

**FIRE HISTORY AND FUEL LOADS
OF UPPER COASTAL PLAIN FORESTS**

Richmond National Battlefield Park, Virginia

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Summary

The objectives of this study were to determine the history and influence of fire on Richmond National Battlefield Park (RICH), to determine the loading of dead and down forest fuels in 6 forest cover types on the upper Coastal Plain of Virginia, and to determine the relationships between the fuels and the vegetation to create fuel load prediction equations.

To evaluate the influence of fire in RICH stands, the presence of fire sign, such as fire scars and charcoal, was searched for in each stand. The occurrence of fires was determined from state and federal records and communication with local individuals. Only one forest fire was reported in the park since 1940; this fire was at Fort Harrison, and the damage to the stand appeared to be minimal.

The forest fuels and vegetation were sampled in stands of the following cover types: conifer, oak-conifer, mixed hardwood-conifer, oak, mixed hardwood, and oak-mixed hardwood. The planar intersect method was utilized to quantify the woody fuels, and the forest floor was sampled in fixed area plots (Brown 1974). The weight, volume, depth, and species of fuel particles were determined for each stand sampled in the park, and this information was combined for an estimate of fuel loading for each cover type. The overstory trees were sampled within prism plots, and standard forestry stand and site information was collected for each sampled stand.

In general, the fuel loading was not different between the 6 cover types as determined with ANOVA procedures, due to the large variation of loads within each cover type. The loads were not different from those reported for similar stands in other forests. To quantify the relationships between the fuel loads and forest vegetation and site variables, Spearman's rank correlation coefficients were calculated between all the variables (SAS Institute, Inc. 1988). Many significant relationships were found, but most were weakly correlated. Forest and site variables significantly related to the fuel loadings were tested for their predictive value with multiple regression statistics. The resulting regressions had low coefficients of determination and varying levels of precision; their usefulness to the resource manager would depend on the level of sampling intensity and precision she/he would want to expend to get an estimate of fuel loading for the stand. If a rough estimate requiring little time in the field is desirable, then these regressions would be useful.

Introduction

Wildfire and human-caused fires have been important influences in the forests of the southeastern United States for centuries. Fires set by native Americans maintained an open, grassy landscape in many of the valleys, aiding in hunting, farming, and travelling. They knew that burning the forest undergrowth protected the forest canopy from crown fires and increased the production of useful plants (Barrett 1980). Many important forest ecosystems developed with high frequencies of fire, and owe their continued existence to periodic fires (Christensen 1987). For example, the distribution and extent of long-leaf (*Pinus palustris* Miller) and short-leaf (*Pinus echinata* Miller) pine communities were maintained by natural fires (Schowalter et al. 1981). The fast early growth and thick bark exhibited by these species made them especially well-suited to areas where burning was frequent. Burning creates favorable regeneration and development conditions for these pine communities, and it kills competing species not adapted to fire.

The suppression of fires in southern pine forest ecosystems has caused changes in forest structure, composition, and health. Understory species otherwise killed by fire become established and grow, competing with the "fire" species and changing forest structure and composition. Fire also helped maintain southern pine stands in ways that may have made them less susceptible to southern pine beetle (*Dendroctonus frontalis* Zimm.)(Schowalter et al. 1981). Richmond National Battlefield Park does not presently have any stands of southern pine species maintained by fire. This is most likely due to fire suppression activities, as eastern Virginia is within the range of long- and short-leaf pine.

Of course, wildfires and large human-caused fires are not compatible with the inhabited and heavily managed landscapes of the Southeast today. Most large landowners have detailed fire management, prevention, and suppression programs to keep wildfires small and manageable. For example, all national parks with a natural resource base are required to have an active plan for managing fires on park lands. Also, when prescribed fire is used in forestry or vegetation management, the burns are small and carefully controlled.

In order to properly manage fire, which involves both suppression and the use of prescribed burning, it is important to know how fires typically behave under different conditions of weather, topography, forest

types, and fuels. Predicting fire behavior is somewhat imprecise, but it is a topic that has received a great deal of recent study. Any fire plan must take into account the constant and variable features of the land that will affect the fire. Topography and aspect are examples of constant features. Weather and moisture conditions, on the other hand, are highly variable. The fuel available to support a fire is also variable, but over longer periods of time.

Usually, fuel loads change slowly as forest stands mature and undergo successional changes. Changes in loads can often be anticipated, as during the transition of pioneer pine stands to hardwoods. Much of Virginia has even-aged stands of Virginia pine due to the abandonment of farmland; these stands decline in an even-aged manner after 50 years, contributing heavy fuel loads to a site for several years. Stand history and future trends must be considered when analyzing fuel loading in stands and planning fuel management. However, sometimes fuels can unexpectedly build to high levels, as when pine bark beetle outbreaks kill many trees quickly. It is important for natural resource managers to quantify the normal fuel loads, then watch carefully for quick build-ups or hot spots. A fuel inventory, with information on the quantity and arrangement of the dead and down forest residue, is the first step towards fuel management.

This research was initiated for the purpose of aiding in forest fuel management and hazard fuels evaluation. Much of the forested land of Richmond National Battlefield Park is undisturbed by maintenance or visitor activities; it was these areas that were focused on for this study. Other sites that had been subject to maintenance activities, such as areas along roads where dying trees had been cut for safety purposes, were sampled separately for fuels information. The forest of Richmond National Battlefield Park is second- and third-growth, as different landowners have both cleared the forest and allowed it to regenerate several times since they first arrived from Europe on the coastal plain.

This project had two main components that resulted in the development of information useful to park resource managers. The first component involved the estimation of historical fires in the various units of the Richmond National Battlefield Park and the surrounding counties. This information helps to predict the natural fire occurrence in the region, and the impact that fire has had on the current vegetation. The second component involved a fuel inventory of all the forested units of the park, as well as the development of

equations to predict fuel loads. This specific fuel information will be helpful in fire management planning and in estimating fire behavior, and the equations will conserve time and money by eliminating the need to sample fuels in the field.

Research Study Areas

The study sites were located within the boundaries of the National Park Service Richmond National Battlefield Park (RICH) (Figure 1). The park consists of ten units, totaling 309 ha located in a semicircle to the north, east, and south of Richmond, Virginia (Appendix I). Richmond is located at the western edge of the Coastal Plain physiographic province, at the fall line which is the physiographic transition between the Coastal Plain and the Piedmont Plateau. The area has a level to gently rolling topography that is drained by the James, Chickahominy, and Pamunky Rivers (Brown 1939). These rivers have built wide floodplains with terraces and steep valley sides, and the smaller tributaries have also cut paths through the landscape (Brown 1939). The bedrock around the Richmond area consists of partially consolidated sedimentary rocks of Cretaceous, Eocene, and Miocene marine sands, gravels, clays, shell marls, and diatomaceous sediment (Dietrich 1970). The soils are primarily sandy loams and silt loams, and agricultural sites range from those on productive bottomland to those on poorly- and well-drained uplands (Brown 1939). Summer and winter temperatures average 24° C and 3° C, respectively (N.O.A.A. 1983). Annual precipitation averages 112 cm, with most months averaging 8 or 9 cm except for June and July, which average 13 cm of rain.

During the Civil War, the battlefield sites were mostly agricultural areas comprised of woodlots and fields. These fields and forests had been manipulated since the first European settlers arrived, if not sooner by the native Americans, so some of the woodlots were probably second-growth in the 1860's. Remains of the military earthworks and forts are now covered with second-growth and third-growth forest except where they have been cleared for interpretive use by the park. Some of the battlefields have been maintained as open fields and cropland through the agricultural leasing program, but many are now covered by forest vegetation (RICH 1989). The general composition of the overstory forest vegetation varies among pine (*Pinus* spp.), oak (*Quercus* spp.), and mixed hardwood species (Appendix II). No federal or state endangered or threatened plant species have been identified within the park. Approximately 24% of the plant species found are exotics, most notable of which are the widely present Japanese honeysuckle (*Lonicera japonica* Thunberg) and tree-of-heaven (*Ailanthus altissima* (Miller) Swingle) (Hayden and Johnson 1986). Wind-throw and insect and disease infestations are common causes of death for mature trees in the study area.

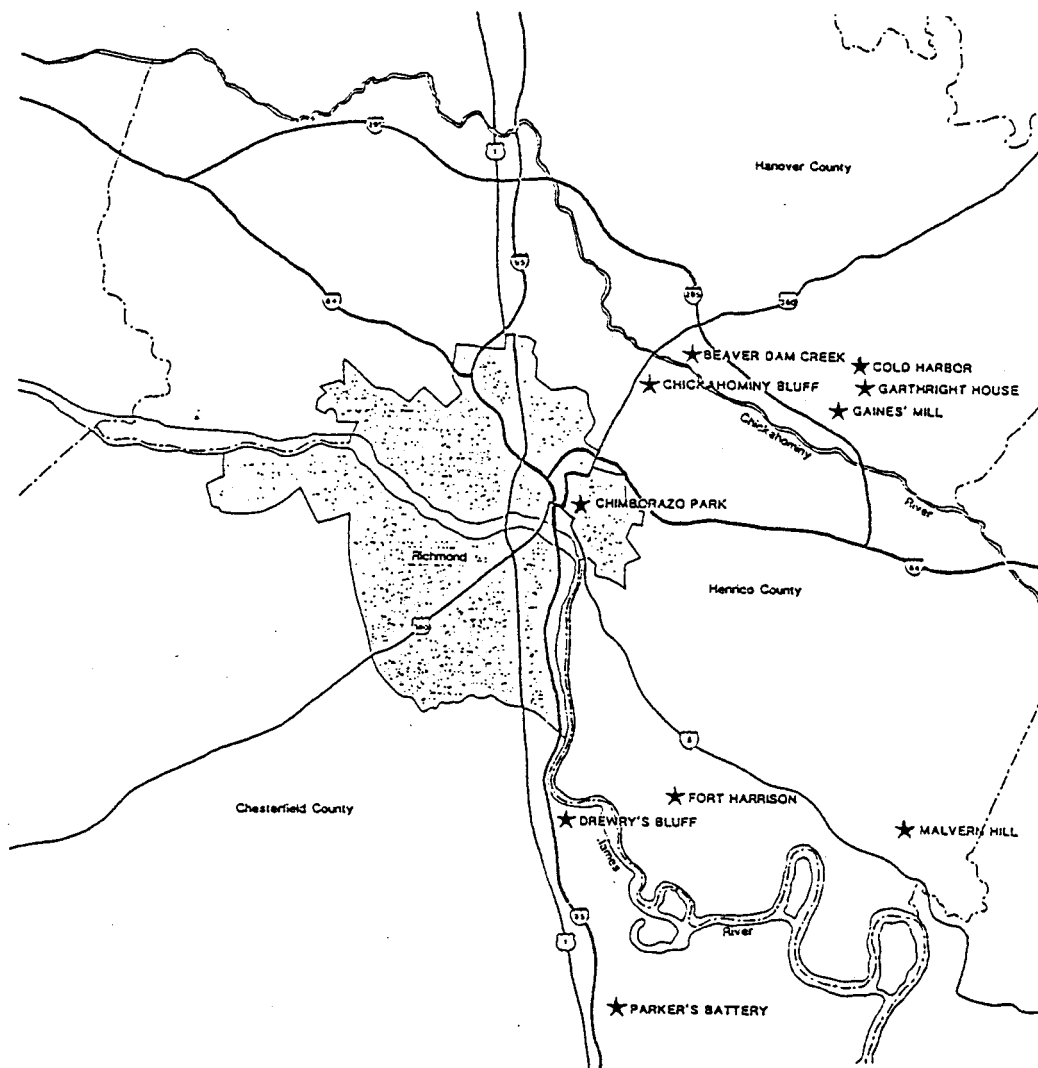


Figure 1. Location of Richmond National Battlefield Park, Virginia (RICH 1989). Stars represent the 10 park units.

Fire History

Methods

Two procedures were used to evaluate the fire history of the Richmond National Battlefield Park and surrounding areas. First, all trees on all plots in the vegetation inventory (Helm and Johnson 1994) were examined for the presence of external fire scars. When scars were present, an attempt was made to determine the number of years since the fire by examining records. The second procedure involved reviewing the fire history records of the Virginia Department of Forestry at the regional office in Sandston, Virginia. Records were reviewed for the number of fires, the acreage burned, and the cause of the fire, by year, for the years 1943-1992.

Results

Fire has not played a major role in shaping the character of the vegetation in the Richmond National Battlefield Park over the past 25 years. In fact, the exclusion of fire by aggressive fire control policies of the Virginia Department of Forestry has allowed forest succession to progress toward the oak-hickory climax. Where pine occurs, it is usually dying, and being replaced by more tolerant hardwood species. These transitional stands had heavier fuel loads due to the fallen pine boles. In the review of 115 vegetation plots, only one showed evidence of fire: the base of the trees had blackened bark. The cambium of the trees was not scarred however. This fire started on private land and spread to the oak stand on the southwest boundary of Fort Harrison (G.I.S. stand number 23, near plot 36). The fire occurred during the 1960's, was of limited acreage, and had no significant ecological impact.

A review of Virginia Department of Forestry records for Chesterfield, Hanover, and Henrico counties revealed some interesting trends. From the 1940's to the 1990's there has been a marked decrease in both the number of fires and the acreage burned (Tables 1 & 2). For example, during the 1940's, Henrico County averaged 104 forest fires per year, with the average fire 10 acres in size. By the 1990's, that had dropped to 12 fires per year, with one acre the average size. These trends are shown graphically in Figure 2. There is no doubt that this remarkable reduction in the frequency and extent of forest fires has had a major impact on

Table 1. Frequency and extent of forest fires in Chesterfield, Hanover, and Henrico Counties, Virginia, from the 1940's through 1990's.

County:	Chesterfield		Henrico		Hanover	
Year	# Fires	Acreage Burned	# Fires	Acreage Burned	# Fires	Acreage Burned
1943	92	1435	129	1686	103	1543
1944	94	1302	95	1547	26	201
1945	90	1420	139	1711	49	1362
1946	99	574	110	951	34	344
1947	90	302	98	1039	35	246
1948	60	141	54	107	14	96
1949	93	215	103	230	32	284
1950	99	361	112	251	38	700
1951	183	709	171	491	40	483
1952	100	360	132	661	33	228
1953	110	402	187	312	28	935
1954	111	1064	182	514	33	192
1955	102	237	91	129	19	719
1956	54	307	126	324	25	122
1957	48	173	73	62	16	56
1958	29	45	92	92	11	16
1959	82	369	196	372	55	93
1960	42	68	142	142	22	173
1961	19	130	95	86	27	52
1962	37	192	124	140	37	393
1963	36	2472	254	615	76	509
1964	29	106	114	94	36	81
1965	40	205	168	182	105	148
1966	47	94	137	113	81	210
1967	44	130	111	83	68	94
1968	38	202	126	142	58	122
1969	22	61	69	79	19	117

Table 1. Continued.

County:	Chesterfield		Henrico		Hanover	
Year	# Fires	Acreage Burned	# Fires	Acreage Burned	# Fires	Acreage Burned
1970	30	58	92	393	28	172
1971	33	296	71	145	26	172
1972	5	29	64	51	35	88
1973	24	146	39	71	26	24
1974	21	59	57	46	48	124
1975	17	81	23	40	32	115
1976	25	163	80	77	97	217
1977	29	314	17	20	73	100
1978	26	73	11	15	18	32
1979	8	24	9	15	12	40
1980	21	47	10	9	22	29
1981	15	81	27	49	32	87
1982	23	67	11	66	22	27
1983	23	152	30	25	12	6
1984	22	104	9	18	14	22
1985	58	176	34	90	72	168
1986	66	93	30	36	46	34
1987	25	65	22	18	20	24
1988	36	60	21	17	34	27
1989	30	58	6	0	10	17
1990	20	61	17	25	14	51
1991	64	88	7	3	22	39
1992	22	40	11	8	25	72

Table 2. Annual average, by decade, of the frequency and extent of forest fires in Chesterfield, Hanover, and Henrico Counties, Virginia, from the 1940's through 1990's.

County:	Chesterfield		Henrico		Hanover	
Year	# Fires	Acreage Burned	# Fires	Acreage Burned	# Fires	Acreage Burned
1940's	88	770	104	1039	42	582
1950's	92	403	136	321	30	354
1960's	35	366	135	168	53	190
1970's	22	124	44	87	40	122
1980's	32	91	20	33	28	44
1990's	35	63	12	12	20	54

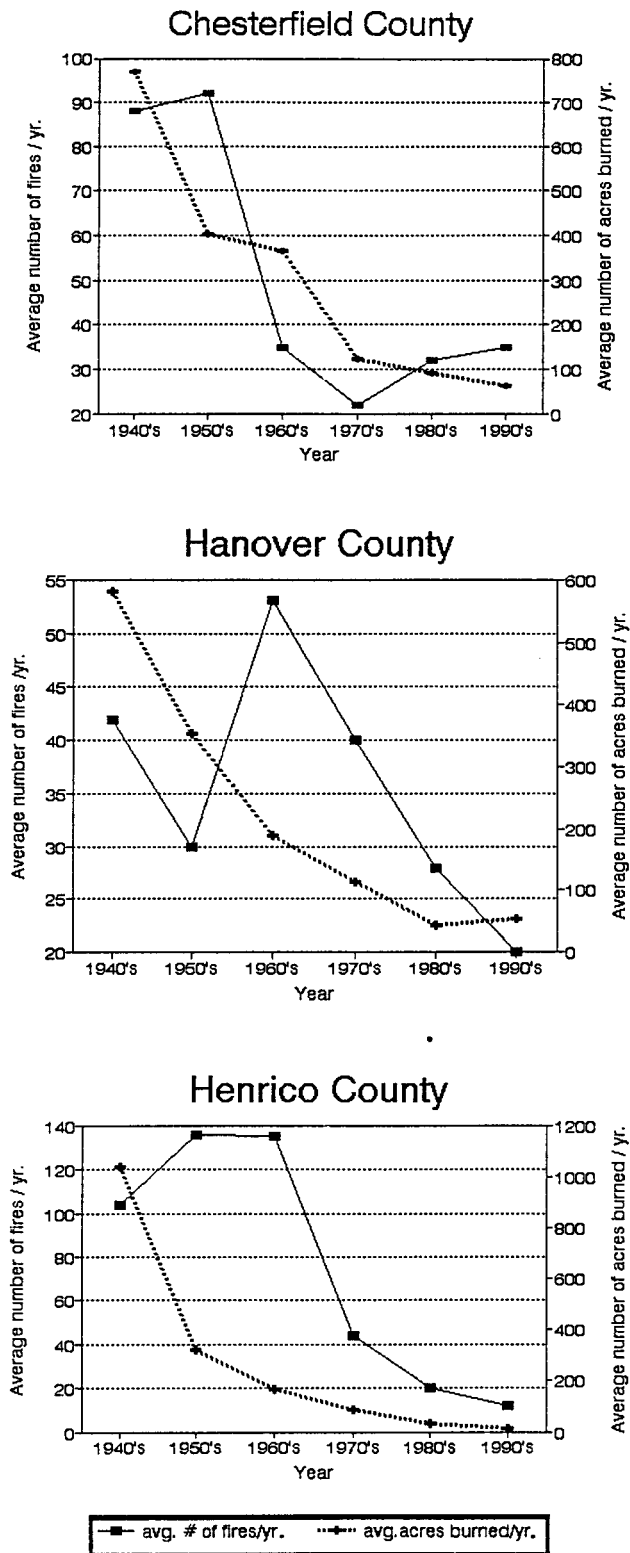


Figure 2. Trends in forest fire frequency and extent in Chesterfield, Hanover, and Henrico Counties, Virginia.

forest vegetation. A trend toward later successional, more tolerant deciduous species like oak (*Quercus* spp.), maple (*Acer* spp.), and hickory (*Carya* spp.) has occurred at the expense of the pines. Likewise, tolerant understories of flowering dogwood (*Cornus florida* L.) and American holly (*Ilex opaca* Aiton) become more prevalent, and invading species like Japanese honeysuckle become more pervasive. The woods also become thicker, with more underbrush and brambles.

Whether or not fire exclusion is good or bad is subject to some debate. Certainly the pre-Columbian native Americans burned areas repeatedly, so that the near exclusion of fire that we have today is a different situation. Fire should be viewed as a useful vegetation management tool. If the desire is to create more open forest, with grassy or herbaceous ground vegetation and more pines, then fire can be beneficial. If, on the other hand, the intent is to allow the forests to thicken and darken, with more deciduous species and more woody understories and vines, then fire suppression is most beneficial.

Also of interest in the review of fire records was the cause of forest fires. Records were available for the region as a whole, for the years 1967-1992 (Table 3). Of particular note is the reduction in forest fires caused by railroads. For example, in 1967, 29% of all fires were caused by railroads, but by 1992 this had dropped to 1%. Most of the other categories show some year to year variation, without major trends. For example, smokers caused the same percentage of fires in 1967 as they did in 1992. It should be pointed out, however, that in 1967 there were many more fires than in 1992, so in a sense the impact of smokers was greater 25 years ago.

Table 3. Causes of forest fires in southeastern Virginia, 1967-1992.

Causes:	Smoking	Debris Burning	Railroads	Miscell.	Incendiary	Children
Year	----- % -----					
1967	16.6	21.3	29.0	19.1	12.8	--
1968	22.7	33.4	15.5	18.9	7.6	--
1969	24.1	27.3	19.4	17.6	9.7	--
1970	16.1	25.3	29.1	8.4	4.6	12.2
1971	19.8	15.7	28.9	9.9	9.1	14.9
1972	6.0	14.5	56.0	6.6	2.4	12.1
1973	10.3	13.0	31.0	20.7	8.3	10.3
1974	19.2	19.2	25.5	11.9	5.5	13.2
1975	17.6	18.2	20.3	14.2	2.7	16.9
1976	18.2	20.1	21.5	5.2	13.9	17.9
1977	19.1	27.6	14.8	6.4	5.9	18.6
1978	29.1	31.0	8.3	7.5	5.0	13.3
1979	21.7	39.1	13.1	10.9	7.6	5.4
1980	17.4	27.8	11.3	13.9	11.3	11.3
1981	17.2	27.2	9.4	13.9	16.7	7.8
1982	16.5	24.8	15.9	9.0	13.1	15.2
1983	15.0	19.0	8.0	9.0	3.0	32.0
1984	11.9	33.6	9.9	13.9	9.9	17.8
1985	12.9	35.2	3.2	15.8	9.4	13.2
1986	12.6	27.8	1.6	11.8	13.1	22.5
1987	13.0	37.9	5.6	5.0	9.3	15.5
1988	18.6	24.4	1.7	8.1	18.0	20.9
1989	7.7	38.5	4.3	12.8	9.4	16.2
1990	12.4	37.1	6.7	13.3	8.6	10.5
1991	6.8	35.2	1.4	14.2	12.8	15.1
1992	16.5	29.0	0.9	21.9	6.3	14.7

Fuel Loads

Methods

Data Collection Procedures

Forest Stand Designation and Plot Location: The undisturbed forest stands in 7 RICH units were sampled for forest vegetation and fuel loadings as part of an inventory for the park. The forest stands were distinguished and mapped for each unit from color-infrared aerial photographs (taken April 9, 1990, Scale: 1"=250'). The maps were then used to organize the sample plots, which were randomly located in each stand along transects systematically run through each unit. Human-caused disturbances in the forest vegetation or residue loads, such as trails and old forest roads, were avoided, and plots were not located on historical relics or earthworks. Stands that were too small, had no overstory vegetation, or had recently been subject to cutting were not considered. The plots were located 15-20 m into the forest to avoid edge effects and changes due to visitor and maintenance activities. A total of 115 plots were sampled for the vegetation and fuels inventory within the park (Appendices III & IV). One hundred and eight stands were represented by these plots.

Each stand was then classified by tree cover type according to its dominant genus as determined by the forest inventory, after those defined by Eyre (1980). These classifications were as follows:

Conifer Cover Types: $\geq 20\%$ pine basal area

Conifer -- $>50\%$ pine basal area.

Oak-Conifer -- 20-50% pine basal area with remaining basal area comprised by a majority of oak species, including the commonly associated hickory and beech (*Fagus grandifolia* Ehrh.).

Mixed hardwood-Conifer -- 20-50% pine basal area with remaining basal area comprised by a majority of mixed hardwood species: sweetgum (*Liquidambar styraciflua* L.), yellow poplar (*Liriodendron tulipifera* L.), black gum (*Nyssa sylvatica* Marshall), and red maple (*Acer rubrum* L.).

Deciduous Cover Types: $<20\%$ pine basal area

Oak -- $>50\%$ oak basal area, including commonly associated hickory and beech.

Oak-Mixed hardwood -- Oak and mixed hardwood species collectively comprise $>50\%$ of the basal area.

Mixed hardwood -- >50% mixed hardwood basal area, comprised by sweetgum, yellow poplar, black gum, and red maple.

