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The Vegetation of Great Smoky Mountains National Park: Past, Present, and Future

Mark D. MacKenzie
University of Tennessee - Knoxville

To the Graduate Council:

I am submitting herewith a dissertation written by Mark D. MacKenzie entitled "The Vegetation of Great Smoky Mountains National Park: Past, Present, and Future." I have examined the final electronic 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 and Evolutionary Biology.

H. Hank Shugart, Major Professor

We have read this dissertation and recommend its acceptance:

Dewey Bunting, Louis Gross, Peter White

Accepted for the Council:

Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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Peter S. White

Accepted for the Council:

Associate Vice Chancellor
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THE VEGETATION OF GREAT SMOKY MOUNTAINS NATIONAL PARK: PAST, PRESENT, AND FUTURE

A Dissertation

Presented for the

Doctor of Philosophy

Degree

The University of Tennessee, Knoxville

Mark D. MacKenzie

May 1993

DEDICATION

This disseration is dedicated to the memory of my father

Joseph H. MacKenzie, Jr. (1929-1992)

My father was always there when I needed him but knew when I did not. Not only did he teach me the importance of asking questions, but he also showed me the joy in seeking the answers.

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ABSTRACT

This research investigates the vegetation of Great Smoky Mountains National Park (GRSM) using three different techniques: 1) analysis of vegetation data collected circa 1930, 2) remote sensing of current (1984) vegetation using Landsat Thematic Mapper (TM) satellite imagery, and 3) the integration of gradient analysis with forest succession modeling.

Analysis of the 1930's data revealed that *Castanea dentata* was the dominant species in the GRSM at that time, even with the introduction of the chestnut blight to the park in 1926. Classification of the 1930's plot data identified 16 unique vegetation types ranging from the low elevation, xeric *Pinus rigida* type to the high elevation, mesic *Abies fraseri* type. Ordination of the data indicated that species are responding to a complex moisture - elevation gradient. Unsupervised classification of the satellite data was able to identify 14 vegetation types. The classification process used all seven TM bands and had an overall classification accuracy of 83%. The types identified were Spruce - Fir, Northern Hardwood, Cove Hardwood, Mesic Oak, Mixed Mesic Hardwood, Tulip Poplar, Xeric Oak, Pine - Oak, Pine, Heath Bald, Grassy Bald, Grape Thicket, Treeless, and Water. The Cove Hardwood type was the most prominent type and occupied 33% of the park's area. The integration of gradient analysis with a forest succession model yielded a model that was capable of replicating vegetation types throughout the entire GRSM landscape. The model was used to provide insights into the dynamics of *Castanea dentata* prior to the chestnut blight and patterns of replacement and biomass dynamics after the blight. The model simulation indicated that replacement of *Castanea dentata*, and its effect on biomass after the blight, took place via multiple pathways depending on site conditions.

This research emphasizes the vegetation of GRSM as a whole rather than as a study of specific types or locations. It provides insights into vegetation dynamics in the context of both space and time.

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INTRODUCTION

The vegetation of Great Smoky Mountains National Park (GRSM) is a complex mix of coniferous and deciduous forests (Whittaker 1956). Though not high enough to support a climatic treeline (Cogbill and White 1991), the highest elevations do support Spruce - Fir forests (Whittaker 1956, Cogbill and White 1991). Pine stands are frequent at low elevation xeric sites (Callaway et al. 1987). Hemlock is scattered through the landscape but typically found in the mesic coves and along streams (Whittaker 1956). While the above discussion has focused on the coniferous types, the deciduous forest types dominate the GRSM landscape (Miller 1938, Whittaker 1956). Braun (1950) placed GRSM in the Oak - Chestnut forest region of the Eastern Deciduous Forest Formation. She described the forests of GRSM as predominately chestnut. This dominance of chestnut has changed drastically due to the effects of the chestnut blight (Nelson 1955; Woods and Shanks 1956, 1957; Arends 1981). Among the deciduous forests of GRSM are the cove forests. Whittaker (1956) describes the cove forests as "among the most beautiful deciduous forests in the world." Braun (1950) states that the cove hardwood forests of GRSM are typical mixed mesophytic communities. Whittaker (1956) takes exception to this classification and prefers to refer to the cove forests as a broader conception of Braun's mixed mesophytic type. Regardless of their classification, the cove forests have been the subject of numerous studies (Cain 1941, Whittaker 1956, Golden 1981, Callaway et al. 1987, Clebsch and Busing 1989) and represent the most diverse of the GRSM vegetation types.

Two non-forest vegetation types occur at high elevations in GRSM. Heath balds, composed primarily of evergreen ericacious shrubs, typically occur at elevations over 1300 m on exposed summits and ridges (Cain 1930, Whittaker 1956). Grassy balds are the other high elevation non-forest type in GRSM. The grassy balds, as the name implies, are dominated by grasses (Stratton and White 1982) and were created by clearing and grazing in the early and mid-1800's (Lindsay and Bratton 1979).

Whittaker (1956) interpreted the vegetation of GRSM based on gradients of elevation and site moisture. Golden (1981) and Callaway et al. (1987) have confirmed the importance of these gradients in explaining the complex vegetation pattern and distribution. Adding to the complexity of vegetation pattern in GRSM is the pattern of disturbance. At the time of park establishment (1934), 20% of the park was free from human disturbance and an additional 8% had experienced only diffuse disturbance (Pyle 1985). The remainder of GRSM had experienced either farming or logging. Since its establishment as a park, GRSM has been subject to various other disturbances (Harmon et al. 1983, Pyle 1985), for example, fire (Harmon 1980, 1981) and exotic species invasions including the chestnut blight (Woods and Shanks 1956, 1957), southern pine beetle (Kuykendall 1978), balsam wooly adelgid (Eagar 1984b), and the european wild boar (Bratton 1974). The gypsy moth represents another potential future invasion (Barett 1993).

Objectives

The above introduction illustrates the complex nature of the GRSM vegetation. The research presented in this dissertation addresses this complexity not from site specific analysis but rather from whole park analysis. This research attempts to describe and predict the vegetation of GRSM in the context of both space and time.

Chapter I describes the vegetation of GRSM during the 1930's. This analysis is possible as the result of a whole park sampling that occurred during this period. Even though the chestnut blight had already invaded the park (Woods and Shanks 1956) chestnut was still the dominant species in the GRSM landscape. This sampling and its subsequent analysis also provides insights into the importance of whole park sampling and its importance for vegetation description. The sampling effort of the 1930's provides us with a snapshot of the vegetation of GRSM at one point in time. The sampling represents the first, and only, whole park sampling effort. While the sampling locations can only be related to specific watersheds, certain spatial attributes of species distribution and vegetation pattern are discernable.

Chapter II provides another snapshot of the vegetation of GRSM at a particular point in time. This chapter describes the analysis of Landsat Thematic Mapper satellite data acquired of GRSM in 1984. This analysis represents the first, and only, spatially explicit whole park inventory of the vegetation of GRSM. Due to the explicit spatial nature of the satellite data, vegetation patterns are readily discernable.

Chapter III involves the incorporation of species responses to the complex moisture-elevation gradient for GRSM, developed in Chapter I, into a model of forest succession. This chapter emphasizes the temporal dynamics of the GRSM vegetation. The resultant model, due to the incorporation of the environmental gradient, also includes a spatial component.

Each of the individual chapters identifies specific objectives for the research presented. The overall goal of this research is to describe, analyze, and predict the vegetation of GRSM, as a whole, in the context of both spatial and temporal dynamics.

Study Area

GRSM encompasses 208,000 ha along the border of North Carolina and Tennessee from 35°29′ to 35°47′ N latitude and 83°05′ to 83°55′ W longitude. The park includes portions of Haywood and Swain counties in North Carolina and Blount, Cocke, and Sevier counties in Tennessee. GRSM is located within the Unaka Mountains of the Blue Ridge physiographic province (Fenneman 1938).

Bedrock geology of GRSM is composed primarily of Precambrian sedimentary rocks of the Ocoee series (King et al. 1968). Sandstones dominate throughout the Ocoee series but the Anakesta formation of the series is composed of slate, phyllite, and schist. Another relatively minor component of the bedrock geology are the Paleozoic rock types. The Knox Group limestones of Cades Cove represent a well known example of this type.

The soils of GRSM remain relatively undescribed (US MAB 1982b). Golden (1974) indicates that colluvial and residual soils cover most of GRSM. Restricted areas of alluvium occur along some of the streams. Inceptisols are the predominate soil type, at least within the central portion of GRSM (Golden 1974). Ultisols occur rarely at elevations less than 1000 m and Spodosols occur at elevations above 1800 m (McCraken et al. 1962). The mountain slope soils of Sevier County have been placed in the Ramsey series and are derived from quartzites, sandstones, and conglomerates (Hubbard et al. 1956). The lower slope soils have been classified as part of the Jefferson series and are predominately colluvial soils. Soil pH is acid to strongly acid and generally decreases with elevation but varies with vegetation type (Cain 1931, Golden 1981).

The climate of GRSM varies from mesothermal-humid at low elevations to microthermal-perhumid at high elevations (Shanks 1954). January temperatures range from a monthly mean of 4.4°C at 445 m to -1.8°C at 1919 m. July temperatures average 22.1°C at 445 m and 13.6°C at 1919 m (Stephens 1969). Maximum precipitation occurs in late winter and early spring with a secondary maximum in July. Minimum precipitation occurs in October. Precipitation increases with elevation (Stephens 1969).

CHAPTER I

THE PAST VEGETATION OF GREAT SMOKY MOUNTAINS NATIONAL PARK: CIRCA 1930

Introduction

GRSM has been the subject of numerous vegetation studies. DeYoung et al. (1982) indexed over 200 studies of the vegetation of GRSM. These studies have typically dealt with one component of the vegetation or with one location in the park. Many of these studies have involved the sampling of plots within the community of interest.

Stanley A. Cain was responsible for some of the earliest sampling with GRSM. These studies include research on Heath Balds (Cain 1930), the Spruce - Fir (Cain 1935) and Cove Hardwoods (Cain 1943). Oostings and Billings (1951) established a number of plots in their research of Spruce - Fir forests. Russell (1953) and Oh (1964) sampled Beech Gaps. Whittaker (1963) sampled and measured productivity in Heath Balds. Woods and Shanks (1959) sampled Oak - Chestnut forests in their study of *Castanea* replacement after the chestnut blight. DeYoung (1979) sampled White Pine - Hardwood vegetation in the western portion of GRSM.

The above studies represent a sampling of those involving particular vegetation types. Another level of sampling has occurred within GRSM that has involved sampling over larger regions. The classic among these studies is Whittaker's (1956) monograph of the vegetation of GRSM. Many people assume that Whittaker (1956) studied the entire GRSM landscape but a close examination of his methods reveal that "the bulk of site-samples were obtained from the mountains surrounding Greenbriar, Sugarland, and Cades Cove..." (Whittaker 1956). This suggests that Whittaker's results best describe the north-central to east-central portion of GRSM.

Harmon (1980) established a number of plots in the western portion of GRSM in his study of fire and site factors and their affect on vegetation pattern and process. Golden (1981) established a number of plots in the central portion of GRSM. His sampling included not only species information but also a number of site variables including various soil parameters. Callaway et al. (1987) performed an analysis similar, in many ways, to Golden (1981) but in the western portion of the park.

There is only one known sampling effort that has occurred across the entire GRSM landscape. During the establishment of GRSM as a National Park in the mid 1930's, the National Park Service hired Frank H. Miller as an Assistant Forester to conduct a vegetation survey of the proposed park area. The purpose of this study was to document the vegetation within the proposed park boundaries and to create a map of the vegetation types (Miller n.d., Miller 1941). Examination of Miller's notes (Miller n.d.) reveals that he used the data collected by his field crews qualitatively to identify the vegetation type represented by each plot. It is clear that Miller never analyzed the data in a quantitative fashion except to summarize stem counts. Upon completion of the vegetation map (Miller 1941), the original field sheets were placed in files and eventually deposited in the GRSM archives and seem to have been ignored until the late 1970's. At that time, Walker (1978) used some of Miller's original data to relocate and resample 31 Cove Hardwood plots. It was also around that time that the Science Division of GRSM initiated a project to convert Miller's raw data to digital form (US MAB 1982b) in the hopes of quantitatively analyzing the data.

This chapter describes the sampling methodology incorporated by Miller and his field crews and a subsequent analysis of his data that I performed approximately 50 years after its collection. There were a number of objectives to the research described in this chapter. These objectives were: 1) to complete the conversion of the Miller data to digital form and to document the structure of the resultant data sets, 2) to analyze the data using simple descriptive techniques and multivariate analysis (Gauch 1982), and 3) to develop coenoclines of species response to the environmental gradient developed using the multivariate analysis for integration into a gap model of forest succession for GRSM (see Chapter III).

Methods

Miller Methods

Miller and his field crews established 1378 rectangular (20 x 40 m) 0.08 ha plots within the park between 1935 and 1938. The locations of these plots were determined using: 1) random points within watersheds, 2) intersection of lines along a grid established on topographic maps, 3) points along transects, or 4) non-random placement along ecotones (Miller n.d.). It is important to note that the exact locations of most of these plots do not seem to have survived. GRSM has been in the process of trying to determine the locations of these plots through analysis of field notes and early maps of the park.

For each plot established by Miller and his crews, trees were identified to species and number of individuals per species was recorded for the following diameter at breast height (dbh) size classes: 1) 10 to < 30 cm, 2) 30 to < 60 cm, 3) 60 to < 91 cm, and 4) ≥ 91 cm. Brush and ground cover were recorded by determining the dominant species, measured using cover, in each of 100, 2 x 2 m subplots nested within the 0.08 ha plot. The following site parameters were also recorded: elevation; slope; aspect; soil depth, penetrability, and character; parent rock; and litter depth. A copy of one of Miller's data sheets can be found in Figures A-1 and A-2.

Quantitative Methods

The methods that follow represent analyses that I have performed on the data. The following equations were used to estimate basal area (*BA*) in meters squared per hectare for each species:

$$BA = 12.36 \sum N_S C_S \qquad \text{(I-1)}$$

where N_S is the number of stems in size class S, where $1 \leq S \leq 4$, and C_S is the conversion constant for size class S calculated as:

$$C_S = \frac{\pi}{4} \left[\frac{\sqrt{L_S U_S}}{100} \right]^2 \qquad \text{(I-2)}$$

where L_S and U_S are the lower and upper limits of size class S in centimeters, respectively. U_4 was set at 122 cm. These equations estimate basal area on the basis of the geometric mean of each size class. A species x plot primary matrix (Whittaker 1975) was constructed using the basal area data. Basal area was chosen as the measure of species importance in the following analyses because it has been shown to parallel biomass and productivity (Reiners 1972).

Species Distribution. Because Miller's crew sampled across the entire landscape, it is possible to make a crude reconstruction of species distribution by watershed. This analysis was performed by summarizing species dominance (BA) by watershed. Location of watershed geographic centroids (Ebdon 1977) were measured using an orthogonal coordinate system placed over a map of watershed boundaries with the x axis parallel to latitude (i.e., east - west) and the y axis parallel to longitude (i.e., north - south). Centroids were located in the context of a geographic information system (GIS). Pearson product-moment correlation coefficients between the latitudinal and longitudinal axes and species basal area were calculated using the CORR procedure of SAS (SAS Institute Inc. 1982a).

Classification. Classification of samples was performed using TWINSPAN (Hill 1979a). TWINSPAN, or two-way indicator species analysis, is a polythetic divisive classification technique which is an improvement upon the original indicator species analysis (Hill et al. 1975) in that species are classified as well as samples (Hill 1979a). Gauch (1982) recommends TWINSPAN for hierarchical classification because of its effectiveness and robustness. Another advantage of TWINSPAN over other classification techniques is that it allows the researcher to develop a key to the vegetation types based on indicator species.

Gradient Analysis. Indirect gradient analysis was performed using DECORANA (Hill 1979b), or detrended correspondence analysis, which is derived from correspondence analysis (also known as reciprocal averaging) (Hill 1973). Detrended correspondence analysis is an improvement upon correspondence analysis in that it eliminates the arch or "horseshoe" effect due to the quadratic dependency of the second ordination axis on the first and it does not compress the ends of the ordination axes (Hill 1979b, Gauch 1982, Hill and Gauch 1982).

Simple single variable linear regression was performed using the four continuous variables in the Miller data (soil depth, litter depth, slope, and elevation) as independent variables and the first and second axis DECORANA ordination scores as the dependent variables. The regressions were performed using the GLM procedure of SAS (SAS Institute Inc. 1982b). Regression was performed in an attempt to further interpret the ordination output.

Gaussian curve fitting was performed using CEP12 of the Cornell Ecology Programs (Gauch 1973) to show species responses to the plot sequence determined by DECORANA. CEP12 plots sample ordination scores on the abscissa against the species response values (basal area in this study) and uses a least squares algorithm to fit a Gaussian curve to these points that accounts for the most variance with the least amount of displacement (Gauch and Whittaker 1972).

Results and Discussion

Summarization

All of the data contained in the original Miller field notes were converted to digital format and placed in two SAS data sets (SAS Institute Inc. 1982a). The first data set contains information pertaining to species, by plot. The second contains the environmental or site data for every plot. Documentation for these data can be found in Appendix A.

Of the 1378 plots sampled by Miller and his crews, 950 had a total BA $\geq$ 8.0 and $\leq$ 110.0 m^2/ha. Plots with a total BA $<$ 8.0 m^2/ha (421 plots) were typically fields or areas that had been recently clearcut and/or burned. These plots were considered non-forested and were not included in further analyses. Plots with a total BA $>$ 110.0 m^2/ha (7 plots) were considered as outliers in the data set. A number of analyses performed with these plots included in the data set (e.g., DECORANA and TWINSPAN) produced spurious results. These plots were therefore not included in further analyses. It is important to note that the results discussed below pertain only to the 950 plots considered forested. Figure I-1 shows the distribution of the 950 plots used in this study by management watershed within GRSM. The management watershed boundaries are those currently being used by the Science and Resources Management Division of GRSM (Peine at al. 1985). Note that these management watersheds are different from the hydrologic watershed described by Parker and Pipes (1990). The reason for the high sampling intensity (226 plots) in the Cataloochee watershed is not known but may be due to the fact that this was the first watershed sampled (Miller n.d.). The low sampling

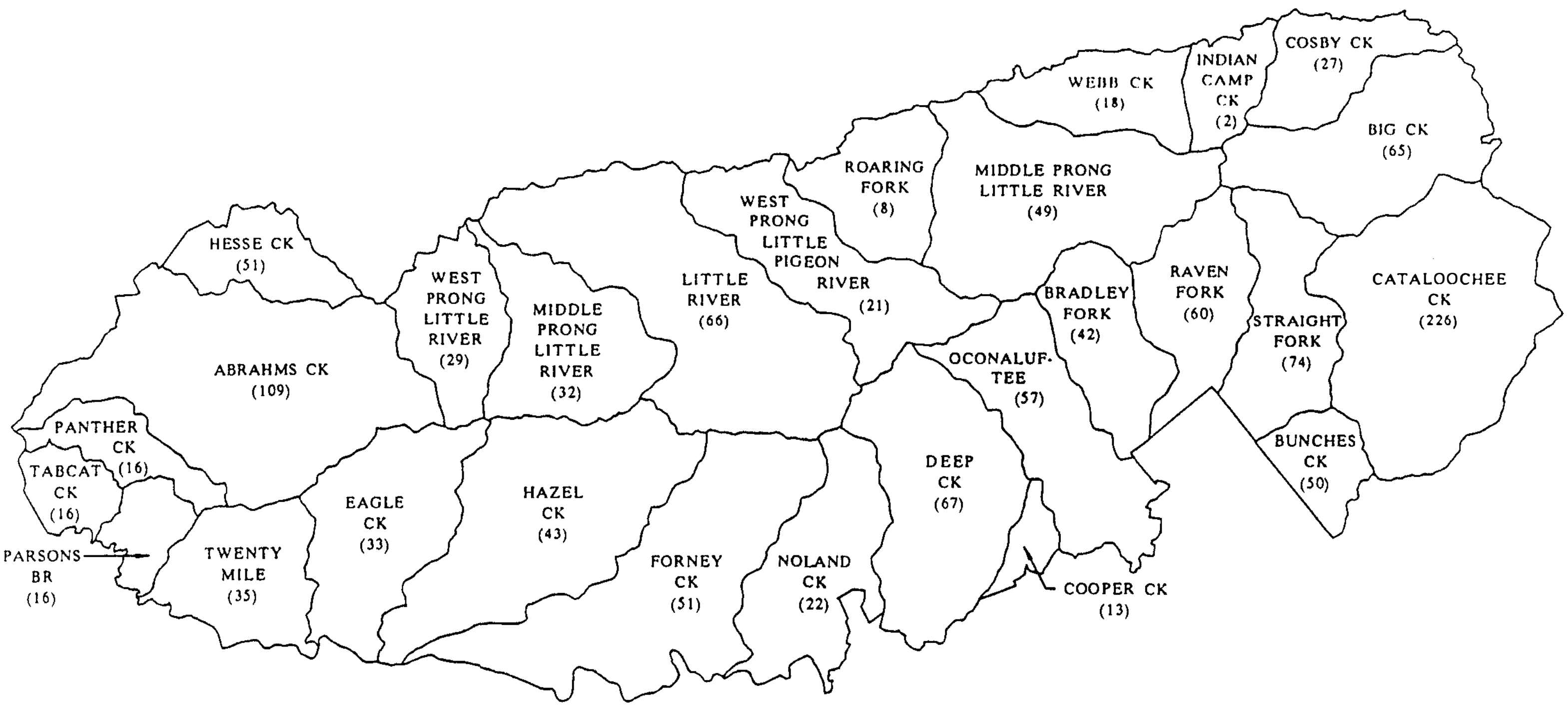


Figure I-1. Number of plots by management watershed.

intensity in the Indian Camp Creek watershed is partially due to the fact that Miller did not recognize this area as a separate watershed.

Miller and his crews measured 20500 live trees. They identified 55 species (Table I-1). At the time of their sampling, *Castanea dentata*[1] was the dominant species in GRSM in terms of both BA and density (Table I-1). Other important species in GRSM, as a whole, included *Tsuga canadensis*, *Picea rubens*, *Betula lutea*, *Quercus prinus*, *Q. rubra*, and *Fagus grandifolia*.

The importance of *Castanea dentata* in the GRSM landscape at the time of the Miller field sampling is significant in light of the fact that the chestnut blight was estimated to have become established in GRSM between 1925 and 1926 (Woods and Shanks 1957). During the time of his field work, Miller (1938) indicated "that fully 85% of the chestnut in the park has been killed or is affected by the blight." Even with the wide spread death of *Castanea dentata* due to the blight, it was still the dominant species in GRSM. Ayres and Ashe (1905) estimated that *Castanea dentata* comprised up to 30-40% of the forest cover in various portions of GRSM. Others have studied the significance of the loss of *Castanea dentata* due to the blight and subsequent recovery patterns (Nelson 1955; Woods and Shanks 1957, 1959; Arrends 1981).

Species Distribution

Of the 55 species sampled, 22 had significant ($p \leq 0.05$) correlations to the watershed centroid UTM coordinates (Table I-2). *Castanea dentata* (Figure I-2A) is an example of a species that was more dominant in the southern portion of GRSM. *Tsuga canadensis* (Figure I-2B) showed a greater dominance to the east while *Pinus rigida* (Figure I-2C) had a greater

[1]Nomenclature, unless otherwise indicated, follows White (1982).

Table I-1. Species summary statistics for the whole park. All values, except frequency and minimum basal area and density, have been calculated assuming n = 950. If a species did not occur in a plot, its basal area and density were set to zero. Frequency represents the number of plots in which the species was present. Minimum basal area and density are non-zero minimums.

			Basal Area (m^2/ha)				Density (stems/ha)			
Species	Code	Freq	Mean	SD	Min	Max	Mean	SD	Min	Max
Abies fraseri	ABSFRS	67	0.62	4.15	0.28	67.94	16.58	133.42	12	3050
Acer pensylvanica	ACRPNS	20	0.01	0.10	0.28	1.65	0.51	4.29	12	74
Acer rubrum	ACRRBR	264	0.73	2.05	0.28	23.20	8.56	20.53	12	259
Acer saccharum	ACRSCR	133	0.58	2.06	0.28	24.05	4.48	14.67	12	148
Acer spicatum	ACRSPC	8	0.01	0.07	0.28	1.38	0.24	3.17	12	61
Aesculus octandra	ASLOCT	107	0.60	2.80	0.28	38.44	3.70	14.22	12	172
Amelanchier laevis	AMLLVS	56	0.04	0.22	0.28	2.75	1.30	6.82	12	123
Betula lenta	BTLLNT	142	0.52	2.35	0.28	37.26	5.47	18.50	12	234
Betula lutea	BTLLUT	267	1.96	4.71	0.28	44.31	16.72	35.84	12	234
Carya cordiformis	CRYCRD	3	0.02	0.29	4.00	5.80	0.12	2.14	24	49
Carya glabra	CRYGLB	79	0.21	1.09	0.28	17.97	3.20	14.08	12	148
Carya ovata	CRYOVT	8	0.02	0.25	0.28	5.25	0.27	3.78	12	86
Carya tomentosa	CRYTMN	98	0.25	1.13	0.28	15.74	3.73	14.45	12	185
Castanea dentata	CSTDNT	416	4.05	7.39	0.28	59.91	32.92	56.40	12	395
Cladastrus kentuckea	CLDKNT	3	0.01	0.19	0.28	5.46	0.08	1.68	12	49
Cornus florida	CRNFLR	43	0.02	0.10	0.28	1.38	0.85	4.54	12	61
Diospyrus virginiana	DSPVRG	1	0.00	0.04	1.10	1.10	0.05	1.59	49	49
Fagus grandifolia	FGSGRN	206	1.04	3.13	0.28	34.32	21.99	63.75	12	543
Fraxinus americana	FRXAMR	53	0.10	0.72	0.28	13.36	1.04	4.93	12	61
Halesia carolina	HLSCRL	182	0.41	1.58	0.28	21.90	8.29	24.26	12	234
Hydrangea arborescens	HYDARB	1	0.00	0.01	0.28	0.28	0.01	0.39	12	12
Ilex montana	ILXMNT	3	0.01	0.13	1.10	3.45	0.14	2.65	24	61
Ilex opaca	ILXOPC	2	0.00	0.03	0.55	0.55	0.05	1.10	24	24
Juglens cineria	JGLCNR	10	0.01	0.16	0.28	3.73	0.31	3.97	12	98
Juglens nigra	JGLNGR	3	0.00	0.08	0.83	1.73	0.06	1.32	12	37
Kalmia latifolia	KLMLTF	4	0.01	0.23	0.28	6.88	0.43	10.29	12	308
Liquidambar styraciflua	LQDSTY	1	0.00	0.01	0.28	0.28	0.01	0.39	12	12
Liriodendron tulipifera	LRDTLP	112	0.55	2.26	0.28	23.80	6.58	32.38	12	481
Magnolia acuminata	MGNACM	36	0.08	0.61	0.28	11.54	0.82	5.28	12	98
Magnolia fraseri	MGNFRS	55	0.09	0.64	0.28	10.78	1.61	8.83	12	98
Nyssa sylvatica	NYSSYL	108	0.23	1.06	0.28	13.96	2.35	8.13	12	98
Ostrya virginiana	OSTVRG	9	0.01	0.23	0.28	6.83	0.23	3.82	12	111
Oxydendron arboreum	OXYARB	114	0.08	0.28	0.28	2.75	3.12	11.25	12	123
Picea rubens	PICRBN	141	2.73	9.89	0.28	94.74	18.95	60.85	12	494
Pinus echinata	PNSECH	4	0.01	0.12	0.83	2.00	0.11	1.80	24	37
Pinus pugens	PNSPNG	10	0.04	0.49	0.28	11.19	0.59	6.95	12	123
Pinus rigida	PNSRGD	116	0.73	2.55	0.28	20.85	12.98	45.90	12	469
Pinus strobus	PNSSTB	54	0.33	2.02	0.28	28.40	2.89	15.96	12	172
Pinus virginiana	PNSVRG	63	0.31	1.42	0.28	13.19	6.35	29.19	12	407
Prunus pensylvanica	PRNPNS	32	0.06	0.47	0.28	7.15	2.39	20.23	12	321
Prunus serotina	PRNSRT	29	0.08	0.69	0.28	10.51	0.49	3.27	12	61
Quercus alba	QRCALB	145	0.58	2.11	0.28	29.33	6.92	22.64	12	284

Table I-1 (continued)

			Basal Area (m^2/ha)				Density (stems/ha)			
Species	Code	Freq	Mean	SD	Min	Max	Mean	SD	Min	Max
Quercus coccinea	QRCCCC	144	0.33	1.29	0.28	16.31	6.13	17.66	12	135
Quercus marilandica	QRCMRL	4	0.01	0.20	0.28	5.53	0.12	1.91	12	37
Quercus prinus	QRCPRN	296	1.56	3.27	0.28	18.24	14.01	27.72	12	222
Quercus rubra	QRCRBR	279	1.44	4.27	0.28	64.71	12.55	28.00	12	197
Quercus velutina	QRCVLT	107	0.21	0.86	0.28	7.93	3.27	12.02	12	160
Rhododendron arborescens	RHDARB	1	0.00	0.04	1.10	1.10	0.05	1.59	49	49
Rhododendron maximum	RHDMXM	6	0.01	0.25	0.28	6.05	0.65	11.09	12	271
Robinia psuedoacacia	RBNPSD	163	0.22	0.93	0.28	18.92	5.11	16.88	12	197
Sassafras albidum	SSSALB	16	0.02	0.26	0.28	7.43	0.76	11.50	12	333
Sorbus americana	SRBAMR	8	0.01	0.10	0.28	2.00	0.18	2.30	12	49
Tilia heterophlya	TILHTR	127	0.70	2.57	0.28	35.52	7.21	23.62	12	234
Tsuga canadensis	TSGCND	232	3.48	10.40	0.28	84.89	16.86	44.97	12	382
Ulmus americana	ULMAMR	1	0.00	0.01	0.28	0.28	0.01	0.39	12	12

Table 1-2. Significant ($p \leq 0.05$) species correlations coefficients to management watershed spatial centroids (UTM Easting and Northing).

Species	Easting[1]	Northing[2]
Acer pensylvanica	-0.532	
Acer rubrum		-0.426
Acer saccharum	-0.568	
Amelanchier laevis		-0.402
Aesculus octandra	-0.602	
Betula lenta	-0.421	
Betula lutea	-0.564	
Carya ovata	-0.409	
Cary tomentosa	-0.646	
Castanea dentata		-0.722
Fagus grandifolia	-0.399	
Halesia carolina	-0.696	
Magnolia fraseri	-0.383	
Nyssa sylvatica		-0.498
Pinus rigida	0.714	0.405
Pinus strobus	0.408	
Pinus virginiana	0.665	
Quercus alba	0.377	-0.413
Quercus coccinea	0.626	
Querucs rubra		-0.607
Tilia heterophylla	-0.566	
Tsuga canadensis	-0.570	

[1]A negative correlation coefficient indicates an increase to the East.
[2]A negative correlation coefficient indicates an increase to the South.

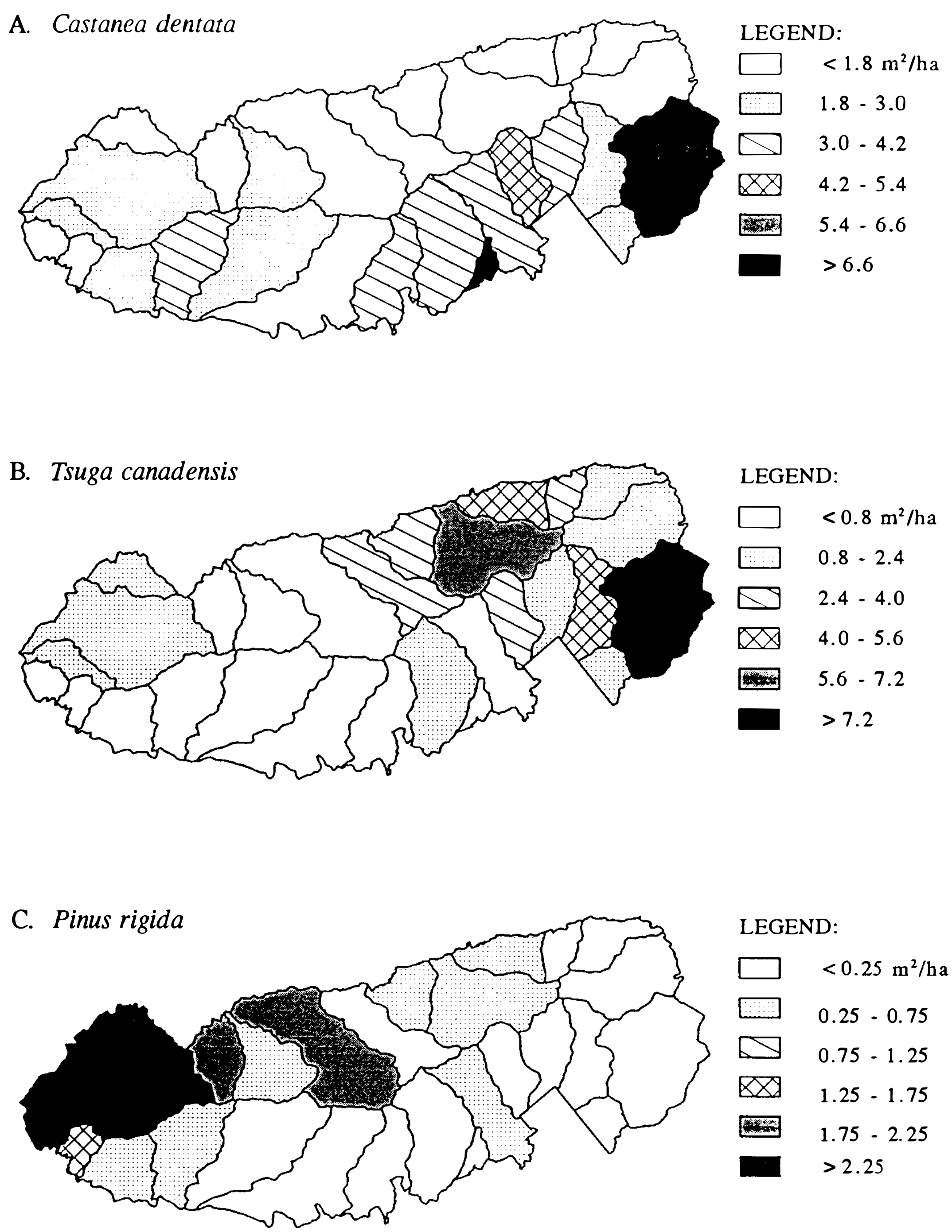


Figure I-2. Mean basal area by management watershed.

dominance to the northwest. The Miller data set is the first to provide researchers with an opportunity to analyze species abundance or importance across the entire GRSM landscape.

Classification

TWINSPAN classification results were interpreted to produce 16 vegetation types (Table I-3). These types have been named using the dominant species, based on BA, and, in most cases, one or two subdominant species (Table I-4). These vegetation types ranged from the dry site *Pinus* types to the mesic *Castanea*, *Tsuga*, and *Tilia* types to the high elevation *Picea* and *Abies* types. Figure I-3 is a dendrogram and key to the types based on indicator species derived from TWINSPAN.

The sequence of types in Table I-3 and Figure I-3 has been ordered relative to ordination results (see Ordination below). Figure I-4 illustrates the trend of increased mean elevation for each classification type along the ordination sequence. A similar trend, though not as strong, is apparent in litter depth (Figure I-5) except for a marked reduction in depth in the high elevation *Abies fraseri* type. Percent slope and soil depth (Figures I-6 and I-7) do not exhibit such trends and are extremely variable within classification type.

Table I-5 compares the classification results presented in this study with of Miller (1938), based on his qualitative interpretation of the field data, Whittaker (1956), Golden (1981) and Callaway et al. (1987). A number of interesting observations are apparent in this comparison. First, Miller's (1938) classification is relatively generic when compared to the others. Second, none of the previous classifications adequately describes, *in toto*, the vegetation types identified using the Miller data. Each of the previous classifications (with the exception of the Miller classification) is unable to adequately describe the total vegetation of GRSM due to their limited geographic scope. This is even true of Whittaker's (1956) classification which,

Table I-3. Descriptive statistics for TWINSPAN classification types.

TWINSPAN Classification Type			No. of Samples	Basal Area (m^2/ha)		Density (stems/ha)	
Dominant	Subdominant(s)	Code		Mean	SD	Mean	SD
Pinus rigida		0	39	14.2	4.6	274.4	111.3
Pinus virginiana	*Pinus rigida*	1	54	16.1	6.6	264.3	99.0
Quercus alba	*Quercus coccinea* *Pinus virginiana*	2	17	13.8	5.4	224.0	63.0
Pinus strobus	*Quercus alba* *Pinus rigida*	3	20	18.1	8.2	279.0	83.8
Pinus strobus	*Quercus alba*	4	17	24.6	9.7	262.7	94.1
Quercus alba	*Castanea dentata* *Quercus prinus*	5	57	18.0	9.2	214.7	92.1
Castanea dentata	*Quercus prinus*	6	219	20.9	12.0	214.1	104.6
Castanea dentata	*Quercus rubra*	7	121	24.4	13.9	230.2	121.9
Tsuga canadensis	*Liriodendron tulipifera*	8	63	25.0	18.4	259.8	118.5
Tsuga canadensis	*Betula lutea*	9	112	35.0	21.6	279.8	147.3
Tilia heterophylla	*Aesculus octandra* *Acer saccharum*	10	58	27.0	14.3	252.5	109.5
Fagus grandifolia	*Betula lutea*	11	60	27.7	13.4	322.7	135.4
Betula lutea	*Picea rubens*	12	40	28.1	12.2	326.8	200.9
Picea rubens	*Tsuga candensis* *Betula lutea*	13	22	41.5	27.2	278.1	170.4
Picea rubens	*Abies fraseri* *Betula lutea*	14	46	41.6	22.7	398.0	311.1
Abies fraseri		15	5	43.0	25.0	1234.2	1099.3

Table I-4. Species mean basal area (m^2/ha) by TWINSPAN classification type.

	TWINSPAN Classification Type[1]															
Species	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Abies fraseri	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.36	0.38	7.08	40.86
Acer pensylvanica	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.03	0.06	0.00	0.03	0.00	0.00	0.00
Acer rubrum	0.02	0.06	0.11	0.27	0.93	0.41	1.27	0.33	0.50	2.13	0.05	0.45	0.68	0.00	0.00	0.00
Acer saccharum	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.26	0.53	0.35	3.65	3.84	0.05	0.00	0.00	0.00
Acer spicatum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.06	0.00	0.04	0.00
Aesculus octandra	0.00	0.00	0.02	0.00	0.00	0.00	0.02	0.06	0.00	0.09	0.00	0.15	0.21	0.06	0.01	0.00
Amelanchier laevis	0.00	0.00	0.00	0.00	0.12	0.00	0.04	0.08	1.04	0.02	4.03	3.75	0.61	0.00	0.00	0.00
Betula lenta	0.00	0.00	0.00	0.00	0.00	0.04	0.10	0.23	0.74	2.39	0.54	0.59	0.47	0.33	0.75	0.00
Betula lutea	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.26	1.87	4.25	2.23	5.61	11.98	4.48	4.02	0.06
Carya cordiformis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.00	0.00	0.00	0.00	0.00
Carya glabra	0.00	0.01	0.00	0.10	0.05	0.09	0.03	0.00	0.03	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Carya ovata	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Carya tomentosa	0.00	0.05	0.00	0.31	1.34	1.30	0.28	0.26	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Castanea dentata	0.00	0.03	0.00	0.00	0.00	0.05	0.04	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cladastrus kentuckea	0.15	0.34	0.66	0.00	1.43	1.50	0.23	0.33	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00
Cornus florida	0.23	1.77	0.85	0.06	1.46	2.98	8.89	11.28	0.69	0.92	0.52	0.80	0.00	0.00	0.00	0.00
Diospyrus virginiana	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fagus grandifolia	0.00	0.00	0.00	0.00	0.35	0.00	0.01	0.18	0.39	2.16	2.00	8.24	1.85	0.16	0.06	0.06
Fraxinus americana	0.00	0.00	0.00	0.00	0.12	0.01	0.01	0.10	0.60	0.00	0.72	0.06	0.00	0.00	0.00	0.00
Halesia carolina	0.00	0.00	0.00	0.00	0.18	0.00	0.13	0.32	0.58	0.98	1.75	1.16	0.01	0.00	0.00	0.00
Hydrangea arborescens	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ilex montana	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.05	0.00	0.00
Ilex opaca	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Juglens cineria	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.05	0.05	0.00	0.02	0.00	0.00	0.00	0.00	0.00
Juglens nigra	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Kalmia latifolia	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00
Liquidambar styraciflua	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Liriodendron tulipifera	0.00	0.00	0.22	0.30	1.88	1.71	0.37	0.28	3.66	0.20	0.28	0.00	0.00	0.00	0.00	0.00
Magnolia acuminata	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.18	0.16	0.19	0.10	0.00	0.00	0.00	0.00	0.00
Magnolia fraseri	0.00	0.00	0.02	0.00	0.00	0.00	0.03	0.06	0.13	0.57	0.04	0.00	0.00	0.00	0.00	0.00

Table I-4 (continued)

Species	TWINSPAN Classification Type[1]															
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Nyssa sylvatica	0.15	0.24	0.37	0.40	0.10	0.28	0.72	0.02	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00
Ostrya virginiana	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.05	0.00	0.00	0.00	0.00	0.00
Oxydendron arboreum	0.01	0.03	0.10	0.48	0.20	0.25	0.18	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00
Picea rubens	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.32	1.21	0.17	0.95	10.24	26.80	29.58	1.44
Pinus echinata	0.00	0.09	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pinus pugens	0.11	0.54	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pinus rigida	10.45	3.60	0.90	2.48	0.00	0.04	0.11	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pinus strobus	0.26	0.17	0.41	6.80	6.86	0.39	0.05	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00
Pinus virginiana	1.16	3.68	1.16	0.89	0.78	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Prunus pensylvanica	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.23	0.16	0.12	0.12	0.13	0.01	0.00
Prunus serotina	0.00	0.00	0.00	0.00	0.00	0.10	0.04	0.05	0.06	0.02	0.46	0.41	0.03	0.00	0.00	0.00
Quercus alba	0.17	0.16	3.66	2.98	4.05	3.16	0.35	0.67	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00
Quercus coccinea	0.75	1.40	2.94	1.37	0.00	0.87	0.36	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Quercus marilandica	0.22	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Quercus prinus	0.46	2.89	1.06	0.03	0.32	2.29	4.95	0.51	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Quercus rubra	0.03	0.28	0.05	0.53	1.70	0.92	1.37	7.47	0.19	0.14	0.35	0.14	0.06	0.00	0.00	0.00
Quercus velutina	0.10	0.70	0.98	0.77	0.00	1.06	0.23	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rhododendron arborescens	0.01	0.11	0.23	0.03	0.57	0.33	0.27	0.66	0.35	0.07	0.04	0.04	0.00	0.00	0.00	0.00
Rhododendron maximum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Robinia psuedoacacia	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.07	0.02	0.00	0.00	0.00	0.00	0.00	0.00
Sassafras albidum	0.00	0.00	0.00	0.04	0.00	0.04	0.01	0.01	0.01	0.08	0.00	0.00	0.00	0.00	0.00	0.00
Sorbus americana	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.03	0.62
Tilia heterophlya	0.00	0.00	0.00	0.00	0.00	0.03	0.02	0.39	2.44	0.28	7.03	0.35	0.00	0.00	0.00	0.00
Tsuga canadensis	0.00	0.00	0.00	0.11	2.20	0.14	0.59	0.02	10.43	18.29	2.50	1.07	0.31	9.14	0.00	0.00
Ulmus americana	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Number of plots	39	54	17	20	17	57	219	121	63	112	58	60	40	22	46	5

[1]TWINSPAN classification type codes are those found in table I-3.

