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Response of southern Appalachian table mountain pine (*Pinus pungens*) and pitch pine (*P. rigida*) stands to prescribed burning

N.T. Welch[a,*,1], T.A. Waldrop[b], E.R. Buckner[c]

[a]*Department of Ecology and Evolutionary Biology, The University of Tennessee, Knoxville, TN 37996, USA*
[b]*Department of Forestry, Wildlife and Fisheries, The University of Tennessee, Knoxville, TN 37996, USA*
[c]*USDA Forest Service, Southern Research Station, Clemson, SC 29643, USA*

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Abstract

Southern Appalachian table mountain pine (*Pinus pungens*) and pitch pine (*P. rigida*) forests require disturbance for regeneration. Lightning-ignited fires and cultural burning practices provided the disturbance that prehistorically and historically maintained these forests. Burning essentially ceased on public lands in the early twentieth century when fire suppression became the primary fire management initiative of federal land managers. The last five to six decades of forest succession in the absence of fire have allowed chestnut oak (*Quercus prinus*), scarlet oak (*Q. coccinea*), and red maple (*Acer rubrum*) to dominate both midstory and understory strata and to become poised to invade table mountain pine and pitch pine canopies. This study examined first-year responses of three 60–80-year-old southern Appalachian table mountain pine and pitch pine stands to prescribed fire. Prior to burning, mean canopy (woody stems ≥2.5 cm DBH), understory (all shrubs and saplings <2.5 cm DBH), and ground layer (all vascular species ≤1 m in height) species richness values ranged 6–8 species/0.02 ha, 2–3 species/0.01 ha, and 1–3 species/m^2, respectively. Mean pre-burn basal area ranged from 23 to 32 m^2/ha for the three stands. Canopy and understory densities averaged 1500–1900 and 70–120 stems/ha, respectively. Mean pre-burn ground layer cover ranged from 28 to 77% per metre square. There were no pine seedlings present in the pre-burn ground layer. On all sites, burning top-killed some overstory and midstory fire-intolerant species such as sassafras (*Sassafras albidum*), red maple, and white pine (*Pinus strobus*). Numerous sprouts of these species appeared in the post-burn understory and ground layers. Canopy species richness was significantly lower (45%) whereas understory and ground layer species richness were significantly higher (two times pre-burn values) following most burns. All three burns significantly reduced canopy basal area (20–30%), canopy density (50–70%), and ground layer cover (40–70%) but increased understory density (two times pre-burn values). Table mountain pine (8000 seedlings/ha) and pitch pine regeneration (15 000 seedlings/ha) was observed following two of these burns but the seedlings were not likely to survive due to shading and competition from overstory, midstory, and understory strata. Future burns to restore similar stands must open the forest canopy, reduce accumulated litter and duff layers, and expose regenerative basal buds of hardwoods to lethal temperatures in order to lessen post-burn sprouting. Prescribed burns that do not accomplish these goals may further encourage succession towards hardwood-dominated stands as sprouts of understory hardwoods grow into midstory and overstory strata.

Keywords: Prescribed burning; Pine-oak forests; Table mountain pine; Pitch pine; Southern Appalachian Mountains

* Corresponding author. Tel.: +1-812-855-4953; fax: +1-812-855-7547.
E-mail address: niwelch@indiana.edu (N.T. Welch)
[1] Present address: School of Public and Environmental Affairs, Indiana University, Bloomington, IN 47405.

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1. Introduction

Southern Appalachian table mountain pine (*Pinus pungens*) and pitch pine (*P. rigida*) forests are fire-dependent. Pre-historic and historic lightning-ignited fires and cultural burning practices maintained these forests on upper, south-to-west-facing slopes (Guffey, 1977; Harmon, 1982; Buckner, 1989; Van Lear and Waldrop, 1989; DeVivo, 1991; Delcourt and Delcourt, 1997; Buckner and Turrill, 1998; Williams, 1998) until declines in Native American populations, establishment of federal fire policies, and public fear of fire resulted in widespread fire suppression and prevention in the region (Pyne, 1982). The past five to six decades of fire suppression efforts have degraded table mountain pine and pitch pine forests and many have converted to, or are in various stages of succession towards, hardwood dominance (Williams and Johnson, 1990, 1992; Sutherland et al., 1995; Turrill et al., 1997; Harrod et al., 1998; Turrill, 1998; Williams, 1998). As Harrod et al. (1998) reported for fire-suppressed pitch pine stands in the Great Smoky Mountains National Park, Tennessee, canopy density, basal area, and canopy species richness of these forests have increased with the invasion of fire-intolerant species such as red maple (*Acer rubrum*), white pine (*P. strobus*), and eastern hemlock (*Tsuga canadensis*).

