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Shifts in Aboveground and Forest Floor Carbon and Nitrogen Pools After Felling and Burning in the Southern Appalachians

Barton D. Clinton, James M. Vose, and Wayne T. Swank

ABSTRACT. Changes in aboveground and forest floor mass, carbon (C), and nitrogen (N) pools were quantified on three sites in the southern Appalachians 2 yr after felling and burning. Before felling and burning, stands were characterized by sparse overstories and dense *Kalmia latifolia* L. understories. Two years after burning, foliar C and N pools had reached 25% and 29% of pretreatment levels, respectively. Foliar N concentrations were not different from pretreatment values. Standing wood C and N pools were 1% and 2%, respectively, of pretreatment values. Wood N concentrations were significantly higher on two sites, likely related to differences in fire intensity. Forest floor N content 2 yr after burning was 90% of pretreatment levels, most contained in unconsumed large woody material. Forest floor mass was significantly lower in the Oi layer and unchanged in the Oe + Oa layers. Forest floor N concentrations were generally lower after treatment. The site with the least intense fire and the lowest mass loss from the forest floor had the highest forest floor, foliage, and wood N concentrations 2 yr after burning. Site recovery after felling and burning was a function of fire severity and the capacity for site-nutrient retention through plant uptake. FOR. SCI. 42(4):431–441.
Additional Key Words. Fire, site preparation, nutrient retention, *Kalmia latifolia* L., stand restoration.

FELLING AND BURNING IS USED AS a management tool in the Southern Appalachians to restore degraded pine–hardwood forest stands on xeric sites to mixed pine–hardwood systems (Abercrombie and Sims 1986, Danielovich et al. 1987, Swift et al. 1993). This degradation is due to the combined effects of land practices (e.g., high grading), fire exclusion, and drought. In particular, presuppression wildfires are thought to have played a major role in maintaining a pine component in these ecosystems (Barden and Woods 1976, Van Lear and Johnson 1983). Fire exclusion, combined with drought-related insect infestations, has resulted in significant reductions in overstory pine and an increased evergreen understory comprised primarily of mountain laurel (*Kalmia latifolia* L.)(Smith 1991, Vose and Swank 1993). The evergreen shrub layer restricts regeneration of overstory species, and a major objective of the fell and bum treatment is to reduce mountain laurel vigor to improve survival of planted and naturally regenerating tree species. The impacts of this treatment on the distribution of carbon (C) and nitrogen (N) pools are largely unknown.

Nitrogen is commonly a limiting nutrient to forest productivity (Vitousek et al. 1982). Nitrogen losses during and following prescribed fire in southern forests range from 20 kg ha^{-1} for low-intensity understory bums (Kodama and Van Lear 1980) to >400 kg ha^{-1} for high-intensity site preparation burns in heavy fuels (Vose and Swank 1993). The significance of these losses depends on inherent site productivity and the magnitude and duration of changes in C and N pools and cycling rates (Wells and Morris 1982, Vitousek and Matson 1985). In pine-hardwood ecosystems in the Southern Appalachians, Knoepp and Swank (1993) found that net soil N mineralization increased immediately following cutting and burning and remained higher than control plots for about 2 yr. Similarly, Dudley and Lajtha (1993) found N availabil-

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ity increased following prescribed fire in a sand plain grassland and remained higher than pretreatment levels for 3 yr. Increased N mineralization rates can offset total N losses from fire; however, the degree to which N losses are ameliorated depends on the magnitude and source (i.e., forest floor vs. wood) of N losses and subsequent N recovery. In Southern Appalachian hardwood ecosystems, forest floor losses are particularly important because release of N from the forest floor provides approximately 50% of the total available N (Monk and Day 1988).

Rapid regrowth following disturbance can be an important retention tool for N and other site nutrients (Boring et al. 1988, Van Lear et al. 1990). Vitousek et al. (1979) suggested that plant accumulation of nutrients may singularly explain patterns of nitrate losses from forest ecosystems. Similarly, Marks and Bormann (1972) implicated elemental accumulation through rapid growth of early successional vegetation as a mechanism for minimizing nutrient losses from a northern hardwood ecosystem. Thus, site preparation treatments that promote regrowth, and, hence, sequester nutrients in biomass, will minimize loss of site nutrients.

This study is a component of an interdisciplinary effort assessing the impacts of the fell and bum treatment on aboveground and belowground ecosystem processes (Ottmar and Vihnanek 1991, Clinton et al. 1993, Elliott and Vose 1993, Knoepp and Swank 1993, Swift et al. 1993, Vose and Swank 1993). The objective of the present study was to identify temporal changes in vegetation and forest floor C and N pools.

