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Effects of understory prescribed burning on shortleaf pine (*Pinus echinata* Mill.)/mixed-hardwood forests

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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 burning on shortleaf pine (*Pinus echinata* Mill.)/mixed-hardwood forests. J. Torrey Bot. Soc. 132: 236–251. 2005.—We examined the effects of a single dormant season fire on overstory and understory species diversity and composition and tree seedling regeneration patterns the first and second years following a prescribed burn in the Conasauga River Watershed of southeastern Tennessee and northern Georgia. We asked: Can a single dormant season fire initiate a trajectory of overstory and understory species change consistent with restoring *Pinus echinata*/mixed-oak/bluestem (*Andropogon gyrans* and *Schizachyrium scoparium*)-grass community types? Six sub-watersheds (similar in vegetation, soil type, stream size, and disturbance history) were located within the Conasauga River Watershed; four of the sites were burned in March 2001, and two sites were designated as controls. Within each site, vegetation was measured in layers: the overstory layer (trees ≥ 5.0-cm DBH), the midstory layer (woody stems < 5.0-cm DBH and ≥ 0.5 m height), and the ground flora layer (woody stems < 0.5-m height and all herbaceous species). All plots were sampled before the prescribed burn (Sept. 2000) and after the burn in July of 2001 and 2002. Consistent with the goals of the land managers, all the prescribed fires resulted in low-to-moderate intensity and low severity fires. However, we found no significant change in overstory, midstory, or ground flora species diversity after burning. We found no regeneration of *P. echinata* seedlings after the prescribed fire. Although fire reduced basal area of woody species in the midstory, prolific sprouting from hardwoods resulted in higher density of fire-sensitive hardwoods such as *Acer rubrum*, *Oxydendrum arboretum*, and *Nyssa sylvatica*. Density of *Pinus strobus*, an undesirable species, was reduced by 20% and its basal area was reduced by 50% after the burn. Overstory mortality occurred in small size class hardwoods as a result of the fire, but most of the mortality occurred in *P. echinata* and *P. virginiana* Miller due to infestation with pine bark beetles. The prescribed fires were not of sufficient intensity to: reduce overstory basal area, prepare a seedbed for successful pine germination, affect diversity of any of the vegetation layers, or promote *A. gyrans* and *S. scoparium* recruitment. Thus, additional fire treatments or a combination of fire and thinning treatments will be necessary to restore these ecosystems to *P. echinata*/mixed-oak/bluestem grass community types.

Key words: prescribed fire; *Quercus*; *Pinus virginiana*; biodiversity; vegetation dynamics, bluestem-grass.

In eastern North America, it is widely accepted that fire has been a major force shaping the composition and structure of forest ecosystems for millennia (Van Lear and Waldrop 1989, Pyne 1995, Delcourt and Delcourt 1997, Guyette and Dey 2000, Van Lear et al. 2000, Brose et al. 2001, Lorimer 2001, Guyette et al. 2002). Many writers have documented early travelers' descriptions of eastern forests being burned by Native People before European settlement (Day 1953, Komarek 1974, Pyne 1983, DeVivo 1991, Hammett 1992, Hicks 2000). Even though settlers gradually replaced the Native People, they continued to use fire for similar purposes (e.g., reduce underbrush and clear the land for agriculture). In the early 1900s, fire suppression became a serious and effective effort in eastern North America (Pyne et al. 1996, Van Lear and Harlow 2000, Brose et al. 2001). Thus, our present forest cover evolved with fire as a component of the environment (and many tree species exhibit fire-adapted traits such as serotinous cones, thick bark, basal sprouting) following nearly 100 years of fire suppression.

For thousands of years, much of the eastern United States was dominated by *Quercus* spp., *Castanea dentata*, and yellow pines (such as *P. rigida*, *P. echinata*, and *P. pungens*); all fire-

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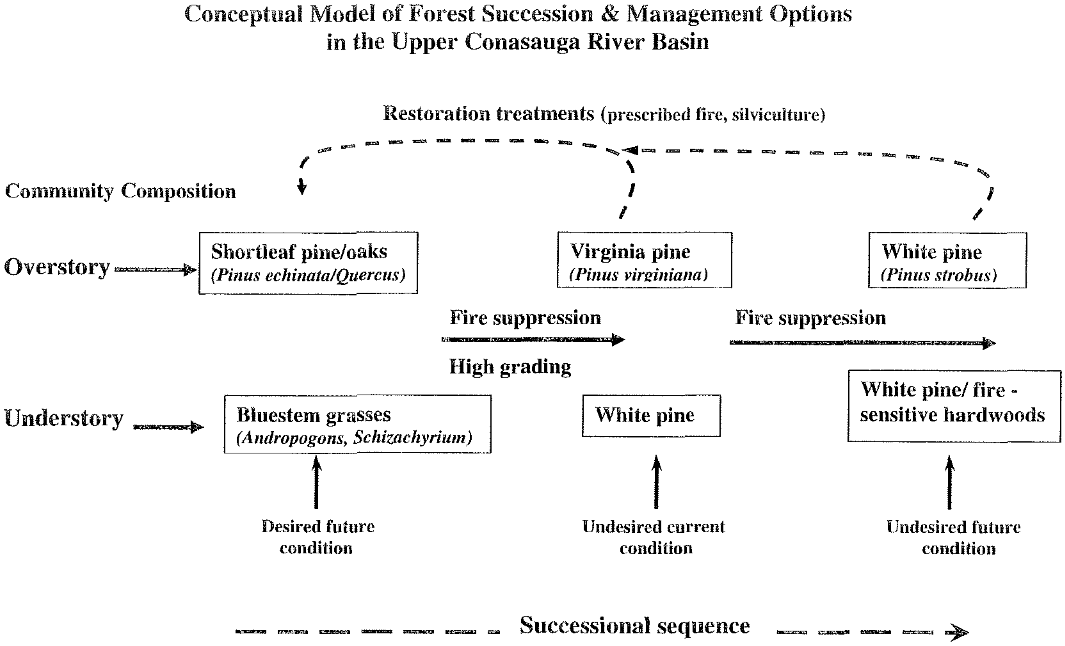

FIG. 1. Conceptual model of forest succession and management options in the Conasauga River Watershed.

tolerant early successional species (Delcourt and Delcourt 1993, Clark and Royall 1995, Delcourt and Delcourt 1997, Kay 2000). Due to fire suppression efforts through the 1900s, oaks and pines are being replaced by later-successional, fire-sensitive species, such as *Acer rubrum* (Crow et al. 1994, Abrams 1996, Abrams 1998, Arthur et al. 1998, Brose et al. 2001, Peterson and Reich 2001), *Pinus strobus* (Welch and Waldrop 2001), and ericaceous shrubs (e.g., *Rhododendron maximum* and *Kalmia latifolia*) (Dobbs 1998).

While it is difficult to establish cause-and-effect relationships between the expansion of certain species and fire suppression, re-introduction of fire may be a useful mechanism to obtain desired future conditions with regards to species composition. Many factors influence the effects of fire on forest ecosystems including the quality and quantity of fuels, soil properties, topography, climate, weather, and fire frequency, intensity and severity. In the southern Appalachians, prescribed fires often have little effect on long-term nutrient reserves or site productivity (Vose and Swank 1993, Vose et al. 1999, Vose 2000) and serve purposes useful to forest management. Although a large amount of information exists on the ecological effects of fire in ecosystems with a long and consistent history of prescribed burning (e.g., southern pines (Carter and Foster 2004)), little fire effects research has been conducted on southeastern ecosystems with long periods of fire exclusion.