Today, the majority of southern Appalachian table mountain and pitch pine forests are located on managed public lands. This offers the opportunity to regenerate degraded stands with prescribed burning. Since many of these stands now contain significant hardwood components, questions arise as to how they will respond to prescribed burning. Ecologists agree that fire established table mountain and pitch pine forests and that fire should be returned to them via prescribed burning (Buckner and Turrill, 1998; Harrod et al., 1998; Williams, 1998), but details of the frequencies, intensities, and severities of fires to encourage pine regeneration remain uncertain.

The purpose of this research was to evaluate the effects of prescribed burning on 60–80-year-old table mountain pine and pitch pine stands. The three prescribed burns described in this study were among the first attempts to regenerate such stands in the southern Appalachian Mountains. Pre- and post-burn species composition, species richness, and stand structure are compared in this paper.

2. Methods

2.1. Community description

Table mountain pine and pitch pine are two of four yellow pines native to the southern Appalachian region. The other native yellow pines are shortleaf pine (*P. echinata*) and Virginia pine (*P. virginiana*). Table mountain pine is an Appalachian endemic distributed along the ridges of the Appalachian Mountains from central Pennsylvania to northern Georgia (Zobel, 1969) (Fig. 1). The range of pitch pine overlaps that of table mountain pine and extends northward into Maine (Sutton and Sutton, 1985). Both species occur on xeric, south-to-west-facing slopes with shallow, acidic, and oligotrophic soils at 300–1370 m elevation. Canopy species most often associated with table mountain pine and pitch pine include chestnut oak (*Quercus prinus*) and scarlet oak (*Q. coccinea*). Associated midstory and understory species are blackgum (*Nyssa sylvatica*) and sourwood (*Oxydendrum arboreum*). Dense thickets of mountain laurel (*Kalmia latifolia*) and species of blueberries (*Vaccinium* spp.) and huckleberries (*Gaylussacia* spp.) comprise the shrub component of the understory. Galax (*Galax aphylla*) is common in the ground layer (Zobel, 1969; Barden, 1977; Williams and Johnson, 1992).

Table mountain pine and pitch pine are pioneer species that establish stands following disturbance. It has been suggested that the disturbance must expose mineral soil and provide full sunlight for successful regeneration (U.S.D.A. Forest Service, 1965; Sanders, 1992; Williams and Johnson, 1992). Table mountain pine cones are serotinous and often mature when the tree is five years of age (Zobel, 1969; Barden, 1978; Della-Bianca, 1990). Pitch pine cones of the southern Appalachian Mountains typically are non-serotinous. Cone serotiny is a polymorphic trait in pitch pine (Ledig and Fryer, 1974; Givnish, 1981; McCune, 1988) and Givnish (1981) showed that clinal variation in this polymorphism is related to clinal variations in fire regime, with non-serotinous individuals more prevalent in areas of infrequent fires. Mature cones are found on pitch pine trees eight to twelve years old and seed dissemination occurs from late October through late November in non-serotinous individuals (Little and Garrett, 1990). Vegetative reproduction from basal buds and epicormic branching is common

