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The Effect of Balsam Woolly Aphid Infestation on Fuel Levels in Spruce-Fir Forests of Great Smoky Mountains National Park

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THE EFFECT OF BALSAM WOOLLY APHID INFESTATION ON FUEL LEVELS IN SPRUCE-FIR FORESTS OF GREAT SMOKY MOUNTAINS NATIONAL PARK

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ABSTRACT

An exotic insect, the balsam woolly aphid (Adelges piceae Ratz.) has infested the spruce-fir zone of the Great Smoky Mountains since 1960. Fraser fir, a southern Appalachian mountain endemic, is highly susceptible to attack by the aphid, with death occurring within 2 to 5 years. The initial infestation in the park was from the east; the insect has since spread throughout the spruce-fir zone, with impacts becoming obvious in western stands near Clingmans Dome in the late 1970s. Because of increased fir mortality, a large increase in fuel loadings is expected. The objectives of this study were to quantify fuels and to investigate differences in fuel volumes due to stand history and elevation. The geographic gradient in aphid spread allowed us to establish a series of plots classified into four infestation histories: 17-23 yrs, 7-17 yrs, 3-7 yrs, and 0-3 yrs. The 0-3 yr class had not yet experienced significant aphid impacts. In addition to the four stand history classes, we classified stands into three elevational zones. Each stratification unit was sampled with three replicates. Dead and downed twigs and boles were sampled using the planar intercept method. Soil organic layer depth was recorded to the nearest 0.5 cm. Standing dead basal area and density were sampled using a Bitterlich 1-factor prism and tree diameter estimates. Analysis of variance and Scheffé comparison of means tests were used to test the significance of differences among stand classes.

The highest fuel volumes observed were in the high elevation, recently impacted stands (3-7 yrs). In these stands, standing dead basal area was 4 times higher, and bole wood and total downed wood were 2 times higher than in unimpacted stands. Soil organic layer depth was the only fuel component that had a minimum value in high elevation, recently impacted stands but was the only fuel component that was unpredictably related to stand history and elevation. Within both recently impacted stands and unimpacted stands, all fuel components except twig volume increased from low to high elevations. For most fuel components, stands impacted for 17 to 23 years had relatively similar values to unimpacted stands, suggesting that decomposition rate was high enough to reduce fuel loadings within this time frame. The presence of standing dead stems tended to spread the fuel loading impact to the forest floor over more years but to reduce peak fuel levels in any single year. The overall fuel patterns correlate well to original patterns of Fraser fir distribution in the pre-aphid landscape. Within the spruce-fir zone, Fraser fir importance increased from low to high elevations. Although average tree size and system biomass decreased along this gradient, the trend was not offset by increasing importance of Fraser fir.

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INTRODUCTION

The balsam woolly aphid (Adelges piceae Ratz.), an exotic pest of Fraser fir (Abies fraseri) (nomenclature follows White 1982) in the southern Appalachians, arrived in Great Smoky Mountains National Park (GRSM) by 1963 (Ciesla et al. 1963) and has spread throughout the natural range of the park's spruce-fir forests (Hay et al. 1978). Fraser fir, a southern Appalachian mountain endemic, is highly susceptible to attack by the aphid with death occurring within two to five (rarely seven) years of initial colonization (Amman and Speers 1965). The eventual death of all mature fir trees in the park is likely within the next 10 to 20 years. Because of increased and relatively synchronous mortality, a large increase in fuel accumulations in spruce-fir forests is hypothesized. Information on aphid-affected fuel loadings was cited as a priority research need in a regional symposium (SARRMC 1980). The objective of this study was to determine the magnitude of this increase in fuels and to document differences in fuel loadings due to elevation and length of time since aphid infestation. The fuels that were measured included live and dead standing basal area and density, dead and downed boles and twigs, and the depth of organic horizons in the soil. The fuels information developed in this report is part of an ongoing effort to quantify park fire fuels; it will also be used with remote sensing data to produce an all-park fuels map.

Our main hypothesis was that forest fire fuels in spruce-fir forests were increased by balsam woolly aphid attack. Because stand composition and structure both change with elevation (Fraser fir importance increases and average tree size decreases from low to high elevations in the spruce-fir zone) (Whittaker 1956), we organized our sampling in three elevation classes. Elevation has also been shown to influence organic matter production and decay (Shanks and Olson 1961, Wilde 1958). Decomposition rates are fairly high in these humid mountains.

LITERATURE REVIEW

GRSM Spruce-Fir Vegetation. Southern spruce-fir forests are dominated by two evergreen coniferous trees: red spruce (Picea rubens) and Fraser fir. Red spruce is found throughout the eastern mountain chain, but Fraser fir is a southern Appalachian endemic restricted to high elevations in the high peaks region (Ramseur 1960). Well developed spruce-fir vegetation in the southern Appalachians is restricted to seven mountain ranges (Ramseur 1960). Of these seven areas, the Great Smoky Mountains has the largest tract of spruce-fir forest. Spruce-fir vegetation occurs only at higher elevations; the average transition from deciduous forest to spruce-fir at this latitude is 5500 ft (1680 m) (Ramseur 1960), but spruce-fir forests can be found at 4500 to 5000 ft (1360-1520 m) on some slopes. Individuals of spruce and fir occur at elevations lower than the spruce-fir forest type. Whittaker (1956) termed GRSM spruce-fir forests the "southern Appalachian subalpine forest."

The composition of spruce-fir forest varies with elevation. At lower elevations (e.g., 4500-5000 ft, 1360-1520 m) and on drier slopes, red spruce dominates and Fraser fir is scarce. On these sites, red spruce may share dominance with yellow birch (Betula lutea) or hemlock (Tsuga canadensis). As elevation increases, Fraser fir becomes more important. Above 6200 ft (1890 m), the vegetation is dominated by Fraser fir. At the higher elevations (6400-6600 ft, 1960-2020 m), Fraser fir is often the sole dominant, and mountain ash (Sorbus americana) may be the only other canopy tree present (Whittaker 1956). Along with the change in composition from low to high elevations and increasing exposure, there is a change in forest structure: average tree size and height decrease as elevation and exposure increase. Most canopy trees in high elevation Fraser fir forests are 18 to 23 cm in diameter and 9 to 12 m tall (Whittaker 1956). Other members of the spruce-fir forests include mountain maple (*Acer spicatum*), striped maple (*Acer pensylvanicum*), and serviceberry (*Amelanchier laevis*). Endemic and northern species at their southern range limits are frequent in GRSM spruce-fir vegetation.