Methods

Study Site Description

In 1990, three ≈4 ha sites located in the Wayah Ranger District of the Nantahala National Forest in western North Carolina, denoted as Jacobs East (JE), Jacobs West (JW), and Devil Den (DD), were cut in early summer and burned in early fall with a high-intensity but low-severity fire (Ottmar and Vihnanek 1991). No material was removed from either site prior to burning. Pretreatment stand age was approximately 80 yr (Swift et al. 1993), and average basal area and density [stems >10 cm diameter at breast height (dbh)] were 14.8 m^2ha^{-1} and 461 stems ha^{-1}, respectively (Vose and Swank 1993). All vegetation was cut by chainsaw during the summer of 1990. Cut vegetation cured for 44, 50, and 55-89 days on DD, JW, and JE, respectively. Average fuel moisture (for all size classes) at the time of burning varied across sites (JE = 33%, JW = 28%, DD = 37%)(Swift et al. 1993, Vose and Swank 1993). Sites were selected as replicates and had similar pretreatment vegetation structure, topographic position, aspect, and soil type (Swift et al. 1993).

Pretreatment Mass

Wood

Estimates of aboveground wood mass were made on five permanently marked 15 x 33 m plots, distributed upslope to ensure representative sampling. Standing vegetation (living and dead) was grouped into two diameter classes (510.2 cm and >10.2 cm). Dbh was measured on stems >10.2 cm at 1.4 m to the nearest 0.1 cm. For hardwoods, total-tree mass (stem, branch, and bark) was estimated from dbh using general allometric equations (Clark and Schroeder 1986). For pines, total-tree mass was estimated from dbh with the allometric equation for loblolly pine (*Pinus taeda* L.)(Van Lear et al. 1986). Stems ≤10.2 cm dbh were measured on a 3 x 3 m plot in a randomly selected corner of each 15 x 33 m plot. For stems with clear boles (no branching below dbh), dbh was measured with calipers or diameter tape. For all other stems 110.2 cm dbh, basal diameter (approximately 3 cm above ground level) was measured with calipers, and mass was estimated using allometric equations of Phillips (198 1). *Kalmia* was measured at the base, and mass was estimated using the equations of McGinty (1972) and Boring and Swank (1986). In addition, mass of all woody plants < 1 cm basal diameter was estimated using the equations for oak seedlings (Boring 1979). Mass for woody plants ≥1 cm basal diameter was estimated with equations from Boring (1982).

Foliage

Foliar mass was sampled from felled vegetation with foliage still attached to the branches using four 1 x 1 m plots randomly located within each 15 x 33 m plot. Foliage was removed from the branches and sorted by major species groups (red oaks, white oaks, sourwood, maple, pine, *Kalmia*, and others) in the field. Samples were dried at 70°C to a constant weight before weighing.

Forest Floor

Estimates of forest floor mass were made on each 15 x 33 m plot on each site. Four forest floor samples were collected by cutting and removing all material in a square (0.1 m^2) sampling frame. Forest floor was separated into Oi (litter) and Oe + Oa (F and H) layers. Samples were dried at 70°C to a constant weight before weighing. Forest floor mass estimates were not ash free corrected; however, care was taken during sampling to minimize mineral soil contamination.

Posttreatment Mass

Wood and Foliage

Plots were re-inventoried in summer 1992 (2 yr after burning). Because all stems were ≤10 cm, only the 3 x 3 m plots were measured for woody mass. Prebum measurement procedures were followed, and basal diameter was measured on each stem. Due to the clumped nature and prolific sprouting exhibited by *Kalmia*, clump area (m^2) estimates were determined based on the average of two diameter measurements and converted to biomass using the equations of Elliott and Clinton (1993). All other tree species were assigned to one of six categories: red oaks, white oaks, sourwood, red maple, pines, and "others" (Table 1). Estimates of foliage and wood mass were made using site- and species-specific allometric equations (Elliott and Clinton 1993). Wood net primary production (NPP) was estimated by subtracting first-year (after first growing season) from second-year wood mass estimates. Foliar NPP estimates were calculated using site- and species-specific allometric equations (Elliott and

Table 1. List of woody species included in the "others" category in rank order by percent woody biomass on JE 2 yr following treatment.

Species	JE	JW	DD
Amelanchier arborea (Michaux f.) Fem. (service berry)	27	25	47
Sassafras albidum (Nutt.) *Ness* (sassafras)	26	24	8
Cornus florida L. (flowering dogwood)	23	5	0
Robiniu pseudoacacia L. (black locust)	7	<1	29
Nyssa sylvatica Marshall (black gum)	7	8	1
Betula lenta L. (black birch)	3	0	<1
Ilex ambigua (Michaux) Torrey (mountain holly)	2	6	<1
Pyrularia puberu Michaux (buffalo nut)	2	<1	4
Rhus glabra L. (smooth sumac)	1	1	0
Liriodendron tulipifera L. (yellow poplar)	1	0	<1
Aralia spinosa L. (devils walking stick)	<1	0	0
Vitus spp. (wild grape)	<1	4	5
Carya spp. (hickory)	<1	6	<1
Diospyros virginiana L. (persimmon)	<1	1	<1
Custuneu pumila Miller (allegheny chinquapin)	<1	20	0
Custuneu dentata (Marshall) Borkh. (American chestnut)	0	0	4

Clinton 1993). Substantial changes can take place in herbaceous vegetation distribution and abundance following fire (Danielovich and Van Lear 1987); however, we did not sample the herbaceous layer for this study.