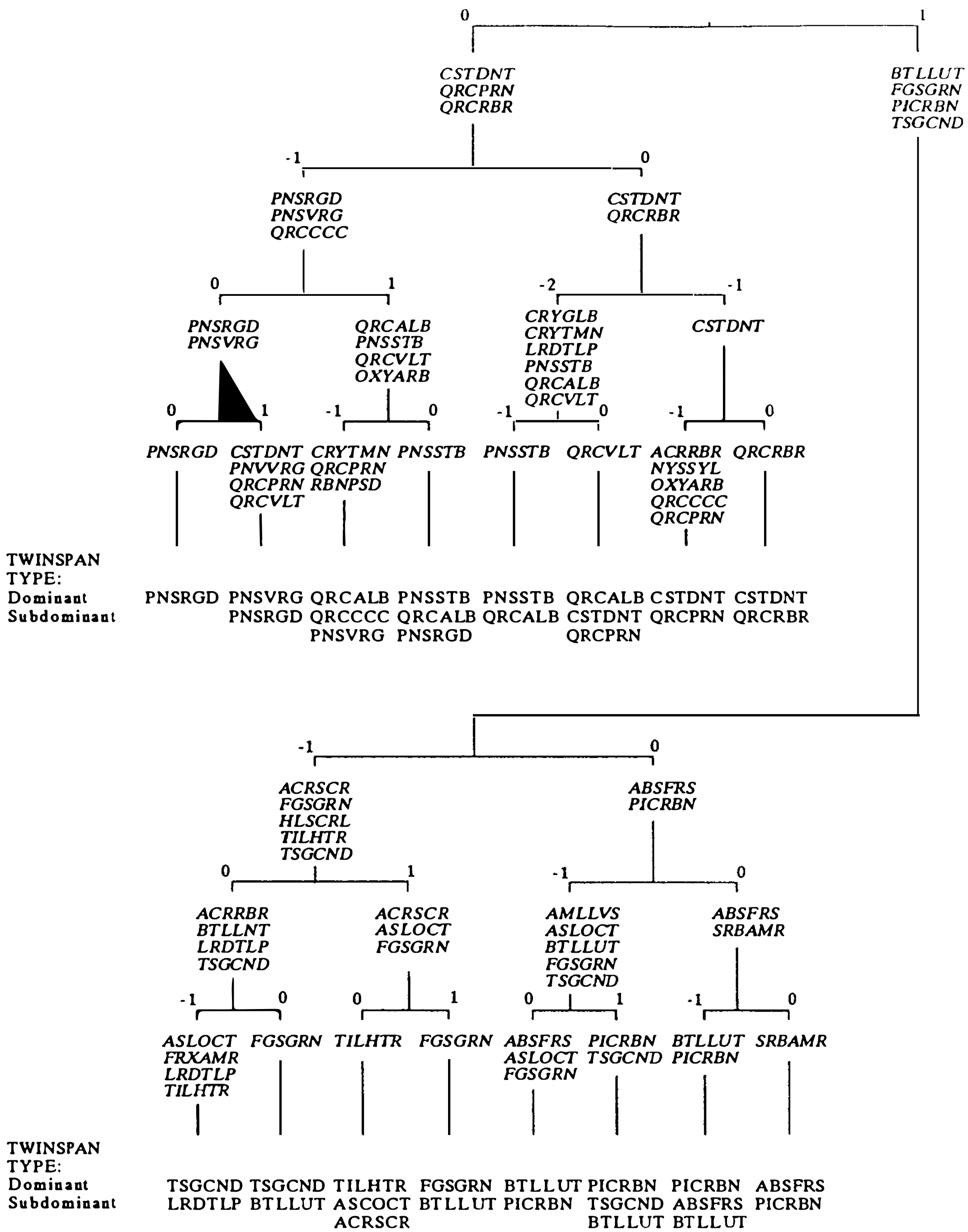


Figure I-3. TWINSPAN classification dendrogram with indicator species. Species codes (see Table I-1) in italics represent indicator species. Numbers are the indicator scores. Using this figure, a plot can be classified using the methodology described in Hill (1979a).

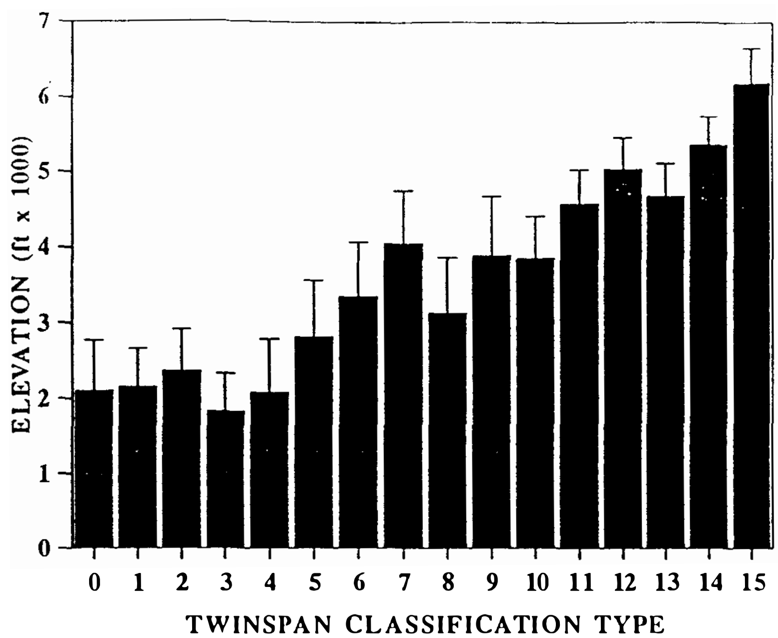


Figure I-4. Mean elevation by TWINSPAN classification type. Refer to Table I-3 for type codes.

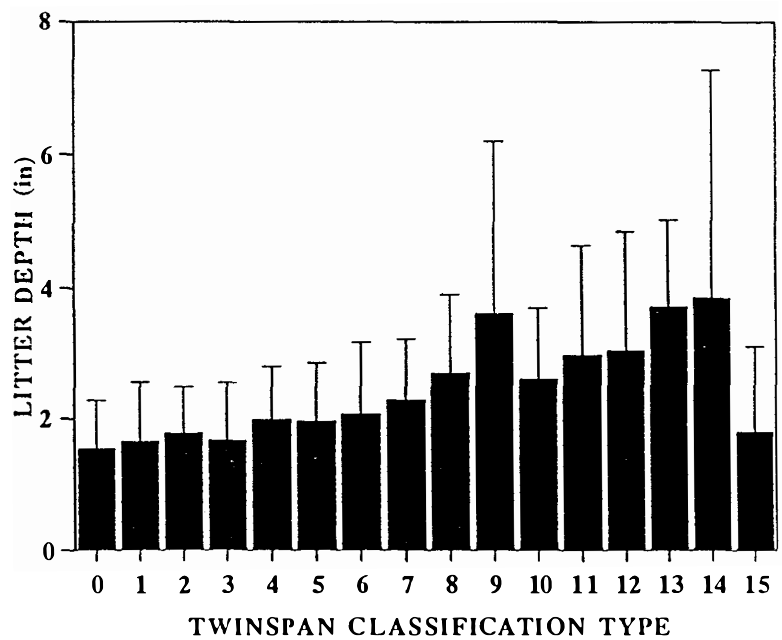


Figure I-5. Mean litter depth by TWINSPAN classification type. Refer to Table I-3 for type codes.

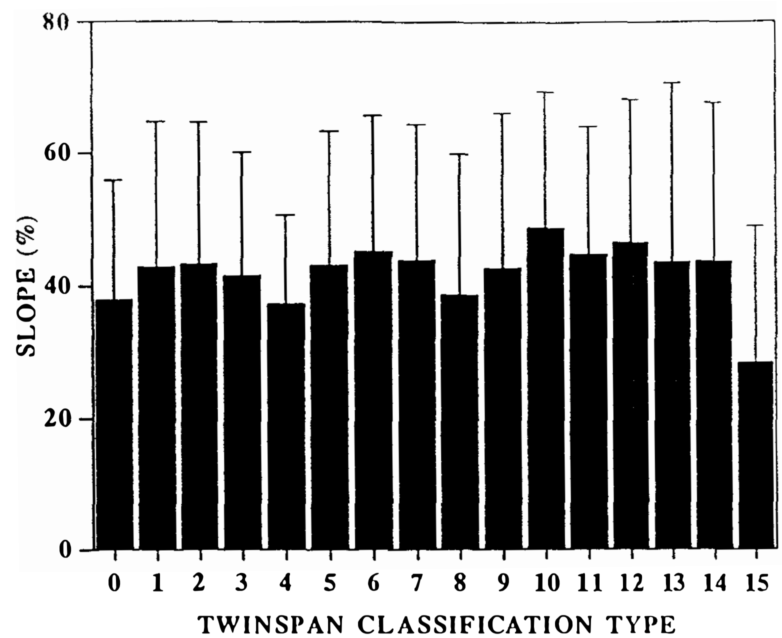


Figure I-6. Mean slope by TWINSPAN classification type. Refer to Table I-3 for type codes.

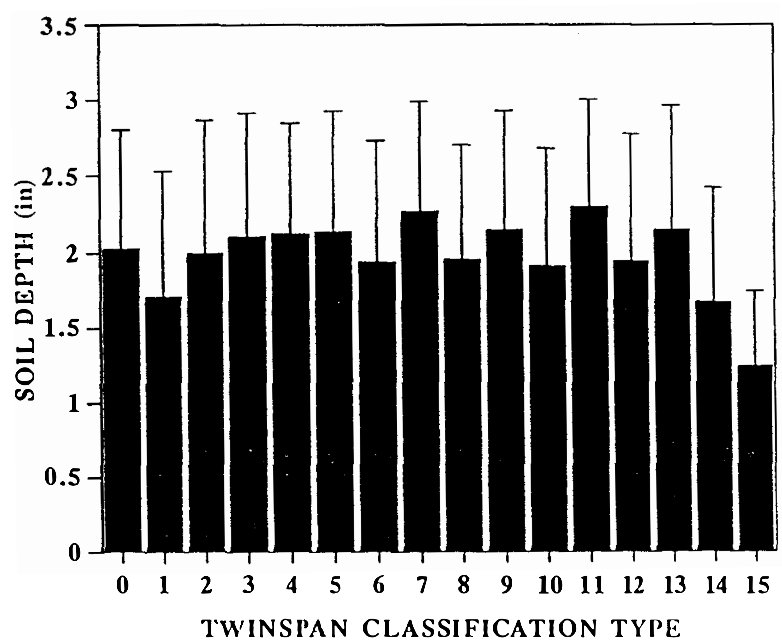


Table I-7. Mean soil depth by TWINSPAN classification type. Refer to Table I-3 for type codes.

Table I-5. Comparison of GRSM classifications.

This study	Miller (1938)	Whittaker (1956)	Golden (1981)	Callaway et al. (1987)
PNSRGD	Yellow Pine	(No equivalent)	(No equivalent)	Yellow Pine
PRNVRG-PNSRGD	Yellow Pine	Virginia Pine	(No equivalent)	Yellow Pine
QRCALB-QRCCCC	Oak-Chestnut	White Oak-Chestnut	(No equivalent)	White Oak-White Pine
PNSSTB-QRCALB, PNSRGD	White Pine-Hardwood	(No equivalent)	(No equivalent)	White Oak-White Pine
PNSSTB-QRCALB	White Pine-Hardwood	(No equivalent)	(No equivalent)	White Oak-White Pine
QRCALB-CSTDNT	Oak-Chestnut	White Oak-Chestnut	(No equivalent)	(No equivalent)
CSTDNT-QRCPRN	Oak-Chestnut	Chestnut Oak-Chestnut	Chestnut Oak	Chestnut Oak
CSTDNT-QRCRBR	Oak-Chestnut	Red Oak-Chestnut	Northern Red Oak	Northern Red Oak
TSGCND-LRDTLP	Hemlock	Eastern Hemlock	Hemlock	Hemlock-Yellow Poplar
TSGCND-BTLLUT	Hemlock	Eastern Hemlock	Hemlock-Red Maple	Hemlock-Silverbell-Beech
TILHTR-ASCOCT	Cove Hardwood	Cove Hardwood	Cove Hardwood	Basswood-Buckeye
FGSGRN-BTLLUT	Northern Hardwood	Gray Beech	Beech	Beech
BTLLUT-PICRBN	Northern Hardwood	Red Spruce	Yellow Birch-Spruce	(No equivalent)
PICRBN-TSGCND	Spruce	Red Spruce	(No equivalent)	(No equivalent)
PICRBN-ABSFRS	Spruce	Red Spruce	(No equivalent)	(No equivalent)
ABSFRS	Spruce	Fraser Fir	(No equivalent)	(No equivalent)

while sampling range was limited, was interpreted to represent the vegetation of GRSM as a whole.

The weaknesses of the sampling efforts that have concentrated on the central portion of GRSM (Whittaker 1956, Golden 1981) are apparent in the their inability to adequately describe the *Pinus rigida* forests of the western portion of the park. Whittaker (1956) recognizes a Pitch Pine - Heath type in his classification. While both his Pitch Pine - Heath type and the *Pinus rigida* type of this study are dominated by *P. rigida*, *Kalmia latifolia*, a major component of Whittaker's Pitch Pine - Heath type does not occur in the *Pinus rigida* type of this study (Table I-4). Golden (1981) indicates that *P. pungens* is a typical subdominant in his Pitch Pine type. *P. pungens* occurs only rarely in the *Pinus rigida* type of this study. It is suggested that the pine types described by Whittaker (1956) and Golden (1981) are more characteristic of those found at higher elevations in the central portion of GRSM relative to those found in the western portion of the park. The Yellow Pine type described by Callaway et al. (1987) is better related to the *Pinus rigida* type of this study. The *Pinus virginiana - Pinus rigida* type of this study is analogous to Whittaker's (1956) Virginia Pine type but has no analog in Golden's (1981) scheme.

The *Quercus alba - Quercus coccinea, Pinus virginiana* type of this study is best compared to the White Oak - White Pine type of Callaway et al. (1987). The type is considered a dry site variant of the Oak - Chestnut of Miller (1938) and of the White Oak - Chestnut type of Whittaker (1956). There is no analog in Golden (1981).

The *Pinus strobus - Quercus alba, Pinus rigida* and *Pinus strobus - Quercus alba* types of this study are analogous to Millers (1938) White Pine - Hardwood and Callaway et al.'s (1987) White Oak - White Pine type. Whittaker (1956) and Golden (1981) do not recognize *Pinus strobus* dominated types.

The three types of this study dominated by *Castanea dentata* (*Quercus alba* - *Castanea dentata*, *Castanea dentata* - *Quercus prinus*, and *Castanea dentata* - *Quercus rubra*) represent variants of Millers (1938) Oak - Chestnut type. The *Quercus alba* - *Castanea dentata* type of this study is represented by the White Oak - Chestnut type of Whittaker (1956). There are no analogs in either Golden (1981) or Callaway et al. (1987) though the type could be considered a variant of the White Oak - White Pine type.

The *Castanea dentata*, *Tsuga canadensis*, *Tilia heterophylla*, and *Fagus grandifolia* types of this study all have analogs in the other classifications. Callaway et al. (1987) did not sample sites high enough to include *Picea rubens* and *Abies fraseri.* Therefore, the high elevation types of this study are not represented on Callaway et al.'s (1987) classification. Golden (1981) did not sample at the higher elevations of GRSM and does not include any *Picea rubens* or *Abies fraseri* dominated types though he does indicate the presence of these species in his Yellow Birch - Spruce type. Miller (1938) considered all of the high elevation samples as belonging to a Spruce type. The *Abies fraseri* type of this study represents a high elevation variant of his Spruce type. Whittaker (1956), on the other hand, did recognize a separate Fraser Fir forest.

Ordination

The order of species on the first axis of the DECORANA ordination (Figure I-8) suggests that this axis represents a moisture-elevation gradient. Dry site species, including various species of *Pinus*, *Quercus marilandica*, and *Q. coccinea*, were found at one end of the gradient. Mesic species, including *Aesculus octandra*, *Acer saccharum*, *Fagus grandifolia*, and *Tsuga canadensis*, were found in the middle of the gradient. The high elevation species *Abies fraseri*, *Picea rubens*, and *Sorbus americana* were found at the opposite end of the gradient.

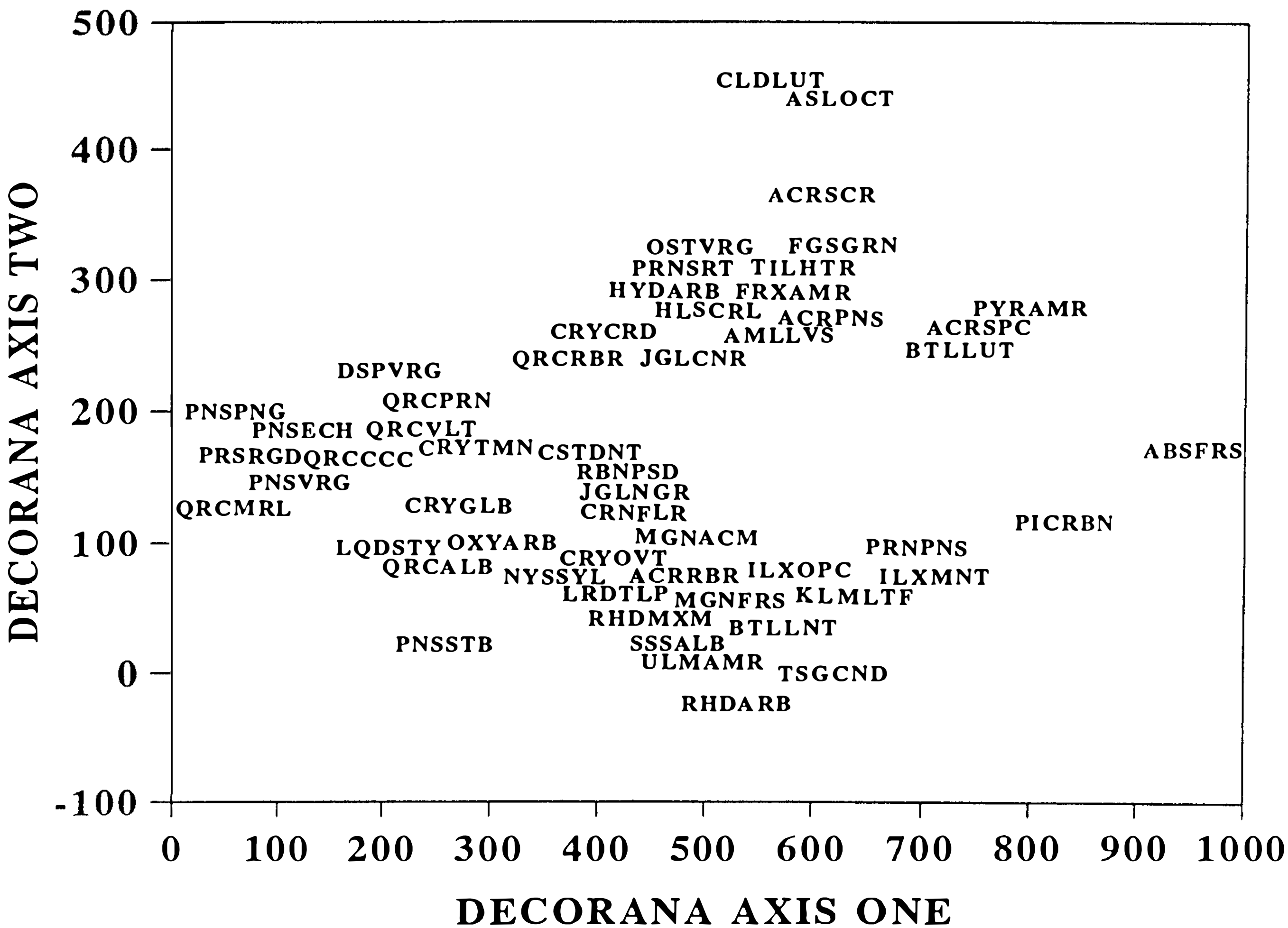


Figure I-8. DECORANA species ordination, axes one and two. See Table I-1 for species codes.

The regression analysis supports the contention that elevation is a critical component of the gradient. The regression of elevation with DECORANA first axis sample ordination scores (Figure I-9) yielded an F value significant at the $p < 0.0001$ level and a coefficient of determination (r^2) value of 0.49. None of the remaining regressions of either the first or second ordination axes yielded significant ($p < 0.01$) values. That elevation accounts for only 49% of the variance in the first axis sample ordination scores indicates that the ordination gradient is not strictly an elevation gradient. Because there was no direct measure of site moisture in the Miller data, the moisture-elevation complex gradient is inferred indirectly based on species ordination scores.

The order of species and vegetation types of second and higher DECORANA axes were uninterpretable. Callaway et al. (1987), in their ordination of samples in the western portion of GRSM, indicate that their second ordination axis was related to site protection. Their site protection index was derived as a function of distance to and elevation of nearby landforms of greater elevation. The generation of a site protection index for the Miller data was not possible due to the lack of requisite site location information.

Group centroids of the 16 vegetation types for DECORANA axes one and two are shown in Figure I-10. Eigenvalues for the first four DECORANA axes were 0.90, 0.53, 0.50, and 0.40, respectively.

Gaussian curve fitting using the first axis ordination scores produced coenoclines (Figures I-11 and I-12) which closely replicate species sequence as found in the species ordination (Figure I-6). The advantage of representation of species response along a coenocline is not only position of maximum response (i.e., basal area) but the magnitude and amplitude of the response are also illustrated. The equations derived from these coenoclines are an

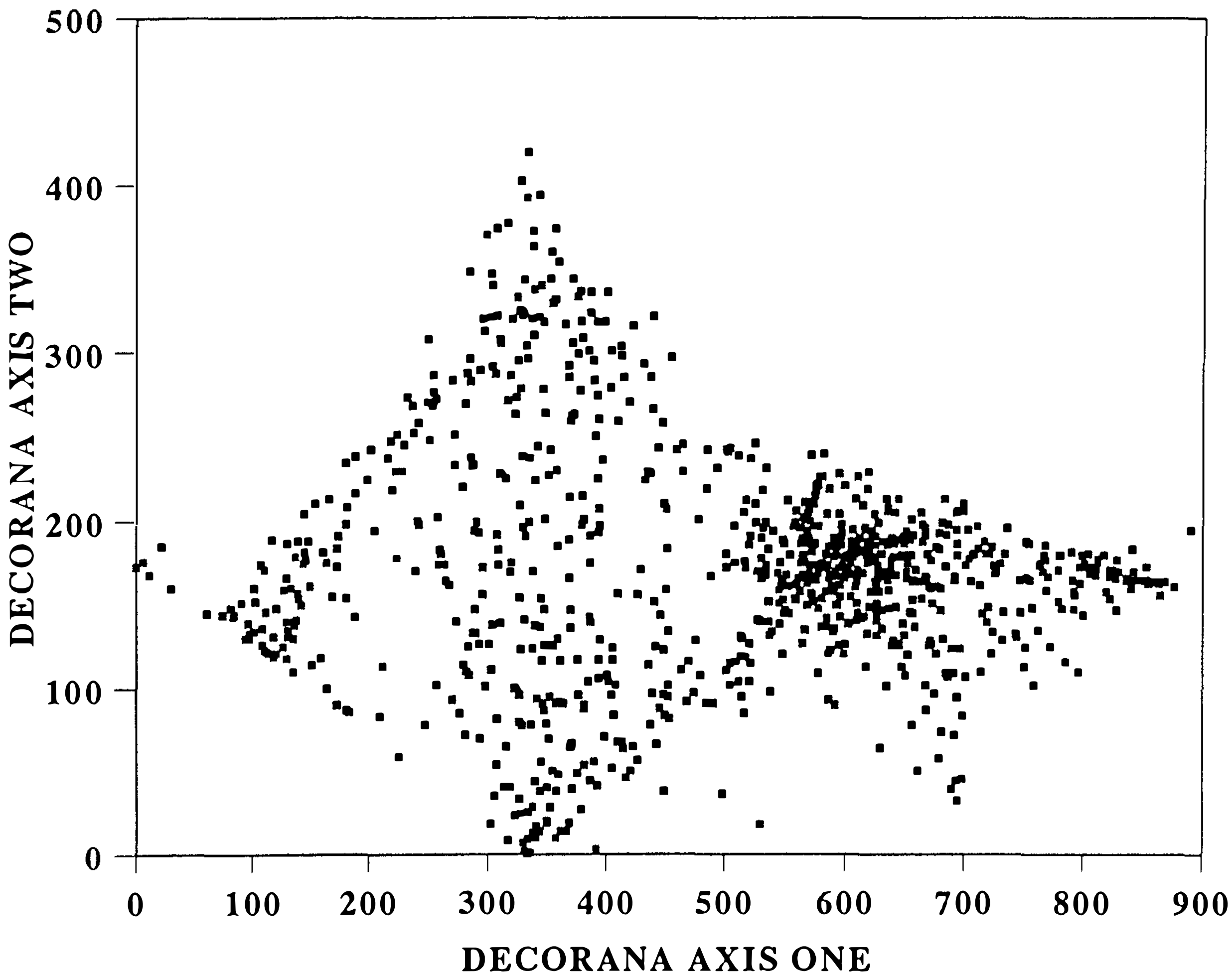


Figure I-9. DECORANA sample ordination, axes one and two.

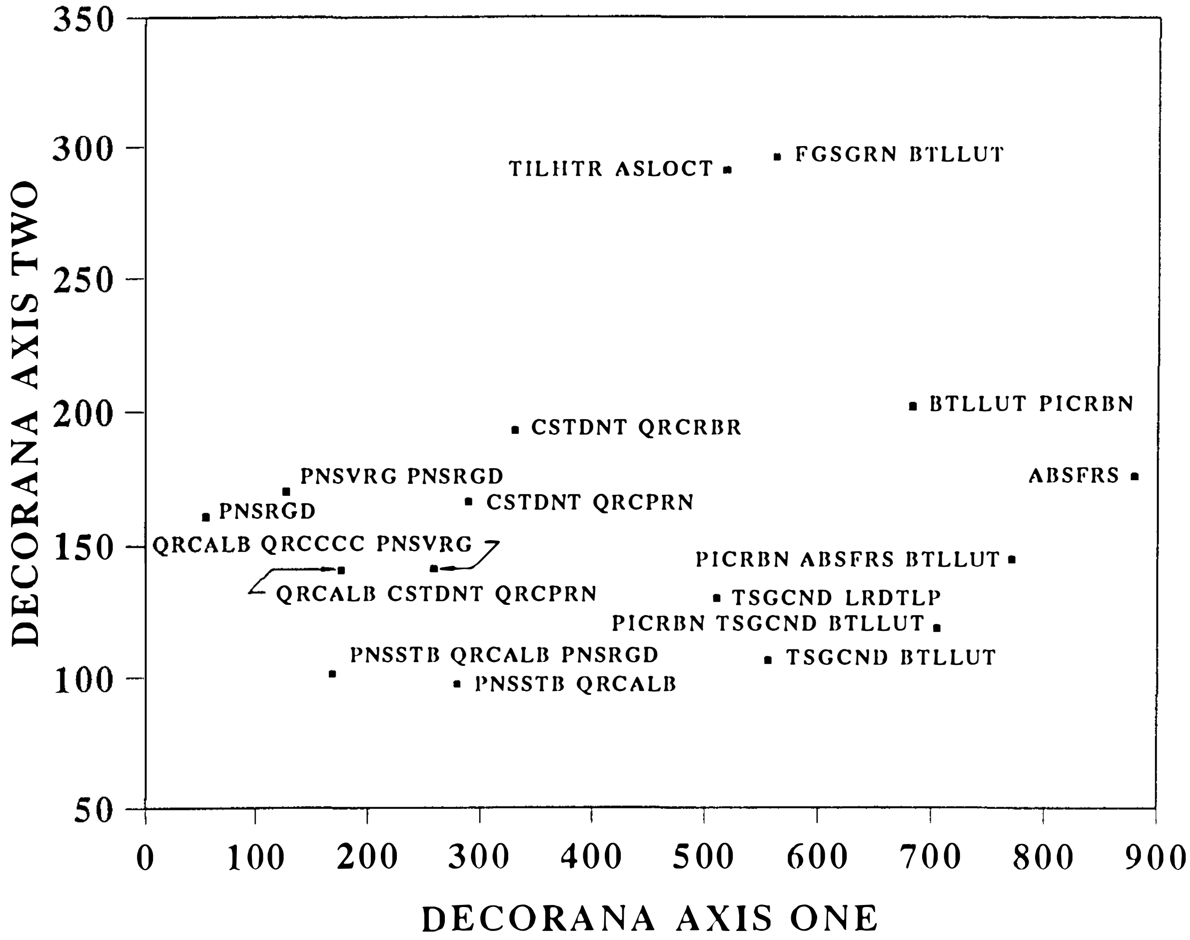


Figure I-10. TWINSPAN classification type centroids in ordination space. See Table I-1 for species codes.

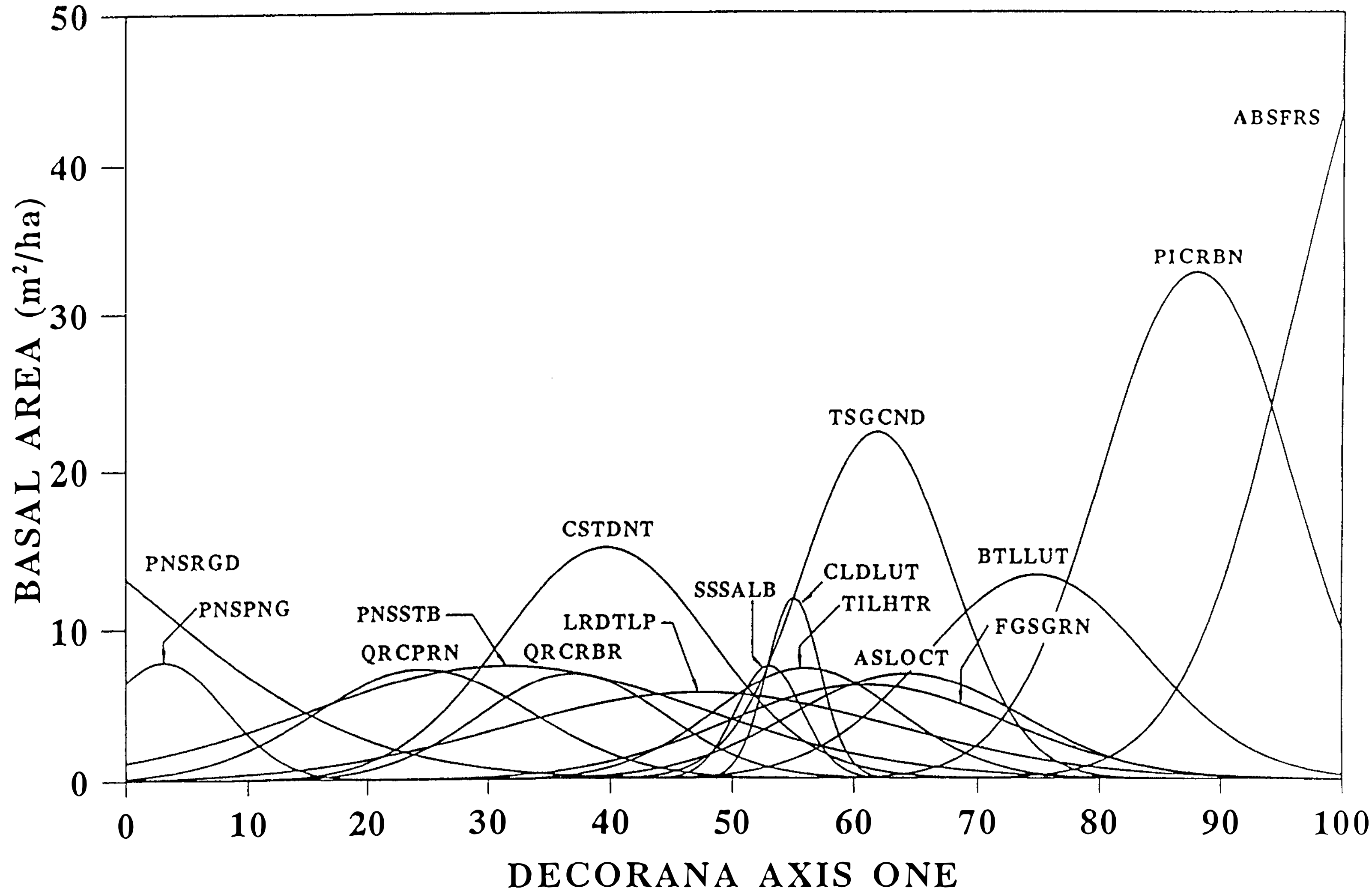


Figure I-11. Coenocline of major species response to the complex moisture-elevation ordination gradient.

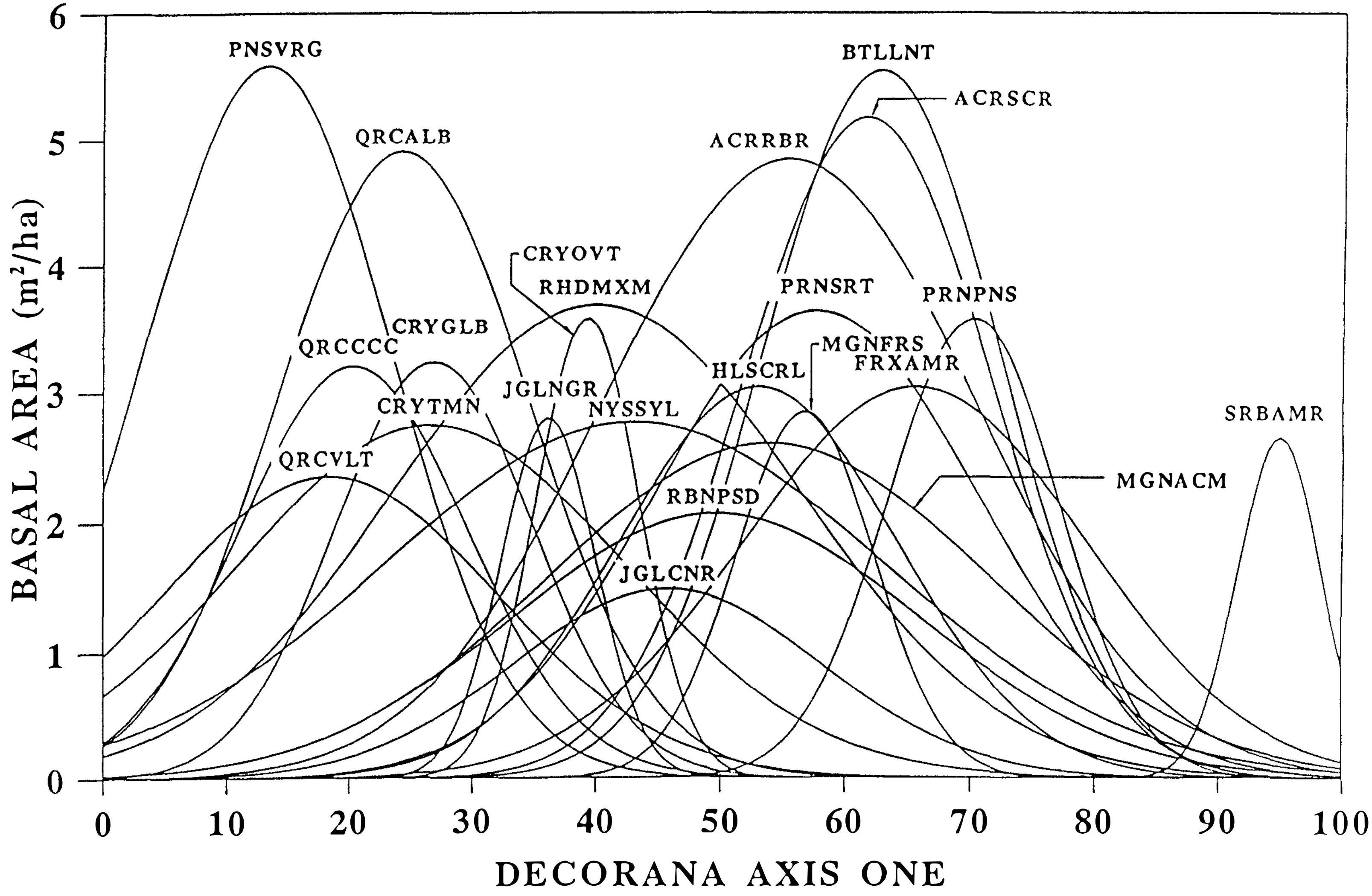


Figure I-12. Coenocline of minor species response to the complex moisture-elevation ordination gradient.

integral part of the development of the FORSMO forest succession model described in Chapter III.

Conclusions

The ordination results presented in this chapter support the results of various researchers (Golden 1981, Callaway et al. 1987) that have identified the major environmental gradient in GRSM as a complex moisture-elevation first described by Whittaker (1956). This conclusion is partially supported by the direct elevation measurements of Miller (1938) but in the main, is derived from the interpretation of the indirect ordination results.

The uniqueness of the Miller data set is fully illustrated by the analysis described in this chapter. This data set provides us with a snapshot in time of the structure of the forests of GRSM during the 1930's, a period of time when the forests were experiencing a fairly unique disturbance due to the chestnut blight. Even though infestation by the blight was firmly established throughout most of GRSM during the time of Miller's sampling, *Castanea dentata* was still the major species in the GRSM landscape. Miller's data provide us with one more example of the importance of *Castanea dentata* in the forests of eastern North America prior to the blight.

The uniqueness of Miller's data set is further illustrated by the results of classification. Because Miller and his crews sampled throughout the entire GRSM landscape, the classification results represent the only true whole park classification. Miller's (1938) classification is felt to be too generic due, in part, to the qualitative nature of its construction. Whittaker's (1956) classification, while the most complete of the previous classification, relies too heavily on sampling in the central portion of the park and does not adequately represent the stands dominated by *Pinus rigida* and *P. virginia* found in the lower elevation western portion of

GRSM. The classifications of Golden (1981) and Callaway et al. (1987), by design, are only appropriate for the regions on the park in which they sampled.

The two points mentioned above lend support to the need for whole park analysis. Research that deals with specific regions or communities, while important for detailed understanding, may tend to make us less apt to understand processes occurring over longer spatial and temporal scales. The vegetation mapping by remote sensing discussed in Chapter II represents just one type of research that attempts to address the issue of whole park analysis.

It is worth mentioning that there are many other potential avenues for research using the Miller data set. None of the overstory information contained in the original data have been analyzed. This data could provide useful insights into understory/overstory relationships. Efforts have been made to map the location of Miller's sampling locations onto modern USGS 7.5′ quadrangle maps using field notes and maps. The availability of location would allow for the generation of additional site parameters (e.g., site protection; Callaway et al. 1987) that may provide additional insights into vegetation pattern. Accurate location information would also allow for resampling of the original plots (see Walker 1978) and subsequent analysis of species change and growth. The research presented in this chapter represents only one aspect of the potential of the Miller data set.

CHAPTER II

THE PRESENT VEGETATION OF GREAT SMOKY MOUNTAINS NATIONAL PARK DERIVED FROM SATELLITE IMAGERY

Introduction

Great Smoky Mountains National Park (GRSM) has been involved in a remote sensing, vegetation mapping project since 1982. The original project was initiated on the recommendation of a Man and the Biosphere (MAB) sponsored review of research in the park (US MAB 1982b). The only park-wide vegetation map currently available for GRSM was produced in 1941 (Miller 1941) and was created on the basis of ground sampling and field reconnaissance (see Chapter I). The MAB review stated that a contemporary park-wide vegetation map was extremely important because most management activities within GRSM center on the distribution of the park's plant communities and because these communities are constantly undergoing change.

The intent of the original 1982 vegetation mapping project was to map the park's vegetation using aircraft collected data. To achieve this goal, two aerial missions were completed over GRSM in 1982. Both missions supplied color infra-red photographs at a scale of 1:38888 and multispectral scanner (MSS) digital data at a picture element (pixel) resolution of 13 x 13 m. An attempt to analyze the digital data was made by the Denver Service Center of the National Park Service and some results were obtained (White and MacKenzie 1986). The original project was abandoned due to two problems: 1) the magnitude of the original data set (approx. 12.5 million pixels) and the lack of computer hardware and software to manipulate this quantity of data and 2) the inability to accurately georeference the aircraft collected digital data due to the extreme topographic variability within GRSM.