Aphid Infestations in GRSM. The balsam woolly aphid is native to Eurasia. It was first identified in North America in 1908 on balsam fir in Maine (Kolinsky 1916). The first evidence of the aphid in the southern Appalachians was on Mount Mitchell, North Carolina, in October 1957 (Speers 1958). The first records of the aphid in GRSM occurred about 1960, with the easternmost part of the park colonized first (Eagar 1978). The aphid has since spread throughout the spruce-fir forests of GRSM, becoming conspicuous in the western part of the spruce-fir zone (Clingmans Dome area) in the late 1970s. Infestations typically begin at lower elevations on a given slope and then progress upslope through the stand (Eagar 1978).

The balsam woolly aphid feeds on the parenchyma of all true firs (Balch 1952). Attack by the insect is fatal to mature Fraser fir trees. Bark of infested trees is covered with patches of white, woolly, waxy material that is produced on the back of the aphids. The insect causes two principal types of damage. Insect attack on the trunk produces thick-walled vessels, reddish discoloration of the wood, and brittleness (Balch 1952, Doerksen and Mitchell 1965). Substances are secreted by the aphid prior to and during feeding on the tree's cortex. Material diffuses through the phloem and cambium and interacts with the xylem. In the xylem occurs a crusting of border pit membranes in tracheids. The resulting effect is a reduction of water and nutrients to the tree crown (Puritch 1971, Puritch and Johnson 1971).

Related Fuel Studies. By definition, fuels consist of both living and dead plant materials (Martin et al. 1979). However, most resources managers are primarily concerned with "available fuels," those that actually burn in a fire.

Fuels may be regarded as the result of a natural lag between the production of natural material and its decay. Forest disturbances of all kinds may suddenly bring about an increase in the volume of dead fuels (Brown and Davis 1973). In a fire history of GRSM, Harmon (1980a) found that fire, insect and fungal epidemics (balsam woolly aphid, southern pine beetle, chestnut blight), ice damage, and windthrow were observed to increase woody fuel levels. Komarek (1974) observed that logging operations also increased fuel levels. The overcutting of the forest put much more flammable fuel on the surface of the ground than could have naturally occurred.

Harmon (1980b) hypothesized that forest fuel levels increased after a major disturbance such as the chestnut blight or insect infestation. In a study examining fuels in yellow pine stands, sampling sites were chosen according to three factors: presence or absence of southern pine beetle (*Dendroctonus frontalis* Zimm.) infestation, elevation, and topography. Infestation by the pine beetle was the most significant factor to influence fuel levels, with total volume of woody debris 3 times higher in infested stands (110.3 m^3/ha) versus unaffected stands (30.6 m^3/ha) (Nicholas and White 1984).

Fuel information for southern forests is most extensive for pine-dominated vegetation. For nonpine forests, the information is generally limited to fire case histories or estimates of biomass for specific areas (Martin et al. 1979).

Little work has been done on spruce-fir forests. Fuels information for spruce-fir is important because of increased fuels due to aphid infestation. The potential energy release of a fire, and thus fire intensity, is directly proportional to fuel mass present (Martin et al. 1979). Hence, there may be a risk of catastrophic fire in aphid-impacted spruce-fir stands.

Most previous fuels research conducted in the southern Appalachian spruce-fir zone are portions of studies comparing fuels of different community types. Shanks and Olson (1961) examined leaf litter decay from five tree species (Morus rubra Acer saccharum, Quercus alba, Q. falcata, and Fagus grandifolia) in six southern Appalachian forests (evergreen versus deciduous at three elevations). The effect of the three variables (altitude, forest cover type, and tree species) were all statistically significant. Leaf breakdown increased in deciduous cover, with decreasing elevation, and varied among species. More recently, Harmon (1980b) studied annual leaf litter production and found that it increased with greater stand basal area and stem density. The organic horizons were also significantly different among forest cover types.

Woody fuel dimension studies have also been undertaken. Bole diameter and bulk density were examined for downed wood in six major GRSM forest types (Harmon et al. 1980). Consistent but nonsignificant differences in downed wood bulk density were observed among forest types. In general, small downed wood biomass diminished with increasing stem density, basal area, and on northern slopes (Harmon 1980b).

Nicholas (1984) used multivariate analysis to predict GRSM fuel levels by using site variables. Elevation was the most significant site variable for describing fuel levels; fuels increased as elevation increased. Fuel differences existed among the nine forest types studied. Overall, the Fraser fir type had the largest fuel levels.

Fire in the Spruce-Fir. Fires are rare in logged spruce-fir forests because of climatic conditions (Wright and Bailey 1982). One of the very rare man-caused fires in an undisturbed mature southern spruce-fir forest occurred in 1955 on Plott Balsam Mountain, North Carolina. An excaped campfire burned approximately 1 hectare at an elevation of 1683 to 1732 m. Twenty-five years later, the tree canopy had a stand basal area of 7.04 m^2/ha and was dominated by Fraser fir. Other important species included yellow birch, fire cherry (Prunus pensylvanica), and mountain ash. Red spruce contributed only 4.0 percent of the stand basal area (Saunders et al. 1983).

The infrequent fires that do occur are generally destructive. Korstian (1937) found that the depletion of the southern Appalachian spruce-fir was due to fire following logging. These fires usually destroyed both vegetation and the organic layer of the soil. The destruction of the forest floor exposed the remaining soil to erosion. In extreme cases, strong rains have eroded the soil (both by widespread sheet erosion and by local gullying), and underlying rock was exposed.

