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Short-term effects of prescribed fire on mixed oak forests in the southern Appalachians: vegetation response[1]

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Elliott, K. J. and J. M. Vose (Coweeta Hydrologic Laboratory, Southern Research Station, USDA Forest Service, Otto, NC 28763). Effects of prescribed fire in mixed oak forests in the Southern Appalachians: vegetation response. J. Torrey Bot. Soc. 137: 49–66. 2010.—We examined vegetation responses to prescribed fire on three mixed-oak sites located in the Blue Ridge Physiographic province of the southern Appalachian Mountains: Alarka Laurel Branch (AL), Robin Branch (RB), and Roach Mill Branch (RM). Each of the study sites was within a sub-watershed that drained a first order stream. Our objectives were to: 1) evaluate overstory mortality following prescribed fire treatments; and 2) assess changes in composition, abundance, and diversity of overstory (stems $\geq$ 5.0 cm dbh), understory (stems $<$ 5.0 cm dbh, $\geq$ 0.5 m height), and herbaceous layer (woody stems $<$ 0.5 m height and all herbaceous plants) vegetation in mixed-oak ecosystems. Each site included a burned and unburned area (control). Before the prescribed fire treatments were applied, we established permanent plots (10 $\times$ 20 m) in the prescribed burn areas (12 plots in AL, 12 plots in RB, and 10 plots in RM) and adjacent unburned areas (5 plots in AL, 6 plots in RB, and 4 plots in RM), for a total of 49 plots. Within the plots, we sampled vegetation before and after the prescribed burns. All of the prescribed fires were low to moderate intensity; i.e., they had moderate flame temperatures and low flame heights. After the prescribed fires, overstory mortality was low for all sites, and there were no significant differences between mortality in burned areas and that in unburned areas. Understory density was lower on the burned than the unburned plots the first ($t = -5.26$, $P < 0.0001$) and second ($t = -3.85$, $P = 0.0020$) growing seasons after burning. There was either an increase (AL, RB) or no change (RM) in herbaceous layer cover depending on the site and no significant change in species diversity after burning for any site. Thus, we found no negative effects of prescribed fire on herbaceous flora.

Key words: diversity, fire, restoration.

National Forest Managers (USDA Forest Service; http://www.fs.usds.gov/fire), National Park Service (http://www.nature.nps.gov/firemanagement), state and private landowners, and the Nature Conservancy (http://www.nature.org/initiatives/fire) are using prescribed fire in mixed hardwood forests to reduce fine fuels, encourage oak regeneration, and enhance biological diversity and rare plant populations. In the central hardwood region, fire effects studies in mixed-oak communities have evaluated oak regeneration and understory vegetation response on intermediate to mesic sites (Arthur et al. 1998, Hutchinson et al. 2005a, Albrecht and McCarthy 2006, Glasgow and Matlack 2007, Alexander et al. 2008), and some studies have been conducted in the Piedmont region of South Carolina and Georgia (Van Lear et al. 2000, Wang et al. 2005). In contrast, most fire effects studies in the Southern Appalachian Mountains have focused on pine-hardwood mixtures on dry to xeric sites (Elliott et al. 1999, Vose et al. 1999, Clinton and Vose 2000, Welch et al. 2000, Randles et al. 2002, Waldrop et al. 2002, Elliott and Vose 2005, Brose and Waldrop 2006a). Since these forest types occupy only about 5% of the southern Appalachian landscape, we know very little about the role or effects of fire in much of the forested areas. One recent study on prescribed fire effects (Phillips et al. 2007, study also in Waldrop et al. 2008) compared hardwood forests in the Central Hardwood region to mixed-hardwood forests in the southern Appalachian Mountains. For the southern Appalachian site, plots were distributed across a hillslope moisture gradient from xeric ridges to moist coves. Vegetation response to prescribed burning was different between these two regions (Phillips et

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al. 2007, Waldrop et al. 2008). For example, at the southern Appalachian site, trees were the only life form in the ground layer vegetation to significantly increase in the burn only treatment; whereas, significant increases in ground layer vegetation were found for all life forms (i.e., forbs, grasses, shrubs, and trees) in the Central Hardwoods (see Figs. 5 and 6, page 3124–3125, Waldrop et al. 2008). This example emphasizes the need to conduct studies across the full range of geographical regions and forest community types to fully understand potential uses and effects of prescribed fire in eastern forests. Wildland fire, including prescribed burning, has the potential to alter plant successional rates and species composition and diversity (Elliott et al. 2004, Hutchinson et al. 2005b). Fire frequency, intensity (measured by fire temperature), and severity (a function of intensity and duration, often measured by tree mortality or forest floor consumption) determine the magnitude of its effects on vegetation and ecosystem processes (Certini 2005).

Over the last several centuries, fire regimes have changed across the Appalachian Mountains. During this time there have been a long period of frequent, low intensity fires ignited by Native Americans and early European settlers; a shorter period of high-intensity, stand-replacing fires during the era of heavy logging in the late 1800s; and a period of infrequent, low-intensity fires or fire suppression beginning in the early 1900s (Brose et al. 2001, Lorimer 2001, Guyette et al. 2002). Many postulate that this reduction in fire frequency in the last century has allowed shade-tolerant, fire-intolerant hardwoods such as maple (*Acer* spp.), beech (*Fagus grandifolia*), sourwood (*Oxydendrum arboreum*), and blackgum (*Nyssa sylvatica*), and the softwood eastern white pine (Elliott and Vose 2005) to invade the overstory (Arthur et al. 1998, Elliott et al. 1999, Abrams 2005, Hutchinson et al. 2005b, Chapman et al. 2006). In addition, the ericaceous species *Rhododendron maximum* and *Kalmia latifolia* have expanded their range; these species currently extend into mid-slope positions, whereas prior to fire suppression *R. maximum* was more restricted to areas immediately adjacent to stream channels and *K. latifolia* was more restricted to xeric ridges (Dobbs and Parker 2004). In some areas, impenetrable thickets of ericaceous species now often dominate understories of hardwood forests (Dobbs and Parker 2004) and prevent tree seedlings from becoming established (Nilsen et al. 1999).

In this paper, we examined prescribed fire effects on overstory, understory, and herbaceous layer vegetation of mixed-oak forests with intermediate to sub-mesic moisture regimes in southern Appalachian forests. Our objectives were to: 1) evaluate overstory mortality following prescribed fire treatments; and 2) assess short-term (the first two years after burning) changes in composition, abundance, and diversity of understory and herbaceous layer vegetation after prescribed burning in mixed-oak ecosystems. In a companion study, prescribed fire effects on forest floor and soil nutrient cycling were addressed for these same sites and treatments (Knoepp et al. 2009).

Methods. Site Descriptions. Three study sites were located in the Blue Ridge Physiographic province of the southern Appalachian Mountains: Alarka Laurel Branch (AL) in the Nantahala National Forest, Swain County, NC (35°20′ N, 84°21′ W); Robin Branch (RB) in the Nantahala National Forest, Macon County, NC (35°09′ N, 83°35′ W); and Roach Mill Branch (RM) in the Chattahoochee-Oconee National Forest, Rabun County, GA (34°53′ N, 83°19′ W). Each site was a 5–10 hectare area within a sub-watershed that drained a first order stream and was named after this stream drainage. Sites and prescribed burn treatments are described in detail in Knoepp et al. (2009).

Alarka Laurel Branch is a sub-mesic (cove, low slope), mixed-oak forest with an overstory dominated by *Acer rubrum L.*, *Carya* spp., *Quercus alba* L., *Q. rubra* L., and *Q. montana* Willd. The understory consisted primarily of *Castanea dentata* (Marsh.) Borkh., *Rubus* spp., *Kalmia latifolia* L., and *Rhododendron calendulaceum* (Michx.) Torrey. Robin Branch is an intermediate-moisture (near stream, low-to-mid slope), mixed-oak forest with an overstory dominated by *Acer rubrum*, *Quercus montana*, *Q. alba*, *Q. rubra*, *Tsuga canadensis* (L.) Carrière, and *Oxydendrum arboreum* (L.) De Candolle. The understory consisted primarily of *Gaylussacia ursina* (M.A. Curtis) T&G, *Hamamelis virginiana* L., and *Pyrularia pubera* Michx. (Appendix II). Roach Mill Branch is a sub-mesic (cove, low slope), mixed-oak forest with an overstory dominated by *A. rubrum*, *Q. alba*, *T. canadensis*, *Q. montana*, and *O. arboreum* (Appendix I). The understory, although sparse, had some *Rhododendron maximum* L. (Appendix II).

FIRE CHARACTERISTICS. For AL, the Wayah Ranger District, Nantahala National Forest implemented the prescribed burn across the study area on March 24, 2004. Air temperature averaged 6 °C and ranged from 6 to 13 °C (1100 hr to 1400 hr EST), relative humidity ranged from 41 to 31 percent, and wind speed was between 5 and 9 km hr^{-1} for the day of the fire. The fire was ignited by helicopter and drip torch along access roads.

For RB, the Wayah Ranger District, Nantahala National Forest implemented the burn across the study area on March 25, 2003. Air temperature averaged 14 °C and ranged from 8 to 18 °C (1000 hr to 1700 hr EST), relative humidity ranged from 42 to 25%, and wind speed was between 1 and 8 km hr^{-1} for the day of the fire. The site was burned in strips using drip torches. A backfire was ignited along the upper ridge and then strip headfires were ignited at about 10–15 m intervals until the entire area had burned from the ridge to the riparian zone.

For RM, the Tallulah Ranger District, Chattahoochee-Oconee National Forest implemented the prescribed burn across the study area on April 3, 2004. Air temperature averaged 8 °C and ranged from 3 to 12 °C (1100 hr to 1700 hr EST), relative humidity ranged from 40 to 25%, and wind speed was between 2 and 8 km hr^{-1} for the day or the fire. The fire was ignited by helicopter and drip torch along access roads.

All three of the prescribed fires were low to moderate intensity burns; i.e., they had moderate flame temperatures and low flame heights. Maximum flame temperatures ranged from 225 to 350 °C and maximum flame heights ranged from 45 to 62 cm across sites (Knoepp et al. 2009). Average maximum temperature was 156 °C for the RB site, a lower average than the AL (210 °C) or RM (250 °C) sites (Knoepp et al. 2009). Rate of spread was slightly greater at RM (5.5–6.7 cm s^{-1}) than at the other two sites (3.0–5.5 cm s^{-1}) (Knoepp et al. 2009).