Previous attempts to use satellite data within GRSM have involved the Landsat 80 m pixel resolution Multispectral Scanner (MSS) (DeSelm and Taylor 1973, Ambrosia 1980). DeSelm and Taylor (1973) were able to discriminate the interface between the Spruce - Fir and deciduous forest types using MSS. Between 1976 and 1981, J. S. Olson and M. E. Harmon attempted to interpret the vegetation of the central part of the park. They were able to identify forest types that corresponded to Anderson et al.'s (1976) level II classification (i.e., Deciduous, Coniferous, Mixed). Identification of more specific types was hampered due to the inherent resolution of the data and the problems of topographic shading (White and MacKenzie 1986). Ambrosia (1980) in his attempt to map the Spruce - Fir forest of GRSM experienced the same problems of sensor resolution and topographic shading. While not mentioned by earlier investigators, some of these attempts to map the vegetation were most likely hindered by the lack of appropriate image processing and visualization software. The aircraft collected digital data described by White and MacKenzie (1986) had been classified to identify a number of types within the Spruce - Fir forests of GRSM (P. White, personal communication) but, as mentioned earlier, this effort was eventually abandoned. The research described in this chapter avoids some of the problems associated with earlier investigations by incorporating data with a finer spatial resolution (30 m) and by incorporating an unsupervised classification that identifies spectral classes (shaded and unshaded) prior to interpretation to vegetation type (see Methods below).

In 1985, the National Park Service made resources available to GRSM to purchase Landsat-2 MSS and Landsat-5 thematic mapper (TM) digital data and to support the analysis of these data through the University of Tennessee. This chapter discusses the results of the analysis of the Landsat-5 TM data. The objectives of this research were to: 1) determine the utility of using TM data to map the vegetation of GRSM and 2) if feasible, produce a contemporary map of the vegetation of GRSM.

Thunderhead Mtn. Test Study Area

To evaluate the utility of TM digital data in vegetation interpretation, the Thunderhead Mtn., 7.5′, United States Geological Survey (USGS) topographic quadrangle (35°30′ to 35°37′30″ N latitude and 83°37′30″ to 83°45′ W longitude) (Figure II-1) was selected. The quadrangle was selected because it contains most of the physical and biological conditions known to affect vegetation within GRSM. Elevation within the Thunderhead Mtn. test study area ranges from 490 m to a high of 1685 m on Thunderhead Mountain. State Line Ridge (which forms the boundary between Tennessee and North Carolina) is the major topographic feature and traverses the center of the study area from east to west. There are a number of minor ridges extending, in general, north and south from State Line Ridge. The various orientation of these ridges assures that all aspects occur in the study area. Slope ranges from 0° to 52°. Various types of disturbance are known to have occurred within the study area (Pyle 1985). These disturbances include farming, logging, fire, pine bark beetle, and rooting by European wild boar (*Sus scrofa* Linnaeus). Research into the effects of the European wild boar on the park's vegetation (e.g., Bratton et al. 1982) resulted in a number of vegetation samples within the study area (C. Eagar, unpublished data) that were used for interpretation of vegetation types in this study. It was felt that all of the vegetation types within GRSM, with the exception of Spruce - Fir occur within this test study area.

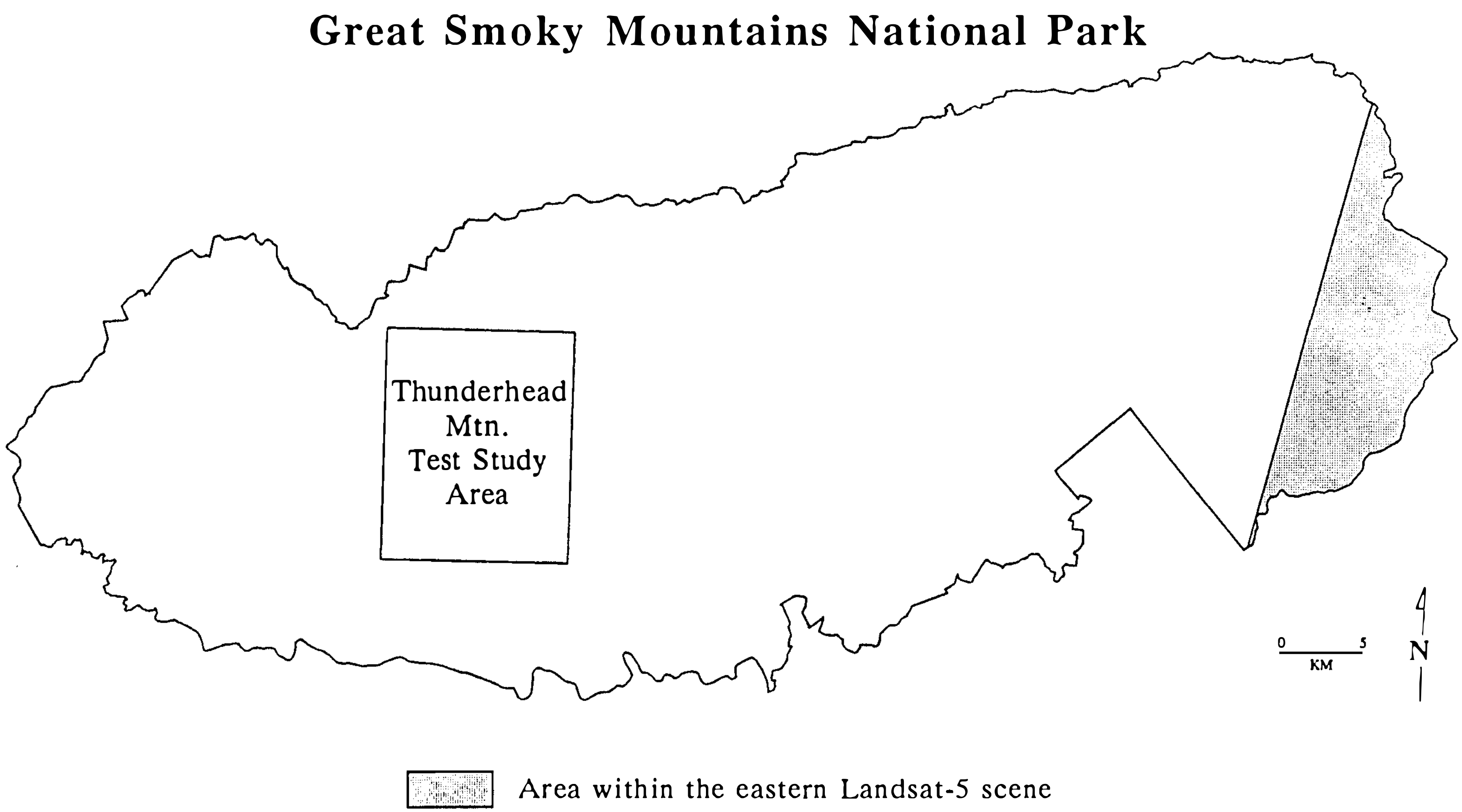


Figure II-1. Location of the Thunderhead Mtn. test study area and Landsat-5 scene boundary. The area not marked as being in eastern scene is in the western scene.

Methods

Thunderhead Mtn. Test Study Area

Digital Data. The majority of the area of GRSM (90%) falls within one Landsat-5 TM scene (Figure II-1). This scene (henceforth referred to as the western scene) is located at Landsat-4,5 coverage index path 19, row 35 (NOAA 1982). Landsat-5 TM digital data were acquired for a September 9, 1984 scene. All seven bands of the scene were downloaded onto an IBM PC-AT using Erdas version 7.3 software image processing and geographic information system (GIS) (Erdas 1988). The data were subset to include only those pixels that fell within a rectangle encompassing the boundaries of GRSM. Erdas was used to georeference the data at a 30 x 30 m pixel size to the universal transverse mercator (UTM) coordinate system, zone 17 (Lee and Walsh 1984) using a first order (linear) transformation and nearest neighbor resampling. After georectification, the data were further subset to include only those pixels within the Thunderhead Mtn. test study area. This resulted in a matrix of 473 rows by 383 columns or 185889 pixels.

Classification. The test study area matrix was transferred to the University of Tennessee Computing Center's IBM 3081 mainframe computer. The data were classified using the SAS version 5.16 FASTCLUS procedure (SAS Institute Inc. 1982b). FASTCLUS is an efficient method for unsupervised, disjoint clustering of large data sets on the basis of Euclidean distances computed from one or more quantitative variables (SAS Institute Inc. 1982b). In this case, the analysis was performed to produce 50 spectral classes using the digital numbers of all seven TM bands. The TM digital numbers were standardized to a mean of zero and a standard deviation of one prior to classification. An unsupervised classification approach (Lillesand and Kiefer 1987) was undertaken for a number of reasons. First, there was a prior lack of knowledge of the relationship of spectral values to vegetation types. Second, the complex topography of GRSM produces a great deal of shading. This shading results in vegetation types having multiple spectral signatures. Third, it was infeasible to collect adequate training sets for all of the requisite spectral signatures in order to perform a supervised classification (Lillesand and Kiefer 1987).

Discriminant analysis was performed using the digital numbers recorded by the seven TM bands as discriminating variables and the results of the FASTCLUS as the *a priori* classification. The analysis was performed using the DISCRIMINANT procedure of SPSS-X release 2.2 (SPSS Inc. 1986). Discriminant analysis derives linear combinations of the discriminating variables, known as discriminant functions, that best distinguish between the *a priori* classes (SPSS Inc. 1986). The discriminant functions can be used to classify a sample in which class membership is unknown. Pixels were reclassified to spectral class using all seven discriminant functions derived from the discriminant analysis.

Canonical discriminant analysis was performed on the results of the spectral classification derived from discriminant analysis using the SAS CANDISC procedure (SAS Institute Inc. 1982b). Canonical discriminant analysis is a data reduction technique related to canonical correlation and principle components analysis. Canonical discriminant analysis derives linear combinations of quantitative variables (i.e., digital number of the seven TM bands) that are referred to as canonical variables (SAS Institute Inc. 1982b). This analysis was performed in an attempt to graphically represent the relationship of the spectral classes to each other.

The results of the 50 spectral class discriminant analysis classification were transferred to an Erdas .GIS file. The .GIS file composed of 30 x 30 m pixels was filtered using a 3 x 3 window to produce a .GIS file composed of 90 x 90 m pixels. The value of the resultant 90 x 90 m pixel was determined to be the value of the majority of pixels within the 3 x 3 window. If there was a tie between pixel values, the window size was increased incrementally (i.e., 5 x 5, 7 x 7, ...) until the tie was broken. This filtering was performed to reduce the effect of mixed pixels and to produce a digital vegetation map with a minimum mapping unit of 90 square meters which had been set *a priori*. This minimum mapping unit was selected for cartographic reasons (i.e., a 90 x 90 m pixel is distinguishable when displayed at the desired scale of 1:100 k) and for the purposes of data reduction. This map, along with results of the canonical discriminant analysis, visual representation of the spectral class matrix on Erdas, a limited number of vegetation samples (C. Eagar, unpublished data), and various color and infrared aerial photographs were used to interpret the 50 spectral classes into vegetation types. The 90 x 90 m spectral class .GIS file was recoded to produce a vegetation type .GIS file or digital vegetation map. The digital vegetation map was also plotted directly onto a copy of the Thunderhead Mtn. 7.5′ quadrangle map using a Hewlett Packard 7580B drafting plotter to produce a draft vegetation map.

Accuracy Assessment. During the summer of 1988, a ground truthing effort was conducted to establish a number of plots within the Thunderhead Mtn. test study area to be used to verify the unsupervised vegetation classification. Field crews were instructed to locate contiguous areas of the same vegetation on the draft vegetation map that were close to recognizable features (i.e., trails, streams, etc). The crews then went to the field, located the plots, recorded the location of the plots in UTM coordinates, and sampled the plots using one of two plotless sampling techniques. The techniques used were either the Bitterlich wedge prism or the stick-type angle gauge (Husch et al. 1982). The majority of plots were sampled using the stick-type angle gauge. Within each plot, three to five subplots were established and sampled. An attempt was made to sample all of the vegetation types listed on the vegetation map that were dominated by trees. Note that while the field sampling was not random, it was stratified by vegetation type. In general, Heath Balds, Grassy Balds, Grape Thickets, Treeless, and Water types were not sampled (see below).

The results of the sampling effort were initially summarized as basal area by species and subplot. Basal area by species was averaged across subplots to produce the final summary of basal area by species by plot. Plots were then classified on the basis of species dominance (basal area) to one of eleven vegetation types as described by Eagar (1984a) plus Heath Bald and Grape Thicket.

A program was written to query the digital vegetation map as to the interpreted vegetation type at a specific location. The output of this program included not only the value of the pixel (cell) at the specified location (target pixel) but also the value of the eight adjacent pixels (neighbor pixels) (Figure II-2). It was felt that the locational accuracy of the field crews

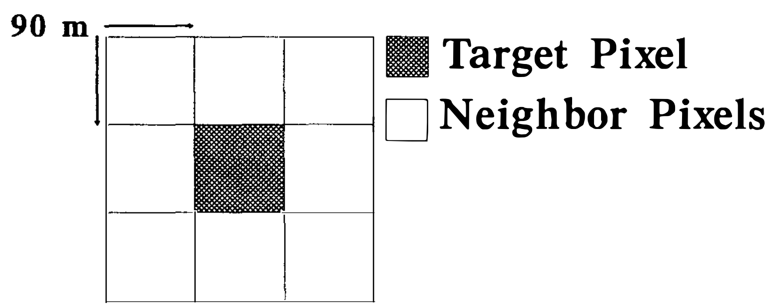


Figure II-2. Illustration of target and neighbor pixels.

and the error in georectification of the digital image data warranted the inclusion of neighboring cells in the accuracy assessment. The ground truth classifications were compared to the interpreted map results. If the ground truth classification value was the same as the interpreted value for the target pixel or one of the eight neighbor pixels then it was felt that the ground truth and the vegetation map agreed. From this process, an accuracy assessment was accomplished.

A KAPPA analysis (Cohen 1960, Congalton et al. 1983, Congalton 1991) was performed using the accuracy assessment (error) matrix to calculate the KHAT statistic using the equation:

$$KHAT = \frac{N\sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r} (x_{i+} * x_{+i})}{N^2 - \sum_{i=1}^{r} (x_{i+} * x_{+i})} \tag{II-1}$$

where r is the number of rows in the matrix, x_{ii} is the number of observations in row i and column i, x_{i+} and x_{+i} are the marginal totals of row i and column i, respectively, and N is the total number of observations (Congalton 1991). KHAT expresses the proportional reduction in error achieved by a classifier relative to the error of a completely random classifier (Lillesand and Kiefer 1987). In other words, a KHAT of 80% indicates that the classifier was able to avoid 80% of the errors that a totally random classifier would have produced.

Whole Park Analysis

Digital Data. As mentioned above, 90% of the area of GRSM falls into the western Landsat-5 scene. The remaining 10% occurs within Landsat-4,5 path 18, row 35 (Figure II-1). Landsat-5 TM digital data of this area (henceforth referred to as the eastern scene) were acquired for a September 1, 1984 scene. These data were downloaded into Erdas, subset to include the area within GRSM, and georectified to the UTM coordinate system, zone 17 using a first order transformation and nearest neighbor resampling.

As the two scenes required for a whole park analysis were acquired on two separate dates, a simple transformation of the eastern scene was performed to standardize the digital numbers of this scene with the western scene. This transformation involved subsetting an area of 156 rows by 136 columns or 21216 pixels common to both scenes and calculating the means of all seven bands by scene. The eastern scene was standardized to the western scene using the following equation:

$$CORR_b = C_b + ORIG_b \tag{II-2}$$

where

$$C_b = \bar{X}w_b - \bar{X}e_b \tag{II-3}$$

and *CORR* is the corrected digital reflectance value, *ORIG* is the original digital reflectance value, $\bar{X}w$ is the band mean for the west scene common subset, $\bar{X}e$ is the band mean for the east scene common subset, and b is the band number where $1 \leq b \leq 7$. The correction coefficients (C_b) were -7.12, -2.83, -2.41, -11.31, -9.27, -9.12, and -2.64 for bands one through seven, respectively.

The data from both scenes were then merged to produce a whole park image. The merging was performed such that in areas of scene overlap, values from the western scene would overwrite values from the eastern scene.

Classification. In most cases, discriminant functions derived from the discriminant analysis classification of the Thunderhead Mtn. test study area were used to classify pixels to spectral class in the whole park data set. Upon analysis of the Thunderhead Mtn. ground truth data (see Results and Discussion below) it was determined that spectral classes interpreted as Hemlock - Hardwood in the unsupervised classification were not Hemlock - Hardwood. It was therefore determined that Hemlock - Hardwood was not represented by a unique spectral class within the Thunderhead Mtn. test study area. Because of this, Hemlock - Hardwood was removed as a candidate vegetation type in the whole park classification by removing Hemlock - Hardwood spectral classes as *a priori* classes in the subsequent discriminant analysis (see below). With the exception of the Hemlock - Hardwood and Spruce - Fir vegetation types, it was felt that the Thunderhead Mtn. test study area contained all of the vegetation types found in GRSM. To develop discriminant functions for the Spruce - Fir type, 100 pixels or 5 training sets (Lillesand and Kiefer 1987) were taken from areas of known Spruce - Fir vegetation outside of the Thunderhead Mtn. test study area. The same procedure was used to identify areas of open water. While areas of open water do not occur in the Thunderhead Mtn. test study area, they do occur elsewhere within GRSM (e.g., Fontana Reservoir). For ease of communication, the water land cover type is here-after referred to as a "vegetation" type. Discriminant analysis was then performed on the Thunderhead Mtn. spectral data with the inclusion of the Spruce - Fir and Water spectral training data and removal of Hemlock - Hardwood spectral classes. Matrix output was obtained (Tables B-1 and B-2) using OPTION 3 of the DISCRIMINANT procedure (SPSS Inc, 1986). The resultant matrix output was then used as input into the DISCRIMINANT procedure (OPTION 2) to classify the whole park data set to spectral class. Spectral classes were converted to vegetation types using the interpretation rules developed for the Thunderhead Mtn. test study area with the addition of Spruce - Fir and Water types (Table B-3).

The geographic distribution of Heath Balds and Grassy Balds, as interpreted from aerial photography and digitized, were overlaid onto the digital map. Special consideration was given to the balds for a number of reasons. First, they represent unique areas for scientific investigation (Cain 1930, Lindsay and Bratton 1976, Stratton and White 1982) and management concerns (Lindsay and Bratton 1979, 1980). Second, due to their small size and linear shape, they have the potential of being underrepresented, even with the 30 m pixel resolution of the Landsat sensor (White and MacKenzie 1986). Third, previous research had resulted in maps of what was felt to be all the balds, both heath and grassy, in GRSM (P. White, personal communication).

Accuracy Assessment. The same methodology used to gather ground truth information in the Thunderhead Mtn. test study area was used in other areas of GRSM. Intensive sampling occurred within the Mt LeConte and Luftee Knob USGS 7.5′ quadrangles. Less intensive sampling occurred in the Cades Cove, Calderwood, Clingmans Dome, and Gatlinburg USGS 7.5′ quadrangles.. As with the field work, the methodology to summarize the field data, compare the field data with classification results, and produce a whole park accuracy analysis was the same as that used for the Thunderhead Mtn. test study area.

Results

Thunderhead Mtn. Test Study Area

Classification. Of the 50 spectral classes derived by the FASTCLUS classification, only three classes had less than 35 pixels in them indicating that there were very few outlier pixels in the Thunderhead Mtn. test study area matrix. The discriminant functions derived from the discriminant analysis of the Thunderhead Mtn. test study area were able to correctly classify 89.5% of the pixels as classified by FASTCLUS. These results indicate that FASTCLUS was capable of deriving mathematically distinct spectral classes. The standardized discriminant function coefficients for the first function, which accounted for 67.79% of the variance in the data set (Table II-1), indicate that the thermal TM band (band six) was of little importance in the first function. Band six was of major importance in the second discriminant function which accounted for 21.2% of the variance in the data set. These results suggest that six TM bands (1-6) are important in discriminating between spectral classes though this hypothesis has not been tested.

Visually displaying the distribution of the spectral classes using Erdas provided insight into some of the relationships between spectral classes but, in general, was inadequate. Canonical discriminant analysis helped to solve this problem. Included among the standard output for the CANDISC procedure are class means for each of the canonical variables. Figure II-3 shows the distribution of the spectral class means for the first two canonical variables. Using the overlay of the spectral classes on the Thunderhead Mtn. quadrangle, it was possible to determine which spectral classes occurred in areas of known vegetation. It was then possible to refer to Figure II-3 and determine which spectral classes were related to each other and to

Table II-1. Discriminant function coefficients and summary information for the Thunderhead Mtn. test study area.

	Discriminant Function						
	1	2	3	4	5	6	7
Band 1	0.30	0.37	0.40	-0.74	0.28	-0.01	0.04
Band 2	0.34	0.20	0.18	0.22	-0.54	-0.75	-0.04
Band 3	0.64	-0.08	0.39	0.26	-0.18	0.85	-0.01
Band 4	0.33	-0.01	-0.74	-0.27	-0.32	0.26	0.49
Band 5	0.32	-0.24	-0.13	-0.03	0.19	-0.05	-1.09
Band 6	0.18	0.67	-0.23	0.55	0.41	0.07	-0.02
Band 7	0.30	-0.40	0.16	0.22	0.47	-0.27	0.82
Eigenvalue	16.60	5.19	1.48	0.66	0.46	0.12	0.01
Percent of Variance	67.79	21.17	6.04	2.71	1.87	0.47	0.65

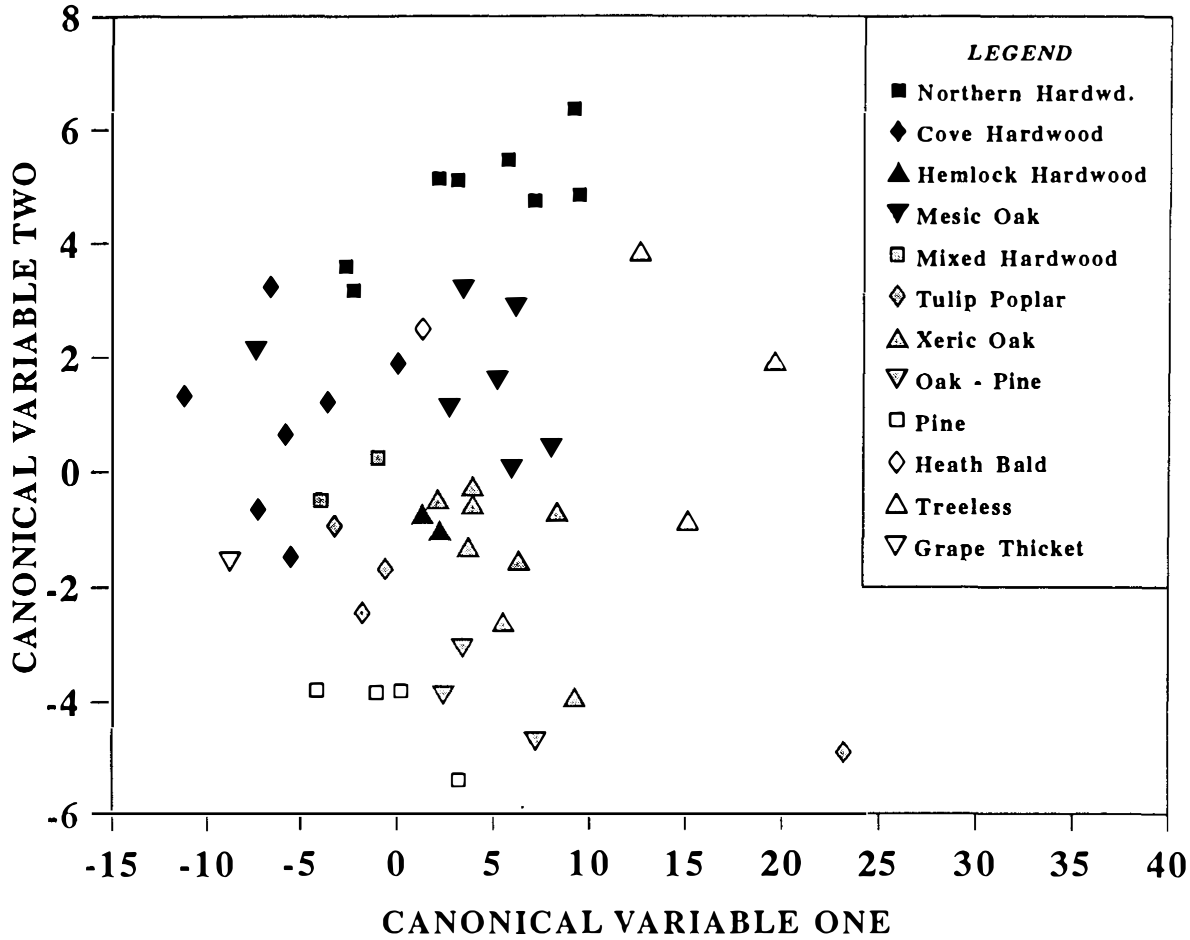


Figure II-3. Thunderhead Mtn. test study area spectral class means for the first two canonical variables by vegetation type.

a specific vegetation type. In general, spectral classes representing similar vegetation types were clustered together (Figure II-3). The disjuncts that do occur are thought to represent vegetation types occurring on different aspects or differences in stand age, both of which could cause differences in spectral characteristics. The occurrence of these disjuncts suggests that the lumping and subsequent statistical summarization of reflectance values for spectral classes that comprise a particular vegetation type is inappropriate. It is important to realize that a vegetation type that occurs on north and south facing slopes may be represented by spectral classes of significantly different characteristics.

After interpreting all of the sources of information available for the Thunderhead Mtn. test study area, the 50 spectral classes were determined to represent 12 vegetation types known to occur in the area. These 12 vegetation types are Cove Hardwood, Northern Hardwood, Hemlock - Hardwood, Mixed Mesic Hardwood, Mesic Oak, Xeric Oak, Oak - Pine, Pine, Tulip Poplar, Treeless, Heath Bald, and Grape Thicket. In most cases, these vegetation types represent a synthesis of GRSM types described by others (Miller 1938, Whittaker 1956, Golden 1981, Eagar 1984a, Callaway et al. 1987). Ten of the twelve types have been described by Eagar (1984a) as follows:

1. Cove Hardwood: Major species include *Tilia heterophylla*, *Halesia carolina*, *Acer saccharum*, *Acer rubrum*, *Aesculus octandra*, *Fagus grandifolia*, *Magnolia acuminata*, *Betula lenta*, and *Tsuga canadensis*. Cove Hardwood forests generally do not have a single dominant species. This type typically occurs in coves, draws, and ravines from 450 to 1200 m.

2. Northern Hardwood: Major species include *Fagus grandifolia* and *Betula lutea*. Minor species include *Acer rubrum*, *A. saccharum*, and *Quercus rubra*. This type generally occurs at elevations above 1075 m.

3. Hemlock - Hardwood: This type is dominated by hemlock ($<50\%$ of stems) but any of the Cove Hardwood species may be found as a minor species. This type is considered a subdivision of the Cove Hardwood type and is found in similar sites.

4. Mixed Mesic Hardwood: This type has no clear dominant but may contain *Quercus*, *Liriodendron tulipifera*, *Pinus*, *Acer rubrum*, *Juglans nigra*, *Liquidambar styraciflua*, *Platanus occidentalis*, *Carya*, *Robinia pseudoacacia*, *Ulmus*, and others. This type is found mainly where farming occurred or in recently logged (approx. 70 years ago) areas. Elevation is typically <750 m.

5. Mesic Oak: Major species include *Quercus rubra*, *Q. prinus*, and *Q. alba*. At higher elevations (>1050 m) this type occurs on ridges and south facing slopes. At lower elevations, this type occurs on ridges and side slopes.

6. Xeric Oak: Major species include *Quercus coccinea*, *Q. prinus*, *Nyssa sylvatica*, *Oxydendron arboreum*, and *Robinia pseudoacacia*. This type typically occurs on ridges and side slopes below 1050 m.

7. Oak - Pine: This type contains an even mixture of oak and pine. It typically occurs on ridges and south facing slopes at middle and lower elevations.

8. Pine: Major species include *Pinus rigida*, *P. pungens*, and *P. echinata*. *Pinus strobus* and *P. virginiana* are minor species of this type. This type has the same site characteristics as the Oak - Pine type.

9. Tulip poplar: This type is dominated by *Liriodendron tulipifera*. The type occurs in coves and valleys at elevations from 300 to 1050 m and is typical of areas that had been logged or farmed prior to the establishment of the park.

10. Treeless: The Treeless vegetation type in the Thunderhead Mtn. test study area represents what Eagar (1984) refers to as a Grassy Bald. The grassy balds within GRSM are dominated by grasses with only minor occurrences of trees. Grassy balds are generally found on mountain tops above 1525 m.

The remaining two types, Heath Bald and Grape Thicket, were not described by Eagar (1984a). Heath Balds have been described by others (Miller 1938, Whittaker 1956) as being dominated by evergreen ericacious shrubs, including *Kalmia latifolia* and various species of *Rhododendron*. Heath Balds occur at elevations of 900 to 2000 m and are usually found on ridge tops and convex slopes. Grape Thickets have long been known to occur within GRSM but the frequency of their occurrence had been greatly underestimated. It was not realized how wide spread Grape Thickets were until aircraft imagery had been acquired in 1982 and analyzed (White and MacKenzie 1986). Grape Thickets tend to occur in low to mid elevations though their exact range is not known. The thickets themselves can be composed of a number of thicket forming *Vitis* species. Grape Thickets have been recognized as a unique vegetation type in this study because they represent a unique spectral class.

Summary statistics for each of the vegetation types within the Thunderhead Mtn. test study area are given in Table II-2. Cove Hardwood was the most dominant type in the test study area followed by the Mesic Oak and Mixed Mesic Hardwood types. Treeless, Heath Bald, and Grape Thicket types had a very limited occurrence. The Grape Thicket type, while a minor component of the test study area, comprised 102 ha.

Accuracy Assessment. A total of 80 plots were sampled within the Thunderhead Mtn. test study area during the summer of 1988. Of the 12 vegetation classes used to classify the spectral data, nine were actually sampled in the ground truth effort. The types Heath Bald,

Table II-2. Summary statistics by vegetation type for the Thunderhead Mtn. test study area. Values are based on 90 m pixels.

Vegetation Type	No. of Pixels	Hectares	% of Area
Northern Hardwood	1706	1381.86	8.24
Cove Hardwood	5083	4117.23	24.56
Hemlock Hardwood	2026	1641.06	9.79
Mesic Oak	3462	2804.22	16.73
Mixed Mesic Hardwood	3402	2755.62	16.44
Tulip Poplar	919	744.39	4.44
Xeric Oak	2307	1868.67	11.15
Oak - Pine	453	366.93	2.19
Pine	1273	1031.13	6.15
Heath Bald	10	8.10	0.05
Treeless	4	3.24	0.02
Grape Thicket	53	42.93	0.26
Totals	20698	16765.38	100.00

Grape Thicket, and Treeless were not sampled due to their unique spectral signatures. The results of the accuracy assessment for the Thunderhead Mtn. test study area are presented in Table II-3. The overall accuracy of the classification was 78.75% with a KHAT of 73.92%. Accuracy for individual types ranged from 0% for Hemlock - Hardwood to 100% for Mesic Oak, Pine - Oak, and Pine types. Note the complete misclassification of the Hemlock - Hardwood type. It was felt that the classification method described in this study was not adequate to discriminate Hemlock - Hardwood from other vegetation types. It was therefore decided to remove Hemlock - Hardwood from the spectral classification of the whole park data set (as described in Methods above). With the removal of the Hemlock - Hardwood type, the overall accuracy of the Thunderhead Mtn. test study area classification rose to 85.14%. It was felt that this level of accuracy was suitable for classification of the whole park.

Whole Park Analysis

Classification. The results of the whole park classification are presented in Appendix D and Figure B-1. The classification yielded 14 vegetation types (Table II-4). Cove Hardwood (Figure B-1C) is the most prevalent type within GRSM (33%) and is generally distributed throughout with the exception of the park's northwest corner. Secondary vegetation types include: 1) mixed mesic hardwood (Figure B-1E) found throughout the periphery of GRSM, 2) Pine (Figure B-1I) found mainly in the northwest corner of GRSM, 3) Mesic Oak (Figure B-1D) distributed throughout but concentrated on the south side of GRSM, 4) Xeric Oak (Figure B-1G) found mainly in the northwest corner, and 5) Northern Hardwood (Figure B-1B) found at higher elevations in the center portion of the park. The Spruce - Fir type (Figure B-1A), an area of recent intense ecological investigation (Eagar and Adams 1992, Nicholas et al.

Table II-3. Thunderhead Mtn. test study area accuracy assessment contingency table. First value in the table is frequency, second value is row percent. Note that the vegetation types Heath Bald, Grape Thicket, and Treeless were not included in the ground truth sampling.

Ground Truth	Vegetation Map: Northern Hardwood	Cove Hardwood	Hemlock Hardwood	Mesic Oak	Mixed Mesic	Tulip Poplar	Xeric Oak	Pine Oak	Pine	Total	Class KHAT
Northern Hardwood	7 87.50%	1 12.50	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	8	86.30%
Cove Hardwood	0 0.00	24 88.89	1 3.70	1 3.70	0 0.00	0 0.00	1 3.70	0 0.00	0 0.00	27	82.91
Hemlock Hardwood	0 0.00	2 100.00	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	2	-5.26
Mesic Oak	0 0.00	0 0.00	0 0.00	5 100.00	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	5	100.00
Mixed Mesic	0 0.00	0 0.00	3 16.67	1 5.56	10 55.56	0 0.00	2 11.11	0 0.00	2 11.11	18	48.47
Tulip Poplar	0 0.00	0 0.00	0 0.00	0 0.00	1 14.29	5 71.43	1 14.29	0 0.00	0 0.00	7	69.52
Xeric Oak	0 0.00	1 14.29	0 0.00	0 0.00	0 0.00	0 0.00	6 85.71	0 0.00	0 0.00	7	83.67
Pine Oak	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	2 100.00	0 0.00	2	100.00
Pine	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	4 100.00	4	100.00
Total										80	

Overall Accuracy = 78.75%
Overall KHAT = 73.92%

Table II-4. Summary statistics by vegetation type for the whole park classification. Values are based on 90 m pixels.

Vegetation Type	No. of Pixels	Hectares	% of Area
Spruce - Fir	6175	5001.75	2.41
Northern Hardwood	23863	19329.03	9.32
Cove Hardwood	85641	69369.21	33.43
Mesic Oak	26330	21327.30	10.28
Mixed Mesic Hardwood	40860	33096.60	15.95
Tulip Poplar	6808	5514.48	2.66
Xeric Oak	25671	20793.51	10.02
Pine - Oak	6256	5067.36	2.44
Pine	28602	23167.62	11.17
Heath Bald	1485	1202.85	0.58
Grassy Bald	68	55.08	0.03
Grape Thicket	400	324.00	0.16
Treeless	1750	1417.50	0.68
Water	2264	1833.84	0.88
Totals	256173	207500.13	100.00

1992) represents 2.4% of the park's vegetation and is found at high elevations in the central eastern portions of GRSM.

Accuracy Assessment. A total of 278 plots were sampled during the summer of 1988. Of these 278 plots, seven were removed from the data set as outliers (i.e., samples taken within Heath Balds or high basal area, pure *Tsuga* stands). This left a total of 271 plots for the accuracy assessment. Of the 14 vegetation types identified on the vegetation map, only 10 were sampled in the ground truth effort. Heath Balds and Grassy Balds were incorporated into the vegetation map using digital boundaries of theses types based on interpretation of aerial photography by NPS personnel (Peter White, personal communication). No Grape Thickets were sampled in the ground truth effort. The Treeless and Water types are so spectrally unique that it was felt these types did not require ground truthing. The low sampling of the Spruce - Fir type (Table II-5) was due to the anticipated use of Spruce - Fir data that were collected as part of another study. Regrettably, the Spruce - Fir data were never incorporated.

The results of the accuracy assessment are presented in Table II-5. The overall accuracy of the vegetation map based on the ground truthing exercise is 83.02%. Individual vegetation type accuracy ranged from 100% for Spruce - Fir and Heath Balds to 50% for Pine-Oak. It should also be noted that these three types also had the smallest sampling effort (n=5,2,4; respectively). While 100% accuracy would be preferred, most of the classification errors that do occur are reasonable. For example, Northern Hardwood being classified as Spruce - Fir, Cove Hardwood, and Mesic Oak is not alarming considering that the Northern Hardwood type grades into all of these types. One of the bothersome misclassifications is the classification of Tulip Poplar as Pine. This is not a logical misclassification.

Table II-5. Whole park accuracy assessment contingency table. First value in the table is frequency, second value is row percent. Note that the vegetation types Grassy Bald, Grape Thicket, Treeless, and Water were not included in the ground truth sampling.

Ground Truth	Vegetation Map: Spruce Fir	Northern Hardwood	Cove Hardwood	Mesic Oak	Mixed Mesic	Tulip Poplar	Xeric Oak	Pine Oak	Pine	Heath Bald	Total	Class KHAT
Spruce Fir	5 100.00 %	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	5	100.00 %
Northern Hardwood	2 3.92	40 78.43	8 15.69	1 1.96	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	51	74.48
Cove Hardwood	0 0.00	0 0.00	68 98.55	1 1.45	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	69	97.88
Mesic Oak	0 0.00	2 10.53	2 10.53	14 73.68	1 5.26	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	19	71.81
Mixed Mesic	0 0.00	0 0.00	5 8.77	1 1.75	40 70.18	0 0.00	8 14.04	0 0.00	3 5.26	0 0.00	57	64.70
Tulip Poplar	0 0.00	0 0.00	2 13.33	0 0.00	0 0.00	10 66.67	1 6.67	0 0.00	2 13.33	0 0.00	15	65.39
Xeric Oak	0 0.00	0 0.00	1 3.03	1 3.03	1 3.03	0 0.00	29 87.88	0 0.00	1 3.03	0 0.00	33	85.84
Pine Oak	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	2 50.00	2 50.00	0 0.00	4	49.63
Pine	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	1 6.25	0 0.00	15 93.75	0 0.00	16	93.17
Heath Bald	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	2 100.00	2	100.00
Total											271	

Overall Accuracy = 83.02%

Overall KHAT = 79.48%

As mentioned in the Methods above, only those ground truth plots that were accurately classified on the vegetation map, minus the Heath Bald plots, were used to numerically describe the vegetation types. A total of 63 different tree species were sampled in the 223 plots (Table B-3). Tables B-3, B-4, and B-5 present means and standard deviations of species basal area and frequency of non-zero occurrence by vegetation type, respectively.

The final summary compares ground truth sampling effort to percent of vegetation type occurrence on the vegetation map (Table II-6). In general, the ground truth effort sampled the various vegetation type in proportion to their occurrence on the vegetation map. The exceptions to this include the Northern Hardwood and Mixed Mesic Hardwood types which were oversampled and the Cove Hardwood and Pine types which were undersampled.

Discussion

The overall accuracy of the vegetation map is quite satisfactory when one considers the complexity of the vegetation of GRSM and complications inherent in the classification of digital satellite data of GRSM. There are very few distinct boundaries between vegetation types. The vegetation generally grades from one type to another (i.e., represents a continuum). The topography of GRSM poses difficulties in that various vegetation types are represented by multiple spectral signatures (i.e., unique combinations of reflected light at various wavelengths) due to the effects of shading. The topography also affects the ability to georectify the digital data to a coordinate system.

A major flaw in the methodology described in this chapter is the inability to identify Hemlock - Hardwood stands using the September TM imagery. The reason for this is due to the inability to derive a unique spectral signature for this type using unsupervised classification techniques. It may be possible that such a signature was derived in the classification but was

Table II-6. Comparison of percent of ground truth with percent of occurrence on the vegetation map by vegetation type.

Vegetation Type	Ground Truth (%)	Vegetation Map (%)	Relative* Difference
Spruce-Fir	1.85	2.41	-0.47
Northern Hardwood	18.82	9.32	9.41
Cove Hardwood	25.46	33.43	-7.97
Mesic Oak	7.01	10.28	-3.27
Mixed Mesic Hardwood	21.03	15.95	5.08
Tulip Poplar	5.54	2.66	2.88
Xeric Oak	12.18	10.00	2.18
Oak - Pine	1.48	2.44	-0.96
Pine	5.90	11.17	-5.27
Heath Bald	0.74	0.58	0.16
Grassy Bald	0.00	0.03	-0.03
Grape Thicket	0.00	0.16	-0.16
Treeless	0.00	0.68	-0.68
Water	0.00	0.88	-0.88
N =	271.	256173.	

*Relative difference is (Ground Truth(%)) - (Vegetation Map(%)). Positive values indicate relative oversampling in the ground truth effort, negative values indicate undersampling.

not appropriately identified. Another possibility is that there is no unique signature for Hemlock - Hardwood in the September imagery. A supervised approach using training sets (Lillesand and Kiefer 1987) in known locations of Hemlock - Hardwoods might result in a unique signature but this is unlikely. If the unsupervised approach is not able to identify a unique signature, the supervised approach is not likely to either.

Another approach that may want to be considered in the future is one of multi-temporal acquisition of imagery. It is assumed that the Hemlock - Hardwood type is being confused with the Cove Hardwood and Northern Hardwood types. A leaf off winter TM acquisition would provide the means for separating Hemlock from the Cove and Northern Hardwoods. This assumes one could separate Hemlock from the other coniferous species. This multi-temporal approach might provide a suitable method for discriminating Hemlock - Hardwood from other types.

