NATIONAL PARK SERVICE

RESEARCH/RESOURCES MANAGEMENT REPORT SER-73

The Effect of the Southern Pine Beetle on Fuel Loading in Yellow Pine Forests of Great Smoky Mountains National Park

United States Department of the Interior

National Park Service
Southeast Region

The Research/Resources Management Series of the Natural Science and Research Division, National Park Service, Southeast Regional Office, is the established in-house medium for distributing scientific information to park Superintendents, resource management specialists, and other National Park Service personnel in the parks of the Southeast Region. The papers in the Series also contain information potentially useful to other Park Service areas outside the Southeast Region and may benefit external (non-NPS) researchers working within units of the National Park System. The Series provides for the retention of research information in the biological, physical, and social sciences and makes possible more complete in-house evaluation of internal research, technical, and consultant reports.

The Series includes:

1. Research reports which directly address resource management problems in the parks.

2. Papers which are primarily literature reviews and/or bibliographies of existing information relative to park resources or resource management problems.

3. Presentations of basic resource inventory data.

4. Reports of contracted scientific research studies funded or supported by the National Park Service.

5. Other reports and papers considered compatible to the Series, including results of applicable university or independent research relating to the preservation, protection, and management of resources administered by the National Park Service.

Southeast Regional Research/Resources Management Reports are produced by the Natural Science and Research Division, Southeast Regional Office. Copies may be obtained from:

National Park Service
Southeast Regional Office
Natural Science and Research Division
75 Spring Street, S.W.
Atlanta, Georgia 30303

THE EFFECT OF THE SOUTHERN PINE BEETLE ON FUEL LOADING IN YELLOW PINE FORESTS OF GREAT SMOKY MOUNTAINS NATIONAL PARK

by N. S. Nicholas and P. S. White

NATIONAL PARK SERVICE - Southeast Region

Research/Resources Management Report SER-73

Uplands Field Research Laboratory
Great Smoky Mountains National Park
Route 2, Box 260
Gatlinburg, Tennessee 37738

December 1984

UNITED STATES DEPARTMENT OF THE INTERIOR
NATIONAL PARK SERVICE

Nicholas, N. S. and P. S. White. 1984. The Effect of the Southern Pine Beetle on Fuel Loading in Yellow Pine Forests of Great Smoky Mountains National Park. U. S. Department of the Interior, National Park Service, Research/Resources Management Report SER-73. 31 pp.

ACKNOWLEDGMENTS

Nat Kuykendall, of the Denver Service Center of the National Park Service, graciously allowed the use of his maps on beetle kills. Craig Fithian, of the Applied Mathematics Department of Cornell University, assisted in writing the program PARK.FUE. Gregory Mueller assisted with all fieldwork and data entry. We thank Chris Eagar, Mark MacKenzie, Charlotte Pyle, Jim Wood, Mark Harmon, and two anonymous reviewers for critical reading of this manuscript.

ABSTRACT

The southern pine beetle (Dendroctonus frontalis Zimm.), a native pest that periodically attacks yellow pine stands in the Southeast, last infested Great Smoky Mountains National Park between 1967 and 1977. Heavy and synchronous mortality of mature canopy pine trees has resulted in the accumulation of organic debris in these stands. During outbreaks, dead trees tend to be concentrated in so-called hot spots. We documented organic fuels in such beetle hot spots and contrasted fuels between these stands and pine stands unaffected or minimally affected by the recent beetle outbreak. Because elevation and topographic exposure both affect organic production and decay (and hence fuel standing crop), we included these factors in our blocked sampling design. Two infestation levels, three elevation classes, and four topographic exposure classes were used, resulting in 22 cells and 66 fuel inventories (3 replicates per cell). Analysis of variance showed that infestation history was the most important influence on all the organic pools quantified except soil organic depth. Total volume of wood debris was three times higher in infested (110.3 m^3/ha) versus uninfested stands (30.6 m^3/ha). Woody debris weights were estimated to be four times higher in former hot spots (49.6 metric tons/ha) than in uninfested stands (12.3 metric tons/ha) and were among the highest values reported for Great Smoky Mountains National Park. In infested stands, standing dead basal area and twig volume increased with elevation and exposure. Bole volume and total wood volume declined with elevation and tended to be highest on exposed sites at low to mid-elevations. These data are part of an ongoing effort to inventory and map the park's fire fuels.

TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

INTRODUCTION

The southern pine beetle (*Dendroctonus frontalis* Zimm.) periodically infests pine forests of the southeastern United States, including those of Great Smoky Mountains National Park (GRSM) and other National Parks. This beetle is considered one of the most destructive insects in eastern commercial forests and is a pest on yard and landscape trees as well (Baker 1972). The southern pine beetle is native to the region and has been a long-term component of wilderness ecosystem dynamics. Because the beetle causes heavy and relatively synchronous tree mortality, the effect of the beetle on fuel loadings has been a primary managerial concern in natural ecosystems. The energy potential of wildfire and thus fire intensity are directly proportional to fuel loading mass (Martin et al. 1979).

The objective of this study was to quantify organic matter pools in infested and uninfested pine forests in GRSM. Harmon (1980b) had previously sampled fuels in a variety of forest types in GRSM but had noted the need for more work in beetle-disturbed stands. Our sampling was organized around stands affected by the most recent beetle outbreak in GRSM, which ended in 1977. Our study areas were largely based on stands used by Kuykendall (1978) in an assessment of beetle effects on stand composition. Because elevation and topographic situation (i.e., slope position and exposure) also affect organic matter production and decay, we included these factors in our blocked sampling design. By definition, fuel consists of both living and dead organic matter (Martin et al. 1979). However, most resource managers are concerned with "available fuels"--those that are most likely to contribute to fire intensity. Thus our fuel inventory included the main fuels that are consumed during fires: soil organic layers, dead and downed twigs and boles, and standing dead boles.

The object of our descriptive work was to test the hypothesis that stands previously infested by the southern pine beetle would have higher fuel loadings than uninfested stands. We also sought to quantify the influences of site factors (elevation and topography) on standing crop fuels and to compare the fuel loadings we documented to published descriptions from other sites. The data published in this report will be used in a remote sensing project to construct a forest fuels map for GRSM.

LITERATURE REVIEW

GRSM Pine Forests. Pines achieve dominance in three ecological situations in GRSM: on dry sites (south to west exposures, on upper slopes and ridges) from 300 m to 1,500 m, on old fields from 300 m to 1000 m, and in stream gorges and mesic flats from 300 m to 900 m (this is the most restricted of the types and the only one dominated by *Pinus strobus* (white pine) (Whittaker 1956, Kuykendall 1978, DeYoung 1979, Harmon 1980b). These three situations are described briefly below. (The common name of a species will be given in the following text the first time a species is mentioned; thereafter, scientific name only will be used.) Nomenclature follows White 1982.

Dry site pine forests are dominated by combinations of the four native GRSM yellow pines (*Pinus* Subgenus Diploxylon). The most obvious feature in the distribution of these species is the turnover along the elevational gradient: *P. virginiana* (Virginia pine) and *P. echinata* (shortleaf pine) are most important below 600 m, *P. rigida* (pitch pine) is the dominant species from 600 m to 900 m, and *P. pungens* (table mountain pine) is dominant from 900 m to 1,500 m. While *P. echinata* is found in the lower elevation pine forests, this species is most conspicuous on old fields. Younger stands are usually mixed in composition (Whitaker 1956), with *Quercus prinus* (chestnut oak), *Q. coccinea* (scarlet oak), *Acer rubrum* (red maple), *Nyssa sylvatica* (black gum), *Carya glabra* (pignut hickory), and *Oxydendrum arboreum* (sourwood) sharing dominance with pines. In relatively low elevation pine forests of western GRSM, *Carya pallida* (sand hickory) and *Q. marilandica* (blackjack oak) are important stand components. Heaths (*Gaylussacia baccata*, *G. ursina*, *Vaccinium vacillans*, *Kalmia latifolia*) are important in the understory of these pine stands (Whittaker 1956).

Old field pine stands are dominated by *P. rigida*, *P. echinata*, and/or *P. virginiana*. *P. strobus* also occurs on these sites (and in some plantations on similar sites as well), but *P. pungens* is scarce. Associated hardwoods include *Liquidambar styraciflua* (sweetgum), *Liriodendron tulipifera* (tuliptree), *Robinia pseudoacacia* (black locust), *Acer rubrum* (red maple), *Q. alba* (white oak), *Q. falcata* (southern red oak), *Q. velutina* (black oak), *Cornus florida* (flowering dogwood), and *Nyssa sylvatica*. *Tsuga canadensis* (hemlock) may be present in the understory. In old field pine stands, the understory is usually less clearly dominated by shrubs than in the more xeric pine stands; instead, saplings of shade tolerant trees are conspicuous.

In western GRSM, *P. strobus* (this is the only eastern member of Subgenus Hyploxylon) can be dominant on mesic sites (coves, stream flats) and is often conspicuous on steep stream gorge sides in scattered locations throughout the park. Sometimes this species is found on upper slopes, usually in relatively mesic situations (e.g., north facing slopes). *P. strobus* overlaps the distribution of many other tree species and thus has many potential associates (DeYoung 1979, Harmon 1980a).

The Successional Status of Pine Forests. The four native GRSM yellow pines (*P. rigida*, *P. virginiana*, *P. pungens*, and *P. echinata*) are early to mid-successional species. They are intolerant of shade and competition and require exposure of mineral soils for optimum seedling germination and survivorship (Harlow et al. 1979; Fowells 1967). Hence, pine reproduction is often scarce within pine-dominated stands, and most successional projections suggest a declining importance of pine in the absence of disturbance. Studies of succession after beetle attack have shown that death of overstory pine releases understory hardwoods and hence speeds succession to hardwood dominance (Kuykendall 1978). Less intense fires may have this effect as well, particularly if they do not result in death of competing hardwoods and do not expose mineral soils (Harmon 1980a).