Vegetation, within a year after a burn, is frequently a dense growth of blackberry and red raspberry (Rubus spp.) briers. This is followed by fire cherry and yellow birch. Fire cherry is dominant for up to 50 years and is replaced by yellow birch and less tolerant hardwoods. Several shrub species, such as rhododendron (Rhododendron spp.), mountain laurel (Kalmia latifolia), serviceberry (Amelanchier laevis) and huckleberry (Gaylussacia spp.), contribute to stand density (Korstian 1937).

Because lightning tends to strike the highest point of the landscape, it might be expected that lightning fires would be more frequent at higher elevations. However, data from GRSM contradicts this idea (Barden and Woods 1973). Fire records of GRSM from 1940 to 1979 indicate that there has been little fire activity in the high elevation spruce-fir communities. Harmon (1981) found that between 1525 m and 1830 m elevation, three man-caused fires burned 6.09 ha, and four lightning-caused fires burned .04 ha. No fires have occurred above 1830 since 1940, and past fire incidence in the higher elevation spruce-fir communities appears very low. Harmon (1981) also calculated fire rotation periods for different areas of the park. Fire rotation is defined as the number of years required to burn an area equivalent to a particular area of interest (Heinselman 1973). High elevation forests in GRSM have extremely long natural rotation periods (Harmon 1981). Therefore, the principal danger is human-caused fires, although extreme drought would increase the likelihood of natural fire.

METHODS

Plot Selection. Sampling sites were chosen by elevation and length of time since aphid infestation (Fig. 1). Three elevation classes were used: low (5000-5500 ft, 1524-1676 m), mid- (5500-6000 ft, 1676-1829 m), and high elevations (6000-6500 ft, 1829-1981 m). Four classes of infestation history were used: long (17-23 yrs), medium (7-17 yrs), short (3-7 yrs), and unimpacted (0-3 yrs). The unimpacted category contained stands which had not yet experienced significant Fraser fir mortality, but aphids were present in many of these stands. The classes of stand history were approximate; no detailed data exists on a stand by stand basis. Our infestation history classes were extrapolated from broader scale patterns of infestation spread in the park (C. Eagar, personal communication). Throughout this paper we refer to infestation classes by such shorthand expressions as "infested" or "impacted" for a given number of years. In some cases, aphids may now be rare in some of these stands, since all of the mature Fraser fir are dead. We use "recently infested" to refer to stands impacted for 3 to 7 years. We refer to the unimpacted stands as "uninfested," although aphids may or may not have been present in 1983 when we sampled. The four infestation history classes and the three elevation classes resulted in 12 total possible combinations. Of these, one combination no longer exists: unimpacted stands at low elevations (in each infested area, aphid infestation started at low elevations). The other 11 "cells" were sampled with three replicates, giving a total sample size of 33 fuel inventories (Fig. 1).

General areas fitting the criteria listed above were located on USGS 7.5' topographic maps. Actual site locations for sampling were randomly determined in the field. Plot locations were recorded on the topographic maps deposited at Uplands Field Research Laboratory.

Data Collection. The following environmental parameters and community data were recorded: forest type; understory type; elevation; topographic class; and slope steepness, aspect, and shape. Dead and downed twigs and boles were sampled using the planar intersect method (Brown and Roussopoulos 1974, Brown 1974, Brown 1971). The method requires counting the number of wood particle intersections

Elevation / Length of Aphid Impact	Long (17-23 yrs)	Medium (7-17 yrs)	Short (3-7 yrs)	No Impact (0-3 yrs)
1524-1676 m (5000-5500 ft)	3	3	3	*
1676-1829 m (5500-6000 ft)	3	3	3	3
1829-1981 m (6000-6500 ft)	3	3	3	3

* This cell does not exist anymore

Figure 1. Sampling design based on elevation versus length of balsam woolly aphid impact. Three plots were sampled for each cell.

with 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 size classes correspond to the 1-hour, 10-hour, 100-hour, and 100-hour-plus lag-time classes that are used for fire management purposes (Martin et al. 1979). The three twig classes (0-7.6 mm diameter) were sampled along 2 m (0-7 mm), 3 m (7-25 mm) and 11 m (25-76 mm) transects. The twig classes were sampled separately because of the need to use separate mean cross-sectional areas in volume calculation and because they require different transect lengths; however, the three volumes were later summed to give total twig volume (reported below). The bole class (>76 mm) was sampled along two 25-m transects and the wood was categorized as sound or rotten. The percentage of sound bole wood as a function of original bole size 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 sampling to aphid-infested stands, a constraint on transect length was imposed. Pickford and Hazard (1978) point out that with increasing transect length there is a decrease in sample variance.

Soil organic layer depth was recorded to the nearest 0.5 cm. Three samples in each stand were used to measure the depth of the litter (undecomposed debris), fermentation (partially decomposed debris), and humus horizons (completely decomposed debris) that comprised the organic layer. The organic layers were then summed to give a total organic soil depth.

Dead, standing trees (the angle for "standing" trees was defined as 45^{o} or greater) and live trees were sampled using a 1-factor metric Bitterlich prism. Diameter at breast height was recorded for each standing stem.

<u>Data Analysis</u>. The data was analyzed using an IBM Personal Computer at Uplands Field Research Laboratory and an IBM 360/65 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 uses Van Wagner's 1968 equation but defines twig diameter as a function of twig average cross-section. For the three twig classes:

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

where:

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

n_i = number of intercepts of twig size class i

d_i = mean diameter for 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 (Dilworth and Bell 1975).

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.

RESULTS

Live Basal Area and Density. Live canopy basal area increased as elevation increased and was lowest in the most recently disturbed stands (Table 2). Analysis of variance showed that infestation level, elevation, and the interaction between these two variables accounted for significant portions of the variance in live basal area (Table 2). Scheffé comparison of means test showed that unimpacted stands (mean live basal area = 21.8 m^2/ha) did not differ significantly (α = .05) from stands infested for 17 to 23 years (mean = 19.2 m^2/ha); but that these two stand classes had significantly higher live basal area than stands impacted for 3 to 7 years (mean = 10.5 m^2/ha) and those infested for 7 to 17 years (10.2 m^2/ha). Within recently infested stands, the lowest live basal areas were found at high elevations (5.7 m^2/ha), corresponding to the natural increase of pre-aphid impact Fraser fir basal area with increasing elevation (Whittaker 1956). The mean live basal area of recently impacted stands at high elevations was about 30 percent of the value of unimpacted stands on equivalent sites (Table 1).