Forest Floor

Sampling was conducted in September just before burning, immediately after burning, and in September 2 yr after burning. Much of the Oi layer had been consumed in the fire. Therefore, the immediate postburn sample has ashes mixed with the Oe + Oa layers, but, where possible, separation by layer was conducted. Pretreatment forest floor sampling procedures were followed. Posttreatment estimates of forest floor mass, C, and N include residual large woody material.

Immediate PostBurn Residual Wood

Residual large woody material (wood not completely consumed by the fire) was sampled using two (2 x 2 m) plots randomly located within each 15 x 33 m plot. All woody material was removed from the plot and weighed on a portable scale. Subsamples of woody material were taken for moisture content determination to convert field-measure weight to ovendry weight. High fire severity prevented reliable identification to species; therefore, all material was classified as "residual wood." Mass loss from residual large woody material was estimated using a decay constant, $k\,(yr^{-1})$, of 0.083 (Mattson et al. 1987). This constant was determined on a comparable site for similar tree species. We assumed that charred materials decompose at a similar rate to unburned large woody debris.

Carbon and Nitrogen

Preburn random samples of wood and foliage were collected from all felled tree species present to determine C and N concentrations. Trees were separated into groups: red oaks, white oaks, sourwood, red maple, pines, mountain laurel, and "others." For preburn wood, all size classes were sampled and pooled to arrive at a representative estimate at each site. Postburn wood and foliage samples were collected randomly on each 15 x 33 m plot on each site during late summer 1992 and sorted into the same groupings. At least three samples were taken for each species within a species group. All samples of wood, foliage, and forest floor were ovendried at 70°C to a constant weight and weighed. Afterward, the entire sample was ground through a 1 mm mesh, mixed, and subsampled for nutrient determination. Percent C and N was determined using a Perkin-Elmer 2400[1] CHN elemental analyzer. No corrections were made for ash content. No distinction was made between size classes for postburn wood. C and N concentrations in residual large woody material were assumed to be constant after treatment (Vose and Swank 1993) for predicting C and N loss from the sites due to decomposition. Estimates of these pools were made by multiplying percent C and N times mass.

Statistical Analysis

A folded-form F-statistic was used to test for homogeneous variances (SAS Institute Inc. 1987) for pre- and postbum wood and foliage C and N. When variances were equal, significant differences between means were evaluated with parametric Student t-tests. When variances were not homogeneous, an approximate t-test and Satterthwaite's method for computing degrees of freedom were used (SAS Institute Inc. 1987). PROC ANOVA was used to test for equality of means for forest floor C and N between sample dates and among sites (SAS Institute Inc. 1987). When differences were significant, Duncan's multiple range test was used to separate means (α = 0.05).

Results

Wood C and N

Burning dramatically reduced aboveground C (Table 2). By year 2, wood NPP for all sites combined was 975 kg C $ha^{-1}yr^{-1}$ compared to 555 kg C $ha^{-1}yr^{-1}$ for the first growing season (Clinton 1994). Much of the regrowth

[1] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the USDA of any product or service.

Table 2. Pretreatment and 2-yr post-treatment C and N content by major species groups and forest floor components.

		Species	Pretreatment' C	Pretreatment' N	2-yr post-treatment C	2-yr post-treatment N
			(kg/ha)			
JW site	Wood	Red oak	24,700	112.0	64.4	0.4
		White oak	17,100	63.0	8.9	0.1
		Sourwood	2,600	13.0	8.7	0.1
		Red maple	2,600	1.1	0.3	<0.1
		Pine	10,100	23.1	12.9	0.1
		Mt. laurel	5,700	32.0	46.4	0.4
		Others	8,900	43.0	320.2	2.8
		Totals	71,700	287.2	461.8	3.9
		% of total	82%	46%	1%	1%
	Foliage	Red oak	742	26	73.4	2.7
		White oak	93	4	6.5	0.2
		Sourwood	77	2	45.3	1.3
		Red maple	34	1	0.1	<0.1
		Pine	123	2	0.1	co.01
		Mt. laurel	409	8	131.8	2.9
		Others	160	6	201.4	7.2
		Totals	1,638	47	458.6	14.3
		% of total	2%	7%	1%	6%
	Forest floor	Oi	5,700	101.9	2,300	27.1
		Oe+Oa	8,600	198.4	6,500	128.2
		Residual woody debris[2]			30,555	83.9
		Totals	14,300	300.3	39,355	239.2
		% of total	16%	47%	98%	93%
		Total	87,638	634	40,276	257.4
JE site	Wood	Red oak	14,400	80.1	8.2	0.05
		White oak	21,900	83	89.3	0.6
		Sourwood	2,900	17		
		Red maple	2,200	8	104.6	0.6
		Pine	25,500	94	2.5	0.02
		Mt. laurel	13,100	56	62.6	0.4
		Others	6,500	51	152.3	1.3
		Totals	86,500	389.1	419.5	3.0
		% of total	83%	51%	1%	1%
	Foliage	Red oak	159	7	8.0	0.3
		White oak	15	1	61.7	2.3
		Sounvood	15	1		
		Red maple	98	4	28.2	0.8
		Pine	475	10	0.02	co.01
		Mt. laurel	798	16	180.3	4.0
		Others	35	1	111.7	3.2
		Totals	1,595	40	389.9	10.6
		% of total	2%	5%	1%	3%

(cont.)