Harmon (1981, 1982) has suggested that the widespread occurrence of pine forests, particularly in western GRSM, is due to more intense and frequent fires in the pre-park era. Pines have a number of adaptations which suggest a dependence on fire or an ability to respond to this kind of disturbance (Komarek 1974). Their dependence on exposure of mineral soils and high light levels has been noted above. *P. rigida* and *P. echinata* are able to sprout back after fire, unlike many other conifers. *P. pungens* has persistent and serotinous cones, about 60 percent of which open only after exposure to the heat of a wildfire (Barden 1979). Pines possess some traits which suggest that they promote fire. Pine litter is more flammable than hardwood litter (Mutch 1970). Lightning strikes are more likely to initiate wild fire on pine trees than on hardwood trees (Barden 1974).

Pines are tolerant of dry site conditions, and some studies have suggested that pines may be able to form self-perpetuating stands on the most xeric southern Appalachian sites (Barden 1977, 1979; Racine 1966; Zobel 1969). On these sites, there is reduced competition from hardwoods. Pine reproduction may be episodic because of periodic drought and windfall. Barden (1977) and Zobel (1969) found that self-maintaining stands of _P. pungens_ can occur on rock outcrops and shallow soils.

Old field pine stands are clearly successional to hardwoods or to hemlock-hardwoods. Fields in the park from 50 to 70 years old are currently experiencing increased mortality of pine canopy trees without pine regeneration.

The successional status of white pine in GRSM is more difficult to assess. Although shade intolerant in the north, _P. strobus_ is intermediately tolerant in GRSM, and there is more understory reproduction for this species than for the other GRSM pines. DeYoung (1979) found that white pine-Virginia pine, white pine-red maple, white pine-hemlock, and some pure white pine stands were even aged and successional after disturbance. White pine-oak and some pure white pine stands were all-aged and occurred on sites of minimal human disturbance. However, even the all-aged stands showed that periodic release, rather than continuous survivorship, characterized pine regeneration.

Southern Pine Beetle Epidemics and Effects. The southern pine beetle is predominantly a pest of the four native GRSM yellow pines. All these pines are highly susceptible to the beetle. The most vulnerable trees are those under drought or competition stress (Lorio and Hodges 1977); those injured by lightning, fire, or wind (Hodges and Pickard 1971); and those growing in pure rather than mixed stands (Osgood 1958). Larger trees are also more susceptible than smaller trees; in one infestation, Hoffman and Anderson (1945) found that 75 percent of the pines larger than 15 cm in diameter were killed but only 57 percent of the pines in the 10 cm diameter class and 19 percent of the pines in the 5 cm diameter class were killed. Death occurs due to mechanical injury to the cambium from beetle gallery construction and from the introduction of blue stain fungus (_Ceratocystis minor_) to the stem (Dixon and Osgood 1961).

Beetle outbreaks are concentrated within pine stands in localized "hot spots" (Kuykendall 1978). Large beetle populations build up on one or a few trees, leading to the term "mass attack" for the behavior of this insect. Beetle epidemics begin when newly emerged unmated female beetles are attracted to the host tree by a volatile terpene, alpha-pinene. Stressed trees emit more of these attractants than vigorous trees (Hodges and Pickard 1971). Healthy trees respond to the attack through production of resins in the inner bark; stressed trees are unable to sustain this resinous response. The resins result in further release of alpha-pinene, which leads to further beetle colonization. The attack proceeds with release of a pheromone by the female beetle which attracts males to the host tree. The population of male beetles builds up until a second male-produced pheromone inhibits further attraction of the male. As the tree succumbs, less attractant is released; as the females engage in gallery construction, less pheromone is released. Hence the mass attack subsides (Renwick and Vite 1970).

In the past 30 years there have been two outbreaks of the southern pine beetle in GRSM. The first epidemic lasted from 1954 until the winter of 1957-1958 (National Park Service 1955, Kuykendall 1978). The second and more extensive outbreak began in the fall of 1967 and lasted, at varying intensities, until the winter of 1976-1977 (Kuykendall 1978). At the height of the beetle outbreak in the late 1960s and early 1970s, the United States Forest Service reported that brood densities in GRSM were among the highest on record in the South (Ward et al. 1971).

Decline of beetle epidemics appears to be associated with severe winter temperatures. Temperatures below $-12.2^{o}C$ ($10^{o}F$) appear to cause heavy mortality of the overwintering broods (Beal 1933). During the most recent outbreak in GRSM, there were significant brood mortalities in the winter of 1968-1969, in January 1970, and in the winter of 1971. In January 1970, 99 to 100 percent mortality was caused by three consecutive days with temperatures below $-18^{o}C$ ($0^{o}F$) (Flavel et al. 1970).

METHODS

Plot Selection. Sampling sites were chosen according to three factors: presence or absence of pine beetle infestation, elevation, and topography (Fig. 1). Three elevation classes (300-600 m, 600-1000 m, 1000-1300 m) and four topography classes (protected lower slope, protected upper slope, exposed mid-slope, and exposed upper slope) were adapted from Kuykendall's (1978) study of forest replacement patterns after beetle infestation. Determination of the infestation date of a hot spot was impossible for several reasons. The two recent GRSM outbreaks occurred only nine years apart. Aerial surveys were not done on a yearly basis. Finally, not all infested trees in a stand die in the same year. Kuykendall (1978) found that infestations were difficult to date for stands affected between 1967 and 1977.

Potential locations for beetle-killed stands were determined from interviews with National Park Service personnel and from previous work based on aerial surveys done

Figure 1. Sampling design used for a study of fuel levels influenced by the southern pine beetle. Three sites were sampled in each cell. High-elevation protected, lower slopes do not occur in the park.

	A1 Pine Beetle Hot Spots				A2 Unaffected Pine Stands			
Elevation (m) / Exposure	Protected		Exposed		Protected		Exposed	
	Lower slopes C1	Upper slopes C2	Mid-slopes C3	Upper slopes C4	Lower slopes C1	Upper slopes C2	Mid-slopes C3	Upper slopes C4
B1 1000-1300	*				*			
B2 600-1000								
B3 300-600								

* - Does not exist

in 1967 and 1968 (Kuykendall 1978). Actual site locations were determined through field reconnaissance. The sampling sites were located in the northwestern quarter of GRSM in Blount and Sevier Counties, Tennessee (Fig. 2). Plot locations were recorded on 1:24,000 topographic U.S. Geological Survey quad sheets deposited at Uplands Field Research Laboratory. Of the 24 possible sampling situations determined by the factorial design (Fig. 1), two are not found in the park landscape. Three replicates were sampled in each of the other 22 cells (Fig. 1) for a total of 66 plots.

Data Collection. Elevation, slope, angle, aspect, slope shape, topographic class, forest type, and understory type were recorded on field data sheets. Dead and downed twigs and boles were sampled using the planar intersect method ("downed" was defined as having $<45^{\circ}$ angle with the horizontal) (Brown and Roussopoulos 1974, Brown 1971, 1974). This method requires counting wood intersections along a vertical plane. Twigs and boles were divided into four diameter classes: 0-7 mm, 7-25 mm, 25-76 mm, and larger than 76 mm. These site classes correspond to the 1-hr, 10-hr, 100-hr, and 100-hr-plus lag time classes that are used for fire management purposes (Martin et al. 1979). The three dead and downed twig classes were sampled along 2-m, 3-m, and 11-m transects, respectively. The bole class (>76 mm) was sampled along two 15-m random transects, and the wood was categorized as sound or rotten. Percent of bole wood still present was estimated. Harmon (1980b) was able to use a single 240-m transect length in his GRSM fuel study. However, because we sought to confine all sampling to hot spots, a constraint on traversed length was imposed. These hot spots were irregular in size and shape and rarely larger than .04 hectare.

Soil organic layer depth was recorded to the nearest 0.5 cm. Three soil samples in each plot were used to measure the depth of the litter, fermentation, and humus horizons that comprised the organic layer. Buried bole wood was not measured separately from these soil organic layers.

Dead, standing trees and live, standing trees ("standing" was defined as an angle $>45^{\circ}$ with the horizontal) were identified and tallied using the horizontal point sampling technique with a 1-factor Bitterlich prism.

Data Analysis. The data was analyzed using an IBM Personal Computer at Uplands Field Research Laboratory and an IBM 370 computer at the University of Tennessee, Knoxville. A FORTRAN program, PARK.FUE (Appendix, Table 1), was written to convert dead and downed fuel information to wood volume per area. The program

Figure 2. Sampling site locations in GRSM for southern pine beetle study.

uses Van Wagner's 1968 equation but defines twig diameter as a function of twig average cross-section. For the three twig classes:

$$V_i = \frac{n \pi^2 d_i^2}{8L}$$

where:

V_i= wood volume per unit area for twig size class i

n = number of intercepts of twig size class i

d_i=mean diameter for twig size class i

$$d_i = \sqrt{\frac{4 A_i}{\pi}}$$

where:

A_i = the average cross section area of twig size class i

L = planar transect length.

The equation was further modified for boles > 76 mm:

$$V = \frac{\pi^2 d^2 p}{8L}$$

where:

d = diameter of the bole, and

p = fraction of wood still present.

The modification of the bole equation (multiplication by p) had the effect of correcting bole wood volume present by calculating only the proportion of undecayed wood.