The distribution of stands by cover type and age is presented in Table 4. Cover types were used to present the forest overstory and fuels data in convenient classes for management purposes, and were considered as a grouping in the analysis of forest overstory and fuels relationships. Stand age classifications were not used since most of the stands fell within a narrow range of ages, relative to the overall life of a stand.

Fuel Loading Inventory: To accomplish the objective of quantifying the fuel loadings, Brown's (1971, 1974) planar intersect method was used. This method was designed to sample dead and downed surface fuels. For sampling purposes, the smaller fuels (branches up to 7.6 cm diameter) were divided into the time-lag size classes based on diameter. Branches with diameters up to 0.6 cm were counted as 1 hour time-lag fuels, from 0.6 to 2.5 cm as 10 hour time-lag fuels, and from 2.5 to 7.6 cm as 100 hour time-lag fuels. Transect lengths for these classes were selected by evaluating the lengths recommended by Brown (1974) and adjusting them proportionally to the 50 m transect used to inventory downed boles. Transect lengths selected for the three size classes were 5, 10, and 15 meters, respectively. These smaller transects were subdivided into 5 sections so that branches were sampled along the entire bole transect. All intersections between fuel particles and the planar intersect were counted, using a "go-no-go" gauge to quickly classify the branches into time-lag classes.

Along each transect, intersecting boles were measured for diameter at the point of intersection, classified as sound or rotten, and identified to genus. Rotten boles were those that fell apart easily when kicked. The number of branches were then tallied by time-lag class along the appropriate transect lengths, and the three most common genera of branches were recorded. The depth of the surface fuel, from the bottom of the litter layer to the top of the bole/branch layer, was measured at three points along the 50 m transect.

The depth of the litter and duff layers were measured at three randomly chosen locations adjacent to each transect. The litter layer consisted of unaltered dead remains of plants, while the duff consisted of

Table 4. Distribution of sample stands by cover type and age at Richmond National Battlefield Park, Virginia.

Average Age	Cover Types ^a					
(years)	C	OC	HC	O	H	OH
# of stands						
10-20	1	0	0	0	0	0
20-30	1	1	1	0	0	0
30-40	2	1	0	2	1	0
40-50	2	1	0	0	2	0
50-60	2	2*	3	1	0	2
60-70	2	5*	4*	1	2	2*
70-80	1	2*	1*	2	4	0
80-90	0	3	2*	5*	3*	4*
90-100	2*	3*	0	4*	4*	4
100-110	0	4	0	4	0	0
110-120	0	2	0	7	1*	3
Total	13	24	11	26	17	15

^a C-Conifer, OC-Oak-Conifer, HC-Mixed Hardwood-Conifer, O-Oak, H-Mixed Hardwood, OH-Oak-Mixed Hardwood

*Some two-aged (dominants with > 20 years difference) stands represented in these groups by a mean age.

fragmented, partly decomposed organic materials and well-decomposed, amorphous organic matter (Pritchett and Fisher 1987). The duff layer included both the fermentation (F) layer and the humification (H) layer of the forest floor. A sample of each layer was collected from three 0.25 m² plots adjacent to each transect. These samples were packed into paper bags, dried to a constant moisture at 65° C, and weighed.

The fuel sampling was done during the summer field seasons of 1991-1992 (May-July) to lessen the effects of different seasonal decomposition rates on the weight and volume results. Several photographs were taken in each stand type with a forest fuel depth pole for visual stand vegetation and fuel descriptions.

Forest Vegetation Inventory: The inventory of forest vegetation involved the sampling of overstory and understory strata in each stand that was sampled for fuel loadings. Sample plots were located at the mid-point of each 50 m transect used to sample fuels. At each plot, general topographic and site information was recorded, including slope position, percent slope, aspect, and notes of any evidence of past disturbances, general tree health, and insect and disease problems.

Overstory trees were classified as stems taller than 5 m. Sample trees were those designated using a 2.5 m BAF prism plot. Each sample tree was identified to species and crown position, and measured for diameter at breast height (1.37 m above the ground on the uphill side of the tree). Age at breast height and total height were measured on three dominant trees with no signs of crown dieback, disease, insect damage, or mechanical damage in each stand from dominant genus groups (oaks, pines, and mixed hardwoods).

The understory, consisting of stems from 1.37 m (breast height) to 5 m in height, was sampled within two 2.3 m circular subplots (0.002 ha), located at the 20 and 30 m marks along the fuel sampling transect. Density and basal area by species of all woody understory stems were determined by counting stems by species and measuring their diameter at breast height (DBH) with calipers.

Data Analysis

Calculation of Fuel Loadings: To convert the field data into fuel loading estimates, Brown's (1974) equations were used to calculate volume and weight. For volume estimates of the bole (>100 hr. time-lag fuels) loads on an area basis, the following equation was used:

$$V = \frac{\Pi^2 \sum d^2}{8 * l} \quad (1)$$

where: V = volume of bole wood per unit area, in m^3/ha
 $\Pi = 3.12$
 d = diameter of bole, in meters
 l = length of transect sampled for boles, in m

Sound and rotten bole volumes were calculated separately for each fuel transect. For the branch (1, 10, 100 hr. time-lag fuels) loads, the field tallies of each time-lag class were used with the following equation to calculate volumes per unit area:

$$V_i = \frac{n_i * \Pi^2 d_i^2}{8 * l_i} \quad (2)$$

where: V_i = volume of wood per unit area in time-lag class i , in m^3/ha
 n_i = # particles tallied in the time-lag class i
 $\Pi = 3.12$
 d_i = mean diameter for time-lag class i , in cm
 l_i = length of plot sampled for time-lag class i , in m

Mean diameters for pines and hardwoods were taken from Harmon et al. (1980)(Table 5). Branch volumes were calculated for each time-lag class on each fuel transect.

To calculate the bole and branch weights per unit area, the volume estimates were multiplied by the relative density for the following species groups: hard hardwoods (oak, hickory), soft hardwoods (yellow poplar, elm (*Ulmus* spp.), maple (*Acer* spp.)), and pines. Relative density values for branches and boles by species group were taken from Phillips (1981) and Harmon et al. (1980)(Table 6). Weights were computed for each branch time-lag class and for sound and rotten boles for each fuel transect. Surface fuel, litter, and duff depths were averaged for each fuel transect. The weights of the litter and duff layers were averaged for each fuel transect, and were converted to a kg/ha basis.

Table 5. Woody branch dimensions for calculating volumes per acre in naturally fallen debris (Harmon et al. 1980).

Forest Type	Geometric mean diameter (cm)
0-0.7 cm diameter	
Conifer	0.36
Oak-hickory and mixed hardwoods	0.40
0.7-2.54 cm diameter	
All types	1.36
2.54-7.6 cm diameter	
All types	4.20

Table 6. Relative density values for branch and bole residue for three species groups.

Average Relative Density (g/m ³)			
Species Group			Source
	Branch Diameter (cm)		
	0-2.54	2.54-7.6	
Pine	0.41	0.40	Harmon et al. (1980)
Hard hardwoods	0.58	0.61	Phillips (1981)
Soft hardwoods	0.50	0.50	Phillips (1981)
	Bole Condition		
	Sound	Rotten	
Pine	0.53	0.49	Harmon et al. (1980)
Hard hardwoods	0.65	0.53	Harmon et al. (1980)
Soft hardwoods	0.56	0.48	Harmon et al. (1980)

Calculation of Vegetation Variables: For each overstory plot, species basal area, density, and frequency were computed, along with species importance values, which are an average of the sum of relative dominance, density, and frequency values for a species. Forest site quality index (FSQI) was also calculated with site information collected on each plot (Walthen 1977)(Appendix V). Although created for use in the Ridge and Valley physiographic province, this method of estimating site quality is based on topographic variables that reflect water availability and insolation (Walthen 1977): aspect, slope position, and slope steepness. These factors strongly influence fuel decomposition rates and vegetation growth rates. Descriptions of the overstory vegetation and typical site of each cover type are presented in Appendix VI.

Statistical Analysis: To develop equations for predicting fuel loadings, a regression approach was used with stand and site variables which were significantly related to the fuel. Bole volume and weight, branch volume and weight, and litter and duff weights were considered as dependent variables. Various stand and site characteristics were used as independent, or predictive, variables: basal area and density by genus, total basal area and density, FSQI, age by genus, stand age, and fuel depths.

To determine if separate regressions should be developed for each forest cover type, the fuel loadings of each cover type were compared. All of the fuel loading variables were tested under the null hypothesis that no significant differences existed between cover types at the $p=0.05$ level. Fuel loading variables with significant differences between cover types were then subjected to Tukey's Studentized Range Test at the $p=0.05$ level. The results of these tests revealed that the differences in fuel loadings between cover types were not consistent between the different sizes of fuels or significant enough to justify creating separate regressions (Tables 7 & 8).

Spearman rank correlation coefficients were computed to test for significant ($p=0.05$) relationships between the fuel loading variables and the stand and site characteristics since the variable distributions were not normal and the variances were not equal. Scatterplots were also made of the variables to determine if non-linear patterns of relationship were occurring. When necessary, the $\log_{10}$ power was applied to the dependent fuel variables when its variance increased with the independent variables' value.

Table 7. Mean weights and volumes of bole and branch fuels for 6 cover types in Richmond National Battlefield Park, Virginia (values within a row followed by different letters are significantly different at $p=0.05$ according to results of a GLM F-test with ranked fuel variables).

Fuel	Cover Types*					
	C	OC	HC	O	H	OH
Weight	kg/ha.....					
Bole						
Sound	15,489	19,383	12,258	15,816	7,019	14,247
Rotten	19,153 ab	8,214 ab	20,297 a	6,624 b	13,753 ab	9,004 ab
Pine	34,128 a	25,875 ab	28,285 ab	9,749 b	12,537 ab	11,580 ab
Total	34,642	27,597	32,555	22,440	20,772	23,251
Branch (T-L)						
1 hr.	389 a	570 bc	440 ac	688 b	440 ac	571 bc
10 hr.	1,997	1,947	1,990	2,109	1,954	2,076
100 hr.	2,716	2,692	2,363	2,294	1,519	2,618
Total	5,082	5,209	4,793	5,091	3,914	5,266
Volume	cubic m/ha.....					
Bole						
Sound	29.3	36.3	22.4	26.4	12.8	24.8
Rotten	39.1 ab	16.7 ab	41.5 a	13.2 b	27.7 ab	17.7 ab
Pine	67.3 a	50.0 ab	56.2 ab	19.0 b	24.9 ab	22.4 ab
Total	68.4	53.0	63.9	39.6	40.5	42.5
Branch (T-L)						
1 hr.	0.9 a	1.1 ab	0.9 ab	1.2 b	0.9 a	1.1 ab
10 hr.	4.3	3.8	4.1	3.7	3.8	3.8
100 hr.	6.0	5.1	4.8	3.9	2.9	4.7
Total	11.2	10.0	9.8	8.8	7.6	9.6

*C-Conifer, OC-Oak-Conifer, HC=Mixed Hardwood-Conifer, O-Oak, H-Mixed Hardwood, OH-Oak-Mixed Hardwood

Table 8. Mean weights and depths of the forest floor for 6 cover types at Richmond National Battlefield Park, Virginia (values within a row followed by different letters are significantly different at $p=0.05$ according to results of a GLM F-test with ranked fuel variables).

Fuel	Cover Types*					
	C	OC	HC	O	H	OH
Weight	kg/ha.....					
L-layer	1,241a	1,383a	1,254ab	1,370ab	792b	1,034ab
F-layer	1,861a	1,759a	1,608ab	1,617ab	1,056b	1,447ab
H-layer	2,813	3,112	2,397	2,075	2,383	2,598
Total	5,915a	6,254a	5,259ab	5,062ab	4,231b	5,079ab
Depth	cm.....					
L-layer	3.6	3.5	3.0	3.1	2.7	3.5
F-layer	2.3	2.1	2.1	2.1	1.6	2.1
H-layer	2.0	1.9	2.0	1.7	1.4	1.9
Total	7.9	7.5	7.1	6.9	5.7	7.5

* C-Conifer, OC-Oak-Conifer, HC=Mixed Hardwood-Conifer, O-Oak, H-Mixed Hardwood, OH-Oak-Mixed Hardwood

Regressions were developed initially using only 60% of the sample observations, which were randomly selected from the total data set. Multiple regression was utilized with independent variables that were not correlated with each other. The remaining observations (40%) were then used to evaluate the fitness of the significant models. Regressions were evaluated for significance at the $p=0.05$ level, and for strength of predictability using the reserved data set and the R^2 value. Plots of the residuals were made to check the "fit" of the models and to determine if the addition of more independent variables might improve the regressions.

Aerial photographs were considered as tools in evaluating fuel loading in forest stands; however, none of the forest stand characteristics that were significantly related to fuel loading levels were interpretable on aerial photographs to sufficient accuracy to make the procedure better than actual field measurement of the information. Although it might have been possible to interpret a high load of bole fuels in pine stands impacted by pine bark beetle, these large fuels do not create a hazardous situation in and of themselves. For the purpose of fire behavior and hazard fuels evaluation, prediction of the load of smaller-sized forest fuels was considered the most important in this research.

Results

Forest Fuels Associated with the Six Cover Types

Conifer Cover Type: The conifer cover type stands had the highest mean *total* volume and weight of woody fuel of all the cover types (Figures 3 & 4). The mean bole (time-lag > 100 hr.) volume was 68.4 cubic m/ha and the mean branch (time-lag $\leq$ 100 hr.) volume was 11.2 cubic m/ha (Table 9, Figures 5 & 6). The mean bole and branch fuel weights were 34,642 kg/ha and 5,082 kg/ha, respectively (Table 10). This type had higher mean bole weights than any other (Figure 7), but one of the lower average branch loads (Figure 8). Pine boles contributed approximately 97% of the bole weights in these stands; the pine bole loads within this cover type were significantly higher than in the oak cover type (Table 7). The mean depth of the surface fuel was 6.3 cm (Table 11).

The woody fuels in pine stands varied with stand age and beetle activity. The mean age of the pines in these stands was positively correlated with bole load weight and volume ($r_s=0.35$ and $r_s=0.30$, respectively; Tables 12 & 13). Those under 30 years of age had no bole loads. With pine bark beetle activity in stands over 50 years old, bole loads increased dramatically from under 20,000 kg/ha to 80,000 kg/ha. Lower bole loads were generally maintained by stands without beetle activity and with younger intermediate or suppressed hardwoods. Even in those stands not showing a long history of beetle activity, as evidenced by smaller bole loads on the ground (<23,000 kg/ha) or by no sign of beetle on the pines, the bole loads were higher and the branch loads lower than those reported by Lynch and Horton (1983) for natural loblolly pine stands:

<u>Component</u>	<u>Weight (kg/ha)</u>	
	<u>Richmond</u>	<u>Lynch and Horton (1983)</u>
Bole	15,062	9,864
Branch	6,228	9,640

The age of the stands used by Lynch and Horton (1983) were not reported, but the pines in the stands were similar in density and diameter to those at RICH.

Lynch and Horton's (1983) Photo Series estimates bole fuels for northern loblolly pine stands; however, the estimates for bole fuels would not be applicable to the pine stands at RICH, which generally had

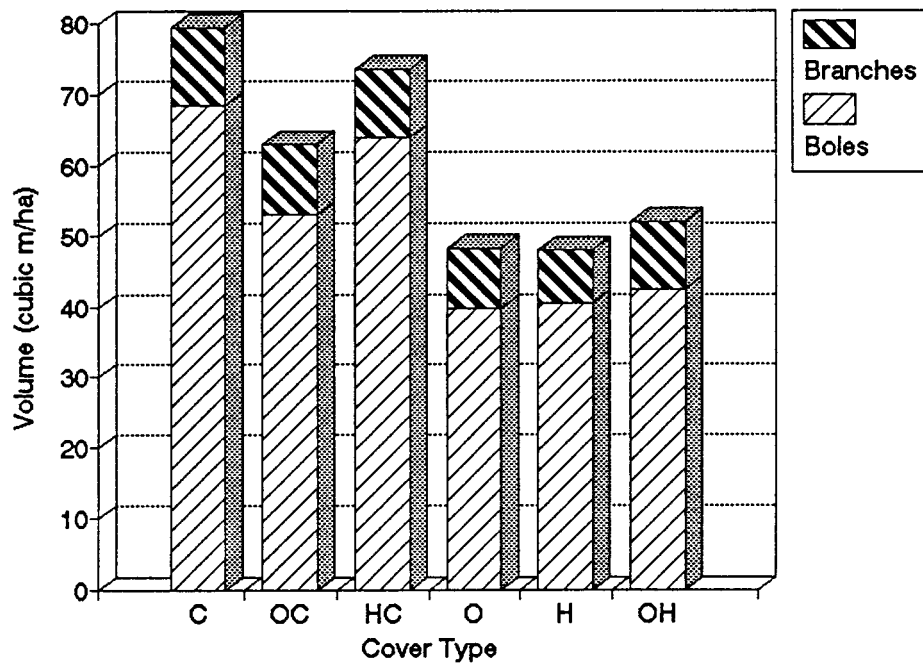


Figure 3. The average volume (cubic m/ha) of branch (1, 10, 100 hr. time-lag) and bole (>100 hr. time-lag) fuels in 6 cover types at Richmond National Battlefield Park, Virginia. Cover types: C-Conifer, OC-Oak-Conifer, HC-Mixed Hardwood-Conifer, O-Oak, H-Mixed Hardwood, OH-Oak-Mixed Hardwood.

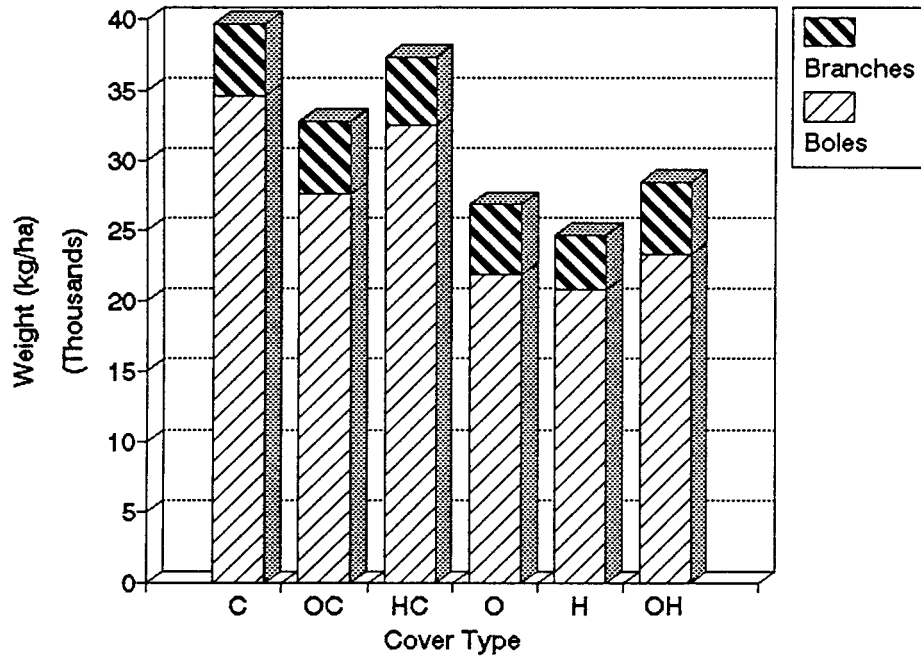


Figure 4. The mean weight (kg/ha) of the branch (1, 10, 100 hr. time-lag) and bole (>100 hr. time-lag) fuels in 6 cover types at Richmond National Battlefield Park, Virginia. Cover types: C-Conifer, OC-Oak-Conifer, HC-Mixed Hardwood-Conifer, O-Oak, H-Mixed Hardwood, OH-Oak-Mixed Hardwood.

Table 9. Mean volume (cubic m/ha) of the forest fuel loads in the conifer cover type at Richmond National Battlefield Park, Virginia (n=13 stands).

Fuel Type	Minimum	Maximum	Mean	Standard Deviation
	cubic m/ha.....			
Boles				
Sound	0.0	128.6	29.3	37.5
Rotten	0.0	141.4	39.1	45.6
Total	0.0	157.9	68.4	61.7
Twigs				
1 hr. time-lag	0.3	1.8	0.9	0.4
10 hr. time-lag	2.1	7.3	4.3	1.6
100 hr. time-lag	1.5	11.6	6.0	3.1
Total	5.4	18.0	11.2	3.7
Total woody fuel load	5.4	175.9	78.5	65.4

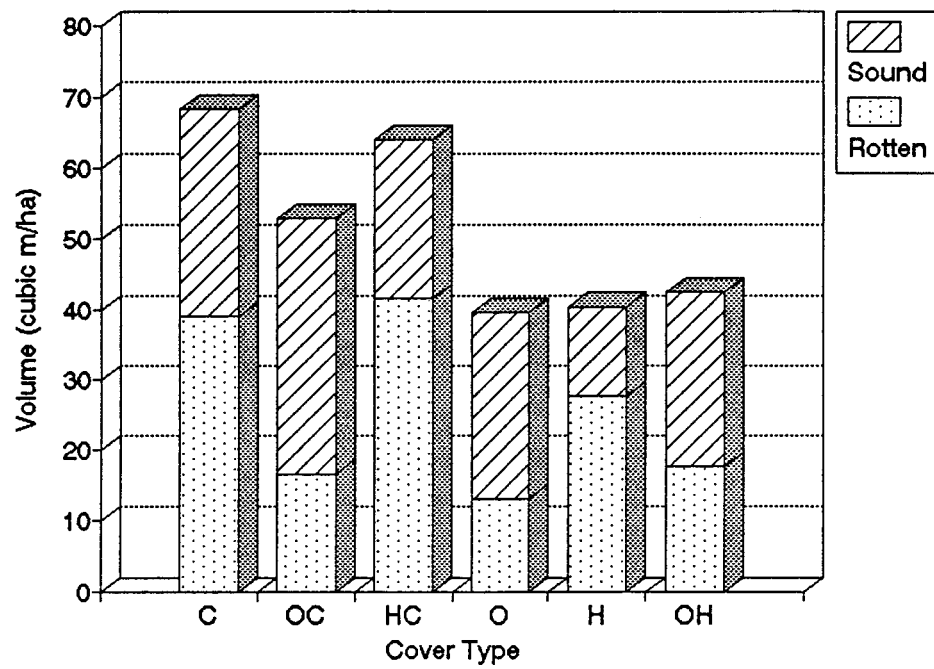


Figure 5. The mean volume (cubic m/ha) of sound and rotten bole (>100 hr. time-lag) fuels in 6 cover types at Richmond National Battlefield Park, Virginia. Cover types: C-Conifer, OC-Oak-Conifer, HC-Mixed Hardwood-Conifer, O-Oak, H-Mixed Hardwood, OH-Oak-Mixed Hardwood.

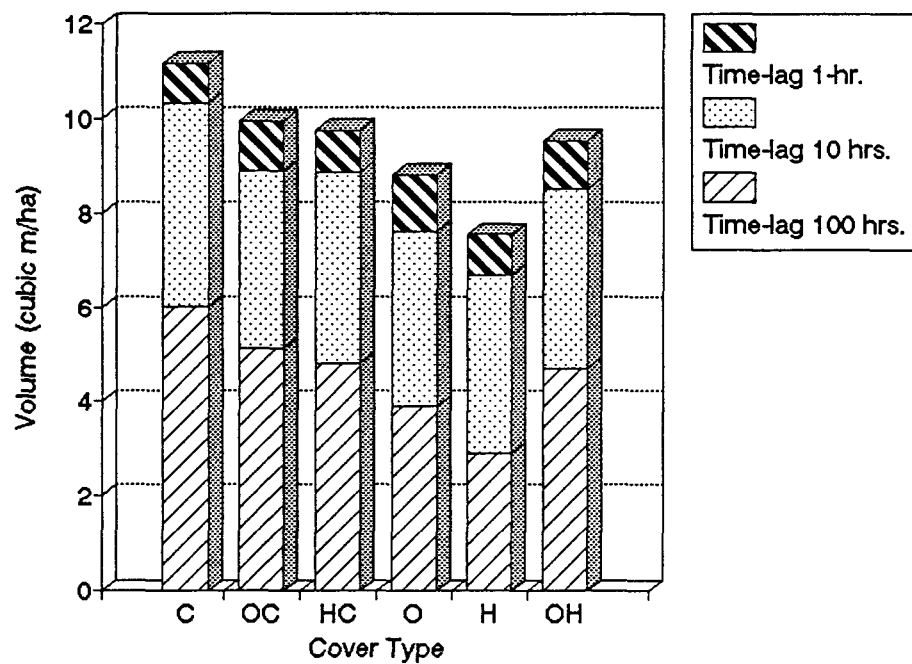


Figure 6. The mean volume (cubic m/ha) of branch (1, 10, 100 hr. time-lag) fuels in 6 cover types at Richmond National Battlefield Park, Virginia. Cover types: C-Conifer, OC-Oak-Conifer, HC-Mixed Hardwood-Conifer, O-Oak, H-Mixed Hardwood, OH-Oak-Mixed Hardwood.

