (1969) success in similar stands. Predicting basal area growth with it was not successful in this study, with low R^2 values and estimated coefficients having "0" within their confidence intervals. When the plot number was reduced by eliminating low basal area plots to try to reduce the variability among them, asymptotic standard error (ASE) increased while residual sum of squares (RSS) decreased by about 50% and R^2 got slightly smaller (Table 4).

Basal area growth and volume growth was linearly related to initial basal area and initial volume by landtype and landtype class. However, the low R^2 values indicated weak relationships. It suggests that past stand productivity on a specific landtypes can be related to future productivity on

the same landtype. However, the strength of the relationship found here is not enough to be used in predicting growth.

A test for homogeneity of regression coefficient using covariance showed that regression coefficients for basal area growth and volume growth among landtypes and landtype classes were homogeneous. It did not support the hypothesis that there were significant differences in productivity among landtypes and among landtype classes on the Cumberland Plateau.

The R^2 values for the linear regression reached 55 - 70% of the expected R^2 values with a "perfect" fit. This indicated that the linear regressions were reliable as a basis for testing hypothesis about productivity.

Also, five orthogonal contrasts among logical groupings of landtypes demonstrated that there was no statistically significant productivity difference among landtypes. This result agreed with results from the nonlinear regression using the Chapman-Richards model and the analysis with linear regression.

Showing that landtype and site class were dependent, a Chi-square test of landtype and site class suggested that potential yield of hardwood stands on the Cumberland Plateau was related with landtypes even though the test was somewhat questionable. However, when the landtypes were grouped to landtype classes, the Chi-square test did not support the argument that a positive relationship exists between the

productivity and landtype. The poor relation between landtype and productivity may be due to a number of reasons. After initial training of field crews, no field checking of landtype classification was conducted. This possibly allowed mis-classification of a significant number of plots. The number of plots in many of the landtypes may have been too few to separate differences in productivity from random noise. Finally, there may not be real differences in productivity among landtypes.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

This study suggests that there may be a positive relationship between landtype and forest type on the Cumberland Plateau in Tennessee. However, there are no significant differences in productivity among landtypes and among landtype classes on the study area. Assuming that landtype determination by field crews was correct, this particular analysis suggested that it is not easy to predict basal area growth and volume growth on Cumberland Plateau using landtype. Several explanations can be suggested why no significant difference was found in productivity among landtypes. A possible reason may be that there were too few plots to adequately represent the many landtypes.

One way of establishing plots can be recommended. For sample plots, select more than 500 distinctive sampling locations having capacity to grow commercially valuable hardwoods in the study area. By doing so, disturbed sample locations can be avoided in advance. Locate each sample point within each designated landtype boundary. Establish 14 points within each sample location so that it can represent more accurately a landtype of the sample location. Use a grid pattern to locate sample points so that there can be an even distribution over the sample location with points far enough

apart to be independent. At this time, the location of the sample points results in equilateral triangles with sides of 25 m (about 82.02 feet). Assign a dominant landtype when a plot has at least 9 points out of 14 with the same landtype.

Quality monitoring is recommended. If sufficient financial resources are provided, have professionals frequently check quality on field work.

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APPENDICES

APPENDIX A - ACRONYMS

ACRONYMS	DESCRIPTION
AGE*	stand age (mid-point of 10 year ranges). 0 - stand recently harvested, not yet regenerated (stand origin is 4). 5 - 0 to 10 years, inclusive 15 - 11 to 20 years, inclusive 25 - 21 to 30 years, inclusive 35 - 31 to 40 years, inclusive 45 - 41 to 50 years, inclusive 55 - 51 to 60 years, inclusive 65 - 61 to 70 years, inclusive 75 - 71 to 80 years, inclusive 85 - 81 years and over 92 - mixed ages
AGEX*	actual stand age. 1 to 79 - actual age 80 - ages 80 to 99 81 - 100 years and over 85 - mixed ages with management 95 - mixed ages without management 0 - nonstocked
AZ*	azimuth to the tree in degrees.
CDATE*	current date by year, month (yymm).
CID*	county identification code; combination of state, and county codes (sscc).
CWC*	crown class. 1 - open grown 2 - dominant 3 - codominant 4 - intermediate 5 - overtopped 6 - cut or mortality trees
CO*	county code. See table 2.
DIST*	distance to the tree in feet and tenths.
EXP*	expansion factor; acres per forested location.
ETIME*	elapsed time from past to current survey, in years.
FTYPEX*	detailed forest type. Forest type is based on a plurality of stocking by tree species.

LO* plot location number.

LT landtype or landtype code. See table 1.

LTCL landtype class. See page 18.

NPT* number of points cruised (usually 5 to 10).

PDATE* past date by year, month (yymm).

PHYC* physiographic class.
1 - pine (Upland sites on which pine is present or was formerly present).
2 - upland hardwood (Upland sites other than pine sites).
3 - bottomland hardwood (Bottomland sites).

PID* plot identification code; combination of state, county, and location (ssccclll). e.g. 47007001 stands for location 1 in Bledsoe, Tennessee. See table 2 for the county code.

PT* point number.

PTC* past tree class or cover class code. See TC.

REXP* remeasurement expansion factor; acres per remeasured location.

SAMP* sample kind.
1 - new plot
3 - lost plot
4 - remeasured plot
6 - remeasured volume plot (TN '80)
7 - National Forest plot
8 - National Forest volume plot

SITEC* site class. See page 14.