Table 2. (cont.)

		Species	Pretreatment[1] C	Pretreatment[1] N	2-yr post-treatment C	2-yr post-treatment N
					(kg/ha)	
JE site (cont.)	Forest floor	Oi	5,900	101.7	1,300	19.8
		Oe+Oa	10,500	238.6	12,200	231.9
		Residual woody debris[2]			28,947	71.6
		Totals	16,400	340.3	42,441	323.3
		% of total	15%	44%	98%	96%
		Total	104,500	769	43,256	336.9
DD site	Wood	Red oak	12,400	52	25.9	0.2
		White oak	2,100	14.1	108.0	1.3
		Sourwood	600	4	2.4	0.1
		Red maple	800	3	76.3	0.6
		Pine	9,500	47	0.5	co.01
		Mt. laurel	13,200	75	97.0	0.8
		Others	3,200	16	296.8	3.4
		Totals `	41,800	211.1	606.9	6.4
		% of total	74%	37%	3%	2%
	Foliage	Red oak	235	8	34.1	1.2
		White oak	41	2	47.5	2.0
		Sourwood	101	2	12.6	0.5
		Red maple	63	2	25.6	0.8
		Pine	102	2	co.01	co.01
		Mt. laurel	1,312	24	266.0	7.9
		Others	289	8	117.5	4.4
		Totals	2,143	48	503.3	16.8
		% of total	4%	8%	2%	6%
	Forest floor	Oi	4,400	82.5	1,600	35.5
		Oe + Oa	8,200	233	6,300	197.8
		Residual woody debris[2]			15,574	68.1
		Totals	12,600	315.5	23,474	301.4
		% of total	22%	55%	95%	92%
		Total	56,500	575	24,584	324.6

[1] Data from Vose and Swank (1993).
[2] Residual is downed material not consumed by the fire. A decay constant (k) of 0.083 (Mattson et al. 1987) was applied to all residual woody material inventoried after burning in 1990.

shifted C away from the pretreatment composition dominated by oak and pine species, into the "others" category (Table 2). The species in this category (Table 1) were present before treatment, but became more abundant after treatment. Mountain laurel was an important component of pretreatment and posttreatment vegetation (Table 2). The proportion of total pretreatment wood C accounted for by mountain laurel ranged from 8% at JW to 32% at DD. The proportion of C in mountain laurel wood 2 yr after treatment was changed only slightly at JE and JW, but decreased from 32% to 16% at DD. All sites had roughly the same proportion of wood C in mountain laurel (≈15%) 2 yr after treatment. In addition, large differences in proportional distributions of C were observed between pre- and 2 yrpostburn (Table 2). Most of the preburn C was in aboveground wood, while in year 2, most C was in the forest floor, most of which was large residual material. Living wood accounted for only 1% to 3% (DD) of total C in year 2.

Wood N concentrations were higher on all sites 2 yr after treatment (Table 3); however, increases were only statistically significant at JW and DD. The increase in N resulted in significant decreases in C:N ratio (Figure la). Like C, most N had shifted to the "others" category on all sites (Table 2). For all sites, total N contained in wood declined sharply. Total N in wood represented between

Table 3. Pre- and 2-yr postburn wood and foliage N concentrations (%) by site with associated test statistics.

Site		Pretreatment N[1]	Post-treatment N	*T*	*df*	*P>T*
Jacobs East	Wood	0.25	0.29	-1.23	11	0.2445
	Foliage	1.51	1.36	0.88	12	0.3944
Jacobs West	Wood	0.24	0.38	-2.56	7	0.0342
	Foliage	1.71	1.52	0.89	12	0.3901
Devil Den	Wood	0.26	0.43	-4.55	11	0.0008
	Foliage	1.38	1.65	-1.56	11	0.1463

[1] Data from Vose and Swank (1993).