Table 10. Mean weight (kg/ha) of the forest fuel loads in the conifer cover type at Richmond National Battlefield Park, Virginia (n=13 stands).

Fuel Type	Minimum	Maximum	Mean	Standard Deviation
.....kg/ha.....				
Boles				
Sound	0	68,158	15,489	19,849
Rotten	0	69,286	19,153	22,242
Total	0	79,963	34,642	31,303
Branches				
1 hr. time-lag	120	720	389	158
10 hr. time-lag	930	3,030	1,977	705
100 hr. time-lag	760	5,780	2,716	1,458
Total	3,020	8,920	5,082	1,691
Total woody fuel load	4,300	84,863	39,724	30,774
Forest floor layers				
Litter	424	1,964	1,241	504
Fermentation	980	3,620	1,861	744
Humus	640	5,164	2,813	1,315
Total	2,248	9,168	5,915	2,156

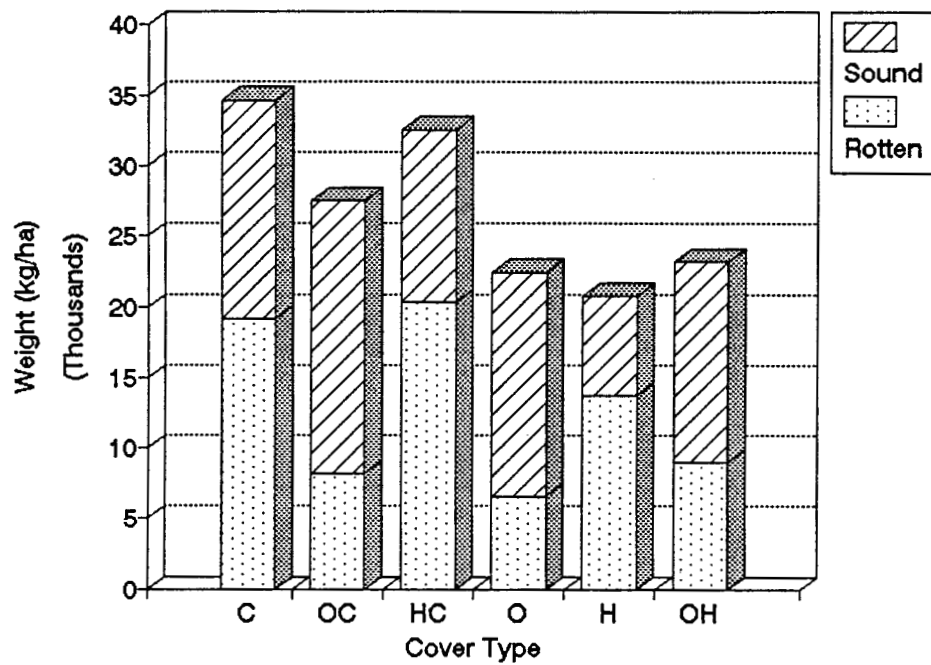


Figure 7. The mean weight (kg/ha) of sound and rotten bole (>100 hr. time-lag) fuels in 6 cover types at Richmond National Battlefield Park, Virginia. Cover types: C-Conifer, OC-Oak-Conifer, HC-Mixed Hardwood-Conifer, O-Oak, H-Mixed Hardwood, OH-Oak-Mixed Hardwood.

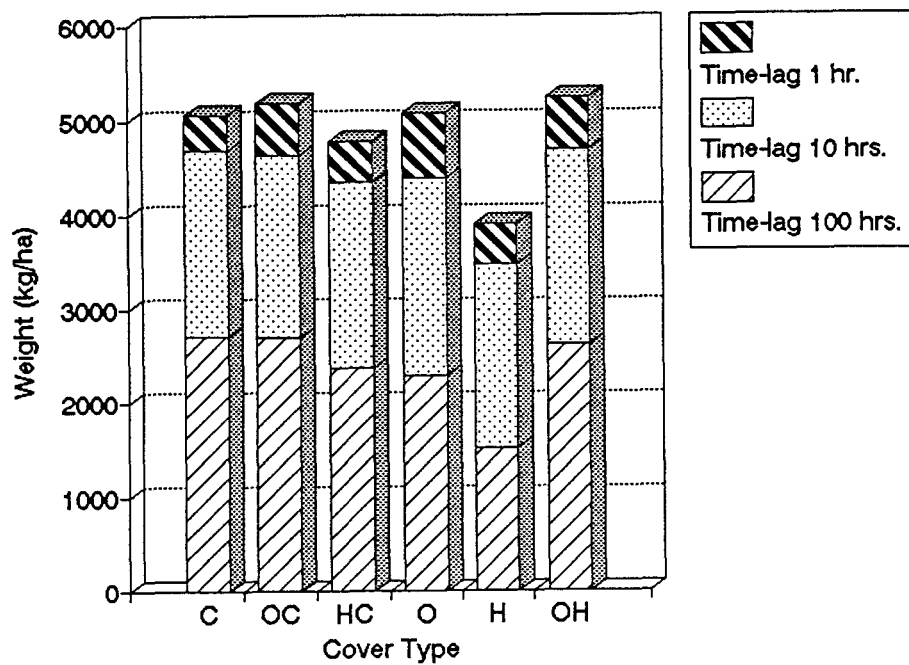


Figure 8. The mean weight (kg/ha) of the branch (1, 10, 100 hr. time-lag) fuels in 6 cover types at Richmond National Battlefield Park, Virginia. Cover types: C-Conifer, OC-Oak-Conifer, HC-Mixed Hardwood-Conifer, O-Oak, H-Mixed Hardwood, OH-Oak-Mixed Hardwood.

Table 11. Mean depth (cm) of the forest fuel loads in the conifer cover type at Richmond National Battlefield Park, Virginia (n=13 stands).

Fuel Type	Minimum	Maximum	Mean	Standard Deviation
	cm.....			
Surface fuel	1.7	59.2	6.3	3.7
Forest floor layers				
Litter	1.3	6.5	3.5	1.7
Fermentation	1.3	4.0	2.3	0.7
Humus	1.0	3.5	2.0	0.9
Total	4.2	12.3	7.9	2.7

Table 12. *Significant* ($p=0.05$) Spearman rank correlation coefficients between woody fuel weights and stand variables.

Woody Fuel Weight (kg/ha)	Stand Variable	r_s	p-value
..Time-lag (hrs.)..			
Boles (>100 hr.)			
	Dead pine BA ^a	0.46	.0001
	Total dead BA	0.39	.0001
	Dead pine DEN	0.43	.0001
	Total dead DEN	0.29	.0025
	Pine stumps	0.55	.0001
	Pine age ^b	0.35	.0323
	Stand age	-0.25	.0096
Branches			
1 hr.	Live pine BA	-0.31	.0012
	% live pine BA	-0.30	.0018
	Live oak BA	0.41	.0001
	Dead oak BA	0.29	.0026
	% live oak BA	0.41	.0001
	Live pine DEN	-0.24	.0122
	Live oak DEN	0.20	.0383
	Dead oak DEN	0.28	.0038
	Stand age	0.22	.0251

Table 12. Continued.

Woody Fuel Weight (kg/ha)	Stand Variable	r_s	p-value
..Time-lag (hrs.)..			
100 hr.	Live pine BA	0.22	.0239
	% live pine BA	0.23	.0151
	Dead mixed hardwood BA	-0.21	.0276
	Live shrub BA	-0.21	.0263
	Live pine DEN	0.20	.0383
	Live oak DEN	0.19	.0472
	Dead mixed hardwood DEN	-0.21	.0272
	Live shrub DEN	-0.26	.0062
	Oak age	-0.27	.0366
	Stand age	-0.20	.0371
Total Woody			
	Dead pine BA	0.47	.0001
	Total dead BA	0.38	.0001
	Dead pine DEN	0.44	.0001
	Total dead DEN	0.29	.0027
	Oak age	-0.50	.0001
	Stand age	-0.20	.0423

^a BA=Basal Area (m^2/ha); DEN=Density (stems/ha); Pine stumps in #/ha;
Age in years.

^b In stands with >20 % live pine basal area.

Table 13. *Significant* (p=0.05) Spearman rank correlation coefficients between woody fuel volumes and variables.

Woody Fuel Volume (cubic m/ha)	Stand Variable	r_s	p-value
..Time-lag (hrs.)..			
Boles (>100 hr.)			
	Dead pine BA ^a	0.48	.0001
	Total dead BA	0.39	.0001
	Dead pine DEN	0.43	.0001
	Total dead DEN	0.29	.0020
	Pine stumps	0.54	.0001
	Pine age ^b	0.30	.0395
	Stand age	-0.26	.0066
Branches			
1 hr.	Live oak BA	0.28	.0039
	Dead oak BA	0.23	.0167
	Dead oak DEN	0.22	.0195
10 hr.	Total live DEN	0.20	.0363
100 hr.	Live pine BA	0.32	.0009
	Live shrub BA	-0.24	.0132
	Live pine DEN	0.28	.0029
	Live shrub DEN	-0.30	.0017
	Oak age	-0.30	.0213
	Stand age	-0.25	.0088
Total	Live pine BA	0.28	.0030
	Live pine DEN	0.26	.0063
	Live shrub DEN	-0.19	.0472
	Stand age	-0.20	.0382

Table 13. Continued.

Woody Fuel Volume (cubic m/ha)	Stand Variable	r_s	p-value
..Time-lag (hrs.)..			
Total Woody			
	Dead pine BA	0.50	.0001
	Total dead BA	0.38	.0001
	Dead pine DEN	0.48	.0001
	Total dead DEN	0.29	.0025
	Oak age	-0.51	.0001
	Stand age	-0.23	.0191

^a BA=Basal Area (m^2/ha); DEN=Density (stems/ha); age in years.

^b In stands with >20 % live pine basal area.

more boles on the ground than are shown in the Series. Since the photo is the primary basis for selection of a suitable fuel load estimate, one would see that the match with many stands in RICH is unacceptable in that the range of Lynch and Horton (1983) is not sufficiently broad at the upper end.

The conifer cover type had the most forest floor material, with an average weight of 5,915 kg/ha (Table 10, Figure 9). The weight of the forest floor material was generally greater for the types with pine than without (Figure 9). The forest floor weight in the conifer type was significantly greater than in the mixed hardwood type (Table 8). This type also had the deepest forest floor, averaging 7.9 cm (Table 11, Figure 10). Much higher forest floor weights have been reported for pine stands in the southeast than were found at RICH. Litter and fermentation layers alone totaled 15,336 kg/ha in mixed loblolly and shortleaf pine stands on the South Carolina piedmont (Metz 1954), 5 times the mean weight of the layers at RICH. Also, forest floor weights of 16,386 to 17,933 kg/ha were reported for 12- and 23-year-old loblolly pine plantations, respectively (Williston 1965, Brender et al. 1976); but, the 12-year-old stand had a mean forest floor depth of only 2 cm, one-fourth the mean depth of those at RICH. The presence of more deciduous trees, with their litter that is more attractive to decomposer organisms than pine litter, in the pine stands at RICH may account for the lower accumulation of forest floor.

Oak-Conifer Cover Type: The mean total woody fuel volumes and weights tended to be higher in the oak-conifer cover type than in any of the types without pines (Figures 3 & 4). Mean total bole and branch volumes were 52.9 and 10.0 cubic m/ha, respectively (Table 14, Figures 5 & 6). Mean total bole weight was 27,598 kg/ha and branch weight was 5,209 kg/ha, for a total woody fuel weight of 32,807 kg/ha (Table 15, Figures 7 & 8). The surface fuel averaged 5.5 cm deep (Table 16).

Oak-pine stands at Spotsylvania Battlefield National Military Park (SNMP), which had originated as mixed stands, had similar branch loads as oak-pine stands at RICH, from 5,692 to 9,211 kg/ha, and the bole loads approached those at RICH, the highest being 20,124 kg/ha (Orwig and Abrams 1991). The SNMP oak-pine stands were oak stands in which Virginia pine (*Pinus virginiana* Miller) had an Importance Value > 10% (Orwig and Abrams 1991); the importance of loblolly pine in RICH was twice as high. Without the same

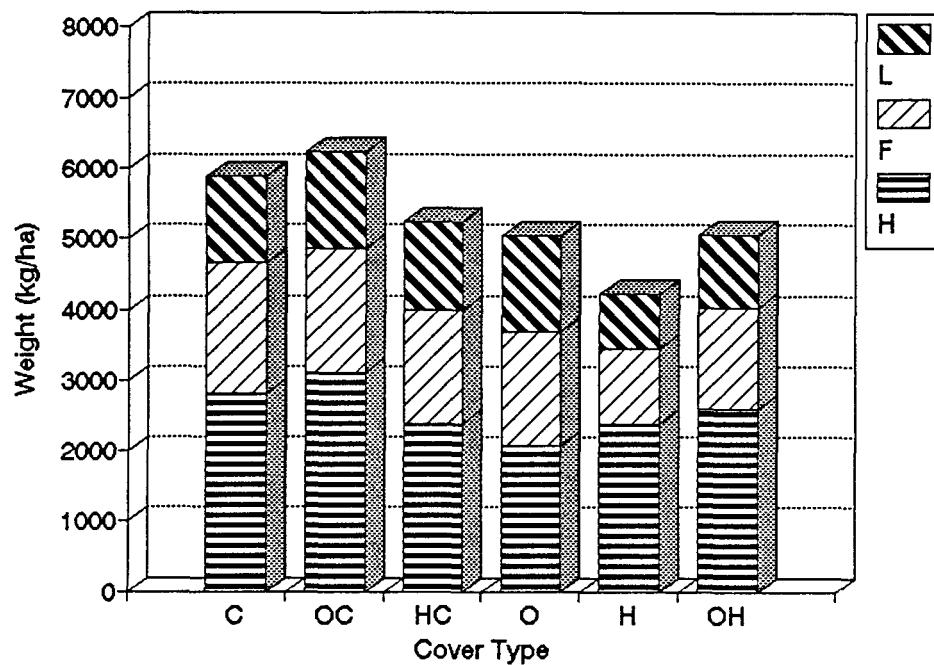


Figure 9. The mean weight (kg/ha) of the forest floor (litter (L), fermentation (F), and humus (H) layers) in 6 cover types at Richmond National Battlefield Park, Virginia. Cover types: C-Conifer, OC-Oak-Conifer, HC-Mixed Hardwood-Conifer, O-Oak, H-Mixed Hardwood, OH-Oak-Mixed Hardwood.

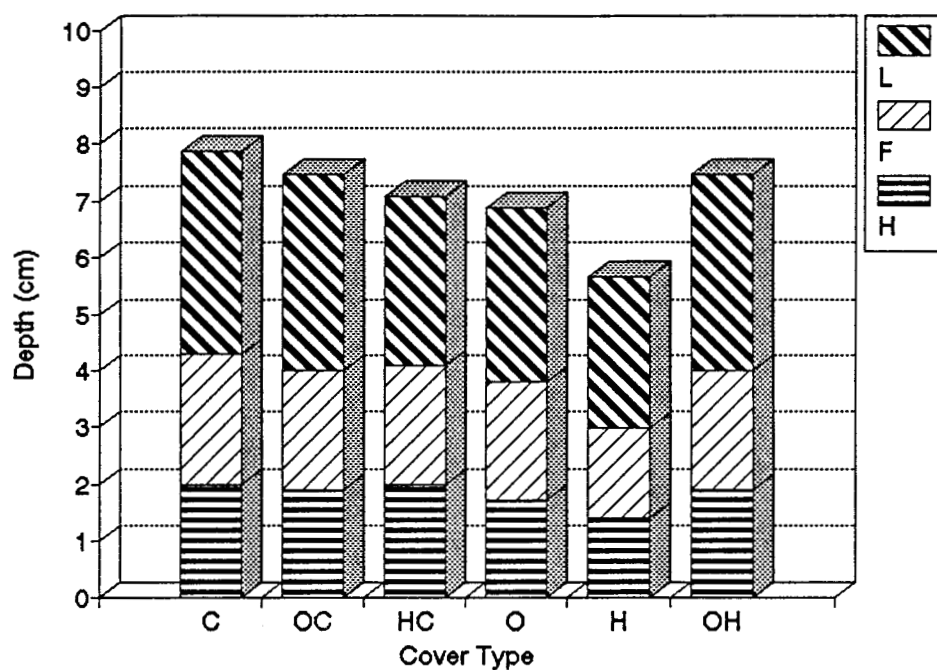


Figure 10. The mean depth (cm) of the forest floor (litter (L), fermentation (F), and humus (H) layers) in 6 cover types at Richmond National Battlefield Park, Virginia. Cover types: C-Conifer, OC-Oak-Conifer, HC-Mixed Hardwood-Conifer, O-Oak, H-Mixed Hardwood, OH-Oak-Mixed Hardwood.

Table 14. Mean volume (cubic m/ha) of the forest fuel loads in the oak-conifer cover type at Richmond National Battlefield Park, Virginia (n=23 stands).

Fuel Type	Minimum	Maximum	Mean	Standard Deviation
.....cubic m/ha.....				
Boles				
Sound	0.0	178.5	36.3	46.0
Rotten	0.0	67.6	16.7	18.6
Total	0.0	224.5	52.9	59.2
Branches				
1 hr. time-lag	0.5	1.7	1.1	0.4
10 hr. time-lag	0.9	8.0	3.8	1.5
100 hr. time-lag	0.0	13.0	5.1	3.2
Total	2.4	19.3	10.0	4.4
Total woody fuel load	2.4	243.8	62.9	63.6

Table 15. Mean weight of the forest fuel loads in the oak-conifer cover type at Richmond National Battlefield Park, Virginia (n=23 stands).

Fuel Type	Minimum	Maximum	Mean	Standard Deviation
.....kg/ha.....				
Boles				
Sound	0	94,383	19,383	24,315
Rotten	0	33,124	8,214	9,105
Total	0	117,145	27,598	30,715
Branches				
1 hr. time-lag	270	930	570	194
10 hr. time-lag	400	3,800	1,947	750
100 hr. time-lag	0	6,280	2,692	1,561
Total	1,230	9,330	5,209	2,153
Total woody fuel load	3,626	122,675	32,807	31,031
Forest floor layers				
Litter	732	3,988	1,383	684
Fermentation	1,036	3,360	1,759	630
Humus	1,448	8,484	3,112	1,871
Total	3,740	11,616	6,254	2,113

Table 16. Mean depth (cm) of the forest fuel loads in the oak-conifer cover type at Richmond National Battlefield Park, Virginia (n=23 stands).

Fuel Type	Minimum	Maximum	Mean	Standard Deviation
	cm.....			
Surface fuel	1.3	16.3	5.5	3.3
Forest floor layers				
Litter	1.5	6.2	3.5	1.3
Fermentation	1.3	3.2	2.1	0.6
Humus	1.0	4.8	1.9	0.9
Total	5.2	14.0	7.5	2.1

prevalence of pine bark beetle activity in SNMP as in RICH (Orwig and Abrams 1991), and with pine as generally less important in the stands, it makes sense that the bole loads were lower in Spotsylvania oak-pine stands.

The forest floor weight within this type was greater than in any other cover type (Table 15, Figure 9). The forest floor weighed an average of 6,254 kg/ha, and averaged 7.5 cm in depth (Table 16, Figure 10). Although these were the greatest floor loads, the floor weights at RICH were about one-third those reported by others for oak-pine stands. Total litter and fermentation layer weight reported by Metz (1954) for mixed pine and upland hardwoods stands, with 21 m²/ha basal area, on old-fields in the South Carolina piedmont was 10,954 kg/ha. In a pine-oak stand in the southern Appalachian mountains, undisturbed for only 10 years, the litter layer alone was found to be 8,873 kg/ha (Sims 1932).

Mixed Hardwood-Conifer Cover Type: The stands in the mixed hardwood-conifer cover type also had higher mean woody fuel volumes and weights than the types without codominant pines (Figure 3 & 4). The mean woody fuel volumes in this cover type consisted of 63.9 cubic m/ha of boles and 9.8 cubic m/ha of branches (Table 17, Figures 5 & 6). The mean weights of the bole and branch fuel were 32,554 kg/ha and 4,793 kg/ha, respectively (Table 18, Figures 7 & 8). Although mean total bole weights were not significantly different between this and other types, the mean rotten boles were significantly heavier in the pine-mixed hardwood stands than in oak stands (Table 7). The depth of the surface residue was 9.9 cm, the deepest of any cover type (Table 19). There were no reports of fuel loads for stands in similar cover types available for comparisons. The total weight of the forest floor was slightly more than the branch weights, at 5,259 kg/ha, and the total depth of these layers was 7.1 cm (Tables 18 & 19, Figure 10). No other published reports of similar cover type forest floors were available for comparison.

Oak Cover Type: Throughout RICH the recent history of the stands affected the fuel loads tremendously; those stands entering the later stages of secondary succession from pine to deciduous species had heavier bole loads from the pines dropping out of the overstory. In the oak cover types, the mean bole volume was 39.6

Table 17. Mean volume (cubic m/ha) of the forest fuel loads in the mixed hardwood-conifer cover type at Richmond National Battlefield Park, Virginia (n=11 stands).

Fuel Type	Minimum	Maximum	Mean	Standard Deviation
.....cubic m/ha.....				
Boles				
Sound	0.0	78.5	22.4	28.4
Rotten	0.0	125.8	41.5	34.4
Total boles	0.0	137.1	63.9	45.0
Branches				
1 hr. time-lag	0.4	1.2	0.9	0.3
10 hr. time-lag	0.9	7.5	4.1	1.9
100 hr. time-lag	0.0	8.7	4.8	3.3
Total	1.7	15.9	9.8	4.2
Total woody fuel load	1.7	153.0	73.7	49.2

Table 18. Mean weight (kg/ha) of the forest fuel loads in the mixed hardwood-conifer cover type at Richmond National Battlefield Park, Virginia (n=11 stands).

Fuel Type	Minimum	Maximum	Mean	Standard Deviation
.....kg/ha.....				
Boles				
Sound	0	41,605	12,258	15,096
Rotten	0	61,642	20,297	16,880
Total	0	67,631	32,554	22,905
Branches				
1 hr. time-lag	170	570	440	130
10 hr. time-lag	450	3,520	1,990	917
100 hr. time-lag	0	4,840	2,362	1,669
Total	840	8,150	4,793	2,146
Total woody fuel load	1970	75,081	37,347	24,223
Forest floor layers				
Litter	596	3,780	1,254	932
Fermentation	780	3,452	1,608	810
Humus	680	7,760	2,397	1,902
Total	2,508	11,988	5,259	2,662

Table 19. Mean depth (cm) of the forest fuel loads in the mixed hardwood-conifer cover type at Richmond National Battlefield Park, Virginia (n=11 stands).

Fuel Type	Minimum	Maximum	Mean	Standard Deviation
	cm.....			
Surface residue	1.7	59.2	9.9	16.5
Forest floor layers				
Litter	1.3	4.5	3.0	0.9
Fermentation	1.2	3.3	2.1	0.7
Humus	1.0	3.5	2.0	0.7
Total	3.8	8.4	7.1	1.4

cubic m/ha, the lowest found (Figure 3), and the mean branch volume was 8.8 cubic m/ha (Table 20, Figures 5 & 6). The mean bole and branch weights were 22,440 and 5,091 kg/ha (Table 21, Figures 7 & 8). The volume and weight of the time-lag 1 hr. branch fuels were significantly higher in the oak than in the mixed hardwood or pine stands (Table 7). The mean depth of this surface fuel was 6.2 cm (Table 22).

Low levels of bole fuels are common in oak-hickory stands (Wilcox et al. 1982). The mean branch loads in oak stands at Spotsylvania National Military Park were similar to those at RICH, but bole loads in SNMP were much lower:

<u>Component</u>	<u>Weight (kg/ha)</u>		
	<u>Richmond</u>	<u>Spotsylvania</u>	<u>Wilcox et al. (1982)</u>
Bole	19,286	3,474	8,295
Branch	5,091	5,468	6,726

The oak stands at SNMP averaged 94 years, and had no history of pine, insect or disease problems (Orwig and Abrams 1991). Forty-two percent of the oak stands at RICH were older than those at Spotsylvania, and many had a history of pine dominance. Even the stands with no recent history of pine averaged 2.3 times greater bole load than that reported for a typical oak-hickory large pole timber stand in Pennsylvania (Wilcox et al. 1982). Also, 88% of the oak stands in RICH had signs of stem disease on some of the oak stems; and root rot and recent leaf loss were noted on others. Disease may have increased mortality and downed bole loads. Windthrow was also observed in some of the stands. However, an old-growth (undisturbed for >250 years) mixed-oak forest in New Jersey had 21,310 kg/ha of boles and 5,690 kg/ha of branches (Lang and Forman 1978). So, heavy forest floor bole loads may be typical of climax oak stands.