A multi-temporal approach is also probably needed to alleviate a second concern with the map. It is felt that the classification of 33.4% of GRSM as Cove Hardwood is probably too high, though there is no direct evidence to support this. At the very least, one should probably assume the term Cove Hardwood is used loosely. This concern is compounded by the fact that the Cove Hardwood type, relative to its occurrence on the map, was the most underrepresented in the ground truth (Table II-6). Examination of the accuracy assessment contingency table (Table II-5) suggests that the classifier might be confusing Cove Hardwood with other deciduous types and the Hemlock - Hardwood type as previously mentioned. Taking advantage of the phenological differences in dates of species leaf out would provide one mechanism for separating out confused types. For example, this would provide a mechanism for separating *Liriodendron tulipifera* dominated types (Mixed Mesic, Tulip Poplar) from others.

It is disappointing that some of the vegetation types were not adequately sampled in the ground truth effort (i.e., Oak - Pine, and Grape Thickets). It is felt that additional ground truthing in these types would increase the overall accuracy due to their unique spectral signatures. The overall accuracy of the map would also increase if one were to include ground truth of Treeless and Water types. As mentioned earlier, these types were not included in the ground truth effort because they are spectrally unique.

It should be noted that the names of the vegetation types used on the vegetation map may not be synonymous with those used by other investigators of vegetation with GRSM (e.g., Whittaker 1956, Golden 1981, Callaway et al. 1987). As mentioned earlier, the type names are based on the classification scheme of Eagar (1984) and represent the philosophy of that classification. Users of the vegetation map are reminded that the summary of mean species basal area by vegetation type (Table B-1) provides a numerical description of the composition of the vegetation types. Users of this summary should also realize that the basal area values presented are *not* based on data collected in a statistically random fashion and the extrapolation to whole park analyses should be done with caution. This is particularly true for those vegetation types with small sample sizes (i.e., Spruce - Fir and Oak - Pine).

Conclusions

The methods described in this chapter have been found capable of producing a vegetative map of GRSM with an overall accuracy of 83%. The level of classification is greater than that obtained for any other attempt to classify the park's vegetation using satellite imagery (i.e., DeSelm and Taylor 1973, Ambrosia 1980). The level of accuracy exceeds the level 2 class of Anderson (1976).

One interesting aspect of the methodology is that the classifier does not require the use of dedicated image processing software. This was not done by design but originally was a function of the inability of the original microcomputer hardware to efficiently process the data volumes required for the whole park classification. Contemporary microcomputer hardware no longer has this limitation and, in many cases, can out perform various mainframe computer configurations. Image processing - GIS software were use for georectification, display, and recoding functions.

It is felt that the vegetation map is a fairly accurate depiction of the park's vegetation at the time of the satellite overpass (September 1984). This map represents the first whole park inventory of vegetation. The vegetation map represents a resource that should be useful to researchers and managers of the park's resources. To date, the map has been integrated into the GRSM GIS data base (Parker et al. 1990) and has been used in the prediction of gypsy moth susceptibility (Barett 1993).

CHAPTER III

THE FUTURE VEGETATION OF GREAT SMOKY MOUNTAINS NATIONAL PARK: SUCCESSION MODEL DEVELOPMENT AND OUTPUT

Introduction

Since their inception in the early 1970's (Botkin et al. 1970, 1972; Shugart and West 1977), gap models of forest succession have been produced to simulate forests of varying composition and structure (Shugart and West 1980, Shugart 1984, Dale et al. 1989, Shugart et al. 1992).

Most gap models in use incorporate environmental factors to provide variability in species growth response and tolerance. The most common of these factors is gross thermal effect (Botkin et al. 1972). The original JABOWA (Botkin et al. 1970, 1972) and FORET (Shugart and West 1977) models both assumed that species respond differently to varying temperature conditions. In these models, and their descendants, the temperature response is simulated by modifying potential species growth as a function of growing degree days (GDD) at the simulated site relative to the GDD extremes of the species. These GDD extremes have typically been estimated using species range maps. It has been assumed that maximal species growth is obtained at the temperature midway between the extremes.

As variations of JABOWA and FORET have evolved, other environmental factors have been incorporated. Shugart and Nobel (1981) modeled factors related to frost and fire intensity as a function of fuel loading in their BRIND model of Australian *Eucalyptus* forests. Weinstein et al. (1982) in the FORNUT model of southern Appalachian forests and Aber and Melillo (1982) in their FORTNITE model of Northern Hardwood forests added nutrient availability as a factor. Solomon et al. (1984) and Solomon (1986) in their FORENA model of forests of eastern North America have incorporated a soil moisture - soil drought factor to the model. As indicated above, the general trend in model development has been to incorporate more environmental factors to refine the model. These factors are generally incorporated in the model based either on inferences from the natural range of the species or from measurements collected in the field at fairly defined sites.

Kessell (1979) has been the main proponent of an alternate type of forest modeling based on gradient analysis. Kessell (1976, 1977, 1979) has developed models of forest succession and fire and fuel behavior based on gradient analysis or ordination (Whittaker 1978) of environmental gradients (topographic - moisture, disturbance, exposure, etc.) of species response. Kessell (1979) used the ordination generated responses in a Markovian forest dynamics model to simulate forest responses across the environmental gradients in Glacier National Park. Ordination, both direct and indirect (Whittaker 1967), has been a very popular tool for the analysis of species response to environmental gradients (e.g., Whittaker 1956, Bray and Curtis 1957, Grigal and Goldstein 1971, Gauch and Whittaker 1972, Peet 1980). Kessell's (1979) modeling efforts provide one example of the integration of gradient analysis with forest modeling.

Harrison and Shugart (1990) described a model (OVALIS) that integrated a traditional gap model of a Chestnut Oak forest in Virginia with gradient analysis. In the OVALIS model, a soil - moisture growth modifier, based on Whittaker's (1956) indirect moisture gradient for GRSM, was incorporated into the model. The soil growth modifier was based on the relative ranking of species on Whittaker's moisture gradient (Harrison and Shugart 1990).

This chapter describes a model that more fully integrates aspects of gap models and gradient analysis. The model, FORSMO (*FOR*ests of the *SMO*kies), replaces the temperature, moisture, and nutrient factors of previous gap models with a single indirect moisture-elevation complex environmental gradient for GRSM. The moisture-elevation gradient is incorporated into the model by means of species responses to the complex gradient as determined by the coenoclines produced in Chapter I (see Growth below).

The objectives of the research presented in this chapter were to:

1. Develop a gap model of forest succession that integrates indirect gradient analysis.
2. Confirm that this model is capable of replicating species compositional changes and stand structural attributes that occur within the GRSM landscape.
3. Use the model to reconstruct the pre-chestnut blight condition of GRSM forests and to investigate the nature of stand recovery from chestnut blight.
4. Use the model to simulate anticipated change in the GRSM Spruce - Fir forest due to infestation by the balsam wooly adelgid.

Methods

Model Mechanics

The FORTRAN code for the FORSMO model is based on that of FORET (Shugart and West 1977, Shugart 1984) (original FORET source code was obtained from M. L. Tharpe of Oak Ridge National Labs). As in FORET, FORSMO is coded to assume a plot size of .08 ha. Shugart and West (1979) have shown this to be an optimal size for running the FORET model.

Input and Initialization. There are two types of model input: 1) simulation parameters and 2) species attributes. Simulation parameters include position along the gradient (*GRADL*), number of years of simulation (*NYEAR*), number of passes (*KTIMES*), and file name of output files. Species attributes used throughout in the model are shown in Table III-1. These

Table III-1. Input and derived species attributes used in FORSMO. Input variables are the species growth constants (B_3 and B_2); shade tolerance (*TOL*; 1 for shade tolerant, 2 for shade intolerant); maximum age (AGE_{MAX}) in years; the growth parameter (*G*); sprouting tendency (*SPRTND*) and minimum (*SPRTMN*) and maximum (*SPRTMX*) sprouting diameter in cm dbh; reproduction switches (*SWTCH*): 1) species requires leaf litter for reproduction, 2) species requires mineral soil for reproduction, 3) species recruitment is reduced by hot year (not used in FORSMO), 4) species is a preferred food of deer or small mammals, and 5) reduced seeding rate of desirable mast; seed source limitation (KTIME) in years; and coenocline mode (*CMODE*) and standard deviation (*CSTD*).

Species	Code[1]	*DBH-MAX*[2]	*HT-MAX*[2]	B_3	B_2	*TOL*	*AGE-MAX*	*G*	*SPR-TND*	*SPR-TMN*	*SPR-TMX*	*SWTCH*	*KTIME*	*CMODE*	*CSTD*
Abies fraseri	ABSFRS	100	3500	0.3363	67.26	2	200	152.4	0	0	0	FFTFF	9999	106.0	9.4
Acer pensylvanica	ACRPNS	23	1002	1.7000	76.70	1	25	150.0	0	0	0	FFFFF	9999	60.4	13.0
Acer rubrum	ACRRBR	100	3000	0.2863	57.26	2	150	176.1	3	12	200	FTTTF	9999	55.5	14.8
Acer saccharum	ACRSCH	150	3000	0.1272	38.17	1	300	89.0	3	12	80	FFTFF	9999	61.7	9.8
Acer spicatum	ACRSPC	13	499	2.0000	53.80	2	30	150.0	0	0	0	FFFFF	9999	76.6	15.6
Aesculus octandra	ASCOCT	100	3000	0.2863	57.26	1	100	264.1	1	12	200	TFTFF	9999	64.2	9.5
Betula lenta	BTLLNT	75	2100	0.3490	52.35	1	265	71.0	3	12	100	FTTTF	9999	62.8	9.4
Betula lutea	BTLLUT	50	2500	0.9452	94.52	1	300	72.8	3	12	100	FFTTF	9999	74.8	9.2
Carya glabra	CRYGLB	100	3000	0.2863	57.26	1	300	88.1	2	12	200	TFTFF	9999	26.9	8.1
Carya ovata	CRYOVT	100	3000	0.2863	57.26	1	275	96.0	1	12	200	TFTFF	9999	39.3	4.2
Carya tomentosa	CRYTMN	100	2800	0.2663	53.26	1	300	82.6	1	12	200	TFTFF	9999	26.6	15.8
Castanea dentata	CSTDNT	150	3499	0.1495	44.84	1	300	102.6	3	12	200	TFFFF	9999	39.6	8.7
Cornus florida	CRNFLR	25	1001	1.3800	69.04	1	100	92.6	3	12	200	FFTFF	9999	36.5	12.6
Fagus grandifolia	FGSGRN	100	3000	0.2863	57.26	1	366	72.2	2	6	30	FFTFF	9999	60.9	11.6
Fraxinus americana	FRXAMR	100	3000	0.2863	57.26	1	300	88.0	2	6	20	FTTTF	9999	65.6	13.8
Juglans nigra	JGLNGR	150	3499	0.1495	44.84	2	250	123.1	1	6	20	TFTFT	20	36.2	3.9
Liriodendron tulipifera	LRDTLP	150	3499	0.1495	44.84	2	300	102.6	2	12	200	FTFFF	9999	47.3	16.2
Nyssa sylvatica	NYSSYL	100	3000	0.2863	57.26	2	300	88.0	1	80	200	FTFFF	9999	43.0	20.2
Ostrya virginiana	OSTVRG	50	1500	0.5452	54.52	1	100	137.7	2	6	20	FTFFF	9999	40.2	2.1
Oxydendron arboreum	OXYARB	61	3050	0.7828	95.51	1	100	259.0	3	12	200	FFFTF	9999	30.9	9.5
Picea rubens	PICRBN	100	3000	0.2863	57.26	1	400	66.0	0	0	0	FFTFF	9999	88.0	7.8
Pinus rigida	PNSRGD	75	2000	0.3312	49.68	2	200	90.4	2	6	20	FTFFF	9999	-16.0	18.2
Pinus strobus	PNSSTR	150	3499	0.1495	44.84	2	450	68.4	0	0	0	TTTFF	9999	31.4	16.5

Table III-1 (continued)

Species	Code[1]	DBH-MAX[2]	HT-MAX[2]	B_3	B_2	TOL	AGE-MAX	G	SPR-TND	SPR-TMN	SPR-TMX	SWTCH	KTIME	CMODE	CSTD
Pinus virginiana	PNSVRG	50	1500	0.5452	54.52	2	250	55.1	0	0	0	FTFFT	9999	13.4	9.9
Prunus pensylvanica	PRNPNS	28	1126	1.2600	70.60	2	30	200.0	0	0	0	FFFFF	9999	70.2	6.8
Prunus serotina	PRNSRT	100	3000	0.2863	57.26	2	200	132.1	3	12	200	FFFTF	9999	57.6	13.0
Pyrus americana	PYRAMR	10	500	3.6300	72.60	2	30	150.0	0	0	0	FFFFF	9999	94.9	3.4
Quercus alba	QRCALB	100	3500	0.3363	67.26	1	400	76.2	2	12	40	TFFFF	9999	24.3	10.1
Quercus coccinea	QRCCCC	75	2500	0.4201	63.01	1	400	55.4	2	12	80	TFFFF	9999	20.3	9.3
Quercus marilandica	QRCMRL	50	1500	0.5452	54.52	2	400	34.0	2	12	40	FFFFF	9999	2.3	2.8
Quercus prinus	QRCPRN	100	3000	0.2863	57.26	1	267	98.9	2	12	40	TFFFF	9999	24.6	9.1
Quercus rubra	QRCRBR	100	3000	0.2863	57.26	1	400	66.0	2	12	40	TFFFF	9999	36.9	7.7
Quercus velutina	QRCVLT	100	3000	0.2863	57.26	1	300	88.0	2	12	40	FTFFF	9999	18.4	13.8
Robinia pseudoacacia	RBNPSD	152	3048	0.1253	38.20	1	200	136.0	3	12	80	FTFTF	20	49.7	16.5
Sassafras albidum	SSSALB	107	2440	0.2021	43.15	2	100	174.0	3	12	200	TFFFF	20	53.0	2.8
Tilia heterophylla	TILHTR	100	3000	0.2863	57.26	1	150	176.1	3	12	80	FTTFF	9999	56.0	10.0
Tsuga canadensis	TSGCND	150	3499	0.1495	44.84	1	650	47.0	0	0	0	FFTTF	9999	61.9	4.8

[1]Species codes (*CODE*) are not a model input. They have been included for reference purposes only.
[2]Derived from growth constants B_3 and B_2.

attributes were obtained from Solomon et al. (1984) or, when not included in Solomon et al. (1984), were derived from the literature (Harlow, Harrar, and White 1979, Fowells 1965, Elias 1980). Species coenocline modes (*CMODE*) and standard deviations (*CSTD*) were derived from coenoclines produced in Chapter I. The species specific growth constants b_2 and b_3 and the growth rate constant G are derived below (see Growth).

Following the input of simulation and species parameters (subroutine INPUT), the model performs an initialization (subroutines PLOTIN and INIT). This initialization consists primarily of resetting a number of arrays to zero.

Birth. The first factor in determining if a given species will be recruited or continue to reproduce (subroutine BIRTH) is based on the gradient position of the stand in relation to the individual species distribution along the environmental gradient as determined by the species coenocline. If the value of GRADM (see Growth below) for the individual species is < 0.05 then that species will not be recruited. Species considered characteristic of old field succession rather than forest clearings are subject to simulated limited seed sources (Shugart and West 1977). Seed source limitations are determined based on time since stand establishment and presence or absence of the species. If time since stand establishment is greater than the viability of the seed source (*KTIME*) and the species is not present, the species will not be recruited into the stand.

There are also three other factors that control species recruitment or reproduction. These factors are related to:

1. species requires leaf litter for reproduction;
2. species requires mineral soil for reproduction;
3. species fruits are a preferred mast of deer or small mammals.

If stand biomass $\geq$ 1.25 kg/ha then species requiring leaf litter for reproduction will reproduce. If stand biomass $\leq$ 2.5 kg/ha then species requiring mineral soil for reproduction will reproduce. In any given year, there is a 50% probability of seed predation by deer and small mammals. If a stand is experiencing seed predation, those species that produce preferred mast will not reproduce.

If a species is allowed to reproduce, a random number of individual saplings will be recruited into the stand. The number of saplings recruited is set to be between zero and eight using a uniform random number generator. The size of saplings when they enter the stand is between 1.27 and 2.27 cm diameter at breast height (dbh). The actual size is determined randomly based on the following equation:

$$SIZE = 1.27 + 0.3(1.0 - \rho)^3 \tag{III-1}$$

where ρ is a random number generated using a uniform number generator such that $0 \leq \rho < 1$.

Growth. An individual's growth (subroutine GROW) is a function of species' intrinsic growth parameters, diameter, position along the environmental gradient, and amount of light reaching the individual. The fundamental growth equation is that of Botkin et al. (1970, 1972) and is:

$$D_{OPT} = \frac{GD\left[\dfrac{1 - DH}{D_{MAX}H_{MAX}}\right]}{274 + 3b_2D - 4b_3D^2} \tag{III-2}$$

where D_{OPT} is the optimal growth increment, G is a growth parameter defined below (Equation III-6), D is tree diameter, D_{MAX} is the maximum diameter recorded for the species, H is tree height, H_{MAX} is the maximum height recorded for the species, b_2 and b_3 are growth parameters derived below (Equations III-4 and III-5) and 274 is two times breast height (137 cm). This equation assumes that height is a function of diameter based on the following equation of Ker and Smith (1955):

$$H = 137 + b_2 D - b_3 D^2 \tag{III-3}$$

If one assumes that maximum height (H_{MAX}) is reached at maximum diameter (D_{MAX}) then:

$$b_2 = \frac{2(H_{MAX} - 137)}{D_{MAX}} \tag{III-4}$$

and:

$$b_3 = \frac{H_{MAX} - 137}{D_{MAX}^2} \tag{III-5}$$

Botkin et al. (1970, 1972) derived the following equation to define G:

$$G = \frac{4H_{MAX}}{AGE_{MAX}} \left\{ \ln\left[2(2D_{MAX} - 1)\right] + \frac{\alpha}{2}\ln\left[\frac{\frac{9}{4} + \frac{\alpha}{2}}{4D_{MAX}^2 + 2\alpha D_{MAX} - \alpha}\right] - \left[\frac{\alpha + \frac{\alpha^2}{2}}{\sqrt{\alpha^2 + 4\alpha}}\right] \ln\left[\frac{\left(3 + \alpha - \sqrt{\alpha^2 + 4\alpha}\right)\left(4D_{MAX} + \alpha + \sqrt{\alpha^2 + 4\alpha}\right)}{\left(3 + \alpha + \sqrt{\alpha^2 + 4\alpha}\right)\left(4D_{MAX} - \alpha + \sqrt{\alpha^2 + 4\alpha}\right)}\right] \right\} \tag{III-6}$$

where $\alpha = 1\text{-}137/H_{MAX}$ and AGE_{MAX} is the maximum age recorded for the species.

Equation III-2 represents the optimal growth that can be obtained by an individual under ideal conditions. This is rarely the case. Individual growth in the model is decreased as a function of deviation from the point of maximum dominance of the species along the environmental gradient using the equation:

$$D_{GRAD} = D_{OPT} GRADM_I \tag{III-7}$$

where D_{GRAD} is the growth decrement as a function of position along the environmental gradient, D_{OPT} is the optimal growth as calculated using equation III-2 and $GRADM_I$ is the deviation from maximum dominance along the environmental gradient for species *I* calculated based on a modification of the equation for a Gaussian (normal) curve (Gauch and Whittaker 1972) as:

$$GRADM_I = \exp(-(CMODE_I - GRADL)^2/2CSTD_I^2) \tag{III-8}$$

where *CMODE* and *CSTD* are the coenocline mode and standard deviation, respectively, for species *I* and *GRADL* is the position along the gradient for which the model is being run. Figure III-1 illustrates the nature of the deviation from maximum dominance (*GRADM*) curve as a function of gradient position (*GRADL*).

Growth is further decreased as a function of the amount of light reaching the canopy of the individual tree. Leaf area (*LA*) is calculated along a vertical profile of the stand at 0.1 m increments using the equation:

$$LA = 1.928 \times 10^{-4} dbh^{2.129} \tag{III-9}$$

The available light reaching a given individual is calculated as:

$$AL_H = \exp(-0.25 \sum LA_H) \tag{III-10}$$

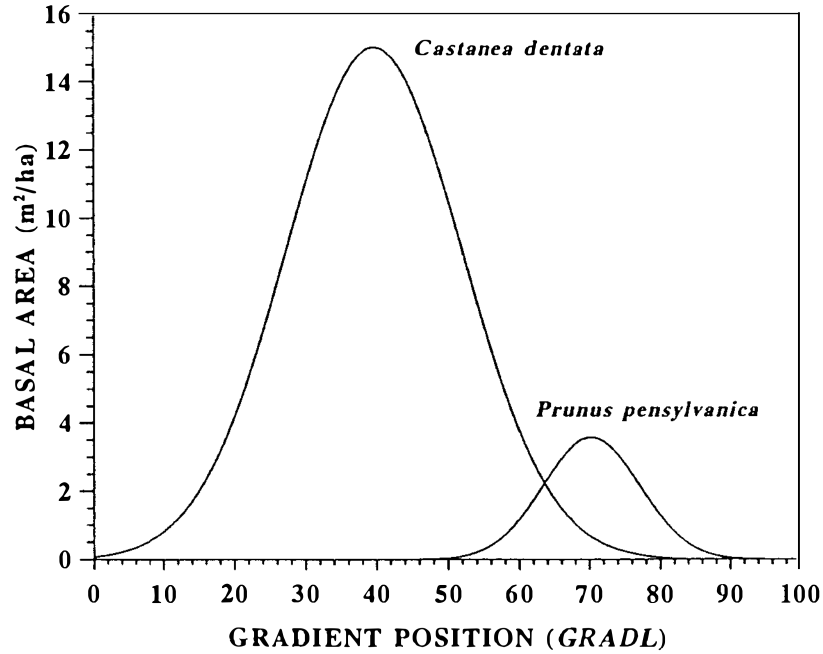
where AL_H is the available light at height *H*, $\sum LA_H$ is the sum of the leaf area for all trees > *H* in height calculated using equation III-3 and 0.25 is the light extinction coefficient.

If an individual is shade tolerant then the actual diameter increment (D_{INC}) is calculated as:

$$D_{INC} = 1 - D_{GRAD} \exp(-4.64(AL-0.05)) \tag{III-11}$$

If an individual is shade intolerant then D_{INC} is calculated as:

A. Species Responses



B. Response of *GRADM*

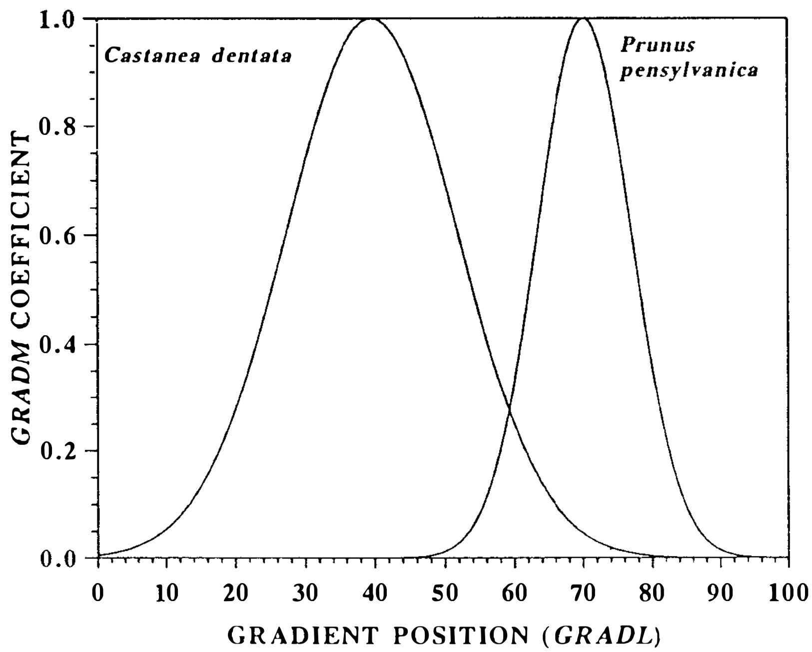


Figure III-1. Deviation for maximum growth (*GRADM*) due to position on gradient (*GRADL*). (A) illustrates basal area response of *Castanea dentata* and *Prunus pensylvanica* as determined in Chapter I. (B) illustrates *GRADM* values for these same species as used in FORSMO.

$$D_{INC} = 2.24\left(1 - D_{GRAD}\exp(-1.136[AL - 0.08])\right) \quad \text{(III-12)}$$

These two equations fit measured photosynthesis curves, as found in Kramer and Kozlowski (1960), scaled such that optimal light conditions equal one (Shugart and West 1977).

Kill. The death of individual trees (subroutine KILL) is a function of the individual's age and recent growth decrement. The model assumes that only 1% of the individuals in the stand will reach their species' specific age maximum (AGE_{MAX}). The probability that an individual will be dead by the n^{th} year is (P_n):

$$P_n = 1 - (1 - \varepsilon)^n \quad \text{(III-13)}$$

where ε is the annual mortality probability. Assuming a 1% survival at AGE_{MAX} then:

$$\varepsilon \sim \frac{4.605}{AGE_{MAX}} \quad \text{(III-14)}$$

Every individual in the plot is checked to see if it will die in that year using a uniform random number generator returning values of ρ such that $0 \leq \rho < 1$. If $\rho \leq \varepsilon$ or the individual's age $> AGE_{MAX}$ then that individual will die.

If a tree has an annual diameter increment (D_{INC}) < 0.1 cm then its mortality probability (ε) is set at 0.386. This allows for only 1% of suppressed individuals to survive up to 10 years.

If it is determined that a tree is going to die in a given year, a check is made to see if the tree can sprout. If, at the time of death, an individual's dbh in relation to its minimum and maximum sprouting size (*SPRTMN* and *SPRTMX*, respectively) is such that *SPRTMN* < dbh < *SPRTMX*, that species is flagged as a candidate for sprouting.

Sprout. If an individual of a species has been found capable of sprouting (see Kill) then that species is eligible to sprout that year (subroutine SPROUT). The model randomly selects one of the eligible species to sprout. The number of sprouts (*NSPRT*) is calculated as:

$$NSPRT = \rho(SPRTND) + 1 \qquad \text{(III-15)}$$

where *SPRTND* is the species specific sprouting tendency (see Input and Initialization) and ρ is a random number generated using a random number generator such that $0 \leq \rho < 0$.

The size (*SIZE*) of each sprout when it enters the plot is calculated as:

$$SIZE = 1 + 0.1(1.0 - \rho)^3 \qquad \text{(III-16)}$$

where ρ is a random number generated using a uniform number generator such that $0 \leq \rho <$ 1.

Output. There is a variety of output that can be generated by the model (subroutine OUTPUT). As in the original FORET model, output of individual dbh (cm), species' basal area (m^2/ha), density (stems/ha), biomass (kg/.08 ha) and percent biomass by year can be printed. Biomass is calculated as a function of individual diameter at breast height (*DBH*) using the following equation derived by Sollins (1973):

$$BIOMASS = 0.1193DBH^{2.393} \qquad \text{(III-17)}$$

A summary of total stand basal area, density, and biomass can also be printed.

The ability to produce binary random access files of species basal area, density, and biomass by year averaged across all passes of a specific model was added to FORSMO. The biomass files generated were used in the model runs described below.

Miscellaneous. Model components not previously mentioned include subroutines ERROR and GGNORD and the RANDU function. Subroutine ERROR is called when the number of trees in a plot exceeds 700. The subroutine displays an error message and then terminates the program. The 700 maximum number of trees was never exceeded in the model runs discussed below.

Function RANDU is a random number generator. The original random number generator used in FORET was designed for a mainframe computer and was not portable to the microcomputer on which FORSMO was run (see Model Compilation below). The random number generator used in FORSMO was extracted from Press et al. (1986) and is based on three linear congruential generators, one each for the most and least significant parts of the output number and the third to control a shuffling routine. The random number generator returns values (ρ) such that $0 \leq \rho < 1$.

Subroutine GGNORD generates normally distributed random numbers with a zero mean and unit variance. The subroutine is the same as that in FORET and is based on equation 7.2.10 in Press et al. (1986).

Model Compilation. The Fortran code for the model was compiled using RM/FORTRAN version 2.4 (Ryan-McFarland, Corp. 1987) on a 66 MHz, 486 DOS based microcomputer. All model runs (see below) were performed on the same computer. For informational purposes, an 800 year simulation takes approximately 25 seconds for one pass or 21 minutes for the standard 50 passes.

Model Simulation

All model runs described below were run for a total of 800 years with 50 passes. Results (below) are based on the annual means for the 50 passes.

GRSM Gradient. The first simulation involved running the model across the entire GRSM gradient. Model runs were performed for gradient positions (*GRADL*) 0 through 100 by increments of 10 (i.e., *GRADL*=0, 10, 20, ...100). In these runs, all species, including *Castanea dentata*, were incorporated into the simulation. This simulation was run to model forest dynamics across the entire GRSM gradient and to reveal patterns of species absence or presence and biomass by time along the gradient. This set of simulations, because of the inclusion of *C. dentata*, is intended to represent forest conditions prior to the chestnut blight. Output from these runs were summarized by graphing percent biomass by year by species.

GRSM Gradient without *Castanea dentata*. Another set of simulations was performed for gradient positions (*GRADL*) 40 and 50 with *C. dentata* excluded as an eligible species in the simulation. This simulation attempts to illustrate the change in forest dynamics as a function of the loss of *C. dentata* due to the chestnut blight. *C. dentata* was a dominant species in only this portion of the gradient (approximately $35 < GRADL < 50$). As above, the output from this simulation was summarized by graphing percent biomass by year by species.

Distribution of *Castanea dentata*. The next simulation involved constructing the pre-blight biomass distribution of *C. dentata* across the gradient. This involved running the model for gradient positions (*GRADL*) 30 through 60 by increments of 2 (i.e., *GRADL*=30, 32, 34, ... 60) with all species. In this simulation, *C. dentata* biomass by year by gradient position was plotted using SURFER version 4.04 contouring and surfacing software (Golden Software, Inc. 1989). *C. dentata* biomass for every 10th year for every other gradient position from 30 to 60 was input into the SURFER package. Gridding of the original input data was performed using the default values of the SURFER GRID module. These defaults include a minimum curvature

(MinCurve) interpolation with an error level of 0.05 to produce an output grid of 76 x 67 points. The SURFER TOPO module was used to convert the resultant grid into a contour plot. Within TOPO, contours were smoothed using a tension factor of two.

Loss of *Abies fraseri*. The final simulation involved running the model to simulate the effects of a loss of *A. fraseri* due to the balsam wooly adelgid (*Adelges piceae* Ratz). The Spruce - Fir forests of GRSM are experiencing a tremendous die-back of *Abies fraseri* due to the balsam wooly adelgid (Eagar 1984b). Nicholas et al. (1992) state that *Abies fraseri* populations in GRSM have been decimated by adelgid infestation. This simulation attempts to illustrate the effects of *Abies fraseri* loss at two locations on the gradient.

The simulation was performed by taking the result of the GRSM gradient run for gradient position (*GRADL*) 100 and adding an additional run at position 95. Another series of runs were performed at gradient positions 95 and 100 but in these runs, the growth increment (*DINC*) for *A. fraseri* was set to 0.0 mm for year $\geq$ 250. Results of these runs were summarized by graphing percent biomass by year by species.

Results and Discussion

GRSM Gradient

Results of model runs across the GRSM gradient are presented in Figures III-2 through III-12. These figures illustrate the model's ability to produce shifts in species dominance as a function of time and position along the gradient. Simulations of stands at the low end (*GRADL* = 10) of the gradient (Figure III-2) are dominated by *Pinus rigida*. *P. rigida* is dominant throughout the 800 years of model simulation. *Quercus velutina* is present throughout as a

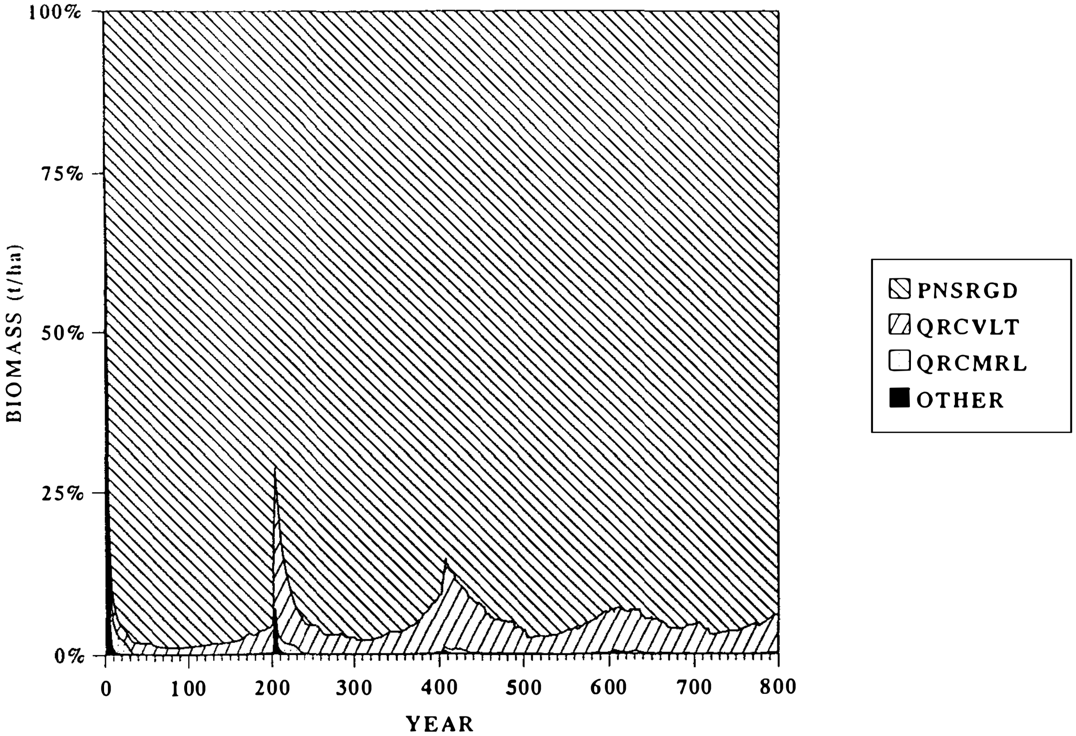


Figure III-2. Percent biomass by year for gradient position zero and all species.

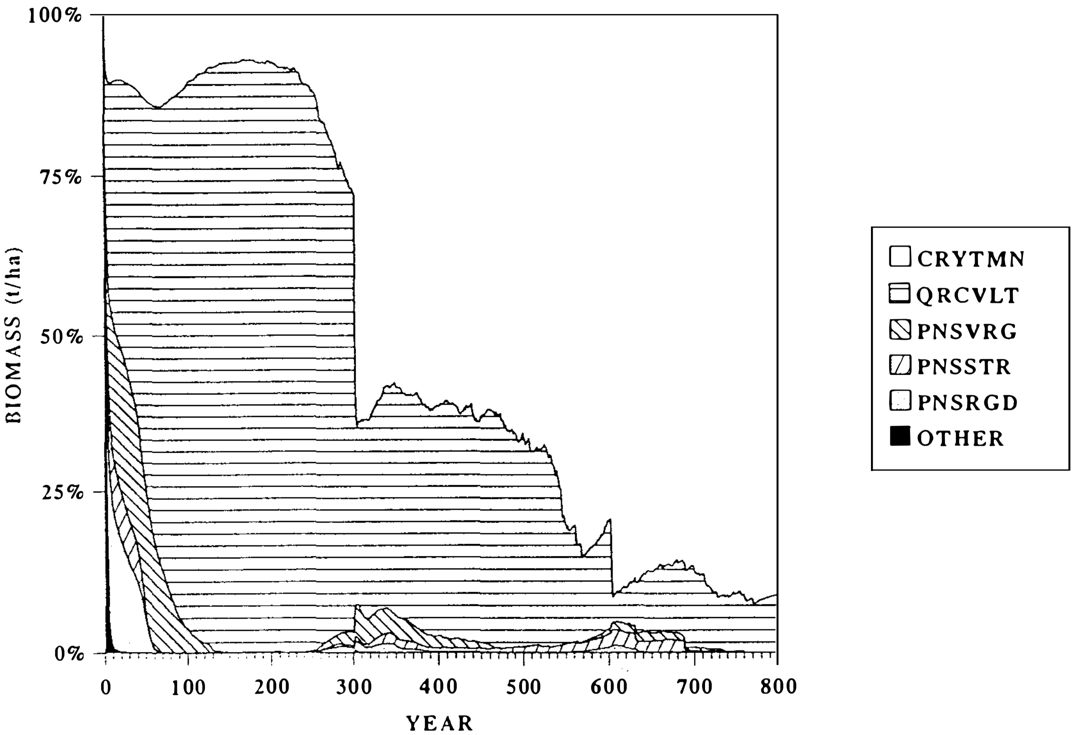


Figure III-3. Percent biomass by year for gradient position 10 and all species.

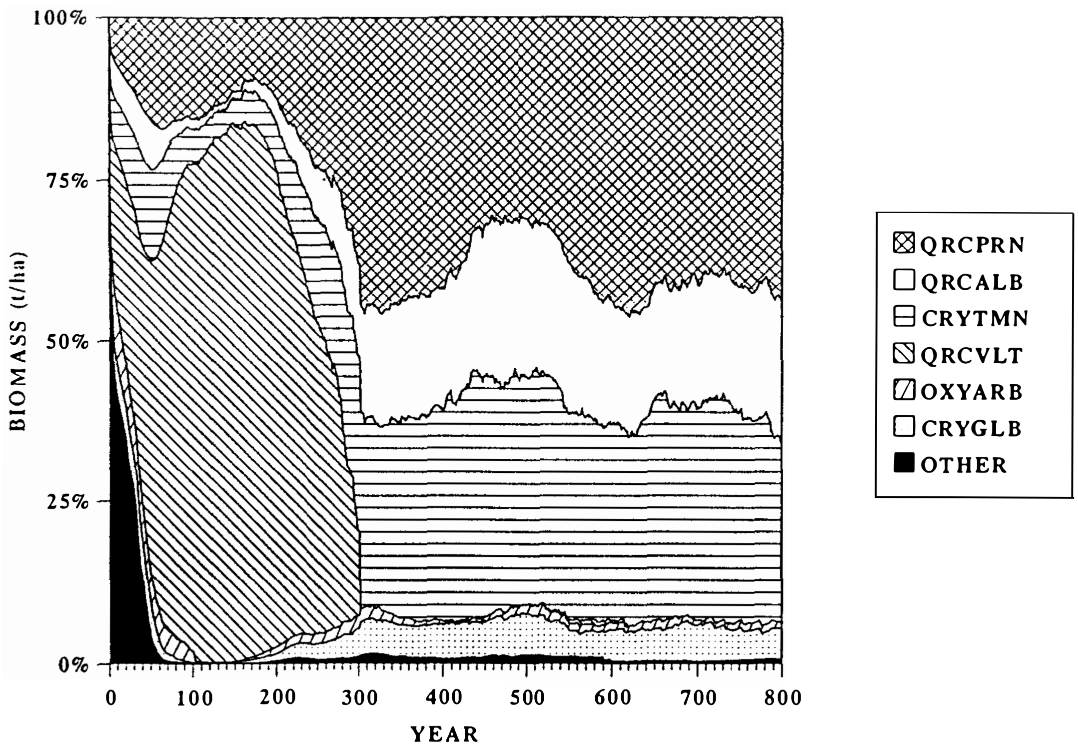


Figure III-4. Percent biomass by year for gradient position 20 and all species.

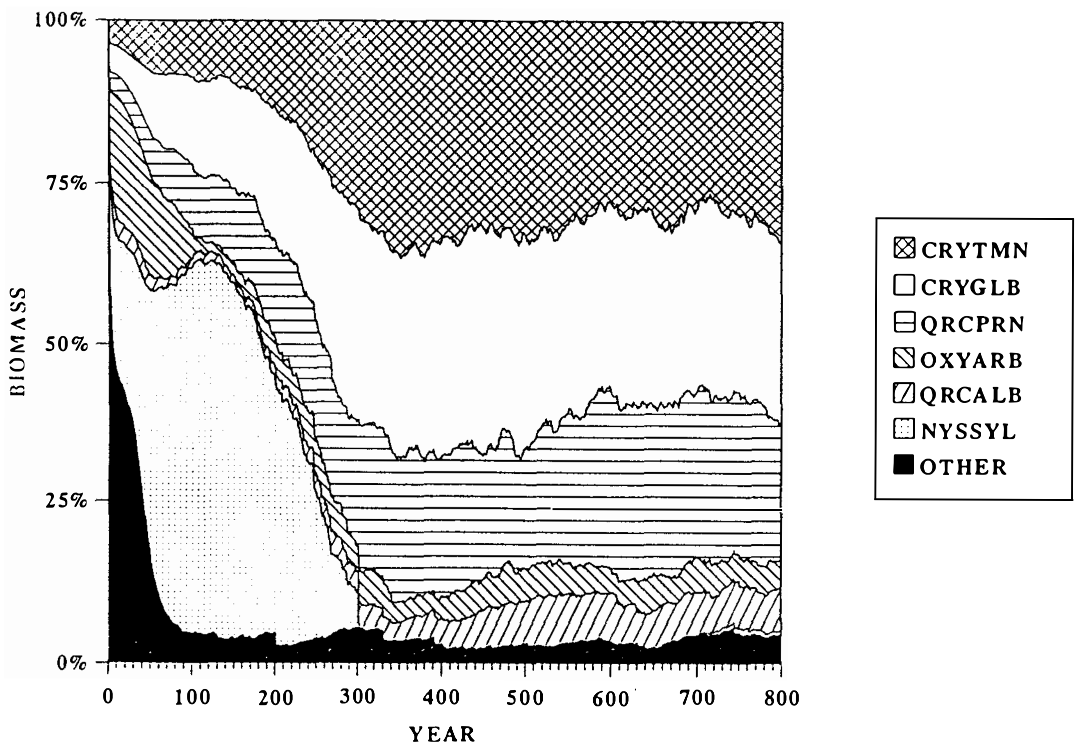


Figure III-5. Percent biomass by year for gradient position 30 and all species.