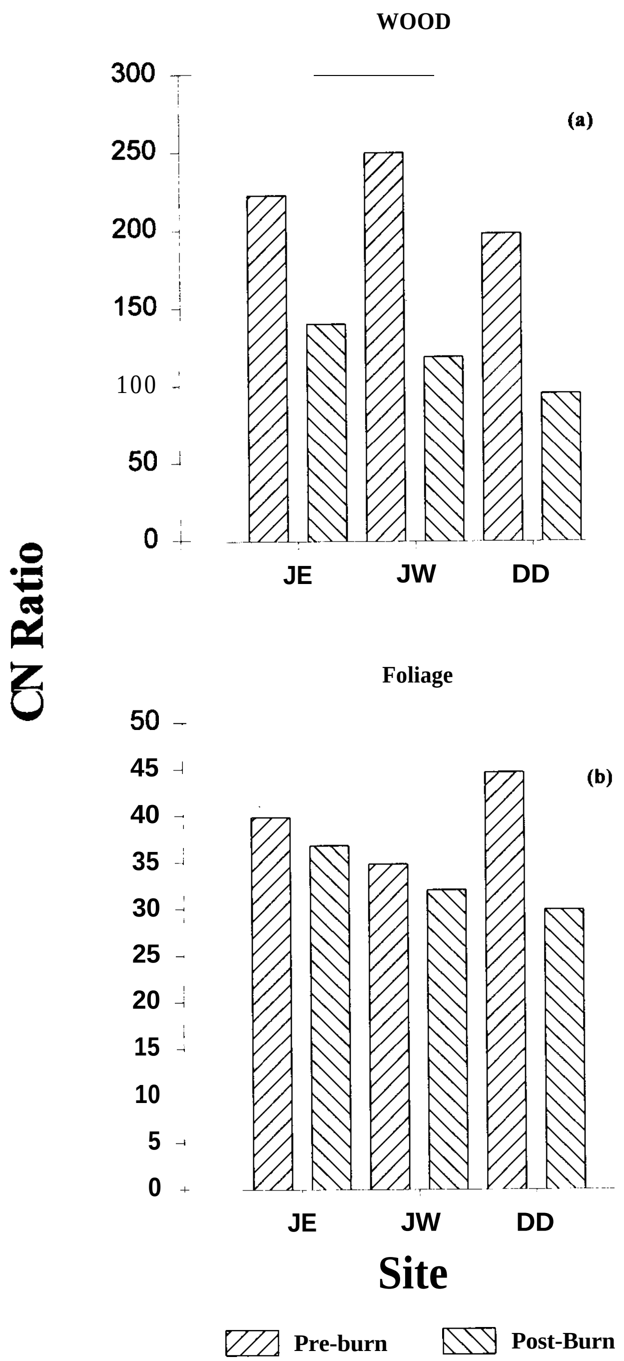

Figure 1. Pretreatment and post-treatment C:Nfor wood (1a) and foliage (1b) by site.

37% and 51% of total N before treatment and 2% or less after treatment (Table 2).

Foliar C and N

Three percent of pretreatment C was in foliage (Table 2). Mountain laurel accounted for 50% of the foliage on JE, 61% on DD, and 25% on JW (Table 2). Mountain laurel had the highest foliar C content among the seven species groups for posttreatment samples on the JE (46%) and DD (53%) sites (Table 2). The "others"category accounted for 23%, 28%, and 44% of total posttreatment foliar C at JE, DD, and JW, respectively. Foliar NPP was greatest at DD and JW and the lowest at JE (Table 2). In general, foliar C had reached approximately 25% of pretreatment levels by year 2.

Total N in foliage responded similarly to total C (Table 2). At JW, the red oak group accounted for 53% of the total pretreatment foliar N but only 19% 2 yr after treatment. Total foliar N in the "others" group increased at all sites after treatment. Increases varied substantially between sites (JW, 13% to 50%; JE, 3% to 30%; DD, 17% to 26%). Foliar C:N ratios decreased slightly on all sites and substantially at DD (Figure lb).

Aboveground N Pools

Substantial reductions in total aboveground N (30-60%) were observed on all sites immediately following prescribed fire (Vose and Swank 1993), and N was still substantially lower 2 yr after burning (Table 2). In addition to declines in pool sizes, shifts in N among major pools (wood, foliage, forest floor) occurred (Table 2). For example, approximately one-half of total N was contained in wood before treatment, whereas posttreatment wood N pools accounted for only 1% to 2% of total N (Table 2). Most posttreatment N (92-96%) was in the forest floor (Table 2).

Significant increases in wood N concentration occurred at JW and DD but not at JE (Table 3). There were no significant differences in foliar N concentration at any of the sites. For all sites combined, foliar N represented a small proportion of total pretreatment (558%) and posttreatment (3-6%) N (Table 2). However, by year 2, foliar N pools had reached 27%-35% of pretreatment levels.

Forest Floor C and N

Total forest floor C decreased in the Oi layer on all sites 2 yr after treatment (Table 4). No changes occurred in C in the

Oe + Oa layers at any of the sites. The proportion of total C in the forest floor relative to wood and foliage increased dramatically following treatment (Table 2). Most of this C was contained in residual large woody material (66-78%).

Total N in the Oi layer declined substantially after treatment on all sites. N pools in the Oe + Oa layers declined, as well, but only slightly on JE (Table 2). The only significant changes in N concentration in the forest floor after treatment occurred in the Oi layer at JW (P = 0.0001, Table 5) and in the Oe + Oa layers on JE (P = 0.04, Table 5). A significant increase in the C:N ratio (P = 0.0004) in the Oi layer on JW occurred, as well (Table 5). N concentrations declined in all forest floor layers except in the Oi layer at DD, where a slight increase was observed (Table 5). The C:N ratios in the Oi layer on JE and JW increased reflecting declines in N. At DD, however, the C:N ratio decreased slightly (P = 0.1041) because N increased in that layer (Table 5). Similarly, the C:N ratio in the Oe + Oa layers decreased at DD but increased at JE and JW (Table 5). Like C, a large proportion of the N on the forest floor resided in residual large woody material (22-35%); however, most of the posttreatment forest floor N was contained in the Oe + Oa layers (54–72%).