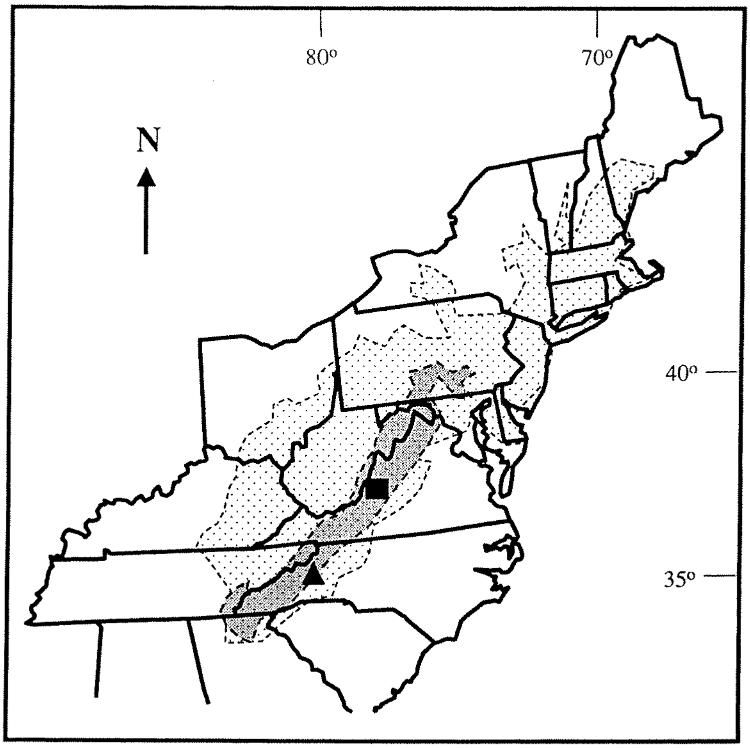

Fig. 1. Geographic distributions of *Pinus pungens* (Della-Bianca, 1990) [dark shading] and *P. rigida* (Little and Garrett, 1990) [dotted] and locations of study sites. Study sites are ■ = Warm Springs Ranger District, George Washington and Jefferson National Forest (GWWS), and ▲ = Grandfather Ranger District, Pisgah National Forest (PSGF).

in pitch pine following fire injury (Ledig and Little, 1979; Little and Garrett, 1990). Table mountain pine does not reproduce vegetatively (Della-Bianca, 1990).

2.2. Study sites

This study was conducted on the Warm Springs Ranger District of the George Washington and Jefferson National Forest (GWWS), Virginia, and the Grandfather Ranger District of the Pisgah National Forest (PSGF), North Carolina (Fig. 1). U.S.D.A. Forest Service crews divided the GWWS stand into two compartments to allow for two burns of different seasons. Pitch pine dominated the canopy of both 60-year-old, 7 ha GWWS sites. Table mountain pine and pitch pine shared canopy dominance of PSGF (7 ha, 77 years old). Virginia pine appeared in the midstory of PSGF but was not a central focus of this research since, generally, it is not a dominant species of table mountain pine and pitch pine stands (Whittaker, 1956). No timber harvests, wildfires, or prescribed fires had occurred on GWWS or PSGF since the time of federal land acquisition in the late 1930s and early 1940s.

2.3. Vegetation sampling

Eight sample plots (10 m × 20 m, 0.02-ha) were established randomly within each study area. Sampling crews tallied all living woody stems ≥2.5 cm diameter breast height (DBH) within each sample plot as to species and DBH. Generally, stems ≥10 cm DBH were in the overstory and those <10 cm and ≥2.5 cm DBH were in the midstory. Understory stems (all shrubs and saplings <2.5 cm DBH) were noted as to species and tallied in 30 cm height classes in two 10 m × 5 m subplots within each sample plot. Litter layer (O_1) depth was obtained from three random measurements within each understory subplot and duff depth (O_2) was measured at the center of each sample plot. One 1-m^2 subplot was located at each of the four corners of the sample plot for ground layer sampling. Within these subplots, % cover was visually estimated for all vascular species, both woody and herbaceous, ≤1 m in height. Nomenclature follows Radford et al. (1968).