Live canopy stem density also decreased from low to high elevations and from unimpacted to recently impacted stands; however, only infestation level was statistically significant. Scheffé comparison of means test showed that unimpacted stands (mean density = 1062.5 stems/ha) had significantly greater density than stands infested for 7 to 17 years (mean = 176.0 stems/ha). Stands impacted for 3 to 7 years had a mean live canopy density of 411.0 stems/ha. Within recently infested stands, the lowest live canopy densities were at high elevations (305.7 stems/ha). This value was only 38 percent of that recorded for umpacted stands on equivalent sites (Table 1). Stands impacted for 17 to 23 years had about 80 percent of the live canopy stem density of unimpacted stands.

Table 1. Cell mean values for all ANOVA tests. (Old = 17-23 yrs infestation; Medium = 7-17 yrs infestation; Recent = 3-4 yrs infestation; None = no impact; L, M, H are low, medium, and high elevation classes)

INFESTATION CLASS	ELEVATION CLASS	LIVE STEM BASAL AREA (m^2/ha)	LIVE STEM DENSITY (stems/ha)	DEAD STEM BASAL AREA (m^2/ha)	DEAD STEM DENSITY (stems/ha)	TWIG VOLUME PER AREA (m^3/ha)	BOLE VOLUME PER AREA (m^3/ha)	TOTAL DOWNED WOOD VOLUME PER AREA (m^3/ha)	MEAN ORGANIC SOIL LAYER DEPTH (cm)
A	B	Y	Y	Y	Y	Y	Y	Y	Y
Old	L	25.0	1368.5	7.0	553.1	54.2	41.2	95.4	7.1
Old	M	9.7	464.9	17.7	500.9	45.8	80.9	126.8	15.4
Old	H	23.0	816.1	13.0	636.2	51.7	109.1	160.8	14.0
Medium	L	11.3	194.4	22.7	457.0	41.4	92.0	133.3	11.1
Medium	M	13.3	243.7	22.0	604.8	29.4	167.5	96.9	11.2
Medium	H	6.0	89.8	27.3	1042.2	41.6	146.9	188.5	11.6
Recent	L	15.0	550.0	12.7	507.8	31.4	39.7	71.0	7.1
Recent	M	10.7	377.2	17.0	491.6	23.9	162.8	186.8	8.2
Recent	H	5.7	305.7	19.7	1142.9	65.1	186.0	251.8	9.9
None	M	24.0	1323.4	8.0	661.6	29.6	90.2	119.9	12.0
None	H	19.7	801.5	5.3	201.7	41.0	92.8	133.8	12.6

Table 2. Analysis of variance F-values for all tests (α = .05). A = Length of aphid infestation; B = Elevation.

Y	Source of Variation	DF	Type IV SS	F-Value	PR>F
Total Twig Volume	A	3	0.08094646	0.72	0.5510
	B	2	0.18852049	2.52	0.1048
	A*B	5	0.15957310	0.85	0.5288
Bole Volume	A	3	2.71542200	2.98	0.0547
	B	2	3.34676529	5.51	0.0120
	A*B	5	1.95705404	1.29	0.3064
Total Wood Volume	A	3	3.07375546	2.49	0.0879
	B	2	4.36511589	5.31	0.0136
	A*B	5	1,54276478	1.24	0.3269
Organic Soil Layer Depth	A	3	97.07458333	5.28	0.0072
	B	2	54.55701550	4.45	0.0245
	A*B	5	55.84943182	1.82	0.1522
Dead, Standing Basal Area	A	3	1007.16666667	6.43	0.0029
	B	2	169.47286822	1.62	0.2210
	A*B	5	132.03535354	0.51	0.7684
Dead, Standing Density	A	3	605901.88605263	0.91	0.4526
	B	2	685192.86902381	1.55	0.2371
	A*B	5	1043421.69876716	0.94	0.4750
Live Canopy Tree Basal Area	A	3	717.66666667	12.43	0.0001
	B	2	136.82170543	3.56	0.0468
	A*B	5	456.80808081	4.75	0.0047
Live Canopy Tree Density	A	3	2766379.05499999	5.00	0.0090
	B	2	375125.36248062	1.02	0.3787
	A*B	5	1018325.94954546	1.10	0.3875

Standing Dead Basal Area and Density. The length of time since aphid infestation accounted for a highly significant portion of the variance in standing dead basal area (Table 2). The highest recorded values were in the 7 to 17 year infestation class (mean = 24.0 m^2/ha); at all elevations the mean dead basal area in this class surpassed 20 m^2/ha (Table 1). Standing dead basal area was also relatively high in the 3 to 7 impact class. The lowest standing dead basal areas recorded were in unimpacted stands which average from 20 to 50 percent of the dead basal areas of impacted stands (Table 1). The Scheffé comparison of means test showed that stands impacted for 7 to 17 years (24.0 m^2/ha) had significantly higher dead basal areas than unimpacted stands (mean = 6.7 m^2/ha). Standing dead stems apparently persisted in these stands; stands impacted for 17 to 23 years had two times the dead basal area of unimpacted stands (Table 1). The effect of elevation in explaining variance in dead basal area was not significant.

While trends in standing dead canopy density were apparent, elevation and infestation level did not account for a significant amount of the variability. Standing dead canopy density increased from low to high elevations and was highest in the most recently impacted stands (Table 1). The highest values were thus at high elevations, in stands infested for 3 to 7 years (mean = 1142.9 stems/ha), and in those infested for 7 to 17 years (mean = 1042.2 stems/ha). Unimpacted stands at high elevations had about 20 percent of the standing dead densities of these values. High elevation stands infested for 17 to 23 years had about two times more standing dead stems per unit area than unimpacted stands on the same kinds of sites. The lowest standing dead densities occurred in high elevation, unimpacted stands (mean = 201.7 stems/ha).