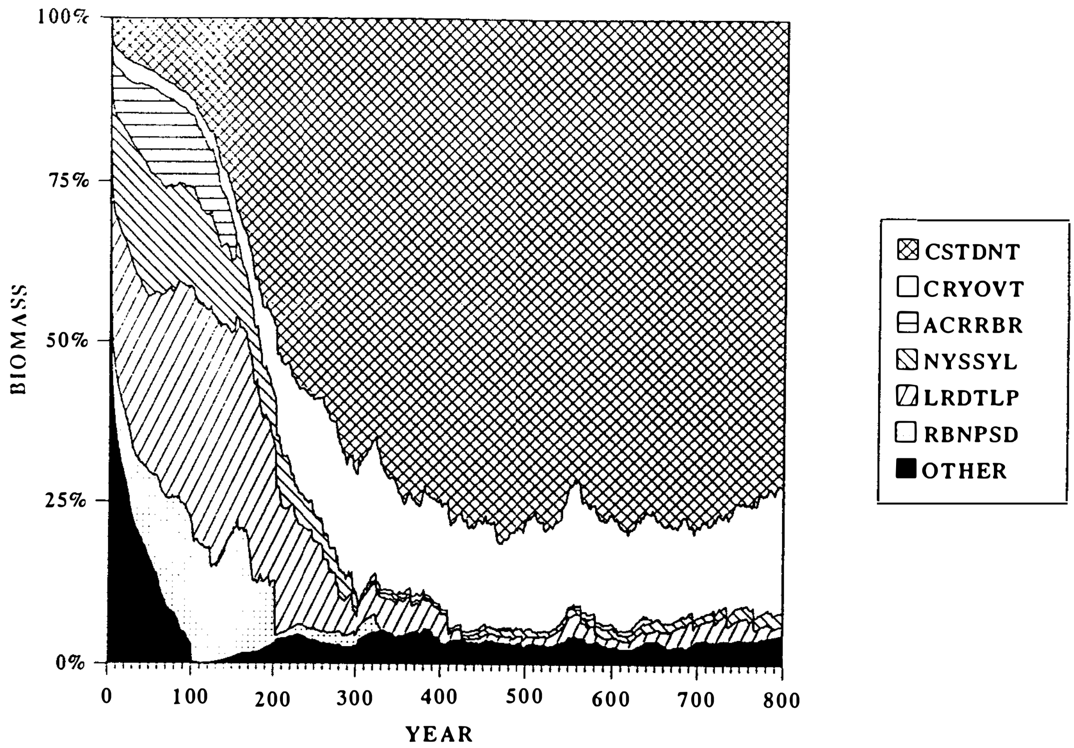


Figure III-6. Percent biomass by year for gradient position 40 and all species.

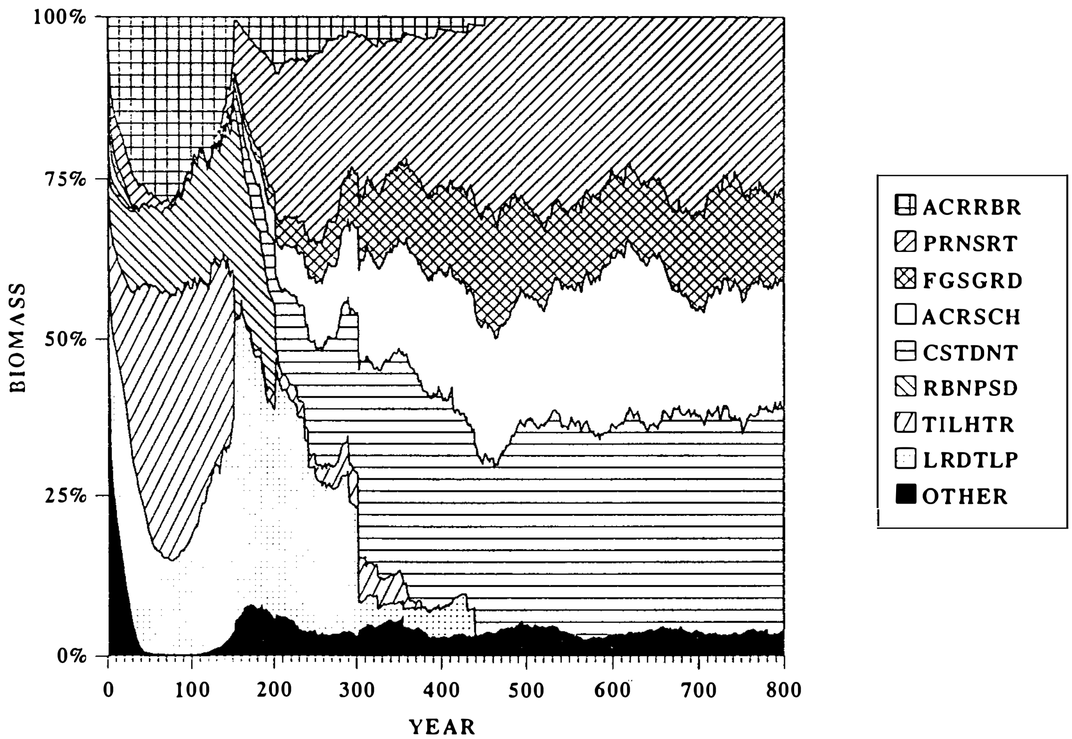


Figure III-7. Percent biomass by year for gradient position 50 and all species.

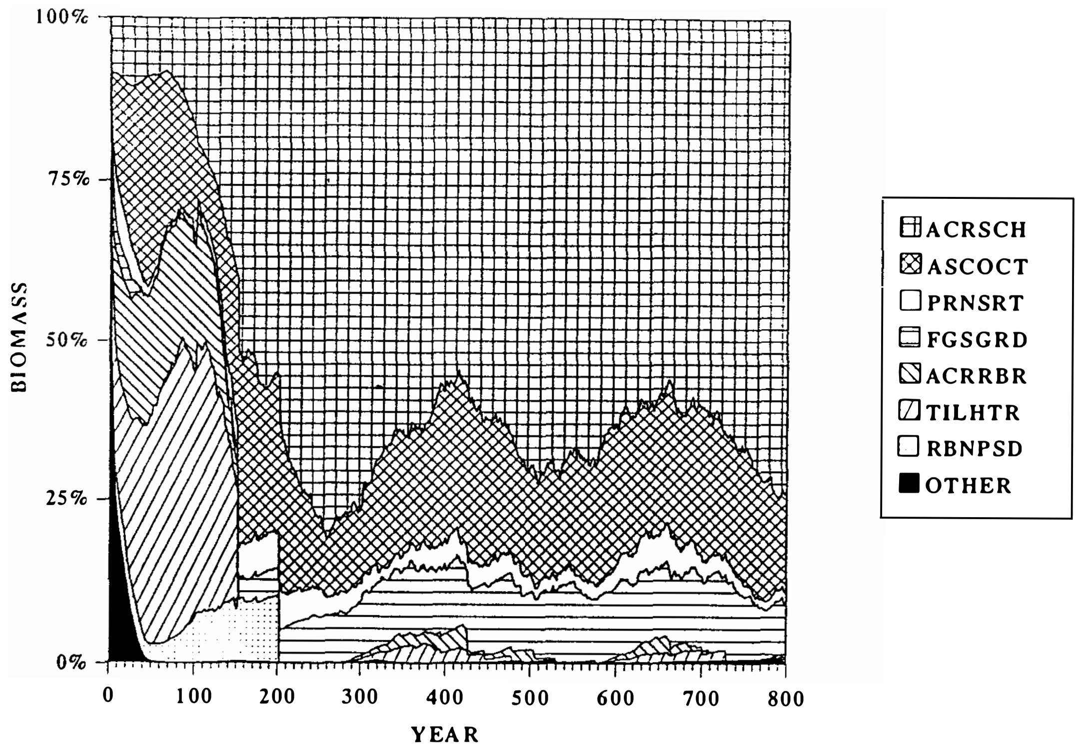


Figure III-8. Percent biomass by year for gradient position 60 and all species.

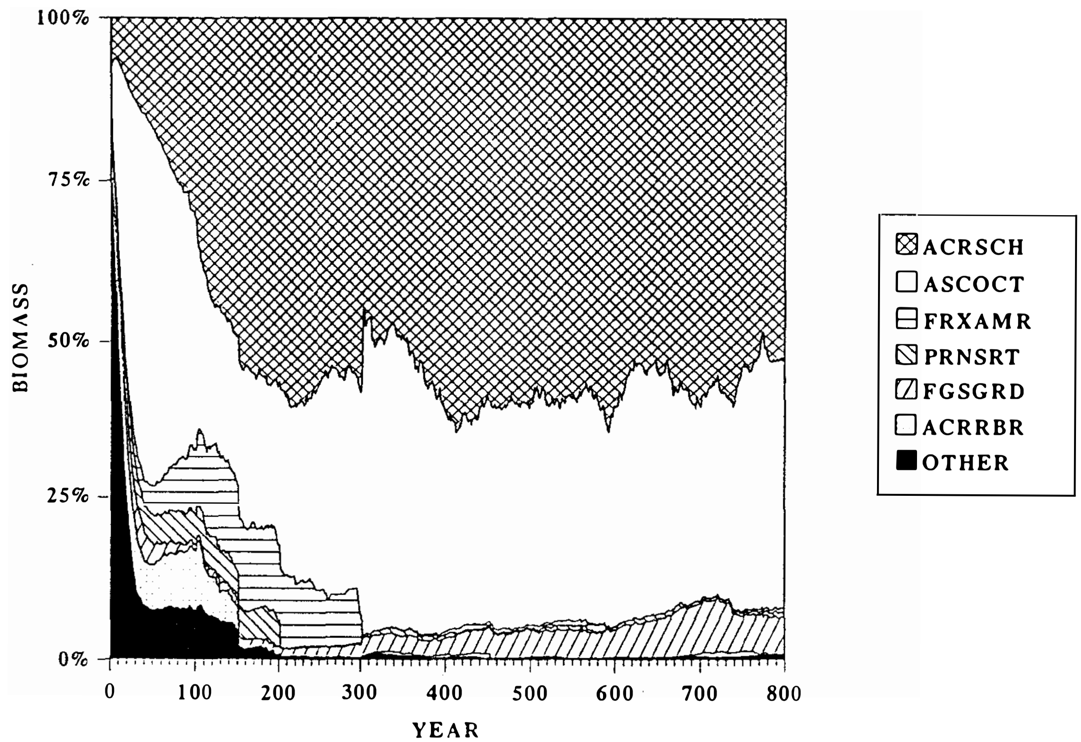


Figure III-9. Percent biomass by year for gradient position 70 and all species.

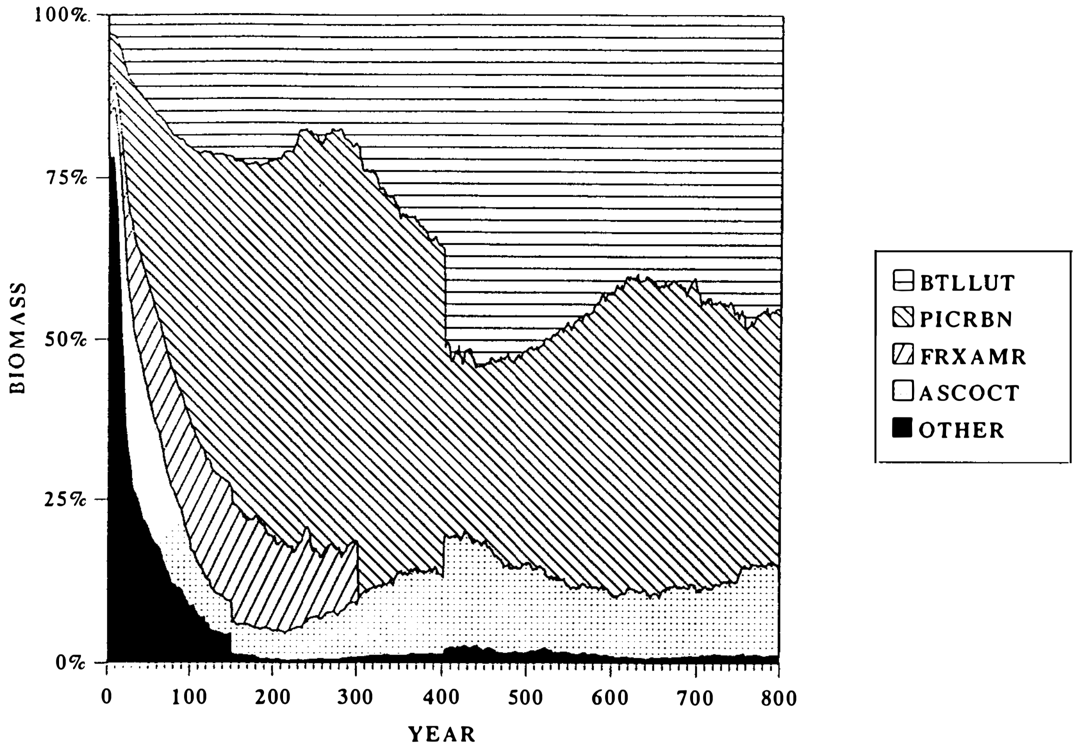


Figure III-10. Percent biomass by year for gradient position 80 and all species.

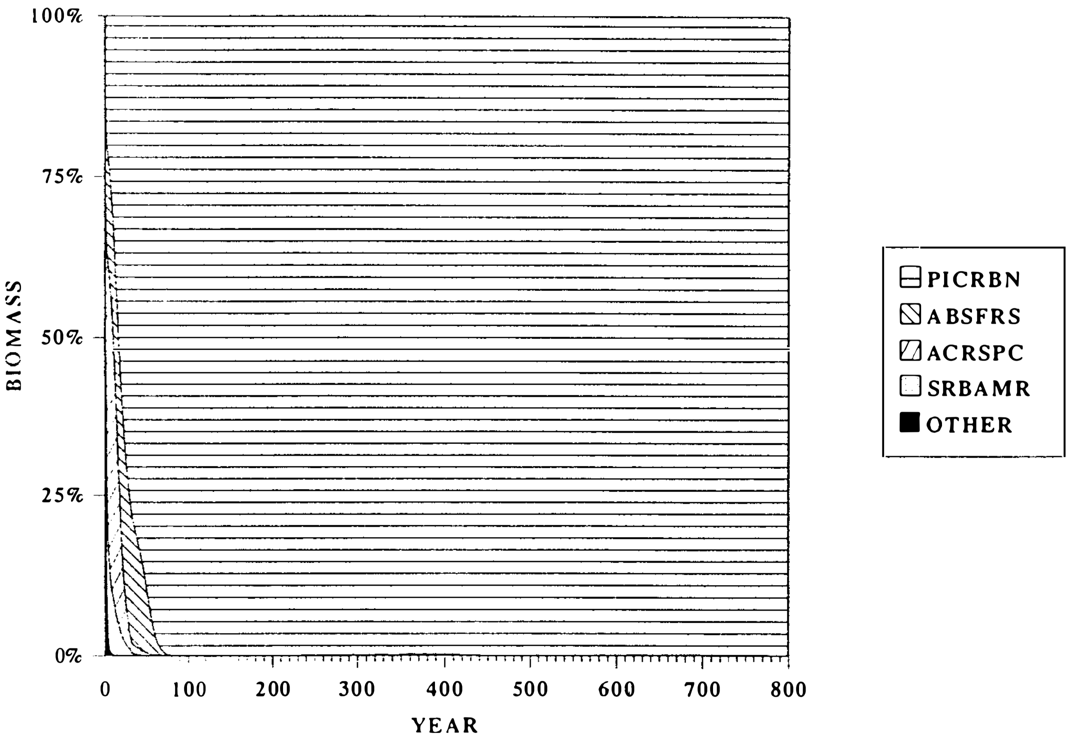


Figure III-11. Percent biomass by year for gradient position 90 and all species.

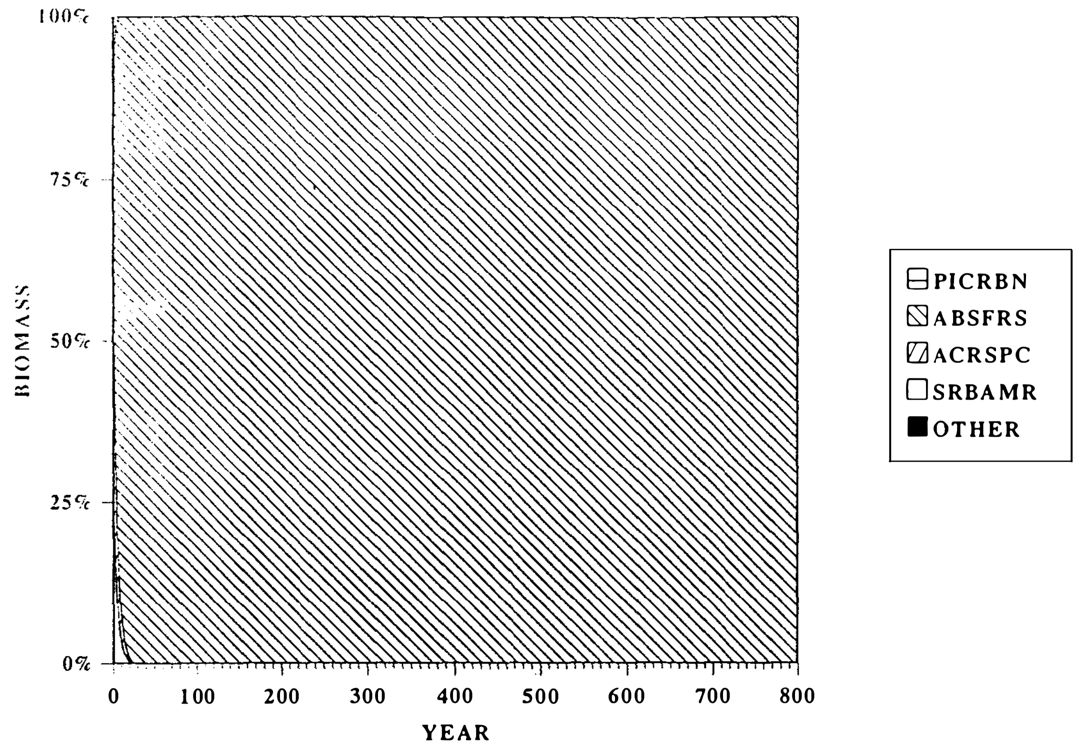


Figure III-12. Percent biomass by year for gradient position 100 and all species.

minor species. *Q. velutina* exhibits a 200 year cyclic increase in biomass throughout the 800 years timed to die-offs of *P. rigida* at its 200 year maximum life span. The forest simulated in this portion of the gradient is felt to represent the *P. rigida* type discussed in Chapter I and what are generally considered to be Yellow Pine stands in other classifications (Miller 1938, Whittaker 1956, Callaway et al. 1987).

At gradient position 10 (Figure III-3) *Quercus velutina* dominates during early successional stages (years 0-300) but is replaced by *Carya tomentosa* in later years. *Pinus virginiana, P. strobus, and P. rigida* are present as minor species during the early successional stage but drop out of the stand by year 130. They re-enter the stand at year 250, timed with the die-off of *Q. velutina,* and exhibit 300 year cyclic increases.

The stand simulated at this gradient position is somewhat of an enigma in that it is not recognized as occurring within GRSM. Whittaker (1956) recognizes a Red Oak - Pignut Hickory forest within GRSM. He describes this type as being dominated by *Quercus rubra*, *Q. alba*, *Carya glabra*, and *C. tomentosa*. *Q. velutina* is typically found in such stands. The stand simulated at this gradient position may represent a dry site variation of Whittaker's (1956) Red Oak - Pignut Hickory type. While not common in GRSM, Braun (1950) states that Oak - Hickory forests are found within the Oak - Chestnut Region but are generally confined to low hills in the Ridge and Valley Section or to the foothills of the southern Appalachians.

A greater diversity of dominant species occurs later in the succession stage at gradient position 20 (Figure III-4). As with gradient position 10, *Quercus velutina* is dominant during the early successional period of 0-250 years. After 250 years, *Q. prinus* becomes established as a co-dominant with *Carya tomentosa. Q. alba* is present as a sub-dominant after 300 years. *Carya glabra* is also present after year 300 but only as a minor species. This type, with its dominance by *Q. prinus*, is felt to represent the Chestnut Oak types of Golden (1981) and

Callaway et al. (1987). As with gradient position 10, the percent biomass of *Carya*, in this case *Carya tomentosa*, is problematic.

Nyssa sylvatica is the dominant early succession species at gradient position 30 (Figure III-5). *Quercus prinus*, *Carya tomentosa*, and *C. glabra* are co-dominant in later successional stages. *Q. alba* and *Oxydendron arboreum* are present throughout but represent a small percentage of the total biomass. This forest is felt to represent another variation of the Chestnut Oak types of Golden (1981) and Callaway et al. (1987). As with gradient positions 10 and 20, the abundance of *Carya* is problematic.

Between gradient position 30 and 40, *Castanea dentata* achieves dominant status (see Distribution of *Castanea Dentata* below). At gradient position 40 (Figure III-6), *Acer rubrum*, *Liriodendron tulipifera*, *Nyssa sylvatica*, *Robinia pseudoacacia* are equally dominant as early successional species. *Castanea dentata* achieves dominance at year 200 and maintains this dominance throughout the remainder of the simulation. *Carya ovata* is also present as a sub-dominant for years 200 and beyond. This type represents the Oak - Chestnut type of Miller (1938). Finding an analog in any of the more recent classifications is difficult due to the loss of *Castanea* due to the chestnut blight. It is felt that the transition from gradient position 30 to 40 represents the range of what were once Oak - Chestnut forests that Miller (1938) described as having the widest distribution of any type in GRSM. This range also represents the range of distribution of the *Quercus alba - Castanea dentata, Quercus prinus* and *Castanea dentata - Quercus prinus* types described in Chapter I.

Castanea dentata is a co-dominant after year 300 at gradient position 50 (Figure III-7). *Robinia pseudoacacia*, *Liriodendron tulipifera*, *Acer rubrum*, and *Prunus serotina* are early successional species at this position on the gradient. *A. rubrum* and *L. tulipifera* persist longer than *P. serotina* and *R. pseudoacacia*. *C. dentata* and *Tilia heterophylla* are co-dominant in the later stages of succession with *Fagus grandifolia* and *A. saccharum* as sub-dominant. The forests in this gradient position represent a transition from the Oak - Chestnut of Miller (1938) to the Cove Hardwood type described by many researchers (Miller 1938, Whittaker 1956, Golden 1981).

At gradient position 60 (Figure III-8), *Acer saccharum* achieves dominance at year 200 and maintains that dominance throughout the remainder of the simulation. *Robinia pseudoacacia* is present in the early successional stage. *Acer rubrum* and *Tilia heterophylla* are also present in the early successional stage and repeat cyclically at later stages of the simulation (i.e., years 300-500 and 600-750). *Aesculus octandra* and *Fagus grandifolia* are sub-dominant in later successional stages. *Prunus serotina*, while not a dominant, persists as a minor species throughout all years of the simulation. Forests at this position on the gradient are the best representatives of the Cove Hardwood forests of Miller (1938), Whittaker (1956), and Golden (1981).

Acer saccharum and *Aesculus octandra* dominate throughout the simulation at gradient position 70 (Figure III-9). *Acer rubrum*, *Prunus serotina*, and *Fraxinus americana* are early successional species. *Fagus grandifolia* is present throughout the simulation but with a low percent biomass. The simulated stand at this position on the gradient is probably best called Cove Hardwood but represents a Cove Hardwood forest of less diversity than that at gradient position 60. The stand seems to be transitional between the Cove Hardwood type and the Northern Hardwood type of gradient position 80.

Gradient position 80 (Figure III-10) represents a Northern Hardwood vegetation type. *Betula lutea* dominates in the later successional stages with *Aesculus octandra* as a sub-dominant. *Fraxinus americana* is an early successional species. *Picea rubens* is present upon stand establishment but is not able to reproduce after its species maximum of 400 years. This stand represents the Northern Hardwood type of Whittaker (1956) and Yellow Birch - Spruce type of Golden (1981). It is also representative of the *Betula lutea - Picea rubens* type described in Chapter I.

Gradient positions 90 and 100 (Figures III-11 and III-12) represent a transition from *Picea* dominated to *Abies* dominated. At gradient position 90, *P. rubens* dominates throughout the simulation with cyclic increases in *Abies fraseri* occurring at approximately 400 year intervals, which corresponds to the maximum age of *P. rubens*. *Acer spicatum* and *Sorbus americana* show the same cyclic tendencies as *A. fraseri* but with less biomass. This stand represents the Red Spruce forest of Whittaker (1956) and Spruce type of Miller (1938) though Whittaker points out that *Abies fraseri* occurs in most Red Spruce forests. *Abies fraseri* does not occur at gradient position 90 but does occur as a codominant with *Picea rubens* at gradient position 95 (see Loss of *Abies Fraseri* below).

At gradient position 100, *Abies fraseri* is the only tree species that occurs except for very small inputs of *Acer spicatum* and *Sorbus americana* at initial stand establishment. This stand represents the Fraser Fir forest of Whittaker (1956) and the *Abies fraseri* type of Chapter I.

The above summary of model output has demonstrated FORSMO's ability to simulate a variety of forest types across the GRSM moisture-elevation gradient. Some general trends in model output are also apparent across the gradient. These trends include an establishment of species which only persist in the early stages of succession (pioneers). These early successional species persist until their maximum age is reached at which point they are replaced by late successional (climax) species that persist throughout the remainder of the simulation. This trend is not apparent at either end of the gradient (gradient positions 0 and 100, Figures III-2 and III-12). The lack of diversity at either end of the gradient reflects the nature of the coenoclines used for species parameterization and ultimately the gradient itself. Figures I-11 and I-12 clearly show the limited diversity of species at either end of the gradient. This paucity of species is the main reason for a decided lack of successional patterns at the ends of the gradient.

Another pattern that is obvious from this series of model runs is that species compositional changes, in general, take place very rapidly across the gradient. Only one species, *Acer saccharum*, maintains a clear dominance at two different gradient positions (positions 60 and 70, Figures III-8 and III-9). This suggests that running the model for smaller increments along the gradient position is important for detailed analysis of particular species and vegetation types (see Distribution of *Castanea Dentata* below).

While the model does show changes across the gradient, not all model output represents vegetation types characteristic of GRSM as reported in the literature. It is also worth mentioning that not all of the vegetation types described in Chapter I have been replicated in this series of simulations. It is assumed that these types would be replicated if gradient positions for model runs were selected more meticulously. That the model simulates forest communities that have not been described in the literature (i.e., the Oak - Hickory type of gradient position 10), while disconcerting, cannot be unexpected. While FORSMO incorporates a gradient developed specifically for GRSM, this gradient is coupled in such a way that species importance, regardless of how it is measured (i.e., basal area, density, or biomass) is not taken into account. Therefore, a locally uncommon species (or genera such as *Carya*) can dominate a stand if its growth parameters allow. This is the case with *Carya*.

It has been shown that FORSMO can vary model stands of varying species composition across the gradient (Figures III-2 to III-12). Figure III-13 provides an example of the structural dynamics of the model for the stand simulated at gradient position 20. As mentioned earlier,

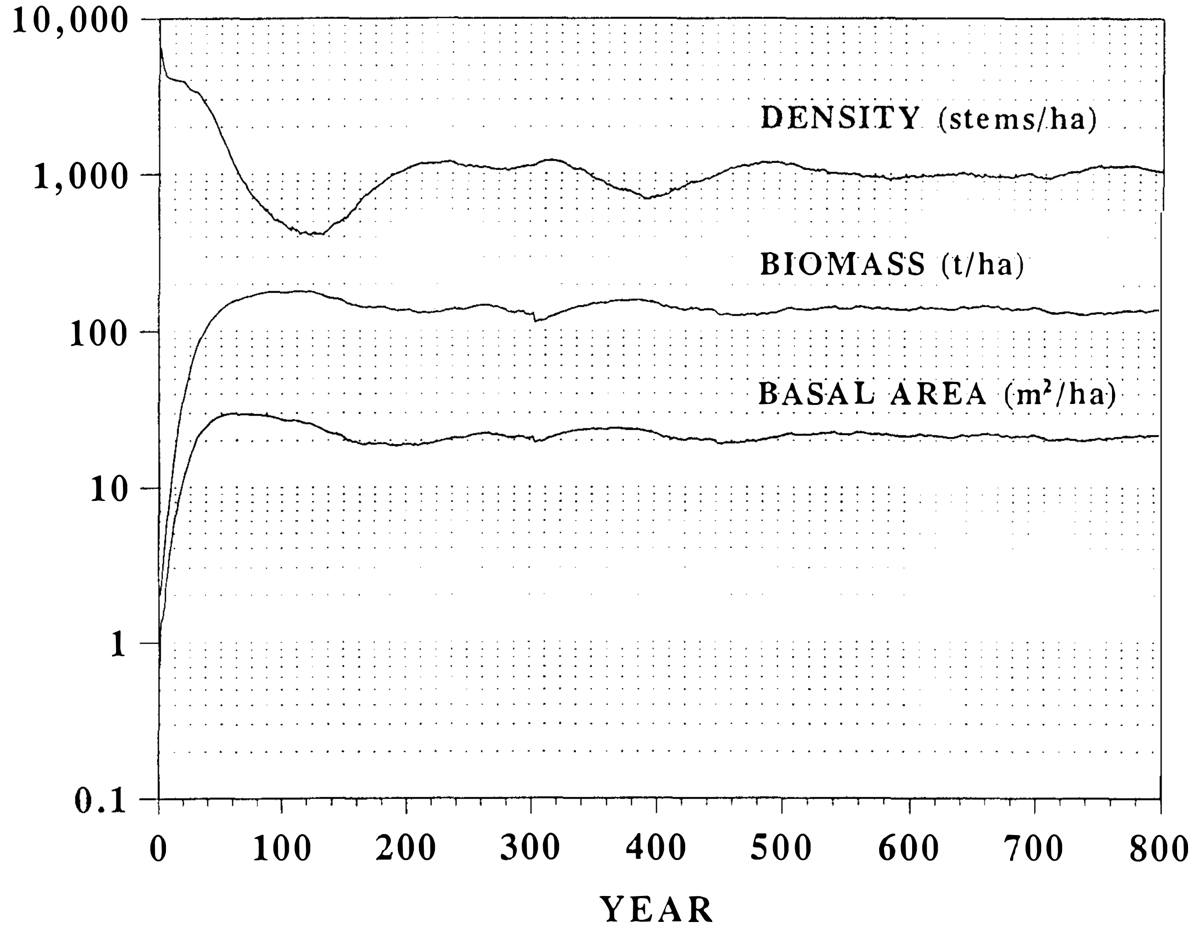


Figure III-13. Total stand basal area, density, and biomass by year for gradient position 20.

this stand represents the Chestnut Oak described by Golden (1981) and Callaway et al. (1987). The mean total basal area, density, and biomass across all 800 years of the simulation are 21.5 m^2/ha, 114.3 stems/ha, and 137.6 t/ha, respectively. The mean basal area for the stand compares well with the mean of 23.6 m^2/ha derived for Chestnut Oak stands in Callaway et al. (1987). The density and biomass values are also comparable to values of 1004 stems/ha and 163.4 t/ha obtained by Harrison and Shugart (1990) for a Chestnut Oak forest in the Blue Ridge Mountains of Virginia. The simulated values are low compared to the values of 35 m^2/ha, 2130 stems/ha, and 420 t/ha, for basal area, density, and biomass, respectively, obtained by Whittaker (1966) for a Chestnut Oak stand in GRSM. Based on the comparison of values in Callaway et al. (1987) and Harrison and Shugart (1990) it is felt that the model adequately replicates the structural attributes of Chestnut Oak forests in GRSM.

GRSM Gradient without *Castanea Dentata*

Output from model runs with *Castanea dentata* removed are presented in Figures III-14 and III-15 for gradient positions 40 and 50, respectively. At gradient position 40, *Castanea dentata* is replaced by *Carya ovata*. *Quercus rubra* appears as a subdominant with the removal of *Castanea dentata*. *Q. rubra* does not grow to any extent in competition with *Castanea dentata* at this gradient position. *Carya tomentosa* is also present in the absence of *Castanea dentata*. The status of the early successional species (i.e., *Acer rubrum*, *Nyssa sylvatica*, *Liriodendron tulipifera*, and *Robinia pseudoacacia*) is unaffected by the removal of *Castanea dentata*. Woods and Shanks (1959) state that one direction of *Castanea* replacement was via an increase on *Quercus*, specifically *Q. prinus* and *Q. rubra*. The appearance of *Q. rubra* as a subdominant in the stand simulated with the exclusion of *Castanea dentata* is in accord with this observation.

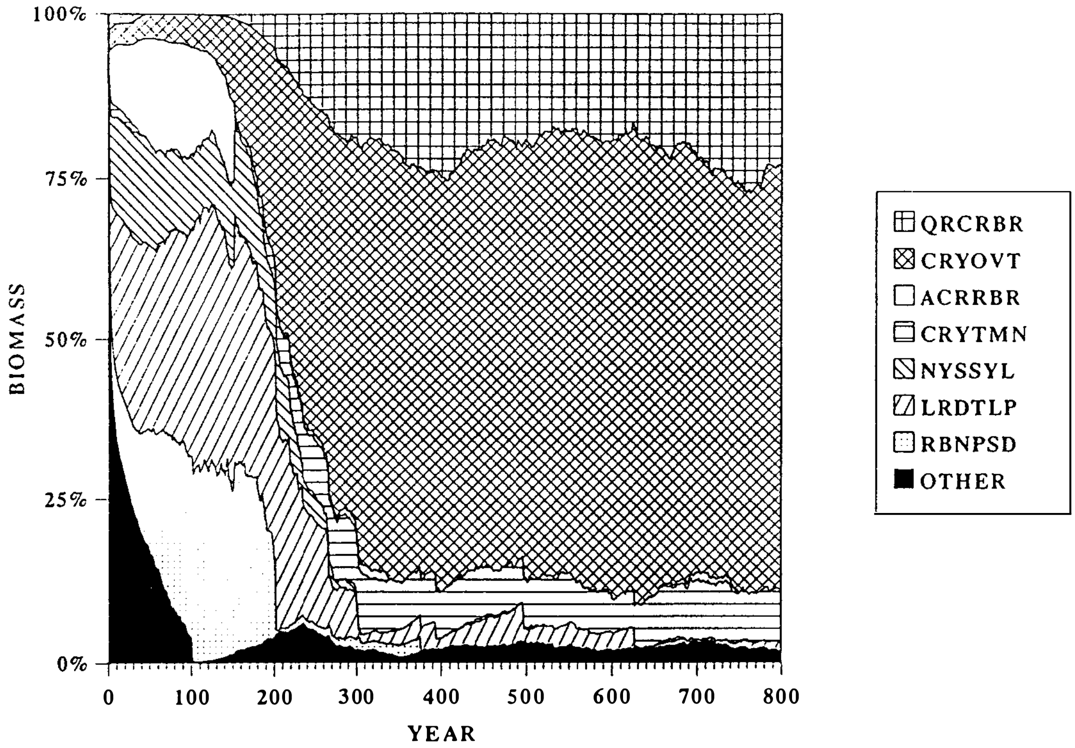


Figure III-14. Percent biomass by year for gradient position 40, without *Castanea dentata*.

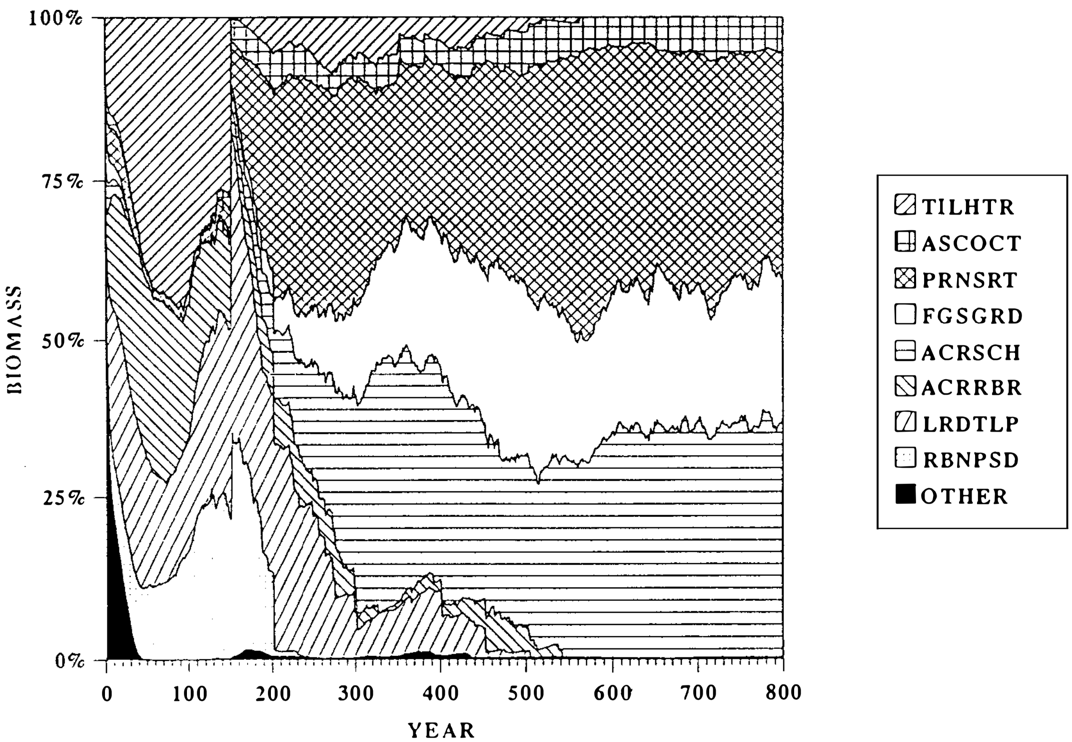


Figure III-15. Percent biomass by year for gradient position 50, without *Castanea dentata*.

At gradient position 50 (Figure III-15), the removal of *Castanea dentata* is mainly offset by an increase in the percent biomass of species already present. *Aesculus octandra*, *Fagus grandifolia*, *Acer saccharum*, and *Prunus serotina* all increase in percent biomass with the removal of *Castanea dentata*. Nelson (1955) described *Castanea dentata* replacement as mainly involving the increased dominance of species present with *Castanea* prior to the blight. This appears to be the case in simulated stand at gradient position 50.

Past research into natural replacement of *Castanea dentata* (Nelson 1955, Woods and Shanks 1959) suggests that replacement took place via multiple pathways depending on the composition and habitat of the original forest. The model supports this assumption, based on the results of simulations at gradient positions 40 and 50. What past research has not shown is the status of biomass in pre- and post-blight stands. Results from the simulation run at gradient position 40 (Figure III-16) indicate that total stand biomass was reduced from 157 to 130 t/ha. This represents a 17% reduction in total stand biomass from pre-blight to post-blight conditions.

As the literature suggests that there were multiple pathways of *Castanea dentata* replacement, the model indicates that not all pathways resulted in an overall loss of biomass. The total stand biomass for pre- and post-blight conditions at gradient position 50 (Figure III-17) indicate a change from 116 to 111 t/ha or a 4% reduction in total stand biomass with the removal of *Castanea dentata*.

Distribution of *Castanea Dentata*

The ability of the model to adequately simulate incremental changes along the moisture-elevation gradient allows one to reconstruct the biomass dynamics of *Castanea dentata* by year and gradient position. The results of this reconstruction are shown in Figure III-18. This

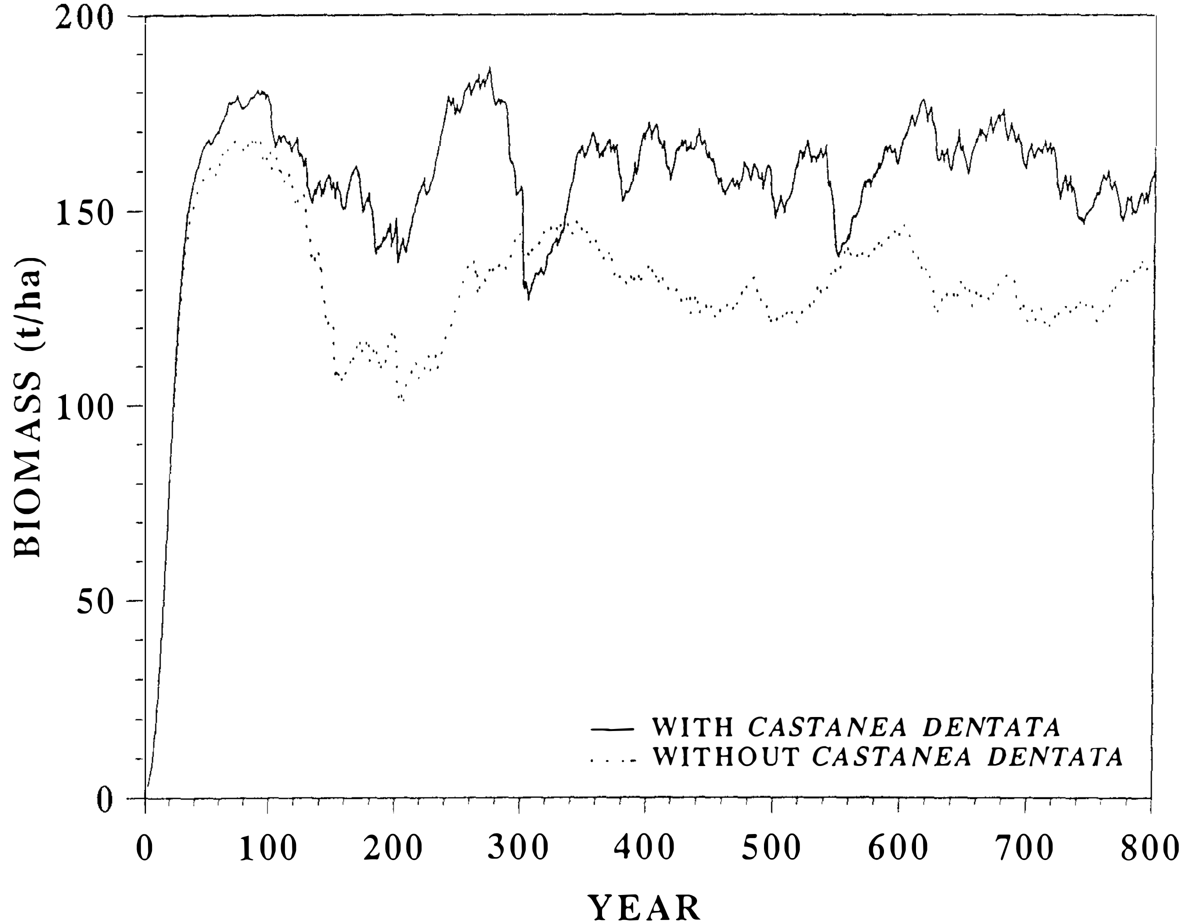


Figure III-16. Total stand biomass by year for gradient position 40. With and without *Castanea dentata*.