2.4. Prescribed burning

USDA Forest Service personnel burned the first 7-ha GWWS compartment in mid-October 1995. Burning crews applied a ring firing technique under warm (air temperatures 22°C), relatively dry (relative humidity 30–40%) conditions. The ring firing technique involved circling the burn area with drip torches and setting one or more spot fires near the center of the burn area to pull the outer circle of fire inward (U.S.D.A. Forest Service, 1989). Flame lengths ranged from 1 to 3 m. The second 7-ha GWWS compartment was burned in mid-May 1996, also using a ring firing technique. Air temperature during the burn was 26°C and relative humidity ranged from 40 to 60%. Flame lengths varied from 1 to 6 m. Bark char (height of fire-blackened bark on the bole of canopy stems) averaged 2 m for both burns. Sampling of post-burn vegetation occurred in August 1996.

Burning crews used a combined ring and head firing technique to burn the PSGF site in early May 1996. The head firing technique involved setting a line of fire upwind at the base of the slope (U.S.D.A. Forest Service, 1989). The air temperature during the burn was 27°C and relative humidity ranged from 36 to 46%. Reported flame heights at greatest intensity varied from 12 to 46 m. However, the mean flame height was probably much lower as indicated by the mean bark char height of 4 m and canopy scorch of 20%. Sampling of post-burn vegetation occurred in August 1996. Post-burn species composition, stand structure and seedling densitites were measured during the first post-burn growing season.

2.5. Data analysis

Mean basal area (m^2/ha) and mean density (number of stems/ha) were calculated for canopy stems (overstory and midstory size classes combined) on each site. The frequencies of canopy stems in 5 cm DBH classes were determined and histograms were constructed for each site. Relative basal area and relative density, both as percent of total, were added to obtain importance values for overstory and midstory species.

Mean understory density (number stems/ha) and mean ground layer cover (% per metre square) were calculated for each site. Importance values of understory species and ground layer species were determined as relative density (% of total) plus relative height (% of total) and relative cover (% of total) plus relative frequency (% occurrence within the 32 1 m^2 plots/site), respectively. Mean litter and mean duff depth values were obtained for each site. Species richness was determined for the canopy, understory, and ground layer as the number of species present in the sampled area. Mean canopy, understory, and ground layer species richness were determined for each site. All pre- and post-burn means were compared within each site using paired t-tests and an α of 0.05 (SAS, 1994). All results are considered descriptive statistics (Hurlbert, 1984) and each of the three burns is treated as an individual case study, lacking replication.

3. Results

3.1. Species composition

Pitch pine and scarlet oak were the most important overstory species both prior to and following the GWWS fall burn (Table 1). The burn reduced basal area and density of black oak (*Q. velutina*) and blackjack oak (*Q. marilandica*). Blackjack oak was the most important pre-burn midstory species but was top-killed by the fire and absent from post-burn sampling (Table 2). Blackgum, chestnut oak, and scarlet oak were the only midstory species after the burn. Sassafras (*Sassafras albidum*) saplings and mountain laurel shrubs dominated the pre- and post-burn understory (Table 3). Huckleberry, blueberry, and bracken fern (*Pteridium aquilinum*) were the most important ground layer species both prior to and following burning (Table 4). Seedlings of sassafras, pitch pine, and black oak were also present in the post-burn ground layer.

Pitch pine and scarlet oak were the most important pre- and post-burn overstory species on the GWWS

Table 1
Pre- and post-burn overstory trees (stems ≥10 cm DBH) of *P. pungens* and *P. rigida* stands[a]