The oak cover type forest floor averaged 5,062 kg/ha and the mean total depth of the forest floor was 7.1 cm, which was much lower than reported for other oak stands in the southern United States (Tables 21 & 22). Metz (1954) found 14,594 kg/ha of forest floor in a 50-year-old oak stand on the South Carolina piedmont, and a floor weighed 10,990 kg/ha in an old mixed-oak forest in New Jersey (Lang and Forman 1978). Perhaps all of the forest floor weights for RICH are low compared to other reports, for all cover types, because the sampling was done in May, June, and July. If other studies measured litter in the fall or winter (none of them mentioned the time of year), soon after leaf-fall, more undecomposed matter would be in the litter layer, and weights would be expected to be greater. However, a sub-sample of litter plots was

Table 20. Mean volume (cubic m/ha) of the forest fuel loads in the oak cover type at Richmond National Battlefield Park, Virginia (n=26 stands).

Fuel Type	Minimum	Maximum	Mean	Standard Deviation
.....cubic m /ha.....				
Boles				
Sound	0.0	104.2	26.4	26.2
Rotten	0.0	75.3	13.2	21.1
Total	0.0	136.8	39.6	39.0
Branches				
1 hr. time-lag	0.7	2.3	1.2	0.3
10 hr. time-lag	1.6	10.3	3.7	1.7
100 hr. time-lag	0.0	14.5	3.9	3.3
Total	3.6	27.0	8.8	4.8
Total woody fuel load	3.6	163.8	48.4	42.5

Table 21. Mean weight (kg/ha) of the forest fuel loads in the oak cover type at Richmond National Battlefield Park (n=26 stands).

Fuel Type	Minimum	Maximum	Mean	Standard Deviation
.....kg/ha.....				
Boles				
Sound	0	67,730	15,816	16,007
Rotten	0	36,897	6,624	10,516
Total	0	70,020	22,440	21,560
Branches				
1 hr. time-lag	410	1,230	688	162
10 hr. time-lag	930	5,620	2,109	918
100 hr. time-lag	0	8,180	2,294	1,911
Total	2,090	15,030	5,091	2,741
Total woody fuel load	4,180	76,070	27,530	22,838
Forest floor layers				
Litter	424	6,756	1,370	1,315
Fermentation	712	5,864	1,617	1,025
Humus	756	4,336	2,075	774
Total	2,592	10,788	5,062	2,080

Table 22. Mean depth (cm) of the forest fuel loads in the oak cover type at Richmond National Battlefield Park, Virginia (n=26 stands).

Fuel Type	Minimum	Maximum	Mean	Standard Deviation
.....cm.....				
Surface fuel	1.8	12.5	6.2	4.7
Forest floor layers				
Litter	1.2	7.8	3.3	1.4
Fermentation	1.2	4.0	2.1	0.8
Humus	0.4	3.5	1.7	0.7
Total	4.0	14.1	7.1	2.3

taken in late-November on 20% of our plots, and no increases in average floor weight were found, although the layer was obviously deeper then.

Mixed Hardwood Cover Type: The mixed hardwood cover type had the lowest mean total volume and weight of fuels of all types (Figure 3 & 4). The mean total bole and branch volumes were 40.5 and 7.5 cubic m/ha, respectively (Table 23), the lowest branch volume of any cover type (Figure 6). The mean bole weight was 20,771 kg/ha, and the branches averaged 3,914 kg/ha (Table 24), also the lowest load of all types (Figures 7 & 8). The surface residue was 4.3 cm deep (Table 25).

A typical red maple stand reported by Wilcox et al. (1982) had similar bole weights for mixed hardwood stands in RICH where pines were not predominant at establishment:

<u>Component</u>	<u>Weight (kg/ha)</u>	
	<u>Richmond</u>	<u>Wilcox et al. (1982)</u>
Bole	20,771	17,712
Branch	3,914	9,865

The branches in the red maple stand weighed more than the average mixed hardwood stand at RICH, though. The Series would provide a reasonable estimate of fuel loads in some mixed hardwood stands at RICH, as judged appropriate with the photo and stand description. The many different compositions of mixed hardwood stands found at RICH are not represented, but for a quick estimate the Photo Series would be useful.

The forest floor of this type was the lightest and shallowest (Figures 9 & 10). The mean total forest floor, L- and F-layer weights were significantly smaller than those in the pine or the oak-pine cover types (Table 8). The floor was 5.8 cm deep and weighed an average of 4,231 kg/ha (Tables 24 & 25). Once again, higher weights were reported for similar stands: a yellow-poplar stand on the piedmont of South Carolina had a forest floor weight of 13,373 kg/ha (Metz 1954), heavier than the average mixed hardwood floor of RICH by 3 times. No other reports were available for comparison.

Oak-Mixed Hardwood Cover Type: The oak-mixed hardwood cover type had fuel loads similar to the oak and mixed hardwood types (Figures 3 & 4). The mean bole fuel volume in this type was 42.6 cubic m/ha,

Table 23. Mean volume (cubic m/ha) of the forest fuel loads in the mixed hardwood cover type at Richmond National Battlefield Park, Virginia (n=18 stands).

Fuel Type	Minimum	Maximum	Mean	Standard Deviation
.....cubic m/ha.....				
Boles				
Sound	0.0	60.8	12.8	19.5
Rotten	0.0	96.4	27.7	31.9
Total	1.5	141.9	40.5	39.5
Branches				
1 hr. time-lag	0.2	1.7	0.8	0.4
10 hr. time-lag	0.9	8.7	3.8	2.2
100 hr. time-lag	0.0	10.1	2.9	2.8
Total	1.1	15.9	7.5	3.4
Total woody fuel load	2.6	197.7	48.1	53.9

Table 24. Mean weight (kg/ha) of the forest fuel loads in the mixed hardwood cover type at Richmond National Battlefield Park, Virginia (n=18 stands).

Fuel Type	Minimum	Maximum	Mean	Standard Deviation
.....kg/ha.....				
Boles				
Sound	0	32,224	7,019	10,622
Rotten	0	47,236	13,753	15,767
Total	720	71,351	20,771	20,061
Branches				
1 hr. time-lag	80	820	440	223
10 hr. time-lag	460	4,330	1,954	1,089
100 hr. time-lag	0	5,620	1,519	1,490
Total	550	7,600	3,914	1,713
Total woody fuel load	1,270	74,951	24,685	20,293
Forest floor layers				
Litter	108	2,352	792	610
Fermentation	120	2,140	1,056	440
Humus	408	12,884	2,383	2,745
Total	1,072	15,708	4,231	3,185

Table 25. Mean depth (cm) of the forest fuel loads in the mixed hardwood cover type at Richmond National Battlefield Park, Virginia (n=18 stands).

Residue Type	Minimum	Maximum	Mean	Standard Deviation
.....cm.....				
Surface fuel	1.8	10.2	4.3	1.9
Forest floor layers				
Litter	0.3	5.0	2.7	1.3
Fermentation	0.7	2.0	1.6	0.4
Humus	0.4	4.3	1.4	0.9
Total	2.3	10.1	5.8	2.0

and the mean branch volume was 9.5 cubic m/ha (Table 26, Figures 5 & 6). Total mean bole and branch weights were 23,251 kg/ha and 5,266 kg/ha (Table 27, Figures 7 & 8). The surface residue was 6.4 cm deep (Table 28). No other reports of woody fuels existed for this type.

The forest floor in this type was low compared to the others. The weight of the forest floor was 5,080 kg/ha (Table 27, Figure 9), and the floor was an average of 7.4 cm deep (Table 28, Figure 10). No similar forest stand fuel loading results were available for comparisons.

Table 26. Mean volume (cubic m/ha) of the forest fuel loads in the oak-mixed hardwoods cover type at Richmond National Battlefield Park (n=17 stands).

Fuel Type	Minimum	Maximum	Mean	Standard Deviation
.....cubic m/ha.....				
Boles				
Sound	0.0	127.2	24.8	37.0
Rotten	0.0	54.6	17.7	17.8
Total	0.0	181.8	42.6	44.1
Branches				
1 hr. time-lag	0.6	1.5	1.0	0.3
10 hr. time-lag	2.3	6.4	3.8	1.1
100 hr. time-lag	0.0	13.0	4.7	3.7
Total	4.0	19.0	9.5	4.4
Total woody fuel load	4.0	200.8	52.1	48.5

Table 27. Mean weight (kg/ha) of the forest fuel loads in the oak-mixed hardwoods cover type at Richmond National Battlefield Park, Virginia (n=17 stands).

Fuel Type	Minimum	Maximum	Mean	Standard Deviation
.....kg/ha.....				
Boles				
Sound	0	67,416	14,247	20,847
Rotten	0	26,754	9,004	8,912
Total boles	0	94,170	23,251	23,883
Branches				
1 hr. time-lag	330	840	571	136
10 hr. time-lag	1,270	3,390	2,076	584
100 hr. time-lag	0	6,940	2,618	2,073
Total	2,200	10,600	5,266	2,455
Total woody fuel load	2,570	100,530	28,517	24,017
Forest floor layers				
Litter	440	1,688	1,034	419
Fermentation	672	4,116	1,447	963
Humus	624	6,480	2,598	1,641
Total	2,224	10,272	5,080	2,647

Table 28. Mean depth (cm) of the forest fuel loads in the oak-mixed hardwoods cover type at Richmond National Battlefield Park, Virginia (n=17 stands).

Fuel Type	Minimum	Maximum	Mean	Standard Deviation
.....cm.....				
Surface fuel	1.0	25.0	6.4	5.6
Forest floor layers				
Litter	1.3	7.8	3.5	1.7
Fermentation	1.2	3.2	2.1	0.6
Humus	0.8	3.8	1.9	0.9
Total	3.3	10.0	7.4	2.8

Prediction of Forest Fuel Loads

Regression models were developed with the stand and site variables that were significantly related to the fuel loads but not to each other. The significant relationships between several forest characteristics and fuel loadings are presented in Tables 12 & 13. The strength of the relationships between forest fuel loads and the stand and site characteristics influenced the strength of the resulting regression models for fuel load prediction. Mostly the regressions had low precision due to the variability of fuel loads within the park forests and to the data distribution's weak meeting of the assumptions for regression analysis (normality, homogeneity of variance, and means falling along a line).

Basal area and density were the best predictors of woody fuel loading. Boles and branches were best predicted by different measures of stand density. The only other variables significantly related to woody fuel loading, shrub density and tree age, were too weakly related to produce better models (Tables 12 & 13). *Total dead* basal area and density were moderately related to total bole weight and volume (Tables 12 & 13). This correlation was due to the relationship between *dead pine* basal area and bole loading. The best regression models for bole loading had a coefficient of determination of 0.27 and a large standard error of estimates (Tables 29 & 30). Tests of these regressions with a sample of the population revealed a low bias, as indicated by the mean close to 0, but generally poor precision, according to the large coefficient of variation of the residuals (Tables 31 & 32).

Oak and *pine* basal areas were weakly related to the weight of the branch loads. In general, as % live pine basal area increased, the load of the 1 hr. time-lag fuel decreased, and as the % live oak basal area increased, the load increased (Table 12). Similar relationships were found between branch load volume and basal area (Table 13). In general, the actual density of the stand was not as relevant to branch loading as the dominant genera in the overstory. The best regression models for branch loadings had a coefficient of determination of 0.10. Tests of the regressions revealed low bias, but again the coefficient of variation represented a great lack of precision in the predictive ability of the equations.

Many stand and site variables were related to the weight of the forest floor, and some relationships were strong enough to create good prediction models (Table 33). Basal area was weakly related to the

Table 29. Final regression models for predicting volume (cubic m/ha), by time-lag class, of dead and down woody fuels from basal area (m²/ha) and density (stems/ha) with their coefficient of determination and standard error of the estimate (SEE)(n=108).

Regressions (Volume, time-lag)	R²	SEE (cubic m/ha)
Boles (>100 hr.) = 35.10+8.94(Dead pine BA ^a)	.27	41.6
1 hr. = 0.90+0.01(Live oak BA)	.08	0.3
10 hr. = 3.37+0.0001(Total DEN)	.04	1.6
100 hr. = 3.80+0.11(Live pine BA)	.06	3.2
≤100 hr. = 8.55+0.14(Live pine BA)	.06	4.2

^a BA=Basal Area (m²/ha); DEN=Density (stems/ha).

Table 30. Final regression models for predicting weight (kg/ha), by time-lag class, of dead and down woody fuels from basal area (m²/ha) and density (stems/ha) with their coefficient of determination and standard error of the estimate (SEE)(n=108).

Regressions (Weight, time-lag)	R²	SEE (kg/ha)
Boles (>100 hr.) = 18982+4449.1(Dead pine BA ^a)	.25	21,932
1 hr. = 510.5+35.1(Dead oak BA)	.10	191
100 hr. = 2007.3+1.4(Live oak DEN)	.07	1,679
≤100 hr. = 5068.8+2.4(Live oak DEN)	.08	2,163

^a BA=Basal Area (m²/ha); DEN=Density (stems/ha).

Table 31. The means, standard deviations, and coefficients of variation of the residuals from fitting significant regression models, by time-lag class, for woody fuel volume to a subset of population data (n=43).

Variables		Residuals		
Y	X	Mean	Standard Deviation	Coefficient of Variation
Volume (time-lag)		cubic m/ha.....		%
> 100 hr.	Dead pine BA ^a	-6.2	37.4	87
1 hr.	Live oak BA	0.1	0.3	27
10 hr.	Total DEN	-0.2	1.6	41
100 hr.	Live pine BA	0.1	3.5	74
≤ 100 hr.	Live pine BA	0.2	4.2	43

^a BA=Basal area (m²/ha); DEN=Density (stems/ha).

Table 32. The means, standard deviations, and coefficients of variation of the residuals from fitting significant regression models, by time-lag class, for woody fuel weight to a subset of population data (n=43).

Variables		Residuals		
Y	X	Mean	Standard Deviation	Coefficient of Variation
Weight (time-lag)		kg/ha.....		%
> 100 hr.	Dead pine BA ^a	-3,259	5,422	24
1 hr.	Dead oak BA	34	173	31
100 hr.	Live oak DEN	212	1,733	69
≤ 100 hr.	Live oak DEN	268	673	13

^a BA=Basal area (m²/ha); DEN=Density (stems/ha).

Table 33. *Significant* ($p=0.05$) Spearman rank correlation coefficients between forest floor weight and stand variables.

Forest Floor Weight (kg/ha)	Stand Variable	r_s	p-value
Layer			
Litter	Live pine BA ^a	0.25	.0099
	Dead pine BA	0.21	.0291
	% live pine BA	0.28	.0031
	Live mixed hardwood BA	-0.39	.0001
	Total live BA	-0.24	.0130
	Live pine DEN	0.28	.0029
	Dead pine DEN	0.20	.0360
	Live oak DEN	0.24	.0124
	FSQI	-0.20	.0341
	Litter layer depth	0.45	.0001
Fermentation	Live pine BA	0.34	.0003
	Dead pine BA	0.35	.0002
	% live pine BA	0.35	.0002
	Live mixed hardwood BA	-0.36	.0001
	Total dead BA	0.21	.0296
	Live pine DEN	0.35	.0002
	Dead pine DEN	0.34	.0004
	Live oak DEN	0.20	.0427
	FSQI	-0.20	.0343
	Fermentation layer depth	0.72	.0001
Humus	Live pine BA	0.27	.0046
	Dead pine BA	0.25	.0093
	% live pine BA	0.28	.0028
	Live mixed hardwood BA	-0.24	.0132
	Live pine DEN	0.29	.0021

Table 33. Continued.

Forest Floor Weight (kg/ha)	Stand Variable	r_s	p-value
Layer			
Humus	Dead pine DEN	0.27	.0046
	Humus layer depth	0.81	.0001
Total	Live pine BA	0.33	.0005
	Dead pine BA	0.35	.0002
	Live mixed hardwood BA	-0.37	.0001
	% live pine BA	0.35	.0003
	Live pine DEN	0.36	.0002
	Dead pine DEN	0.35	.0002
	Live oak DEN	0.22	.0211
	FSQI	-0.20	.0388
	Forest floor depth	0.75	.0001

^a BA=Basal Area (m^2/ha); DEN=Density (stems/ha); Depth in cm.

weights of all the forest floor layers. As *live* and *dead* pine basal area increased in the stands, total floor weight increased, and as *live* mixed-hardwood basal area increased, total weight decreased (Table 33). Each layer of the forest floor was correlated to these basal area variables as well (Table 33). Pine was influential in increasing floor weight, as the % *pine* basal area was positively related with forest floor (Table 33). Stand density was also weakly correlated with floor weights, an expected result since density is related to basal area values. *Live* and *dead* pine densities were both positively correlated with total weights of the forest floor, and also to the individual floor layers (Table 33). *Live* oak density was also positively correlated to floor weight, as were the litter and fermentation layer weights (Table 33). Mixed hardwood stand density did not correlate to floor weights, however. Site quality was also related to forest floor weight. Forest floor weight, litter, and fermentation layer weights decreased with increasing FSQI (Table 33).

Despite all of these relationships with forest characteristics, the best regressions for the *total* forest floor, the *fermentation*, and the *humus* layer weights used forest floor depth as the independent variable (Table 34). Although the linear relationships between these forest floor weights and depths were significant, they were still fairly weak, with the best regressions accounting for only slightly over one-half of the variation in the sample data (Table 34). When these regressions were tested to see how well they would predict for the population, high precision and low bias indicated that the regressions were potentially suitable for fuel prediction uses (Table 35).

The *litter* layer was also significantly predicted by the litter depth variables, but the addition of the live mixed-hardwood basal area variable slightly improved the regression's explanation of variance (Table 34). The litter layer had the most variation within each cover type, as was revealed by the weaker coefficients of determination for the L-layer compared to the others (Table 34). Only 21% of the variance was explained by litter depth, and the addition of a basal area variable only increased this to 30% (Table 35).

Table 34. Final regression models for predicting weight (kg/ha) of the forest floor from depths (cm) and basal area (m²/ha) with their coefficient of determination and standard error of the estimate (SEE)(n=108).

Regressions (Weight)	R ²	SEE (kg/ha)
Total = exp[7.43+0.15(total floor depth ^a)]	.54	1.4
F ^b -layer = exp[6.12+0.54(F-layer depth)]	.51	1.1
H ^b -layer = exp[6.62+0.59(H-layer depth)]	.73	1.1
L ^b -layer = exp[6.23+0.21(L-layer depth)]	.21	1.7
L-layer = exp[6.53+0.18(L-layer depth)- 0.02(Live mixed-hardwood BA)]	.30	1.7

^a Depth in cm; BA=Basal Area (m²/ha).

^b F=fermentation, H=humification, L=litter.

Table 35. The means, standard deviations, and coefficients of variation of the residuals from fitting significant regression models for forest floor weights to a subset of population data (n=43).

Variables		Residuals		
Y	X	Mean	Standard Deviation	Coefficient of Variation
Weight		kg/ha.....		%
Total	Total depth ^a	1.1	1.5	0.03
F ^b -layer	F-layer depth	1.0	1.6	0.10
H ^b -layer	H-layer depth	1.7	1.4	0.05
L ^b -layer	L-layer depth	1.0	1.7	0.14
L-layer	L-layer depth & Live mixed hardwood BA	1.0	1.7	0.14

^a Depth in cm; BA=basal area (m²/ha).

^b F=fermentation, H=humification, L=litter.

Discussion

Prediction of Forest Fuel Loads

The relatively weak relationships found between forest stand and site characteristics and woody fuel loads prevented the creation of a highly precise regression for the prediction of woody fuel loadings. Since woody fuel accumulation is controlled by the input rate and the decomposition rates, and many factors influence these two driving forces, prediction of woody fuel loads is difficult from only stand and site characteristics. For example, inputs of woody fuel occur from mortality due to such factors as insects, disease, wind, and succession (Harmon et al. 1986). Since the main causes of tree death in the park (insect attack and windthrow), were not very dependent on stand age, the unrelatedness of stand age and bole loading was not surprising. See and Brown (1980) note that many causes of mortality and treefall are unrelated to stand age. For example, environmental stresses, such as water stress due to drought, which can contribute to oak decline or increase the risk of the southern pine bark beetle infestations, occur unpredictably and affect immature as well as overmature stands (NAPAP 1989).

Even the variables that created the best prediction equations for boles, dead pine basal area, have numerous factors influencing them, preventing a stronger relationship from being found. Standing dead pine snags, which are represented as dead pine basal area, contribute branches and boles to the surface fuel as they decay. Keen (1929, 1955) studied pine snags in northern California, and found that the rate at which snags fell was related to the time elapsed since death, the activity of decay agents, the size of the snag and proportion of heartwood, and environmental conditions such as climate, soil moisture, and the prevalence of windstorms.

In addition, the distribution of the woody fuel within stands influences the relationships between the fuel loads and stand characteristics. Boles are often not regularly or evenly distributed, except perhaps with suppression mortality (Harmon et al. 1986). In the mature deciduous stands in RICH, windthrow was observed to be the main disturbance mechanism and cause of mortality, creating patchy distributions of bole fuels, as found in old-growth deciduous stands. Coarse woody debris distribution in old-growth deciduous stands is patchy due to the typically irregular and gradual turnover of the stand, called gap-phase dynamics

(Muller and Liu 1991). This uneven distribution of large woody fuel loads partially causes the weak relationships found between bole loads and stand and site characteristics at RICH.

The best model for forest floor loads was created with a variable not directly related to the vegetation: forest floor depth. The relationship between forest floor weight and depth has been documented in other forest types, but strong regressions only resulted from relationships within stands with homogeneous forest floors, as in pine plantations. The variability of forest floor accumulation in stands can be influenced by a variety of factors beyond the natural cycles of production. Events such as storms, insect attacks, disease outbreaks, and drought or extremes of temperature (that affect a tree's physiology) will cause variations in litter production and accumulation within a stand (Bray and Gorham 1964). In RICH, bark beetles had attacked many of the mature pine stands, resulting in the demise of many mature pines. The bark, branches, and stems fragments that fell as the stems degenerated added to the litter and duff loads around the beetle infested spots.

All of these factors overshadowed the effects of the dominant genus of the stand on forest floor loading: as species with fast decomposing litter (mixed hardwoods) increase in dominance and density, the average forest floor weight decreases. The overstory species composition seems to be more influential to floor weight than the actual density of the stand, as neither *total* density nor basal area was significantly correlated with floor weights.

This conclusion was supported by Bray and Gorham (1964), who found that litter production was little affected by differences in tree density within closed canopy forests. Until a stand's canopy has closed, litter production and accumulation increase with density, as there is more canopy annually to produce litter (Dickinson and Pugh 1974). When the stand canopy closes and full stocking is reached, the production of litter levels off to an equilibrium for the stand, and the forest floor load reaches an equilibrium between the litter input and the decomposition rate. Then, stand age appears to have little affect on litter production (Dickinson and Pugh 1974). Kittredge's (1940) observations that older natural forests do not have excessive amounts of forest floor compared to younger stands supports this. Consequently, neither stand basal area, density, nor age was related strongly enough to improve the regressions for predicting forest floor loads.

Several of the regressions are suitable for attaining rough generalizations of fuel loadings, if the reported level of precision is acceptable. A decision to use the equations would depend on a combination of the amount willing to be expended for field sampling and the precision required. These are not a substitute for the precision of field sampling, as the forest floor and woody fuel loads in different stands can vary tremendously.

Fuel Loads and Fire Behavior

To examine the fire hazard represented by the fuel loads at RICH, BEHAVE Fire Behavior Prediction and Fuel Modeling System was used to predict potential fire behavior. BEHAVE is a series of interactive fire behavior computer programs for estimating wildland fire potential (Burgan and Rothermel 1984). The BEHAVE program requires input about meteorologic, topographic, and fuel conditions, including a fuel model supplying fuel loading information representative of the stand where the fire is located. Thirteen fuel models encompassing many North American forest ecosystems are supplied with the program; if specialized fuel loading information is available for a particular stand type, new fuel models can be created.

For the fuel situations at RICH, BEHAVE fuel models 8 and 9, representing Closed Timber Litter and Hardwood Litter, have been used (E. Gasser, personal communication). These models provide suitable estimates for most dead and down forest fuel loads at the park, as most stands are closed canopy with few shrubs (Anderson 1982). Only time-lag 100-hr. and less fuels are considered in fire behavior prediction, as larger bole fuels do not affect a fire's flame height or rate of spread nearly as much as the smaller fuels. The presence of heavy bole loads in some pine stands is not necessarily a fire hazard, though they do affect the fire's intensity and duration in areas that are in close proximity to them. Consequently, fuel model 10, representing Timber (litter and understory) with greater quantities of larger limbwood, may also be of use in the park.