EXPERIMENTAL DESIGN. We used a Before-After/Control-Impact experimental design (BACI) (van Mantgem et al. 2001) with three replicates (sites). Each site included a burned area and an adjacent unburned area (control). Before the prescribed fire treatments, we established permanent plots (10 × 20 m) in the prescribed burn areas (12 plots in AL, 12 plots in RB, and 10 plots in RM) and unburned areas (5 plots in AL, 6 plots in RB, and 4 plots in RM) for a total of 49 plots. The sites were comparable in pre-burn overstory species composition, except that *Rhododendron maximum* was more abundant at RM than elsewhere (Appendix I). Burned and unburned areas had Sorensen's similarity indices of 74%, 78%, and 72% for AL, RB, and RM, respectively (Appendix I). All sites were dominated by *Quercus* species; importance values of all *Quercus* species combined totaled 23% to 38%.

VEGETATION SAMPLING. Vegetation was measured in layers. The overstory layer (10 × 20 m permanent plots) included all woody stems ≥ 5.0 cm diameter at breast height (DBH, 1.37 m above ground). The understory layer (one nested 5 × 5 m subplot placed in the SE corner of each 10 × 20 m plot) included all woody stems < 5.0 cm DBH and ≥ 0.5 m height. The herbaceous layer included woody stems < 0.5 m height and all herbaceous species (four 1.0 m^2 quadrats, one placed in each corner of each 10 × 20 m plot). Numbered tags were nailed to all overstory stems before the prescribed fire treatments so mortality could be calculated. We present mortality as death of the aboveground main stem, since hardwoods sprout from the surviving root systems (Dey and Fan 2009) unless heat penetration into the mineral soil is sufficiently high to kill roots (i.e., high fire severity) (Simard 1991). In our study, the low-to-moderate intensity fires would not likely kill root systems.

The overstory, understory, and herbaceous layers were measured before and the first and second growing seasons after the prescribed burn at all three sites. Diameter of each overstory tree was measured to the nearest 0.1 cm and recorded by species. In the understory layer, basal diameter (3 cm above ground line) of trees and shrubs was measured to the nearest 0.1 cm and recorded by species. The herbaceous layer was measured before (July 2003) and after the burn (July 2004 and 2005) at Alarka Laurel and Roach Mill, but only after the burn at Robin Branch (July 2003 and 2004); hence, no pre-treatment data are available for this vegetation layer at Robin Branch. Cover of herbaceous layer species was visually estimated using a scale that emphasizes intermediate accuracy (Gauch 1982): 1% intervals from 1–5%, 5% intervals from 5–20%, and in 10% intervals above 20%. All species nomenclature follows Gleason and Cronquist (1991).

DATA ANALYSES. Species diversity (alpha diversity) was evaluated using species richness (S) and Shannon's index of diversity (H′). Shannon's index incorporates both species richness and the evenness of species abundance (Magurran 2004). For the understory, H′ was calculated based on density and basal area. For the herbaceous layer, H′ was calculated based on percent cover. Species richness (S) was calculated as the total number of species per quadrat (1.0 m^2) for the herbaceous layer, total number of species per plot (0.02 ha), and total number of species per site for all vegetation layers. Shannon's index (H′) was calculated at the plot level and averaged for each site. Importance values (IV) for woody species were calculated as: (relative density + relative basal area) ÷ 2. Sorenson's similarity index (SI) (beta diversity) was calculated to obtain an estimate of similarity in species composition (Magurran 2004) between burned areas and unburned areas within and among sites. Percent SI was calculated using the formula: $SI = (2c/a + b) \times 100$; where c is the number of species in common in both areas, a is the total number of species in area a, and b is the total number of species in area b.

To analyze the data for the BACI experimental design, we used a mixed linear model with repeated measures (PROC MIXED, SAS 2002–2003) to identify significant treatment-to-treatment differences in vegetation. We used the unstructured covariance option in the repeated statement because it produced the largest value for the Akaike's Information Criterion (AIC) and Schwarz' Bayesian Criterion (SBC) (Little et al. 1996). The three study sites were treated as random block effects and fire treatment was a fixed effect. Pre-treatment data were used as the covariate to test for post-treatment effects of fire. We evaluated the main effects of site, treatment, and time, and site × time × treatment interactions. If overall F-tests were significant ($p \leq 0.05$) then least squares means (LS-means, Tukey-Kramer adjusted t-statistic) tests were used to evaluate significance among sites (AL, RB, and RM), treatment (burned and unburned), and time (1st and 2nd sample dates post-burn) interactions. The LSMEANS statement within PROC MIXED allows for examination of interactions. When site was significant we assessed the effect of fire treatment for each site separately. Separate statistical analyses were performed for each vegetative layer (i.e., overstory, midstory, and herbaceous layer). We used repeated measures ANOVA (PROC MIXED, SAS 2002–2003) to determine significant differences between overstory mortality in burned and unburned treatments for the 1st and 2nd growing seasons after the burn. At Robin Branch, no pretreatment data were collected for the herbaceous layer; therefore, we made comparisons between burned and unburned treatments using repeated measures ANOVA (PROC MIXED, SAS 2002–2003) for post-burn 2003 and 2004.

Results. OVERSTORY RESPONSE. Density and basal area were not significantly different between burned and unburned areas on any site after the burn (Table 1). Overstory mortality was low for all sites, and mortality in burned areas did not differ significantly from that in unburned areas (Table 1).

UNDERSTORY RESPONSE. For understory density, site ($F = 6.33$, $P = 0.0038$) and treatment ($F = 18.99$, $P < 0.0001$) main effects, and site × time × treatment ($F = 5.92$, $P = 0.0001$) interaction were significant in the repeated measures ANCOVA model. Understory density was lower on the burned than the unburned plots the first ($t = -5.26$, $P < 0.0001$) and second ($t = -3.85$, $P = 0.0020$) growing seasons after burning (Table 2). At RB, density of all woody stems was lower on the burned than the unburned plots the first ($t = -6.75$, $P < 0.0001$) and second ($t = -6.42$, $P < 0.0001$) growing season after burning (Fig. 1). Oak (*Quercus* spp.) density was lower on the burned than unburned plots the first and second growing season after the burn on AL (Fig. 1).

For understory basal area, the site × time × treatment interaction ($F = 2.76$, $P = 0.0229$) was significant in the repeated measures model. RB was the only site that had lower understory basal area on the burned than the

Table 1. Overstory average density (stems ha^{-1}) and basal area (BA; $m^2\ ha^{-1}$) on the burned and unburned areas before the burn treatments, and mortality[a] after the 1st and 2nd growing seasons after prescribed fire for three mixed-oak sites in the southern Appalachians.

	Burned				Unburned[b]			
	Density	BA	Mortality (%)		Density	BA	Mortality (%)[c]	
			1st year	2nd year			1st year	2nd year
Alarka Laurel	1029 (72)	24.05 (1.90)	1.76 (0.77)	3.00 (1.47)	1170 (168)	27.14 (2.38)	2.18 (1.43)	2.18 (1.43)
Robin Branch	1125 (161)	34.39 (2.56)	2.68 (1.18)	4.72 (1.32)	1208 (109)	31.18 (2.36)	3.58 (1.24)	5.73 (1.36)
Roach Mill	1590 (234)	35.97 (3.28)	7.02 (2.40)	11.17 (3.64)	1550 (267)	35.49 (9.29)	8.28 (3.45)	9.60 (4.50)

[a] Mortality is death of the aboveground main stem.
[b] No significant ($P \leq 0.05$) differences were found between density, BA, or mortality values for burned plots and corresponding values for unburned plots before or after the prescribed fire for any site.
[c] The 2nd year mortality is cumulative.

unburned plots the first ($t = -3.39$, $P = 0.0190$) and second ($t = -3.37$, $P = 0.0197$) growing seasons; whereas, there were no significant differences in understory basal area between burned and unburned treatments at AL or RM (Table 2). Because few species were found and diversity was so low at RM (Table 2), we tested only AL and RB sites for changes in diversity (i.e., $H'_{density}$ and $H'_{basal\ area}$). For $H'_{basal\ area}$, treatment ($F = 5.17$, $P = 0.0298$) main effect, and time × treatment ($F = 3.83$, $P = 0.0591$) interaction were significant in the repeated measures ANCOVA model. The burned plots had lower $H'_{basal\ area}$ ($t = -2.76$, $P = 0.0445$) than unburned plots by the second growing season after burning (Table 2). See Appendix II for individual species density and basal area of the understory layer for each site.

Herbaceous Layer Response. Across the three sites, the herbaceous layer responded differently to prescribe burning. For cover on AL, the treatment ($F = 5.34$, $P = 0.0366$) main effect was significant in the repeated measures model. Burned plots had higher cover of herbaceous layer species than the unburned plots for the first and second growing seasons after burning (Table 3). For H' cover, the time ($F = 5.17$, $P = 0.0393$) main effect was significant, but the treatment ($F = 1.50$, $P = 0.2414$) main effect and the time × treatment ($F = 3.02$, $P = 0.1043$) interaction were not significant. For cover at RB, the time ($F = 25.37$, $P = 0.0001$) main effect and the time × treatment ($F = 10.75$, $P = 0.0047$) interaction were significant in the repeated measures ANOVA model. Cover increased on burned plots ($t = -7.20$, $P < 0.0001$) after the first growing season, whereas there was no change on the unburned plots (Table 3). H' cover and S per quadrat ($1.0\ m^2$) in burned areas did not differ from that in unburned areas at any site (Table 3). RM had consistently lower cover and H' cover (Table 3), and fewer species, than the other two sites. On the burned area of RM, 20 of the 40 herbaceous layer species occurred in only one plot and their cover was less than 1.0%.