Species	Pre-burn			Post-burn		
	Basal area (m^2/ha)	Density (# stems/ha)	IV	Basal area (m^2/ha)	Density (# stems/ha)	IV
GWWS Fall Burn						
Pinus rigida	11.3	206.3	86.8	9.6	168.8	89.0
Quercus coccinea	3.9	193.8	47.2	3.8	187.5	56.8
Nyssa sylvatica	1.6	93.8	21.4	1.5	87.5	24.9
Q. prinus	1.5	93.8	20.9	1.2	75.0	20.9
Q. velutina	0.8	62.5	12.7	0.2	12.5	3.4
Q. marilandica	0.6	56.3	11.0	0.2	12.5	3.3
Q. alba[b]	–	–	–	0.1	6.3	1.6
Total	19.7	706.5		16.6	550.1	
GWWS Spring Burn						
P. rigida	14.4	200.0	84.1	13.9	181.3	157.8
Q. coccinea	6.5	262.5	61.0	1.4	62.5	32.5
Q. prinus	1.8	112.5	22.4	–	–	–
Q. velutina	0.8	43.8	9.2	0.3	6.3	4.1
N. sylvatica	0.3	25.0	4.4	0.1	12.5	5.7
Q. alba	0.3	18.8	3.6	–	–	–
Sassafras albidum	0.2	1838	3.2	–	–	–
Acer rubrum	0.2	6.3	2.2	–	–	–
Total	25.2	744.0		15.7	262.6	
PSGF Spring Burn						
Pinus pungens	12.0	225.0	66.3	13.8	287.5	98.0
P. rigida	9.0	256.3	59.4	5.3	137.5	41.7
N. sylvatica	1.4	106.3	16.6	1.3	81.3	17.4
Pinus virginiana	2.2	62.5	14.4	2.4	56.3	17.9
Q. coccinea	1.8	68.8	13.7	0.6	25.0	6.0
A. rubrum	1.1	68.8	11.5	0.9	50.0	11.0
Q. prinus	0.9	56.3	9.3	0.4	18.8	4.2
Oxydendron arboreum	0.7	56.3	8.7	0.3	18.8	3.8
Total	29.1	900.3		25.0	675.2	

[a] Importance value (IV) calculated as relative basal area (% of total) plus relative density (% of total).
[b] Omitted or misidentified during pre-burn sampling.

spring burn site (Table 1). The dominance of pitch pine increased after the burn as stems of chestnut oak, white oak (*Q. alba*), sassafras, and red maple were top-killed by the fire. Blackjack oak and sassafras were the most important pre-burn midstory species whereas blackgum and chestnut oak were the most important post-burn midstory species (Table 2). Midstory stems of blackjack oak, scarlet oak, black oak, red maple, and hickory (*Carya* sp.) were top-killed by the fire. Huckleberry and sassafras dominated the pre-burn understory whereas sprouts of sassafras dominated the post-burn understory (Table 3). Huckleberry was the most important ground layer species both prior to and following burning (Table 4). Seedlings and sprouts of sassafras were prevalent in the post-burn ground layer.

Table mountain pine and pitch pine dominated the PSGF pre- and post-burn overstory (Table 1). Blackgum was the most important midstory species both prior to and following burning (Table 2). Midstory stems of chestnut oak, scarlet oak, Virginia pine, sassafras and white pine were top-killed by the fire. Mountain laurel dominated the pre- and post-burn understory (Table 3). Stump sprouts of sourwood, red maple, and blackgum were present in the post-burn understory. Mountain laurel and blueberry

Table 2
Pre- and post-burn midstory trees (stems <10 and ≥2.5 cm DBH) of *P. pungens* and *P. rigida* stands[a]

Species	Pre-burn			Post-burn		
	Basal area (m^2/ha)	Density (# stems/ha)	IV	Basal area (m^2/ha)	Density (# stems/ha)	IV
GWWS Fall Burn						
Quercus marilandica	1.7	400.0	98.1	–	–	–
Q. velutina	0.6	143.8	34.1	–	–	–
Nyssa sylvatica	0.5	112.5	26.4	0.2	37.5	98.2
Q. prinus	0.4	62.5	17.3	0.1	18.8	56.1
Q. coccinea	0.2	37.5	10.1	0.1	18.8	45.7
Sassafras albidum	0.1	31.3	5.5	–	–	–
Q. alba	0.1	6.3	3.2	–	–	–
Amelanchier arborea	0.1	12.5	3.1	–	–	–
Pinus rigida	0.0	6.3	1.2	–	–	–
Acer rubrum	0.0	6.3	1.0	–	–	–
Total	3.7	819.0		0.4	75.1	
GWWS Spring Burn						
Q. marilandica	1.1	306.3	71.3	–	–	–
S. albidum	0.6	243.8	47.7	0.0	6.3	15.8
Q. prinus	0.5	106.3	26.8	0.1	18.8	76.6
Q. cocccinea	0.5	81.3	23.9	–	–	–
Q. velutina	0.3	50.0	14.2	–	–	–
N. sylvatica	0.2	50.0	13.1	0.1	18.8	79.7
A. rubrum	0.0	6.3	1.7	–	–	–
Carya sp.	0.0	6.3	1.3	–	–	–
Total	3.2	850.3		0.2	33.9	
PSGF Spring Burn						
N. sylvatica	1.3	375.0	76.5	0.5	93.8	95.7
Oxydendron arboreum	0.6	168.8	35.9	0.1	37.5	30.0
A. rubrum	0.5	150.0	30.4	0.2	68.8	59.0
Hamamelis virginiana	0.1	93.8	12.4	–	–	–
P. rigida	0.2	43.8	10.8	0.1	12.5	15.3
Q. prinus	0.2	37.5	9.1	–	–	–
Q. coccinea	0.1	43.8	8.7	–	–	–
P. virginiana	0.1	12.5	2.9	–	–	–
A. arborea	0.0	12.5	2.3	–	–	–
S. albidum	0.0	6.3	1.0	–	–	–
P. strobus	0.0	6.3	0.7	–	–	–
Total	3.2	950.3		0.9	212.6	