Total twig volume was computed as the sum of the volume in the three twig size classes. Total downed wood volume was computed as the sum of twig volume and bole volume. Table 2 of the Appendix lists all volumetric data for each plot.

A BASIC program NEWPR.BAS (Appendix, Table 3) was written to convert Bitterlich prism raw data to basal area and density per hectare (Mueller-Dumbois and Ellenberg 1974).

Statistical Analysis System (SAS82) was used to calculate analysis of variance (ANOVA) and the Scheffé comparison of means test (SAS Institute 1982). The dependent variables tested included: twig volume, bole volume, total downed wood volume, total organic depth, standing dead basal area, standing dead density, live stem basal area, and live stem density.

We then converted our twig and bole measurements from volumetric to biomass units, using the organic matter density values reported in Harmon et al. (1980). This conversion facilitated comparison of our data to those of previous investigators of GRSM fuel loadings (see Discussion). Since different weighted averages of wood density were required for different wood sizes and for infested and uninfested stands (Harmon et al. 1980), these conversions are presented in detail in the following section.

RESULTS

Basal Area and Density of Live Canopy Stems. ANOVA showed that the only significant source of variance (α = .05) in the live basal area was infestation level (Table 1). Uninfested stands had a mean live basal area of 26.1 m^2/ha (range: 15-49 m^2/ha), over twice the value of former hot spots (mean = 11.6 m^2/ha; range: 2-30 m^2/ha). Live pine basal area varied in a similar way, averaging 20.8 m^2/ha (79.9 percent of total stand basal area) in uninfested stands and 6.2 m^2/ha (53.4 percent of total stand basal area) in former beetle hot spots (Table 2).

Infestation was the only significant source of variance for live density (Table 1). Density of live canopy stems was significantly higher (mean = 6713 stems/ha) in uninfested than in infested stands (3239 stems/ha; range: 222.0-9704.9 stems/ha).

Standing Dead Basal Area and Density. Standing dead basal area was greatest in former beetle hot spots (Table 2). Infestation level was a highly significant source of variance in this regard, and there was an additional interaction between elevation and infestation level (Table 1). The range in dead basal area for former beetle hot spots was 5.3 to 16.3 m^2/ha (mean = 9.3 m^2/ha), whereas the range in uninfested stands was 0.7 to 4.5 m^2/ha (mean = 2.7 m^2/ha). The highest values encountered were on high elevation exposed sites (mean = 16.3 m^2/ha). On these sites, uninfested stands had dead basal areas of 4.3 m^2/ha (29.3 percent of the infested stand value). The Scheffé comparison of means showed that high elevation stands (mean = 7.5 m^2/ha) had significantly higher dead basal areas than lower elevation stands (4.7 m^2/ha) and that upper slope, exposed site, dead basal areas were significantly higher (7.6 m^2/ha) than lower slope, protected site, dead basal areas (4.1 m^2/ha).

Table 1. Analysis of variance and F-values for basal area and fuels of beetle-infested and unaffected yellow pine stands (A = infestation level, B = elevation, and C = slope exposure).

Y	Source of Variation	Degrees of Freedom	Type IV SS	F-value	P R > F
Total Twig Volume	A	1	.1353	9.68	.0034
	B	2	.0236	.84	.4379
	C	3	.0279	.67	.5782
	A*B	2	.0207	.74	.4826
	A*C	3	.0189	.45	.7188
	B*C	5	.0546	.78	.5686
	A*B*C	5	.0525	.75	.5903
Total Bole Volume	A	1	8.1972	64.03	.0001
	B	2	1.7092	6.68	.0032
	C	3	1.7539	4.57	.0077
	A*B	2	1.0476	4.09	.0242
	A*C	3	1.1994	3.12	.0364
	B*C	5	2.2875	3.57	.0092
	A*B*C	5	1.9736	3.08	.0191
Total Downed Wood Volume	A	1	10.6118	81.68	.0001
	B	2	1.3218	5.09	.0108
	C	3	1.8171	4.66	.0069
	A*B	2	.7470	2.88	.0681
	A*C	3	1.3010	3.34	.0287
	B*C	5	2.3574	3.63	.0084
	A*B*C	5	2.4504	3.77	.0068
Total Soil Organic Layer Depth	A	1	6.4201	1.60	.2137
	B	2	468.1496	58.20	.0001
	C	3	17.2720	1.43	.2478
	A*B	2	10.7234	1.33	.2751
	A*C	3	4.6018	0.38	.7669
	B*C	5	8.5638	0.43	.8279
	A*B*C	5	9.6450	0.48	.7893
Dead, Standing Stem Basal Area	A	1	606.6806	56.92	.0001
	B	2	36.9078	1.73	.1900
	C	3	29.0310	0.91	.4458
	A*B	2	94.0142	4.41	.0186
	A*C	3	2.8971	0.09	.9648
	B*C	5	56.9332	1.07	.3923
	A*B*C	5	43.2925	0.81	.5479

Table 1. (cont.)

Y	Source of Variation	Degrees of Freedom	Type IV SS	F-Value	PR > F
Dead, Standing Density	A	1	1111888.43	1.03	.3168
	B	2	6600091.65	3.05	.0585
	C	3	7727473.66	2.38	.0839
	A*B	2	615349.43	0.28	.7540
	B*C	5	1939092.93	0.60	.6205
	B*C	5	20571028.49	3.80	.0065
	A*B*C	5	7220286.31	1.33	.2695
Live Density	A	1	174078204.4	5.05	.0301
	B	2	31215170.1	0.45	.6404
	C	3	174761153.5	1.68	.1863
	A*B	2	39596523.7	0.57	.5692
	A*C	3	97893303.9	0.94	.4294
	B*C	5	263790177.2	1.52	.2044
	A*B*C	5	145759531.0	0.84	.5283
Live, Standing Stem Basal Area	A	1	2938.8889	53.43	.0001
	B	2	114.7270	1.04	.3618
	C	3	111.9282	0.68	.5705
	A*B	2	189.7553	1.72	.1912
	A*C	3	191.1933	1.16	.3375
	B*C	5	193.8931	0.70	.6231
	A*B*C	5	212.9594	0.77	.5740
Live *Pinus* Basal Area	A	1	3118.3886	77.07	.0001
	B	2	133.3081	1.65	.2053
	C	3	40.6446	.33	.8002
	A*B	2	31.1265	.38	.6832
	A*C	3	78.9881	.65	.5872
	B*C	5	145.9137	.72	.6114
	A*B*C	5	229.9540	1.14	.3570

Table 2. Cell mean values for all ANOVA tests. (A1 = beetle hot spots; A2 = stands not infested by beetle; B1, B2, and B3 are high, medium, and low elevations; and C1, C2, C3, and C4 are slope exposure classes (see Fig. 1).

INFESTATION CLASS	ELEVATION CLASS	TOPOGRAPHY CLASS	TWIG VOLUME PER AREA (m^3/ha)	BOLE VOLUME PER AREA (m^3/ha)	TOTAL DOWNED WOOD VOLUME PER AREA (m^3/ha)	TOTAL ORGANIC DEPTH (cm)	DEAD STANDING STEM BASAL AREA (m^2/ha)	DEAD STANDING DENSITY (stems/ha)	LIVE STEM BASAL AREA (m^2/ha)	LIVE PINUS BASAL AREA (m^2/ha)	LIVE DENSITY (stems/ha)
A	B	C	Y	Y	Y	Y	Y	Y	Y	Y	Y
A1	B1	C2	39.3	71.2	115.7	12.4	9.7	730.4	11.3	5.3	3055.6
A1	B1	C3	33.1	39.7	73.0	10.1	13.0	1219.1	6.7	2.0	5586.3
A1	B1	C4	31.5	34.0	65.3	11.4	16.3	2109.8	6.3	7.3	1143.3
A1	B2	C1	19.6	99.1	118.7	5.7	6.3	353.8	8.7	3.5	2844.6
A1	B2	C2	31.3	83.0	114.0	7.9	8.7	507.9	17.0	14.3	6532.7
A1	B2	C3	38.5	63.0	101.7	7.4	8.3	299.0	7.3	7.3	2092.6
AL	B2	C4	22.1	89.6	112.0	5.8	10.0	336.1	13.0	6.7	2289.1
A1	B3	C1	17.8	71.7	89.3	4.3	5.3	365.9	11.7	2.0	2850.8
A1	B3	C2	24.4	98.7	123.0	4.7	10.0	167.3	16.0	2.5	1918.5
A1	B3	C3	21.9	46.3	68.5	4.4	6.0	531.7	15.5	6.5	1395.1
A1	B3	C4	27.5	250.6	278.5	5.1	6.5	783.5	19.0	10.0	5673.3
A2	B1	C2	16.3	8.6	25.0	15.0	.7	339.5	22.0	19.3	7465.9
A2	B1	C3	12.6	5.9	18.7	12.0	1.0	214.9	34.7	24.7	17363.8
A2	B1	C4	24.5	3.6	28.0	13.0	4.3	3902.0	23.3	20.3	3970.5
A2	B2	C1	13.6	9.4	23.3	7.8	2.0	412.3	27.0	24.0	2429.2
A2	B2	C2	26.0	11.4	37.4	7.5	4.3	2186.6	24.3	24.0	7074.5
A2	B2	C3	21.5	18.0	43.0	5.2	3.3	734.1	25.7	17.8	6572.8
A2	B2	C4	19.2	22.4	41.3	7.0	2.7	289.3	28.7	23.3	2934.8
A2	B3	C1	16.1	9.6	25.7	4.8	2.7	439.7	23.3	17.0	3534.9
A2	B3	C2	10.7	17.4	28.0	4.7	1.7	117.0	29.7	20.7	14644.6
A2	B3	C3	27.0	9.8	37.0	4.5	3.3	532.9	25.7	21.5	3244.8
A2	B3	C4	15.7	20.8	36.5	4.7	4.5	1218.4	21.5	14.5	3600.8

For former beetle hot spots, dead basal area increased with increasing elevation, from 6.8 m^2/ha at low elevation to 8.3 m^2/ha at mid-elevations, and 13.0 m^2/ha at high elevations. For uninfested stands, this trend was absent. The mean values were: low elevation stands, 2.0 m^2/ha; mid-elevation stands, 3.1 m^2/ha; and high elevation stands, 2.9 m^2/ha. For former beetle hot spots, the effect of topographic exposure was similar: exposed, upper slopes had significantly higher values (11.5 m^2/ha) than protected, lower slopes (5.8 m^2/ha for uninfested stands; the trend was reversed (2.3 and 3.8 m^2/ha for more and less exposed sites, respectively). Thus the effect of both elevation and exposure on dead basal area was strongly expressed in formerly infested stands but less strongly expressed in unaffected stands.