Model 8 represents closed canopy stands of short-neededled conifers and hardwoods that have leafed out and have a compacted litter layer of needles, leaves, and occasional twigs, with little undergrowth (Anderson 1982). This model would be appropriate for the hardwood stands in the summer months, when their litter has become compacted. Model 9 represents long-neededled conifers and hardwood stands such as oak-hickory, with loose hardwood litter, typical of fall months (Anderson 1982). This model would be appropriate for predicting fuel loads under hardwood stands during the fall months and for the healthy loblolly pine stands. Model 10 represents any forest type with heavy down material from trees killed by insects or disease, windthrown trees, and overmature or overcrowded stands with deadfall; this model would apply to areas with a large component of loblolly pine that was dying from overcrowding or insect attack.

Specialized fuel models for each cover type at RICH were also created using the NEWMDL procedure of BEHAVE with the specific fuel loading information collected within them. The surface-area-to-volume ratios, extinction moisture for dead fuel, and heat content values selected for the models were near those used for BEHAVE models 8 and 9. In general, lower levels (1/3 to 1/2) of 1 hr. time-lag fuels were recorded in RICH compared to those reported for the BEHAVE models 8 and 9, so total branch fuel loads (≤ 100 hr. time-lag) were lower in the RICH models for all but the oak cover type (Table 36). The depth of the fuel beds was similar between the BEHAVE and RICH specialized models. These specialized models were only created to compare the fire behavior of park fuel loads to standard BEHAVE fuel model loads. New fuel models should be tested with BEHAVE TSTMDL procedure, at many environmental conditions, before they are used operationally (Burgan and Rothermel 1984).

The predicted fire behavior information for similar environmental conditions was calculated for each cover type with its fuel model. In addition, fire behavior was predicted for the same conditions using models 8 and 9 provided by BEHAVE. The conditions selected for running the program were similar to those used by Anderson (1982) in his comparison of results between the BEHAVE fuel models. The conditions were as follows: dead fuel moisture content, 8%; slope, 5%; effective windspeed at midflame height, 8 km/hr with the wind direction uphill. This is the lowest fuel moisture content that could be expected for wood on the forest floor (Panshin and de Zeeuw 1980). Increasing the windspeed had no effect on the results as a "wind limit" was reached by the program.

The mixed hardwood cover type fuels supported the coolest and slowest spreading fire of all types (Table 37). This type had the lowest 1 hr. time-lag and total branch loads, and the shallowest surface fuels, 1/3 of the load of BEHAVE fuel model 8 for closed timber stands. The oak and oak-mixed hardwood cover types had greater fuel loads, but they were still lower than those represented by model 8. Although the conifer cover types had similar fuel load levels, the more volatile pine needles and slightly deeper surface fuels caused hotter, faster fires (Table 37). The flame lengths and fireline intensity values were low with regards to fire suppression interpretation; the fires could generally be attacked at the head or flanks by persons using handtools (Andrews 1986)(Table 38).

Table 36. Fuel load values for estimating fire behavior for two BEHAVE models and six cover types at Richmond National Battlefield Park as entered into BEHAVE fire behavior program. BEHAVE model 8 & 9 values from Anderson (1982).

Fuel Attribute	Fuel Values							
	BEHAVE Model #		Richmond National Battlefield Park Cover Types ^a					
	8	9	C	OC	HC	O	H	OH
Total fuel load, <7.6 cm, kg/ha	11,110	7,777	6,323	6,592	6,046	6,461	4,705	6,299
Dead fuel load, 0.6 cm, kg/ha	3,333	6,444	1,630	1,953	1,694	2,058	1,232	1,604
Live fuel load, foliage, kg/ha	0	0	0	0	0	0	0	0
Fuel bed depth, meters	0.06	0.06	0.06	0.06	0.09	0.06	0.03	0.06

^a C-Conifer, OC-Oak-Conifer, HC-Mixed Hardwood-Conifer, O-Oak, H-Mixed Hardwood, OH-Oak-Mixed Hardwood

Table 37. Rate of spread (chains/hr), fireline intensity (BTU/m/s), and flame length (m) of two BEHAVE timber litter fuel models and six Richmond National Battlefield Park forest cover type litter fuel models when the dead fuel moisture content is 8 percent, slope is 5 percent, and the effective windspeed at midflame height is 8 km/hr, blowing uphill.

Model	Rate of spread	Fireline intensity	Flame length
	(meters/hr)	(BTU/m/s)	(meters)
Behave # 8	40.22	20	0.3
Behave # 9	160.88	158	0.8
RICH Oak	60.33	20	0.3
RICH Mixed hardwoods	20.11	7	0.2
RICH Oak-Mixed hardwoods	40.22	16	0.2
RICH Conifer	60.33	20	0.3
RICH Oak-Conifer	40.22	16	0.3
RICH Mixed hardwoods-Conifer	100.55	43	0.4

Table 38. Fire suppression interpretation of flame length and fireline intensity (From Andrews 1986).

Flame length	Fireline Intensity	Interpretation
<i>Meters</i>	<i>Btu/m/s</i>	
< 1.2	<328	Fire can generally be attacked at the head or flanks by persons using handtools.
1.2 - 2.4	328 - 1,640	Fires are too intense for direct attack on the head by persons using handtools. Hand line cannot be relied on to hold fire. Equipment such as plows, dozers, pumpers and retardant aircraft can be effective.
2.4 - 3.4	1,640 - 3,281	Fires may present serious control problems--torching out, crowning, and spotting. Control efforts at the fire head will probably be ineffective.
> 3.4	> 3,281	Crowning, spotting, and major fire runs are probable. Control efforts at head of fire are ineffective.

The new fuel models created with data from RICH generally had lower fireline intensities and flame lengths. According to Anderson (1982), only under severe weather conditions involving high temperatures, low humidities, and high winds do the fuels represented by model 8, such as the hardwoods with compacted litter layers, pose fire hazards. Stands with fuels like those of model 9, such as the loblolly and the hardwood stands soon after leaf-fall in RICH, generally have fires that travel faster through the surface litter than model 8 fires, with higher flames (Anderson 1982). High winds will cause higher rates of spread in loose hardwood litter. Areas of stands with fuels like those represented by model 10 will have fires of greater intensity than the other two timber litter models, and these fires are at the upper limit of control by direct attack. Since the BEHAVE models' fuel loads are similar to those at RICH, they are recommended for use at the park when fuel and fire behavior specialists, the intended users of the BEHAVE system, are not available for consultation. Fuel inventory data can be used to adjust the BEHAVE models to specific stands with the TSTMDL procedure (Burgan and Rothermel 1984); this should serve the needs of the park well.

Hazard Fuels Management

Hazard fuels management requires that hazardous fuel situations be identified, modified, and monitored over time throughout the landscape. Hazardous fuel loads that lead to hazardous fires are created with a combination of the quantity and arrangement of fuel in a stand. Hazardous fires, those that generally cannot be controlled by people on foot and with handtools (Table 38), occur when such fuel loads are influenced by environmental conditions that favor fire: low humidity, high temperatures, and wind speeds that carry the fire to more fuel while supplying it with plenty of oxygen. So, the identification of a hazardous fuel load in an area requires an examination of the quantity of fuel and its arrangement.

The quantity of fuel in a stand can be determined with fuel load models such as those developed for RICH, Photo Series such as Lynch and Horton's (1983) or Wilcox et al.'s (1982), or a field inventory. Determining whether the quantity is potentially hazardous requires extensive experience with fuels and fire, or results from fire behavior prediction systems such as BEHAVE or the National Fire-Danger Rating System (NFDRS). The use of these computer programs offers another source of fuels information, as they contain fuel models for many forest types within their systems. BEHAVE and NFDRS fuel models can be used when running these systems for a particular area, or specific inventoried information can be substituted. Since fire behavior is primarily influenced by the 1 to 100 hr. time-lag fuel sizes, only these fuels are considered in the fire behavior models. Larger branches and boles do not carry the fire front as smaller fuels do. Larger fuels influence the fire's intensity and duration in close proximity to where they occur and burning boles can cause severe damage to nearby vegetation because of their extended burning time at relatively high heat values. Smoldering boles can also be a source of firebrands should high winds fan them.

The horizontal and vertical arrangements of the fuel bed are additional considerations in determining whether a specific fuel situation is hazardous. Fuel levels may be high, but if they are patchy, the hazard is not as great as if they are continuous, allowing a fire front to quickly move through the stand. Aerial fuels, which are those above 1.2 meters such as dead and attached branches, leaning or upright snags, and standing, live vegetation, must also be considered when assessing the fuel hazard of a site. These are generally not considered in fire behavior programs as they are not dead and down surface fuels. If a vertical continuum

exists that could carry the fire off the ground and through a stand, this could be considered a hazardous situation, since a break in the fuel is usually needed to stop the fire.

In Richmond National Battlefield Park, the dead and down surface fuels would contribute to a hazardous fire situation only underneath the very best environmental conditions for fire. However, there are a few areas in the park where fuel management would be a good preventative measure against a hazardous fuel situation. Areas where maintenance activities have resulted in small buildups of boles and branches, mostly along roadsides, should be considered for fuel management. Other areas are sites where the arrangement of the dead fuels create potential hazards. Many of these sites are small gaps in mature pine or mixed pine-deciduous stands that formed when a few trees died or fell, creating openings with masses of live and dead vegetation that could carry a surface fire off the ground temporarily. The loblolly pine plantations are additional sites where preventative fuel management would be beneficial for the stand's health as well as its fuel situation.

Fuel management is necessary at the roadside areas where dead and dying trees have been felled and left on the site, such as near the exit of the loop road from Cold Harbor. The branch and litter fuel loading in these areas is no greater than in the rest of the forest; but the great mass of bole fuels (approximately 150,000 kg/ha) could smolder for extended periods of time if the piles were ignited by a passing surface fire. Greater damage would occur to the living vegetation of the area due to the longer duration of the fire. Fuel model 10 would apply in these areas. The hazard of a surface fire could also increase due to chance spreading of the fire to other areas by wind and firebrands. "Clean" these areas by completely removing the large piles of logs, or simply scatter small piles so each bole rests on the ground where it will decompose faster having contact with soil moisture and organisms.

Pine and mixed pine-deciduous stands that are losing mature pine in patches are areas where fuel management would be beneficial in controlling the arrangement of the fuels. In these areas, scattered pines have fallen or are leaning against trees creating ladders of dead fuel up into the lower canopy. Understory trees and vines, responding to light from the gap in the canopy, are creating masses of vegetation which could help carry a fire off the ground temporarily (See Appendix IV: Figure A-IV-3, Cold Harbor--Plots 16 & 25;

Figure A-IV-5, Fort Harrison--Plot 3). A cleaning could be done at these sites to move the dead and leaning pines to the forest floor and cut and scatter piles of logs. Climbing vegetation would also be cleared with this activity. This would keep any passing surface fires on the ground and improve the conditions for decomposition to occur in the boles.

The final forest situation warranting fuel management at RICH is in the pine plantations. The potentially hazardous loblolly pine plantations, approximately 20 to 30 years old, are located near the entrances to Drewry's Bluff and to Fort Harrison off Picnic Road (See Appendix IV: Figure A-IV-5, Fort Harrison-Plot 5; Figure A-IV-6, Drewry's Bluff-Plot 1). These young stands are dense, with codominant and suppressed stems beginning to die, occasionally falling and leaning against other standing trees. The young pines have not self-pruned completely, so dead branches are still attached fairly close to the ground on many of the trees. The slowed growth in these stands due to the high density of trees also makes them attractive to pine bark beetle infestation, whose impacts would add to the fuels in these presently healthy stands.

One fuel management recommendation is to thin the pines to a level that will stimulate and maximize the growth of the remaining pines to keep them vigorous and prevent the addition of more dead trees to the fuel load. A suggested basal area to thin to is 18 m²/ha, from their current 25 and 35 m²/ha at Fort Harrison and Drewry's Bluff, respectively. Favor (leave) trees with larger canopies, no sign of insects or disease in the crowns or on the trunk, and those showing signs of being used by wildlife. A forester could mark the trees to be cut to insure that a well-stocked, healthy stand is left after the operation. Thinning will break the vertical continuum of fuel as the spacing increases between the trees and dead branches lower on the trunks are broken. Vigorously growing pines will reduce the chances of pine beetle attack also. In less dense and smaller pine plantation stands, such as the one below the scenic view at Chickahominy Bluff (See Appendix IV: Figure A-IV-1, Chickahominy Bluff-Plot 1), another fuel management option is pruning. Pruning of the dead branches near the ground will break up the vertical fuels which could carry a fire off the ground.

A fuel monitoring program should be established at RICH to identify sites where the quantity or arrangement of fuels have the potential to be hazardous. Knowing how fuel loads will change in different cover types over time can aid in establishing the frequency of monitoring visits and plans for manipulating

fuels when necessary. Oak and mixed hardwood stands, which contain a majority of climax species, should have relatively stable fuel loading rates, assuming healthy stands undisturbed by insect or disease outbreaks. As climax vegetation, these stands are made up by relatively long-lived and self-perpetuating shade-tolerant species, regenerating in gaps formed when mature individual trees die or blow over. Fuel loads may increase temporarily in these gaps where trees have died and fallen, but overall the stands' fuels would support surface fires only.

Stands of early successional, shade-intolerant species, or even-aged plantations predominated by a single shade-intolerant species, have more fluctuating fuel loads. The initial density-induced mortality of trees that are suppressed or below the dominant canopy that is common in such stands can result in a relatively large amount of dead fuels over a short period of time. Steep spikes in fuel loading can occur over a period of 2-5 years. This is the case of the young loblolly pine stands in RICH that need a thinning to reduce stand density before the trees die. Following the initial mortality, the fuel load will decrease for a period of 10 years or so, as the stand grows, building up density without much mortality. If the density reaches high levels again, mortality will occur and fuel levels will increase again. This phenomenon is not likely to occur in mixed stands typical of more advanced successional stages, and/or when shade-tolerant species are present. Tolerant trees slow down in growth, rather than die, when the stand becomes dense.

Beyond monitoring fuels through the natural changes that occur in forest stands with time, the effects of natural disasters, severe storms, and disease and insect outbreaks on fuel loading need to be assessed when these occur in the park. Tree damage from natural disasters, such as hurricanes, and severe storms is typically from mechanical breakage or blowdown. Monitor hard hit areas to determine if fuel reduction activities are necessary. If entire stands are destroyed in the park, the clean-up activities will be necessary for aesthetic and safety reasons as well as for fuel reduction. Economically beneficial operations such as selling the down and damaged trees to firewood cutters could be considered as a way to remove the wood and clean up the stand's forest floor.

Insect outbreaks and disease should be monitored for their extensiveness and severity. If large areas of trees are killed, or are dying, consider salvaging the stand for timber to remove the trees before they add to

the fuel hazard. Such a drastic action, to remove the mature trees of a stand, would apply to damage initiated by a gypsy moth (*Lymantria dispar* L.) outbreak in the park. Should the gypsy moth invade the Richmond area, the stands within the oak and oak-conifer cover types will be affected the most. Oaks and sweetgum are favored food for gypsy moth larvae during all larval stages (Gansner et al. 1987). The later larval stages prefer all pine species too. When the preferred species are not available, American beech, black gum, elms, hickories, and red maple will be fed upon. The stands least affected by gypsy moth in RICH will be those dominated by yellow poplar. Eastern red cedar and American holly are also rarely fed upon (Gansner et al. 1987).

The amount of mortality in a stand after gypsy moth attack is influenced by a number of factors: the intensity, distribution, and frequency of defoliation; tree vigor previous to attack; environmental conditions; and the extent of disease and insect invasion (Gansner et al. 1987). Typically the defoliation results in trees becoming stressed and succumbing to secondary organisms such as two-lined chestnut borer (*Agrilus bilineatus* (Weber)) or shoe-string root rot (*Armillaria mellea* (Vahl.:Fr.)). Trees killed after gypsy moth attack will not resprout since their root reserves have already been spent refoliating or fighting off insect or disease attacks. The understory will remain green and attractive however, and shrubs, tree seedlings, and saplings should survive and grow quickly with the removal of the overstory.

Conclusions

The average forest fuels of the six cover types inventoried at Richmond National Battlefield Park were unique, in that so many different stand histories comprised each type, making the fuels extremely variable within each. In general, though, the bole loads were heavier than those reported in similar cover types in the eastern United States, and the forest floor loads were lighter. The common occurrence of stem disease, root rot, and pine bark beetle in all cover types seemed to induce heavier bole loads in the park's stands.

Secondary succession also played a part in the bole loading of stands in RICH in which pine had been dominant or codominant in recent history. These are now in the middle to late stages of succession from coniferous to deciduous compositions. In these stands, the gradual loss of pine from the overstory meant the accumulations of heavy pine boles on the ground. These pine boles constituted a load that was typically twice as high as in those stands which were not experiencing the dynamics of secondary succession.

The branch and forest floor loads were influenced by the composition of the stand overstory, as smaller particles that respond quickly to overstory changes. Branch volumes and weights were relatively the same in all cover types, except for the 1 hr. time-lag fuels, which were significantly higher in the stands with oak. The forest floor weight was primarily related to the decomposition of the litter: the mixed hardwoods had the least amount of forest floor, and the litter of these species is the most easily decomposed by organisms. Also, the sites where mixed hardwoods were located were generally of higher quality (coves, bottomlands), which would provide a more suitable environment for decomposition than the drier, upland sites commonly dominated by pines and oaks.

Although relationships were significant between several forest stand and site characteristics and fuel loads in the forests of RICH, none was strong enough to provide a highly precise regression model for predicting fuel loads. Variability in fuel loads within and between stands was high for a number of reasons: natural tree and species production variability, stand history differences, insect and disease influences, and microsite and topographic influences on decomposition and distribution. The models would be useful in a situation when a rough estimate of fuel loading was desired that only required a small amount of field work

for data collection.

In general, the forests of Richmond National Battlefield Park do not carry hazardous levels of fuels. Scattered areas have heavier loads or arrangements of fuel that could create a hazardous fire situation if the environmental conditions were favorable, however these sites are discontinuous and fuel management will lower their hazard.

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Appendix I. Richmond National Battlefield Park Management Unit Descriptions.

Chickahominy Bluffs

The 15.9 ha Chickahominy Bluffs unit lays mostly on a northeastern aspect, its steep slopes running down to the Chickahominy River floodplain. The elevation change from bluff to bottom is approximately 24 meters. The southeast edge of the unit is crossed by an intermittent stream. The unit is wooded, except for the parking area and access roads. Japanese honeysuckle and tree-of-heaven have become established in the understory of some areas.

The slopes of the unit are located on Ochrept and Udult soils; these soils have rapid runoff, are droughty at times, and have a severe erosion hazard if disturbed and unvegetated (U.S.D.A. 1975). The floodplain terrace is located on well drained Kempsville fine sandy loam (flooded), where runoff is medium, and hazard of erosion from seepage and runoff from higher areas is moderate if soil is disturbed and unvegetated (U.S.D.A. 1975). The floodplain soils, deep, poorly drained, Myatt fine sandy loam and Chewacla and Riverview loam or silt loams, have low erosion hazard and slow runoff (U.S.D.A. 1975).

Watt House

The land surrounding the Watt house and nearby fields is relatively level. The unit contains 24.4 ha of gentle to moderately steep slopes, which drop off to Boatswain Creek, the northern boundary of the unit, on a northwestern slope. Forest covers the slopes and drainage of this unit. Japanese honeysuckle and tree-of-heaven occur here.

The uplands and slope shoulders are underlain by well drained and moderately well drained Suffolk loamy fine sand and Kempsville-Bourne fine sandy loams, on which runoff is medium and erosion is a moderate hazard (U.S.D.A. 1980). These soils are well suited to cultivated crops and to pasture and hay. The slightly steeper mid-slope and toe slopes have eroded Caroline-Dogue complex soils, which are well-drained and moderately well-drained. Runoff is medium to rapid on these soils, and erosion is a severe hazard. These soils are suited to trees, with a potential productivity of moderately high to high (U.S.D.A. 1980). The slopes along the drainageway have Udult-Ochrept complex soils, which are moderately well-drained to excessively drained soils. Runoff is rapid and erosion is a very severe hazard on these soils.

Cold Harbor

This 60.3 ha unit consists of gentle slopes crossed by intermittent streams that drain to the west. Forest covers all of the unit except for an agricultural field on the south side. The soil of the unit is primarily a well drained Suffolk loamy fine sand, that has medium to rapid runoff and a severe erosion hazard (U.S.D.A. 1980). It is suited to trees, with a high potential productivity. Along the drainageways is the Udult-Ochrept complex.

Malvern Hill

The Malvern Hill unit of 52.9 ha is intersected by Carters Mill Road. The uplands are primarily agricultural fields, while the slopes, terrace and floodplain are wooded. The land to the east of the highway is an upland with gentle slopes, and is underlain by well-drained State fine sandy loam (clayey substratum) (U.S.D.A. 1975). This soil has medium runoff and moderate erosion hazard if the soil is disturbed and left unvegetated.

The land to the west of the highway slopes gently, then drops off steeply to the floodplain of Crewe's Channel. There is an approximately 18 m elevation change from the hilltop to the floodplain. The upland area has Kempsville very fine sandy loam soils (clayey substratum), which extends down the slopes to the floodplain (U.S.D.A. 1975). Intermittent streams that drain the area have Ochrept and Udult soils. The older stream terrace has a somewhat poorly drained Lenoir silt loam, with slight erosion hazard and slow runoff (U.S.D.A. 1975). Crewe's channel terrace is underlain by poorly drained Roanoke silt loam, and the floodplain has Chewacla and Riverview soils.

Fort Harrison

Fort Harrison, Fort Gilmer and Fort Brady total 126.7 ha and are located on the gently rolling topography through which the park road runs. The soils along the road are primarily Roanoke silt loam and Angie loam, which are poorly to moderately well-drained, with slow runoff and slight erosion hazards (U.S.D.A. 1975). Fort Harrison, the largest park section in this unit, is forested with second-growth mixed pine-hardwood stands. A marshy area is found at the southwest boundary of this section. The Fort Brady unit is bordered on the south by wooded, steep slopes that drop 24 feet down to the James River. The bluff

is underlain by well drained Pamunkey fine sandy loam, and the slopes have Ochrept and Udult soils (U.S.D.A. 1975).

Drewry's Bluff

Fort Darling, with 15.9 ha located on the gently sloping land behind the bluff, has a slight eastern aspect, and a stream intersects the unit south of the fort earthworks. The northern boundary of the unit is the James River, with steep slopes dropping 21 m from the bluff. The unit is wooded except for the parking area and an old landfill area currently maintained as a field. Periwinkle is one exotic that occurs in this unit. The ridgetop area is underlain by well-drained Masada loam and Tetotum loam (clayey substratum), on which runoff is medium and erosion hazard is moderate (U.S.D.A. 1978). The bluff is mostly of well-drained Gritney fine sandy loam, which has a medium to rapid runoff and severe erosion hazard if disturbed and unvegetated. Ochrepts and Udults are located on the slope down to the river (U.S.D.A. 1978).

Parker's Battery

This small, 4.0 ha, wooded unit has a level topography, with well- drained Lucy-Orangeburg loamy sands. Runoff is medium, and the hazard of erosion is moderate where soils have been disturbed and exposed (U.S.D.A. 1978).

Appendix II. Forest overstory species inventoried at Richmond National Battlefield Park, Virginia.

Scientific Name	Common Name
<i>Acer rubrum</i> L.	Red Maple
<i>Carpinus caroliniana</i> Walter	American Hornbeam
<i>Carya glabra</i> (Mill.) Sweet	Pignut Hickory
<i>Carya tomentosa</i> (Poir.) Nutt.	Mockernut Hickory
<i>Cornus florida</i> L.	Flowering Dogwood
<i>Diospyros virginiana</i> L.	Common Persimmon
<i>Fagus grandifolia</i> Ehrhart	American Beech
<i>Ilex opaca</i> Aiton	American Holly
<i>Juniperus virginiana</i> L.	Eastern Red Cedar
<i>Liquidambar styraciflua</i> L.	Sweetgum
<i>Liriodendron tulipifera</i> L.	Yellow Poplar
<i>Magnolia virginiana</i> L.	Sweet Bay
<i>Nyssa sylvatica</i> Marshall	Black Gum
<i>Pinus echinata</i> Miller	Short-leaf Pine
<i>Pinus taeda</i> L.	Loblolly Pine
<i>Pinus virginiana</i> Miller	Virginia Pine
<i>Prunus avium</i> L.	Sweet Cherry
<i>Quercus alba</i> L.	White Oak
<i>Quercus coccinea</i> Muenchh.	Scarlet Oak
<i>Quercus falcata</i> Michaux	Southern Red Oak
<i>Quercus palustris</i> Muenchh.	Pin Oak
<i>Quercus phellos</i> L.	Willow Oak
<i>Quercus prinus</i> L.	Chestnut Oak
<i>Quercus rubra</i> L.	Northern Red Oak
<i>Quercus stellata</i> Wang.	Post Oak
<i>Quercus velutina</i> Lam.	Black Oak
<i>Ulmus alata</i> Michaux	Winged Elm
<i>Ulmus americana</i> L.	American Elm
<i>Ulmus rubra</i> Muhl.	Slippery Elm

Appendix III. Inventory and site data for 115 fuel sample plots at Richmond National Battlefield Park, Virginia. Definitions of variables on the data sheets are as follows:

Standard Plot Inventory Identification Variables

Unit -- 1 - Chickahominy Bluff
 3 - Watt House
 4 - Cold Harbor
 6 - Malvern Hill
 7 - Fort Harrison, section with fort
 8 - Drewry's Bluff
 9 - Parker's Battery

Standnum -- Stand number in G.I.S. database

Plot -- Plot number within unit

Appendix III-1. Site data.