We used Sorensen's coefficient of community (Magurran 2004) to assess the similarity in herbaceous layer species composition (i.e., beta diversity) between burned and unburned areas for the AL and RB sites. For AL, species compositions in the burned and unburned

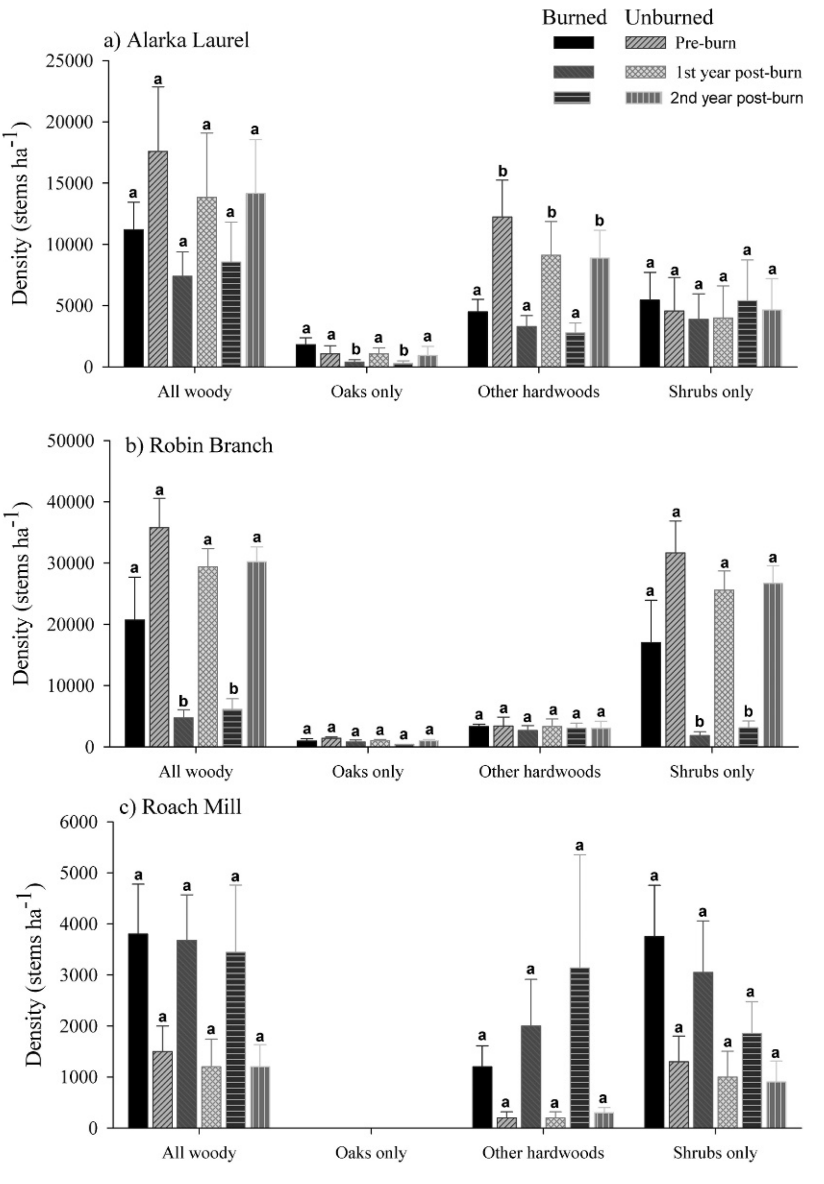

FIG. 1. Understory (≥ 0.5 m height, < 5.0 cm dbh) average density before (pre-burn) and the 1st and 2nd growing seasons after prescribed fire for burned and unburned area at the three mixed-oak sites. Different letters indicate significant differences ($P \leq 0.05$) between burned and unburned areas. Errors bars represent ± 1 SE.

areas were 75% similar before the prescribed burn treatment, and 74% and 76% similar the first and second growing seasons, respectively (Table 3). The burned and unburned areas had 55 species in common (11 trees, 2 shrubs, 1 woody vine, 3 ferns, 3 graminoids, and 35 forbs) (Appendix III).

For RB, herbaceous layer species compositions in the burned and unburned areas were 73% and 66% similar the first and second growing seasons, respectively, after prescribed burning (Table 3). The burned and unburned areas had 39 species in common (11 trees, 2 shrubs, 1 woody vine) (Appendix III). In addition, species compositions in burned areas of AL and RB were 76% similar and had 52 species in common (13 tree species, 3 shrubs, 1 woody vines, 3 ferns, 3 graminoids, and 29 forbs) the first growing season after prescribed burning (Appendix III). Species compositions

Table 2. Understory (≥ 0.5 m height, < 5.0 cm dbh) basal area ($m^2\ ha^{-1}$) and diversity based on density ($H'_{density}$) and basal area ($H'_{basal\ area}$) before and the 1st and 2nd growing seasons after prescribed fire for burned and unburned areas at the three mixed-oak sites.

		Pre-burn		1st yr post-burn		2nd yr post-burn	
Alarka Laurel		Burned	Unburned	Burned	Unburned	Burned	Unburned
Basal area	All woody	1.80 (0.46)	3.00 (0.63)	1.60 (0.62)	2.45 (0.65)	1.36 (0.44)	2.63 (0.60)
$H'_{density}$		1.33 (0.13)	1.51 (0.05)	0.95 (0.19) a	1.55 (0.10) b	0.87 (0.21) a	1.44 (0.05) b
$H'_{basal\ area}$		1.08 (0.11)	1.04 (0.15)	0.79 (0.16)	0.99 (0.10)	0.61 (0.16) a	0.98 (0.11) b
Robin Branch		Burned	Unburned	Burned	Unburned	Burned	Unburned
Basal area	All woody	1.90 (0.61)	3.18 (0.52)	0.94 (0.29)	3.00 (0.52)	0.95 (0.27)	2.97 (0.58)
$H'_{density}$		0.91 (0.12)	0.89 (0.18)	1.01 (0.14)	1.00 (0.20)	0.90 (0.15)	0.90 (0.19)
$H'_{basal\ area}$		1.02 (0.13)	1.26 (0.12)	0.79 (0.13)	1.17 (0.14)	0.68 (0.13) a	1.18 (0.14) a
Roach Mill		Burned	Unburned	Burned	Unburned	Burned	Unburned
Basal area	All woody	5.70 (1.56)	1.99 (0.94)	5.24 (1.45)	1.80 (1.25)	3.70 (1.23)	1.60 (0.90)
$H'_{density}$		0.57 (0.11)	0.10 (0.10)	0.54 (0.13)	0.10 (0.10)	0.57 (0.15)	0.27 (0.14)
$H'_{basal\ area}$		0.39 (0.08)	0.15 (0.15)	0.39 (0.11)	0.12 (0.12)	0.43 (0.13)	0.15 (0.14)

[a] Where values for corresponding burned and unburned areas within a site are followed by different letters, the values for the burned areas differ significantly ($p \leq 0.05$) from those for the unburned areas.
[b] Standard errors are in parentheses.

in unburned areas of AL and RB were 62% similar and had 36 species in common.

Discussion. Low severity burning can promote abundant and diverse herbaceous flora (Elliott et al. 1999, Gilliam 1988, Hutchinson et al. 2005a), increase plant available nutrients (Knoepp et al. 2004, Elliott et al. 2004, Certini 2005, Knoepp et al. 2005), and thin overcrowded forests from below (Elliott et al. 2004, Elliott and Vose 2005). In oak-dominated forests, prescribed fire is often applied to improve *Quercus* regeneration (Dey and Hartman 2005, Alexander et al. 2008). *Quercus* regeneration failure has been attributed to a combination of factors (see Loftis and McGee 1993, Abrams 2005) including competition from faster growing hardwoods following disturbance, predation of acorns by insects and small mammals, and poor acorn production that may be climate induced. If fire played a significant role in the developmental history of mixed-oak communities (Brose et al. 2001, Lorimer 2001, Guyette et al. 2002, Abrams 2005, Brose and Waldrop 2006b, Hutchinson et al. 2008), then re-introduction of prescribed fire in these ecosystems should be beneficial to *Quercus*. Fire should favor *Quercus* species more than many other common hardwoods because *Quercus* species have thick bark, sprout vigorously, and resist rotting after scarring, and because fire-created seedbeds are suitable for acorn germination (Abrams 1996). In our study, which was conducted on intermediate to sub-mesic oak sites, fire severity was not high enough to induce mortality in overstory trees of any species. With little to no overstory mortality and little reduction in basal area or canopy leaf area, these forests will remain closed canopy stands with low light transmittance. *Quercus* species are intermediate in shade tolerance, and *Quercus* reproduction requires a partially open canopy to grow and compete successfully (Loftis 1990, Alexander et al. 2008).

We found a significant reduction in understory stem density at RB, and much of this was due to reduction in *Gaylussacia ursina*, a low ericaceous shrub. A significant reduction in understory *Quercus* and *Carya* advance regeneration was recorded at AL and RB, and stem density remained low through the second growing season. Generally, *Quercus* and *Carya* seedlings and saplings are more tolerant of fire than many of their common associates such as *Acer rubrum*, *Nyssa sylvatica*, and *Liriodendron tulipifera* (Kruger and Reich 1997, Barnes and Van Lear 1998, Elliott et al. 1999, Elliott et al. 2004). For example, in a study of post-fire community dynamics in a mesic hardwood forest (Kruger and Reich 1997), spring burning had little effect on the survival and height growth of northern red oak regeneration, but it decreased the density and growth rate of key hardwood competitors. In our study, we found little to no change in densities of *A. rubrum*, *Nyssa sylvatica*, and *Oxydendrum arboreum*, most likely because these species were relatively minor components in the understory of the stands prior to burning. In general, hardwoods other than *Quercus* and *Carya* were not significantly affected by the prescribed fires on

Table 3. Herbaceous-layer cover (%), diversity (H' cover, Shannon's index), and species richness per quadrat (S, number of species m^{-2}) before (pre-burn) and the 1st and 2nd growing seasons after prescribed fire for burned and unburned areas at the three mixed-oak sites. Sorensen's Index of similarity (SI) between the burned and unburned areas for each site and time.