[a] Importance value (IV) calculated as relative basal area (% of total) plus relative density (% of total).

dominated the pre- and post-burn ground layer (Table 4).

Mean canopy species richness was significantly lower whereas understory species richness was significantly higher following all three burns (Table 5). Post-burn ground layer species richness increased significantly after the GWWS fall burn and the GWWS spring burn but was unchanged following the PSGF burn.

3.2. Stand structure

Mean canopy basal area and mean canopy density was significantly reduced on all sites after burning (Table 6). Mean canopy basal area was reduced by 27% for the GWWS fall burn, 32% for the GWWS spring burn, and 20% for the PSGF burn. Greater reductions were observed for mean canopy density (60% for the GWWS fall burn, 73% for the GWWS

Table 3
Pre- and post-burn understory saplings and shrubs (stems <2.5 cm DBH) of *P. pungens* and *P. rigida* stands[a]

Species	Pre-burn			Post-burn		
	Density (# stems/ha)	Height (m)	IV	Density (# stems/ha)	Height (m)	IV
GWWS Fall Burn						
Saplings						
Sassafras albidum	406.3	2.2	91.6	1537.4	0.5	106.3
Quercus coccinea	312.5	1.2	50.3	193.8	0.5	13.1
Q. marilandica	43.8	0.8	6.2	81.3	0.7	6.6
Q. velutina	–	–	–	381.3	0.6	29.0
Nyssa sylvatica	–	–	–	75.0	0.4	4.8
Q. prinus	–	–	–	56.3	0.6	4.1
Acer rubrum	–	–	–	12.5	0.4	0.7
Shrubs						
Kalmia latifolia	325.0	0.9	47.4	575.0	0.4	35.0
Gaylussacia sp.	18.8	1.0	2.8	–	–	–
Rhododendron sp.	6.3	1.5	1.1	–	–	–
Total	1112.7			2912.7		
GWWS Spring Burn						
Saplings						
S. albidum	537.5	1.0	61.0	2675.0	0.5	167.9
Q. coccinea	31.3	0.7	3.2	106.3	0.4	6.0
A. rubrum	12.5	0.7	1.2	6.3	0.4	0.3
Q. marilandica	6.3	0.7	0.6	–	–	–
Q. velutina	–	–	–	231.3	0.4	13.4
Q. prinus	–	–	–	56.3	0.4	3.1
N. sylvatica	–	–	–	25.0	0.4	1.3
Castanea dentata	–	–	–	6.3	0.4	0.3
Shrubs						
Gaylussacia sp.	1006.3	0.8	98.7	–	–	–
K. latiolia	193.8	2.3	35.5	143.8	0.4	7.6
Total	1787.7			3250.3		
PSGF Spring Burn						
Saplings						
Oxydendron arboreum	31.3	2.8	3.6	156.0	0.0	6.0
Pinus strobus	12.5	3.3	1.6	–	–	–
Q. coccinea	12.5	2.9	1.5	19.5	0.4	5.1
A. rubrum	12.5	1.8	1.2	344.5	0.1	10.7
Q. prinus	6.3	2.9	0.7	26.0	0.1	4.7
N. sylvatica	–	–	–	552.5	0.1	12.9
Shrubs						
K. latifolia	1581.3	2.8	184.8	975.0	0.1	147.5
Hamamelis virginiana	31.3	2.8	3.6	19.5	0.1	4.5
Symplocos tinctoria	12.5	4.0	1.8	195.0	0.0	8.2
Vaccinium sp.	12.5	1.5	1.1	–	–	–
Rhododendron sp.	–	–	–	6.5	0.4	0.5
Total	1712.7			2294.5		