<u>Site Variables</u>	<u>Definition</u>
Coverttype	Forest cover type: C-Conifer, OC-Oak-Conifer, HC-Mixed Hardwood-Conifer O-Oak, H-Mixed Hardwood, OH-Oak-Mixed Hardwood
Ageclass	Age class: S-Seedling/Sapling 0-20 years, Y-Young 21-50 years, I-Intermediate/Immature 51-100 years, O-Old/Mature >100 years
Aspect	Aspect, degrees
Slopepos	Slope Position: A-plateau, B-hilltop, ridge, C-shoulder, D-sideslope E-toeslope, draw, F-floodplain, G-bottom
Slope	Slope, %

Appendix III-2. Woody fuel weight data.

<u>Fuel Variables</u>	<u>Definition</u>
Bolewt	Weight of >100 hr. T-L fuels, kg/ha
Branchwt	Weight of ≤100 hr. T-L fuels, kg/ha
Wttl1	Weight of 1 hr. T-L fuels, kg/ha
Wttl10	Weight of 10 hr. T-L fuels, kg/ha
Wttl100	Weight of 100 hr. T-L fuels, kg/ha

Appendix III-3. Forest floor weight data.

<u>Fuel Variables</u>	<u>Definition</u>
Floorwt	Weight of L-F-H layers, kg/ha
Litterwt	Weight of litter layer, kg/ha
Fermwt	Weight of fermentation layer, kg/ha
Humuswt	Weight of humus layer, kg/ha

Appendix III-4. Woody fuel volume data.

<u>Fuel Variables</u>	<u>Definition</u>
Bolevol	Volume of >100 hr. T-L fuels, cubic m/ha
Branchvol	Volume of $\leq$ 100 hr. T-L fuels, cubic m/ha
Voltl1	Volume of 1 hr. T-L fuels, cubic m/ha
Voltl10	Volume of 10 hr. T-L fuels, cubic m/ha
Voltl100	Volume of 100 hr. T-L fuels, cubic m/ha

Appendix III-5. Fuel depth data.

<u>Fuel Variables</u>	<u>Definition</u>
Srfdpth	Depth of surface fuels, cm
Flrdpth	Depth of L-F-H layers, cm
Litdpth	Depth of litter layer, cm
Ferdpth	Depth of fermentation layer, cm
Humdpth	Depth of humus layer, cm

Appendix III-1. Site data.

UNIT	STANDNUM	PLOT	COVERTYPE	AGECLASS	ASPECT (degrees)	SLOPEPOS	SLOPE %
1	6	1	OC	Y	37	D	30
1	7	2	H	O	12	C	28
1	9	3	HC	I	198	D	20
1	13	4	O	O	0	D	23
1	7	5	H	O	20	E	8
1	24	6	HC	Y	999	F	1
1	21	7	C	Y	999	F	1
1	19	8	H	I	10	F	1
1	17	9	H	I	5	F	1
1	17	10	H	I	999	F	1
3	1	1	OH	O	312	E	20
3	2	2	O	O	10	D	18
3	10	3	C	I	225	D	6
3	11	4	O	I	350	E	10
3	2	5	O	I	285	D	10
3	9	6	HC	I	310	B	3
3	2	7	O	O	350	D	15
3	11	8	O	I	24	D	12
3	2	9	O	O	340	D	22
3	2	10	O	I	5	E	20
4	12	1	OH	I	265	D	10
4	16	2	H	O	250	E	2
4	11	3	O	I	315	C	9
4	4	4	O	I	100	D	10
4	3	5	C	I	999	B	0
4	9	6	OC	I	295	D	15
4	8	7	O	I	85	D	15
4	17	8	OC	O	230	D	9
4	23	9	OC	I	15	A	0
4	19	10	OH	I	195	A	3
4	20	11	OC	O	260	A	3
4	15	12	OC	O	340	D	10
4	16	13	H	O	126	E	14
4	22	14	O	O	176	A	5
4	22	15	OH	O	30	D	5
4	26	16	OC	I	6	A	2
4	30	17	OH	I	310	E	1
4	29	18	C	I	330	A	1
4	16	19	H	I	220	E	25
4	23	20	OC	I	240	B	2
4	22	21	O	O	3	D	3
4	11	22	O	O	12	C	7
4	16	23	H	O	999	E	0
4	22	24	O	I	15	A	1
4	26	25	OC	I	292	A	1
6	27	1	HC	I	313	D	6
6	27	2	HC	I	10	A	1
6	24	3	HC	I	275	B	0
6	23	4	H	Y	8	B	1
6	12	5	C	I	230	D	10
6	15	6	OC	I	30	B	1
6	11	7	OC	I	230	C	8

Appendix III-1. Continued.

UNIT	STANDNUM	PLOT	COVERTYPE	AGECLASS	ASPECT (degrees)	SLOPEPOS	SLOPE %
6	21	8	HC	I	196	E	13
6	20	9	C	I	265	D	8
6	18	10	H	I	257	D	14
6	10	11	H	I	152	E	10
6	16	12	OH	I	120	D	20
6	9	13	H	I	260	C	7
6	8	14	HC	I	280	F	2
6	1	15	H	I	273	F	1
6	2	16	H	I	262	F	1
6	4	17	OH	I	250	F	1
6	5	18	H	O	264	F	1
6	6	19	H	I	240	F	4
6	7	20	HC	I	265	F	2
6	13	21	OH	I	275	D	10
6	23	22	H	Y	999	B	0
7	2	1	OC	I	270	A	1
7	5	2	HC	I	290	A	1
7	8	3	C	Y	285	A	2
7	7	4	HC	I	999	A	1
7	11	5	C	Y	999	A	1
7	12	6	O	I	230	D	3
7	16	7	H	O	6	E	4
7	19	8	OH	O	100	E	4
7	18	9	O	I	70	C	5
7	39	10	OC	Y	270	A	2
7	29	11	O	Y	345	A	2
7	24	12	OC	O	999	G	0
7	26	13	HC	I	999	G	0
7	30	14	OH	I	240	G	1
7	27	15	OH	I	245	E	7
7	49	16	O	I	80	A	1
7	36	17	HC	I	180	A	2
7	41	18	OC	I	280	A	2
7	43	19	O	O	110	A	3
7	6	20	C	I	999	A	2
7	4	21	O	O	36	A	2
7	2	22	OC	I	265	A	1
7	2	23	O	O	279	A	2
7	2	24	OC	O	999	A	2
7	5	25	OC	Y	250	A	2
7	5	26	OC	I	260	A	1
7	15	27	H	I	999	E	0
7	10	28	HC	I	999	A	1
7	45	29	OC	I	260	A	1
7	45	30	OC	I	260	A	2
7	44	31	O	I	242	A	1
7	31	32	O	O	300	C	6
7	24	33	OC	O	999	G	3
7	29	34	O	Y	270	D	7
7	25	35	HC	I	999	G	0
7	23	36	O	O	999	G	0
7	5	37	HC	I	999	A	1

Appendix III-1. Continued.

UNIT	STANDNUM	PLOT	COVERTYPE	AGECLASS	ASPECT (degrees)	SLOPEPOS	SLOPE %
7	43	38	O	O	110	A	3
8	1	1	C	S	25	A	1
8	14	2	O	I	98	D	5
8	7	3	O	I	40	C	20
8	13	4	O	O	150	D	2
8	13	5	O	O	205	C	10
9	2	1	C	I	180	A	2
9	5	2	OC	I	999	A	1
9	7	3	C	I	340	A	1
9	6	4	OC	I	0	A	1
9	8	5	OC	O	340	A	1

Appendix III-2. Woody fuel weight data.

UNIT	STANDNUM	PLOT	BOLEWT	BRANCHWT	WTTL1	WTTL10	WTTL100
					-----kg/ha-----		
1	6	1	1610	8470	520	3800	4150
1	7	2	3010	7600	820	4010	2770
1	9	3	67650	7450	560	3520	3370
1	13	4	0	5640	650	2440	2550
1	7	5	36220	4170	700	3470	0
1	24	6	0	1970	410	1560	0
1	21	7	0	4300	590	1870	1840
1	19	8	20010	2870	430	1710	730
1	17	9	1050	3890	290	1310	2290
1	17	10	1280	3900	590	3310	0
3	1	1	13660	5730	760	3390	1580
3	2	2	1050	4310	700	1850	1760
3	10	3	68960	3960	260	1700	2000
3	11	4	12190	2550	740	930	880
3	2	5	21370	2090	630	1460	0
3	9	6	8120	3760	570	3190	0
3	2	7	25360	5130	990	2380	1760
3	11	8	74270	3610	610	2120	880
3	2	9	27570	3920	700	1460	1760
3	2	10	5970	3710	1010	1880	820
4	12	1	15460	5770	560	1830	3180
4	16	2	4780	1970	520	1450	0
4	11	3	22550	10400	790	3440	6170
4	4	4	27530	5530	540	1460	3530
4	3	5	61720	3020	350	930	1740
4	9	6	2530	2880	410	1680	790
4	8	7	11480	3560	610	1190	1760
4	17	8	6500	3390	520	1160	1710
4	23	9	39740	5480	580	2460	2440
4	19	10	30720	3660	350	1570	1740
4	20	11	22380	1970	300	400	1270
4	15	12	5520	6260	930	1930	3400
4	16	13	4970	2560	450	1270	840
4	22	14	18090	2390	410	1980	0
4	22	15	0	2570	470	2100	0
4	26	16	81000	8300	630	2380	5290
4	30	17	980	3600	580	2220	800
4	29	18	8550	4300	510	3030	760
4	16	19	13200	4610	710	1400	2500
4	23	20	17450	5270	690	2380	2200
4	22	21	6530	4000	500	1800	1700
4	11	22	58030	6060	810	1720	3530
4	16	23	19400	2660	490	2170	0
4	22	24	47390	3470	610	1980	880
4	26	25	21090	4600	570	3270	760
6	27	1	94200	6360	680	2450	3230
6	27	2	75910	5200	300	1790	3110
6	24	3	33510	2200	330	1870	0
6	23	4	0	4080	280	1280	2520
6	12	5	79940	4900	120	1310	3470
6	15	6	40010	7540	540	2540	4460
6	11	7	22170	3870	480	1930	1460
6	21	8	54020	4760	250	1590	2920

Appendix III-2. Continued.

UNIT	STANDNUM	PLOT	BOLEWT	BRANCHWT	WTTL1	WTTL10	WTTL100
					-----kg/ha-----		
6	20	9	69920	3590	320	1860	1410
6	18	10	37420	3350	490	1980	880
6	10	11	30730	5100	350	1910	2840
6	16	12	4990	7730	580	2150	5000
6	9	13	5110	3530	220	1140	2170
6	8	14	35770	8150	490	2820	4840
6	1	15	34410	6710	230	860	5620
6	2	16	700	550	90	460	0
6	4	17	23610	4530	560	1320	2650
6	5	18	5210	2740	80	1350	1310
6	6	19	71380	3600	230	1310	2060
6	7	20	5160	4050	170	1180	2700
6	13	21	58100	15030	1230	5620	8180
6	23	22	6970	5920	1020	2250	2650
7	2	1	2410	1230	390	840	0
7	5	2	40000	7830	380	1720	5730
7	8	3	19290	8920	330	2810	5780
7	7	4	57890	5010	420	1610	2980
7	11	5	17690	6350	470	2990	2890
7	12	6	1670	7090	480	2680	3930
7	16	7	16840	10080	630	2510	6940
7	19	8	65270	4280	670	2050	1560
7	18	9	67820	6050	590	2050	3410
7	39	10	117160	5530	850	2500	2180
7	29	11	19140	7390	710	2350	4330
7	24	12	49090	9330	740	2310	6280
7	26	13	51040	2520	370	1440	710
7	30	14	28890	3850	550	1770	1530
7	27	15	5730	2210	530	1680	0
7	49	16	48020	6550	600	2790	3160
7	36	17	23030	840	390	450	0
7	41	18	84270	3950	270	1480	2200
7	43	19	4100	2710	430	2280	0
7	6	20	23550	7210	430	2230	4550
7	4	21	4750	4730	670	1440	2620
7	2	22	23020	5540	510	1990	3040
7	2	23	2830	3440	800	1790	850
7	2	24	3970	4890	490	2640	1760
7	5	25	70140	5300	320	1970	3010
7	5	26	51250	7090	730	2020	4340
7	15	27	29550	5840	780	4330	730
7	10	28	46800	4960	520	2440	2000
7	45	29	12860	3420	930	870	1620
7	45	30	32180	1770	670	1100	0
7	44	31	21570	4440	560	1300	2580
7	31	32	8260	6510	690	2350	3470
7	24	33	8580	6010	760	1910	3340
7	29	34	7540	4060	540	1760	1020
7	25	35	20360	6050	530	2000	3520
7	23	36	5140	2160	660	1500	0
7	5	37	39510	3580	670	1330	1580
7	43	38	5140	3310	690	2620	0
8	1	1	0	5080	720	2620	1740

Appendix III-2. Continued.

UNIT	STANDNUM	PLOT	BOLEWT	BRANCHWT	WTTL1	WTTL10	WTTL100
					-----kg/ha-----		
8	14	2	14290	10600	840	2950	6810
8	7	3	19400	4590	510	1790	2290
8	13	4	0	4180	700	1860	1620
8	13	5	6210	4890	630	2620	1640
9	2	1	22890	3200	250	1190	1760
9	5	2	0	7940	500	2450	4990
9	7	3	2630	6030	400	1370	4260
9	6	4	2380	5730	330	2120	3280
9	8	5	8120	5970	630	1930	3410

Appendix III-3. Forest floor weight data.

UNIT	STANDNUM	PLOT	FLOORWT	LITTERWT	FERMWT	HUMUSWT
-----kg/ha-----						
1	6	1	5496	2004	1500	1992
1	7	2	15708	1280	1544	12884
1	9	3	7376	3780	1316	2280
1	13	4	4684	864	852	2968
1	7	5	4552	552	696	3304
1	24	6	4476	756	1028	2692
1	21	7	4496	868	980	2648
1	19	8	1072	544	120	408
1	17	9	3716	160	1676	1880
1	17	10	4112	2352	800	960
3	1	1	2224	808	792	624
3	2	2	4700	1812	1420	1468
3	10	3	2248	576	1032	640
3	11	4	3260	1024	1332	904
3	2	5	4172	856	1176	2140
3	9	6	2512	832	820	860
3	2	7	5728	1860	1580	2288
3	11	8	2752	524	936	1292
3	2	9	4333	358	1469	2506
3	2	10	4792	506	1780	2506
4	12	1	3824	1116	1128	1580
4	16	2	3304	734	812	1758
4	11	3	5468	948	1580	2940
4	4	4	6568	956	2408	3204
4	3	5	5936	936	1612	3388
4	9	6	8360	3988	2924	1448
4	8	7	7052	1184	2960	2908
4	17	8	3860	852	1076	1932
4	23	9	4200	1168	1204	1828
4	19	10	3544	1176	672	1696
4	20	11	5796	1660	1488	2648
4	15	12	4844	1016	1536	2292
4	16	13	5544	1552	1844	2148
4	22	14	4952	1108	1780	2064
4	22	15	2780	628	768	1384
4	26	16	11350	863	1501	8986
4	30	17	4848	668	992	3188
4	29	18	8228	1544	3620	3064
4	16	19	4264	1688	736	1840
4	23	20	7536	2192	3360	1984
4	22	21	3987	598	939	2450
4	11	22	10788	6756	1444	2588
4	16	23	3228	612	858	1758
4	22	24	4896	1096	1350	2450
4	26	25	12224	1686	1552	8986
6	27	1	10272	1372	2420	6480
6	27	2	7036	1116	1880	4040
6	24	3	6928	1672	1076	4180
6	23	4	3922	501	565	2856
6	12	5	2804	424	1156	1224
6	15	6	4272	996	1196	2080
6	11	7	4968	812	1636	2520

Appendix III-3. Continued.

UNIT	STANDNUM	PLOT	FLOORWT	LITTERWT	FERMWT	HUMUSWT
-----kg/ha-----						
6	21	8	5036	612	2444	1980
6	20	9	7676	1964	1724	3988
6	18	10	2932	324	1192	1416
6	10	11	4044	536	1280	2228
6	16	12	3036	440	1296	1300
6	9	13	3320	644	996	1680
6	8	14	3788	596	900	2292
6	1	15	4080	712	1068	2300
6	2	16	2900	596	776	1528
6	4	17	2208	108	1020	1080
6	5	18	2360	644	804	912
6	6	19	6184	1868	1324	2992
6	7	20	2508	1048	780	680
6	13	21	7764	584	5864	1316
6	23	22	4252	387	1009	2856
7	2	1	7260	1080	2940	3240
7	5	2	7821	1912	2663	3246
7	8	3	6364	1756	2420	2188
7	7	4	4312	1364	1508	1440
7	11	5	9168	1376	2628	5164
7	12	6	9732	1612	3280	4840
7	16	7	3520	796	1316	1408
7	19	8	4172	680	980	2512
7	18	9	10428	3444	2648	4336
7	39	10	5412	732	1592	3088
7	29	11	5176	1144	1744	2288
7	24	12	7028	1176	2344	3508
7	26	13	7032	1712	2140	3180
7	30	14	5752	768	1328	3656
7	27	15	2660	404	976	1280
7	49	16	4048	424	1460	2164
7	36	17	5024	1732	1700	1592
7	41	18	4728	1272	1388	2068
7	43	19	4035	457	838	2740
7	6	20	3364	712	1176	1476
7	4	21	3676	872	880	1924
7	2	22	5312	1960	1272	2080
7	2	23	3368	660	1176	1532
7	2	24	4924	1548	1304	2072
7	5	25	5884	1316	1472	3096
7	5	26	3740	932	1208	1600
7	15	27	2928	696	980	1252
7	10	28	4368	652	1672	2044
7	45	29	5544	1196	1488	2860
7	45	30	7804	1260	1828	4716
7	44	31	2632	580	900	1152
7	31	32	6284	2920	1556	1808
7	24	33	4276	1320	1036	1920
7	29	34	2856	504	980	1372
7	25	35	11988	776	3452	7760
7	23	36	4352	552	1628	2172
7	5	37	6092	1374	1472	3246

Appendix III-3. Continued.

UNIT	STANDNUM	PLOT	FLOORWT	LITTERWT	FERMWT	HUMUSWT
-----kg/ha-----						
7	43	38	5457	2133	584	2740
8	1	1	6460	1696	1976	2788
8	14	2	10032	1192	4116	4724
8	7	3	3248	836	960	1452
8	13	4	2592	1040	796	756
8	13	5	4504	1840	1152	1512
9	2	1	5436	1772	1784	1880
9	5	2	8036	1064	1984	4988
9	7	3	7680	1396	2204	4080
9	6	4	5852	1008	2084	2760
9	8	5	11616	1152	2276	8188

Appendix III-4. Woody fuel volume data.

UNIT	STANDNUM	PLOT	BOLEVOL	BRANCHVOL	VOLTL1	VOLTL10	VOLTL100
-----cubic meter/ha-----							
1	6	1	3.0	17.7	1.1	8.0	8.7
1	7	2	5.4	15.9	1.7	8.4	5.8
1	9	3	137.1	15.9	1.2	7.5	7.2
1	13	4	0.0	9.8	1.2	4.3	4.3
1	7	5	73.9	7.7	1.3	6.4	0.0
1	24	6	0.0	4.3	0.9	3.4	0.0
1	21	7	0.0	10.0	1.3	4.3	4.3
1	19	8	37.4	5.7	0.9	3.4	1.5
1	17	9	2.2	7.4	0.6	2.5	4.3
1	17	10	2.6	7.8	1.2	6.6	0.0
3	1	1	25.5	10.7	1.4	6.4	2.9
3	2	2	1.6	7.3	1.2	3.2	2.9
3	10	3	136.5	8.5	0.5	3.6	4.3
3	11	4	18.8	4.3	1.3	1.6	1.5
3	2	5	34.0	3.6	1.1	2.5	0.0
3	9	6	16.6	7.5	1.1	6.4	0.0
3	2	7	39.7	8.7	1.7	4.1	2.9
3	11	8	114.3	6.2	1.1	3.6	1.5
3	2	9	42.4	6.6	1.2	2.5	2.9
3	2	10	9.2	6.7	1.8	3.4	1.5
4	12	1	31.4	10.3	1.0	3.4	5.8
4	16	2	9.6	3.7	1.0	2.7	0.0
4	11	3	37.1	17.4	1.4	5.9	10.1
4	4	4	54.0	9.2	0.9	2.5	5.8
4	3	5	122.2	7.5	0.9	2.3	4.3
4	9	6	5.0	5.4	0.8	3.2	1.4
4	8	7	20.2	6.0	1.1	2.0	2.9
4	17	8	13.3	5.9	0.9	2.1	2.9
4	23	9	75.6	10.0	1.1	4.6	4.3
4	19	10	54.4	6.2	0.6	2.7	2.9
4	20	11	43.9	4.5	0.7	0.9	2.9
4	15	12	9.3	10.9	1.6	3.4	5.8
4	16	13	7.6	4.5	0.8	2.3	1.4
4	22	14	29.7	4.1	0.7	3.4	0.0
4	22	15	0.0	4.5	0.8	3.7	0.0
4	26	16	159.6	13.9	1.1	4.1	8.7
4	30	17	1.5	6.6	1.1	4.1	1.4
4	29	18	17.4	8.4	1.0	5.9	1.5
4	16	19	24.9	8.1	1.3	2.5	4.3
4	23	20	34.3	10.5	1.4	4.8	4.3
4	22	21	11.2	7.0	0.9	3.2	2.9
4	11	22	95.4	10.1	1.4	3.0	5.8
4	16	23	38.8	5.3	1.0	4.3	0.0
4	22	24	89.4	6.0	1.1	3.4	1.5
4	26	25	39.8	9.0	1.1	6.4	1.5
6	27	1	181.9	11.6	1.3	4.6	5.8
6	27	2	144.4	12.0	0.7	4.1	7.2
6	24	3	58.5	4.0	0.6	3.4	0.0
6	23	4	0.0	7.1	0.5	2.3	4.3
6	12	5	157.9	12.2	0.3	3.2	8.7
6	15	6	75.7	14.7	1.0	5.0	8.7
6	11	7	42.3	7.7	1.0	3.9	2.9

Appendix III-4. Continued.

UNIT	STANDNUM	PLOT	BOLEVOL	BRANCHVOL	VOLTL1	VOLTL10	VOLTL100
-----cubic meter/ha-----							
6	21	8	105.8	9.5	0.5	3.2	5.8
6	20	9	142.7	7.4	0.7	3.9	2.9
6	18	10	71.4	5.7	0.9	3.4	1.5
6	10	11	62.7	10.4	0.7	3.9	5.8
6	16	12	7.7	13.6	1.0	3.9	8.7
6	9	13	10.5	7.0	0.4	2.3	4.3
6	8	14	68.1	14.8	0.9	5.2	8.7
6	1	15	64.5	12.1	0.4	1.6	10.1
6	2	16	1.5	1.1	0.2	0.9	0.0
6	4	17	36.3	7.6	1.0	2.3	4.3
6	5	18	10.7	6.0	0.2	3.0	2.9
6	6	19	142.0	7.5	0.5	2.7	4.3
6	7	20	10.8	8.7	0.4	2.5	5.8
6	13	21	114.2	27.0	2.2	10.3	14.5
6	23	22	13.2	10.0	1.8	3.9	4.3
7	2	1	4.0	2.3	0.8	1.6	0.0
7	5	2	80.5	17.7	0.8	3.9	13.0
7	8	3	37.4	18.0	0.7	5.7	11.6
7	7	4	112.6	9.8	0.8	3.2	5.8
7	11	5	34.0	15.7	1.1	7.3	7.2
7	12	6	3.2	13.2	0.9	5.0	7.2
7	16	7	30.3	19.0	1.2	4.8	13.0
7	19	8	105.6	8.0	1.3	3.9	2.9
7	18	9	133.6	10.5	1.0	3.6	5.8
7	39	10	224.5	11.0	1.7	5.0	4.3
7	29	11	36.5	12.6	1.2	4.1	7.2
7	24	12	93.0	19.3	1.5	4.8	13.0
7	26	13	101.0	5.1	0.7	3.0	1.4
7	30	14	54.5	7.4	1.1	3.4	2.9
7	27	15	11.9	4.2	1.0	3.2	0.0
7	49	16	84.9	12.2	1.1	5.2	5.8
7	36	17	46.8	1.7	0.8	0.9	0.0
7	41	18	164.1	7.9	0.5	3.0	4.3
7	43	19	6.3	4.9	0.8	4.1	0.0
7	6	20	45.7	13.8	0.8	4.3	8.7
7	4	21	7.3	8.0	1.2	2.5	4.3
7	2	22	44.7	10.6	1.0	3.9	5.8
7	2	23	5.8	6.0	1.4	3.2	1.4
7	2	24	7.5	8.3	0.9	4.6	2.9
7	5	25	135.0	10.3	0.6	3.9	5.8
7	5	26	96.7	14.2	1.5	4.1	8.7
7	15	27	61.5	11.7	1.6	8.7	1.5
7	10	28	89.2	10.7	1.1	5.2	4.3
7	45	29	24.6	6.2	1.7	1.6	2.9
7	45	30	63.6	3.3	1.2	2.0	0.0
7	44	31	40.1	7.6	1.0	2.3	4.3
7	31	32	15.6	11.1	1.2	4.1	5.8
7	24	33	15.1	10.6	1.4	3.4	5.8
7	29	34	13.5	7.1	1.0	1.8	4.3
7	25	35	42.2	12.4	1.1	4.1	7.2
7	23	36	7.9	3.9	1.2	2.7	0.0
7	5	37	68.1	6.6	1.2	2.5	2.9

Appendix III-4. Continued.