	Time	Burned	Unburned	SI[d]	Burned		Unburned	
		Cover (%)			H' cover	S	H' cover	S
Alarka Laurel								
Total	pre-burn	135.4 (8.3)	121.3 (9.3)	75%	2.66 (0.11)	14.3 (0.8)	3.01 (0.11)	15.6 (1.6)
Herbs[c]		121.9 (8.5)	97.8 (8.6)					
Woody		13.5 (3.0)	23.5 (4.1)					
Total	1st	134.7 (9.2) a	100.5 (7.4) b	74%	2.43 (0.10)	14.5 (0.8)	2.86 (0.13)	15.8 (1.4)
Herbs[c]		126.4 (8.6)	82.2 (5.7)					
Woody		8.3 (1.9)	18.2 (3.8)					
Total	2nd	138.4 (8.9) a	105.7 (5.8) b	76%	2.52 (0.10)	14.9 (0.8)	2.87 (0.13)	16.9 (1.7)
Herbs[c]		132.0 (8.7)	88.1 (6.4)					
Woody		6.4 (1.4)	17.6 (2.7)					
Robin Branch	pre-burn	–	–		–		–	
Total	1st	56.7 (8.6)	65.8 (9.2)	73%	2.24 (0.11)	8.8 (0.9)	2.13 (0.18)	8.6 (1.1)
Herbs[c]		42.0 (7.9)	29.8 (6.0)					
Woody		14.7 (3.0)	36.0 (4.7)					
Total	2nd	86.5 (11.1)	72.1 (9.0)	66%	2.43 (0.10)	9.7 (1.0)	2.21 (0.14)	8.8 (0.9)
Herbs[c]		55.4 (10.1)	37.5 (6.4)					
Woody		31.0 (5.2)	34.6 (4.2)					
Roach Mill								
Total	pre-burn	11.7 (2.2)	4.7 (1.1)	-	1.76 (0.12)	3.4 (0.4)	1.11 (0.38)	2.4 (0.5)
Herbs[c]		2.0 (0.4)	1.8 (0.8)					
Woody		18.7 (4.5)	3.4 (0.8)					
Total	1st	10.7 (2.1)	5.4 (1.2)	-	1.77 (0.07)	3.7 (0.4)	1.37 (0.16)	2.7 (0.4)
Herbs[c]		2.4 (0.4)	1.5 (0.6)					
Woody		13.9 (2.9)	4.2 (1.3)					
Total	2nd	10.2 (2.5)	3.7 (1.0)	-	1.82 (0.09)	4.4 (0.6)	1.32 (0.15)	2.4 (0.3)
Herbs[c]		2.2 (0.5)	1.3 (0.6)					
Woody		16.2 (4.5)	2.8 (1.2)					

[a] Where corresponding cover values for burned and unburned areas are followed by different letters, these values differ significantly ($p \leq 0.05$).
[b] Standard errors are in parentheses.
[c] Herbs subgroup includes forb, fern, and grass species. Woody subgroup includes shrub and tree species.
[d] Sorensen's index of similarity; $SI = 2c/a + b$; where c was the number of species in common in both areas, and a and b were the total number of species in burned area a and unburned area b, respectively. SI was converted into percentages by multiplying by 100.

any of our sites. Dey and Hartman (2005) found that after one dormant season fire, most advance regeneration with basal diameter less than 15 cm was damaged by fire, which caused shoot dieback (death of the aboveground portion of the stem) and formation of sprout clumps. Blankenship and Arthur (2006) reported that *A. rubrum* accounted for the greatest proportion of basal sprouts for mixed-oak sites with single and repeated fires; however, their burned and unburned sites had a large proportion of midstory and overstory *A. rubrum* and *Oxydendrum arboreum*. Wang et al. (2005) reported increased establishment of *Q. alba* on prescribed burn sites in the Piedmont of South Carolina.

In mixed-oak communities, herbaceous layer species tend to be more diverse after moderate-intensity fire (Elliott et al. 1999) partly due to removal of the litter layer, increased nutrient cycling rates, and increased light levels. With dormant season fires of low-intensity the herbaceous layer may not be affected by prescribed burning treatments. In some studies in eastern hardwood forests, prescribed fire resulted in increased cover and diversity of herbaceous layer species (Arthur et al. 1998, Elliott et al. 1999, Clinton and Vose 2000, Hutchinson and Sutherland 2000, Clendenin and Ross 2001). However, low intensity fires often have little effect on plant community composition (McGee et al. 1995, Kuddes-Fischer and Arthur 2002), and in some cases they have little effect on diversity (Franklin et al. 2003, Dolan and Parker 2004, Hutchinson et al. 2005a, Waldrop et al. 2008).

In our study, there was either an increase (AL, RB) or no change (RM) in herbaceous layer cover depending on the site and no significant change in diversity (H′ cover) after burning for any site. Thus, we found no negative effects of prescribed fire on herbaceous flora.

An initial increase in nitrogen availability after fire may have contributed to increased herbaceous layer cover (Elliott et al. 2004, Knoepp et al. 2009). The herbaceous layer, as defined in this paper (all vascular plants $<$ 0.5 m height), includes several life forms that may respond differently to fire disturbance; i.e., tree seedlings, shrubs, forbs, ferns, and graminoids. In addition, these low to moderate intensity and low severity prescribed fires coupled with dormant season ignition, allowed the root systems and seed banks of herbaceous layer species to survive; thus, species were able to re-emerge in the spring and summer after the burn treatments.

Conclusions. Clearly, initial forest conditions (e.g., community composition, site moisture regime, and fuel loads) and fire intensity and severity must be considered before application of prescribed fire in the Eastern U.S. In our study with low-to-moderate intensity fires, we detected no overstory mortality associated with burning, while understory density was reduced. *Quercus* and *Carya* species did not respond favorably and fire-sensitive hardwoods (e.g., *Acer rubrum*, *Nyssa sylvatica*, *Oxydendrum arboreum*) showed no significant response to prescribed fire in these intermediate to sub-mesic oak ecosystems. We also found that prescribed fire, in late-winter or early-spring before the herbaceous flora has emerged, can be used without negatively impacting herbaceous layer diversity.

In a companion study on our sites, Knoepp et al. (2009) found that fire reduced fine fuels (litter and small wood) and resulted in a short-term pulse of soil NH4-N; and we found a corresponding increase in herbaceous layer cover, likely in response to this short-term pulse in available nitrogen. However, either more intense burns, repeated burning, or both will be necessary in these ecosystems to stimulate recruitment of *Quercus* and *Carya* species or increase diversity. For example, Phillips et al. (2007) found that a combined treatment of thinning from below followed by prescribed fire resulted in increased herbaceous layer cover and richness because fire in the combined treatment was more intense than the burn only treatment. On the same treatment sites as Phillips et al. (2007), silvicultural thinning created canopy light gaps sufficient for oak recruitment, however, these gaps were captured by maple while oak recruitment was minimal (Chiang et al. 2008). Holzmueller et al. (2009) examined the influence of repeated burning on understory communities using a chronosequence of oak-hickory stands in the Smoky Mountains National Park. They compared understory herbaceous, shrub, and tree species diversity and composition among four burn categories: unburned stands, and stands that had burned once, twice, and three times over a 20-year period. No significant differences were found among the burn categories in herbaceous, shrub, or tree seedling cover (Holzmueller et al. 2009). Indeed, predicting the outcomes of vegetation response to prescribed fire is complex, even within a single geographical location such as the southern Appalachians; and long-term data is lacking. Fire managers must decide on their desired forest condition, and then consider numerous factors such as topography, terrain, season of burn, plant phenology, initial forest condition and composition, as well as fire behavior, to achieve their desired outcome.

Literature Cited

Abrams, M. D. 1996. Distribution, historical development and ecophysiological attributes of oak species in the eastern United States. Ann. For. Sci. 53: 487–512.

Abrams, M. D. 2005. Prescribing fire in eastern oak forests: Is time running out? North. J. Appl. For. 22: 190–196.

Albrecht, M. A. and B. C. McCarthy. 2006. Effects of prescribed fire and thinning on tree recruitment patterns in central hardwood forests. Forest Ecol. Manage. 226: 88–103.

Alexander, H. D., M. A. Arthur, D. L. Loftis, and S. R. Green. 2008. Survival and growth of upland oak and co-occurring competitor seedlings following single and repeated prescribed fires. Forest Ecol. Manage. 256: 1021–1030.

Arthur, M. A., R. D. Paratley, and B. A. Blankenship. 1998. Single and repeated fires affect survival and regeneration of woody and herbaceous species in an oak-pine forest. J. Torrey Bot. Soc. 125: 225–236.

Barnes, L. S. and D. H. Van Lear. 1998. Prescribed fire effects on advanced regeneration in mixed hardwood stands. South. J. Appl. For. 22: 138–142.

Blankenship, B. A. and M. A. Arthur. 2006. Stand structure over 9 years in burned and fireexcluded oak stands on the Cumberland Plateau, Kentucky. Forest Ecol. Manage. 225: 134–145.

Brose, P. H., D. H. Van Lear, and R. Cooper. 1999. Using shelterwood harvests and prescribed fire to regenerate oak stands on productive upland sites. Forest Ecol. Manage. 118: 125–141.

Brose, P., T. Schuler, D. Van Lear, and J. Berst. 2001. Bringing fire back: The changing regimes of the Appalachian mixed-oak forests. J. Forest. 99: 30–35.

Brose, P. H. and T. A. Waldrop. 2006a. Changes in the disturbance regime of upland yellow pine stands in the Southern Appalachian Mountains during the 20th century, p. 467–470. USDA For. Serv. Gen. Tech. Rep. SRS-92, Asheville, NC.

Brose, P. H. and T. A. Waldrop. 2006b. Fire and the origin of the Table Mountain pine-pitch pine communities in the southern Appalachian mountains, USA. Can. J. Forest Res. 36: 710–718.

Carson, W. S. and T. W. Green. 1981. Soil Survey of Rabun and Towns Counties Georgia. USDA Soil Conservation Service. 131 p.

Certini, G. 2005. Effects of fire on properties of forest soils: a review. Oecologia 143: 1–10.

Dey, D. C. and Z. Fan. 2009. A review of fire and oak regeneration and overstory recruitment, p. 2–20. *In* T. F. Hutchinson [ed.], Proceedings of the 3rd fire in eastern oak forests conference. USDA For. Serv. Gen. Tech. Rep. NRS-P-46, Newtown Square, PA.

Chapman, R. A., E. Heitzman, and M. G. Shelton. 2006. Long-term changes in forest structure and species composition of an upland oak forest in Arkansas. Forest Ecol. Manage. 236: 85–92.