Density of dead canopy stems was unrelated to infestation level. ANOVA showed that the interaction of elevation and slope exposure was the only significant source of variance in density (Table 1). High elevation stands had a significantly higher density (1419.3 stems/ha) than mid-elevation (639.9 stems/ha) or low elevation stands (488.4 stems/ha). Exposed upper slopes had significantly higher density (1494.7 stems/ha) than protected lower slopes (704.6 stems/ha).

Twig Volume. Infestation history was the only significant source of variance in twig volume (Table 1). For infested stands, there was an increase in twig volume with increasing elevation, from 22.9 m^3/ha at mid-elevations and 34.6 m^3/ha at high elevations. In uninfested stands, there was no clear pattern with elevation (Table 2). In infested stands, twig volume also tended to be higher on exposed sites (29.1 m^3/ha) than on protected sites (26.5 m^3/ha). A similar trend was present for unaffected stands, in which exposed sites averaged 20.1 m^3/ha and protected sites averaged 16.5 m^3/ha.

Bole Volume. All main and interaction effects were significant sources of variance in dead and downed bole volume (Table 1). Bole volume was of the same order of magnitude as twig volume. The most significant difference was between former hot spots (81.5 m^3/ha) and unaffected stands (12.2 m^3/ha; about 15 percent of the value for infested stands). The range in downed bole volume for former beetle hot spots was 25.5 to 342.4 m^2/ha, whereas the range in uninfested stands was 0.0 to 40.3 m^2/ha. The Scheffé comparison of means test showed that high elevation stands had lower bole volumes (mean = 27.2 m^3/ha) than low elevation stands (57.9 m^3/ha); thus this trend was opposite that found for twig volume and standing dead basal area. Exposed upper slopes had higher bole volumes (62.0 m^3/ha) than exposed mid-slopes (29.5 m^3/ha). Protected slopes were intermediate (46.4 m^3/ha.)

For infested stands, the decrease in bole volume with increase in elevation changed from 111.8 m^2/ha in low elevation stands to 83.7 m^3/ha in mid-elevation stands, and 48.3 m^3/ha in high elevation stands. In unaffected stands, high elevation stands had the lowest bole volume (6.0 m^3/ha), but low (13.8 m^3/ha) and mid-elevation (15.3 m^3/ha) stands were similar to one another.

Total Dead and Downed Wood Volume. All main and interactions effects except the Infestation by Elevation interaction were significant sources of variance in total downed wood volume (Table 1). In infested stands, there was a decrease in total dead and downed wood volume as elevation increased, from 134.2 m^3/ha in low elevation stands to 111.6 m^3/ha in mid-elevation stands and 84.7 m^3/ha in high elevation stands. In unaffected stands, the lowest total wood volume was also in high elevation stands (23.9 m^3/ha); but low (31.4 m^3/ha) and mid-elevation stands (35.0 m^3/ha) were similar to one another. For infested stands, exposed upper slopes had higher total dead and downed wood volumes (136.1 m^3/ha) than exposed midslopes (82.6 m^3/ha).

Organic Layer Depth. Elevation was the only significant source of variance in organic layer depth (Table 1). The Scheffé comparison of means test showed that low elevation stands had shallower organic layers (4.6 cm; range: 2.3-8.8 cm) than mid- (6.8 cm; range: 3.7-9.7 cm), and high (12.3 cm; range: 8.7-19.3 cm) elevation stands (the latter two means were also significantly different). Lower protected slopes also had significantly shallower depths (mean = 5.6 cm; range = 2.3-1.0 cm) than other slope types (group mean = 8.2 cm). Unlike other fuels, infestation history had no effect on organic layer depth; the increase in organic layer depth with elevation was nearly identical between infested and unaffected stands (Table 2).

Fuel Mass. Harmon et al. (1980) developed data on woody fuel dimensions in GRSM: Harmon (1980b) then applied these data, along with volumetric data, decay class ratio, and density values, to fuels in a series of forest types. We have used his data in this section to convert our total downed wood volumetric data to total fuel weights. Freshly fallen wood, as Harmon et al. (1980) argued, is denser than the average woody debris in a stand, which includes both freshly fallen wood and older debris. Harmon et al. (1980) used a weighted average of wood in three decay classes to compute the average wood density for a particular stand. In recently disturbed stands, he suggested the ratio 100:50:5 for freshly fallen, moderately decomposed, and well decomposed debris, respectively. Using a conservative estimate of density in pine wood, this weighted average is 0.45 g/cm^3. In undisturbed stands, Harmon et al. (1980) used the ratio 5:10:1 for the three decay classes, giving a weighted average in pine stands of 0.4 g/cm^3.

Using these data, the effect of conversion from volumetric to mass units increases the contrast between disturbed and undisturbed stands. Because we did not collect data on decay class ratios and wood densities, this conversion must be regarded as preliminary; it serves the purpose of setting a rough order of magnitude on the fuel mass of these stands. The values we derived were 12.3 metric tons/ha in undisturbed stands and 49.6 metric tons/ha in beetle infested stands. These are conservative estimates because we took pine wood density values from Harmon's 1980 data. It is likely that mean wood density in recently impacted pine stands is higher than the 0.45 value we derived from his work.

DISCUSSION

Six years after the cessation of the most recent pine beetle outbreak in GRSM, infestation history significantly affected stand fuels. The total volume of downed woody fuels in former hot spots was three times higher than in unaffected stands, and the total weight of downed woody fuels was four times higher than in unaffected stands. Much of this difference was accounted for by the increase of downed bole volume; this parameter was six times higher in formerly infested than in unaffected stands. Live pine basal area in former hot spots was less than one-third the value found in comparable unaffected stands. Total live basal area in former hot spots was less than one-half the live basal area of uninfested stands. Standing dead basal area was over three times higher in infested versus uninfested stands. Standing dead basal area added to the fuels discrepancy between the infested and uninfested stands noted above and has the further consequence that there are continued inputs of woody debris to formerly infested stands as these standing dead trees disintegrate and fall.

The effect of elevation and exposure varied with the stand characteristic measured. In former hot spots, dead basal area doubled from low to high elevation stands, but downed bole volumes decreased by roughly the same factor. In former hot spots, dead basal area increased two-fold from protected to exposed sites. Although dead and downed bole volume in former hot spots was highest in exposed upper slopes, there was no clear trend for the other three topographic classes (e.g., the minimum value was in exposed mid- slopes). In former hot spots, twig volume increased by a factor of 1.5 from low to high elevations and by a factor of 1.4 from protected to exposed sites. Thus there was a general trend for highest fuel loadings towards exposed sites. Of the 22 combinations of stand conditions examined, the highest total downed wood volume observed was in formerly infested stands on exposed sites; the value for such sites was roughly one order of magnitude greater than the value for unaffected stands on protected sites. Organic layer depth was unrelated to beetle infestation history but almost tripled from low to high elevation sites.

The accumulation of organic matter is, in part, a function of such parameters as elevation and topographic exposure because these are related to environmental constraints on organic production and decay (e.g., Shanks and Olson 1961). As elevation increases (and temperature decreases) in GRSM, production and decay rates both decrease; there is some evidence (J. S. Olson, personal communication) that production decreases linearly on such a gradient, but decay rates decrease exponentially. All else being equal (e.g., moisture and the chemical composition of organic substrates for decay), the net result would be for increasing organic accumulations (fuels) with elevation. Topographic exposure influences site moisture and causes a similar pattern in elevation: towards sites of increasing aridity, both organic production and decay rates decrease. We know of no *a priori* reason why either of the rates decrease faster than the other; therefore, a prediction about fuel accumulations is difficult, without actually measuring decay and production rates along the elevation and topographic gradients.

Our results for soil organic depth supported the increase of organic accumulations with increasing elevation predicted above. This increase was unaffected by infestation history. It is expected that a length of time is required for wood to be incorporated into the duff. The pattern was more difficult to interpret for woody debris. Harmon (1980b), using a different range of community types, also concluded that soil organic layers were also more predictable than woody debris on an elevation gradient. In unaffected stands, the prediction discussed above for elevation is not supported; in fact, total downed wood volume decreased as elevation increased. The highest values we observed in unaffected stands for total woody volume were on topographically exposed mid-elevation slopes. The pattern for former hot spots is difficult to interpret because trees killed by the beetle outbreak contribute to two organic pools: standing dead basal area (which increased roughly twofold with elevation) and total wood volume (which decreased roughly twofold with elevation). The standing dead organic pool contributes to the total downed wood pool at an unquantified and probably variable rate. The major environmental influence on present downed wood volumes appeared to be topographic exposure rather than elevation. Harmon (1980b) came to a similar conclusion.