SIZEC* stand size class (growing stock trees only). Stand size is based on a plurality of stocking percent in 3 tree size categories.
0 - understocked (less than 16.7% stocking - total)
1 - seedling and sapling
2 - poletimber
3 - sawtimber

SP* species.

SPG* species group.
1 - pine
2 - other softwood
3 - soft hardwood

4 - hard hardwood

ST* state code.

state	ST	STA	UN
Alabama	1	AL	1-6
Arkansas	5	AR	1-5
Louisiana	22	LA	1-5
Mississippi	28	MS	1-5
Oklahoma	40	OK	1-2
Tennessee	47	TN	1-5
Texas	48	TX	1-2

STA* state abbreviation code. See ST.

SYEAR* year of the survey.

TC* current tree class or cover class code.
20 - acceptable (includes former 10 class)
30 - rough cull
40 - rotten cull
50 - inhibiting vegetation
60 - nonstocked
70 - nonstocked to overtopped
80 - nonstockable

TG* current tree grade.
0 - on cut, mortality, and rough or rotten trees
1 - on red cedar
1 to 3 - on softwoods
1 to 4 - on white pine
1 to 5 - hardwood grades
6 - cull tree; indicates presence of short log
9 - cull tree
Note and this is based only on first log for Tennessee 1989 earlier surveys.

THIS* tree history. See table 3.

TN* tree number.

TPBAPA past total basal area per acre.

TRID* tree location ID code for specific locations using point and tree combination (pptt).

UN* unit number. See ST.

VOLC* stand volume class (volume for growing stock trees only).
1 - less than 1500 board feet per acre
2 - 1500 to 4999 board feet per acre

3 - 5000 board feet or more per acre

VOLQ* volume equation species code.
1 - longleaf/slash
2 - shortleaf/loblolly
3 - cypress/water tupelo
4 - other softwoods
5 - oaks
6 - sweet gum/black gum/yellow poplar
7 - other hardwoods
8 - noncommercial

* Source: Todd, Connie L. (1990)

APPENDIX B - An example of tree level data.

PID	CID	ST	STA	UN	CO	LO	EXP
47007001	47007	47	TN	4	7	1	5820.498
47007001	47007	47	TN	4	7	1	5820.498
47007001	47007	47	TN	4	7	1	5820.498
47007001	47007	47	TN	4	7	1	5820.498
47007001	47007	47	TN	4	7	1	5820.498
47007001	47007	47	TN	4	7	1	5820.498
47007001	47007	47	TN	4	7	1	5820.498
47007001	47007	47	TN	4	7	1	5820.498
47007001	47007	47	TN	4	7	1	5820.498
47007001	47007	47	TN	4	7	1	5820.498

REXP	SYEAR	TRID	PT	TN	AZ
6422.619	1989	101	1	1	73
6422.619	1989	102	1	2	0
6422.619	1989	103	1	3	0
6422.619	1989	104	1	4	311
6422.619	1989	105	1	5	217
6422.619	1989	106	1	6	217
6422.619	1989	107	1	7	217
6422.619	1989	201	2	1	108
6422.619	1989	202	2	2	0
6422.619	1989	203	2	3	16

DIST	SP	VOLEQ	SPG	THIS	TC	PTC	CWC	TG
3.000	837	5	4	11	20	20	3	0
0.000	693	6	3	21	30	30	6	0
0.000	931	7	3	21	20	20	6	0
10.000	802	5	4	11	20	20	3	0
5.500	591	7	4	11	20	20	4	0
5.500	591	7	4	2	30	0	4	0
5.500	591	7	4	2	30	0	4	0
5.700	832	5	4	11	20	20	3	0
0.000	693	6	3	21	40	40	6	0
1.300	316	7	3	11	20	20	4	0

Refer to Appendix A - Acronyms for acronym description.

APPENDIX C - An example of plot level data.

PID	CID	ST	STA	UN	CO	LO	EXP
47007001	47007	47	TN	4	7	1	5820.498
47007003	47007	47	TN	4	7	3	5820.498
47007005	47007	47	TN	4	7	5	5820.498
47007006	47007	47	TN	4	7	6	5820.498
47007007	47007	47	TN	4	7	7	5820.498
47007011	47007	47	TN	4	7	11	5820.498
47007012	47007	47	TN	4	7	12	5820.498
47007013	47007	47	TN	4	7	13	5820.498
47007016	47007	47	TN	4	7	16	5820.498
47007018	47007	47	TN	4	7	18	5820.498

REXP	SYEAR	CDATE	PDATE	ETIME
6422.619	1989	8902	7910	9.333
6422.619	1989	8901	7910	9.250
6422.619	1989	8902	7910	9.333
6422.619	1989	8902	7911	9.250
6422.619	1989	8902	7911	9.250
6422.619	1989	8902	7911	9.250
6422.619	1989	8902	7911	9.250
6422.619	1989	8902	7911	9.250
6422.619	1989	8902	7910	9.333
6422.619	1989	8902	7910	9.333

SAMP	SITEC	PHYC	AGE	AGEX	NPT	VOLC	SIZEC
4	5	1	92	95	10	2	2
4	6	2	92	95	10	1	2
4	5	2	92	95	10	2	3
4	6	2	92	95	10	1	2
4	6	1	15	15	10	1	1
4	5	1	92	95	10	2	3
4	5	2	92	95	10	2	2
4	5	1	55	60	10	3	3
4	4	1	92	95	10	1	1
4	5	1	15	15	10	1	2

Refer to Appendix A - Acronyms for acronym description.

VITA

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