UNIT	STANDNUM	PLOT	BOLEVOL	BRANCHVOL	VOLTL1	VOLTL10	VOLTL100
-----cubic meter/ha-----							
7	43	38	10.0	6.1	1.3	4.8	0.0
8	1	1	0.0	12.5	1.8	6.4	4.3
8	14	2	24.5	18.3	1.5	5.2	11.6
8	7	3	40.0	8.7	1.0	3.4	4.3
8	13	4	0.0	7.6	1.3	3.4	2.9
8	13	5	11.7	8.8	1.1	4.8	2.9
9	2	1	46.6	5.4	0.4	2.0	2.9
9	5	2	0.0	16.1	1.0	5.0	10.1
9	7	3	5.1	14.2	0.9	3.2	10.1
9	6	4	4.0	10.3	0.6	3.9	5.8
9	8	5	13.6	10.3	1.1	3.4	5.8

Appendix III-5. Fuel depth data.

UNIT	STANDNUM	PLOT	SRFDPTH	FLRDPH	LITDPH	FERDPH	HUMDPH
-----cm-----							
1	6	1	7	7	3	2	2
1	7	2	4	10	4	2	4
1	9	3	11	8	3	3	2
1	13	4	5	8	4	2	2
1	7	5	3	7	3	2	2
1	24	6	3	6	2	2	2
1	21	7	4	4	2	1	1
1	19	8	2	4	3	1	0
1	17	9	2	3	0	2	1
1	17	10	5	6	3	2	1
3	1	1	1	3	1	1	1
3	2	2	4	6	3	2	1
3	10	3	5	5	2	2	1
3	11	4	6	6	3	2	1
3	2	5	6	7	3	2	2
3	9	6	2	4	1	2	1
3	2	7	7	7	3	2	2
3	11	8	2	5	2	2	1
3	2	9	5	7	3	2	2
3	2	10	6	7	3	2	2
4	12	1	3	6	3	2	1
4	16	2	3	5	2	1	2
4	11	3	13	7	3	2	2
4	4	4	5	9	4	3	2
4	3	5	2	8	4	2	2
4	9	6	7	10	5	3	2
4	8	7	7	10	5	3	2
4	17	8	5	6	4	1	1
4	23	9	5	7	4	2	1
4	19	10	4	8	4	2	2
4	20	11	4	7	4	2	1
4	15	12	1	7	3	2	2
4	16	13	2	7	3	2	2
4	22	14	3	6	3	2	1
4	22	15	7	5	3	1	1
4	26	16	3	7	3	1	3
4	30	17	4	6	2	2	2
4	29	18	4	7	3	2	2
4	16	19	3	7	3	2	2
4	23	20	4	10	6	3	1
4	22	21	2	4	2	1	1
4	11	22	4	9	5	2	2
4	16	23	4	6	2	2	2
4	22	24	3	5	3	1	1
4	26	25	5	10	5	2	3
6	27	1	13	13	6	3	4
6	27	2	15	13	7	3	3
6	24	3	4	9	4	2	3
6	23	4	5	5	2	1	2
6	12	5	4	8	4	2	2
6	15	6	3	7	3	2	2

Appendix III-5. Continued.

UNIT	STANDNUM	PLOT	SRFDPTH	FLRDPTH	LITDPTH	FERDPTH	HUMDPTH
-----cm-----							
6	11	7	6	8	4	2	2
6	21	8	4	8	3	3	2
6	20	9	9	8	3	2	3
6	18	10	4	6	2	2	2
6	10	11	3	7	4	2	1
6	16	12	25	6	3	2	1
6	9	13	4	7	4	2	1
6	8	14	7	8	5	1	2
6	1	15	6	6	4	1	1
6	2	16	4	6	3	1	2
6	4	17	4	3	1	1	1
6	5	18	5	7	4	2	1
6	6	19	10	9	5	2	2
6	7	20	5	6	3	2	1
6	13	21	6	10	5	4	1
6	23	22	6	6	3	1	2
7	2	1	8	8	3	3	2
7	5	2	10	9	4	2	3
7	8	3	8	6	1	4	1
7	7	4	7	8	4	2	2
7	11	5	5	10	3	3	4
7	12	6	5	10	4	3	3
7	16	7	5	6	2	2	2
7	19	8	4	7	3	2	2
7	18	9	4	11	4	3	4
7	39	10	5	7	2	2	3
7	29	11	8	8	3	2	3
7	24	12	16	6	2	2	2
7	26	13	6	8	3	2	3
7	30	14	5	7	2	2	3
7	27	15	2	5	1	2	2
7	49	16	4	4	1	1	2
7	36	17	3	6	3	2	1
7	41	18	4	6	2	3	1
7	43	19	3	7	3	2	2
7	6	20	4	5	2	2	1
7	4	21	5	6	3	1	2
7	2	22	10	9	5	2	2
7	2	23	3	5	2	2	1
7	2	24	2	7	3	2	2
7	5	25	8	6	2	2	2
7	5	26	5	5	3	1	1
7	15	27	5	5	2	2	1
7	10	28	59	7	3	2	2
7	45	29	3	9	4	3	2
7	45	30	8	8	3	2	3
7	44	31	6	4	2	1	1
7	31	32	3	9	5	2	2
7	24	33	2	6	3	2	1
7	29	34	15	4	1	1	2
7	25	35	4	9	2	3	4

Appendix III-5. Continued.

UNIT	STANDNUM	PLOT	SRFDPTH	FLRDPTH	LITDPTH	FERDPTH	HUMDPTH
-----CM-----							
7	23	36	4	6	2	2	2
7	5	37	3	9	4	2	3
7	43	38	4	6	3	1	2
8	1	1	12	12	6	3	3
8	14	2	10	14	8	3	3
8	7	3	8	10	6	2	2
8	13	4	7	9	5	4	0
8	13	5	4	5	3	1	1
9	2	1	4	8	4	2	2
9	5	2	4	10	4	3	3
9	7	3	7	13	6	3	4
9	6	4	5	9	5	2	2
9	8	5	4	14	6	3	5

Appendix IV. Location maps of fuel inventory plots for each unit of Richmond National Battlefield Park, Virginia. Lines within cover types signify a change in stand age that was noted from the aerial photo and included in the Geographic Information System files, from which these maps were generated.

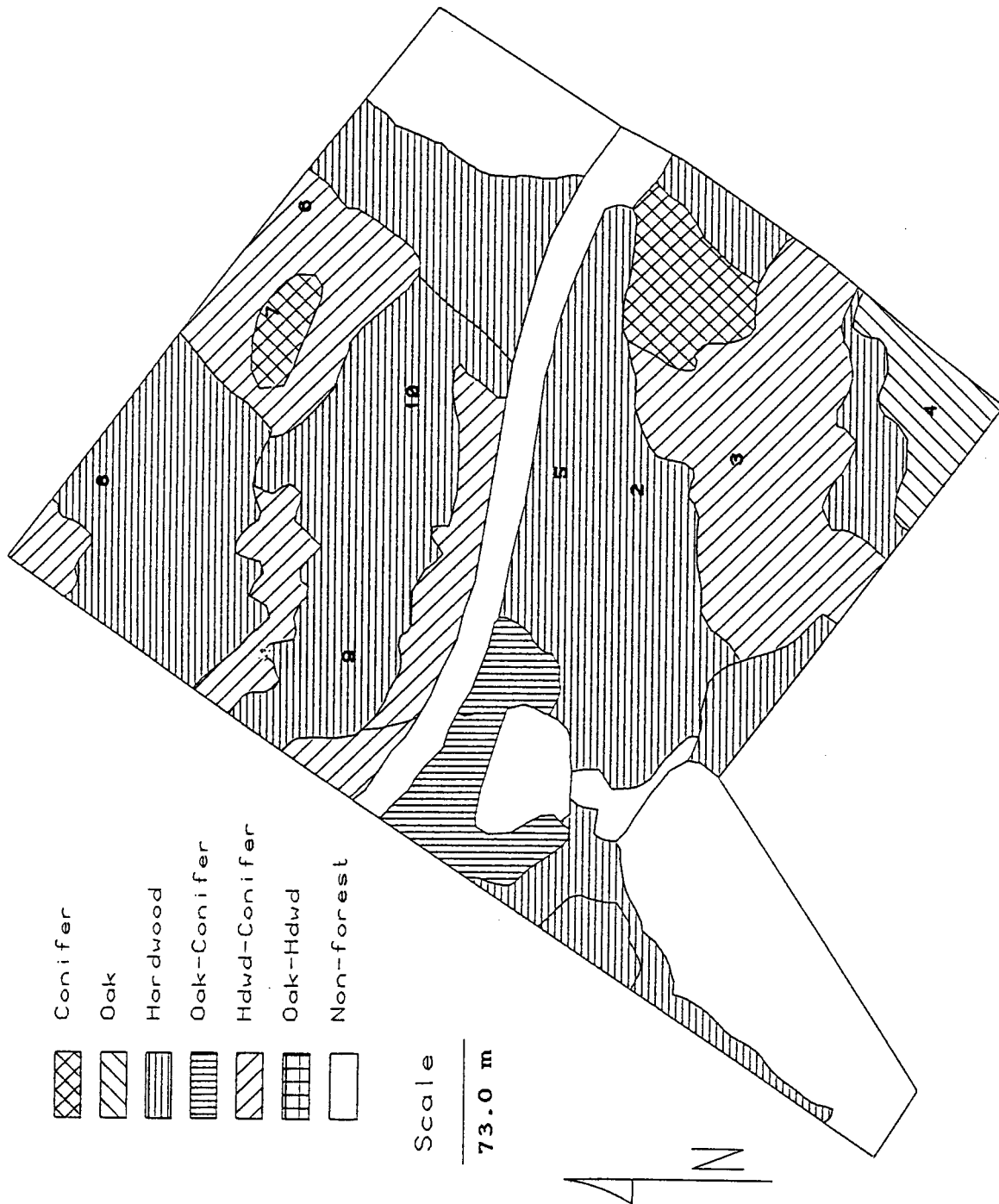


Figure A-IV-1. Forest cover types and plots of Chickahominy Bluff, RICH, Virginia.

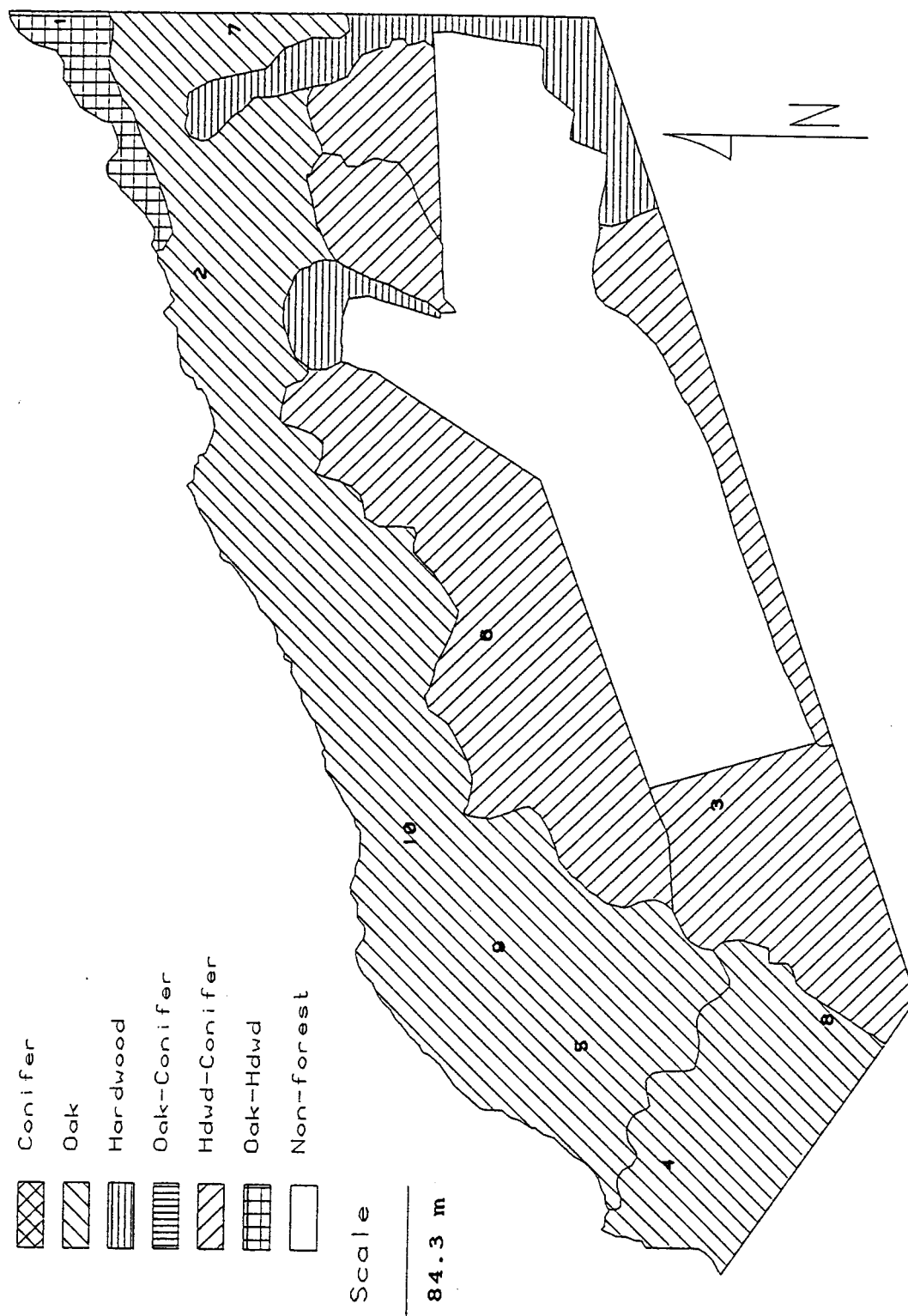


Figure A-IV-2. Forest cover types and plots of Watt House, RICH, Virginia.

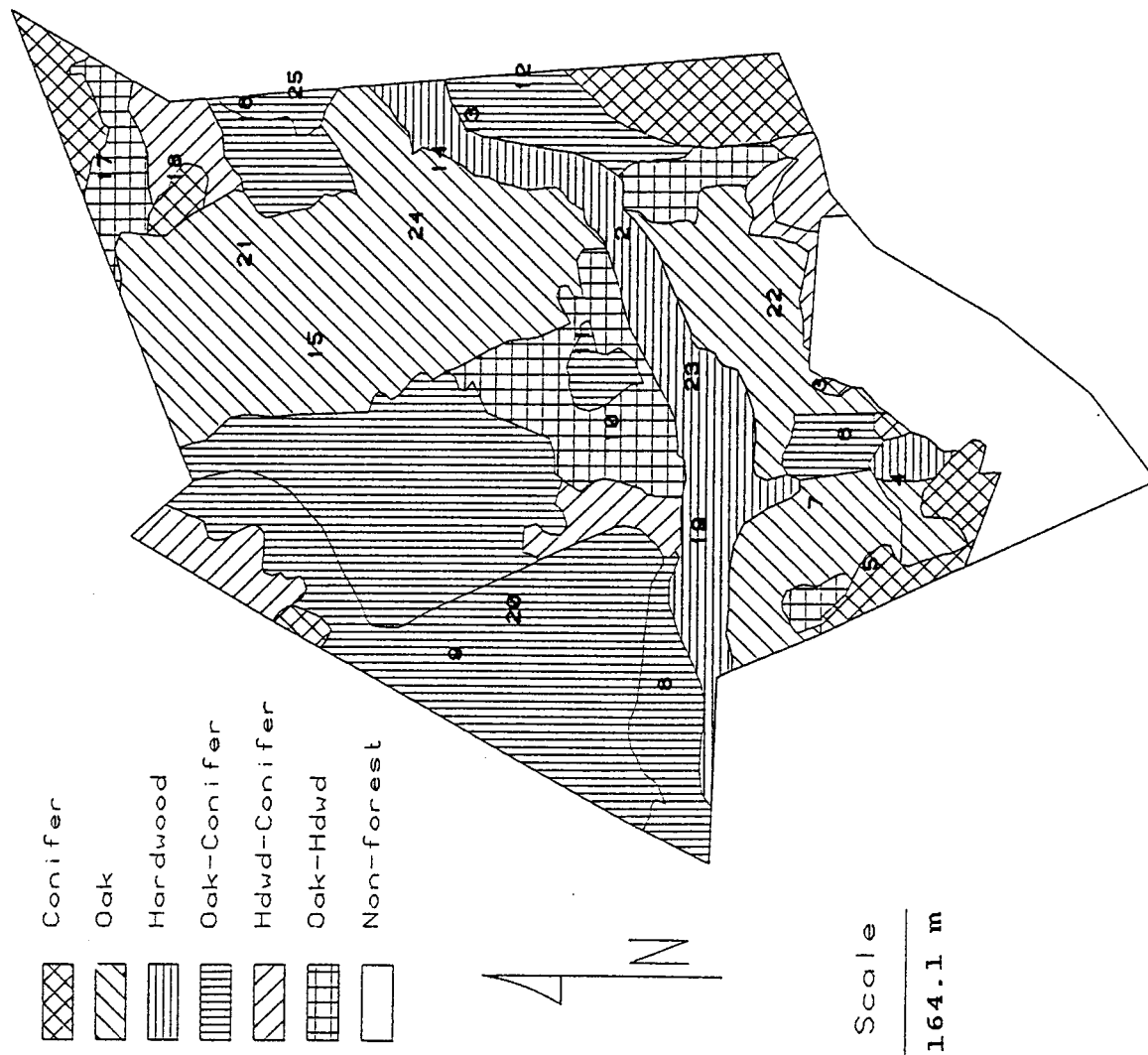


Figure A-IV-3. Forest cover types and plots of Cold Harbor, RICH, Virginia.

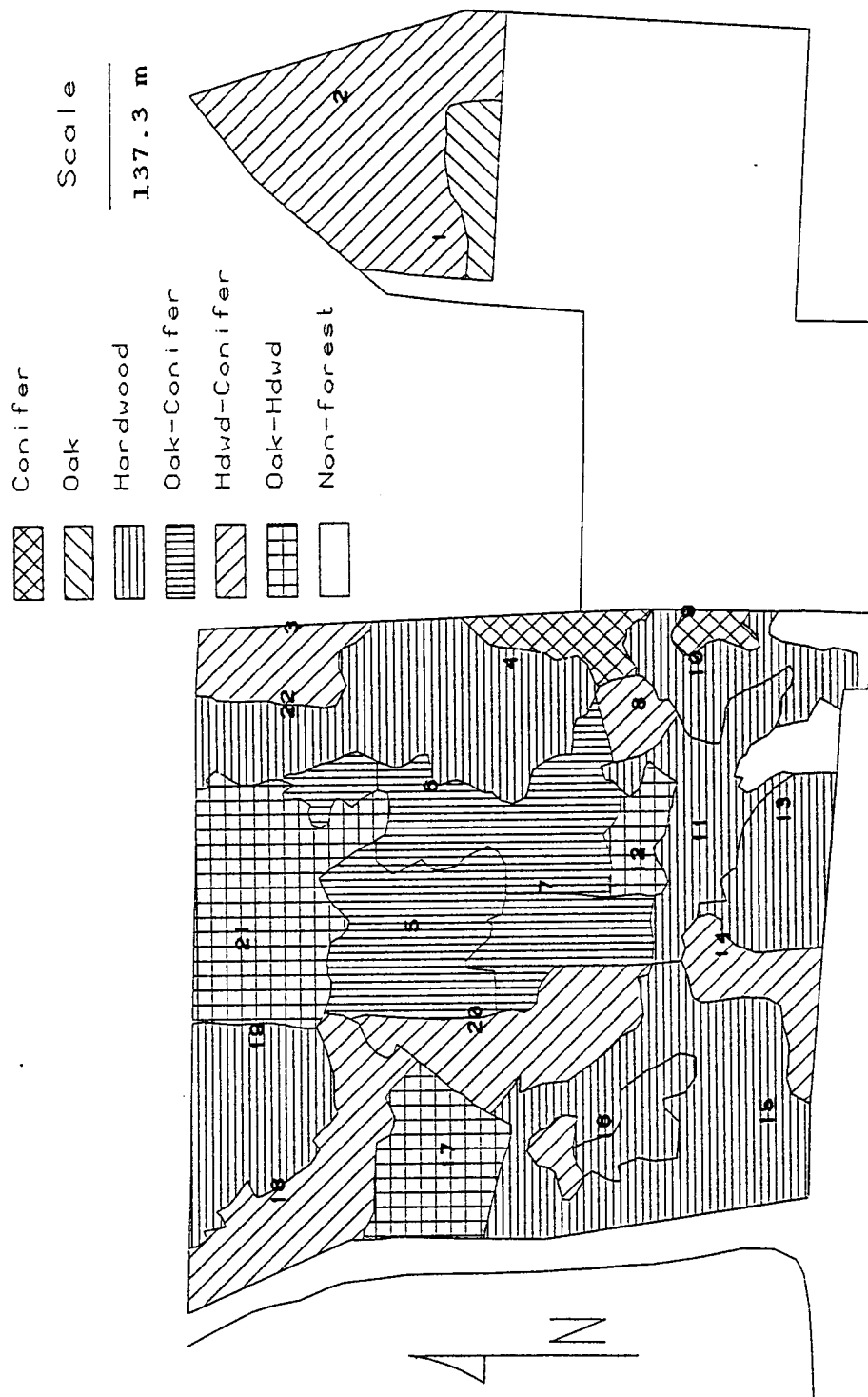


Figure A-IV-4. Forest cover types and plots of Malvern Hill, RICH, Virginia.