Discussion

Wood C and N

Much of the vegetation following treatment developed from sprouts, capitalizing on stored carbohydrates in existing root systems. Similar to our study, Augspurger et al. (1987) found that broadcast burning of logging slash on clearcut sites in the southern Appalachians doubled the number of basal sprouts in oak species. In established stands in the southern Appalachians, repeated fire has been shown to maintain oak stands through sprouting (Van Lear 1990). Sprouts following burning generally experience less mortality compared to unburned sites (Augspurger et al. 1987) because susceptibility of sprouts of groundline origin to various forms of decay is reduced (Smith 1979, Watt 1979).

Wood NPP by year 2 was approximately 975 kg C ha^{-1} yr^{-1}. Boring and Swank (1986) reported NPP of ≈1200 kg C $ha^{-1} yr^{-1}$ for comparable xeric sites on a clearcut watershed at Coweeta 3 yr after treatment. In that study, fire was not used as a site-preparation treatment. Furthermore, averaged across the watershed, black locust *(Robiniapseudoacacia* L.) fixed IO kg N $ha^{-1} yr^{-1}$ in Boring and Swank's (1 984) study. Black locust was not abundant on this study's sites (with the exception of DD). Although it is difficult to accurately estimate ecosystem level N pools and fluxes under natural conditions due to uncertainties in measuring inputs and outputs (Bormann et al. 1993), additions of N on our sites are assumed to have come primarily from the atmosphere and associative or free-living N_2-fixation.

Shifts in the distribution of C among species occurred on all sites, in addition to changes in total site C. The most important species group 2 yr following fire was the "others" category. This group was composed primarily of species that sprout vigorously following treatment. The number of species in the "others" category also increased due to recruitment of early successional species *(Diospyros Virginia* L., *Ilex* spp., *Rhus* spp., *Sassafras albidum* [Nutt.] Nees, *Vitus* spp.).

Prebum wood N concentrations were similar on all sites (Table 3), but large differences were observed 2 yr after prescribed fire. Wood (excluding residual large woody material) N concentrations were higher in the posttreatment samples at JW and DD (Table 3). This is probably a result of higher proportions of living tissue associated with small diameter stems. The significantly higher postfire wood N concentration at the DD site (Table 3) may be partially explained by the low fire intensity at DD, which resulted in minimal N losses from the forest floor (Vose and Swank 1993). To a lesser extent, postfire wood N concentrations at JW (second to JE in fire intensity) exhibited the same trend (Table 3).

Foliar C and N

Proportionally more posttreatment foliar C was concentrated in mountain laurel, a prolific sprouterafterfire (Clinton et al. 1993), on all sites (Table 2). Mountain laurel can retain foliage for up to 3 yr, and the sclerophyllous foliage decomposes slowly (Monk et al. 1985). Monk et al. (1985) estimated that mountain laurel loses only 10–15% of its total leaf nutrient standing crop annually through litter fall. In the short term, mountain laurel may play an important role in the retention of site nutrients after disturbance. However, this retention might decrease long-term soil nutrient availability due to foliar accumulation of nutrients and slow release from decomposing mountain laurel litter. However, it is important to note that although mountain laurel resprouts vigorously and rapidly sequesters proportionally more site nutrients, initial reduction in mountain laurel allows other woody species to successfully regenerate.

Table 4. Preburn and 2-yr postburn forest floor mass (Mg/ha) by layer with associated test statistics,

Site		Pretreatment'	2-yr post - treatment	T	df	$P>T$
Jacobs East	Oi	12.6	2.8	7.768	4	0.0011
	Oa+Oe	27.0	32.9	-0.824	8	0.4340
Jacobs West	Oi	10.8	4.8	3.624	8	0.0067
	Oa+Oe	20.2	16.7	0.456	8	0.6605
Devil Den	Oi	9.5	3.4	5.826	8	0.0004
	Oa+Oe	22.7	19.2	0.645	8	0.5370

[1] Data from Vose and Swank (1993).

Table 5. Forest floor pretreatment, immediate posttreatment, and 2-yr posttreatment nitrogen (N) and carbon (C) concentration (%), and C:N ratio by layer and site.

Site	Layer		Pretreatment[1]	Immediate post-treatment[1]	2-yr post-treatment	F-value	*df*	*P>F*
JW	Oi	N	0.96(0.04)a[2,3]	1.27(0.08)b	0.56(0.04)c	40.60	2	0.000 1
		C	46.34(0.80)a	50.08(2.00)a	47.75(3.35)a	0.61	2	0.5601
		C:N	49.58(2.36)a	39.83(4.26)a	87.47(8.74)b	17.55	2	0.0004
	Oe+Oa	N	0.95(0.04)a	0.84(0.06)a	0.74(0.06)a	3.62	2	0.5900
		C	38.74(3.26)a	32.46(3.38)a	35.28(3.65)a	0.84	2	0.4550
		C:N	40.51(2.41)a	38.32(1.22)a	48.46(5.38)a	2.33	2	0.1398
JE	Oi	N	0.82(0.04)a	0.96(0.32)a	0.73(1.12)a	0.68	2	0.5288
		C	46.68(1.25)a	44.43(1.58)a	46.21(1.37)a	0.45	2	0.6540
		C:N	57.78(3.40)a	52.65(19.19)a	70.54(12.74)a	0.67	2	0.5354
	Oe+Oa	N	0.90(0.03)a	0.93(0.07)a	0.68(0.09)b	4.14	2	0.0428
		C	37.15(2.52)a	36.47(2.85)a	35.24(3.41)a	0.11	2	0.8965
		C:N	41.70(3.91)a	39.86(3.24)a	54.54(8.21)a	2.06	2	0.1702
Dl	Oi	N	0.89(0.06)a	1.17(0.16)a	1 .00(0. 14)a	1.28	2	0.3128
		C	47.03(0.92)a	43.84(4.54)a	45.91(1.83)a	0.32	2	0.7349
		C:N	54.30(4.40)a	38.40(3.30)a	49.38(6.46)a	2.75	2	0.1041
	Oe+Oa	N	1.00(0.08)a	1.22(0.09)a	0.93(1.12)a	2.28	2	0.1453
		C	35.07(3.55)a	37.22(2.15)a	29.67(3.69)a	1.47	2	0.2678
		C:N	34.80(2.05)a	30.80(1.20)a	32.36(1.32)a	1.67	2	0.2293