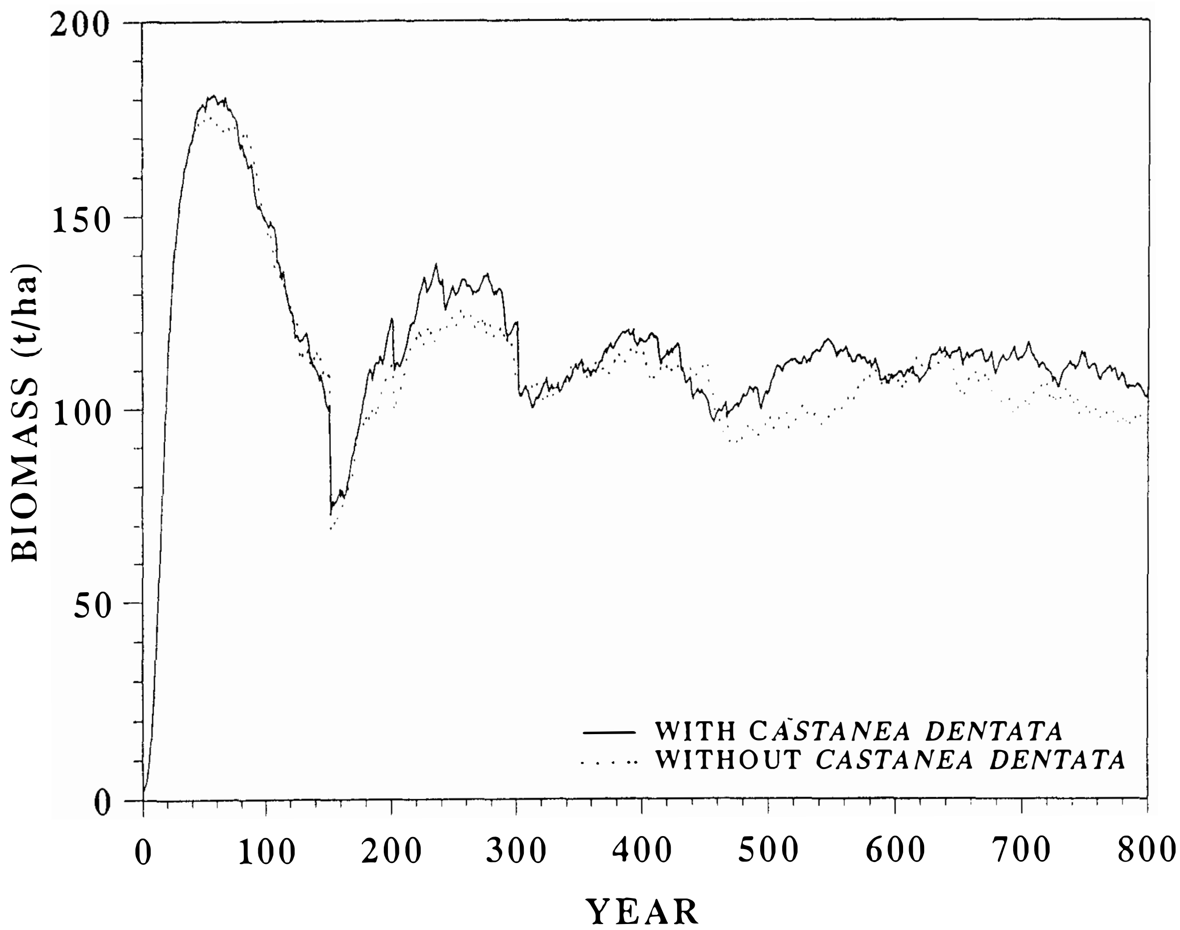


Figure III-17. Total stand biomass by year for gradient position 50. With and without *Castanea dentata*.

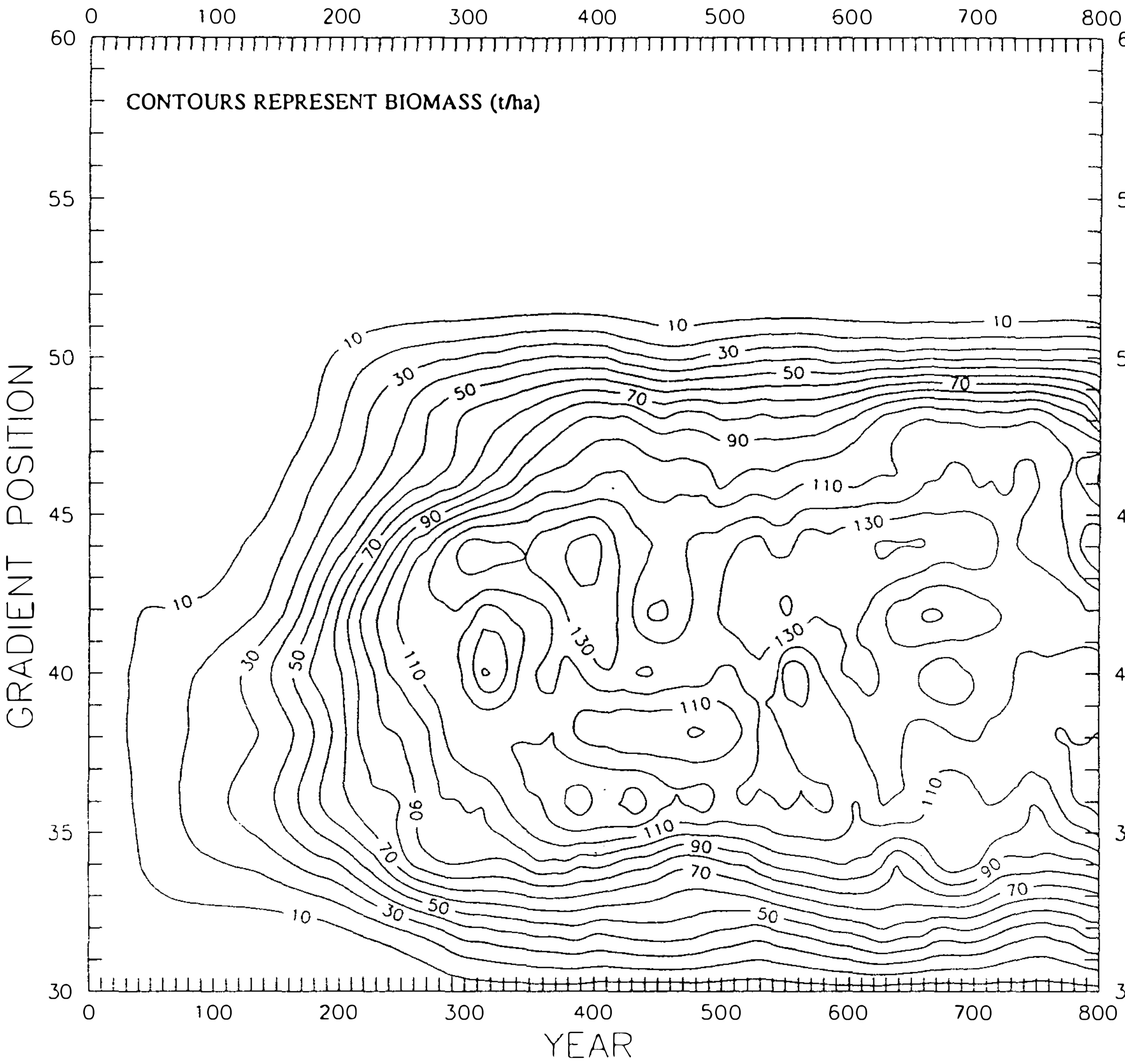


Figure III-18. *Castanea dentata* biomass by gradient position and year.

figure illustrates that *C. dentata* occurs with biomass > 10 t/ha from gradient positions 30 to 51 with maximum biomass occurring between gradient positions 40 and 45. The actual biomass maximum was 146 t/ha at gradient position 44 and year 400. This figure also illustrates that *C. dentata* biomass pattern at both ends of its distribution on the gradient is relatively abrupt with biomass increasing from 10 t/ha to 100 t/ha in 5 units along the gradient. After 300 years, *C. dentata* biomass remains relatively constant ranging from 110-140 t/ha between gradient positions 35 and 46. At its optimal position along the gradient (44) it takes *C. dentata* 300 years to achieve maximum biomass. At this position, biomass after 300 years remains relatively constant with time. This figure helps to emphasize the previous importance of *C. dentata* in the GRSM landscape prior to the chestnut blight, as mentioned in Chapter I and as discussed by others (Miller 1938, Braun 1950, Whittaker 1956, Woods and Shanks 1959).

Loss of *Abies Fraseri*

Results of the model runs simulating the loss of *Abies fraseri* are only marginally insightful. At gradient position 95 *Abies fraseri* and *Picea rubens* exist as codominants (Figure III-19). The stand simulated at this position, without the removal of *Abies fraseri*, is characteristic of the Spruce type described by Miller (1938) and the Spruce - Fir type described by others (Oostings and Billings 1951, Cogbill and White 1991, Nicholas et al. 1992). The simulated loss of *Abies fraseri* results in *Picea rubens* becoming the sole dominant (Figure III-20). Figure III-21 illustrates that this shift due to the loss of *Abies fraseri* takes place with an initial loss of biomass but that total stand biomass recovers in the course of 150 years. The results are consistent with the model results of Busing and Clebsch (1987) using their Spruce - Fir gap model. Busing and Clebsch (1987) predicted that total stand basal area in disturbed stands (i.e., adelgid infested) returns to the level of undisturbed stands. These modeled results,

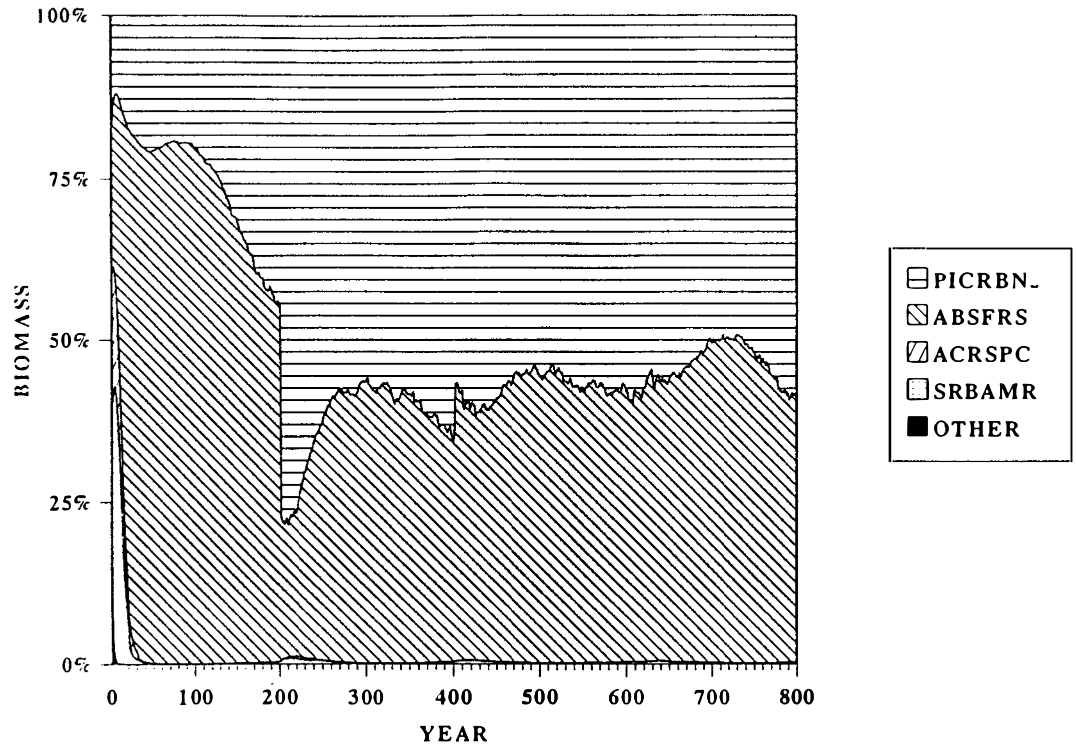


Figure III-19. Percent biomass by year for gradient position 95 and all species.

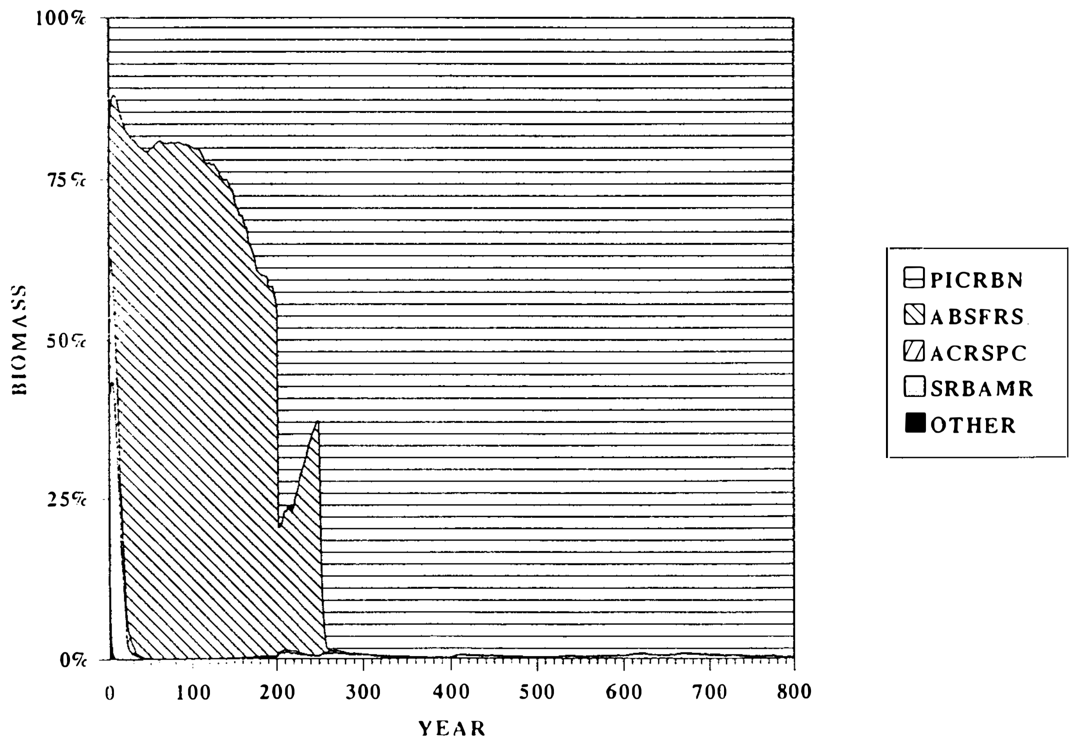


Figure III-20. Percent biomass by year for gradient position 95, *Abies fraseri* death at 250 yr.

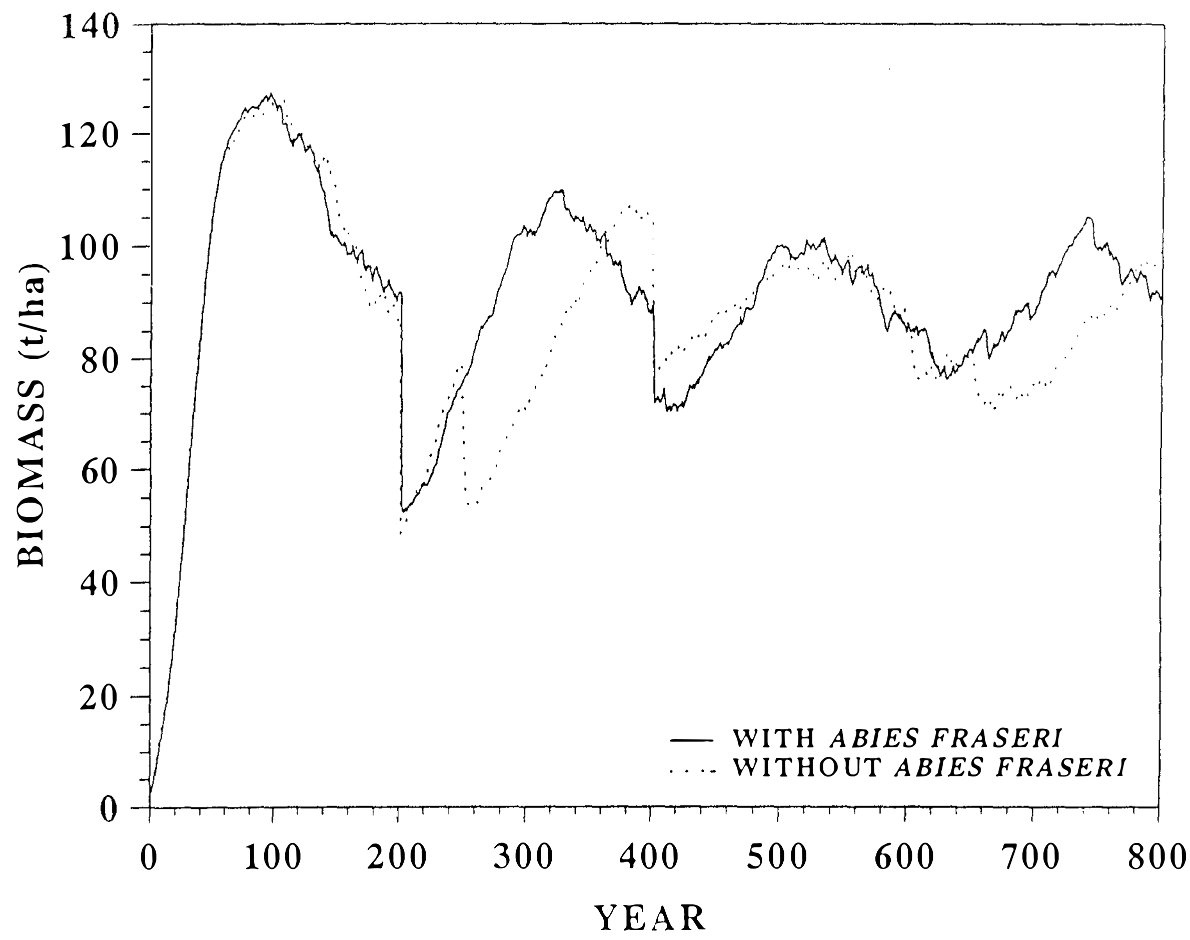


Figure III-21. Total stand biomass by year for gradient position 95. With *Abies fraseri* and without *A. fraseri* (i.e., *A. fraseri DINC* = 0.0 at year ≤ 250).

both FORSMO and those of Busing and Clebsch (1987) are not in agreement with the findings of Nicholas et al. (1992) and Zedacker et al. (1988) who suggest that, at least in the short term, the Spruce - Fir forest under balsam wooly adelgid infestation is susceptible to being decimated. They feel that *Picea rubens* in adelgid infested stands may have increased mortality rates due to the shock of sudden exposure with the rapid removal of the *Abies fraseri* canopy. This thinning shock has not been incorporated into FORSMO or the Spruce - Fir model of Busing and Clebsch (1987).

The loss of *Abies fraseri* at gradient position 100 produces a totally different result due to the inability of *Picea rubens* to successfully grow at this position along the gradient. The loss of *Abies fraseri* results in the near total removal of tree biomass (Figure III-22). What biomass is present in the tree stratum is split between *Sorbus americana* and *Acer spicatum* (Figure III-23). It is felt that this portion of the gradient represents a very small percentage of the GRSM landscape. Whittaker (1956) indicates that pure *Abies fraseri* stands occur only above 1890 m. Based on the model results, it is this area that will experience the greatest impact, both compositionally and structurally, due to infestation of the balsam wooly adelgid.

Conclusions

The FORSMO model presented in this chapter represents a successful integration of gap models of forest succession (Shugart 1984) and gradient analysis (Kessell 1979). The model produces stands of varying species composition that replicate forest types that occur within GRSM. The model tends to replicate stand structural characteristics that have been measured in similar forests. The model has been shown to simulate forest types that do not occur within GRSM, the Oak - Hickory forest type in particular. It is felt that this fault is due to the way in which the complex moisture-elevation gradient is integrated into the model. While the

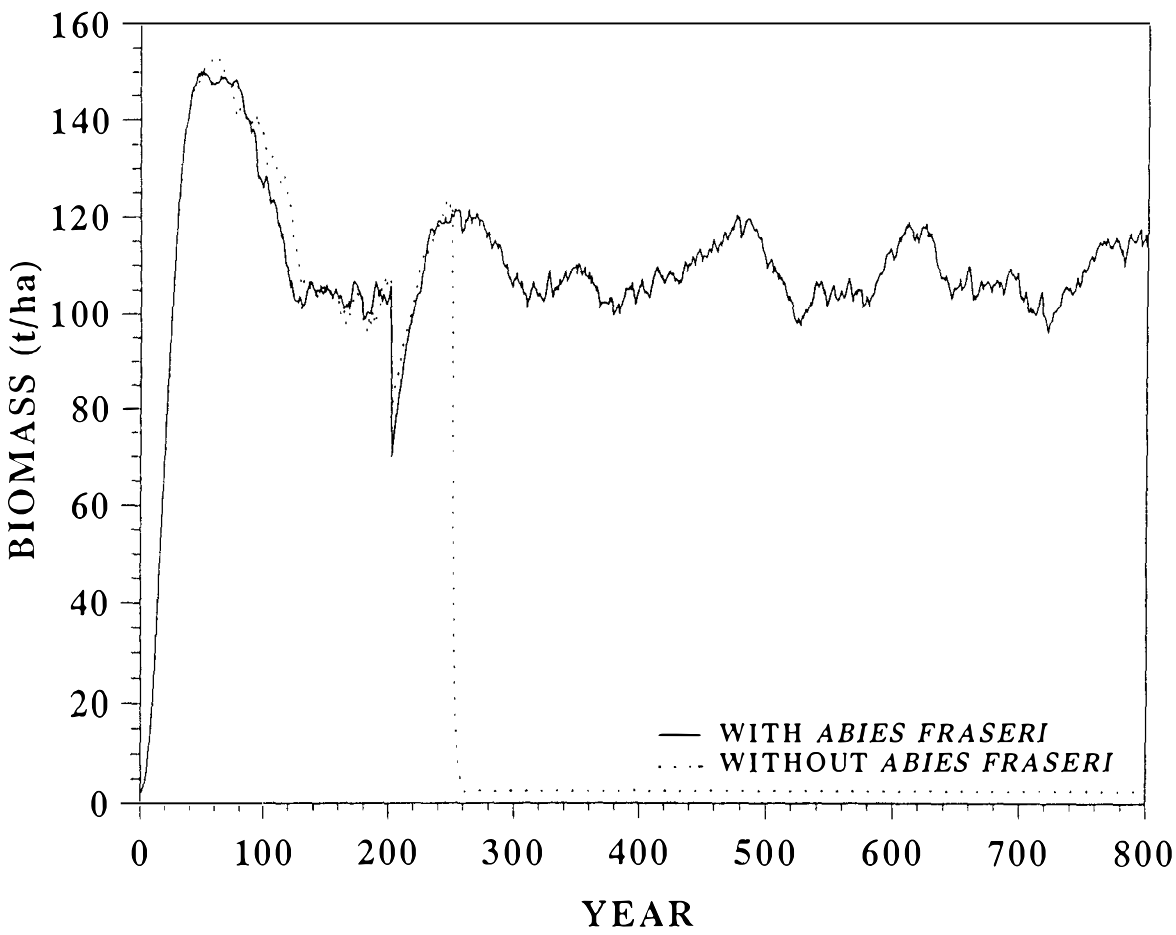


Figure III-22. Total stand biomass by year for gradient position 100. With *Abies fraseri* and without *A. fraseri* (i.e., *A. fraseri DINC* = 0.0 at year ≤ 250).

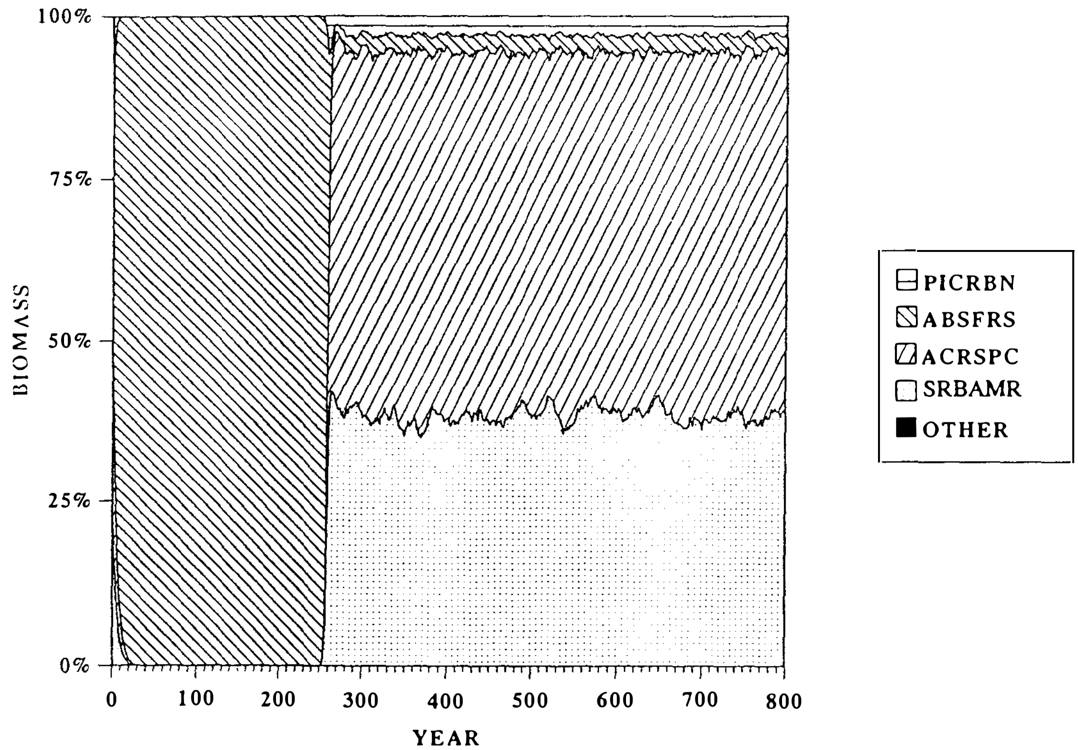


Figure III-23. Percent biomass by year for gradient position 100, *Abies fraseri* death at 250 yr.

coenoclines produced in Chapter I provide some insight into species abundance along the gradient, this information is not incorporated into the model. It was felt that incorporating dominance information would put too much emphasis on the gradient and reduce the importance of the independently determined species growth parameters.

The integration of the gradient information into the model extends the simpler functions of growth rates and competition for light. The gradient, while in many ways an abstraction, provides the necessary information to allow the model to replicate vegetation across the entire GRSM landscape. That the model is able to replicate these observed patterns suggests that the vegetation of GRSM responds to simple natural history rules, most of which operate at the species level. Gap models, which were originally designed to function at the stand level seem capable, with the addition of the appropriate drivers, of modeling patterns observed at landscape scales. These results suggest that gap models are capable of being "scaled up" to study processes at larger spatial scales. These results also imply that successional patterns at the landscape level are ultimately controlled by processes at the stand and species level.

The general trend in gap models of forest succession has been to apply the models to questions being addressed at larger scales or areas such as global change, and in particular, global climate change (Solomon 1986, Shugart et al. 1992). The FORSMO model represents what appears to be model development in the opposite direction. This direction was taken in order to develop a model that better represents forest response to change in the moisture-elevation gradient of GRSM. The dependence of the model on a gradient developed specifically for GRSM limits the applicability of the model, as it is currently parameterized, to use in GRSM. Having said this, it is also felt that FORSMO represents the best model yet developed to simulate forest responses within the entire GRSM landscape. The model has simulated forest recovery from the chestnut blight in a fashion similar to that reported in the literature (Nelson

1955, Woods and Shanks 1959). The model also confirms the importance of *Castanea dentata* in the pre-blight forest landscape of GRSM. FORSMO results also provide some insights into anticipated forest change due to the balsam wooly adelgid. The model, in its current form or with minor modifications, represents what could be a valuable tool for resources management within GRSM. FORSMO has the potential to address many management issues such as fuel loading, modeling impacts of infestation (i.e., pine bark beetle, gypsy moth, balsam wooly adelgid), and impacts of prescribed burning and wildfire on species composition and successional patterns.

While FORSMO has been parameterized specifically for GRSM, it does not mean that the model philosophy cannot be applied to other areas or larger regions. All that is required is the development of an environmental gradient for the area of interest. For example, the USDA Forest Service's continuous forest inventory (CFI) data set (Olson et al. 1980, Birdsey and Schreuder 1992) could provide the information required to develop an indirect environmental gradient for eastern North America. It may also be possible to tie a gradient into the general circulation models (GCMs) that are currently being developed or manipulated (Manabe and Wetherald 1986, White 1990) thus providing a mechanism to apply the integration gradient analysis with gap models to global scale studies.

SUMMARY

The research presented in the dissertation provides insights into the vegetation of GRSM in the context of both space and time. Chapter I and II consider the vegetation from a whole park perspective. This research represents the first quantitative summary of the park's vegetation *in toto*. A comparison of the classification results presented in Chapter I with previous descriptions of the vegetation of GRSM (Whittaker 1956, Golden 1981, and Callaway et al. 1987) reveals the importance of the whole park perspective. Previous research has not provided an adequate summary of the complete vegetation of GRSM. Even Whittaker's (1956) classic monograph of the park's vegetation does not adequately describe the xeric Pine, Oak - Pine, and Oak types in the western portion of GRSM. The results presented in Chapter II indicate that these types represent 20% of the park's vegetation. The results of Callaway et al. (1987) provide the best contemporary description of these xeric types.

It is important to recognize that the vegetation of GRSM has changed considerably since the 1930's when Miller conducted his field sampling. The primary source of this change has been the loss of *Castanea dentata* due to the chestnut blight. It can be assumed that the vegetation has also been altered due to changes in other disturbance factors such as reduced fire and the introduction of other exotic species. Eagar (1984b) has described the changes in Spruce -Fir due to the balsam wooly adelgid, a pest that was not present in GRSM at the time of Miller's field sampling. These contemporary disturbances make the results of Millers sampling out of date for many of the communities. For this reason, the results presented in Chapter I represent a description of the vegetation of GRSM at one specific point in time (circa 1930) and cannot be expected to completely describe the current vegetation.

The results of the vegetation mapping presented in Chapter II provide insights into the distribution patterns of the park's current vegetation. The sampling done for the ground truthing exercise effort was not designed to provide a quantitative description of the park's current vegetation. This discussion leads one to conclude that a contemporary whole park sampling effort should be conducted within GRSM to provide an adequate description of the current vegetation of GRSM. The vegetation map presented in Chapter II could be a useful tool for designing an appropriate stratified sampling design for such an effort.

The indirect ordination results presented in Chapter II indicate that the vegetation of GRSM, as sampled in the 1930's, is responding to a complex moisture-elevation gradient. It is assumed that the gradient is similar to that reported by other investigators (Whittaker 1956, Golden 1981, Callaway et al. (1987). It is recommended that any future sampling effort within GRSM include sampling of environmental parameters as described by Golden (1981) and Callaway et al. 1987) to provide further direct measures of this complex gradient.

The results of the vegetation mapping presented in Chapter II provide an example of the importance of sensor spectral and spatial resolution relative to classification ability. Earlier attempts at mapping the vegetation of GRSM using the MSS sensor (DeSelm and Taylor 1973, Ambrosia 1981) with its 80 m pixel resolution and four spectral bands were only able to classify the vegetation into relative crude classes of deciduous, coniferous, and mixed types. The increased spectral and spatial resolution of the TM sensor allowed for a more detailed classification and resultant map. It should be emphasized that even the TM sensor was not adequate for mapping of the Hemlock - Hardwood types. It is assumed that this is the result of the mixed compositional nature of most Hemlock - Hardwood types and that the 30 m pixel resolution of the TM sensor was not fine enough to discriminate Hemlock in this mixed condition. It is suggested that interpretation of imagery acquired during "leaf off" of the deciduous types would help to overcome this problem. It was also assumed that the 30 m resolution of the TM sensor was not adequate to map the relatively small Heath Balds and Grassy Balds (White and Mackenzie 1986). It has previously been shown that digital data collected using an airborne TM simulator with a pixel resolution of 13 m can provide for even more detailed classifications (White and Mackenzie 1986; Peter White, personal communication) but are subject to other problems (e.g., difficulties in georectification due to topography). These results indicate the importance of considering spatial attributes in the context of both extent and grain (Turner et al. 1989).

Chapter III considers the vegetation of GRSM in the context of both space and time. This chapter provides insights into the successional dynamics of the park's vegetation and how these dynamics vary in relation to position along the complex moisture-elevation gradient. The integration of gradient analysis (Kessell 1979) with gap models of forest succession (Shugart 1984) provides a mechanism for the concurrent analysis of both spatial and temporal dynamics of species response. For example, this integration allowed for the analysis of the distribution of *Castanea dentata* in GRSM prior to the chestnut blight, in the context of both space and time. It also showed that the replacement of Castanea dentata after the blight varied as a function of position along the complex moisture-elevation gradient. Most gap models of forest succession have dealt mainly with temporal features. The integration of gradient analysis with gap models provides one mechanism for adding a spatial component to forest succession models.

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APPENDIXES

Appendix A. Documentation for Miller data.

Plot No. 1 Tract Cataloochee

North of Deep Gap near Park Boundary Line
Geographic Location

Elevation 5200

Taken by G. A. MacPherson Date July 8, 1935

Brush and Ground Cover Plot 100 Milacres

F.g.	Ac.sm.	Ac.sm.	F.g.	Ac.sm.
Ac.sm.	F.g.	Ac.sm.	Ac.sm.	F.g.
Am.c.	Ac.sm.	Ac.sm.	Ac.sm.	Ac.sm.
Ac.sm.	Ac.sm.	Ac.sm.	F.g.	Ac.sm.
F.g.	Ann.	Ac.sm.	Ac.sm.	F.g.
Ac.sm.	Ac.sm.	F.g.	F.g.	Ac.sm.
Ann.	F.g.	Ac.sm.	F.g.	Ann.
F.g.	Ann.	Ac.sm.	Ac.sm.	F.g.
F.g.	F.g.	Ac.sm.	F.g.	Ac.sm.
Ac.sm.	F.g.	Ac.sm.	Ann.	Ac.sm.
Ac.sm.	F.g.	F.g.	F.g.	Ac.sm.
F.g.	Ac.sm.	Ae.g.	F.g.	Ac.sm.
Ac.sm.	F.g.	F.g.	Ac.sm.	Ae.g.
F.g.	Ae.g.	Ae.g.	Ann.	F.g.
Ann.	F.g.	F.g.	F.g.	F.g.
Ac.sm.	Ae.g.	Ae.g.	Ae.g.	Ae.g.
Q.mo.	Ae.g.	F.g.	Ae.g.	F.g.
Ae.g.	Ae.g.	Ac.sm.	F.g.	Ac.sm.
Ae.g.	Ac.sm.	Ac.sm.	F.g.	F.g.
Ae.g.	Ac.sm.	F.g.	F.g.	F.g.

Summary Brush and Ground Cover Plot

Species	o/o	Ht. Ft.	Lit. Dept. In.	Species	o/o	Ht. Ft.	Litter Depth Inches
Acer saccharum	39	12	2				
Fagus grandifolia	38	10					
Aesculus glabra	14	6					
Annuals	7						
Quercus montana	1	20					
Amelanchier canadensis	1	8					
				Total	100		

*Tree Tally - - .2 Acres

Species	Diameter Classes 4-11	12-23	24-35	36 +	Total	Ht. Ft.
Fagus grandifolia	9	(1) 1			11	35
Aesculus glabra	3	10	1		14	47
Halesia carolina	1				1	25
Acer saccharum	1		1		2	40
Total	14	12	2		28	

* 2 x 1 chains

Figure A-1. Copy of the front of a Miller field data sheet.

Type ____ Cove Hardwoods AA ____

Exposure ____ North ____ Slope per cent ____ 25 ____

Year of last burn ____ Undetermined ____

Site Index ____

Penetrability (indicate by check ✓)

easy ✓ | medium

difficult | impenetrable

SOIL
(Check terms applicable ✓)

Depth	Shallow (under 1')	Medium ✓ (1'-3')	Deep (over 3'

Character			
	Rocky	Loam ✓	
	Gravelly	Silt	Abode
	Sandy ✓	Clay	

Origin (Parent rock)

IGNEOUS	✓ SEDIMENTARY	METAMORPHIC
felsite	alluvium	schist
basalt	sandstone	gneiss
granite	shale	slate
gabbro	limestone	quartzite
porphyry	____	serpentine
tuff	____	____
obsidian	____	____
____		____
____		
____		

Additional Ground Cover Species

Aesculus glabra, Acer saccharum, Ferns, Annuals

Remarks

Figure A-2. Copy of the back of a Miller field data sheet.

DATA DOCUMENTATION:

VARIABLE FORMAT

Data Set Name: MILLER.RAW

Created by: Mark MacKenzie

Description: Species data, both overstory and understory, collected by Miller and his field crews in the 1930's. These data were originally derived from the Miller field data sheets on file in the archives of Great Smoky Mountains National Park. Data are in a SAS data format and must be read using the SAS statistical package. There is one record per species per plot.

Variable Name:	FORTRAN Format:	Coded (X):	Missing Value Code:
WS	Not applicable	X	Missing value
PLOT	in SAS data		information is
SPC	format	X	incorporated in
BRUSH			the SAS data
BA			format
DBA			
DEN			
DDEN			
NUM			
DNUM			
SUMBA			
SUMDEN			
RELBA			
RELDEN			
IV200			

DATA DOCUMENTATION:

VARIABLE DESCRIPTION

Data Set Name: MILLER.ENV

Variable Name:	Units:	Precision:	Brief Description of Variable:
WS			Watershed
PLOT			Plot number within watershed
SPC			Species Code
BRUSH			Percent species shrub dominance
BA			Species basal area of live trees (m^2/ha)
DBA			Species basal area of dead trees (m^2/ha)
DEN			Species density of live trees (stems/ha)
DDEN			Species density of dead trees (stems/ha)
NUM			Number of live trees in plot
DNUM			Number of dead trees in plot
SUMBA			Total basal area in plot
SUMDEN			Total density in plot
RELBA			Species relative basal area
RELDEN			Species relative density
IV200			Species IV200 (relba+relden)

DATA DOCUMENTATION:

VARIABLE CODES

Data Set Name: MILLER.ENV

Variable Name:	Code:	Brief Description of Code:
WS	1	Cosby Creek
	2	Indian Camp Creek
	3	Webb Creek
	4	Middle Prong Little Pigeon River
	5	Roaring Fork
	6	West Prong Little Pigeon River
	7	Little River
	8	Middle Prong Little River
	9	West Prong Little River
	10	Hesse Creek
	11	Abrams Creek
	12	Panther Creek
	13	Tabcat Creek
	14	Parson Branch
	15	Twenty-Mile
	16	Eagle Creek
	17	Hazel Creek
	18	Forney Creek
	19	Noland Creek
	20	Deep Creek
	21	Cooper Creek
	22	Oconaluftee
	23	Bradley Fork
	24	Raven Fork
	25	Straight Fork
	26	Bunches Creek
	27	Cataloochee
	28	Big Creek
SPC		See Table I-1 for codes

DATA DOCUMENTATION:

VARIABLE FORMAT

Data Set Name:MILLER.ENV

Created by:Mark MacKenzie

Description: Environmental or site data collected by Miller and his field crews in the 1930's. These data were originally derived from the Miller field data sheets on file in the archives of Great Smoky Mountains National Park. Data are in ASCII format. There is one record per plot.

Variable Name:	FORTRAN Format:	Coded (X):	Missing Value Code:
WS	I2	X	
PLOT	I3		
ELEV	1X,I4		Blank
SURVEY	1X,I2		Blank
LITDEPTH	1X,F4.1		Blank
MILLTYPE	1X,A2	X	Blank
ASPECT	1X,I1	X	Blank
SLOPE	1X,I2		Blank
SOILDEPT	1X,I2	X	Blank
SOILCH1	1X,I1	X	Blank
SOILCH2	I1	X	Blank
SOILCH3	I1	X	Blank
PARENTM	1X,I1	X	Blank
BURNED	2X,I2		Blank
LOGGED	3X,12		Blank

DATA DOCUMENTATION:

VARIABLE DESCRIPTION

Data Set Name: MILLER.ENV

Variable Name:	Units:	Precision:	Brief Description of Variable:
WS			Watershed
PLOT			Plot number within watershed
ELEVATION	ft	10 ft	Elevation of plot
SURVEY			Year surveyed. Survey date is 19xx
LITDEPTH	in	0.5 in	Litter depth
MILLTYPE			Vegetation type assigned by Miller.
ASPECT		45°	Aspect of plot
SLOPE	%	1%	Slope of plot
SOILDEPT			Soil depth
SOILCH1			Primary soil character
SOILCH2			Secondary soil character
SOILCH3			Tertiary soil character
PARENTM			Parent material
BURNED			Year last burned. Values > 38 are 18xx. A value of -1 represents indeterminable; 0 indicates no sign of fire.
LOGGED			Year last logged. Values > 38 are 18xx. A value of -1represents indeterminable; 0 indicates no logging.