Twig Volume. Variance in total dead and downed twig volume was not significantly accounted for by either infestation history or elevation or the interaction of these variables (Table 2). The maximum recorded value was for high elevation recently impacted stands (mean = 65.1 m^2/ha), but there was no consistent patterns in the full data set (Table 1).

Bole Volume. Dead and downed bole volume generally increased from low to high elevations and, for a given elevation class, was highest in the more recently impacted stands (Table 1). The highest value recorded for any stand class was that for high elevation stands impacted for 3 to 7 years (mean = 186.0 m^3/ha). The only other values to exceed 100 m^3/ha were the mid- and high elevation stands infested for 3 to 7 years or 7 to 17 years (Table 1).

While infestation level was not a statistically significant variable, volume of dead and downed bole wood was generally low in stands impacted for 17 to 23 years. The minimum value we recorded for any stand class was 9.1 m^3/ha, which was in high elevation stands impacted for 17 to 23 years. This value was about 10 percent of the value of unimpacted stands and 5 percent of the value of recently impacted stands on equivalent sites. This may reflect high decomposition rates. A second factor is that high elevation stands were dominated by relatively pure Fraser fir forests. After the pulse-like input of dead wood following aphid attack, there would be few other mature trees left standing to contribute new quantities of bole wood over time.

Highly significant increases in dead bole volume occurred as elevation increased (Table 1). Scheffé comparison of means test showed that high elevation stands (mean = 133.7 m^3/ha) had significantly higher downed bole volumes than low elevation stands (59.7 m^3/ha). Mean bole volume in low elevation, impacted forests was about one-half of the downed bole volume in high elevation impacted forests (Table 4). This likely resulted from the original increase in Fraser fir importance from low to high elevations in the pre-aphid landscape.

Total Downed Wood Volume. Elevation accounted for a significant portion of the variance of total downed wood volume (Table 1). Scheffé comparison of means test showed that high elevation stands (mean = 183.6 m^3/ha) had significantly higher total downed wood volumes than low elevation stands (100.5 m^3/ha; Table 1). Mid-elevation stands were intermediate (132.6 m^3/ha).

While infestation level was not a statistically significant variable, recently impacted stands (154.6 m^3/ha) had higher downed wood volumes than unimpacted and long-impacted stands (129.3 m^3/ha). The highest value observed was 251.1 m^3ha on high elevation sites impacted for 3 to 7 years. This was 1.8 times the values for impacted and long impacted stands on equivalent sites. Stands impacted for 17 to 23 years had total downed wood volumes only 10 to 20 percent higher than unimpacted stands (Table 1).

Organic Layer Depth. Total soil organic layer varied significantly among elevation and infestation classes (Table 1). As elevation increased, depth of these organic layers increased: the lowest elevation stands had a mean depth of 8.6 cm, the mid-elevation stands had a mean depth of 11.7 cm, and the high elevation stands had a mean depth of 12.0 cm (Table 1). The difference between the latter two means was not significant, but these two means were significantly higher than the value for low elevation stands. Organic layer depth was lowest in the most recently impacted stands. The mean organic layer depth in stands impacted for 3 to 7 years was significantly lower (8.4 cm) than in the other three impact age classes, which had means of 11.3 cm (7 to 17 years), 12.3 cm (unimpacted stands), and 12.8 cm (17 or more years). In high elevation stands, organic layer depth was 9.9 cm in stands impacted for 3 to 7 years, 11.6 cm in stands impacted for 7 to 16 years, 14.0 cm in stands impacted 17 to 23 years, and 12.6 cm in unimpacted stands (Table 1).

DISCUSSION

The broadscale patterns in our data set are summarized as follows. Fuel levels in GRSM spruce-fir vegetation were highest in recently impacted, high elevation stands. In these stands, standing dead basal area was 4 times greater, and downed bole wood and total downed wood volumes were 2 times greater than they were in unimpacted stands on equivalent sites. Twig volume was highest in high elevation, recently impacted stands, but this fuel component behaved in an unpredictable manner among the other stand classes. A strong elevational gradient was also present for fuel levels. Within recently impacted spruce-fir stands, live basal area decreased, while standing dead basal area, downed bole wood volume, and total downed wood volume increased from low to high elevations. In unimpacted stands, all fuel components except standing dead basal area increased from low to high elevations but at a more gradual rate than was the case for recently impacted stands. Standing dead basal area was unrelated to elevation in unimpacted stands. Soil organic layer depth also increased from low to high elevations, both in unimpacted and recently impacted stands. Interestingly, soil organic layer depth was the only fuel component which was lower in recently impacted stands compared to unimpacted stands. This pattern was consistent in all three elevation classes. This may be the result of increased solar radiation, increased forest floor temperature allowing an increase in microbe and insect activity, and therefore faster decomposition rates.

For several fuel components, recently impacted stands and stands impacted for 17 to 23 years had only 15 percent less live basal area, had similar or lower bole wood volumes, and had only 10 to 20 percent higher total downed wood volumes when compared to unimpacted stands. The only fuel component that differed from this pattern was standing dead basal area. Stands impacted for 17 to 23 years had 3 times the dead basal area than unimpacted stands, which supports Harmon's (1982) statement that standing dead stems decay more slowly than fallen stems. The similarity of unimpacted stands and stands impacted for 17 to 23 years supports the interpretation that decomposition rates are high enough so that 90 percent of the fallen woody debris has disappeared within the longest aphid infestation period. Standing dead basal area was only about 40 percent lower over this time period. Further, all stems do not die in the same year-- standing dead basal areas were higher in the 7-to-17-year class than the 3-to- 7-year class. Our findings differ from those of a study done in a subalpine balsam fir forest (Lambert et al. 1980), in which 50 percent of the total bole mass was lost by 23 years, while 90 percent was lost by 77 years.