1 Data from Vose and Swank (1993).
2 Data in parentheses are standard errors.
3 Values with the same letter are not significantly different within rows at the a = 0.05 level.

DD had the lowest pretreatment foliar N concentrations of the three sites but had the highest concentration 2 yr after treatment (Table 3). There are at least two reasons for this increase: (1) higher available forest floor N and (2) species composition (i.e., the presence of N-fixing black locust, 1389 stems ha^{-1} compared to 56 stems ha-' for JE and 111 stems ha^{-1} for JW, Clinton et al. 1992). DD had the lowest intensity fire of all sites and the least amount of mass loss from the forest floor during the fire (Vose and Swank 1993). This may volatilize less N and result in high N concentrations in the forest floor. Even though foliage accounted for a small proportion of total posttreatment N at DD (Table 2), the relatively rapid turnover for most hardwood foliage (foliar k = 0.314, Seastedt et al. 1983) makes it an important source of available N.

Forest Floor C and N

Although the Oi layer was completely consumed by the fire on all sites, C losses from the Oe + Oa layers were slight. Variation in Oe + Oa losses among sites was probably related to differences in fire severity (JE > JW > DD, Swift et al. 1993). Severity was directly related to fuel load and forest floor moisture content (Swift et al. 1993). For example, moisture levels in forest floor fuels at DD were nearly 100% immediately before the burn (Vose and Swank 1993). Consequently, less forest floor was consumed, and C reductions in the Oe + Oa layers were minimal on that site. Averaged across sites, total C loss from the forest floor was 39% of total pretreatment C (Figure 2). However, two-thirds of this C was in the Oi layer, which was completely consumed; therefore, losses of C and other nutrients from the Oe + Oa layers were minimal.

Maintenance of the Oe + Oa layers result in minimal losses of total C and N from this important nutrient reservoir (Figure 2). The higher N concentrations in the Oe + Oa layers observed immediately after the fire on JE and DD may be a result of condensation of volatilized organic N (Rauch 1991, Vose and Swank 1993). Subsequently, N concentrations tended to decline (although variability was high) on all sites in the Oe + Oa layers by year 2 (Table 5). In the Oi layer, N concentrations were higher at DD 2 yr after the fire reflecting higher foliar N concentrations on that site. Pietikainen and Fritze (1993) reported that total N in the Oa layer following prescribed fire remained elevated for 3 yr. However, available N returned to pretreatment levels soon after the fire. Vose and Swank (1993) reported increases in N in the Oe + Oa layers immediately following the fire (Table 5).

Even though mass in the Oe + Oa layers was unchanged (Table 4), N concentrations declined by year 2 and, therefore, total N pools declined. Vose and Swank (1993) reported that JE had the greatest preburn forest floor mass and the most intense fire. Because the total mass present in Oe + Oa layers (a major reservoir of N) was only slightly reduced by the fire (–14%), N content remained relatively intact (-11%). Wood N concentrations did not change significantly after treatment, which may indicate only minor changes in soil N availability and may also be related to changes in litter quality. For example, C:N in the Oe + Oa layer on JE increased after fire (+3 1%; Table 5) which indicates slow decomposition and slow release of available N.

Of the major pools (wood, foliage, and forest floor), wood, the largest pretreatment pool of both C and N (Table