The absolute wood volumes and weights that we reported for beetle infested stands are at the upper extreme of the fuel values reported by Harmon (1980b) for other kinds of disturbed forests in GRSM. They are roughly twice the fuel loadings present in any undisturbed forest type in GRSM. Only accumulations of chestnut logs (which decay slowly) typically result in higher fuel loadings on a stand basis. Our total wood mass values for beetle hot spots was higher than that predicted by Harmon (1980b), who cited a value of 27 metric tons/ha. However, our sampling was confined to beetle hot spots themselves, whereas Harmon's sampling was oriented around larger plots. The overall purpose of this study was to provide a general inventory of fuel conditions due to the southern pine beetle infestations. Several sources of uncertainty should be pointed out. The length of the bole transect lines had to be confined by the size of the hot spots and so were shorter than what is prescribed by Pickford and Hazard (1978). According to Kuykendall (1978), the majority of beetle hot spots in GRSM are less than .1 ha. Documentation was unavailable to determine the length of time since infestation of particular stands. Furthermore, not all of the trees die in the same year; this is underlined by the continued presence of standing dead pines. We did not quantify the transfer rate of standing dead wood to downed woody debris; this would require a series of measurements over several years. Finally, we did not measure changing wood density but relied on estimates from Harmon et al. (1980). Future studies are planned for permanent plots in pine stands to monitor organic matter input and output as well as standing crop.

While southern pine beetle outbreaks result in a dramatic increase in forest fuels, the effect of these fuels on fire intensity and community dynamics cannot now be predicted. The data reported here can be used in conjunction with a fire behavior model for wildfire management decision making.

A primary reason for documenting fuel conditions after beetle infestation of pine stands is the relationship between fuel loading and potential fire intensity. The risk of catastrophic fire is only one aspect of the importance of this work, however. Periodic beetle outbreaks and natural fire may result in a synergism that benefits pine.

The southern pine beetle is a highly specific disturbance factor which removes one group of canopy trees only, leaves the rest of the community intact (including reproductive layers and soil organic matter), and has a concentrated effect centering on the infestation hot spots. Consequently, the effect on fuels and potential fire intensity is localized and patch-like in the GRSM landscape. Beetle infestations, acting alone, reduce pine canopy importance by 20 to 30 percent (Barden 1974) and release understory stems, which are usually heavily dominated by hardwood species (Kuykendall 1978, Hoffman and Anderson 1945). Thus beetle epidemics tend to speed the successional conversion of pine stands to hardwood dominance. The relatively low intensity fires characterizing the post-park fire regime have the same effect. These fires may increase mortality, but understory hardwoods sprout prolifically (Harmon 1980a). Such fires also produce more fuel (in newly killed stems) than they consume. Windfall has not been studied in GRSM pines but very likely has the same effect. Thus the effect of the present day disturbance regime in GRSM pine stands (Bratton et al. 1981) is generally to hasten the replacement of canopy pine stems by understory hardwood stems. An ongoing decline in the areal coverage by pine in GRSM has thus been predicted (Harmon 1981, 1982).

Pine regeneration could, however, be stimulated if beetle infestations increase the likelihood of hot fires; drought would be an added factor in promoting such a relationship. Because beetle kills result in increased fuel levels, ignitions may escalate into crown fires. Hot fires favor pine establishment while surface fires favor hardwood seedlings and sprouts (Barden 1974). Kuykendall (1978) suggested that infestation may encourage reestablishment of pine dominated stands by increasing the stand's flammability. Barden (1974) found that pine forests in Cherokee National Forest were more likely to have lightning fire than hardwood stands because of the flammability of the forest type and the inherent topographic position of pines. No comparisons can be made between fire and forest type in the park because forest type is not recorded in park fire reports.

Thus one of the few scenarios for a natural pine regeneration is the combined effect of beetle-increased fuels and lightning fire. Whether such a scenario is realistic is presently untested; the park's fire suppression policy has greatly reduced the frequency and areal extent of fires in GRSM (Harmon 1981, 1982). In fact, reduced fire in the last 40 to 60 years has allowed hardwoods on some sites to enter size classes that are more resistant to surface fire because of increasing bark thickness (Harmon 1980a). Thus the ability of fire to promote pine regeneration is a complex function of fuel loadings and the state of the community.

Anthropogenic fire dominated GRSM fire history for at least 150 years (Bratton et al. 1981; Harmon 1981, 1982). The present areal extent of pine stands is, at least in part, an artifiact of that history. Whether a natural interaction of mature pine stands, the southern pine beetle, drought, and fire could have resulted in natural pine stands is an intriguing, though untested, possibility.

CONCLUSIONS

1. Infestations by the southern pine beetle are the most significant factor influencing fuel loadings in the yellow pine stands of GRSM, with total volume of woody debris three times higher in infested stands (110.3 m^3/ha) versus unaffected stands (30.6 m^3/ha).

2. Standing dead basal area was also three times higher in infested stands (9.3 m^2/ha) compared to unaffected stands (2.7 m^2/ha). These standing dead stems represent an ongoing source of woody debris that will increase total woody debris volume.

3. Soil organic layer depth was unrelated to infestation history but increased 2.7 times from low to high elevation pine stands. Therefore, the most important beetle-caused fuel increase is in woody debris.

4. Total mass of woody debris was 49.6 metric tons/ha in beetle-infested stands and 12.3 metric tons/ha in unaffected stands. The beetle-infested stands had values only surpassed in GRSM by heavy accumulations of chestnut logs.

5. Standing dead basal area increased from low to high elevations, but downed bole volume and total wood volume decreased along this gradient. Peak fuels tended to occur on exposed sites on mid-slope positions.

6. Twig volume increased with elevation and with increasing topographic exposure.

7. Further work is needed to gain a more complete understanding of organic matter dynamics in pine stands. Permanent plot monitoring is necessary to quantify organic pool input (production) and output decay) as well as standing crop. With a full description of the system dynamics, we can answer a pertinent resource management question: how long will there be an intense fire risk as a function of post-beetle woody debris?

REFERENCES CITED

Baker, W. L. 1972. Eastern forest insects. USDA Forest Service Misc. Publ. 1175. 642 p.

Barden, L. S. 1974. Lightning fire in southern Appalachian forests. Ph.D. Dissert., Univ. Tennessee, Knoxville. 65 p.

Barden, L. S. 1977. Self-maintaining populations of Pinus pungens Lam. in the southern Appalachian Mountains. Castanea 42:316-323.

Barden, L. S. 1979. Serotiny and seed viability of Pinus pungens in the southern Appalachians. Castanea 44:44-47.

Beal, J. A. 1933. Temperature extremes as a factor in the ecology of the southern pine beetle. J. Forestry 31:329-336.

Bratton, S. P., P. S. White, and M. E. Harmon. 1981. Disturbance and recovery of plant communities in Great Smoky Mountains National Park: successional dynamics and concepts of naturalness. Pages 42-79 in M. A. Hemstrom and J. F. Franklin (eds.). Proc. 2nd US-USSR Symp. on Biosphere Reserves. U.S. National Committee for Man and the Biosphere, Washington, DC.

Brown, J. K. 1971. A planar intersect method for sampling fuel volume and surface area. For. Sci. 17:96-102.

Brown, J. K. 1974. Handbook for inventorying downed woody material. USDA Forest Service Gen. Tech. Rep. INT-16. Intermountain Forest and Range Exp. Sta., Ogden, Utah. 24 p.

Brown, J. K., and P. T. Roussopoulos. 1974. Eliminating bias in the planar intersect method for estimating volumes of small fuels. For. Sci. 20:350-356.

DeYoung, H. R. 1979. The white pine-hardwood vegetation types of the Great Smoky Mountains National Park. M.S. Thesis, Univ. Tennessee, Knoxville. 190p.

Dixon, J. C., and E. A. Osgood. 1961. Southern pine beetle: a review of present knowledge. USDA Forest Service, SE For. Exp. Sta., Asheville, NC. 34 p.

Flavel, T. H., P. J. Barry, J. D. Ward, and W. M. Clerke. 1970. An evaluation of the effects of subzero temperatures on an epidemic southern pine beetle population, Nantahala and Cherokee National Forests and the Great Smoky Mountains National Park, Tennessee and North Carolina. USDA Forest Service, Div. of For. Pest Control Rep. 70-1-46, Asheville, NC.

Fowells, H. 1965. Silvics of forest trees of the United States. USDA Forest Service Agric. Handbook 271. 762 p.

Harlow, W. M., E. S. Harrar, and F. M. White. 1979. Textbook of dendrology. McGraw-Hill, Inc., New York. 510 p.

Harmon, M. E. 1980a. The influence of fire and site factors on vegetation patterns and process: a case study of the western portion of Great Smoky Mountains National Park. Master's Thesis, Univ. Tennessee, Knoxville. 170p.

Harmon, M. E. 1980b. The distribution and dynamics of forest fuels in the low elevation forests of Great Smoky Mountains National Park. NPS-SER Res./ Resour. Manage. Rep. 30. 65 p.

Harmon, M. E. 1981. Fire history of Great Smoky Mountains National Park, 1940-1979. NPS-SER Res./Resour. Manage. Rep. 46. 39 pp.

Harmon, M. E. 1982. Fire history of the westernmost portion of Great Smoky Mountains National Park. Bull. Torrey Bot. Club 109:74-79.

Harmon, M. E., T. Hennessy, and D. G. Silsbee. 1980. Woody fuel dimensions within Great Smoky Mountains National Park. NPS-SER Res./Resour. Manage. Rep. 31. 28 p.