DATA DOCUMENTATION:

VARIABLE CODES

Data Set Name: MILLER.ENV

Variable Name:	Code:	Brief Description of Code:
WS	1	Cosby Creek
	2	Indian Camp Creek
	3	Webb Creek
	4	Middle Prong Little Pigeon River
	5	Roaring Fork
	6	West Prong Little Pigeon River
	7	Little River
	8	Middle Prong Little River
	9	West Prong Little River
	10	Hesse Creek
	11	Abrams Creek
	12	Panther Creek
	13	Tabcat Creek
	14	Parson Branch
	15	Twenty-Mile
	16	Eagle Creek
	17	Hazel Creek
	18	Forney Creek
	19	Noland Creek
	20	Deep Creek
	21	Cooper Creek
	22	Oconaluftee
	23	Bradley Fork
	24	Raven Fork
	25	Straight Fork
	26	Bunches Creek
	27	Cataloochee
	28	Big Creek
MILLTYPE	B	Burned Over
	CH	Cove Hardwood
	CO	Cut Over
	CR	?
	G	Grassland
	H	Hemlock
	NH	Northern Hardwood
	OC	Oak Chestnut
	OF	Old Field

DATA DOCUMENTATION:

VARIABLE CODES

Data Set Name: MILLER.ENV

Variable Name:	Code:	Brief Description of Code:
MILLTYPE (cont)	S	Spruce
	SL	Heath Bald
	WP	White Pine - Hardwood
	YP	Yellow Pine - Hardwood
ASPECT	1	SW
	2	S
	3	W
	4	SE
	5	NW
	6	E
	7	N
	8	NE
SOILDEPT	1	Shallow
	2	Medium
	3	Deep
SOILCHR 1-3	0	?
	1	Rocky
	2	Gravely
	3	Sandy
	4	Loam
	5	Silt
	6	Clay
	7	?
PARENTM	1	Igneous
	2	Sedimentary and Metamorphic
	3	Metamorphic
	4	?
	5	Sedimentary
	6	?
	7	?

Appendix B. Supplemental tables and figures for Chapter II.

Table B-1. Discriminant analysis matrix parameters.

Spectral*		Mean TM Digital Number						
Class	Frequency	Band 1	Band 2	Band 3	Band 4	Band 4	Band 6	Band 7
1	3901	58.644	19.458	15.672	67.719	42.053	122.803	10.510
2	11710	61.135	22.323	18.278	100.627	62.303	123.277	16.180
3	3538	63.295	24.344	20.682	85.360	55.125	129.051	14.716
4	1909	62.544	24.380	23.302	94.752	90.859	117.457	28.938
5	2362	61.029	22.887	21.464	77.615	74.497	116.670	23.985
6	400	67.698	28.278	23.425	103.730	71.010	129.273	19.963
7	2582	66.844	26.229	22.011	89.648	59.014	130.101	16.281
8	147	66.864	29.272	23.299	130.490	83.585	131.912	21.939
10	5349	58.354	19.234	16.012	63.968	44.829	116.409	12.647
11	547	64.420	26.048	25.665	99.344	101.267	117.839	33.163
13	3282	58.140	21.581	18.352	86.697	62.168	119.066	17.870
14	4762	66.430	26.517	22.001	121.403	80.328	125.125	20.895
15	5381	59.485	21.189	19.009	73.437	61.241	115.901	19.086
16	5586	62.667	22.490	17.745	92.573	56.697	127.875	14.431
17	1141	63.336	27.778	22.472	116.422	75.096	122.632	20.186
18	4278	59.098	22.181	17.567	85.384	52.978	124.406	13.867
19	9986	59.132	19.717	16.175	76.738	50.724	120.847	13.964
20	1821	65.717	23.166	19.111	98.679	65.401	123.380	17.035
21	18142	62.717	23.801	19.982	101.986	66.806	124.868	17.665
22	5224	64.696	24.105	19.962	124.445	78.145	126.444	20.281
23	397	66.174	29.270	24.174	125.401	83.793	124.015	22.338
25	301	65.133	27.365	22.096	138.821	88.392	124.518	24.269
26	7848	61.939	23.685	21.370	108.094	80.833	119.034	22.638
28	5063	66.005	24.431	20.543	100.818	65.522	128.674	17.171
29	1	81.000	35.000	41.000	79.000	82.000	133.000	41.000
30	11205	62.888	24.945	21.473	125.498	83.236	122.365	21.884
31	706	65.625	24.754	22.303	115.527	87.289	119.535	24.836
32	221	66.837	24.882	21.674	93.914	75.448	126.738	20.638
33	9794	61.031	22.484	19.313	96.944	70.078	119.604	19.720
34	2	73.000	33.500	38.000	114.000	102.500	122.000	38.000
35	2270	56.663	19.740	17.038	69.780	52.282	116.571	15.172
36	1784	62.659	24.799	22.496	119.298	95.848	119.235	27.910
37	4773	65.516	24.237	21.244	118.409	76.110	123.027	19.684
38	8442	61.904	23.277	19.815	119.173	76.287	122.430	20.009
39	867	59.803	18.667	14.934	54.243	34.245	123.839	9.355
40	1	73.000	33.000	33.000	110.000	80.000	120.000	28.000
41	17052	61.686	21.593	17.648	83.060	52.004	123.168	13.589
43	8569	60.436	21.625	17.913	84.851	55.577	117.807	14.685
44	4012	64.907	23.473	19.552	77.680	49.371	126.640	13.309
45	26	67.192	29.115	30.808	99.231	98.154	120.385	32.346
46	1717	61.665	21.137	16.717	66.274	39.641	122.597	10.330
47	559	55.603	17.966	14.692	50.626	34.388	118.585	9.585
48	1063	59.770	23.182	20.916	99.250	84.877	117.892	24.921
49	2531	61.834	23.934	20.391	118.583	73.734	128.502	19.416
50	4316	64.470	26.794	21.982	117.690	74.898	128.792	19.840
60	321	61.000	24.324	21.561	102.751	64.044	116.436	18.165
61	5140	52.821	16.864	13.933	31.496	22.640	114.191	7.303
62	4849	58.278	20.529	18.231	64.736	54.163	115.698	18.054
63	2296	59.954	22.972	21.553	71.187	66.105	116.446	23.343
64	248	75.089	26.806	20.315	11.883	6.923	135.363	3.286

*Missing spectral classes between 1 and 50 represent spectral signatures that were originally interpreted as Hemlock - Hardwood and were subsequently removed. Spectral classes 60 through 64 represent spectral signatures for Water and Spruce - Fir that were added after the original classification of the Thunderhead Mountain test study area.

Table B-2. Pooled within group discriminant analysis covariance matrix.

Band[1]	1	2	3	4	5	6	7
1	1.449						
2	0.110	0.878					
3	0.053	0.357	1.201				
4	1.377	1.217	0.427	68.404			
5	0.358	0.306	0.200	17.189	30.314		
6	0.177	-0.183	-0.216	0.970	0.735	3.749	
7	0.016	0.076	0.147	2.088	4.726	0.104	2.888

[1]Bands are thematic mapper bands one through seven.

Table B-3. Spectral class to vegetation type interpretation rules.

Spectral Class	Vegetation Type	Spectral Class	Vegetation Type
1	Cove Hardwood	30	Cove Hardwood
2	Cove Hardwood	31	Mesic Oak
3	Pine	32	Pine - Oak
4	Northern Hardwood	33	Cove Hardwood
5	Northern Hardwood	34	Treeless
6	Pine - Oak	35	Northern Hardwood
7	Xeric Oak	36	Northern Hardwood
8	Xeric Oak	37	Mesic Oak
10	Northern Hardwood	38	Mesic Oak
11	Northern Hardwood	39	Grape Thicket
13	Cove Hardwood	40	Treeless
14	Xeric Oak	41	Mixed Mesic Hardwood
15	Northern Hardwood	43	Cove Hardwood
16	Tulip Poplar	44	Pine
17	Mesic Oak	45	Treeless
18	Tulip Poplar	46	Cove Hardwood
19	Cove Hardwood	47	Cove Hardwood
20	Mixed Mesic Hardwood	48	Northern Hardwood
21	Mixed Mesic Hardwood	49	Cove Hardwood
22	Xeric Oak	50	Xeric Oak
23	Xeric Oak	60	Treeless
25	Mesic Oak	61	Spruce - Fir
26	Mesic Oak	62	Spruce - Fir
28	Mixed Mesic Hardwood	63	Spruce - Fir
29	Treeless	64	Water

Table B-4. Mean of species basal area (m^2/ha) and number (N) of plots by vegetation type.

	Vegetation Type								
Species	Spruce Fir	Northern Hardwood	Cove Hardwood	Mesic Oak	Mixed Mesic	Tulip Poplar	Xeric Oak	Oak Pine	Pine
ACRPNS	1.05	0.43	0.21	0.00	0.18	0.00	0.03	0.00	0.05
ACRRBR	2.04	2.34	4.60	8.11	5.47	4.86	5.41	2.28	1.89
ACRSCC	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
ACRSCR	0.00	0.75	1.59	0.80	0.58	0.50	0.03	0.00	0.00
ACRSPC	0.00	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00
AMLARB	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00
AMLLVS	0.00	0.42	0.23	0.28	0.17	0.00	0.06	0.00	0.00
ARLSPN	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
ASLOCT	0.36	0.88	1.49	0.46	0.49	0.22	0.03	0.00	0.00
BTLLNT	0.00	3.33	4.61	0.62	1.98	0.35	0.55	0.00	0.08
BTLLUT	17.66	11.54	2.28	0.57	0.86	0.16	0.00	0.00	0.00
BTLSPP	0.00	0.17	0.06	0.00	0.00	0.00	0.00	0.00	0.00
CLDKNT	0.00	0.00	0.00	0.00	0.00	0.22	0.00	0.00	0.00
CRNFLR	0.00	0.00	0.00	0.00	0.13	0.12	0.41	0.00	0.34
CRPCRL	0.00	0.00	0.00	0.00	0.15	0.00	0.05	0.00	0.00
CRYCRD	0.00	0.00	0.01	0.00	0.10	0.00	0.00	0.00	0.00
CRYGLB	0.00	0.00	0.00	0.28	0.44	0.00	0.54	0.00	0.00
CRYOVL	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00
CRYPLL	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
CRYSPP	0.00	0.00	0.03	0.00	0.12	0.16	0.13	0.00	0.00
CRYTMN	0.00	0.00	0.00	0.19	0.14	0.00	0.45	0.00	0.33
CSTDNT	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00
FGSGRN	0.17	5.23	1.58	0.51	0.07	0.00	0.09	0.00	0.00
FRXSPP	0.00	0.00	0.37	0.19	0.23	0.35	0.03	0.00	0.05
HLSCRL	0.00	1.39	4.25	0.65	0.59	3.66	0.18	0.00	0.05
HMMVRG	0.00	0.00	0.00	0.00	0.02	0.12	0.03	0.24	0.00
ILXMNT	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00
ILXOPC	0.00	0.00	0.05	0.00	0.02	0.00	0.00	0.00	0.08
JGLCNR	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00
JGLNGR	0.00	0.00	0.00	0.00	0.08	0.12	0.18	0.00	0.00
JNPVRG	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.05
KLMLTF	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
LQDSTY	0.00	0.00	0.00	0.00	0.20	0.00	0.11	0.00	0.34
LRDTLP	0.23	0.00	3.24	0.51	10.60	23.56	2.87	0.00	1.47
MGNACM	0.00	0.00	0.35	0.00	0.18	0.32	0.00	0.00	0.00
MGNFRS	0.00	0.15	1.31	0.53	0.24	0.12	0.12	0.00	0.00
MRSRBR	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00
NYSSYL	0.00	0.00	0.08	1.87	0.17	0.00	0.22	2.90	0.91
OSTVRG	0.00	0.00	0.02	0.00	0.00	0.00	0.03	0.00	0.00
OXYARB	0.31	0.00	0.21	1.04	1.11	0.62	2.42	0.47	1.68
PICRBN	15.76	2.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PLTOCC	0.00	0.00	0.00	0.00	0.08	0.16	0.04	0.00	0.00
PNSECH	0.00	0.00	0.00	0.00	0.02	0.00	0.29	0.00	0.94
PNSPNG	0.00	0.00	0.00	0.00	0.04	0.00	0.19	13.93	11.54
PNSRGD	0.00	0.00	0.00	0.00	0.71	0.12	1.96	4.25	9.39
PNSSTB	0.00	0.00	0.02	0.00	0.28	0.00	0.18	0.00	0.37
PNSVRG	0.00	0.00	0.00	0.00	0.13	0.00	0.61	0.00	2.47
PRNPNS	0.65	1.76	0.16	0.00	0.00	0.00	0.00	0.00	0.00
PRNSRT	0.00	0.53	1.04	0.50	0.14	0.08	0.00	0.00	0.00
QRCALB	0.00	0.00	0.01	0.63	0.42	0.00	1.84	1.34	0.09
QRCCCC	0.00	0.05	0.02	0.50	0.22	0.00	2.05	5.55	2.30
QRCFLC	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00
QRCPRN	0.00	0.10	0.59	5.99	2.43	0.00	5.80	2.61	1.28
QRCRBR	0.00	2.28	3.16	14.68	1.63	0.00	1.62	0.63	0.23
QRCRED	0.00	0.00	0.12	0.09	0.13	0.00	0.23	0.00	0.00
QRCVLT	0.00	0.00	0.00	0.00	0.16	0.00	1.67	0.00	0.17
RBNPSD	0.33	0.03	0.76	1.75	0.69	1.62	0.49	0.40	0.08
RHDMXM	0.00	0.00	0.02	0.00	0.04	0.00	0.00	0.00	0.00
RHDSPP	0.00	0.00	0.06	0.00	0.00	0.00	0.03	0.00	0.00
SRBAMR	0.00	0.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SSSALB	0.00	0.00	0.17	0.10	0.58	0.27	0.18	0.00	0.00
TILHTR	0.00	0.51	2.29	1.36	0.43	1.12	0.04	0.00	0.00
TSGCND	0.32	2.46	7.59	1.28	2.79	1.88	1.57	0.37	1.37
N of plots	5	40	68	14	40	10	29	2	15

Table B-5. Standard deviation of species basal area and number (N) of plots by vegetation type.

	Vegetation Type								
Species	Spruce Fir	Northern Hardwood	Cove Hardwood	Mesic Oak	Mixed Mesic	Tulip Poplar	Xeric Oak	Oak Pine	Pine
ACRPNS	1.56	1.47	0.64	0.00	0.71	0.00	0.16	0.00	0.21
ACRRBR	3.85	4.18	4.24	4.54	4.92	5.76	4.07	3.22	2.34
ACRSCC	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00
ACRSCR	0.00	1.64	3.50	1.93	1.24	0.87	0.17	0.00	0.00
ACRSPC	0.00	0.16	0.11	0.00	0.00	0.00	0.00	0.00	0.00
AMLARB	0.00	0.00	0.23	0.00	0.00	0.00	0.00	0.00	0.00
AMLLVS	0.00	0.84	0.66	0.82	0.81	0.00	0.22	0.00	0.00
ARLSPN	0.00	0.00	0.00	0.00	0.13	0.00	0.00	0.00	0.00
ASLOCT	0.80	2.41	3.29	1.39	1.27	0.47	0.14	0.00	0.00
BTLLNT	0.00	5.74	5.35	1.34	3.14	0.87	1.28	0.00	0.30
BTLLUT	9.12	11.65	3.39	1.77	2.00	0.50	0.00	0.00	0.00
BTLSPP	0.00	0.66	0.29	0.00	0.00	0.00	0.00	0.00	0.00
CLDKNT	0.00	0.00	0.00	0.00	0.00	0.47	0.00	0.00	0.00
CRNFLR	0.00	0.00	0.00	0.00	0.42	0.37	0.91	0.00	0.68
CRPCRL	0.00	0.00	0.00	0.00	0.80	0.00	0.28	0.00	0.00
CRYCRD	0.00	0.00	0.05	0.00	0.51	0.00	0.00	0.00	0.00
CRYGLB	0.00	0.00	0.00	0.73	0.91	0.00	1.47	0.00	0.00
CRYOVL	0.00	0.00	0.00	0.00	0.18	0.00	0.00	0.00	0.00
CRYPLL	0.00	0.00	0.00	0.00	0.15	0.00	0.00	0.00	0.00
CRYSPP	0.00	0.00	0.17	0.00	0.49	0.49	0.34	0.00	0.00
CRYTMN	0.00	0.00	0.00	0.72	0.44	0.00	1.12	0.00	1.29
CSTDNT	0.00	0.00	0.14	0.00	0.00	0.00	0.00	0.00	0.00
FGSGRN	0.37	6.92	3.25	1.15	0.32	0.00	0.28	0.00	0.00
FRXSPP	0.00	0.00	1.08	0.49	0.57	0.87	0.14	0.00	0.20
HLSCRL	0.00	3.40	5.44	1.27	1.06	3.66	0.43	0.00	0.18
HMMVRG	0.00	0.00	0.00	0.00	0.15	0.37	0.16	0.33	0.00
ILXMNT	0.00	0.00	0.48	0.00	0.00	0.00	0.00	0.00	0.00
ILXOPC	0.00	0.00	0.39	0.00	0.13	0.00	0.00	0.00	0.30
JGLCNR	0.00	0.00	0.21	0.00	0.00	0.00	0.00	0.00	0.00
JGLNGR	0.00	0.00	0.00	0.00	0.38	0.36	0.46	0.00	0.00
JNPVRG	0.00	0.00	0.00	0.00	0.24	0.00	0.00	0.00	0.20
KLMLTF	0.00	0.00	0.00	0.00	0.14	0.00	0.00	0.00	0.00
LQDSTY	0.00	0.00	0.00	0.00	1.01	0.00	0.45	0.00	0.92
LRDTLP	0.51	0.00	6.18	0.89	9.60	5.68	4.76	0.00	2.29
MGNACM	0.00	0.00	0.86	0.00	0.46	1.02	0.00	0.00	0.00
MGNFRS	0.00	0.58	2.30	1.49	0.52	0.38	0.41	0.00	0.00
MRSRBR	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.00	0.00
NYSSYL	0.00	0.00	0.41	5.36	0.51	0.00	0.55	0.38	1.09
OSTVRG	0.00	0.00	0.14	0.00	0.00	0.00	0.17	0.00	0.00
OXYARB	0.70	0.00	0.74	1.48	1.36	1.95	1.88	0.66	1.92
PICRBN	11.62	3.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PLTOCC	0.00	0.00	0.00	0.00	0.49	0.49	0.19	0.00	0.00
PNSECH	0.00	0.00	0.00	0.00	0.12	0.00	0.69	0.00	3.64
PNSPNG	0.00	0.00	0.00	0.00	0.27	0.00	0.71	19.70	13.47
PNSRGD	0.00	0.00	0.00	0.00	1.65	0.37	2.61	2.64	6.04
PNSSTB	0.00	0.00	0.19	0.00	0.83	0.00	0.57	0.00	1.44
PNSVRG	0.00	0.00	0.00	0.00	0.52	0.00	1.22	0.00	2.65
PRNPNS	1.46	4.08	1.14	0.00	0.00	0.00	0.00	0.00	0.00
PRNSRT	0.00	1.59	2.26	1.32	0.74	0.25	0.00	0.00	0.00
QRCALB	0.00	0.00	0.10	1.76	1.58	0.00	3.21	1.89	0.35
QRCCCC	0.00	0.32	0.20	1.87	0.66	0.00	3.19	4.47	2.60
QRCFLC	0.00	0.00	0.00	0.00	0.00	0.00	0.22	0.00	0.00
QRCPRN	0.00	0.61	1.84	6.40	4.01	0.00	6.10	3.02	2.64
QRCRBR	0.00	5.25	4.87	9.22	1.93	0.00	2.54	0.23	0.71
QRCRED	0.00	0.00	0.70	0.32	0.48	0.00	0.58	0.00	0.00
QRCVLT	0.00	0.00	0.00	0.00	0.57	0.00	4.53	0.00	0.65
RBNPSD	0.74	0.20	1.61	2.64	1.21	1.69	1.01	0.56	0.30
RHDMXM	0.00	0.00	0.14	0.00	0.25	0.00	0.00	0.00	0.00
RHDSPP	0.00	0.00	0.48	0.00	0.00	0.00	0.16	0.00	0.00
SRBAMR	0.00	1.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SSSALB	0.00	0.00	0.73	0.36	1.43	0.45	0.53	0.00	0.00
TILHTR	0.00	2.97	4.02	3.46	1.12	2.61	0.24	0.00	0.00
TSGCND	0.72	4.63	9.02	4.78	3.99	2.04	2.47	0.52	3.59
N of plots	5	40	68	14	40	10	29	2	15

Table B-6. Frequency of species occurence and number (N) of plots by vegetation type.

	Vegetation Type								
Species	Spruce Fir	Northern Hardwood	Cove Hardwood	Mesic Oak	Mixed Mesic	Tulip Poplar	Xeric Oak	Oak Pine	Pine
ACRPNS	2.00	8.00	8.00	0.00	3.00	0.00	1.00	0.00	1.00
ACRRBR	2.00	16.00	55.00	13.00	35.00	7.00	29.00	1.00	8.00
ACRSCC	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
ACRSCR	0.00	9.00	24.00	4.00	12.00	3.00	1.00	0.00	0.00
ACRSPC	0.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
AMLARB	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
AMLLVS	0.00	10.00	9.00	2.00	3.00	0.00	2.00	0.00	0.00
ARLSPN	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00
ASLOCT	1.00	7.00	27.00	2.00	6.00	2.00	1.00	0.00	0.00
BTLLNT	0.00	20.00	51.00	3.00	22.00	2.00	8.00	0.00	1.00
BTLLUT	5.00	33.00	40.00	2.00	8.00	1.00	0.00	0.00	0.00
BTLSPP	0.00	3.00	3.00	0.00	0.00	0.00	0.00	0.00	0.00
CLDKNT	0.00	0.00	0.00	0.00	0.00	2.00	0.00	0.00	0.00
CRNFLR	0.00	0.00	0.00	0.00	4.00	1.00	6.00	0.00	4.00
CRPCRL	0.00	0.00	0.00	0.00	2.00	0.00	1.00	0.00	0.00
CRYCRD	0.00	0.00	1.00	0.00	2.00	0.00	0.00	0.00	0.00
CRYGLB	0.00	0.00	0.00	2.00	10.00	0.00	4.00	0.00	0.00
CRYOVL	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00
CRYPLL	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00
CRYSPP	0.00	0.00	2.00	0.00	3.00	1.00	4.00	0.00	0.00
CRYTMN	0.00	0.00	0.00	1.00	4.00	0.00	5.00	0.00	1.00
CSTDNT	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
FGSGRN	1.00	24.00	23.00	3.00	2.00	0.00	3.00	0.00	0.00
FRXSPP	0.00	0.00	11.00	2.00	7.00	2.00	1.00	0.00	1.00
HLSCRL	0.00	9.00	45.00	4.00	12.00	9.00	5.00	0.00	1.00
HMMVRG	0.00	0.00	0.00	0.00	1.00	1.00	1.00	1.00	0.00
ILXMNT	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
ILXOPC	0.00	0.00	1.00	0.00	1.00	0.00	0.00	0.00	1.00
JGLCNR	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
JGLNGR	0.00	0.00	0.00	0.00	2.00	1.00	4.00	0.00	0.00
JNPVRG	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	1.00
KLMLTF	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00
LQDSTY	0.00	0.00	0.00	0.00	2.00	0.00	2.00	0.00	3.00
LRDTLP	1.00	0.00	22.00	4.00	34.00	10.00	17.00	0.00	6.00
MGNACM	0.00	0.00	12.00	0.00	6.00	1.00	0.00	0.00	0.00
MGNFRS	0.00	3.00	25.00	3.00	8.00	1.00	3.00	0.00	0.00
MRSRBR	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00
NYSSYL	0.00	0.00	3.00	3.00	5.00	0.00	5.00	2.00	7.00
OSTVRG	0.00	0.00	1.00	0.00	0.00	0.00	1.00	0.00	0.00
OXYARB	1.00	0.00	6.00	6.00	22.00	1.00	27.00	1.00	9.00
PICRBN	4.00	21.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PLTOCC	0.00	0.00	0.00	0.00	1.00	1.00	1.00	0.00	0.00
PNSECH	0.00	0.00	0.00	0.00	1.00	0.00	5.00	0.00	1.00
PNSPNG	0.00	0.00	0.00	0.00	1.00	0.00	3.00	1.00	9.00
PNSRGD	0.00	0.00	0.00	0.00	9.00	1.00	14.00	2.00	15.00
PNSSTB	0.00	0.00	1.00	0.00	6.00	0.00	3.00	0.00	1.00
PNSVRG	0.00	0.00	0.00	0.00	3.00	0.00	8.00	0.00	11.00
PRNPNS	1.00	13.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00
PRNSRT	0.00	8.00	30.00	2.00	2.00	1.00	0.00	0.00	0.00
QRCALB	0.00	0.00	1.00	2.00	4.00	0.00	11.00	1.00	1.00
QRCCCC	0.00	1.00	1.00	1.00	6.00	0.00	16.00	2.00	10.00
QRCFLC	0.00	0.00	0.00	0.00	0.00	0.00	2.00	0.00	0.00
QRCPRN	0.00	1.00	10.00	8.00	17.00	0.00	19.00	2.00	5.00
QRCRBR	0.00	11.00	35.00	13.00	25.00	0.00	15.00	2.00	2.00
QRCRED	0.00	0.00	2.00	1.00	3.00	0.00	4.00	0.00	0.00
QRCVLT	0.00	0.00	0.00	0.00	4.00	0.00	6.00	0.00	1.00
RBNPSD	1.00	1.00	18.00	7.00	15.00	6.00	7.00	1.00	1.00
RHDMXM	0.00	0.00	2.00	0.00	1.00	0.00	0.00	0.00	0.00
RHDSPP	0.00	0.00	1.00	0.00	0.00	0.00	1.00	0.00	0.00
SRBAMR	0.00	3.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SSSALB	0.00	0.00	4.00	1.00	10.00	3.00	3.00	0.00	0.00
TILHTR	0.00	2.00	26.00	2.00	7.00	2.00	1.00	0.00	0.00
TSGCND	1.00	18.00	48.00	1.00	25.00	7.00	15.00	1.00	4.00
N of plots	5	40	68	14	40	10	29	2	15

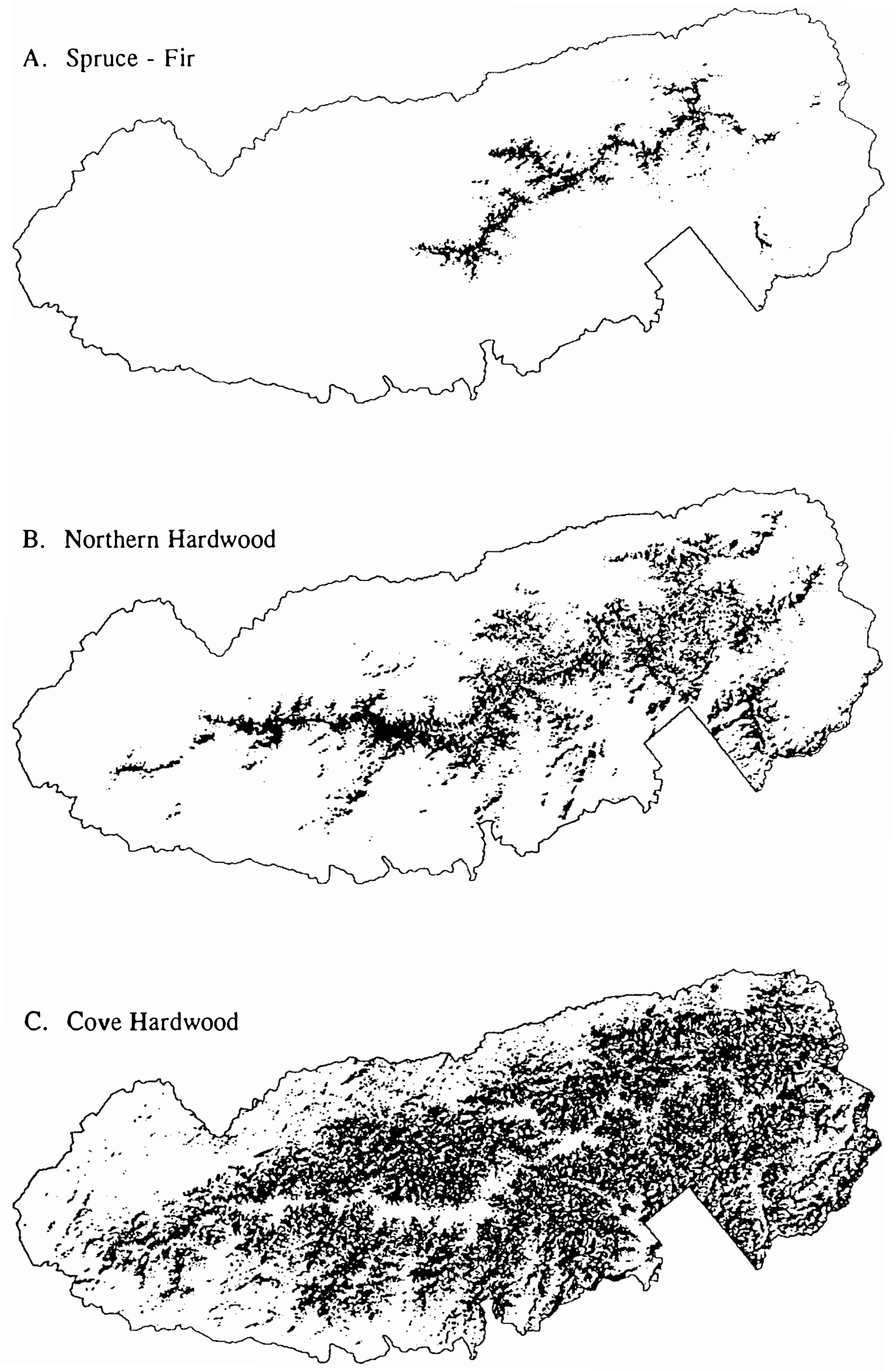
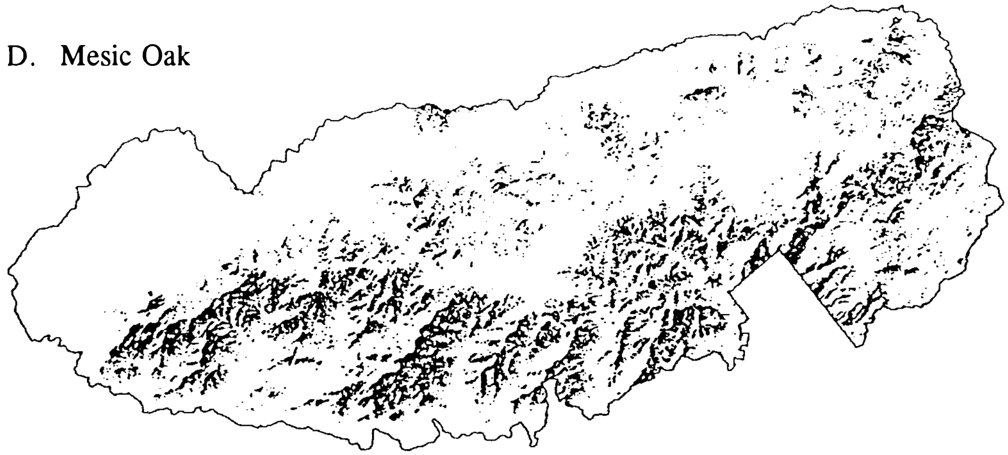
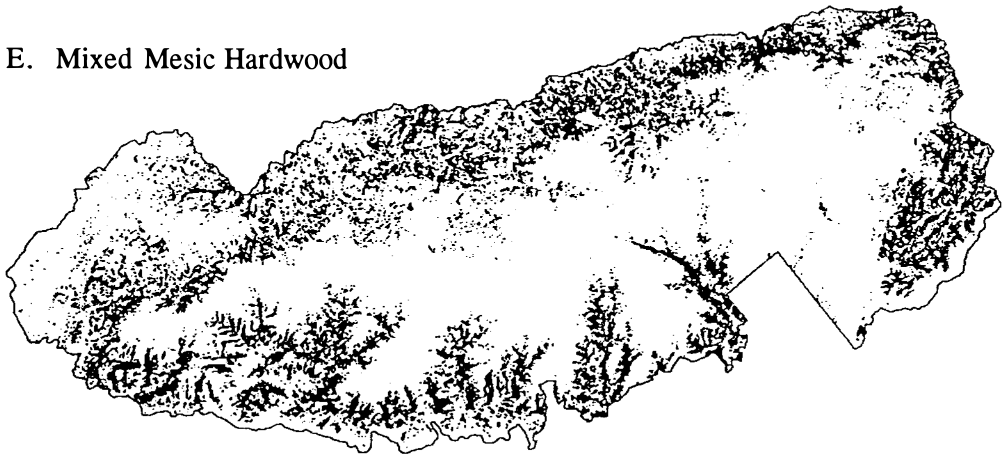


Figure B-1. Distribution of vegetation types within GRSM.

D. Mesic Oak



E. Mixed Mesic Hardwood



F. Tulip Poplar

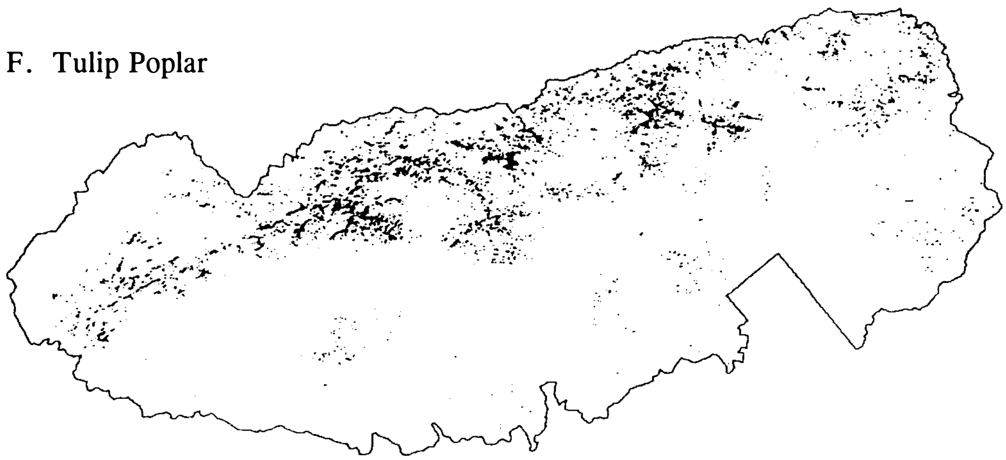


Figure B-1 (continued)

G. Xeric Oak

H. Oak - Pine

I. Pine

Figure B-1 (continued)

J. Heath Bald

K. Grassy Bald

L. Grape Thicket

Figure B-1 (continued)

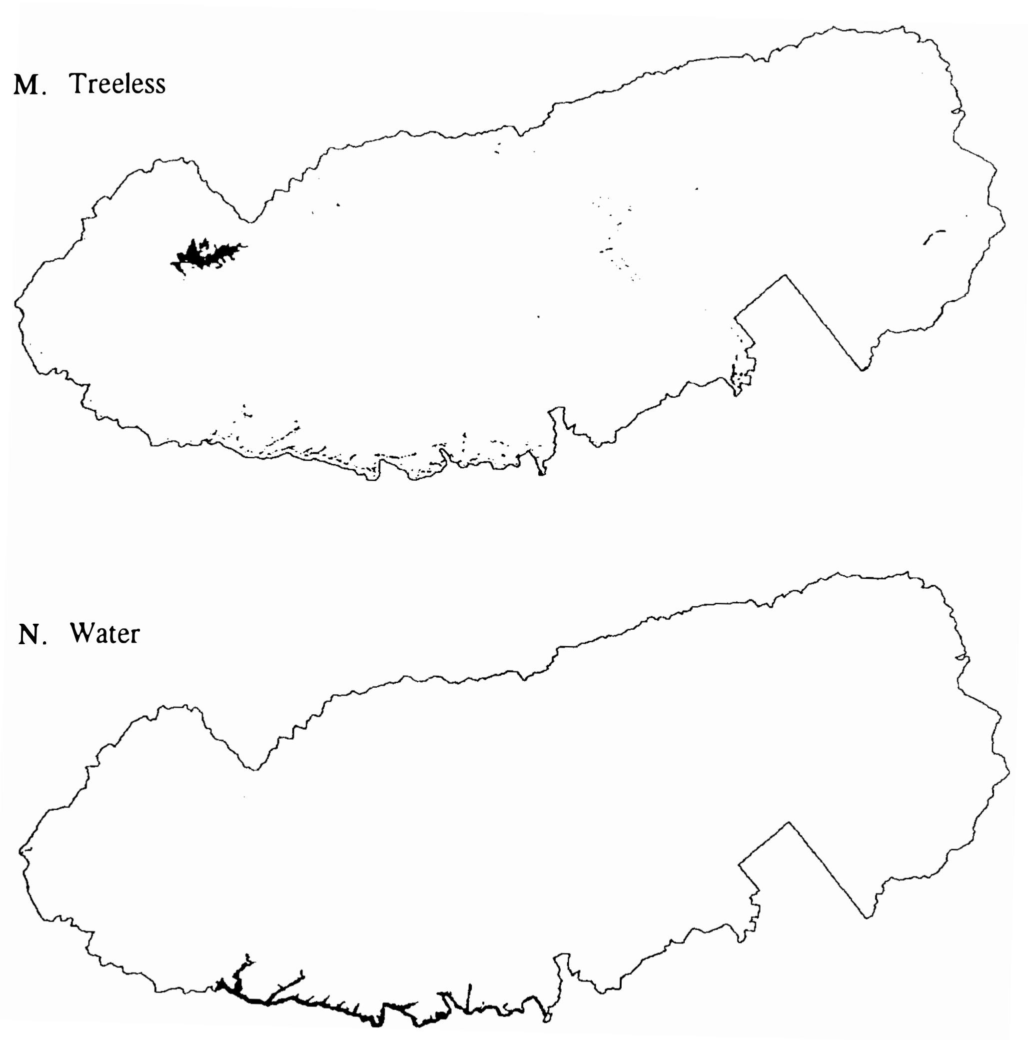


Figure B-1 (continued)