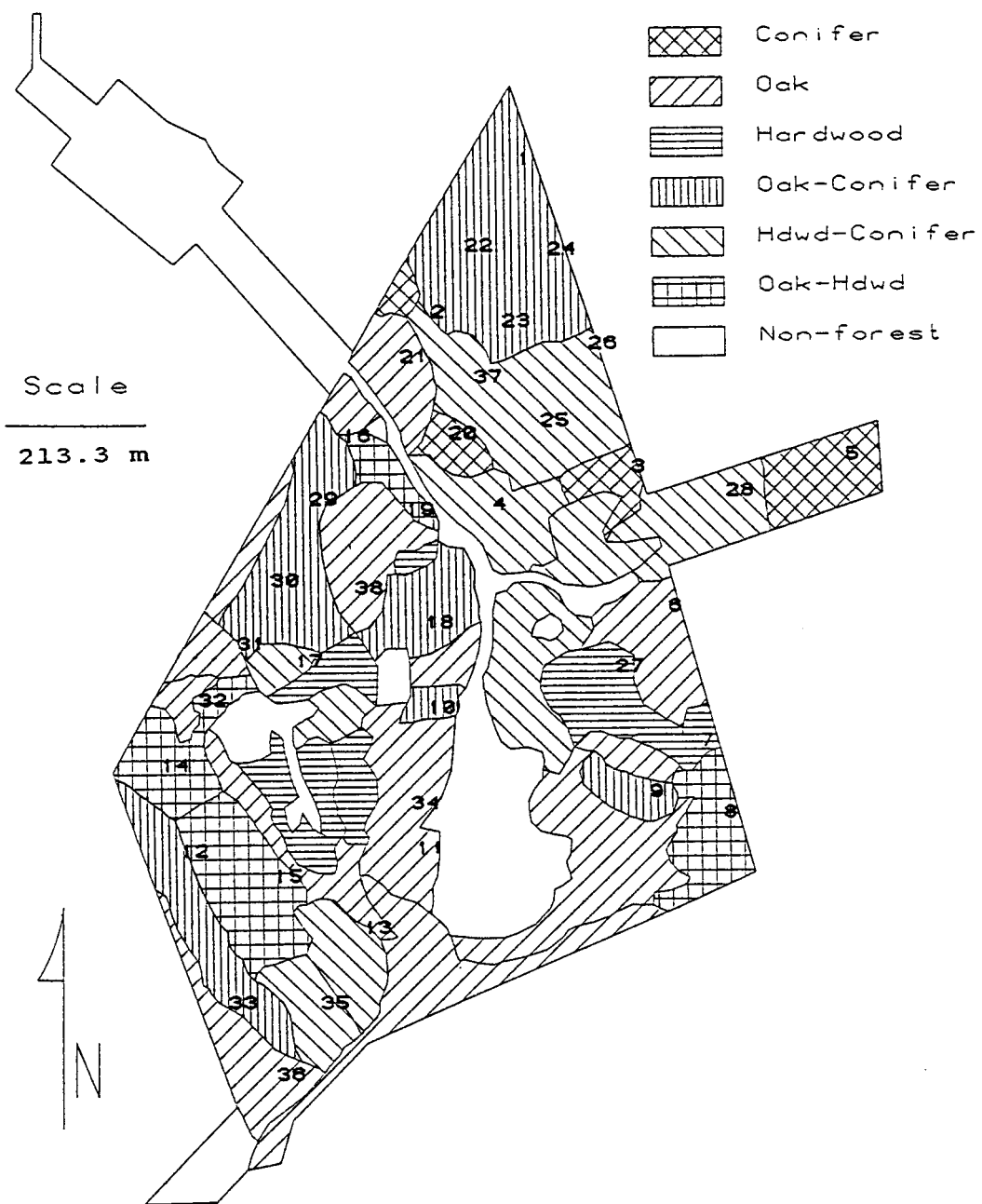


Figure A-IV-5. Forest cover types and plots of Fort Harrison, RICH, Virginia.

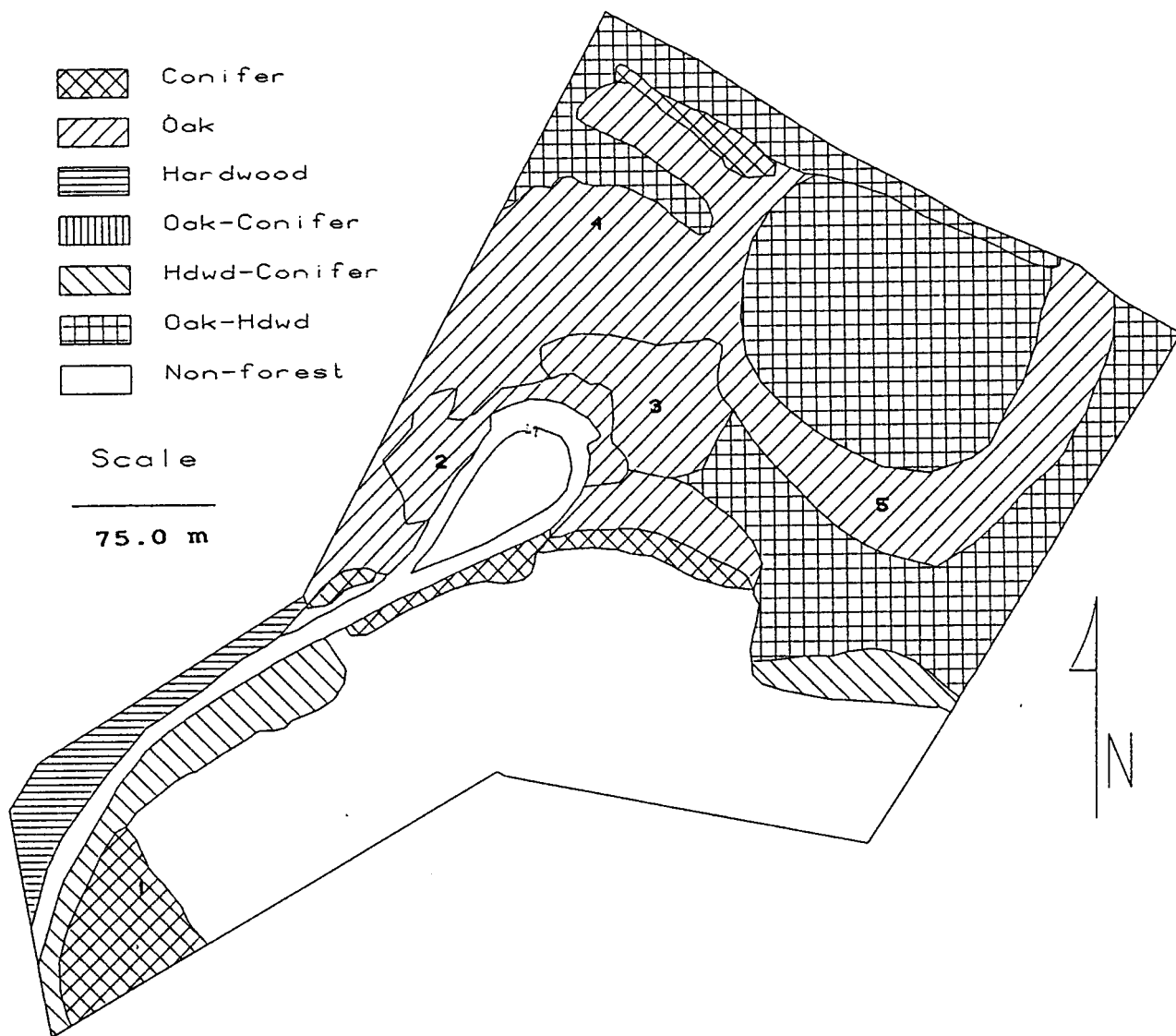


Figure A-IV-6. Forest cover types and plots of Drewry's Bluff, RICH, Virginia.

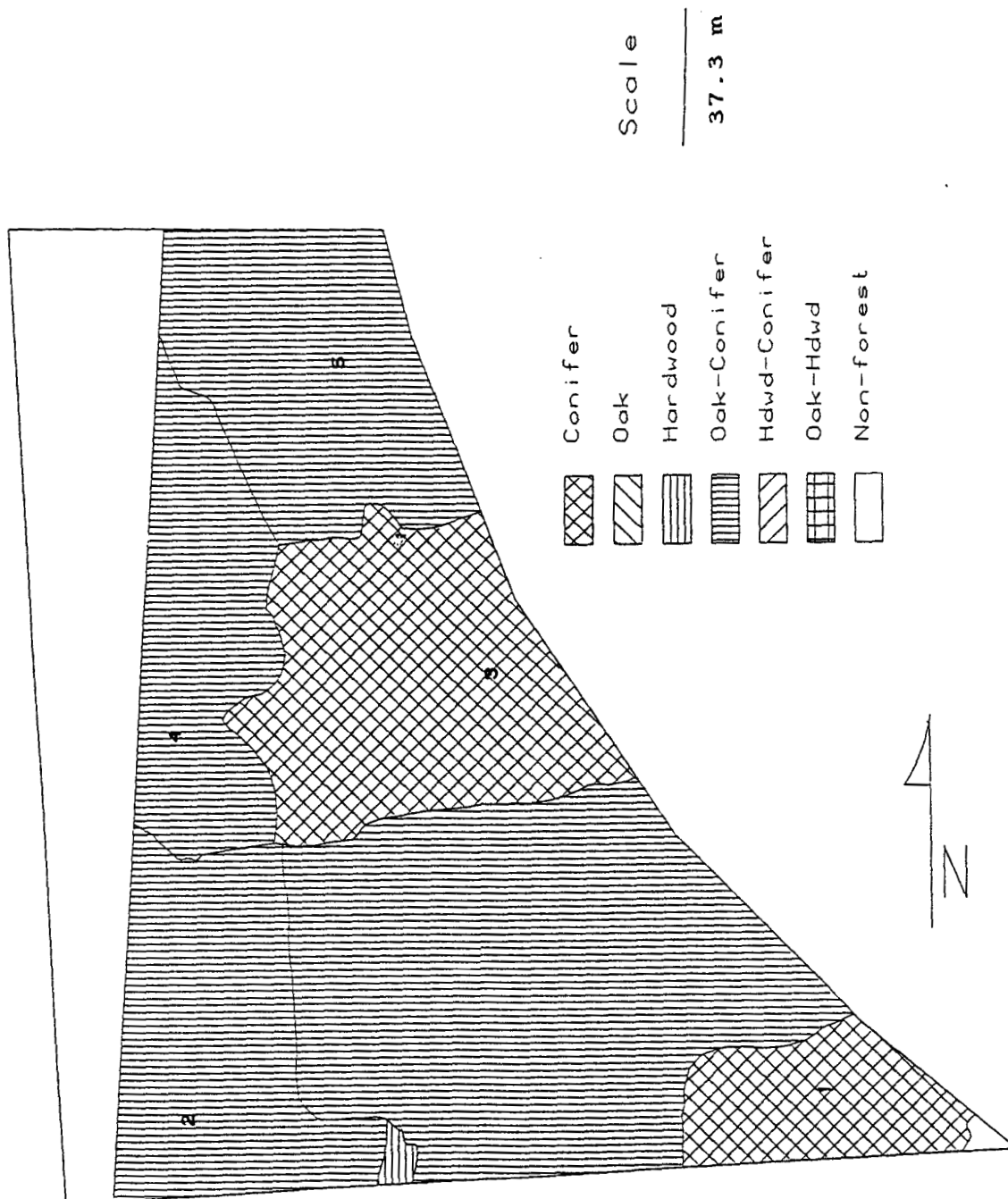


Figure A-IV-7. Forest cover types and plots of Parker's Battery, RICH, Virginia.

Appendix V. Calculation of Forest Site Quality Index (FSQI). A higher index value represents better site quality.

$$\text{FSQI} = \text{Azimuth value} + \text{Percent Slope value} + \text{Slope Position value.}$$

Azimuth (°)	Percent Slope	Value	Slope Position	Value
196-260	≥ 60	1	Shoulder	1
166-195	45-59	2	High	2
261-280			Backslope Mid-	2.5
			Lower	3
146-165	30-44	3	Summit	3
281-340				
0- 20	15-29	4	Footslope	4
341-360				
81-145	0-14	5	Toe, terrace, and floodplain	5
21- 81		6		

Examples:

$$\text{FSQI} = \text{Azimuth value} + \text{Percent Slope value} + \text{Slope Position value}$$

1) FSQI of an east-facing mountain cove with moderately steep slope:

Azimuth -- 90° Azimuth value = 5
Percent Slope -- 20% Percent Slope value = 4
Slope Position -- Footslope Slope Position value = 4

$$\text{FSQI} = 5 + 4 + 4 = 13$$

2) FSQI of an very steep, southwest-facing shoulder of a mountain:

Azimuth -- 225° Azimuth value = 1
Percent Slope -- 45% Percent Slope value = 2
Slope Position --Shoulder Slope Position value = 1

$$\text{FSQI} = 1 + 2 + 1 = 4$$

Appendix VI. Descriptions of the vegetation and typical sites of the six forest cover types sampled at Richmond National Battlefield Park, Virginia.

Conifer Cover Type

The conifer cover type included stands with a range of ages and conditions, from young plantations, to middle-aged stands with signs of pine beetle activity, to older, healthy ones. Pine species comprised at least 50% of the basal area of these stands (Table A-VI-1). Most of these stands are beginning the middle stage of secondary succession from old-fields to the oak-hickory-pine climax, with deciduous species increasing in importance; Switzer et al. (1979) suggested that the early stage ends when pines drop below 80% of the basal area. The average diameter breast height (DBH) was 32.8 cm for the pines, 11.0 cm for oaks, and 14.9 cm for other hardwoods. The age of the stands ranged from 17 to 95 years at breast height (Table 1). These stands were found on a variety of slope positions and aspects.

Oak-Conifer Cover Type

The 23 stands within the oak-conifer cover type contained from 20% to 50% live pine basal area (Table A-VI-2). The average oak DBH was 34.6 cm, and the average height was 20.6 m. The average DBH of the mixed hardwoods was 14.9 cm, and they averaged 11.4 m tall. Pine bark beetle was found in a majority of these stands. This cover type was found on a variety of slope positions and aspects within RICH.

Mixed Hardwood-Conifer Cover Type

The 11 mixed hardwood-conifer stands were those with 20 to 50% live pine basal area within mixed hardwood stands (Table A-VI-3). The mixed hardwoods averaged 19.9 cm DBH and ranged from 13.0 to 27.4 m in height. The average DBH and height of the pines were 38.9 cm and 24.3 m, respectively. Pine bark beetle activity was observed on a majority of these stands with pines over 50 years of age. This forest type was found on all slope positions and aspects.

Oak Cover Type

The 26 stands in the oak cover type had a majority of oak live basal area in the overstory (Table A-VI-4). The average oak DBH was 42.1 cm, and the average DBH of the other hardwoods was 22.1 cm. This cover type rarely occurred in bottoms, floodplains, or draws; it was found mostly on upland plateaus and sideslopes, on all aspects.

Mixed Hardwood Cover Type

The 18 stands in the mixed hardwood cover type had a majority of the live basal area comprised of mixed hardwoods (Table A-VI-5). The average DBH of the mixed hardwoods was 28.1 cm. These stands were in various stages of development, from pole-sized to sawtimber size, yet all of them had sign of stem disease on approximately one-half of the trees. These stands were located primarily on floodplains and toeslopes, and on all aspects.

Oak-Mixed Hardwood Cover Type

The 17 stands in the oak-mixed hardwood cover type had a majority of the live basal area from a combination of species typically found in each of the last two cover types (Table A-VI-6). The oaks had an average DBH of 38.2 cm. The other hardwoods had an average DBH of 33.8 cm. This cover type occurred at all slope positions and aspects. Pine bark beetle was obvious in one of the stands with pines still dominant. The downed boles were not examined for cause of death. All of the stands without pine had stems with disease in them; root rot and insects were occasionally noted also.

Table A-VI-1. Average forest overstory stand information for the conifer cover type at Richmond National Battlefield Park, Virginia (n=13 stands).

Species	Basal Area (m ² /ha)		Density (stems/ha)		Frequency (% of stands)	Importance Value (%)
	Live	Dead	Live	Dead		
<i>Acer rubrum</i>	1.15	0.00	105	0	38	8
<i>Carya tomentosa</i>	0.19	0.00	4	0	8	1
<i>Ilex opaca</i>	0.19	0.00	50	0	8	2
<i>Liquidambar styraciflua</i>	2.50	0.00	144	0	46	12
<i>Liriodendron tulipifera</i>	0.38	0.00	9	0	15	2
<i>Nyssa sylvatica</i>	0.19	0.00	16	0	8	1
<i>Pinus echinata</i>	1.15	0.00	19	0	15	4
<i>Pinus taeda</i>	20.19	2.69	462	129	100	46
<i>Pinus virginiana</i>	0.00	0.19	0	8	0	0
<i>Quercus alba</i>	0.19	0.00	3	0	8	1
<i>Quercus falcata</i>	1.54	0.00	171	0	31	10
<i>Quercus palustris</i>	0.19	0.00	16	0	7	1
<i>Quercus rubra</i>	0.19	0.00	32	0	8	2
<i>Quercus stellata</i>	0.19	0.00	2	0	8	1
<i>Quercus velutina</i>	1.92	0.19	80	1	31	7
Total	30.16	3.07	1113	138		

Table A-VI-2. Average forest overstory stand information for the oak-conifer cover type at Richmond National Battlefield Park, Virginia (n=23 stands).

Species	Basal Area (m ² /ha)		Density (stems/ha)		Frequency (% of stands)	Importance Value (%)
	Live	Dead	Live	Dead		
<i>Acer rubrum</i>	0.22	0.00	15	0	9	2
<i>Cornus florida</i>	0.43	0.11	71	19	9	4
<i>Carya glabra</i>	0.11	0.00	23	0	4	1
<i>Carya tomentosa</i>	0.54	0.11	19	2	17	3
<i>Diospyros virginiana</i>	0.11	0.00	49	0	4	2
<i>Ilex opaca</i>	0.11	0.00	20	0	4	1
<i>Juniperus virginiana</i>	0.11	0.00	41	0	4	2
<i>Liquidambar styraciflua</i>	1.74	0.11	102	7	48	10
<i>Liriodendron tulipifera</i>	0.33	0.00	5	0	9	1
<i>Nyssa sylvatica</i>	0.22	0.00	68	0	9	4
<i>Pinus echinata</i>	0.43	0.00	5	0	17	2
<i>Pinus taeda</i>	7.45	2.45	119	27	100	23
<i>Pinus virginiana</i>	0.11	0.00	10	0	4	1
<i>Quercus alba</i>	3.37	0.11	55	6	48	11
<i>Quercus coccinea</i>	0.38	0.11	11	1	17	2
<i>Quercus falcata</i>	3.64	0.00	117	0	57	14
<i>Quercus phellos</i>	0.43	0.00	30	0	9	2
<i>Quercus stellata</i>	0.43	0.33	9	18	4	1
<i>Quercus velutina</i>	2.99	0.65	136	68	52	13
Total	23.15	3.98	905	148		

Table A-VI-3. Average forest overstory stand information for the mixed hardwoods-conifer cover type at Richmond National Battlefield Park, Virginia (n=11 stands).

Species	Basal Area (m ² /ha)		Density (stems/ha)		Frequency (% of stands)	Importance Value (%)
	Live	Dead	Live	Dead		
<i>Acer rubrum</i>	3.86	0.00	312	0	64	16
<i>Cornus florida</i>	0.45	0.00	140	0	18	5
<i>Fagus americana</i>	0.23	0.00	6	0	9	1
<i>Juniperus virginiana</i>	0.23	0.23	54	28	18	2
<i>Liquidambar styraciflua</i>	8.41	0.45	441	49	82	26
<i>Liriodendron tulipifera</i>	3.18	0.00	36	0	27	6
<i>Nyssa sylvatica</i>	1.48	0.00	132	0	27	7
<i>Pinus taeda</i>	10.00	3.75	88	48	100	20
<i>Quercus alba</i>	0.12	0.00	1	0	9	1
<i>Quercus falcata</i>	0.91	0.00	31	0	18	3
<i>Quercus phellos</i>	0.23	0.12	1	1	9	1
<i>Quercus rubra</i>	0.23	0.00	51	0	9	2
<i>Quercus velutina</i>	0.68	0.00	52	0	18	3
<i>Quercus spp.</i>	0.00	0.12	0	0	0	0
<i>Ulmus americana</i>	0.91	0.00	44	0	18	3
<i>Ulmus rubra</i>	0.45	0.00	28	0	9	2
Total	31.37	4.67	1417	126		

Table A-VI-4. Average forest overstory stand information for the oak cover type at Richmond National Battlefield Park, Virginia (n=26 stands).

Species	Basal Area (m ² /ha)		Density (stems/ha)		Frequency (% of stands)	Importance Value (%)
	Live	Dead	Live	Dead		
<i>Acer rubrum</i>	0.29	0.00	24	0	12	2
<i>Carpinus caroliniana</i>	0.10	0.00	15	0	4	1
<i>Cornus florida</i>	0.10	0.00	14	0	4	1
<i>Carya glabra</i>	0.29	0.00	14	0	12	2
<i>Carya tomentosa</i>	0.92	0.00	63	0	23	5
<i>Fagus grandifolia</i>	1.54	0.00	44	0	23	5
<i>Ilex opaca</i>	1.44	0.00	222	0	42	13
<i>Juniperus virginiana</i>	0.09	0.00	0	0	1	0
<i>Liquidambar styraciflua</i>	1.30	0.15	72	4	42	7
<i>Liriodendron tulipifera</i>	1.40	0.00	25	0	35	5
<i>Nyssa sylvatica</i>	0.48	0.00	53	0	12	3
<i>Pinus echinata</i>	0.00	0.10	0	1	0	0
<i>Pinus taeda</i>	0.87	0.48	9	5	23	3
<i>Pinus virginiana</i>	0.10	0.00	1	0	4	0
<i>Quercus alba</i>	9.96	0.63	158	29	92	25
<i>Quercus coccinea</i>	1.01	0.10	26	4	19	4
<i>Quercus falcata</i>	2.21	0.24	38	2	50	8

Table A-VI-4. Continued.

Species	Basal Area (m ² /ha)		Density (stems/ha)		Frequency (% of stands)	Importance Value (%)
	Live	Dead	Live	Dead		
<i>Quercus prinus</i>	0.10	0.00	9	0	4	1
<i>Quercus rubra</i>	1.54	0.10	10	0	19	4
<i>Quercus stellata</i>	0.24	0.05	3	0	12	1
<i>Quercus velutina</i>	3.22	0.58	52	36	42	9
<i>Quercus</i> spp.	0.00	0.10	0	27	0	0
Total	27.20	2.53	852	109		

Table A-VI-5. Average forest overstory stand information for the mixed hardwoods cover type at Richmond National Battlefield Park, Virginia (n=18 stands).

Species	Basal Area (m ² /ha)		Density (stems/ha)		Frequency (% of stands)	Importance Value (%)
	Live	Dead	Live	Dead		
<i>Acer rubrum</i>	6.04	0.28	220	18	72	19
<i>Carpinus caroliniana</i>	0.14	0.00	8	0	6	1
<i>Cornus florida</i>	0.14	0.07	28	6	16	1
<i>Carya tomentosa</i>	0.42	0.00	40	0	17	3
<i>Diospyros virginiana</i>	0.14	0.00	6	0	6	1
<i>Fagus grandifolia</i>	0.07	0.00	17	0	6	1
<i>Ilex opaca</i>	0.56	0.00	110	0	11	5
<i>Juniperus virginiana</i>	0.21	0.14	21	17	11	2
<i>Liquidambar styraciflua</i>	13.82	0.14	327	15	89	32
<i>Liriodendron tulipifera</i>	3.96	0.42	48	3	56	10
<i>Magnolia virginiana</i>	0.00	0.14	0	9	0	0
<i>Nyssa sylvatica</i>	1.88	0.07	73	0	28	6
<i>Prunus avium</i>	0.14	0.00	3	0	6	0
<i>Pinus taeda</i>	1.39	0.83	9	24	44	5
<i>Quercus alba</i>	0.21	0.28	6	34	11	1
<i>Quercus coccinea</i>	0.14	0.00	1	0	6	0
<i>Quercus falcata</i>	1.25	0.00	3	0	28	3

Table A-VI-5. Continued.

Species	Basal Area (m ² /ha)		Density (stems/ha)		Frequency (% of stands)	Importance Value (%)
	Live	Dead	Live	Dead		
<i>Quercus phellos</i>	0.42	0.00	4	0	11	1
<i>Quercus velutina</i>	0.21	0.00	17	0	6	1
<i>Ulmus americana</i>	0.14	0.00	10	0	6	1
<i>Ulmus rubra</i>	0.97	0.00	24	0	28	4
Total	32.25	2.37	975	126		

Table A-VI-6. Average forest overstory stand information for the oak-mixed hardwoods cover type at Richmond National Battlefield Park, Virginia (n=17 stands).

Species	Basal Area (m ² /ha)		Density (stems/ha)		Frequency (% of stands)	Importance Value (%)
	Live	Dead	Live	Dead		
<i>Acer rubrum</i>	1.47	0.15	66	10	35	6
<i>Carya glabra</i>	0.29	0.00	2	0	12	1
<i>Carya tomentosa</i>	0.88	0.00	24	0	29	4
<i>Cornus florida</i>	0.29	0.00	85	0	12	4
<i>Fagus grandifolia</i>	0.44	0.00	2	0	12	1
<i>Ilex opaca</i>	1.18	0.00	104	0	24	7
<i>Juniperus virginiana</i>	0.15	0.15	0	9	6	1
<i>Liquidambar styraciflua</i>	3.53	0.00	243	0	53	17
<i>Liriodendron tulipifera</i>	6.32	0.00	41	0	65	13
<i>Nyssa sylvatica</i>	0.74	0.00	12	0	24	3
<i>Pinus taeda</i>	0.88	0.15	9	2	35	3
<i>Quercus alba</i>	4.56	0.59	91	27	76	13
<i>Quercus coccinea</i>	0.44	0.00	6	0	18	2
<i>Quercus falcata</i>	1.32	0.00	41	0	41	6
<i>Quercus phellos</i>	0.15	0.00	1	0	6	1
<i>Quercus rubra</i>	0.57	0.00	4	0	15	2
<i>Quercus stellata</i>	0.38	0.00	3	0	15	2
<i>Quercus velutina</i>	3.26	0.00	141	0	62	13
<i>Ulmus alata</i>	0.19	0.00	5	0	8	1
Total	28.08	1.19	874	49		