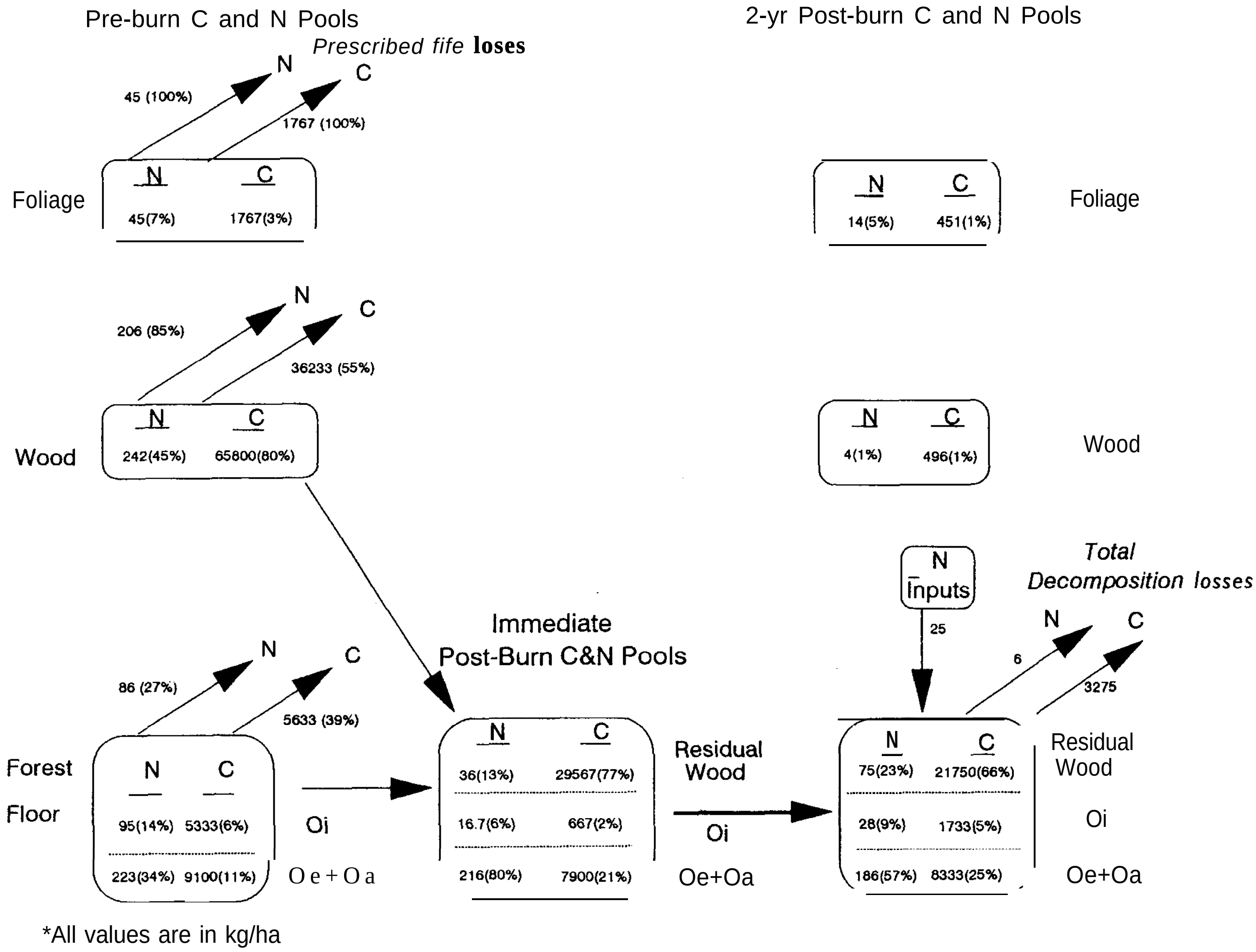

Figure 2. Conceptual flow chart showing C and N pool sizes and fluxes (kg/ha) before and after site-preparation fire. Values in parentheses arefractions of total C or N pools and fractions of total pools lost due to fire or decomposition. Decompositional losseswere based on published decay constants for similar stands and material type and size.

2, Figure 2), showed the greatest losses of C and N (C, –55%; N, –85%)(Figure 2). While the Oi was completely consumed, the Oe + Oa remained relatively intact. Because the Oi layer represented a small fraction of total site C (<8%) and N (<16%), total losses from the forest floor were slight.

Maintenance of the Oe + Oa layers is critical for site nutrient retention and soil stabilization. Large woody material unconsumed by the fire contributes substantially to total forest floor C (71%) and N (25%) and provides long-term inputs of N and other nutrients.

Conclusions

Losses and subsequent recovery of C and N pools after fire is a function of fire severity. Fire severity depends on ignition techniques, fuel load, size distribution, flammability, and moisture content, all of which can influence fire residence time. Hence, the magnitude of C and N losses and recovery depends on the interaction of these parameters.

In undisturbed forest stands the greatest proportions of aboveground (i.e., forest floor, coarse woody debris, and vegetation) mass, and usually C and N, are contained in the vegetation, as was the case in our study. However, following fire or other major disturbances which remove site nutrients, there is a shift in the magnitude and distribution of major nutrient pools so that the greatest postdisturbance proportions of site C and N are found on or within the forest floor. This shift emphasizes the importance of maintaining an intact forest floor (especially the Oe + Oa layers) because sources of nutrient recirculation (i.e., litterfall) are at least temporally reduced. Hence, in the first few years after disturbance, the Oe + Oa layers are the most important sources of availability nutrients. For example, although posttreatment aboveground C and N pools were well below pretreatment levels, forest floor N was 90% of its pretreatment amount by year 2. Residual wood contributes substantially to total C and N pools in the forest floor but decays slowly and contributes little toward plant growth early in succession. Therefore, to maximize site nutrient retention through rapid recovery of aboveground biomass and avoid degradation of site productivity, land managers should strive to use burning prescriptions which minimize consumption of the Oe + Oa layers.

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