Appendix C. FORSMO source code.

```
C.....
C.....FORSMO FOREST SUCCESSION MODEL - VERSION 6.0
C.....3/2/92
C.....
      COMMON/FOREST/NTREES(100),DBH(700),IAGE(700),KSPRT(100),
     1NEWTR(100),SUMLA(700),NEW(100),SWTCH(5)
      COMMON/PARAM/AAA(100,6),DMAX(100),DMIN(100),B3(100),B2(100),
     1ITOL(100),AGEMX(100),CURVE(100),G(100),SPRTND(100),SPRTMN(100),
     2SPRTMX(100),SWITCH(100,5),KTIME(100),CMODE(100),CSTD(100),
     3GRADM(100)
      COMMON/CONST/GRADL,NSPEC,SOILQ,DEGD
      COMMON/RAN/YFL
      COMMON NSELCT(100)
      COMMON/OUTPT/IO1,IO2,PLOT,PRINT,LIST
      COMMON/PAREA/HTREE(700)
      COMMON/DEAD/NOGRO(700),NTEMP(700)
      COMMON/COUNT/NTOT,NYEAR
      COMMON/TEMP/DTEMP(700),ITEMP(700)
      COMMON/OUTSWT/OUTSWT(4)
      DIMENSION Z(2)
      character*50 filenam,filenam1,filenam2,filenam3,filenam4,
     >             filenam5,filenam6
      LOGICAL SWITCH,SWTCH,PLOT,PRINT,LIST,OUTSWT
      DATA NCT/0/
      VERS=6.0
      write(*,5) vers
5     format(' FORSMO Version ',f8.3,//)
C.....
C.....**********************************************
C.....ARRAYS USED IN THE MODEL
C.....NTREES - NUMBER OF TREES FOR EACH SPECIES
C.....DBH - DIAMETER AT BREAST HEIGHT FOR EACH TREE
C.....KSPRT - TREES THAT CAN SPROUT
C.....NOGRO - TREES THAT DON'T GROW
C.....IAGE - THE AGE OF EACH TREE
C.....NEWTR - NEW TREES WHICH ARE ADDED TO PLOT
C.....SUMLA - LEAF AREA OF EACH TREE
C.....NEW - SPECIES ELIGIBLE TO SPROUT
C.....DTEMP - TEMPORARY STORAGE FOR DBH
C.....ITEMP - TEMPORARY STORAGE FOR TREE AGES
C.....**********************************************
C.....
C.....The current random number generator has an
C....."infinite" period thereby eliminating the
C.....need for indiviudal seeds as in the original
C.....FORET model
C.....
C.....SELECT OUTPUT MODE
C.....
      PLOT = .FALSE.
      LIST = .TRUE.
C.....
C.....SET DEVICE SWITCHES
C.....
C.....SWITCH      IBM DEVICE #
C.....  IO1         5 (CARDS)
C.....  IO2         6 (PRINTER)
C.....  IO3         4 (TAPE)
C.....
      IO1 = 5
      IO2 = 11
      IO3 = 4
      open(10,file='forsmo.dat')
      CALL INPUT(KTIMES,NYEAR,VERS,filenam)
      print=outswt(1)
        do 500 i=1,50
          if(filenam(i:i).eq.' ') goto 510
500     continue
510     filenam1=filenam(1:i)//'.ba'
        filenam2=filenam(1:i)//'.den'
        filenam3=filenam(1:i)//'.bio'
        filenam4=filenam(1:i)//'.age'
        filenam5=filenam(1:i)//'.per'
       if(outswt(3)) open(15,file=filenam1,access='direct',
     >                     status='new',recl=4*nspec)
       if(outswt(3)) open(16,file=filenam2,access='direct',
     >                     status='new',recl=4*nspec)
       if(outswt(3)) open(17,file=filenam3,access='direct',
     >                     status='new',recl=4*nspec)
       if(outswt(2)) open(12,file=filenam4,status='new')
       if(outswt(4)) open(9,file=filenam5,status='new')
C.....
C.....SET SIMULATION PARAMETERS
C.....
C.....KTIMES - NUMBER OF RUNS
C.....NYEAR - LENGTH OF RUN (YEARS)
C.....KPRNT - PRINT INTERVAL (YEARS)
C.....KPLOT - PLOT INTERVAL (YEARS)
C.....
      KPLOT = 1000
      IF(.NOT.PLOT)     GO TO 10
      N3 = NSPEC+3
      DO 100 IVA = 1,NYEAR
      DO 100 IVS = 1,M3
```

```
  100 CONTINUE
C.....
C.....SITE VARIABLES
C.....SOILQ - THE MAXIMUM BIOMASS RECORDED FOR FORESTS IN THE AREA
C.....Note: The following GDD site parameters are not implemented
C.....in this version of the model
C.....AM - MEAN NUMBER OF DEGREE DAYS FOR AREA (42 DEGREE F. BASE)
C.....S - STANDARD DEVIATION OF DEGREE DAY DISTRIBUTION
C.....
   10 SOILQ = 50833.33333
      IPLOT = 0
      KYR = 0
      DO 200 JJ = 1,KTIMES
      CALL PLOTIN(IPLOT)
      if(print) WRITE(11,2000) IPLOT
 2000 FORMAT(58X,'PLOT NUMBER  ',I4)
      CALL INIT
      write(*,*)
      DO 250 I = 1,NYEAR
      write(*,7654) i,iplot
7654  format('+','YEAR: ',i5,'  PASS: ',i5)
      KYR = I
      NCT = NCT+1
      IF(NCT.EQ.2)      GO TO 30
      CALL GGNORD(Z)
      GO TO 40
   30 Z(1) = Z(2)
      NCT = 0
   40 CALL KILL
      CALL BIRTH(KYR)
      CALL GROW(IPLOT)
      CALL OUTPUT (KYR,IPLOT)
  250 CONTINUE
  200 CONTINUE
      if(print) write(11,*) char(12)
      IF(.NOT.PLOT)     STOP
      ZNYR = IPLOT
      NYR1 = NYEAR+1
      DO 300 IV1 = 1,NYR1
      TIMEX = IV1-1
      write(11,2010) TIMEX
 2010 FORMAT(' ',E10.3)
  350 CONTINUE
  300 CONTINUE
      STOP
      END
C.....
```

```
C.....
C.....
      SUBROUTINE INPUT(KTIMES,NYEAR,VERS,filenam)
      COMMON/PARAM/AAA(100,6),DMAX(100),DMIN(100),B3(100),B2(100),
     > ITOL(100),AGEMX(100),CURVE(100),G(100),SPRTND(100),SPRTMN(100),
     > SPRTMX(100),SWITCH(100,5),KTIME(100),CMODE(100),CSTD(100),
     > GRADM(100)
      COMMON/CONST/GRADL,NSPEC,SOILQ,DEGD
      COMMON/OUTSWT/OUTSWT(4)
      LOGICAL OUTSWT,switch
      character*50 filenam,filenam6
      DIMENSION NSELCT(100)
C.....
C.....NSPEC - NUMBER OF SPECIES
C.....    NSELCT    CONTAINS THE SPECIES NUMBER FOR THOSE SPECIES
C.....    THAT WILL BE USED IN THE SIMULATION
C.....
      write(*,*) 'Enter Gradient Position, number of passes, and'
      write(*,*) 'number of years (seperated by commas):'
      read(*,*) gradl,ktimes,nyear
      write(*,*)
      write(*,*) 'Do you want printed output?'
      write(*,*) 'Do you want age and dbh data?'
      write(*,*) 'Do you want den, ba, and bio files?'
      write(*,*) 'Do you want percent biomass file?'
      write(*,*)
      write(*,*) 'Answer the above 4 questions with logicals T or F'
      write(*,*) 'not separated by commas:'
      read(*,'(4l1)') outswt
      if(outswt(2)) open(12,file='agedbh.dat')
      if(outswt(2).or.outswt(3).or.outswt(4)) then
        write(*,*) 'Enter output file name (without ext) for data ',
     >             'output.'
        write(*,*) 'Input string must be enclosed with single quotes.'
        write(*,*) 'Extension will be added by program.'
        write(*,*)
        read(*,*) filenam
      endif
      do 500 i=1,50
        if(filenam(i:i).eq.' ') goto 510
500   continue
510   filenam6=filenam(1:i)//'.out'
      open(11,file=filenam6,status='new')
      READ(10,9000) NSPEC
9000  FORMAT(I5)
       write(11,9911) GRADL,(OUTSWT(I),I=1,4),VERS
9911   FORMAT('LOCATION ON THE GRADIENT IS ',F5.1,'     OUTPUT',
```

```
     >       ' OPTIONS: ',4L1,'    MODEL VERSION: ',F8.3)
      write(11,100) nyear,ktimes
100   format(/,'YEARS:  ',I5,5X,'PASSES:  ',I5)
      write(11,110) filenam
110   format(/,'Output filename: ',a50)
      write(11,9912)
 9912 FORMAT(/,51X,'T      C',/,27X,'DBH   HT',16X,'0 AGE  U',8X,
     1        '---SPROUT---',
     2       /,26X,' MAX   MAX     B3   B2   L MAX  R    G  TND  MIN',
     3       2X,'MAX SWTCH KTIM CMODE CSTD GRADM')
      write(11,9913)
 9913 FORMAT(/)
C.....
C.....INPUT INDIVIDUAL SPECIES INFORMATION
C.....AAA - SPECIES NAME
C.....DMAX - MAXIMUM GROWING DEGREE DAYS (not used)
C.....DMIN - MINIMUM GROWING DEGREE DAYS (not used)
C.....B3 - INDIVIDUAL SPECIES CONSTANT USED IN GROW
C.....B2 - INDIVIDUAL SPECIES CONSTANT USED IN GROW
C.....ITOL - LIGHT TOLERANCE CLASS
C.....AGEMX - MAXIMUM AGE OF SPECIES
C.....CURVE - DENOTES TYPE OF CURVE FOR CALCULATING BIOMASS
C.....    (NOT CURRENTLY USED)
C.....G - SCALES THE GROWTH RATE OF EACH SPECIES
C.....SPRTND - TENDENCY TO STUMP SPROUT
C.....SPRTMN - MINIMUM SIZE TREE THAT WILL SPROUT
C.....SPRTMX - MAXIMUM SIZE TREE THAT WILL SPROUT
C.....SWITCH - REPRODUCTION SWITCHES USED IN BIRTH
C.....KTIME - DESIGNATES SEED SOURCE LIMITATION FOR CERTAIN SPECIES
C.....NUM - INDIVIDUAL SPECIES NUMBER
C.....CMODE - COENOCLINE MODE
C.....CSTD  -  COENOCLINE STANDARD DEVIATION
C.....
      J=1
      DO 10 K=1,NSPEC
         read(10,9001) (AAA(J,I),I=1,6),DMAX(J),DMIN(J),B3(J),B2(J),
     >    ITOL(J),AGEMX(J),CURVE(J),G(J),SPRTND(J),
     >    SPRTMN(J),SPRTMX(J),
     >    (SWITCH(J,I),I=1,5),KTIME(J),NUM,CMODE(J),CSTD(J)
         IF((CMODE(J)-GRADL)**2/(2*CSTD(J)**2).GT.20.) GO TO 20
         GRADM(J)=EXP(-(CMODE(J)-GRADL)**2/(2*CSTD(J)**2))
         GO TO 30
   20    GRADM(J)=0.00
   30    DBHMAX=B2(J)/(2*B3(J))
         HTMAX=B2(J)**2/(4*B3(J))+137
         write(11,9002) (AAA(J,I),I=1,6),DBHMAX,HTMAX,B3(J),B2(J),
     >    ITOL(J),AGEMX(J),CURVE(J),G(J),
     >    SPRTND(J),SPRTMN(J),SPRTMX(J),
     >    (SWITCH(J,I),I=1,5),KTIME(J),CMODE(J),CSTD(J),GRADM(J)
         J=J+1
   10    CONTINUE
      write(11,*) char(12)
      RETURN
 9001 FORMAT(6A4,F6.0,F5.0,F4.4,F5.2,I1,F4.0,F2.0,F5.1,F2.0,F4.1,F4.0,
     > 5L1,I4,I5/2F6.1)
 9002 FORMAT(6A4,F7.0,F6.0,F7.4,F6.2,I2,F5.0,F3.0,F6.1,F3.0,F5.1,
     > F5.0,1X,5L1,I5,2F6.1,F5.2)
      END
      SUBROUTINE PLOTIN(IPLOT)
      COMMON/FOREST/NTREES(100),DBH(700),IAGE(700),KSPRT(100),
     > NEWTR(100),SUMLA(700),NEW(100),SWTCH(5)
      COMMON/CONST/GRADL,NSPEC,SOILQ,DEGD
C.....
C.....INITIALIZE VARIABLES TO START SIMULATION ON BARE PLOT
C.....NTREES CONTAINS NUMBER OF TREES FOR EACH SPECIES
C.....DBH CONTAINS DIAMETER AT BREAST HEIGHT FOR EACH TREE
C.....
      IPLOT = IPLOT+1
      DO 10 I=1,NSPEC
         NTREES(I) = 0
         DBH(I) = 0.
   10    CONTINUE
      NSPE1 = NSPEC+1
      DO 20 I=NSPE1,700
         DBH(I) = 0.
   20    CONTINUE
      RETURN
      END
      SUBROUTINE INIT
      COMMON/FOREST/NTREES(100),DBH(700),IAGE(700),KSPRT(100),
     > NEWTR(100),SUMLA(700),NEW(100),SWTCH(5)
      COMMON/CONST/GRADL,NSPEC,SOILQ,DEGD
      COMMON/DEAD/NOGRO(700),NTEMP(700)
C.....
C.....INITIALIZE VARIABLES TO ZERO FOR REPLICATE PLOTS
C.....
C.....KSPRT IS USED TO FLAG THE TREES THAT CAN SPROUT
C.....NOGRO IS USED TO FLAG THE TREES THAT DON'T GROW
C.....IAGE CONTAINS THE AGE FOR EACH TREE
C.....
C.....
      DO 10 I=1,NSPEC
         NOGRO(I) = 0
         KSPRT(I) = 1
```

```
         IAGE(I) = 0
   10    CONTINUE
      NSPE1 = NSPEC+1
      DO 20 I=NSPE1,700
         NOGRO(I) = 0
         IAGE(I) = 0
   20    CONTINUE
      RETURN
      END
      SUBROUTINE RANDOM
      COMMON/RAN/YFL
C.....
C.....SUBROUTINE RANDOM CALLS THE UNIFORM RANDOM NUMBER GENERATOR AND
C.....    RETURNS THE RANDOM NUMBER IN YFL
C.....
      YFL = RANDU()
      RETURN
      END
      SUBROUTINE KILL
      COMMON/FOREST/NTREES(100),DBH(700),IAGE(700),KSPRT(100),
     > NEWTR(100),SUMLA(700),NEW(100),SWTCH(5)
      COMMON/PARAM/AAA(100,6),DMAX(100),DMIN(100),B3(100),B2(100),
     > ITOL(100),AGEMX(100),CURVE(100),G(100),SPRTND(100),SPRTMN(100),
     > SPRTMX(100),SWITCH(100,5),KTIME(100),CMODE(100),CSTD(100),
     > GRADM(100)
      COMMON/CONST/GRADL,NSPEC,SOILQ,DEGD
      COMMON/RAN/YFL
      COMMON/DEAD/NOGRO(700),NTEMP(700)
      COMMON/COUNT/NTOT,NYEAR
      COMMON/TEMP/DTEMP(700),ITEMP(700)
      LOGICAL SWITCH,SWTCH
      KNT = 0
      DO 30 I=1,NSPEC
         IF (NTREES(I).EQ.0) GO TO 30
         NL = KNT+1
         NU = NTREES(I)+KNT
         DO 20 K=NL,NU
            CALL RANDOM
C.....
C.....KILL TREES BASED ON PROBABILITY THAT ONLY 1% REACH MAXIMUM AGE
C.....
            IF (YFL.LE.(4.605/AGEMX(I)).OR.IAGE(K).GT.AGEMX(I))
     >         GO TO 10
C.....
C.....CHECK TO SEE IF THERE WAS ANY GROWTH FOR TREE
C.....
            IF (NOGRO(K).EQ.0) GO TO 20
            CALL RANDOM
            IF (YFL.GT.0.368) GO TO 20
   10       CONTINUE
            NTREES(I) = NTREES(I)-1
C.....
C.....CHECK TO SEE IF DEAD TREE CAN STUMP SPROUT. SET KSPRT = -1
C.....IF TREE CAN SPROUT
C.....
            IF (DBH(K).GT.SPRTMN(I).AND.DBH(K).LT.SPRTMX(I))
     >         KSPRT(I) = -1
            DBH(K) = -1.0
   20       CONTINUE
         KNT = NU
   30    CONTINUE
C.....
C.....REWRITE DIAMETERS AND AGES TO ELIMINATE DEAD TREES
C.....
      K = 0
      DO 40 I=1,700
         IF (DBH(I).EQ.0.) GO TO 50
         IF (DBH(I).LT.0.) GO TO 40
         K = K+1
         DBH(K) = DBH(I)
         IAGE(K) = IAGE(I)
         NOGRO(K) = NOGRO(I)
   40    CONTINUE
   50 NTOT = K
      IF (NTOT.EQ.0) RETURN
      NTOT1 = K+1
      DO 60 I=NTOT1,NU
         DBH(I) = 0.
         IAGE(I) = 0
         NOGRO(I) = 0
   60    CONTINUE
      RETURN
      END
      SUBROUTINE SPROUT
      COMMON/FOREST/NTREES(100),DBH(700),IAGE(700),KSPRT(100),
     > NEWTR(100),SUMLA(700),NEW(100),SWTCH(5)
      COMMON/PARAM/AAA(100,6),DMAX(100),DMIN(100),B3(100),B2(100),
     > ITOL(100),AGEMX(100),CURVE(100),G(100),SPRTND(100),SPRTMN(100),
     > SPRTMX(100),SWITCH(100,5),KTIME(100),CMODE(100),CSTD(100),
     > GRADM(100)
      COMMON/CONST/GRADL,NSPEC,SOILQ,DEGD
      COMMON/RAN/YFL
      COMMON/DEAD/NOGRO(700),NTEMP(700)
      COMMON/COUNT/NTOT,NYEAR
```

```
      COMMON/TEMP/DTEMP(700),ITEMP(700)
      LOGICAL SWITCH,SWTCH
C.....
C.....SMALLEST AVERAGE STUMP SPROUT IS .1 CM
C.....
      SIZE = .1
C.....
C.....SUM TOTAL NUMBER OF TREES
C.....
      NTOT = 0
      DO 10 I=1,NSPEC
         IF (NTREES(I).EQ.O) GO TO 10
         NTOT = NTOT+NTREES(I)
   10    CONTINUE
C.....
C.....DETERMINE WHICH SPECIES CAN SPROUT
C.....
      NW = 0
      DO 20 I=1,NSPEC
         IF (SPRTND(I).LE.O.) GO TO 20
         IF (KSPRT(I).GE.O) GO TO 20
         NW = NW+1
         NEW(NW) = I
   20    CONTINUE
C.....
C.....CHECK FOR SPROUTS
C.....
      IF (NW.EQ.O) GO TO 90
      DO 30 J=1,NTOT
         ITEMP(J) = IAGE(J)
         DTEMP(J) = DBH(J)
         NTEMP(J) = NOGRO(J)
   30    CONTINUE
C.....
C.....CHOOSE RANDOM NUMBER OF SPROUTS
C.....
      CALL RANDOM
      NW = NW*YFL+1.0
C.....
C.....SELECT SPECIES TO SPROUT
C.....
      NSPC = NEW(NW)
      NSUM = 0
      DO 40 I=1,NSPC
   40    NSUM = NSUM+NTREES(I)
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.....
      CALL RANDOM
C.....
C.....RANDOMLY SELECT NUMBER OF TREES TO SPROUT
C.....
      NSPRT = YFL*SPRTND(NSPC)+1
      NL = NSUM+1
      NUP = NTOT
      DO 50 I=1,NSPRT
         NSUM = NSUM+1
         NTREES(NSPC) = NTREES(NSPC)+1
         NTOT = NTOT+1
         IF (NTOT.GT.700) CALL ERR
         ITEMP(NSUM) = 0
         CALL RANDOM
         DTEMP(NSUM) = SIZE+.1*(1.0-YFL)**3
         NTEMP(NSUM) = 0
C.....
C.....STORE DIAMETERS AND AGES FOR NEW SPROUTS
C.....
   50    CONTINUE
      IF (NL.GT.NUP) GO TO 70
      N1 = NSUM+1
      DO 60 J=NL,NUP
         DTEMP(N1) = DBH(J)
         ITEMP(N1) = IAGE(J)
         NTEMP(N1) = NOGRO(J)
         N1 = N1+1
   60    CONTINUE
C.....
C.....REINITIALIZE ORIGINAL DIAMETERS AND AGES
C.....
   70 DO 80 L=1,NTOT
         IAGE(L) = ITEMP(L)
         NOGRO(L) = NTEMP(L)
   80    DBH(L) = DTEMP(L)
   90 CONTINUE
C.....
C.....REINITIALIZE SPROUT SWITCH FOR EACH SPECIES
C.....
      DO 100 I=1,NSPEC
  100    KSPRT(I) = 1
      RETURN
      END
      SUBROUTINE GROW(IPLOT)
```

```
      COMMON/FOREST/NTREES(100),DBH(700),IAGE(700),KSPRT(100),
     > NEWTR(100),SUMLA(700),NEW(100),SWTCH(5)
      COMMON/PARAM/AAA(100,6),DMAX(100),DMIN(100),B3(100),B2(100),
     > ITOL(100),AGEMX(100),CURVE(100),G(100),SPRTND(100),SPRTMN(100),
     > SPRTMX(100),SWITCH(100,5),KTIME(100),CMODE(100),CSTD(100),
     > GRADM(100)
      COMMON/CONST/GRADL,NSPEC,SOILQ,DEGD
      COMMON/RAN/YFL
      COMMON/DEAD/NOGRO(700),NTEMP(700)
      COMMON/COUNT/NTOT,NYEAR
      COMMON/TEMP/DTEMP(700),ITEMP(700)
      LOGICAL SWITCH,SWTCH
C.....
C.....DBH IS IN CENTIMETERS
C.....EACH TREE IS REQUIRED TO ADD A 1.0 MM GROWTH RING EACH YEAR
C.....
      TINC = .1
      PHI = 1.
C.....
C.....CALCULATE TOTAL NUMBER OF TREES
C.....
      NTOT = 0
      DO 10 I=1,NSPEC
   10    NTOT = NTOT+NTREES(I)
      IF (NTOT.EQ.0) RETURN
C.....
C.....SUM LEAF AREA OF ALL TREES THAT ARE OF APPROXIMATELY
C.....THE SAME HEIGHT
C.....
      DO 20 I=1,700
         NOGRO(I) = 0
   20    SUMLA(I) = 0.
      NL = 1
      SBIO = 0.
      DO 40 J=1,NSPEC
         IF (NTREES(J).EQ.0) GO TO 40
         NU = NL+NTREES(J) -1
         DO 30 K=NL,NU
C.....
C.....CALCULATE STAND BIOMASS
C.....
            SBIO = SBIO+.1193*DBH(K)**2.393
C.....
C.....HEIGHT PROFILE IS CALCULATED IN .1 METER UNITS
C.....
            IHT = (B2(J)*DBH(K)-B3(J)*DBH(K)**2)/10.+1.
            IF (IHT.GT.700) GO TO 90
            SUMLA(IHT) = SUMLA(IHT)+1.9283295E-4*DBH(K)**2.129
   30       CONTINUE
         NL = NL+NTREES(J)
   40    CONTINUE
      DO 50 J=1,699
         J1 = 700-J
         SUMLA(J1) = SUMLA(J1)+SUMLA(J1+1)
   50    CONTINUE
C.....
C.....CALCULATE AMOUNT OF GROWTH FOR EACH TREE
C.....
      NL = 1
      DO 80 I=1,NSPEC
         IF (NTREES(I).EQ.0) GO TO 80
         NU = NL+NTREES(I)-1
         DO 70 J=NL,NU
            HT = B2(I)*DBH(J)-B3(I)*DBH(J)**2
            IHT = HT/10.+2.
            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)*DBH(J)*(1.0-(137.*DBH(J)+B2(I)*DBH(J)**2-B3(I)
     >       *DBH(J)**3)/GR)/(274.+3.0*B2(I)
     >       *DBH(J)-4.0*B3(I)*DBH(J)**2)
C    >       *(1.0-SBIO/SOILQ)
C    >       *4.0*(DEGD-DMIN(I))*(DMAX(I)-DEGD)/(DMAX(I)-DMIN(I))**2
C.....
C.....DECREMENT GROWTH AS A FUNCTION OF POSITION ON GRADIENT
       DNC=DNC*GRADM(I)
C.....
            DINC = 2.24*(1.-EXP(-1.136*(AL-.08)))*DNC
C.....
C.....CHECK FOR SHADE-TOLERANT
C.....
            IF (ITOL(I).LT.2) DINC=(1.0-EXP(-4.64*(AL-.05)))*DNC
C.....
C.....CHECK INCREMENT LESS THAN 1.0 MM REQUIRED GROWTH
            IF (DINC.LT.TINC) DINC=0.0
            IF (DINC.NE.0.) GO TO 60
            NOGRO(J) = -1
   60       DBH(J) = DBH(J)+DINC
   70       CONTINUE
         NL = NL+NTREES(I)
   80    CONTINUE
      RETURN
   90 write(11,9000)
      STOP
```

```
 9000 FORMAT('1 IHT EXCEEDED 700')
      END
      SUBROUTINE BIRTH(KYR)
      COMMON/FOREST/NTREES(100),DBH(700),IAGE(700),KSPRT(100),
     > NEWTR(100),SUMLA(700),NEW(100),SWTCH(5)
      COMMON/PARAM/AAA(100,6),DMAX(100),DMIN(100),B3(100),B2(100),
     > ITOL(100),AGEMX(100),CURVE(100),G(100),SPRTND(100),SPRTMN(100),
     > SPRTMX(100),SWITCH(100,5),KTIME(100),CMODE(100),CSTD(100),
     > GRADM(100)
      COMMON/CONST/GRADL,NSPEC,SOILQ,DEGD
      COMMON/RAN/YFL
      COMMON/DEAD/NOGRO(700),NTEMP(700)
      COMMON/COUNT/NTOT,NYEAR
      COMMON/TEMP/DTEMP(700),ITEMP(700)
      LOGICAL SWITCH,SWTCH
C.....
C.....SAPLINGS ENTER THE PLOT AT AVERAGE SIZE OF 1.27 CM DBH
C.....
      SIZE = 1.27
      CALL RANDOM
C.....
C.....SELECT A SPECIES FROM 1 TO 3 TIMES
C.....
      NPLANT = 3.*YFL+1.
      CALL RANDOM
C....
C.... RAT  RANDOM NUMBER IS FIXED FOR YEAR - USED IN SWITCH 4
C....
      RAT = YFL
      DO 140 JK=1,NPLANT
   10    BIOM = 0.
         NL = 1
C.....
C.....CALCULATE BIOMASS (LEAF MASS) FOR EACH SPECIES
         DO 30 J=1,NSPEC
            IF (NTREES(J).EQ.0) GO TO 30
            NU = NL+NTREES(J)-1
            DO 20 K=NL,NU
               BIOM = BIOM+1.9283295E-4*DBH(K)**2.129
   20          CONTINUE
            NL = NL+NTREES(J)
   30       CONTINUE
C.....
C.....TOTAL NUMBER OF TREES IN STAND
C.....
         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 THE SPECIES RECRUITMENT IS REDUCED
c.....  BY HOT YEAR (not used, set to false)
C.....SWITCH 4 IS TRUE IF THE SPECIES IS A PREFERRED FOOD OF DEER
C.....OR SMALL MAMMALS
C.....SWITCH 5 REDUCES SEEDING RATE OF DESIRABLE MAST
         DO 40 J=1,5
            SWTCH(J) = .TRUE.
   40       CONTINUE
C.....SET SWITCHES BASED ON VALUE OF BIOMASS, DEGD, AND RANDOM NUMBER
C.....
         IF (BIOM.GE..1) SWTCH(1) = .FALSE.
         IF (BIOM.LE..2) SWTCH(2) = .FALSE.
         SWTCH(3) = .FALSE.
         IF (RAT.GT..5) SWTCH(4) = .FALSE.
         CALL RANDOM
         IF (YFL.GE..5) SWTCH(5) = .FALSE.
C.....
C.....CHECK SWITCHES TO DETERMINE IF SEEDING IS ALLOWED
C.....
         NW = 0
         DO 60 J=1,NSPEC
C.....
C.....DO NOT PLANT IF GROWTH IS DECREMENTED BY MORE THAN 95%
C.....DUE TO POSITION ALONG GRADIENT
C.....
          IF (GRADM(J).LT.0.05) GO TO 60
            DO 50 K=1,5
               IF (SWITCH(J,K).AND.SWTCH(K)) GO TO 60
   50          CONTINUE
            IF (KYR.GT.KTIME(J).AND.NTREES(J).LE.0) GO TO 60
            NW = NW+1
            NEWTR(NW) = J
   60       CONTINUE
C.....
C.....CHECK TO SEE IF THERE ARE ANY NEW TREES
C.....
         IF (NW.EQ.0) GO TO 130
C.....
C.....CALCULATE AGE AND DIAMETER FOR NEW TREES
C.....
         DO 70 I=1,NTOT
            ITEMP(I) = IAGE(I)
            DTEMP(I) = DBH(I)
            NTEMP(I) = NOGRO(I)
```

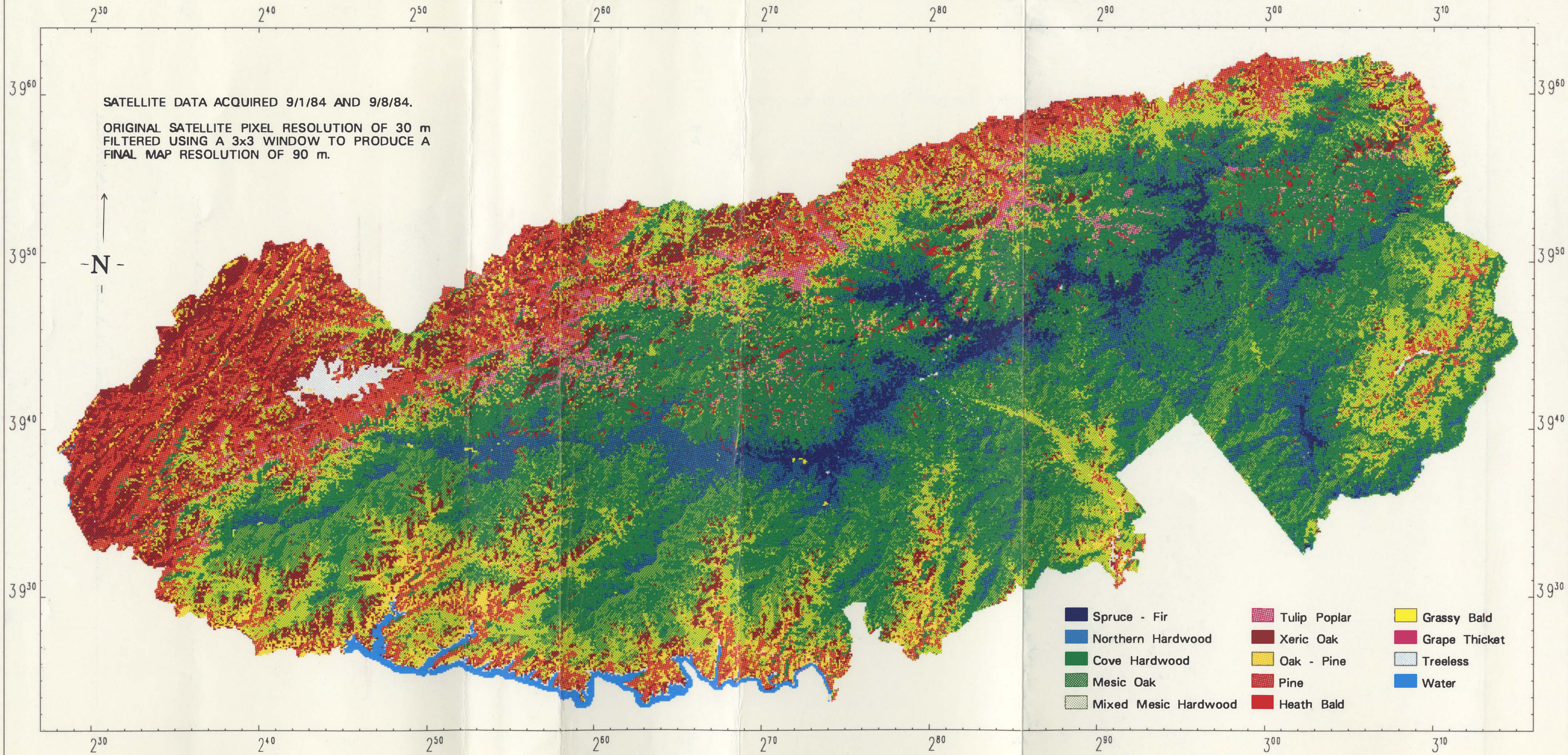
```
   70       CONTINUE
C.....
C.....DETERMINE THE NUMBER OF SEEDLINGS TO PLANT  0 TO 8
C.....
         CALL RANDOM
         MPLANT = 8.*YFL
C.....
C.....SELECT SEEDLINGS (PARTICULAR SPECIES)
C.....
         CALL RANDOM
         NW = NW*YFL+1.0
         NSP = NEWTR(NW)
         NSUM = 0
         DO 80 I=1,NSP
   80       NSUM = NSUM+NTREES(I)
C.....
C.....PLANT RANDOM NUMBER OF SEEDLINGS
C.....
         NL = NSUM+1
         NUP = NTOT
         DO 90 J=1,MPLANT
            NTOT = NTOT+1
            IF (NTOT.GT.700) CALL ERR
            NSUM = NSUM+1
            NTREES(NSP) = NTREES(NSP)+1
            ITEMP(NSUM) = 0
C.....
C.....CALCULATE DBH FOR SEEDLINGS
C.....
            CALL RANDOM
            DTEMP(NSUM) = SIZE+.3*(1.0-YFL)**3
            NTEMP(NSUM) = 0
   90       CONTINUE
         IF (NL.GT.NUP) GO TO 110
         N1 = NSUM+1
         DO 100 L=NL,NUP
            DTEMP(N1) = DBH(L)
            ITEMP(N1) = IAGE(L)
            NTEMP(N1) = NOGRO(L)
            N1 = N1+1
  100       CONTINUE
C.....
C.....REINITIALIZE ORIGINAL DBH AND AGE ARRAYS - INCLUDING NEW TREES
C.....
C.....
  110    DO 120 I=1,NTOT
            IAGE(I) = ITEMP(I)
            DBH(I) = DTEMP(I)
            NOGRO(I) = NTEMP(I)
  120       CONTINUE
  130    CONTINUE
         CALL SPROUT
         IF (BIOM.LT.0.2) GO TO 10
  140    CONTINUE
C.....
C.....INCREMENT AGES
C.....
      DO 150 I=1,NTOT
         IAGE(I) = IAGE(I)+1
  150    CONTINUE
      RETURN
      END
      SUBROUTINE OUTPUT(KYR,IPLOT)
      COMMON/FOREST/NTREES(100),DBH(700),IAGE(700),KSPRT(100),
     > NEWTR(100),SUMLA(700),NEW(100),SWTCH(5)
      COMMON/PARAM/AAA(100,6),DMAX(100),DMIN(100),B3(100),B2(100),
     > ITOL(100),AGEMX(100),CURVE(100),G(100),SPRTND(100),SPRTMN(100),
     > SPRTMX(100),SWITCH(100,5),KTIME(100),CMODE(100),CSTD(100),
     > GRADM(100)
      COMMON/COUNT/NTOT,NYEAR
      COMMON/CONST/GRADL,NSPEC,SOILQ,DEGD
      COMMON/OUTPT/IO1,IO2,PLOT,PRINT,LIST
      COMMON/OUTSWT/OUTSWT(4)
      DIMENSION BAR(100),NDEN(100),BA(100),PPER(100)
      dimension bah(100),ndenh(100),barh(100),bba(100),nnden(100),
     >          bbar(100)
      real*4 bar,ba
      integer*4 nden
      LOGICAL PRINT,PLOT,OUTSWT
      KYR1 = KYR+1
      NL=1
      AREA=0.0
      TBAR=0.0
      TOBAR=0.0
      NTOT = 0
      DO 100 I=1,NSPEC
      BA(I)=0.0
      BAR(I)=0.0
      IF(NTREES(I).EQ.0) GO TO 100
      NU=NL+NTREES(I) - 1
      DO 150 J =NL,NU
      IF (OUTSWT(2)) write(12,3030) IPLOT,KYR,
     > (AAA(I,K),K=1,6),IAGE(J),DBH(J)
3030  FORMAT(2I3,6A4,I4,F6.1)
```

```
C.....
C.....BA(I) - BASAL AREA OF SPECIES I IN M2/HA
C.....TOBAR - TOTAL BASAL AREA ON PLOT IN M2/HA
C.....TBAR - TOTAL BIOMASS ON PLOT
C.....BAR(I) - BIOMASS OF SPECIES I
C.....NDEN(I) - DENSITY OF SPECIES I IN STEMS/HA
C.....PPER(I) - PERCENT BIOMASS OF SPECIES I
C.....
      BA(I)=BA(I)+0.7854*(DBH(J)*DBH(J))*0.0012
      AREA=AREA+1.9283295E-4*DBH(J)**2.129
      BAR(I)=BAR(I)+.1193*DBH(J)**2.393
  150 CONTINUE
      TBAR=TBAR+BAR(I)
      TOBAR=TOBAR+BA(I)
      NTOT=NTOT+NTREES(I)
      NL=NL+NTREES(I)
      NDEN(I)=NTREES(I)*12
  100 CONTINUE
      PER=(BAR(I)/TBAR)*100.
      DO 400 I=1,NSPEC
         PPER(I)=BAR(I)/TBAR*100.
400   CONTINUE
      if(iplot.gt.1.and.outswt(3)) then
        read(15,rec=kyr) (bah(i),i=1,nspec)
        read(16,rec=kyr) (ndenh(i),i=1,nspec)
        read(17,rec=kyr) (barh(i),i=1,nspec)
        do 5000 i=1,nspec
          bba(i)=(bah(i)*(iplot-1)+ba(i))/iplot
          nnden(i)=(ndenh(i)*(iplot-1)+nden(i))/iplot
          bbar(i)=(barh(i)*(iplot-1)+bar(i))/iplot
5000    continue
      elseif(iplot.eq.1.and.outswt(3)) then
        do 5010 i=1,nspec
          bba(i)=ba(i)
          nnden(i)=nden(i)
          bbar(i)=bar(i)
5010    continue
      endif
      IF (OUTSWT(3)) WRITE(15,rec=kyr) (bba(nn),nn=1,nspec)
      IF (OUTSWT(3)) WRITE(16,rec=kyr) (nNDEN(nn),nn=1,nspec)
      IF (OUTSWT(3)) WRITE(17,rec=kyr) (bBAR(nn),nn=1,nspec)
      IF (OUTSWT(4)) WRITE(9,3000) GRADL,IPLOT,KYR
      IF (OUTSWT(4)) WRITE(9,3010) (PPER(I),I=1,NSPEC)
 3000 FORMAT(F8.1,2I8)
 3010 FORMAT(10F8.2)
 3020 FORMAT(10I8)
      IF(.NOT.PRINT) RETURN
      IF (PRINT) WRITE(IO2,2000) KYR
 2000 FORMAT('0YEAR',I5)
      IF (PRINT) WRITE(IO2,2010)
 2010 FORMAT('0SPECIES',17X,'STEMS',2X,'S/HA',2X,'M2/HA',2X,'BIOMASS',
     12X,'% BIOM',38X,'DBH')
      NL=1
      DO 200 I =1,NSPEC
      IF(NTREES(I).EQ.0)        GO TO 200
       NDEN(I)=NTREES(I)*12
      PER=(BAR(I)/TBAR)*100.
      NU=NL+NTREES(I) - 1
      NLINES=((NTREES(I)-1)/8)+1
      NLINES=NLINES-1
      IF (NLINES.EQ.0)  GO TO 10
      L1=NL+7
      IF (PRINT) WRITE(IO2,2020)(AAA(I,J),J=1,6),NTREES(I),NDEN(I),
     1 BA(I),BAR(I),PER,(DBH(II),II=NL,L1)
 2020 FORMAT('0',6A4,2X,I3,2X,I4,2X,F6.2,1X,F7.1,2X,F6.1,7X,
     18(F6.1,2X))
      DO 250 J=1,NLINES
      L2=L1+1
      L1=L1+8
      IF (J.EQ.NLINES)  L1=NU
      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(IO2,2020)(AAA(I,J),J=1,6),NTREES(I),NDEN(I),
     1 BA(I),BAR(I),PER,(DBH(II),II=NL,NU)
   20 NL=NL+NTREES(I)
  200 CONTINUE
      NTOTHA=NTOT*12
      WRITE(IO2,2050) NTOT,NTOTHA,TOBAR,TBAR
 2050 FORMAT('0',18X,'TOTALS',2X,I3,2X,I4,2X,F6.2,1X,F7.1)
      IF(.NOT.PLOT)     RETURN
C     DO 300 IV1 = 1,NSPEC
C 300 CONTINUE
C     ATOT=NTOT
C     N1 = NSPEC+1
C     N2 = N1+1
C     N3 = N2+1
      RETURN
      END
      SUBROUTINE ERR
      write(11,9000)
      STOP
 9000 FORMAT('1 THE NUMBER OF TREES HAS EXCEEDED 700')
```

```
      END
      function randu()
C.....Code for random number generator obtained from
C.....Press et al. 1986. Numerical Recipes. Cambridge
C.....University Press. p 197.
      integer*4 m1,m2,m3,ix1,ix2,ix3,ic1,ic2,ic3
      dimension r(97)
      parameter (m1=6655,ia1=936,ic1=1399,rm1=1./m1)
      parameter (m2=6075,ia2=1366,ic2=1283,rm2=1./m2)
      parameter (m3=11979,ia3=430,ic3=2531)
      data iff /0/
C.....idum is the generator seed
      idum=1231
      if(idum.lt.0.or.iff.eq.0) then
        iff=1
        ix1=mod(ic1-idum,m1)
        ix1=mod(ia1*ix1+ic1,m1)
        ix2=mod(ix1,m2)
        ix1=mod(ia1*ix1+ic1,m1)
        ix3=mod(ix1,m3)
        do 10  j=1,97
          ix1=mod(ia1*ix1+ic1,m1)
          ix2=mod(ia2*ix2+ic2,m2)
          r(j)=(float(ix1)+float(ix2)*rm2)*rm1
10      continue
        idum=1
      endif
      ix1=mod(ia1*ix1+ic1,m1)
      ix2=mod(ia2*ix2+ic2,m2)
      ix3=mod(ia3*ix3+ic3,m3)
      j=1+(97*ix3)/m3
      if(j.gt.97.or.j.lt.1) stop
      randu=r(j)
      r(j)=(float(ix1)+float(ix2)*rm2)*rm1
      return
      end
      SUBROUTINE GGNORD(Z)
      DIMENSION Z(1)
      DATA PI2/0.62831853E01/
C.....
C.....CALCULATES NORMALLY DISTRIBUTED RANDOM NUMBERS
C.....
      K = 0
      A1 = RANDU()
      A2 = RANDU()
      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
```

Appendix D. Vegetation map of Great Smoky Mountains National Park. The bound copy of the map (scale 1:256955) and the map in the pocket (scale 1:100000) contain the same information but are of different scale and have different color schemes. A copy of the 1:100000 scale map has been placed in the University of Tennessee, Knoxville Map Library in case it is missing from the pocket.

VEGETATION OF GREAT SMOKY MOUNTAINS NATIONAL PARK
DERIVED FROM LANDSAT-5 THEMATIC MAPPER SATELLITE DATA



PROJECTION AND GRID COORDINATES,
UNIVERSAL TRANSVERSE MERCATOR, ZONE 17.

MAP SCALE 1:256955

PREPARED BY MARK D. MacKENZIE, NOVEMBER 28, 1992

VITA

Mark D. MacKenzie was born in New Castle, Pennsylvania on November 29, 1955. He attended elementary schools in Wilmette, Illinois and was graduated from New Trier East High School, in Winnetka, Illinois in June 1973. In June 1977 he received a Bachelor of Arts degree in Biology from Kalamazoo College, Kalamazoo, Michigan. In May 1981 he received a Master of Science degree in Botany from Southern Illinois University, Carbondale. He received the Doctor of Philosophy degree with a major in Ecology from the University of Tennessee, Knoxville in May 1993.

Mr. MacKenzie has been employed as a Biologist by the National Park Service, Great Smoky Mountains National Park and as a Researcher in the Geography Department at the University of Tennessee, Knoxville. He is currently employed as a Researcher at the University of Wisconsin-Madison where he is involved in the National Science Foundation sponsored Long-Term Ecological Research (LTER) program.

Mr. MacKenzie is a member of Phi Kappa Phi, the Ecological Society of America, and the American Society for Photogrametry and Remote Sensing.

VEGETATION OF GREAT SMOKY MOUNTAINS NATIONAL PARK
DERIVED FROM LANDSAT-5 THEMATIC MAPPER SATELLITE DATA

SATELLITE DATA ACQUIRED 9/1/84 AND 9/8/84.

ORIGINAL SATELLITE PIXEL RESOLUTION OF 30 m FILTERED USING A 3x3 WINDOW TO PRODUCE A FINAL MAP RESOLUTION OF 90 m.

PROJECTION AND GRID COORDINATES, UNIVERSAL TRANSVERSE MERCATOR, ZONE 17

MAP SCALE 1:100000

THIS MAP IS APPENDIX D IN:

MacKenzie, M.D. 1993. The Vegetation of Great Smoky Mountains National Park: Past, Present, and Future. Ph.D. Disseration, University of Tennessee, Knoxville.