Hodges, J. D., and L. S. Pickard. 1971. Lightning in the ecology of southern pine beetle Dendroctonus frontinalis (Coleoptera: Scolytidae). Can Entomol. 103:44-51

Hoffman, C. H., and R. F. Anderson. 1945. Effect of southern pine beetle on timber losses and natural restocking. J. Forestry 43:436-439.

Komarek, E. V. 1974. Effects of fire on temperate forests and related ecosystems in Southeastern United States. Pages 251-277 in Kozlowski, T. T., and C. E. Ahlgren, eds. Fire and Ecosystem. Academic Press, Inc., New York.

Kuykendall, N. W. 1978. Composition and structure of replacement forest stands following southern pine beetle infestation as related to selected site variables in the Great Smoky Mountains National Park. Master's Thesis, Univ. Tennessee, Knoxville. 122 p.

Lorrio, P. I., and J. D. Hodges. 1977. Tree water status affects induced southern pine beetle and brood production. Southern For. Exp. Sta., New Orleans, LA. USDA Forest Service Res. Pap. SO-135. 7 p.

Martin, R. E., H. E. Anderson, W. D. Boyer, J. H. Dietrich, S. N. Hirsch, V. P. Johnson, and W. H. McNab. 1979. Effects of fires on fuels. Forest National Fire Effects Workshop. USDA Forest Service Gen. Tech. Rep. WO-13. 64 p.

Mueller-Dombois, D., and H. Ellenberg. 1974. Aims and methods of vegetative ecology. John Wiley and Sons, New York. 547 p.

Mutch, R. W. 1970. Wildland fires and ecosystems--a hypothesis. Ecology 51: 1046-1051.

National Park Service. 1955. Great Smoky Mountains National Park, summary of southern pine beetle 1954-1955. Unpublished report, Gatlinburg, TN, dated Sep. 24, 1955.

Osgood, E. A. 1958. A study of site and stand characteristics of southern pine beetle infestation. USDA Forest Service, Southern For. Exp. Sta. Off. Rep. 5 p.

Pickford, S. G., and J. W. Hazard. 1978. Simulation studies on line transect sampling of forest residue. For. Science 24:469-483.

Racine, C. H. 1966. Pine communities and their site characteristics in the Blue Ridge Encarpment. Elisha Mitchell Soc. 82:172-181.

Renwick, J. A., and J. P. Vite. 1970. Systems of chemical communication in *Dendroctonus*. Contributions of the Boyce Thompson Institute 24:283-291.

SAS Institute. 1982. SAS users' guide: statistics, 1982 ed. SAS Institute, Cary, NY. 584 p.

Shanks, R. E., and J. S. Olson. 1961. First-year breakdown of leaf litter in southern Appalachian forests. Science 134:194-195.

Van Wagner, C. E. The line intersect method in forest fuel sampling. For. Sci. 14:20-26.

Ward, J. D., E. T. Wilson, and W. E. McDowell. 1971. An evaluation of southern pine beetle infestations on the Great Smoky Mountains National Park. USDA Forest Service, Div. of For. Pest Manage., Asheville, NC, Rep. 72-1-14.

White, P. S. 1982. The flora of Great Smoky Mountains National Park: an annotated checklist of the vascular plants and a review of previous floristic work. USDI, National Park Service, Southeast Regional Office Res./Resour. Manage. Rep. SER-55. 219 p.

Whittaker, R. H. 1956. Vegetation of the Great Smoky Mountains. Ecol. Monogr. 26:1-80.

Zobel, D. B. 1969. Factors affecting the distribution of *Pinus pungens*, an Appalachian endemic. Ecol. Monogr. 39:303-333.

APPENDIX

Table 1. FORTRAN program PARK.FUE to convert dead and downed fuel information.

```
C       PROGRAM TWGVOL
C
C************************************************************************
C
C       THIS PROGRAM CALCULATES THE VOLUMES OF TWIGS AND BOLES FROM DATA
C       COLLECTED FOR THE PARK SERVICE.
C
C         IDPLOT - PLOT ID #
C         NTREE  - NUMBER OF DOWNED BOLES(D > 7.6 CM)
C         TDIAM  - DIAMETER (CM) OF EACH BOLE
C         TPCENT - % OF EACH BOLE PRESENT
C         NTWIG  - NUMBER OF TWIGS COUNTED ON TRANSECT FOR EACH TWIG CLASS
C         CONST  - BROWN (1974) EQUATION - PI**2/8L
C         TCONST -        "
C         TREVOL - VOLUME/AREA OF BOLES
C         ROTVOL - TOTAL VOLUME/AREA OF ROTTEN BOLES
C         SNDVOL - TOTAL VOLUME/AREA OF SOUND BOLES
C         DAV1,DAV2,DAV3 - SQUARE OF AVERAGE DIAMETER OF TWIG CLASSES 1-3
C         TVOL1,TVOL2,TVOL3 - VOLUME/AREA OF TWIGS IN CLASSES 1-3
C            TWIG CLASS 1 - (0-0.7 CM)
C            TWIG CLASS 2 - (0.7 - 2.5 CM)
C            TWIG CLASS 3 - (2.5 - 7.6 CM)
C          VOL123 - TOTAL VOLUME/AREA OF TWIGS
C
C       INPUT FILE - PARK.DAT
C          IDPLOT    - PLOT ID # (W/O "F")
C          NTREE       - NUMBER OF BOLES FOR PLOT
C          36,34,-56,...       - BOLE DIAMETERS (CM), DIAM < 0 FOR ROTTEN BOLES
C          90,34,30,...        - BOLE % PRESENT
C          12,23,24            - TWIGS IN CLASSES 1,2,3
C         IDPLOT    - PLOT ID FOR NEXT PLOT
C           ...
C
C       TO PRINT THE INPUT FILE USE THE COMMAND:
C       PRINT PARK.DAT/FILE:ASCII/DEST:RMT2
C
C
C************************************************************************
C
        DIMENSION TDIAM(40),TPCENT(40),NTWIG(3),CONST(3)
        DATA TCONST/2.467396E-4/
        DATA CONST/6.168492E-3,4.112328E-3,1.121544E-3/
        DATA DAV1,DAV2,DAV3/0.12,2.7033,27.67/
C
C......OPEN INPUT AND OUTPUT FILES
C
        OPEN(UNIT=5,FILE='PARK.DAT',ACCESS='SEQIN',DEVICE='DSK')
        OPEN(UNIT=6,FILE='PARK.TVL',ACCESS='SEQOUT',DEVICE='DSK')
        OPEN(UNIT=7,FILE='PARK.ECH',ACCESS='SEQOUT',DEVICE='DSK')
C
C......WRITE HEADINGS
C
        WRITE(6,1000)
        WRITE(6,1010)
1000    FORMAT(10X,'TWIG CLASS 1  -  2 M TRANSECT',/,
```

Table 1. (cont.)

```
        1      10X,'TWIG CLASS 2  -  3 M TRANSECT',/,
        1      10X,'TWIG CLASS 3  - 11 M TRANSECT',/,
        1      10X,'BOLES         - 50 M TRANSECT',/,
        1      11X,'(VOLUMES FOR SOUND AND ROTTEN BOLES ASSUME 100',
        1                               ' % PRESENT)')
1010    FORMAT(/,/,
        1      /,34X,'VOLUME/AREA (CM)',/,
        1      26X,'TWIGS',33X,'BOLES',/,
        1      'PLOT #',2X,'CLASS 1',4X,'CLASS 2',4X,'CLASS 3',5X,
        1            'TVL123',6X,'SOUND',5X,'ROTTEN',
        1             6X,'TOTAL',/)
C
C......READ DATA FILE
C
10      READ(5,1020,END=999)IDPLOT
1020    FORMAT(A5)
        READ(5,*,END=50)NTREE
        IF(NTREE.GT.0)READ(5,*,END=50)(TDIAM(I),I=1,NTREE)
        IF(NTREE.GT.0)READ(5,*,END=50)(TPCENT(I),I=1,NTREE)
        READ(5,*,END=50)(NTWIG(I),I=1,3)
C
C......ECHOPRINT INPUT DATA
C
        WRITE(7,1025)IDPLOT,NTREE,(NTWIG(I),I=1,3),(TDIAM(I),TPCENT(I),
        1                                                      I=1,NTREE)
1025    FORMAT(/,'PLOT F',A5,' HAS ',I3,' BOLES',/,
        1      'TWIGS: ',3I5,/,
        1      'BOLES (D,%): ',/,6(7('(',F6.1,F6.1,' )'),/))
C
C......CALCULATE DOWNED TREE VOLUMES
C
        TREVOL=0.0
        ROTVOL=0.0
        SNDVOL=0.0
        IF(NTREE.LE.0)GOTO 40
         DO 30 I=1,NTREE
           TREVOL=TREVOL+TCONST*ABS(TDIAM(I))**2.0*TPCENT(I)/100.0
           IF(TDIAM(I).LT.0.0)ROTVOL=ROTVOL+TCONST*ABS(TDIAM(I))**2.0
           IF(TDIAM(I).GE.0.0)SNDVOL=SNDVOL+TCONST*TDIAM(I)**2.0
30       CONTINUE
C
C......CALCULATE TWIG VOLUMES
C
40      TVOL1=CONST(1)*DAV1*NTWIG(1)
        TVOL2=CONST(2)*DAV2*NTWIG(2)
        TVOL3=CONST(3)*DAV3*NTWIG(3)
        VOL123=TVOL1+TVOL2+TVOL3
C
C......WRITE OUTPUT
C
        WRITE(6,1030)IDPLOT,TVOL1,TVOL2,TVOL3,VOL123,
        1      SNDVOL,ROTVOL,TREVOL
1030    FORMAT('F',A5,1P7E11.4)
C
C......NEXT PLOT
```

Table 1. (cont.)

```
C
        GOTO 10
C
C......ERROR FOR MISSING LINE
C
50      TYPE 1040
1040    FORMAT(' INPUT FILE HAS WRONG NUMBER OF INPUT LINES -',
        1                          ' EXECUTION STOPPED')
C
C......THAT'S ALL
C
999     CLOSE(UNIT=5)
        CLOSE(UNIT=6)
        CLOSE(UNIT=7)
        CALL EXIT
        END
```

Table 2. Converted wood volume values for each plot.