Standing dead stems represent a pool of woody debris that is gradually released to the downed woody debris pool. This phenomenon results in a less sharply defined pulse of dead wood to the forest floor (as compared to, for example, single season clearcut) and thus tends to spread total fuel loading impact to the forest floor over more years. This results in a longer period of increased fuel loadings combined with lower peak downed fuel loading in any one year.

Several sources of uncertainty underlie this interpretation. The length of the bole transect lines was confined by the size of aphid-infested stands and were shorter than what have been prescribed elsewhere (Pickford and Hazard 1978). We used a time series of aphid infestation periods rather than decomposition experiments in our sampling design. Further, not all of the trees die in the same year; this itself could explain the continued presence of standing dead stems relative to downed bole wood. We did not quantify the rate of fall of dead stems and branches (that is, the transfer rate between standing dead stems and downed woody debris); this would require a series of measurements over several years. Finally, we did not measure changing wood density along our time series but relied on wood volumes to gauge decomposition. In our work on pine beetle infestations (Nicholas and White 1984), we had wood density estimates from work of Harmon et al. (1980) that we used to convert volumetric data on fuels to mass. We presently have no data on southern Appalachian spruce-fir forests but plan to acquire these data in the future.

One management action that has been suggested is the cutting and felling of Fraser fir stems to promote decay and reduce fire hazard. Our data certainly support a hypothesis of faster rate of decay for fallen stems. Ideally, however, several of the uncertainties cited above would need to be investigated in order to fully justify such a management action. For example, natural rates of tree fall for aphid-killed Fraser fir should be quantified, and experimental cutting should be undertaken to quantify the fuel loadings and decay rates that would result.

The fuel patterns reported above correlate strongly to the original, pre-aphid distribution of Fraser fir. From low to high elevations in the spruce-fir zone, Fraser fir becomes more important and, at high elevations, occurs in relatively pure stands (Whittaker 1956). Thus, potential impact of the aphid increases on the same gradient. It should be noted, however, that the elevational gradient in stand structure would tend to diminish aphid impacts from low to high elevations: average tree size (diameter and height), and system biomass decrease from low to high elevation. Although the potential impact of the aphid in terms of fuels will be complicated by these interacting and opposite gradients, we found that fuel loadings were strongly and directly related to elevation. Evidently, the increase in relative importance of Fraser fir is enough to offset decreasing stand biomass. Further, decomposition rate declines strongly with elevation (Wilde 1958), leading to longer residence time of a given amount of organic matter across the gradient we sampled. We chose not to include topographic exposure in this sampling design for the following reason. As elevation increases, the effect of topographic exposure on site moisture relations in GRSM becomes diminished; that is, exposure classes do not influence stand characteristics as strongly in high elevation spruce-fir forests as they do in lower elevation forests.

The fact that decomposition rates fall with increasing elevation is the most frequent explanation of the increase in soil organic layer depth with increasing elevation (Wilde 1958, McGinnis 1958, Wolfe 1967, Shanks and Olson 1961). The fact that organic layer depth was at its minimum in recently impacted stands is intriguing. We have no direct evidence from our stands, but this phenomenon is consistent with the hypothesis that opening of the canopy results in higher forest floor temperatures, which would result in faster decomposition rates. There are several additional factors. With the death of the canopy Fraser fir and after the first pulse of dead needles, yearly inputs of new leaf liter would be reduced for several years and would be subsequently dominated by broad-leaved species whose leaves decay faster than coniferous needles. Further, as woody debris was converted to humus, organic layers would build quickly again.

CONCLUSIONS

1. The infestation of balsam woolly aphid has resulted in increased fuel loadings in GRSM spruce-fir vegetation. These fuel loadings were, in most cases, strongly related to the two characteristics used to classify sampled stands: infestation history and elevation.

2. The highest fuel loadings tended to occur at the high elevations (6000-6500 ft, 1821-1981 m) in recently impacted (3 to 7 years) stands. In these stands, standing dead basal area was 4 times higher, and downed bole wood and total downed wood volumes were 2 times higher than in unimpacted stand on equivalent sites.

3. The maximum values recorded for each woody fuel component were as follows: standing dead basal area, 24.0 m^2/ha (high elevation stands impacted for 7 to 17 years); downed twig volume, 65.1 m^3ha (high elevation stands impacted for 3 to 7 years); downed bole wood volume, 186.0 m^3/ha (high elevation stands impacted for 3 to 7 years); and total downed wood volume, 251.8 m^3/ha (high elevation stands impacted for 3 to 7 years).

4. Soil organic layer depth reached its maximum value on mid-elevation stands impacted for 17 to 23 years. This parameter was the only fuel component that was at its minimum value in stands impacted for 3 to 7 years. This may be related to increased soil temperature with opening of the canopy (producing faster decay rates), lower leaf litter input after aphid attack, and/or a change in leaf litter character.

5. Twig volume was highest in high elevation stands impacted for 3 to 7 years, but was the only fuel component that was unpredictably related to elevation and infestation history when the full data set was considered.

6. Within recently impacted stands, standing dead basal area, downed bole volume, total downed wood, and soil organic layer depth all increased from low to high elevations. These parameters also increased from low to high elevations for unimpacted stands but at a more gradual rate.

7. For all fuel components except standing dead basal area, stands impacted for 17 to 23 years were relatively similar to unimpacted stands. Stands impacted for 17 to 23 years had only 15 percent less live basal area, had similar or lower downed bole wood volumes, and had only 10 to 20 percent higher total downed wood volumes when compared to unimpacted stands. This strongly suggests that decomposition rates are fairly high and serve to reduce fuel volumes relatively quickly.

8. Standing dead basal area was 4 times higher in high elevation, recently impacted stands compared to unimpacted stands at the same elevation. Standing dead basal area was about 3 times higher in stands infested for 17 to 23 years compared to unimpacted stands. These data suggest the need to test the hypothesis that standing dead stems decay more slowly than fallen stems and that standing dead stems tend to spread the increased forest floor fuel loadings caused by the balsam woolly aphid over more years. This would also work to lower peak volumes at the forest floor in any one year. This phenomenon is probably also related to the fact that not all trees in a given stand die in the same year.