Chiang, J., R. W. McEwan, D. A. Yaussy, and K. J. Brown. 2008. The effects of prescribed fire and silvicultural thinning on the aboveground carbon stocks and net primary production of overstory trees in an oak-hickory ecosystem in southern Ohio. Forest Ecol. Manage. 255: 1584–1594.

Clendenin, M. and W. G. Ross. 2001. Effects of cool season prescribed fire on understory vegetation in a mixed pine hardwood forest of east Texas. Texas J. Sci. 53: 65–78.

Clinton, B. D. and J. M. Vose. 2000. Plant succession and community restoration following felling and burning in the southern Appalachians, p. 22–29. *In* W. K. Moser and C. F. Moser [eds.], Fire and forest ecology: innovative silviculture and vegetation management. Tall Timbers Fire Ecology Conference Proceedings, No. 21, Tall Timbers Research Station, Tallahassee, FL.

Cutter, B. E. and R. P. Guyette. 1994. Fire frequency on an oak-hickory ridgetop in the Missouri Ozarks. Am. Midl. Nat. 132: 393–398.

Day, G. M. 1953. The Indian as an ecological factor in the Northeastern forest. Ecology 34: 329–346.

DeBano, L. F., D. G. Neary, and P. F. Ffolliott. 1998. Fire's effects on ecosystems. John Wiley & Sons, Inc, New York, NY. 333 p.

Delcourt, P. A. and H. R. Delcourt. 1993. Paleoclimate, paleovegetation and paleofloras during the late Quaternary, p. 1010–1014. *In* The Flora of Northern America Editorial Committee, Flora of Northern America, Vol. 1. Oxford University Press, New York, NY.

Delcourt, H. R. and P. A. Delcourt. 1997. Pre-Columbian Native American use of fire on southern Appalachian landscapes. Conserv. Biol. 11: 1010–1014.

DeVivo, M. S. 1991. Indian use of fire and land clearance in the southern Appalachians, p. 306–312. *In* S. C. Nodvin and T. A. Waldrop [eds.], Fire and the Environment: Ecological and Cultural Perspectives. USDA For. Serv. Gen. Tech. Rep. SE-69, Asheville, NC.

Dey, D. C. and G. Hartman. 2005. Returning fire to Ozark Highland forest ecosystems: Effects on advance regeneration. Forest Ecol. Manage. 217: 37–53.

Dobbs, M. M. and A. J. Parker. 2004. Evergreen understory dynamics in Coweeta Forest, North Carolina. Phys. Geogr. 6: 481–498.

Dolan, B. J. and G. R. Parker. 2004. Understory response to disturbance: An investigation of prescribed burning and understory removal treatments, p. 285–291. *In* M. A. Spetich [ed.], Upland oak ecology symposium: history, current conditions, and sustainability. USDA For. Serv. Gen. Tech. Rep. SRS-73, Asheville, NC.

Elliott, K. J., R. L. Hendrick, A. E. Major, J. M. Vose, and W. T. Swank. 1999. Vegetation dynamics after a prescribed fire in the southern Appalachians. Forest Ecol. Manage. 114: 199–213.

Elliott, K. J., J. M. Vose, B. D. Clinton, and J. D. Knoepp. 2004. Effects of understory burning in a mesic, mixed-oak forest in the southern Appalachians, p. 272–283. *In* T. T. Engstrom, K. E. M. Galley, and W. J. de Groot [eds.], Fire in temperate, boreal, and montane ecosystems, Proceedings of the 22nd Tall Timbers Fire Ecology Conference. Tall Timbers Research Station, Tallahassee, FL.

Elliott, K. J. and J. M. Vose. 2005. Effects of understory prescribed burning on shortleaf pine (*Pinus echinata* Mill.)/mixed hardwood forests. J. Torrey Bot. Soc. 132: 236–251.

Elliott, K. J. and J. M. Vose. 2006. Fire effects on water quality: A synthesis of response regulating factors among contrasting ecosystems, p. 77–87. *In* D. L. Fowler [compl.], Proceedings of the 2nd Interagency Conference on Research in the Watersheds, 16–18 May 2006. USDA For. Serv. SRS-Coweeta Hydrologic Laboratory, Otto, NC.

Franklin, S. B., P. A. Robertson, and J. S. Fralish. 2003. Prescribed burning effects on upland *Quercus* forest structure and function. Forest Ecol. Manage. 184: 315–335.

Gauch, H. G. 1982. Multivariate analysis in community ecology. Cambridge University Press, New York, NY. 298 p.

Gilliam, F. S. 1988. Interactions of fire with nutrients in the herbaceous layer of a nutrient-poor Coastal Plain forest. Bull. Torrey Bot. Club 115: 265–271.

Glasgow, L. S. and G. R. Matlack. 2007. Prescribed burning and understory composition in a temperate deciduous forest, Ohio, USA. Forest Ecol. Manage. 238: 54–64.

Gleason, H. A. and A. Cronquist. 1991. Manual of Vascular Plants of Northeastern United States and Adjacent Canada, second edition. The New York Botanical Garden, Bronx, NY. 910 p.

Guyette, R. P., R. M. Muzika, and D. C. Dey. 2002. Dynamics of an anthropogenic fire regime. Ecosystems 5: 472–486.

Holzmueller, E. J., S. Jose, and M. A. Jenkins. 2009. The response of understory species composition, diversity, and seedling regeneration to repeated burning in southern Appalachian oak-hickory forests. Nat. Areas J. 29: 255–262.

Hubbard, R. T., B. D. Clinton, J. M. Vose, J. D. Knoepp, and K. J. Elliott. 2004. Stand restoration burning in oak-pine forests in the southern Appalachians: Effects on aboveground biomass and carbon and nitrogen cycling. Forest Ecol. Manage. 190: 311–321.

Hutchinson, T. F. and S. Sutherland. 2000. Fire and understory vegetation: a large-scale study in Ohio and a search for general response patterns in central hardwood forests, p. 64–74. *In* D. A. Yaussy [compl.], Proceedings: Workshop on Fire, People, and the Central Hardwoods Landscape. Richmond, KY, 12–14 March 2000. USDA For. Serv. Gen. Tech. Rep. NE-274, Newtown Square, PA.

Hutchinson, T. F., B. E. J. Boerner, S. Sutherland, E. K. Sutherland, M. Ortt, and L. R. Iverson. 2005a. Prescribed fire effects on the herbaceous layer of mixed-oak forests. Can. J. Forest Res. 35: 877–890.

Hutchinson, T. F., E. K. Sutherland, and D. A. Yaussy. 2005b. Effects of repeated prescribed fires on the structure, composition, and regeneration of mixed-oak forests in Ohio. Forest Ecol. Manage. 218: 210–228.

Hutchinson, T. F., R. P. Long, R. D. Ford, and E. K. Sutherland. 2008. Fire history and the establishment of oaks and maples in second-growth forests. Can. J. Forest Res. 38: 1184–1198.

Knoepp, J. D. and W. T. Swank. 1993. Site preparation burning to improve southern Appalachian pine-hardwood stands: nitrogen responses in soil, soil water, and streams. Can. J. Forest Res. 23: 2263–2270.

Knoepp, J. D., J. M. Vose, and W. T. Swank. 2004. Long-term soil response to site preparation burning in the southern Appalachians. For. Sci. 50: 540–550.

Knoepp, J. D., L. F. Debano, and D. G. Neary. 2005. Soil chemistry, p. 53–71. *In* D. G. Neary, K. C. Ryan, and L. F. Debano [eds.], Wildland Fire in Ecosystems: Effects of fire on soil and Water. USDA For. Serv. Gen. Tech. Rep. RMRS-GTR-42-vol. 4, Ogden, UT.

Knoepp, J. D., K. J. Elliott, J. M. Vose, and B. D. Clinton. 2009. Effects of prescribed fire in mixed-oak forests of the southern Appalachians: forest floor, soil, and soil solution nitrogen responses. J. Torrey Bot. Soc. 136: 380–391.

Kruger, L. and P. B. Reich. 1997. Responses of hardwood regeneration to fire in mesic forest openings. I. Post-fire community dynamics. Can. J. Forest Res. 27: 822–1831.

Kuddes-Fischer, L. M. and M. A. Arthur. 2002. Response of understory vegetation and tree regeneration to a single prescribed fire in oak-pine forests. Nat. Areas J. 22: 43–52.

Little, R. C., G. A. Milliken, W. W. Stroup, and R. D. Wolfinger. 1996. SAS System for Mixed Models. SAS Institute, Inc., Cary, NC.

Loftis, D. L. 1990. A shelterwood method for regenerating red oak in the southern Appalachians. For. Sci. 36: 917–929.

Lorimer, C. G. 2001. Historical and ecological roles of disturbance in eastern North American forests: 9,000 years of change. Wildlife Soc. Bull. 29: 425–439.

Magurran, A. E. 2004. Measuring Biological Diversity. Blackwells, Oxford, UK. 256 p.

McEwan, R. W., R. Long, T. F. Hutchinson, R. P. Long, R. D. Ford, and B. C. McCarthy. 2007. Temporal and spatial patterns of fire occurrence during the establishment of mixed-oak forest in eastern North America. J. Veg. Sci. 18: 655–664.

McGee, G. G., D. J. Leopold, and R. D. Nyland. 1995. Understory response to springtime prescribed fire in two New York transition oak forests. Forest Ecol. Manage. 76: 149–168.

Nilsen, E. T., J. F. Walker, O. K. Miller, S. W. Semones, T. T. Lei, and B. D. Clinton. 1999. Inhibition of seedling survival under *Rhododendron maximum* (Ericaceae): Could allelopathy be a cause? Am. J. Bot. 86: 1597–1605.

Phillips, R., T. Hutchinson, L. Brudnak, and T. Waldrop. 2007. Fire and fire surrogate treatments in mixed-oak forests: Effects on herbaceous layer vegetation, p. 1–11. *In* B. W. Butler and W. Cook [compls.], The fire environment—innovations, management, and policy; conference proceedings, 26–30 March 2007, Destin, FL. USDA For. Serv. RMRS-P-46, Fort Collins, CO.

Pyne, S. J. 1995. World Fire: The Culture of Fire on Earth. Holt, New York, NY. 379 p.