TWIG CLASS 1 - 2 M TRANSECT
TWIG CLASS 2 - 3 M TRANSECT
TWIG CLASS 3 - 11 M TRANSECT
BOLES - 50 M TRANSECT
(VOLUMES FOR SOUND AND ROTTEN BOLES ASSUME 100 % PRESENT)

	VOLUME/AREA (CM)						
	TWIGS				BOLES		
PLOT #	CLASS 1	CLASS 2	CLASS 3	TVL123	SOUND	ROTTEN	TOTAL
F25201	3.0349E-02	5.5584E-02	3.4136E-01	4.2730E-01	1.4903E-01	1.5791E-02	1.5323E-01
F25202	1.9246E-02	3.3351E-02	2.4826E-01	3.0086E-01	5.5319E-01	5.5516E-02	5.8643E-01
F25203	2.8869E-02	8.8935E-02	3.1033E-01	4.2813E-01	3.9552E-01	4.5647E-02	3.9409E-01
F25204	8.8826E-03	4.4467E-02	1.2413E-01	1.7748E-01	4.4660E-02	6.5386E-02	6.9408E-02
F25205	3.9232E-02	5.5584E-02	1.5517E-01	2.4998E-01	0.0000E+00	2.0356E-01	1.4002E-01
F25206	3.1829E-02	4.4467E-02	3.1033E-02	1.0733E-01	2.4674E-02	4.1699E-02	5.3863E-02
F25207	3.4050E-02	6.6701E-02	1.8620E-01	2.8695E-01	0.0000E+00	2.1762E-01	1.3057E-01
F25208	2.6648E-02	1.0005E-01	1.8620E-01	3.1290E-01	0.0000E+00	4.5647E-02	3.9503E-02
F25209	1.7765E-02	8.8935E-02	1.5517E-01	2.6187E-01	8.7839E-02	1.5791E-02	9.1688E-02
F32401	2.7388E-02	1.0005E-01	6.2066E-02	1.8951E-01	2.4674E-02	7.7476E-02	7.6859E-02
F32402	3.0349E-02	2.2234E-02	1.5517E-01	2.0775E-01	0.0000E+00	3.7628E-01	3.0781E-01
F32403	2.1466E-02	2.2234E-02	6.2066E-02	1.0577E-01	9.8696E-02	0.0000E+00	5.9218E-02
F24401	2.7388E-02	1.0005E-01	6.2066E-02	1.8951E-01	5.4653E-01	1.0980E-01	5.5233E-01
F24402	2.1466E-02	4.4467E-02	1.2413E-01	1.9007E-01	0.0000E+00	2.9855E-02	2.6870E-02
F24403	2.8869E-02	4.4467E-02	1.2413E-01	1.9747E-01	1.5791E-02	9.8696E-02	3.2372E-02
F24404	1.5545E-02	4.4467E-02	2.7930E-01	3.3931E-01	4.1699E-02	4.3204E-01	3.2824E-01
F24405	1.5545E-02	5.5584E-02	3.1033E-02	1.0216E-01	5.1322E-02	4.0465E-02	7.2048E-02
F24301	2.7388E-02	5.5584E-02	1.8620E-01	2.6917E-01	4.5227E-01	4.7818E-01	7.2482E-01
F24302	2.5167E-02	3.3351E-02	0.0000E+00	5.8518E-02	9.8943E-02	0.0000E+00	8.2312E-02
F24303	2.0726E-02	3.3351E-02	1.2413E-01	1.7821E-01	1.1128E-01	1.5791E-02	1.1560E-01
F24304	2.3687E-02	4.4467E-02	6.2066E-02	1.3022E-01	2.1096E-01	8.2905E-02	2.5846E-01
F24305	1.0363E-02	2.2234E-02	3.1033E-02	6.3630E-02	0.0000E+00	0.0000E+00	0.0000E+00
F33201	1.5545E-02	3.3351E-02	9.3099E-02	1.4199E-01	1.3053E-01	0.0000E+00	1.0442E-01
F33202	1.8505E-02	4.4467E-02	3.1033E-02	9.4006E-02	0.0000E+00	7.9944E-02	3.9972E-02
F33203	2.6648E-02	7.7818E-02	3.1033E-02	1.3550E-01	2.9855E-02	1.4138E-01	1.3400E-01
F33204	1.5545E-02	3.3351E-02	6.2066E-02	1.1096E-01	0.0000E+00	4.1699E-02	3.3359E-02
F33205	1.4064E-02	1.1117E-02	9.3099E-02	1.1828E-01	0.0000E+00	0.0000E+00	0.0000E+00
F33103	2.7388E-02	5.5584E-02	9.3099E-02	1.7607E-01	3.0053E-01	2.6401E-01	4.6380E-01
F33102	1.9986E-02	4.4467E-02	6.2066E-02	1.2652E-01	1.1414E+00	1.2855E-01	1.0660E+00
F33103	1.3324E-02	4.4467E-02	2.1723E-01	2.7502E-01	3.7998E-01	0.0000E+00	3.5385E-01
F33104	3.0349E-02	7.7818E-02	2.4826E-01	3.5643E-01	3.5531E-02	0.0000E+00	3.1977E-02
F23401	2.6648E-02	5.5584E-02	9.3099E-02	1.7533E-01	3.7529E-01	0.0000E+00	3.7529E-01
F23402	2.9609E-02	7.7818E-02	1.5517E-01	2.6259E-01	2.1688E-01	0.0000E+00	1.9320E-01
F22401	3.0349E-02	6.6701E-02	1.2413E-01	2.2118E-01	5.6429E-01	3.7554E-01	8.0573E-01
F22402	2.5167E-02	3.3351E-02	1.2413E-01	1.8265E-01	2.5760E-01	0.0000E+00	2.2828E-01
F34101	2.3687E-02	4.4467E-02	1.2413E-01	1.9229E-01	7.1308E-02	0.0000E+00	7.1308E-02
F33301	1.2584E-02	5.5584E-02	2.7930E-01	3.4747E-01	1.1720E-01	2.4304E-01	2.2360E-01
F33302	2.5908E-02	1.1117E-01	1.8620E-01	3.2327E-01	2.2700E-01	0.0000E+00	1.9983E-01
F33303	1.0363E-02	1.1117E-01	1.8620E-01	3.0773E-01	2.0948E-01	1.5224E-01	2.9893E-01
F32101	3.4790E-02	6.6701E-02	2.1723E-01	3.1872E-01	7.6859E-01	3.0620E-01	9.5313E-01
F32102	2.7388E-02	3.3351E-02	9.3099E-02	1.5384E-01	0.0000E+00	3.0226E-01	2.4180E-01
F32103	3.7011E-02	6.6701E-02	9.3099E-02	1.9681E-01	6.0204E-02	1.9986E-02	6.1537E-02
F32104	2.9609E-02	7.7818E-02	1.2413E-01	2.3156E-01	6.6866E-01	0.0000E+00	6.5818E-01

Table 2 (cont.)

F32105	2.8869E-02	7.7818E-02	1.2413E-01	2.3082E-01	1.6862E+00	4.7769E-01	2.0545E+00
F32106	2.2947E-02	7.7818E-02	1.5517E-01	2.5593E-01	9.8696E-02	5.7959E-01	5.2674E-01
F26301	2.4427E-02	4.4467E-02	1.5517E-01	2.2406E-01	7.7427E-01	2.0603E-01	8.5614E-01
F26302	3.1829E-02	5.5584E-02	1.2413E-01	2.1155E-01	7.9253E-01	1.5791E-02	7.7765E-01
F26303	6.4399E-02	4.4467E-02	3.1033E-02	1.3990E-01	0.0000E+00	1.5791E-02	7.8957E-03
F26304	3.6271E-02	5.5584E-02	6.2066E-01	7.1252E-01	1.7519E-01	4.0465E-02	1.9727E-01
F26305	3.6271E-02	5.5584E-02	0.0000E+00	9.1855E-02	4.1625E-01	1.5791E-02	4.0626E-01
F26306	3.4790E-02	1.0005E-01	3.4136E-01	4.7621E-01	4.4586E-01	1.1942E-01	4.9062E-01
F26307	1.9986E-02	5.5584E-02	1.8620E-01	2.6177E-01	3.3048E+00	0.0000E+00	3.9779E-01
F26308	2.6648E-02	1.1117E-02	4.0343E-01	4.4120E-01	3.6937E-01	5.5516E-02	3.9308E-01
F26309	1.8505E-02	4.4467E-02	1.5517E-01	2.1814E-01	3.2224E-01	1.2855E-01	3.4509E-01
F26310	8.8826E-03	0.0000E+00	6.2066E-02	7.0949E-02	6.3165E-02	0.0000E+00	5.6849E-02
F26311	3.1089E-02	7.7818E-02	4.3446E-01	5.4337E-01	3.2372E-01	0.0000E+00	3.2372E-01
F26312	1.7765E-02	8.8935E-02	1.8620E-01	2.9290E-01	1.7000E-01	8.3891E-02	1.9344E-01
F26313	1.8505E-02	5.5584E-02	9.3099E-02	1.6719E-01	1.6433E-01	4.1699E-02	1.9769E-01
F26314	3.1089E-02	4.4467E-02	9.3099E-02	1.6866E-01	1.5791E-02	0.0000E+00	1.5791E-02
F26315	2.5908E-02	3.3351E-02	3.1033E-01	3.6959E-01	1.9986E-02	0.0000E+00	1.9986E-02
F26316	2.8128E-02	7.7818E-02	9.3099E-02	1.9905E-01	3.1583E-02	0.0000E+00	3.0004E-02
F26317	1.8505E-02	2.2234E-02	1.5517E-01	1.9590E-01	4.1699E-02	1.0980E-01	1.2954E-01
F26318	1.7025E-02	5.5584E-02	6.2066E-02	1.3468E-01	0.0000E+00	2.4674E-02	9.8696E-03
F26319	1.2584E-02	2.2234E-02	1.2413E-01	1.5895E-01	1.5791E-02	0.0000E+00	1.5791E-02
F26320	2.5167E-02	1.1117E-02	9.3099E-02	1.2938E-01	0.0000E+00	1.5791E-02	4.7374E-03
F26321	3.0349E-02	2.2234E-02	1.2413E-01	1.7672E-01	5.1322E-02	0.0000E+00	4.4611E-02
F26322	1.7765E-02	6.6701E-02	1.8620E-01	2.7067E-01	1.4484E-01	6.8347E-02	1.8952E-01
F26323	3.9972E-02	1.3340E-01	2.1723E-01	3.9061E-01	1.5791E-02	0.0000E+00	1.5791E-02
F26324	2.8869E-02	7.7818E-02	4.0343E-01	5.1012E-01	4.5227E-01	0.0000E+00	4.1025E-01