[a] Importance value (IV) calculated as relative density (% of total) plus relative height (% of total).

Table 4
Pre- and post-burn ground layer vegetation (≤1 m in height) of *P. pungens* and *P. rigida* stands[a]

Species	Pre-burn			Post-burn		
	Cover (% per metre square)	Frequency (% occurrence)	IV	Cover (% per metre square)	Frequency (% occurrence)	IV
GWWS Fall Burn						
Tree species						
Sassafras albidum	3.9	28.1	15.3	3.7	46.9	21.8
Quercus marilandica	1.7	12.5	6.8	–	–	–
Q. coccinea	0.3	9.4	3.8	0.0	3.1	1.0
Acer rubrum	0.0	3.1	1.2	–	–	–
Pinus rigida	–	–	–	1.5	3.1	16.3
Q. velutina	–	–	–	3.9	8.3	13.9
Nyssa sylvatica	–	–	–	0.1	3.1	1.1
Shrub species						
Gaylussacia sp.	45.1	81.3	88.2	17.0	56.3	52.6
Kalmia latifolia	7.9	18.8	17.1	3.8	12.2	11.8
Herbaceous species						
Vaccinium sp.	13.7	62.5	40.6	13.5	81.3	52.9
Pteridium aquilinum	4.0	81.3	23.4	3.9	56.3	25.2
Panicum sp.	0.2	3.1	1.4	0.1	3.1	1.1
Vicia sp.	0.1	3.1	1.3	–	–	–
Smilax rotundifolia	0.0	3.1	1.2	0.1	3.1	1.1
Iris cristata	–	–	–	0.1	3.1	1.1
Total	76.9			47.7		
GWWS Spring burn						
Tree species						
S. albidum	6.5	37.5	21.8	5.1	65.6	55.2
Q. coccinea	0.2	9.4	4.2	0.3	9.4	5.7
Q. marilandica	0.3	2.6	3.0	–	–	–
A. rubrum	0.1	3.1	1.3	–	–	–
Q. velutina	–	–	–	0.1	3.1	1.7
N. sylvatica	–	–	–	0.0	3.1	1.5
Shrub species						
Gaylussacia sp.	49.2	78.1	105.2	11.1	96.9	100.4
K. latifolia	1.3	15.6	8.4	0.8	15.6	10.7
Herbaceous species						
Vaccinium sp.	10.5	59.4	40.0	0.5	3.1	4.0
P. aquilinum	1.2	28.1	13.4	1.1	31.3	19.3
Gaultheria procumbens	0.1	6.3	2.8	0.0	3.1	1.5
Total	69.4			19.0		
PSGF Spring Burn						
Tree species						
Q. coccinea	0.4	7.8	4.3	0.9	9.4	13.9
A. rubrum	0.3	7.8	4.1	0.8	6.3	10.4
Oxydendron arboreum	0.3	1.6	1.2	–	–	–
P. strobus	0.2	1.6	1.0	–	–	–
N. sylvatica	0.1	1.6	0.9	0.0	3.1	2.1
P. pungens	–	–	–	0.1	3.1	2.9
Shrub species						
K. latifolia	18.2	68.8	60.9	4.7	62.5	78.6
Gaylussacia sp.	–	–	–	2.7	40.7	47.6
Rhododendron sp.	–	–	–	0.0	3.1	2.1
Symplocos tinctoria	–	–	–	0.0	3.1	2.1

Table 4 (*Continued*)