In the Conasauga River Watershed of southeastern Tennessee and northern Georgia, interactions between past land-use and fire exclusion have resulted in alternative successional trajectories in these pine/oak forest ecosystems (Fig. 1). Early descriptions of pine/oak communities suggest that many were maintained as open pine/hardwood-grass savannas with frequent fire (DeVivo 1991). Only remnants of the pine/hardwood-grass savanna exist in the southern Appalachians (G. Kaufmann, Nantahala National Forest Botanist; personal communication) and these areas are maintained with a fire regime (periodic, low intensity surface fires) similar to the dominant regime prior to the mid-1800's (Brose et al. 2001). On dry to xeric sites, long-term data first collected in the 1930's (Harrod et al. 1998) describe a mosaic of open woodland and closed-canopy forests dominated by yellow pine species (i.e., *Pinus* subgenus *Pinus*; *P. echinata*, *P. pungens*, *P. rigida* and *P. virginiana*) and to a lesser extent *Quercus* species (mostly *Q. alba*, *Q. coccinea*, *Q. prinus*, *Q. rubra*, and *Q. velutina*).

Restoring and maintaining pine/hardwood-grass savannas on dry sites in the Conasauga River Watershed is a desired future condition

(Fig. 1). Heavy logging at the turn of the century (Brose et al. 2001) has increased densities of *P. virginiana* in many natural *P. echinata*/mixed-oak stands, which are now succeeding to *P. strobus*. We hypothesize that with repeated cutting, these forests will most likely become *P. virginiana* dominated with a dense *P. strobus* understory. With no management, these forest communities will likely succeed to *P. strobus* (a more shade-tolerant and fire-intolerant species relative to *P. echinata*; Welch and Waldrop 2001) and mixed-hardwoods (primarily fire-sensitive species such as *A. rubrum* and *Nyssa sylvatica*) (Cain and Shelton 1994, Cain and Shelton 1995, Stambaugh et al. 2002). However, if silvicultural treatments and prescribed fire are implemented, these communities may be restored to a *P. echinata*/mixed-oak forest type (Fig. 1). Anecdotal information, from prescribed burning treatments currently being applied in the Conasauga River Watershed (personal communication, Baker Allen, Silviculuralist, Cohutta Ranger District, Chattahooche-Oconee National Forest), suggests that prescribed burning might be an effective tool for restoring these stands to a *P. echinata*/mixed-oak/bluestem (*Andropogon gyrans* and *Schizachyrium scoparium*) community type. In the southern Appalachians, single dormant season fires are often used to reduce fuels, enhance diversity, and initiate regeneration of desirable species (Clinton et al. 1993, Elliott et al. 1999, Waldrop et al. 2000, Welch and Waldrop 2001, Elliott et al. 2004). For example, between 2001 and 2003, the Chattahoochee and Cherokee National Forests prescribe burned 4,552 and 18,962 hectares of mixed pine-hardwood forests, respectively. Most of these were single dormant season prescribed fires. In addition, recent information suggests that historically the Cherokee people ignited fires in the dormant season, both in the spring and fall (Cooley 2004). In this study, we examined the effects of a single dormant season fire on overstory and understory species diversity and composition and tree seedling regeneration patterns the first and second years following the prescribed burn. We asked: Can a single dormant season fire initiate a trajectory of overstory and understory species change consistent with restoring *P. echinata*/mixed-oak/bluestem-grass community types?

Methods. SITE DESCRIPTION. The study area was located in the extreme southwestern edge of the Blue Ridge Physiographic province of the southern Appalachian Mountains. Six sub-watersheds (similar in vegetation, soil type, stream size and location within the sub-watershed, and disturbance history) were located within the Conasauga River Watershed; four of the sites were burned in March 2001, and two sites were designated as controls. Three sites were located in the Chattahoochee National Forest, Murray County, Georgia (34°49′ N, 84°41′ W), while the other three sites were located in the Cherokee National Forest, Polk County, Tennessee (35°00′ N, 84°39′ W). We named each site after the nearest stream and type of treatment: Georgia sites—Muskrat Branch Control (MRC), Muskrat Branch Burn (MRB), and Conasauga Springs Burn (CSB); Tennessee sites–Sawmill Branch Control (SMC), Sawmill Branch Burn (SMB), and Halfway Branch Burn (HWB). All sites were less than 21 km from each other. Elevations ranged from 260 m to 415 m. The site aspects were between 120 to 200 degrees. At a nearby weather station (Cleveland, TN, National Climatic Database: www.ncdc.noaa.gov), mean annual temperature is 14 °C and average annual precipitation is 1350 mm. The soils on all sites were classified as Junaluska and Junaluska-Citico or Junaluska-Brasstown complexes. The Junaluska series is a fine-loamy, mixed, mesic Typic Hapludults. The Citico series is a fine-loamy, mixed, mesic Typic Dystrochrept and the Brasstown is a fine-loamy, mixed, mesic Typic Hapludult (Newton and Moffitt 2001). The sites were mixed pine-oak forests with an overstory dominated by *Pinus virginiana*, *P. echinata*, *Quercus coccinea*, *Q. alba*, *Acer rubrum*, *Oxydendrum arboreum*, and *Nyssa sylvatica*. Understory composition consisted primarily of *Pinus strobus* and *Kalmia latifolia*. A southern pine beetle (*Dendroctonus frontalis* Zimm.) outbreak occurred throughout the region during our study. In the second year after the burn, this infestation caused extensive mortality of pine in four of the study sites: MRC, MRB, SMC, and SMB.

Within each site, we established five 10-m × 20-m permanent plots along a hill-slope gradient from the ridge to the riparian area. All plots were sampled before the prescribed burn (Sept. 2000), and after the burn in July of 2001 and 2002.

FIRE TREATMENTS. On the day of the prescribed fire treatment (March 28, 2001), air temperature averaged 14 °C (SE = 1.4) and ranged from 8 to 18 °C for the duration of the fire pre-

Table 1. Fire characteristics of the four burned sites in the Conasauga River Watershed, prescribed burn on March 28, 2001.

Site*	Fire behavior		Mean (± SE) soil depth (cm) of heat penetration		Temperature (°C) at 30 cm height	
	Flame height (cm)	Rate of spread (cm s^{-1})	45°C	59°C	Mean (± SE)	Range
HWB	30–45	3.3–5.5	1.20 (0.40) a	0.60 (0.22) a	39.2 (7.7) a	0–100
CSB	90–152	16–30	2.69 (1.11) a	1.44 (0.61) ab	105.4 (11.3) b	52–184
MRB	90–122	12–30	1.11 (0.23) a	0.94 (0.53) a	128.0 (16.8) b	0–267
SMB	30–62	5.5–6.7	3.11 (0.34) a	1.89 (0.35) b	111.9 (14.4) b	59–344

* HWB = Halfway Branch Burn; CSB = Conasauga Springs Burn; MRB = Muskrat Branch Burn; SWB = Sawmill Branch Burn.

scription (1000 hr to 1700 hr EST). Relative humidity ranged from 42 to 25 percent, decreasing as the afternoon progressed. Wind speed was between 1 and 8 km hr^{-1} across all sites for the day. The sites were burned in strips using drip torches. The burning technique was to backfire along the upper ridge, and then ignite strip headfires at about 10–20 m intervals until the entire watershed had burned from the ridge to the riparian zone. Burning intensity varied within and among watersheds, but the burning resulted in low to moderate intensity surface fires. To characterize the temperature of the burn, we placed four ceramic tiles (10 × 20 cm) in random locations within each of the permanent vegetation plots (n = 20 tiles per site). We applied heat-sensitive chalk and paint (Omega Engineering, Inc., Stamford, CT) to the ceramic tiles. Two days prior to burning, tiles were suspended with metal conduit at 30-cm aboveground. Chalk temperature sensitivity ranged from 52 to 427 °C in approximately 14 °C increments. Heat sensitivities of the paint were 500, 550, 732, 804, and 899 °C. We also monitored heat penetration into the forest floor using a similar technique as above. In each 10 × 20 m plot, two long narrow tiles painted with heat sensitive paint were inserted 15 cm into the soil with the top edge being flush with the top of the litter layer. The threshold temperature sensitivity of the paints was 45 °C and 59 °C, a range that brackets the thermal lethal point for most plants (Hare 1961).