Randles, R. B., D. H. Van Lear, T. A. Waldrop, and D. M. Simon. 2002. Periodic burning in Table Mountain-pitch pine stands, p. 114–118. *In* K. W. Outcalt [ed.], Proceedings of the eleventh biennial southern silvicultural research conference. USDA For. Serv. Gen. Tech. Rep. SRS-48, Asheville, NC.

Roberts, M. R. and F. S. Gilliam. 2003. Response of the herbaceous layer to disturbance in eastern forests, p. 302–320. *In* F. S. Gilliam and M. R. Roberts [eds.], The herbaceous layer in forests of eastern North America. Oxford University Press, New York, NY.

Ryan, K. C. and N. V. Noste. 1985. Evaluating prescribed fire, p. 230–238. *In* Proceedings of the Symposium on Wilderness Fire. USDA For. Serv. Gen. Tech. Rep. INT-48, Ogden, UT.

SAS Institute Inc., 2002–2003. SAS/STAT Guide for Personal Computers. Vers. 9.1. Cary, NC.

Schuler, T. M. and A. R. Gillespie. 2000. Temporal patterns of woody species diversity in a central Appalachian forest from 1856 to 1997. J. Torrey Bot. Soc. 127: 149–161.

Schulze, E. D. and H. A. Mooney. 1993. Biodiversity and ecosystem function. Springer-Verlag, Berlin, Germany. 525 p.

Simard, A. J. 1991. Fire severity, changing scales, and how things hang together. Int. J. Wildland Fire 1: 23–34.

STEINER, K. C., J. C. FINLEY, P. J. GOULD, S. FEI, AND M. MCDILL. 2008. Oak regeneration guidelines for the Central Appalachians. North. J. Appl. For. 25: 5–16.

THOMAS, D. J. 1996. Soil Survey of Macon County, North Carolina. USDA Natural Resources Conservation Service. 322 p.

VAN LEAR, D. H. AND T. A. WALDROP. 1989. History, use, and effects of fire in the Appalachians. USDA For. Serv. Gen. Tech. Rep. SE-54, Asheville, NC.

VAN LEAR, D. H., P. H. BROSE, AND P. D. KEYSER. 2000. Using prescribed fire to regenerate oaks, p. 97–102. *In* D. A. Yaussy [compl.], Proceedings: Workshop on Fire, People, and the Central Hardwoods Landscape. USDA For. Serv. Gen. Tech. Rep. NE-274, Newtown Square, PA.

VAN LEAR, D. H., W. D. CARROLL, P. R. KAPELUCK, AND R. JOHNSON. 2005. History and restoration of the longleaf pine-grassland ecosystem: Implications for species at risk. Forest Ecol. Manage. 211: 150–165.

VAN MANTGEM, P., M. SCHWARTZ, AND M. KEIFER. 2001. Monitoring fire effects for managed burns and wildfires: Coming to terms with pseudoreplication. Nat. Areas J. 21: 266–273.

WALDROP, T. A., P. H. BROSE, N. T. WELCH, H. H. MOHR, E. A. GRAY, F. H. TAINTER, AND L. E. ELLIS. 2002. High-intensity fires may be unnecessary for stand replacement of Table Mountain pine: An overview of current research, p. 137–142. *In* K. W. Outcalt [ed.], Proceedings of the eleventh biennial southern silvicultural research conference. USDA For. Serv. Gen. Tech. Rep. SRS-48, Asheville, NC.

WALDROP, T. A., D. A. YAUSSY, R. J. PHILLIPS, T. A. HUTCHINSON, L. BRUDNAK, AND R. E. J. BOERNER. 2008. Fuel reduction treatments affect stand structure of hardwood forests in western North Carolina and southern Ohio, USA. Forest Ecol. Manage. 255: 3117–3129.

WANG, G. G., D. H. VAN LEAR, AND W. L. BAUERLE. 2005. Effects of prescribed fires on first-year establishment of white oak (*Quercus alba* L.) seedlings in the upper Piedmont of South Carolina, USA. Forest Ecol. Manage. 213: 328–337.

WARD, J. S. AND P. H. BROSE. 2004. Mortality, survival, and growth of individual stems after prescribed burning in recent hardwood clearcuts, p. 194–199. *In* Proceedings of the 14th Central Hardwoods Forest Conference. USDA For. Serv. Gen. Tech. Rep. NE-316, Newton Square, PA.

WELCH, N. T., T. A. WALDROP, AND E. R. BUCKNER. 2000. Response of southern Appalachian Table Mountain pine (*Pinus pungens*) and pitch pine (*P. rigida*) stands to prescribed burning. Forest Ecol. Manage. 136: 185–197.

Appendix I

Overstory (woody stems ≥ 5.0 cm dbh) species importance values (IV = (relative density + relative basal area) ÷ 2) for burned and unburned areas on three mixed-oak sites in the southern Appalachians. Sorensen's Index of similarity (SI) between the burned and unburned areas for each site.

	Alarka Laurel		Robin Branch		Roach Mill	
Species[a]	Burned	Unburned	Burned	Unburned	Burned	Unburned
Acer rubrum	22.79	14.23	19.74	27.27	9.92	4.81
Quercus alba	19.36	1.42	4.74	8.50	15.62	21.21
Carya spp.	14.23	10.37	7.19	1.26	6.80	4.66
Quercus rubra	7.03	23.45	9.14	1.60	1.58	5.49
Acer pensylvanicum	4.85	0.55	3.44	0.43	-	-
Amelanchier arborea	4.48	0.53	1.00	1.18	-	-
Robinia pseudoacacia	4.31	-	1.38	0.74	0.84	-
Rhododendron maximum	3.25	-	8.92	2.09	18.33	22.08
Magnolia acuminata	3.04	2.75	1.92	3.95	-	-
Tilia americana	2.10	1.35	-	-	-	-
Nyssa sylvatica	1.97	-	-	2.16	6.40	0.72
Sassafras albidum	1.71	0.74	-	1.69	0.18	-
Castanea dentata	1.70	0.47	0.83	-	-	-
Acer saccharum	1.63	3.48	-	0.77	-	-
Quercus velutina	1.38	4.91	0.21	1.79	4.90	-
Fraxinus americana	1.30	-	0.20	-	0.30	-
Quercus montana	1.12	7.76	10.88	9.43	6.63	2.55
Prunus serotina	1.06	1.38	-	-	-	-
Betula alleghaniensis	0.89	3.44	-	1.55	-	-
Hamamelis virginiana	0.71	12.03	1.43	8.77	0.17	-
Tsuga canadensis	0.57	-	8.25	2.42	8.39	19.39
Fagus grandifolia	-	4.10	2.96	-	-	-
Halesia tetraptera	-	3.16	1.39	-	-	-
Betula lenta	-	2.08	1.03	1.26	0.54	-
Oxydendrum arboreum	-	1.78	6.61	8.91	5.95	2.87
Pinus strobus	-	-	5.31	5.60	0.58	3.44
Kalmia latifolia	-	-	1.26	5.81	2.54	7.36
Quercus coccinea	-	-	1.58	1.90	2.52	-
Magnolia fraseri	-	-	0.53	0.50	-	-
Cornus florida	-	-	-	-	3.67	4.86
Pinus rigida	-	-	-	-	2.41	-
Diospyros virginiana	-	-	-	-	0.63	0.54
Liriodendron tulipifera	-	-	-	-	0.58	-
Pinus pungens	-	-	-	-	0.32	-
All *Quercus* combined	28.89	37.54	26.55	23.22	28.73	29.25
Sorenson' similarity index (SI)[b]	74%		78%		72%	

[a] Species nomenclature follows Gleason and Cronquist (1991).

[b] Sorensen's index of similarity; SI = $2c/a + b$; where c was the number of species in common in both areas, and a and b were the total number of species in burned area a and unburned area b, respectively. SI was converted into percentages by multiplying by 100.

Appendix II

Understory (woody stems < 5.0 cm dbh, ≥ 0.5 m height) average density (stems ha^{-1}), basal area (BA; m^2 ha^{-1}), and importance value (IV; (relative density + relative basal area) ÷ 2) for the three mixed-oak sites before and the 1st and 2nd growing seasons after the prescribed burn treatments.