Table 3. The BASIC program NEWPR.BAS for analyzing raw Bitterlich prism data.

```
10 'NEWPR.BAS was written by Peter S. White in August, 1983, using BASIC
20 'release 2.0.
30 '
40 'The purpose of this program is to analyze Bitterlich prism plot data, print
50 'stand summary data, and write such data (if desired) to a diskette (drive
60 'B). This program is interactive, requiring keyboard input of project name,
70 'stand number, number of plots, prism factor, number of tree species,
80 'names or codes of the tree species, number of stems of the tree
90 'species and diameter of each stem.
100 '
110 'Note that the program DENSBITT.BAS distinguishes between canopy and
120 'subcanopy stems, because it was written for ground truth data in the
130 'remote sensing project. This distinction has not been used here.
140 '
150 CLS
160 PRINT "THIS PROGRAM ANALYZES BITTERLICH PRISM PLOT DATA."
170 PRINT "YOU MAY ENTER ANY COMBINATION OF NUMBERS AND ALPHABETIC"
180 PRINT "CHARACTERS FOR THE STAND NUMBER."
190 PRINT "YOU MAY USE ANY CHARACTERS FOR SPECIES—INCLUDING COMMON NAMES
200 PRINT "OR UPLANDS 6 LETTER CODES."
210 PRINT "BE SURE THAT YOUR DATA DISK (FOR DATA OUTPUT) IS LOADED IN
220 PRINT "POSITION B—WHATEVER DISK IS IN B WILL BE WRITTEN TO."
230 PRINT "BOTH RAW DATA AND SUMMARY STATISTICS ARE WRITTEN TO THE DISK."
240 CLS
250 WIDTH "LPT1:",84
260 PRINT
270 LPRINT
280 PRINT "DATE AND TIME FOR THIS PRINTOUT",DATE$;"; "TIME$
290 LPRINT "DATE AND TIME FOR THIS PRINTOUT",DATE$;"; ";TIME$
300 PRINT
310 LPRINT
320 PRINT "DO YOU WANT TO WRITE DATA TO AN OUTPUT FILE (YES/NO)";
330 INPUT ANS$
340 IF ANS$="no" THEN ANS$="NO"
350 IF ANS$="NO" GOTO 500
360 PRINT "WHAT PROJECT (ENTER HOG,FUELS,VEGMAP) ";
370 INPUT PRJ$
380 LPRINT "PROJECT NAME - ";PRJ$
390 IF PRJ$="HOG" GOTO 440
400 IF PRJ$="FUELS" GOTO 460
410 IF PRJ$="VEGMAP" GOTO 480
420 PRINT "INCORRECT PROJECT NAME--REENTER"
430 GOTO 370
440 FILE$ = "B:HOG.VEG"
450 GOTO 500
460 FILE$ = "B:FUELS.VEG"
470 GOTO 500
480 FILE$ = "B:VEGMAP.VEG"
490 GOTO 500
500 IF ANS$<>"NO" THEN OPEN FILE$ FOR APPEND AS #1
510 PRINT "STAND NO.";
520 LPRINT "STAND NO. ";
530 INPUT S$
540 LPRINT S$
550 LET TOTCBA=0
```

Table 3. (cont.)

```
560 DIM SP$(25)
570 DIM BA(25)
580 DIM RBA(25)
590 DIM DENS(25)
600 DIM RDENS(25)
610 DIM RIV(25)
620 LET TCDENS=0
630 LET TBAC=0
640 PRINT "NO. OF PLOTS ";
650 LPRINT "NO. OF PLOTS ";
660 INPUT P
670 LPRINT P
680 PRINT "PRISM FACTOR ";
690 LPRINT "PRISM FACTOR ";
700 INPUT PRF
710 LPRINT PRF
720 PRINT "NO. OF TREE SPP";
730 LPRINT "NO. OF TREE SPP ";
740 INPUT SP1
750 LPRINT  SP1
760 IF ANS$<>"NO" THEN WRITE #1,PRJ$,S$,P,PRF,SP1
770 FOR I=1 TO SP1
780 PRINT
790 LPRINT
800 PRINT "WHAT IS SPECIES ";I;
810 LPRINT "WHAT IS SPECIES ";I;
820 INPUT SP$(I)
830 LPRINT SP$(I)
840 PRINT
850 LPRINT
860 FOR L=1 TO P
870 PRINT "NO. OF STEMS OF ";SP$(I);" IN PLOT ";L;" IS ";
880 LPRINT "NO. OF STEMS OF ";SP$(I);" IN PLOT ";L;" IS ";
890 INPUT I1
900 LPRINT I1
910 IF ANS$<>"NO" THEN WRITE #1,SP$(I),I1
920 LET ST=ST+I1
930 IF I1=0 GOTO 1110
940 PRINT
950 LPRINT
960 FOR J=1 TO I1
970 PRINT "DIAMETER ";
980 LPRINT "DIAMETER ";
990 INPUT D
1000 LPRINT D
1010 IF ANS$<>"NO" THEN WRITE #1,D
1020 IF D=0 GOTO 1120
1030 LET D=D/100
1040 LET PI=3.141593
1050 LET BAC=((D/2)^2)*PI
1060 LET BACD=PRF/BAC
1070 LET TBAC=TBAC+BACD
1080 NEXT J
1090 PRINT
1100 LPRINT
```

Table 3. (cont.)

```
1110 NEXT L
1120 PRINT
1130 LPRINT
1140 LET FTBAC=TBAC/P
1150 LET TBAC=0
1160 LET TOTCBA=TOTCBA+FTBAC
1170 LET DENS(I)=TOTCBA
1180 LET BA(I)=(ST/P)*PRF
1190 LET TOTBA=TOTBA+BA(I)
1200 LET TCDENS=TCDENS+TOTCBA
1210 LET TOTCBA=0
1220 LET ST=0
1230 NEXT I
1240 FOR I=1 TO SP1
1250 LET RBA(I)=100*(BA(I)/TOTBA)
1260 LET RDENS(I)=100*(DENS(I)/TCDENS)
1270 LET RIV(I)=(RDENS(I)+RBA(I))/2
1280 NEXT I
1290 PRINT
1300 LPRINT
1310 PRINT "STAND SUMMARY TABLE FOR STAND ";S$
1320 LPRINT "STAND SUMMARY TABLE FOR STAND ";S$
1330 PRINT "SPECIES","BA","RBA","DENS","RDENS","RIV"
1340 LPRINT "SPECIES","BA","RBA","DENS","RDENS","RIV"
1350 PRINT ,"M2/HA","%","PER HA","%","%"
1360 LPRINT ,"M2/HA","%","PER HA","%","%"
1370 PRINT
1380 LPRINT
1390 FOR I=1 TO SP1
1400 PRINT SP$(I),BA(I),RBA(I),DENS(I),RDENS(I),RIV(I)
1410 LPRINT SP$(I),BA(I),RBA(I),DENS(I),RDENS(I),RIV(I)
1420 NEXT I
1430 PRINT
1440 LPRINT
1450 PRINT "TOTALS",TOTBA,,TCDENS
1460 LPRINT "TOTALS",TOTBA,,TCDENS
1470 IF ANS$<>"NO" THEN WRITE #1,S$,P,PRF,SP1
1480 FOR I=1 TO SP1
1490 IF ANS$<>"NO" THEN WRITE #1,SP$(I),BA(I),RBA(I),DENS(I),RDENS(I),RIV(I)
1500 NEXT I
1510 IF ANS$<>"NO" THEN WRITE #1,TOTBA,TCDENS
1520 CLOSE
1530 LPRINT CHR$(12)
1540 END
```

U.S. DEPARTMENT OF THE INTERIOR
NATIONAL PARK SERVICE
SCIENCE PUBLICATIONS OFFICE
75 SPRING ST., S.W.
ATLANTA, GEORGIA 30303

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE $300

POSTAGE AND FEES PAID
U. S. DEPARTMENT OF THE INTERIOR
INT-417

U.S.MAIL