VEGETATION SAMPLING. Vegetation was measured in layers: the overstory layer (10- × 20 m plots) included all trees ≥ 5.0-cm diameter at breast height (DBH, 1.37 m above ground); the midstory 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 ground flora layer included woody stems < 0.5-m height and all herbaceous species (four 1.0-m^2 quadrats placed in each corner of the 10 × 20 m plots). Diameter of all overstory trees was measured to the nearest 0.1 cm and recorded by species. To calculate mortality, numbered tags were nailed to all overstory trees in Sept. 2000 before the prescribed fire treatment. In the midstory layer, basal diameter (3 cm above ground line) of trees and shrubs was measured to the nearest 0.1 cm and recorded by species. In addition, all woody stems < 0.5 m height were counted in the 5 × 5 m midstory plots.

The ground flora layer was measured only after the burn (July 2001 and 2002); hence, no pretreatment data are available for this vegetation layer. Percent cover of ground flora 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. For the fire characteristics (soil depth of heat penetration and temperature at 30 cm height), we used analysis of variance (PROC GLM, SAS 1999) to determine significant differences among sites. A significant test was followed by Ryan-Einot-Gabriel-Welsch multiple range test. This test controls the Type I experiment-wise error rate.

Species diversity was evaluated using species richness (S) and Shannon-Wiener's index of diversity (H′). Shannon-Wiener's index incorporates both species richness and the evenness of species abundance (Magurran 1988). The Shannon-Wiener index is most sensitive to the number of species in a sample, and considered to be biased toward measuring species richness (Christensen and Peet 1984). For the overstory and midstory, H′ was calculated based on density and basal area. For the ground flora layer, H′ was calculated based on percent cover. Shannon-Wiener index was calculated as: $H' = p_i$ ln

Table 2. Overstory mean density (stems ha^{-1}), basal area (m^2 ha^{-1}), diversity (H′, Shannon's index), and richness (S = number of species present per plot or per site) pre-burn (2000) and post-burn (2001, 2002) for burn and control treatments in the Conasauga River Watershed. Based on repeated measures ANOVA (PROC GLM, SAS, 1999), no significant differences ($P > 0.10$) were found between burn and control treatments in any year. Diversity (H′) was calculated on a per plot basis. Standard errors are shown in parentheses.

	Pre-burn 2000		Post-burn 2001		Post-burn 2002	
Parameter	Burn	Control	Burn	Control	Burn	Control
Density	1485 (61)	1240 (0)	1362 (55)	1205 (35)	1150 (124)	870 (0)
Basal area	31.1 (1.8)	36.2 (2.9)	28.8 (2.2)	34.8 (5.0)	23.9 (5.1)	20.4 (0.4)
H′ density	1.88 (0.12)	1.72 (0.26)	1.86 (0.13)	1.71 (0.29)	1.79 (0.12)	1.75 (0.20)
H′ basal area	1.40 (0.11)	1.19 (0.05)	1.44 (0.14)	1.16 (0.09)	1.42 (0.13)	1.36 (0.09)
S/plot	8.8 (0.7)	8.1 (1.3)	8.6 (0.7)	8.1 (1.5)	7.8 (0.7)	7.4 (1.0)
S/site	16.8 (1.4)	15.0 (0)	16.8 (1.4)	15.0 (0)	15.8 (1.1)	15.0 (0)

p_i, where p_i = proportion of total density, total basal area, or total percent cover of species *i*. Species richness (S) was calculated as the total number of species per quadrat (1.0 m^2) for ground flora and total number of species per plot (0.02 ha) and total number of species per site (five plots combined) for all vegetation layers. 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.

Separate statistical analyses were performed for each vegetative layer (i.e., overstory, midstory, and ground flora). We used repeated measures ANOVA (PROC GLM, SAS 1999) to determine significant differences between burn and control treatments before and after the burn. With the repeated measures ANOVA, we evaluated the effects of treatment, time (pre-burn 2000, post-burn 2001, and post-burn 2002), and time * treatment interactions. For overstory mortality, we used repeated measures ANOVA (PROC GLM, SAS 1999) to determine significant differences between burn and control treatments for post-burn 2001 and post-burn 2002. Because no pretreatment data were collected for the ground flora layer, we made comparisons between control and burn treatments after the burn using repeated measures ANOVA for post-burn 2001 and 2002 (PROC GLM, SAS 1999).

Results. FIRE CHARACTERISTICS. Fire behavior, flame temperature, and heat penetration were variable within and among the 4 burned watersheds (Table 1). Fire intensity is defined by the upward heat pulse produced by the fire (Ryan and Noste 1985), while fire severity is defined by depth of heat penetration and consumption of the forest floor layer (Wells et al. 1979, Simard 1991). Consistent with the goals of the land managers, all the prescribed fires resulted in low-to-moderate intensity and low severity fires. Fire severity was considered low based on criteria from Waldrop and Brose (1999); the litter

Table 3. Mean percent overstory mortality of hardwoods and pines the first (2001) and second (2002) growing seasons after the prescribed fire for burn and control treatments in the Conasauga River Watershed. All overstory trees were tagged to determine mortality after the burn. In 2002, mortality is cumulative for both years after the fire. No significant differences were detected between burn and control treatments in 2002. Standard errors are in parentheses.

	2001		2002	
	Burn	Control	Burn	Control
Hardwoods	8.3 (3.6)	1.0 (1.0)	16.1 (6.2)	6.0 (0.1)
Quercus spp.*	3.1 (1.9)	0	11.6 (3.6)	5.4 (2.1)
Other hardwoods	9.1 (4.9)	1.0 (1.0)	16.6 (7.3)	5.0 (0.3)
Pines	13.9 (3.5)	4.8 (3.6)	42.5 (13.9)	51.2 (9.0)
P. echinata	14.2 (11.3)	22.1 (19.6)	41.0 (20.1)	79.2 (12.5)
P. virginiana	3.9 (2.5)	9.4 (7.2)	29.8 (15.2)	46.7 (15.8)
P. strobus	18.4 (4.1)**	0	29.3 (8.4)	12.5 (12.5)
All species	9.2 (2.7)	3.1 (2.5)	22.7 (7.5)	27.9 (0.6)

* Includes *Q. alba*, *Q. coccinea*, *Q. falcata*, *Q. prinus*, *Q. velutina*.
** Denotes a significant ($P < 0.10$) differences between burn and control treatments within a year.