9. The fuel distribution patterns discussed above correlate with the original distribution of Fraser fir in the GRSM landscape. Within the spruce-fir zone, Fraser fir importance increased with increasing elevation. Thus potential balsam woolly aphid impacts also increase along this gradient. Although average tree size and system biomass tend to decrease on the elevational gradient, this trend did not offset that caused by increasing original density of mature Fraser fir trees.

10. Further work is necessary to gain a more complete understanding of organic matter dynamics in impacted spruce-fir stands before management action may be taken to reduce fire hazard. Permanent plot monitoring is needed to quantify organic pool input (production) and output (decay) as well as further standing crop inventorying.

REFERENCES CITED

Amman, G. D., and C. F. Speers. 1965. Balsam woolly aphid in the southern Appalachians. J. For. 63:18-20.

Balch, R. E. 1952. Studies of the balsam woolly aphid (Adelges piceae Ratz.) and its effects on balsam fir (Abies balsamea L. Miller). Can. Dept. of Agric. Publ. No. 867. 76 p.

Barden, L. S., and F. W. Woods. 1973. Characteristics of lightning fires in Southern Appalachian Forests. Proc. 12th Annu. Tall Timbers Fire Ecology Conf. 12:345-361.

Brown, A. A., and K. P. Davis. 1973. Forest fire: control and use. McGraw-Hill Book Co., New York. 686 p.

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 wood material. USDA Forest Service Gen. Tech. Rep. INT-16. Intermountain For. and Range Exp. Stn., 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.

Ciesla, W. M., H. L. Lambert, and R. T. Franklin. 1963. The status of the balsam woolly aphid in North Carolina and Tennessee. USFS-SA, S&PF, Div. FPM, Asheville, NC., Rep. No. 1-11-63. (unpublished)

Dilworth, J. R., and J. F. Bell. 1975. Variable probability sampling - variable plot in 3P. Oregon State Univ. Book Store, Corvallis, OR. 130 p.

Doerksen, A. H., and R. G. Mitchell. 1965. Effects of the balsam woolly aphid upon wood anatomy of some western true firs. For. Sci. 11:181-188.

Eagar, C. C. 1978. Distribution and characteristics of balsam woolly aphid infestation in the Great Smoky Mountains. M.S. Thesis, Univ. Tennessee, Knoxville. 72 p.

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

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. 32. 65 p.

Harmon, M. E. 1981. Fire history of the Great Smoky Mountains National Park, 1940-1979. NPS-SER Res./Resour. Manage. Rep. 46. 53 p.

Harmon, M. E. 1982. Decomposition of standing dead trees in the southern Appalachian Mountains. Oecologia 52:214-215.

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.

Hay, R. L., C. C. Eagar, and K. D. Johnson. 1978. Fraser fir in the Great Smoky Mountains National Park: its demise by the balsam woolly aphid (Adelges piceae Ratz.). Contract Rep. NPS-SER, Atlanta. 125 p.

Heinselman, M. C. 1973. Fire in the virgin forests of the Boundary Waters Canoe Area, Minnesota. Quaternary Res. 3:329-382.

Komarek, E. V. 1974. Effects of fire on temperate forests and related ecosystems: southeastern United States. Pages 252-278 in T. T. Kozlowski and C. E. Ahlgren, eds. Fire and ecosystems. Academic Press, New York.

Korstian, C. F. 1937. Perpetuation of spruce on cut-over and burned lands in the higher southern Appalachian Mountains. Ecol. Monogr. 7:125-167.

Kotinsky, J. 1916. The European fir trunk louse, Chermes (Dreyfusia) piceae (Ratz.). Entomol. Proc. Soc. Washington 18:14-16.

Lambert, R. L., G. E. Lang, and W. A. Reiners. 1980. Loss of moss and chemical change in decaying boles of a subalpine balsam fir forest Ecology 61:1460-1473.

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, a state of knowledge review. Forest Service National Fire Effect Workshop. USDA Forest Service Gen. Tech. Rep. WO-13. 64 p.

McGinnis, J. 1958. Forest litter and humus types of East Tennessee. Master's Thesis, Univ. Tennessee, Knoxville. 82 p.

Nicholas, N. S. 1984. Fuel levels in forests of the Great Smoky Mountains National Park, M.S. Thesis, Univ. Tennessee, Knoxville. 89 p.

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. USDI, National Park Service Res./Resour. Manage. Rep. SER-73. 31 p.

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

Puritch, G. S. 1971. Water permeability of the wood of grand fir (Abies grandis Dougl. Lidl.) in relation to infestations of balsam woolly aphid (Adelges piceae Ratz.). J. Exper. Bot. 22:936-945.

Puritch, G. S., and R. P. Johnson. 1971. Effects of infestation by the balsam woolly aphid (Adelges piceae Ratz.) on ultrastructure of border pit membranes of grand fir (Abies grandis Dougl. Lidl.). J. Exper. Bot. 22:953-958.

Ramseur, G. S. 1960. The vascular flora of the high mountain communities of the southern Appalachians. J. Elisha Mitchell Sci. Soc. 76:82-112.

SARRMC. 1980. Fraser fir and balsam woolly aphid: a problem analysis. Southern Appalachian Res./Resources Manage. Cooperative, Western Carolina Univ. 68 p.

SAS Institute. 1982. SAS user's guide: statistics, 1982 ed., SAS Institute, Cary, NC. 584 p.

Saunders, P. R., G. A. Smathers, and G. S. Ramseur. 1983. Secondary succession of a spruce-fir burn in the Plot Balsam Mountains, North Carolina. Castanea 48:41-47.

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

Speers, C. F. 1958. The balsam woolly aphid in the Southeast. J. For. 56:515-516.

Van Wagner, C. E. 1968. The line intersect method in forest fuel sampling. For. Sci. 14:20-26.

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, NPS Res./Resour. Manage. Rep. SER-55. 219 p.

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

Wilde, S. A. 1958. Forest soils. Ronald Press, New York. 537 p.

Wolfe, J. A. 1967. Forest soil characteristics as influenced by vegetation and bedrock in the spruce-fir zone of the Great Smoky Mountains. Ph.D. Dissert., Univ. of Tennessee, Knoxville. 193 p.