Species	Density	BA	IV	Density	BA	IV	Density	BA	IV
Alarka Laurel, Swain County, NC									
Burned	Pre-burn 2003			Post-burn 2004			Post-burn 2005		
Acer pensylvanicum	100	0.002	0.50	-	-	-	33	0.001	0.23
Acer rubrum	300	0.054	2.82	433	0.045	4.34	367	0.040	3.57
Acer saccharum	33	< 0.001	0.16	-	-	-	-	-	-
Amelanchier arborea	467	0.071	4.06	67	0.044	1.83	133	0.042	2.30
Carya spp.	333	0.182	6.53	233	0.172	6.95	200	0.283	11.31
Castanea dentata	1933	0.325	17.67	1600	0.200	17.03	1467	0.140	13.58
Fraxinus americana	433	0.058	3.54	133	0.036	2.02	100	0.038	1.94
Halesia tetraptera	33	0.002	0.20	-	-	-	33	0.002	0.20
Hamamelis virginiana	33	< 0.001	0.16	-	-	-	-	-	-
Kalmia latifolia	367	0.384	12.29	67	0.375	12.15	67	0.310	11.53
Magnolia acuminata	300	0.173	6.12	267	0.172	7.16	300	0.170	7.85
Nyssa sylvatica	67	0.063	2.04	67	0.058	2.27	33	0.071	2.74
Prunus serotina	200	0.012	1.22	67	0.001	0.48	67	0.001	0.42
Quercus rubra	1333	0.109	8.97	300	0.067	4.12	200	0.045	2.79
Rhododendron calendulaceum	300	0.053	2.82	267	0.209	8.31	100	0.043	2.12
Rhododendron maximum	300	0.070	3.27	267	0.82	4.34	200	0.052	3.03
Robinia pseudoacacia	200	0.055	2.41	200	0.040	2.60	67	0.036	1.68
Rubus spp.	3767	0.059	18.46	2933	0.050	21.40	4866	0.076	31.14
Sassafras albidum	400	0.072	3.80	467	0.033	4.19	200	0.024	2.03
Vaccinium corymbosum	200	0.055	2.42	33	0.019	0.82	67	0.021	1.13
Viburnum nudum	67	0.001	0.32	-	-	-	67	0.001	0.41
Unburned	Pre-burn 2003			Post-burn 2004			Post-burn 2005		
Acer rubrum	80	0.003	0.28	320	0.012	1.40	240	0.006	0.96
Acer saccharum	240	0.034	1.24	240	0.033	1.55	320	0.031	1.72
Amelanchier arborea	160	0.003	0.51	80	0.003	0.35	80	0.002	0.32
Betula alleghaniensis	80	0.005	0.31	80	0.003	0.35	-	-	-
Carya spp.	160	0.009	0.61	80	0.006	0.42	80	0.016	0.59
Castanea dentata	960	0.130	4.89	720	0.096	4.56	480	0.086	3.33
Cornus alternifolia	160	0.033	1.00	160	0.031	1.21	80	0.020	0.67
Fagus grandifolia	3440	0.429	16.93	3120	0.423	19.92	3120	0.472	20.00
Fraxinus americana	80	0.001	0.24	80	0.001	0.31	-	-	-
Halesia tetraptera	800	0.282	6.99	880	0.284	8.98	720	0.238	7.40
Hamamelis virginiana	5120	1.437	38.52	2960	0.970	30.51	3760	1.124	34.67
Prunus serotina	320	0.005	1.00	160	0.003	0.64	160	0.002	0.61
Pyrularia pubera	1360	0.080	5.20	1040	0.050	4.78	1440	0.060	6.23
Quercus alba	240	0.007	0.80	240	0.006	0.70	240	0.009	1.02
Quercus rubra	400	0.011	1.32	400	0.012	1.96	320	0.008	1.28
Rhododendron calendulaceum	2720	0.446	15.17	2480	0.449	18.13	2560	0.476	18.11
Robinia pseudoacacia	240	0.001	0.070	80	0.001	0.31	-	-	-
Sassafras albidum	240	0.003	0.074	80	0.001	0.31	-	-	-
Tilia americana	320	0.070	2.08	160	0.055	1.70	80	0.53	1.29
Viburnum nudum	480	0.007	1.48	480	0.007	1.88	480	0.005	1.79
Robin Branch, Macon County, NC									
Burned	Pre-burn 2002			Post-burn 2003			Post-burn 2004		
Acer rubrum	133	0.110	3.21	100	0.110	6.94	233	0.004	2.12
Amelanchier arborea	200	0.005	0.61	-	-	-	-	-	-
Castanea dentata	733	0.189	6.74	900	0.041	11.71	1,100	0.059	12.12
Fagus grandifolia	33	0.003	0.16	-	-	-	-	-	-
Fraxinus americana	400	0.100	3.59	200	0.085	6.66	233	0.072	5.71
Gaylussacia ursina	14,800	0.339	44.59	267	0.009	3.32	600	0.036	6.82
Halesia tetraptera	33	0.020	0.62	133	0.022	2.57	33	< 0.001	0.28
Hamamelis virginiana	767	0.353	11.11	333	0.218	15.14	433	0.208	14.45
Kalmia latifolia	33	0.065	1.80	67	0.111	6.62	67	0.151	8.47
Magnolia acuminata	667	0.077	3.64	500	0.070	9.00	200	0.043	3.89

Appendix II
Continued.

Species	Density	BA	IV	Density	BA	IV	Density	BA	IV
Magnolia fraseri	100	0.018	0.71	33	< 0.001	0.36	233	0.026	3.30
Nyssa sylvatica	67	0.002	0.20	100	0.002	1.15	67	0.002	0.66
Oxydendrum arboreum	100	0.004	0.35	300	0.005	3.42	333	0.008	3.16
Pyrularia pubera	2,133	0.449	16.93	1,467	0.124	22.11	2,367	0.166	28.11
Quercus montana	167	0.008	0.63	167	0.003	1.91	-	-	-
Quercus rubra	233	0.035	1.49	100	0.033	2.83	67	0.057	3.51
Rhododendron maximum	67	0.097	2.70	33	0.068	3.99	33	0.085	4.73
Robinia pseudoacacia	-	-	-	-	-	-	33	0.001	0.31
Rubus sp.	-	-	-	-	-	-	33	0.001	0.31
Sassafras albidum	33	0.001	0.10	-	-	-	-	-	-
Tsuga canadensis	33	0.028	0.83	33	0.036	2.26	33	0.001	2.05
Unburned	Pre-burn 2002			Post-burn 2003			Post-burn 2004		
Acer pensylvanicum	-	-	-	67	< 0.001	0.12	-	-	-
Acer rubrum	67	0.008	0.23	67	0.009	0.26	67	0.012	0.31
Amelanchier arborea	67	0.005	0.18	133	0.003	0.28	67	< 0.001	0.12
Carya spp.	267	0.208	3.64	133	0.167	3.00	200	0.163	3.08
Castanea dentata	400	0.073	1.70	400	0.098	2.31	400	0.107	2.46
Fraxinus americana	-	-	-	67	0.001	0.14	67	0.002	0.15
Gaylussacia ursina	26,067	0.645	46.53	20,800	0.459	43.02	21,067	0.521	43.67
Hamamelis virginiana	1,000	0.529	9.71	1,000	0.526	10.46	867	0.441	8.86
Kalmia latifolia	1,400	0.833	15.04	1,400	0.918	17.68	1,266	0.714	14.13
Magnolia acuminata	200	0.068	1.35	200	0.042	1.04	133	0.067	1.36
Magnolia fraseri	67	0.021	0.42	67	0.023	0.50	133	0.001	0.24
Nyssa sylvatica	67	< 0.001	0.10	67	< 0.001	0.12	133	0.001	0.24
Pyrularia pubera	2,467	0.095	4.93	1,667	0.095	4.41	2,600	0.195	7.60
Quercus rubra	467	0.017	0.92	333	0.014	0.79	333	0.011	0.73
Rhododendron calendulaceum	1,466	0.386	8.11	1,333	0.296	7.19	1,267	0.368	8.30
Robinia pseudoacacia	200	0.016	0.53	133	0.013	0.44	133	0.014	0.46
Sassafras albidum	1,067	0.056	2.37	800	0.029	1.84	867	0.048	2.25
Tsuga canadensis	267	0.073	1.52	33	0.079	1.89	267	0.057	1.40
Vaccinium corymbosum	267	0.148	2.70	400	0.230	4.51	467	0.244	4.88
Roach Mill, Rabun County, GA									
Burned	Pre-burn 2003			Post-burn 2004			Post-burn 2005		
Carya spp.	160	0.358	4.22	80	0.317	3.41	80	0.290	4.49
Ilex opaca	80	0.039	1.14	80	0.127	1.99	80	0.133	2.96
Kalmia latifolia	640	0.883	13.05	240	0.443	6.44	400	0.789	16.00
Nyssa sylvatica	80	0.002	0.87	-	-	-	-	-	-
Pinus strobus	480	0.679	9.91	400	0.626	9.90	80	0.204	3.65
Rhododendron maximum	3,040	5.085	68.20	2,240	5.064	67.08	1,760	3.723	72.89
Unburned	Pre-burn 2003			Post-burn 2004			Post-burn 2005		
Acer rubrum	100	0.332	11.66	100	0.273	11.76	100	0.264	11.76
Rhododendron maximum	1,300	1.659	84.96	1,000	1.525	84.01	900	1.326	79.04
Tsuga canadensis	100	0.002	3.38	100	0.002	4.22	100	0.003	4.25

Appendix III

Frequency (%) of herbaceous layer species (woody species < 0.5 m height, and all herbaceous species) in burned and unburned areas of the three mixed-oak sites. Before the burn (pre) treatments and the 1st and 2nd growing seasons after prescribed burning.

	Alarka Laurel						Robin Branch				Roach Mill					
	Burned			Unburned			Burned		Unburned		Burned			Unburned		
	pre	1yr	2 yr	pre	1 yr	2 yr	1 yr	2 yr	1 yr	2 yr	pre	1 yr	2 yr	pre	1 yr	2 yr
Tree species																
Acer pensylvanicum	35	17	6	5	5	5	25	19	38	25	70	18	72	88	88	81
Acer rubrum	42	23	25	10	5	10	52	62	83	79	-	-	-	-	-	-
Amelanchier arborea	17	21	21	20	10	10	12	21	21	21	-	-	2	-	12	6
Carya spp.	2	2	4	10	10	10	8	14	4	-	8	-	2	-	-	-
Hamamelis virginiana	4	2	4	60	60	65	8	21	29	42	-	-	-	-	-	-
Prunus serotina	14	6	2	30	30	20	2	10	4	4	-	-	-	-	-	-
Quercus alba	8	6	6	15	15	15	12	6	12	12	10	2	32	-	-	12
Quercus montana	4	2	-	10	10	10	10	12	21	21	10	8	22	-	-	-
Quercus rubra	38	23	23	45	35	20	10	10	4	4	2	5	5	-	-	-
Fraxinus americana	2	4	4	5	5	5	6	6	-	-	2	-	-	-	-	-
Castanea dentata	2	6	8	-	-	-	10	10	8	8	-	-	-	-	-	-
Halesia tetraptera	-	-	-	5	5	10	-	-	-	-	-	-	2	-	-	-
Magnolia acuminata	2	2	-	-	-	-	2	2	-	-	-	-	-	-	-	-
Magnolia fraseri	-	-	-	-	-	-	-	2	-	-	2	-	-	-	-	-
Liriodendron tulipifera	-	-	-	-	-	-	8	2	-	-	8	38	18	-	-	-
Nyssa sylvatica	-	-	-	-	-	-	-	-	4	-	15	18	18	12	19	19
Oxydendrum arboreum	-	-	-	-	-	-	2	2	-	-	-	-	-	-	-	-
Pinus strobus	-	-	-	-	-	-	-	-	-	-	5	-	2	-	-	-
Quercus velutina	2	2	-	-	-	-	-	-	-	-	2	2	5	-	-	-
Robinia pseudoacacia	-	-	-	-	-	5	6	2	-	-	2	8	5	-	-	-
Sassafras albidum	2	8	4	-	-	-	2	-	21	12	-	12	8	-	-	-
Tsuga canadensis	-	-	-	-	-	-	-	2	-	12	2	-	-	19	19	6
Acer saccharum	2	-	-	5	10	10	-	-	-	-	-	-	-	-	-	-
Fagus grandifolia	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-
Shrub species																
Rhododendron calendulaceum	4	4	4	15	15	15	2	2	12	8	-	-	-	-	-	-
Gaylussacia ursina	-	-	-	-	-	-	40	40	83	83	5	8	8	-	-	-
Pyrularia pubera	-	2	-	20	30	35	38	40	21	25	-	-	-	-	-	-
Rhododendron maximum	-	-	-	-	-	-	-	2	-	-	8	5	5	25	25	25
Crataegus flava	2	2	2	-	-	-	-	-	-	-	-	-	-	-	-	-
Euonymus americanus	-	-	-	-	-	-	-	-	-	-	8	8	5	-	-	-
Kalmia latifolia	-	-	-	20	20	20	2	-	12	12	10	10	10	-	-	-
Ilex montana	-	-	-	-	20	20	-	-	-	-	-	-	-	-	-	-
Rhododendron roseum	-	-	-	-	-	-	-	-	-	-	2	2	2	-	-	-
Rubus spp.	29	27	19	5	-	-	2	2	-	-	-	-	2	-	-	-
Vaccinium vacillans	-	-	2	5	5	5	-	-	4	4	15	12	12	-	-	-
Viburnum acerifolium	-	-	-	10	10	10	-	-	-	-	-	8	-	-	-	-
Woody vine species																
Smilax rotundifolia	4	4	4	30	35	40	38	46	25	21	15	8	18	6	6	6
Smilax glauca	-	-	2	15	10	15	6	10	8	4	48	60	58	31	31	31
Parthenocissus quinquefolia	-	-	-	-	-	-	-	-	-	-	2	-	-	6	6	6
Fern species																
Athryium filix-femina	19	17	17	5	5	5	10	10	-	-	-	-	-	-	-	-
Dennstaedtia punctilobula	10	12	12	15	20	15	12	14	12	8	-	-	-	-	-	-
Osmunda cinnamomea	23	23	23	-	-	-	-	-	8	8	-	-	-	-	-	-
Polystichum acrostichoides	-	-	-	10	10	10	-	-	-	-	2	2	2	-	-	-
Thelypteris noveboracensis	98	100	100	95	95	95	79	79	71	67	2	2	2	6	6	6