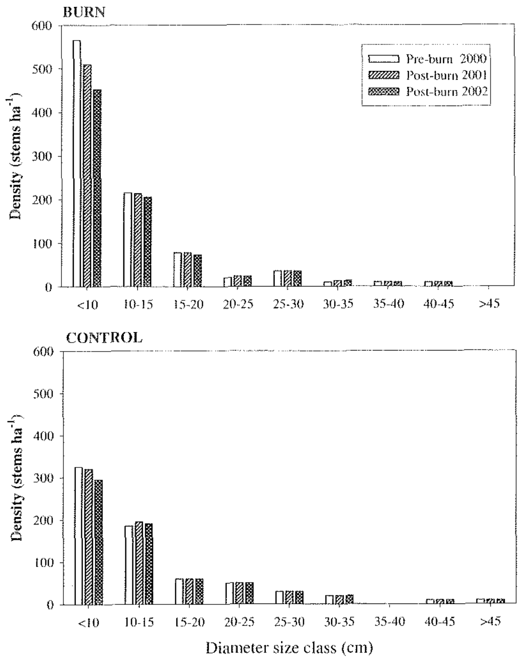

FIG. 2. Diameter size class distribution of hardwood overstory pre-burn 2000 and post-burn (2001, 2002) for burn and control treatments in the Conasauga River Watershed.

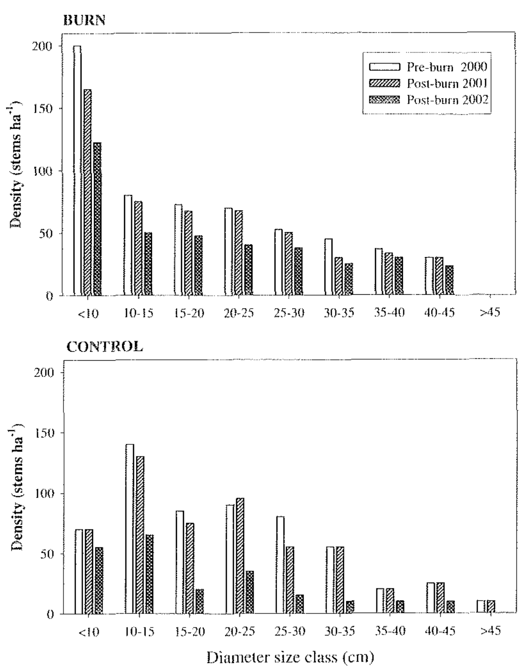

FIG. 3. Diameter size class distribution of pine overstory pre-burn 2000 and post-burn (2001, 2002) for burn and control treatments in the Conasauga River Watershed.

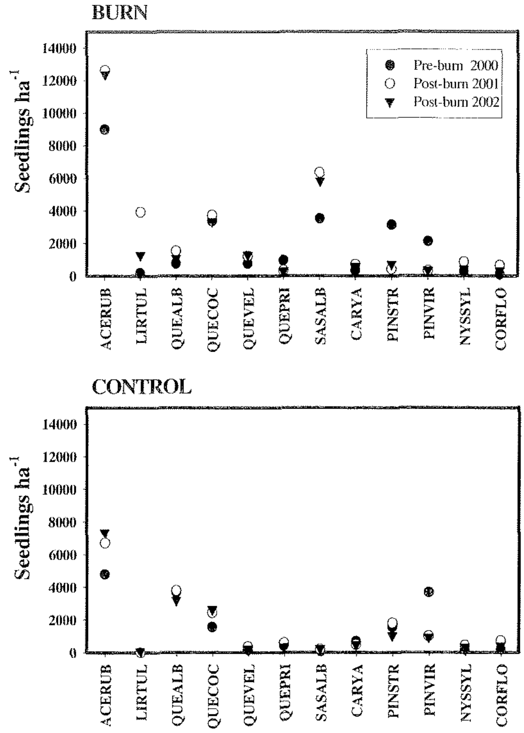

FIG. 4. Most abundant tree seedlings pre-burn 2000 and post-burn (2001, 2002) for burn and control treatments in the Conasauga River Watershed. Species codes: ACERUB = *Acer rubrum*; LIRTUL = *Liriodendron tulipifera*; QUEALB = *Quercus alba*; QUECOC = *Quercus coccinea*; QUEVEL = Quercus velutina; QUEPRI = *Quercus prinus*; SASALB= *Sassafrass albidum*; CARYA = *Carya* spp.; PINSTR = *Pinus strobus*; PINVIR = *Pinus virginiana*; NYSSYL = *Nyssa sylvatica*; CORFLO = *Cornus florida*.

layer (Oi layer) was reduced but the duff layer (Oe + Oa layer) remained essentially intact (Hubbard et al. 2004), little soil was exposed, and heat penetration was limited to the soil surface (Table 1). CSB and MRB had higher flame heights and rates of spread than the other two sites. However, fire severity (based on soil depth of heat penetration) was significantly higher on SMB than on HWB and MRB. HWB had significantly lower fire intensity (temperature at 30 cm) and lower fire severity; it also experienced the slowest rate of spread allowing a longer fire residence time compared to the other three sites (Table 1). Because fire intensities were relatively low on our burn sites, total live biomass consumption was small (Hubbard et al. 2004) and no change in litterfall was detected (Hubbard et al. 2004). In addition, coarse wood (> 7.5 cm diameter) was only reduced by 12%, forest floor litter (Oi layer) consumption was 70%, and hu-

Table 4. Mean density (stems ha^{-1}), basal area (m^2 ha^{-1}), and importance value ((relative density + relative basal area)/2) of overstory species pre-burn (2000) and post-burn (2001, 2002) for the burn and control treatments in the Conasauga River Watershed.

	Density			Basal area			Importance value		
	Pre-burn	2001	2002	Pre-burn	2001	2002	Pre-burn	2001	2002
Burn									
Pinus virginiana	300	285	202	10.56	10.06	8.66	26.7	27.9	26.9
Pinus echinata	122	95	58	7.40	5.66	3.63	15.8	13.3	10.1
Acer rubrum	245	228	200	1.78	1.75	1.71	11.0	11.4	12.3
Oxydendrum arboretum	192	180	168	1.50	1.49	1.45	8.8	9.2	10.3
Pinus strobus	148	122	102	2.17	2.17	1.03	8.4	8.2	6.6
Quercus alba	65	62	62	1.40	1.42	1.44	4.4	4.8	5.7
Quercus coccinea	60	52	48	1.11	1.08	1.08	3.8	3.8	4.3
Nyssa sylvatica	70	65	65	0.48	0.47	0.48	3.1	3.2	3.8
Quercus falcate	27	27	25	1.28	1.29	1.31	3.1	3.1	3.6
Liquidamber styraciflua	20	18	18	1.19	1.18	1.19	2.7	2.7	3.2
Cornus florida	48	50	45	0.21	0.20	0.19	1.9	2.2	2.4
Quercus prinus	28	28	22	0.60	0.61	0.54	1.9	2.1	2.1
Tsuga canadensis	28	28	25	0.23	0.24	0.24	1.4	1.4	1.6
Amelanchier arborea	25	25	25	0.19	0.20	0.20	1.1	1.3	1.5
Quercus velutina	25	25	25	0.16	0.16	0.14	1.0	1.2	1.0
Liriodendron tulipifera	22	22	22	0.18	0.19	0.22	1.0	1.2	1.4
Carya spp.	12	12	12	0.28	0.28	0.29	0.9	1.0	1.1
Control									
Pinus virginiana	315	305	150	11.36	11.24	3.91	28.4	28.8	18.2
Pinus echinata	185	155	10	9.79	7.99	1.00	21.0	17.9	3.0
Quercus alba	75	75	75	4.19	4.29	4.34	8.8	9.3	14.9
Acer rubrum	165	165	160	1.24	1.29	1.33	8.4	8.7	12.4
Oxydendrum arboretum	75	75	75	0.82	0.86	0.90	4.2	4.4	6.5
Quercus coccinea	55	55	55	1.29	1.33	1.16	4.0	4.2	6.0
Pinus taeda	10	10	10	2.53	2.57	2.68	3.9	4.1	7.1
Quercus prinus	50	50	45	1.06	1.10	1.10	3.5	3.6	5.3
Pinus strobus	55	55	50	0.90	0.97	0.95	3.5	3.7	5.2
Cornus florida	50	50	45	0.33	0.34	0.33	2.5	2.6	3.4
Nyssa sylvatica	40	40	35	0.36	0.38	0.37	2.1	2.2	2.9
Quercus falcate	30	30	25	0.56	0.56	0.50	2.0	2.0	2.6
Tsuga canadensis	35	35	35	0.27	0.30	0.31	1.8	1.9	2.8
Carya spp.	25	25	25	0.28	0.28	0.29	1.4	1.4	2.1
Fraxinus pensylvanica	5	5	5	0.78	0.78	0.78	1.3	1.3	2.2
Quercus velutina	25	25	20	0.15	0.15	0.15	1.2	1.2	1.5
Acer nigra	20	25	25	0.07	0.08	0.08	0.9	1.1	1.6

mus and fermentation (Oe + Oa layer) consumption was minimal (Hubbard et al. 2004).