Wright, H. A., and A. W. Bailey. 1982. Fire ecology. John Wiley & Sons, New York. 501 p.

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',/,
```

```
       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 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
F27401	2.8869E-02	5.5584E-02	6.2066E-02	1.4652E-01	3.5777E-01	3.2471E-01	3.9520E-01
F27202	6.9581E-02	6.2254E-01	1.5517E-01	8.4729E-01	1.4247E+00	9.7141E-01	1.8786E+00
F27203	8.3645E-02	3.5574E-01	2.1723E-01	6.5662E-01	6.2474E-01	3.0122E+00	2.0962E+00
F27207	2.8869E-02	8.8935E-02	1.5517E-01	2.7297E-01	1.0523E+00	1.2502E+00	1.3311E+00
F27208	6.2178E-02	2.5569E-01	9.3099E-02	4.1097E-01	0.0000E+00	2.1419E+00	1.2322E+00
F27204	5.4776E-02	1.4452E-01	1.5517E-01	3.5446E-01	3.7850E-01	1.6137E-01	2.6287E-01
F27205	4.3673E-02	2.1122E-01	5.2756E-01	7.8246E-01	1.0980E-01	2.2855E+00	1.4060E+00
FPART2	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	3.3038E-01	1.1819E+00	9.4294E-01
F27206	2.5908E-02	1.1117E-01	1.8620E-01	3.2327E-01	1.0511E+00	1.0245E+00	1.3575E+00
F28103	6.1438E-02	2.1122E-01	2.4826E-01	5.2092E-01	7.1308E-02	5.3542E-01	3.7305E-01
F28102	4.6634E-02	1.8899E-01	1.5517E-01	3.9079E-01	1.2108E+00	1.6095E+00	1.8207E+00
F28101	1.1251E-01	2.7792E-01	2.4826E-01	6.3870E-01	6.4152E-02	1.8180E+00	1.0781E+00
F29101	5.5516E-02	4.4467E-02	2.4826E-01	3.4825E-01	3.1410E-01	8.3743E-01	8.1977E-01
F29102	4.2192E-02	5.5584E-02	4.6550E-01	5.6327E-01	5.9069E-01	2.7561E-01	7.5332E-01
F29103	6.5879E-02	2.1122E-01	1.8620E-01	4.6330E-01	9.0479E-01	2.4674E-02	8.5537E-01
F36101	5.9958E-02	8.8935E-02	3.1033E-02	1.7993E-01	4.2933E-01	4.6708E-01	6.6953E-01
F36102	5.5516E-02	1.1117E-01	1.2413E-01	2.9082E-01	6.0920E-01	1.3842E+00	1.2487E+00
F36104	6.9581E-02	1.6675E-01	4.9653E-01	7.3286E-01	1.0997E+00	6.1685E-01	1.3488E+00
F36105	4.8114E-02	1.6675E-01	9.3099E-02	3.0797E-01	9.8202E-01	7.7822E-01	1.1078E+00
F36106	5.3296E-02	6.6701E-02	9.3099E-02	2.1310E-01	7.9080E-01	2.3268E-01	8.1735E-01
F36107	3.1829E-02	1.8899E-01	6.2066E-02	2.8288E-01	2.1047E-01	9.0775E-01	6.1727E-01
F36108	4.6634E-02	1.0005E-01	1.5517E-01	3.0185E-01	1.3053E-01	1.3748E+00	8.2937E-01
F36109	4.6634E-02	7.7818E-02	1.5517E-01	2.7962E-01	4.6091E-01	5.7145E-01	7.6820E-01
F37301	7.1801E-02	1.3340E-01	1.5517E-01	3.6037E-01	2.1146E-01	7.2689E-01	5.9331E-01
F36302	5.8477E-02	1.0005E-01	2.4826E-01	4.0679E-01	8.5175E-01	1.2863E+00	1.5119E+00
F36303	6.5879E-02	6.6701E-02	3.4136E-01	4.7394E-01	2.1960E-01	1.0037E+00	6.4626E-01
F36304	2.5167E-02	6.6701E-02	1.2413E-01	2.1600E-01	3.9972E-02	2.8079E-01	1.8584E-01
F27201	2.4427E-02	7.7818E-02	2.1723E-01	3.1948E-01	3.1607E-01	1.3766E+00	9.7556E-01
F28201	3.7751E-02	1.0005E-01	1.2413E-01	2.6194E-01	5.8502E-01	0.0000E+00	5.2097E-01
F35401	6.0698E-02	1.4452E-01	3.7240E-01	5.7761E-01	2.4304E-01	2.3514E-01	3.1092E-01
F35402	6.4399E-02	6.6701E-02	9.3099E-02	2.2420E-01	8.3398E-02	2.3539E-01	2.5237E-01
F35403	4.3673E-02	3.3351E-02	6.2066E-02	1.3909E-01	2.9855E-01	4.1502E-01	6.2741E-01
F29101	5.5516E-02	4.4467E-02	2.4826E-01	3.4825E-01	3.1410E-01	8.3743E-01	8.1977E-01
F29102	4.2192E-02	5.5584E-02	4.6550E-01	5.6327E-01	5.9069E-01	2.7561E-01	7.5332E-01
F29103	6.5879E-02	2.1122E-01	1.8620E-01	4.6330E-01	9.0479E-01	2.4674E-02	8.5537E-01
F29104	1.9986E-02	0.0000E+00	6.2066E-02	8.2052E-02	1.0684E-01	5.0162E-01	3.0332E-01
F38201	5.4776E-02	1.5564E-01	9.3099E-02	3.0351E-01	3.1706E-01	5.3937E-01	5.5625E-01
F38202	8.7346E-02	1.8899E-01	1.5517E-01	4.3150E-01	5.5837E-01	7.1308E-02	5.9454E-01
F38203	5.7737E-02	1.0005E-01	2.1723E-01	3.7502E-01	5.9686E-01	0.0000E+00	5.8169E-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
```

```
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
```

```
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
```

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