Appendix III
Continued.

	Alarka Laurel						Robin Branch				Roach Mill					
	Burned			Unburned			Burned		Unburned		Burned			Unburned		
	pre	1yr	2 yr	pre	1 yr	2 yr	1 yr	2 yr	1 yr	2 yr	pre	1 yr	2 yr	pre	1 yr	2 yr
Graminoid species																
Carex spp.	4	2	2	60	70	70	2	-	8	8	5	10	12	-	-	-
Luzula sp.	-	-	-	35	35	35	-	-	-	-	-	-	-	-	-	-
Panicum spp.	14	31	33	35	45	45	6	4	4	4	10	32	25	-	-	-
Poa spp.	48	46	48	35	35	40	6	6	4	4	-	-	-	-	-	-
Forb species																
Anemone quinquefolia	4	2	4	5	5	5	17	19	8	12	-	-	-	-	-	-
Clintonia umbellulata	17	19	19	5	5	5	17	19	21	17	-	-	-	-	-	-
Dioscorea quaternata	52	56	56	30	25	35	12	17	-	12	2	2	2	-	-	-
Gentiana sp.	10	8	8	35	35	30	8	12	17	17	-	-	-	-	-	-
Eupatorium purpureum	42	42	38	30	25	20	10	10	4	4	-	-	-	-	-	-
Goodyera pubescens	4	4	4	5	5	15	2	6	8	8	8	-	-	-	-	-
Hedyotis purpurea	12	8	12	35	50	50	6	6	8	4	-	-	-	-	6	-
Medeola virginiana	35	33	35	45	45	45	27	33	17	21	-	-	-	-	-	-
Melampyrum lineare	6	6	19	10	10	15	2	19	29	25	-	-	-	-	-	-
Prenanthes trifoliolata	64	69	73	75	65	80	38	38	8	21	-	-	-	-	-	-
Solidago arguta	8	6	4	25	15	15	12	14	4	4	-	-	-	-	-	-
Solidago curtisii	64	64	71	60	50	50	17	19	8	8	-	-	-	-	-	-
Viola hastata	10	4	2	15	10	10	83	79	67	79	12	12	12	31	25	31
Viola rotundifolia	4	4	4	10	10	10	4	4	4	4	-	-	-	-	-	-
Viola spp.	75	77	83	50	35	50	14	25	8	8	2	2	5	-	-	-
Amphicarpaea bracteata	14	19	19	5	5	10	-	-	-	-	-	-	-	-	-	-
Arisaema triphyllum	14	14	21	5	5	5	-	-	-	-	-	-	-	-	-	-
Aster divaricatus	44	46	48	50	55	50	12	10	-	-	-	-	-	-	-	-
Aster sp.	8	27	33	15	30	30	4	4	-	-	-	-	-	-	-	-
Campanula divaricata	2	2	2	15	15	15	6	6	-	-	-	-	-	-	-	-
Chimaphila maculata	10	4	6	20	15	20	-	-	-	4	-	-	5	6	6	6
Collinsonia canadensis	27	31	33	10	20	20	-	-	-	-	-	-	-	-	-	-
Desmodium nudiflorum	10	6	8	15	15	15	-	-	-	-	-	-	-	-	-	-
Erigeron pulchellus	14	14	14	5	5	5	-	-	-	-	-	-	-	-	-	-
Eupatorium rugosum	35	46	44	5	10	5	-	-	-	-	-	-	-	-	-	-
Galium spp.	23	25	25	35	40	40	2	2	-	-	-	-	-	-	-	-
Polygonatum biflorum	29	42	44	35	30	45	17	21	-	-	2	-	2	-	-	-
Potentilla simplex	29	27	25	20	30	35	-	2	-	-	-	-	-	-	-	-
Pycnanthemum muticum	17	17	19	15	20	25	6	6	-	-	-	-	-	-	-	-
Smilacina racemosa	54	52	54	40	50	50	19	19	-	-	2	-	2	-	-	-
Smilax herbacea	27	31	29	-	10	5	10	10	-	-	2	2	-	-	-	-
Thaspium trifoliatum	10	12	10	30	35	30	-	-	-	-	-	-	-	-	-	-
Uvularia perfoliata	42	42	42	5	5	5	4	4	-	-	-	-	-	-	-	-
Hieracium paniculatum	-	-	6	45	45	50	12	10	8	8	2	2	2	-	-	-
Lilium superbum	-	-	-	5	5	5	6	4	4	17	2	2	2	-	-	-
Lysimachia quadrifolia	-	4	6	5	5	5	6	6	-	-	-	-	-	-	-	-
Veratrum parviflorum	29	31	31	-	-	-	4	6	8	8	-	-	-	-	-	-
Angelica triquinata	2	2	2	-	-	-	-	-	-	-	-	-	-	-	-	-
Aralia nudicaulis	4	4	4	-	-	-	2	2	-	-	-	-	-	-	-	-
Asclepias sp.	2	4	2	-	5	5	-	-	-	-	-	-	-	-	-	-
Aster macrophyllus	14	14	14	-	-	-	-	-	-	-	-	-	-	-	-	-
Aster undulatus	4	6	2	5	5	5	-	-	-	-	-	-	-	-	-	-
Aureolaria flava	2	-	-	15	10	10	2	2	-	-	-	-	-	-	-	-
Caulophyllum thalictroides	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Conopholis sp.	4	4	4	-	-	-	-	2	-	-	-	-	-	-	-	-
Coreopsis major	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Disporum lanuginosum	21	21	25	-	-	-	2	6	-	-	-	-	-	-	-	-
Epigaea repens	-	-	-	20	10	15	-	-	-	-	-	-	-	-	-	-
Erechtites hieraciifolia	-	-	-	-	-	-	-	-	-	-	-	2	2	-	-	-
Galax aphylla	-	-	-	-	-	-	-	-	54	62	-	-	-	-	-	-

Appendix III
Continued.

	Alarka Laurel						Robin Branch				Roach Mill					
	Burned			Unburned			Burned		Unburned		Burned			Unburned		
	pre	1yr	2 yr	pre	1 yr	2 yr	1 yr	2 yr	1 yr	2 yr	pre	1 yr	2 yr	pre	1 yr	2 yr
Geranium maculatum	2	2	6	-	-	-	-	-	-	-	-	-	-	-	-	-
Helianthus sp.	-	-	-	-	-	-	-	-	-	-	-	2	2	-	-	-
Impatiens pallida	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Iris verna	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ligusticum canadense	-	-	-	30	15	30	2	2	-	-	-	-	-	-	-	-
Mitchella repens	-	-	-	-	-	-	-	-	-	-	2	2	2	-	-	6
Pedicularis canadensis	-	-	-	5	5	5	-	-	-	-	-	-	-	-	-	-
Podophyllum peltatum	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Silene stellata	4	4	4	-	-	-	4	2	-	-	-	-	-	-	-	-
Stellaria sp.	41	50	46	5	-	10	-	-	-	-	2	2	2	-	-	-
Thalictrum dioicum	2	2	2	-	-	-	-	-	-	-	-	-	-	-	-	-
Tradescantia subaspera	-	-	-	5	5	5	-	-	-	-	-	-	-	-	-	-
Trillium spp.	21	21	29	-	-	-	-	-	8	12	-	-	-	6	6	6
Uvularia puberula	-	-	-	15	20	15	12	14	-	-	2	2	2	-	-	-
Vicia caroliniana	-	-	-	5	5	5	-	-	-	-	-	-	-	-	-	-
Total number of species/ site	77	73	72	71	72	75	63	67	44	45	40	33	39	11	13	12

[a] Frequency was calculated based on the total number of subplots (1.0 m^2) measured in each burned or unburned area (AL: 48 subplots burned, 20 subplots unburned; RB: 48 subplots burned, 24 subplots unburned; RM: 40 subplots burned, 16 subplots unburned). Species nomenclature follows Gleason and Cronquist (1991).