OVERSTORY LAYER. Based on repeated measures analysis of variance, we found no significant differences between burn and control treatments in any of the measurement years for density, basal area, H′ based on density or basal area, or species richness (Table 2). However, in post-burn 2001, there was a trend towards higher mortality on burn sites (Table 3), principally occurring among smaller size class (< 20 cm dbh) hardwoods (Fig. 2) and pines (Fig. 3). In post-burn 2001, *P. strobus* had significantly higher mortality on the burn sites than the control sites. By post-burn 2002, the southern pine beetle had infested many of the *P. virginiana* and *P. echinata* trees resulting in high mortality of these individuals in both the burn and control treatments (Table 3). By the second growing season after the burn, *Quercus* spp. (*alba*, *coccinea*, *falcata*, *prinus*, and *velutina*) average mortality was not significantly different between the burn sites and the control sites (Table 3). However, there was a trend towards higher mortality of other fire-sensitive hardwoods on the burn sites than the control sites in both years after the burn (Table 3) and these individuals were from small size class trees (Fig. 2).

On the burn treatment, *Acer rubrum* and *Oxydendrum arboreum* decreased in density, remained about the same in basal area, and increased in IVs after burning (Table 4); whereas,

Table 5. Midstory mean density (stems ha^{-1}), basal area (m^2 ha^{-1}), diversity (H′ = Shannon's index of diversity), and richness (S = number of species present per plot or per site) pre-burn (2000) and post-burn (2001, 2002) for burn and control treatments in the Conasauga River Watershed. Within a year, values in rows followed by different letters denote a significant difference ($P < 0.10$) between burn and control treatments based on repeated measures ANOVA (PROC GLM, SAS, 1999). Basal area was calculated for only the sapling size class because stems < 0.5 m height did not have a diameter measurement. $H'_{density}$ was not significantly different between treatments whether calculated by only saplings, only seedlings or all understory woody stems (< 5.0 cm dbh). Values presented for $H'_{density}$ and $H'_{basal\ area}$ were based on the sapling size class. Standard errors are in parentheses.

	Pre-burn 2000		Post 2001		Post 2002	
	Burn	Control	Burn	Control	Burn	Control
Density						
Seedlings (woody stems < 0.5 m height)						
All seedlings	68,480 b	48,480 a	138,120 **b**	58,120 **a**	113,740 **b**	54,080 **a**
	(4234)	(2480)	(18742)	(600)	(14190)	(5760)
V. vacillans	34,840 a	19,360 a	83,040 **b**	21,120 **a**	71,560 **b**	25,770 **a**
	(5764)	(13760)	(17515)	(11099)	(24913)	(13929)
Other species	33,640 a	29,120 a	55,080 a	37,000 a	42,180 a	32,280 a
	(6908)	(7600)	(5929)	(6919)	(4324)	(4199)
Saplings (< 5.0 cm dbh, ≥ 0.5 m height)						
	9100 a	12,320 a	5900 **a**	11,840 **b**	9525 a	9,480 a
	(1122)	(4480)	(369)	(4160)	(1344)	(4360)
Total density (seedlings + saplings)	77,580 a	60,800 a	144,020 **b**	69,960 **a**	122,660 **b**	63,560 **a**
	(4665)	(2000)	(18971)	(3560)	(14932)	(1400)
Saplings only						
Basal area	2.85 a	2.88 a	1.23 **a**	2.91 **b**	1.44 **a**	2.44 **b**
	(0.92)	(1.49)	(1.06)	(1.16)	0.73)	1.61)
$H'_{density}$	1.54 a	1.52 a	1.43 a	1.62 a	1.46 a	1.49 a
	(0.14)	(0.23)	(0.12)	0.18)	0.10)	(0.24)
$H'_{basal\ area}$	1.17 a	0.98 a	1.22 a	1.01 a	1.27 a	1.13 a
	(0.16)	(0.09)	(0.07)	(0.09)	(0.14)	(0.08)
S/plot	11.6 a	11.1 a	12.4 a	12.1 a	12.8 a	11.1 a
	(1.6)	(1.9)	(1.0)	(2.1)	(1.5)	(1.7)
S/site	26.8 a	25.5 a	27.8 a	27.5 a	29.8 a	27.0 a
	(2.4)	(0.5)	(2.3)	(0.5)	(3.2)	(1.0)

on the control treatments, these species remained about the same for density, increased slightly in basal area, but their IVs increased due to the decline in *P. virginiana* and *P. echinata*.

MIDSTORY LAYER. Density and basal area of seedlings and saplings were significantly different between burn and control treatments after burning (Table 5). However, we found no significant changes in H′ based on density, H′ based on basal area, or species richness between treatments (Table 5). After the prescribed fire, midstory stem density was significantly higher and basal area was significantly lower on the burn sites than the control sites. By the second growing season after the burn, there was no longer a significant difference in sapling density between the burn and control treatments (Table 5).

After the burn treatment, species that substantially increased in density were *Acer rubrum*, *Nyssa sylvatica*, *O. arboretum*, *Amelanchier arborea*, *Quercus velutina*; whereas, *P. strobus*, *P. virginiana*, *Q. coccinea*, and *Q. rubra* decreased (Table 6). New seedlings (< 0.5 m height) that recruited into the burned sites were *A. rubrum*, *Liriodendron tulipifera*, and *Sassafras albidum* (Figure 3). We observed no recruitment of either *P. echinata* or *P. virginiana* in the first two growing seasons after burning (Figure 3). *Vaccinium vacillans* was a major component of the seedling size class (stems < 0.5 m height) before and after the burn (Table 5). Before the burn, *V. vacillans* accounted for 51% of the total stems in the seedling size class with no significant difference between burned and control sites. After the burn, numbers of *Vaccinium vacillans* doubled on the burned sites and contributed 60% and 65% to the total number of stems in 2001 and 2002, respectively.

Before the burn, species importance ranked *A. rubrum* > *P. strobus* > *Vaccinium arboreum* > *Nyssa sylvatica* > *V. corymbosum* > *O. arboreum*. By the second growing season after the

Table 6. Mean density (stems ha^{-1}), basal area (m^2 ha^{-1}), and importance value ((relative density + relative basal area)/2) of the most abundant midstory (woody stems < 5.0 cm dbh, > 0.5 m height) species pre-burn 2001 and post-burn (2001, 2002) for burn and control treatment in the Conasauga River Watershed. Only species with an importance value > 1.0 in at least one year were included in the table*. Species were ranked by IV in pre-burn 2000.

	Density			Basal area			Importance value		
	Pre-burn	2001	2002	Pre-burn	2001	2002	Pre-burn	2001	2002
Burn									
Acer rubrum	1420	2280	3420	0.53	0.15	0.25	17.1	23.8	28.5
Pinus strobes	1240	240	160	0.58	0.23	0.20	16.9	11.0	8.2
Vaccinium arboretum	740	340	700	0.33	0.07	0.03	9.9	5.3	5.1
Nyssa sylvatica	380	260	560	0.28	0.16	0.33	6.9	8.6	15.2
Vaccinium corymbosum	920	440	880	0.09	0.01	0.04	6.6	4.0	6.3
Oxydendrum arboretum	460	940	780	0.12	0.05	0.05	4.7	9.4	6.3
Quercus alba	220	80	260	0.16	0.06	0.005	4.1	3.2	1.6
Pinus virginiana	140	20	0	0.18	0.07	0	3.8	3.0	0
Carya spp.	240	140	200	0.11	0.06	0.03	3.2	3.4	2.1
Vaccinium vacillans	460	0	0	0.01	0	0	2.7	0	0
Kalmia latifolia	400	0	0	0.01	0	0	2.4	0	0
Quercus coccinea	360	300	280	0.02	0.01	0.02	2.4	2.9	2.3
Quercus velutina	120	100	320	0.09	0.07	0.09	2.3	3.8	5.0
Calycanthus floridus	340	160	200	0.01	0.003	0.005	2.0	1.3	1.3
Sassafras albidum	180	220	140	0.02	0.02	0.01	1.4	2.6	1.0
Quercus rubra	140	0	60	0.03	0	0.002	1.3	0	0.4
Castanea dentate	20	20	20	0.06	0.05	0.07	1.2	2.4	2.7
Tsuga canadensis	20	20	20	0.05	0.06	0.06	1.1	2.8	2.3
Pyrularia pubera	160	0	20	0.01	0	0.001	1.0	0	0.1
Fagus grandifolia	60	40	40	0.03	0.04	0.001	0.8	1.9	0.2
Amelanchier arborea	80	120	240	0.01	0.02	0.08	0.7	1.9	4.4
Quercus prinus	60	60	100	0.02	0.06	0.06	0.6	2.8	2.9
Control									
Kalmia latifolia	5400	4760	4040	1.29	1.11	1.00	44.4	37.3	41.8
Acer rubrum	1080	1400	880	0.25	0.41	0.12	8.7	12.4	7.1
Vaccinium corymbosum	1360	1320	1240	0.17	0.18	0.16	8.5	8.1	9.8
Vaccinium vacillans	1720	2000	720	0.03	0.06	0.02	7.5	8.7	4.3
Pinus strobus	400	360	360	0.20	0.15	0.13	5.0	3.9	4.6
Nyssa sylvatica	120	120	80	0.24	0.31	0.10	4.6	5.8	2.4
Cornus florida	80	80	80	0.20	0.22	0.20	3.7	4.1	4.5
Pyrularia pubera	520	640	680	0.04	0.06	0.06	2.8	3.4	4.7
Quercus alba	120	0	0	0.09	0	0	2.1	0	0
Quercus prinus	120	120	120	0.08	0.11	0.12	2.0	2.3	3.1
Tsuga canadensis	80	120	120	0.08	0.09	0.10	1.8	2.0	2.7
Carya spp.	240	320	280	0.02	0.03	0.02	1.3	1.7	1.8
Prunus serotina	120	120	40	0.04	0.03	0.002	1.1	1.0	0.2
Fagus grandifolia	80	40	40	0.04	0.06	0.06	1.1	1.1	1.3
Quercus coccinea	240	80	120	0.01	0.003	0.003	1.1	0.4	0.7
Oxydendrum arboretum	40	40	80	0.05	0.06	0.05	1.0	1.2	1.4
Pinus virginiana	0	40	40	0	0.001	0.17	0	0.2	3.6
Quercus falcata	0	0	40	0	0	0.09	0	0	2.1

* Other minor species (< 1.0 importance value) included: *Acer nigra, Asimina triloba, Carpinus caroliniana, Cercis candensis, Diospyros virginiana, Euonymus americanus, Hamamelis virginiana, Ilex ambigua, Liriodendron tulipifera, Rhododendron nudiflorum, Rhus copallinum, Symplocos tinctoria, Ulmus alata, Viburnum acerifolium.*

burn, species ranked *A. rubrum* > *N. sylvatica* > *P. strobus* > *V. corymbosum* = *O. arboreum* > *Q. velutina* > *V. arboreum*. In addition, *A. arborea* and *Q. prinus*, species that ranked 21st and 22nd in importance value before the burn were ranked 7th and 8th after the burn, respectively (Table 6).

GROUND FLORA LAYER. We found no significant differences between treatments for percent cover, diversity (H′ based on percent cover), or species richness in the first growing season (2001) or the second growing season (2002) after the prescribed fire (Table 7). However, both burn and control treatments significantly in-

Table 7. Mean percent cover, species diversity (H′ = Shannon's index of diversity), and species richness (S) of ground flora the first (2001) and second (2002) growing seasons after the prescribed fire for burn and control treatments in the Conasauga River Watershed.

	2001		2002	
	Burn	Control	Burn	Control
Cover (%)	17.8 (2.0) a	21.9 (4.6) a	26.3 (3.8) a	24.4 (4.3) b
H′ cover	1.12 (0.16) a	0.99 (0.24) a	1.31 (0.10) a	10.8 (0.19) a
S/m²	5.6 (0.8) a	5.4 (1.4) a	6.2 (0.7) a	5.6 (1.6) a
S/plot	22.5 (3.1) a	21.8 (5.4) a	24.6 (3.0) a	22.5 (6.5) a
S/site	35.0 (5.2) a	36.5 (5.2) a	34.2 (7.5) a	34.0 (8.0) a

Note: Within a year, values in rows followed by different letters denote a significant difference ($P < 0.10$) between burn and control treatments based on repeated measures ANOVA (PROC GLM, SAS, 1999). Standard errors are in parentheses.

creased in percent cover ($P = 0.004$) and H′ ($P = 0.053$) from 2001 to 2002. In addition, we found changes in species numbers and occurrence between years in both treatments.

Across the burn treatment sites, 78 ground flora species (37 herbaceous and 41 woody vines, shrubs, or trees) were recorded in the sample quadrats. Of the species with > 5% frequency, 18 species increased in frequency and percent cover, 9 decreased in frequency, and 5 did not change in frequency (Table 8). Three infrequent species; *Melampyrum linear*, *Epigea repens*, and *Lespedeza* sp., occurred in only one quadrat in 2001 and did not emerge in 2002. Four infrequent species; *Fagus grandifolia*, *Galium* sp., *Rubus* sp., and *Trillium cernuum*, were not observed in 2001 and appeared in only one sample quadrat in 2002.

Across the control sites, 60 ground flora species (30 herbaceous and 30 woody vines, shrubs, or trees) were present in the sample quadrats. Of these species with > 5% frequency, 6 species increased in frequency and percent cover, 6 species decreased in frequency, and 21 species did not change in frequency (Table 8). Three infrequent species (occurring in only one sample quadrat); *Aureolaria pedicularia*, *Desmodium nudiflorum*, *Duchesnea indica*, that were recorded in 2001, were not observed in 2002. Three species that were recorded in only one sample quadrat in 2002 were *Amphicarpa bracteata*, *Carex* sp., and *Viola hastata*.

Discussion. Previous research has shown that *P. echinata* dominated forests evolved under a frequent fire regime (Cutter and Guyette 1994, Batek et al. 1999, Stambaugh et al. 2002). *P. echinata* is well adapted to fire, as characterized by its thick bark and ability to sprout from axillary buds following top-kill. Therefore, we did not expect to see mortality of *P. echinata* trees in the overstory from our low-to-moderate intensity understory burns. In our study, the mortality of *P. echinata* and *P. virginiana* in the first growing season after burning was attributed to the presence of pine bark beetles that were observed on only the upper ridge plots. In addition, mortality of *P. echinata* was slightly higher, but not significantly, on the control sites than the burn sites. Pine mortality occurred in larger sized trees and pine beetle symptoms were observed. By 2002, mortality was much higher than in 2001 and most of the *P. virginiana* and *P. echinata* mortality was attributed to bark beetle infestation as most of the pine trees had a substantial number of pitch tubes (Ebel et al. 1964, Hyche 1977). In contrast, the first growing season after burning, *P. strobus* mortality was attributed to the effects of fire, since no pitch tubes were observed, mortality occurred on small size class individuals, and no mortality of this species occurred on the control sites. Regionally, the pine bark beetle was already at epidemic levels and mortality of nearby pines was substantial. In addition, we found higher percent mortality of *P. echinata* and *P. virginiana* in the control sites than the burned sites in our study. Prescribed burning has been found to reduce competition and increase stand vigor in beetle infested stands, resulting in decreased losses to southern pine beetle (Belanger and Malac 1980, Porterfield and Rowell 1981). In our study, the prescribed fire did substantially reduce density and basal area of midstory species. However, we have no direct evidence to show an interaction between the prescribed fires and pine bark beetle mortality.

McGee et al. (1995) showed that relatively infrequent (1 or 2 fires over a 12 year period), low-intensity, prescribed fires in *Quercus rubra* stands in New York resulted in only minor changes to understory and tree regeneration and

Table 8. Percent frequency of occurrence and average percent cover of ground flora species the first (2001) and second (2002) growing season after the prescribed fire for burn and control treatments in the Conasauga River Watershed. Only species with ≥ 5.0 percent frequency of occurrence in either year were included in the table**. Species were ranked by highest percent frequency in 2001.

	Frequency (%)			Percent cover (%)	
	2001	2002		2001	2002
Burn					
Smilax glauca	66.25	77.50	+	0.94	1.60
Vaccinium vacillans	56.25	55.00	−	4.02	4.81
Acer rubrum	47.50	48.75	+	1.91	1.95
Quercus coccinea	32.50	31.25	−	1.15	1.34
Panicm spp.	28.75	32.50	+	0.18	0.68
Smilax rotundifolia	26.25	26.25	Nc	0.62	0.79
Mitchella repens	20.00	22.50	+	0.78	1.90
Sassafras albidum	20.00	21.25	+	0.56	1.11
Quercus alba	17.50	16.25	−	0.72	0.72
Vaccinium corymbosum	15.00	21.25	+	1.28	2.11
Liriodendron tulipifera	13.75	8.75	−	0.19	0.25
Pyrularia pubera	13.75	13.75	Nc	0.41	0.40
Erechitites hieracifolia	11.25	8.75	−	0.14	0.28
Aster sp.	10.00	7.50	−	0.12	0.08
Poa spp.	10.00	10.00	Nc	0.11	0.21
Rhus copallina	10.00	10.00	Nc	0.02	0.12
Chimaphila maculata	6.25	10.00	+	0.02	0.11
Pinus strobus	6.25	13.75	+	0.001	0.03
Quercus velutina	6.25	8.75	+	0.19	0.26
Solidago odora	6.25	5.00	−	0.09	0.09
Carya glabra	5.00	6.25	+	0.44	0.29
Hexastylis minor	5.00	6.25	+	0.12	0.11
Iris verna	5.00	6.25	+	0.10	0.14
Lysimachia quadrifolia	5.00	2.50	−	0.08	0.05
Pteridium aquilinum	5.00	7.50	+	0.36	0.39
Toxicodendron radicans	5.00	3.75	−	0.16	0.10
Vaccinium arboretum	5.00	8.75	+	0.10	0.46
Viola hastate	5.00	5.00	Nc	0.11	0.11
Vitis rotundifolia	5.00	6.25	+	0.11	0.92
Amphicarpa bracteata	3.75	5.00	+	0.14	0.35
Calycanthus floridus	3.75	5.00	+	0.22	0.39
Parthenocissus quinquefolia	3.75	6.25	+	0.15	0.18
Sub-total			18+ 9− 5Nc		
Control					
Acer rubrum	57.50	57.50	Nc	1.00	1.35
Smilax glauca	52.50	65.00	+	0.68	1.15
Mitchella repens	45.00	45.00	Nc	3.18	4.55
Vaccinium vacillans	32.50	32.50	Nc	3.35	3.38
Kalmia latifolia	30.00	30.00	Nc	4.00	3.95
Pinus strobus	27.50	20.00	−	0.43	0.25
Quercus alba	25.00	25.00	Nc	0.55	0.58
Chimaphila maculate	22.50	22.50	Nc	0.30	0.42
Quercus coccinea	17.50	17.50	Nc	0.50	0.60
Hexastylis minor	15.00	15.00	Nc	0.40	0.35
Smilax rotundifolia	15.00	20.00	+	0.68	1.23
Panicum spp.	12.50	12.50	Nc	0.08	0.28
Pinus virginiana	12.50	12.50	Nc	0.30	0.50
Antennaria plantaginifolia	10.00	10.00	Nc	0.50	0.25
Vaccinium corymbosum	10.00	10.00	Nc	0.90	0.95
Acer nigra	7.50	5.00	−	0.25	0.15
Amelanchier arborea	7.50	2.50	−	0.25	0.12
Poa spp.	7.50	5.00	−	0.18	0.08
Prunus serotina	7.50	10.00	+	0.28	0.35
Sassafras albidum	7.50	7.50	Nc	0.28	0.28

Table 8. Continued.

	Frequency (%)			Percent cover (%)	
	2001	2002		2001	2002
Trillium cernuum	7.50	7.50	Nc	0.18	0.18
Tsuga canadensis	7.50	7.50	Nc	0.55	0.28
Vitis rotundifolia	7.50	10.00	+	0.40	0.45
Carya glabra	5.00	5.00	Nc	0.15	0.05
Carya tomentosa	5.00	5.00	Nc	0.15	0.12
Chamaelirium luteum	5.00	5.00	Nc	0.30	0.18
Goodyera pubera	5.00	2.50	−	0.10	0.08
Pteridium aquilinum	5.00	7.50	+	0.32	0.55
Pyrularia pubera	5.00	2.50	−	0.18	0.08
Quercus velutina	5.00	5.00	Nc	0.10	0.28
Solidago sp.	5.00	5.00	Nc	0.10	0.10
Uvularia perfoliata	5.00	5.00	Nc	0.05	0.02
Viola hastate	0.00	10.00	+	0.00	0.05
Sub-total			6+ 6− 21Nc		

* + denotes an increase in frequency, − denotes a decrease in frequency, Nc denotes no change in frequency.

** Other minor species (< 5.0 percent frequency) included: *Andropogon gyrans, Asimina triloba, Aster divaricatus, Aureolaria pedicularia, Bigonia capreolata, Cercis canadensis, Chamaelirium luteum, Clitoria mariana, Desmodium nudiflorum, Dioscorea quadrafolia, Epigaea repens, Euonymus americanus, Euphorbia corolatta, Fagus grandiflolia, Galium* spp., *Geranium maculatum, Hamamelis virginiana, Hieracium paniculatum, Hypoxis hirsuta, Lespedeza* spp., *Liquidamber styraciflua, Lonicera* sp., *Luzula* sp., *Melampyrum lineare, Phlox carolina, Phytolacca americana, Polystichum acrostichoides, Polygonum cilinode, Potentilla candensis, Prenanthes trifoliolata, Prunus serotina, Ranuculus recurvatus, Rhododendron nudiflorum, Rubus* spp., *Sclerio triglomerata, Solidago odora, Succisella inflexa, Ulmus alata, Uvularia perfoliata, Viburnum acerifolium, Viola blanda.*

species composition. In oak savannas in Minnesota, Peterson and Reich (2001) concluded that annual burning was needed to reduce overstory density and suppress growth of understory shrubs and saplings while a healthy, productive herbaceous layer develops. In *P. taeda* and *P. echinata* stands in Arkansas, Cain (1993) suggested a 6-year burning cycle had better stocking of pine regeneration than a 3-year cycle. Attention to expected seed-crops following a burn treatment was also recommended for successful pine regeneration (Cain 1993, Cain et al. 1998).

We found no regeneration of *P. echinata* seedlings after the prescribed fire. In the absence of disturbance, shade-intolerant *P. echinata* cannot regenerate beneath a closed canopy composed of midstory hardwood species (Cain and Shelton 1995). To facilitate the establishment and growth of pine regeneration, Cain (1994) recommended a series of annual or biennial burns in *P. echinata* stands to keep the fire-sensitive hardwoods reduced. In addition, Cain (1994) suggested that the last burn in a series should coincide with a better-than average pine seed-crop and should be completed by early autumn, before the majority of pine seed have disseminated. However, in further studies on the effects of burning in *P. echinata* stands, longer intervals between burning were suggested for higher ground flora diversity (Cain et al. 1998).

In our study, residual basal area may have been too high to facilitate successful *P. echinata* establishment. In the second year after burning, overstory basal area was only reduced to 24 m^2 ha^{-1} even with the bark beetle induced mortality of the pines. Guidelines for successful regeneration of *Pinus echinata* are 10–14 m^2 ha^{-1} of overstory basal area. If basal area exceeds 17 m^2 ha^{-1}, pine regeneration will be adversely affected by shading and root competition (Shelton and Cain 2000). Although seedlings of *P. echinata* can germinate under a dense canopy, survival of these new germinants is very low (Shelton and Cain 2000). We did not observe any seed germination of *P. echinata* or *P. virginiana* after fire in our study. The single, dormant season burn did not have the intensity to sufficiently consume forest floor mass (Hubbard et al. 2004) and adequately prepare a seed bed for pine seeds to germinate. In addition, poor pine regeneration may have been due to drought, poor seed production, and hardwood competition during the study.

In our study, we found no pine regeneration and prolific sprouting from hardwoods in the midstory. Fire reduced basal area of woody species and *P. strobus* density was < 20% and basal area was < 50% of the pre-burn condition. However, prolific sprouting resulted in much higher density of fire-sensitive hardwoods. For example, number of *A. rubrum* stems increased by 140% and *N. sylvatica*, *O. arboreum*, and *A. arborea* increased by 50%, and 70%, and 200%, respectively. In contrast, *Quercus* species were only minimally affected by the fire treatment; *Q. alba* and *Q. velutina* increased in stem density; whereas, *Q. coccinea* and *Q. rubra* had fewer stems after the burn than before the burn. Clendenin and Ross (2001) reported a similar pattern of regeneration in a *P. taeda*, mixed hardwood forest in east Texas. They found that pine regeneration was scarce and that regeneration was primarily from hardwood sprouts after fire and concluded that infrequent cool season fire favored hardwood regeneration in these communities.

In contrast to other studies in eastern hardwood forests, where prescribed fire resulted in increased percent cover and diversity of ground flora species (Arthur et al. 1998, Elliott et al. 1999, Clinton and Vose 2000, Hutchinson and Sutherland 2000, Clendenin and Ross 2001, Elliott et al. 2004), we found no significant increase in ground flora percent cover or diversity after burning in our study. However, low intensity fires similar to the fires in our study often have little effect on plant community composition (McGee et al. 1995, Kuddes-Fischer and Arthur 2002) and in some cases diversity (Franklin et al. 2003). One of the goals of our burn treatment was to enhance bluestem-grass growth in the ground flora layer. However, we found very little bluestem-grass (*Andropogon gyrans* or *Schizachyrium scoparium*) recruitment (< 0.1 percent cover and < 2.0 percent frequency) after fire in our study sites. Additional burning treatments may be necessary to stimulate bluestem recruitment and growth on these sites. For example, Tester (1989) found that the percent cover of grass species increased with an increasing number of prescribed burns. Although we did not measure the seed pool, the low abundance of bluestem-grasses suggests that these species may need to be seeded or planted for successful establishment on these sites. In *Pinus palustris*/*Aristida beyrichiana* restoration in the southern U.S. (Mulligan et al. 2002), reintroduction required planting seedlings to successfully established wiregrass in these community types.

Conclusions. The USDA Forest Service has made application of prescribed fire one of its priorities for restoration of forest ecosystems that have been altered by fire suppression, insect or disease outbreaks, or past management (Hardy and Arno 1996, USDA Forest Service 2000). The purpose of the burning treatments in the Conasauga River Watershed was to restore *P. echinata*/mixed-hardwood/bluestem-grass forest communities. The fire was intended to reduce or eliminate *P. strobus*, a late-successional fire sensitive species, from the understory; promote regeneration of *Pinus echinata*, a fire tolerant species; and promote a diverse ground flora including native bluestem-grasses (*Andropogon gyrans* and *Schizachyrium scoparium*).

The prescribed fires were successful in reducing *P. strobus* in the midstory. Although we found some overstory mortality of small size class hardwoods as a result of the fire, most of the mortality occurred in *P. echinata* and *P. virginiana* due to infestation with pine bark beetles. We conclude that the prescribed fires were not of sufficient intensity to: reduce overstory basal area, prepare a seedbed for successful pine germination, affect diversity of any of the vegetation layers, or promote bluestem grass recruitment. Thus, additional fire treatments or a combination of fire and thinning treatments may be necessary to restore these ecosystems to *P. echinata*/mixed-hardwood/bluestem-grass community types.

Little is known about the ecological consequences of reintroducing fire to forest ecosystems where it has been absent for 80 years of more. Because of the long period of fire exclusion in the Conasauga River Watershed, more aggressive silvicultural treatments will be required to restore *P. echinata*/bluestem-grass dominated communities. These aggressive treatments might include: additional prescribed fires with consideration of altering season, intensity, and frequency of the burns; thinning overstory trees and midstory shrubs; and planting desirable species. Reduction of undesirable, fire-sensitive species such as *P. strobus* and *A. rubrum* may require repeated burning at frequent intervals (e.g., 3–6 years). Thinning the overstory to reduce basal areas between 10–14 m^2 ha^{-1}, as suggested by Shelton and Cain (2000), would enhance the success of pine regeneration by increasing sunlight for the shade-intolerant pines. If mature cone bearing pine trees are not present in the overstory, then planting seedlings of *P. echinata* may be necessary to provide successful regeneration. Where natural regeneration is being relied on, Cain et al. (1998) suggested that the prescribed burn be planned for years with above average seed crops and that the burn treatment be completed in early autumn before pine seeds have disseminated. To re-introduce bluestem-grass into the watershed, either seeding or planting seedlings of bluestem-grass may also be necessary. After re-introduction of bluestem-grass, thinning to maintain low overstory basal area and frequent fires to reduce midstory cover should also enhance a diverse ground flora with bluestem grass as a major component.

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