Species	Pre-burn			Post-burn		
	Cover (% per metre square)	Frequency (% occurrence)	IV	Cover (% per metre square)	Frequency (% occurrence)	IV
Herbaceous species						
Vaccinium sp.	36.5	67.2	89.2	1.7	28.1	31.3
S. rotundifolia	2.3	45.3	24.7	0.1	9.4	6.3
Galax aphylla	3.9	4.7	8.4	0.1	3.1	2.7
P. aquilinum	0.4	4.7	2.9	–	–	–
Panicum sp.	0.5	3.1	2.2	–	–	–
Total	63.1			11.1		

[a] Importance value (IV) calculated as relative cover (% of total) plus relative frequency (% of total).

Table 5
Pre- and post-burn species richness of *P. pungens* and *P. rigida* forest strata[a]

Forest strata	Site					
	GWWS fall burn		GWWS spring burn		PSGF spring burn	
	Pre-burn	Post-burn	Pre-burn	Post-burn	Pre-burn	Post-burn
Canopy (0.02 ha)	5.9 ± 0.6 a	3.6 ± 0.3 b	5.9 ± 0.4 a	2.8 ± 0.6 b	7.9 ± 0.3 a	4.6 ± 0.7 b
Understory (0.01 ha)	2.6 ± 0.3 a	5.4 ± 0.5 b	2.7 ± 4.6 a	3.7 ± 0.3 b	2.1 ± 0.3 a	4.5 ± 0.3 b
Ground layer (1 m^2)	2.8 ± 0.3 a	6.0 ± 0.8 b	2.5 ± 0.2 a	4.3 ± 0.4 b	1.9 ± 0.2 a	1.8 ± 0.2 a

[a] Values given are mean number of species present ±1 standard error per stated unit area. Pre- vs. post-burn comparisons within each site followed by different superscripts are significantly different ($n = 8$, $p < 0.05$).

spring burn, and 47% for the PSGF burn). Prior to burning, the majority of trees were between 5 and 20 cm DBH on the GWWS fall burn and the GWWS spring burn sites and between 5 and 25 cm DBH on the PSGF site (Fig. 2). Burning reduced the number of living stems in all size classes below 25 cm DBH on all sites. Few trees larger than 25 cm DBH were top-killed or killed by the fires.

Table 6
Effects of prescribed burning on *P. pungens* and *P. rigida* stand variables[a]

Variable	Site					
	GWWS fall burn		GWWS spring burn		PSGF spring burn	
	Pre-burn	Post-burn	Pre-burn	Post-burn	Pre-burn	Post-burn
Canopy basal area (m^2/ha)	23.3 ± 2.9 a	16.9 ± 2.6 b	28.5 ± 2.0 a	19.2 ± 1.7 b	32.0 ± 2.0 a	25.9 ± 5.0 b
Canopy density (#stems/ha)	1525.0 ± 188.0 a	625.0 ± 97.5 b	1594.0 ± 163.0 a	431.5 ± 90.5 b	1900.0 ± 166.5 a	887.5 ± 193.5 b
Understory density (#stems/ha)	69.9 ± 11.4 a	168.8 ± 32.2 b	120.3 ± 28.9 a	203.1 ± 29.6 b	116.3 ± 9.4 a	165.5 ± 11.9 b
Ground layer Cover (% per metre square)	76.9 ± 8.1 a	47.0 ± 3.0 b	60.1 ± 6.6 a	18.8 ± 2.5 b	28.4 ± 6.4 a	11.4 ± 2.9 b
Litter depth (cm)	4.0 ± 1.2 a	0.2 ± 0.6 b	4.4 ± 0.3 a	0.9 ± 0.1 b	5.7 ± 0.3 a	2.5 ± 0.5 b
Duff depth (cm)	4.8 ± 2.1 a	2.3 ± 0.9 b	3.6 ± 1.1 a	2.1 ± 0.3 a	5.6 ± 1.2 a	3.8 ± 0.6 a

[a] Values given are means ±1 standard error. Pre- vs. post-burn comparisons for each site followed by different superscripts are significantly different ($n = 8$, $p < 0.05$)

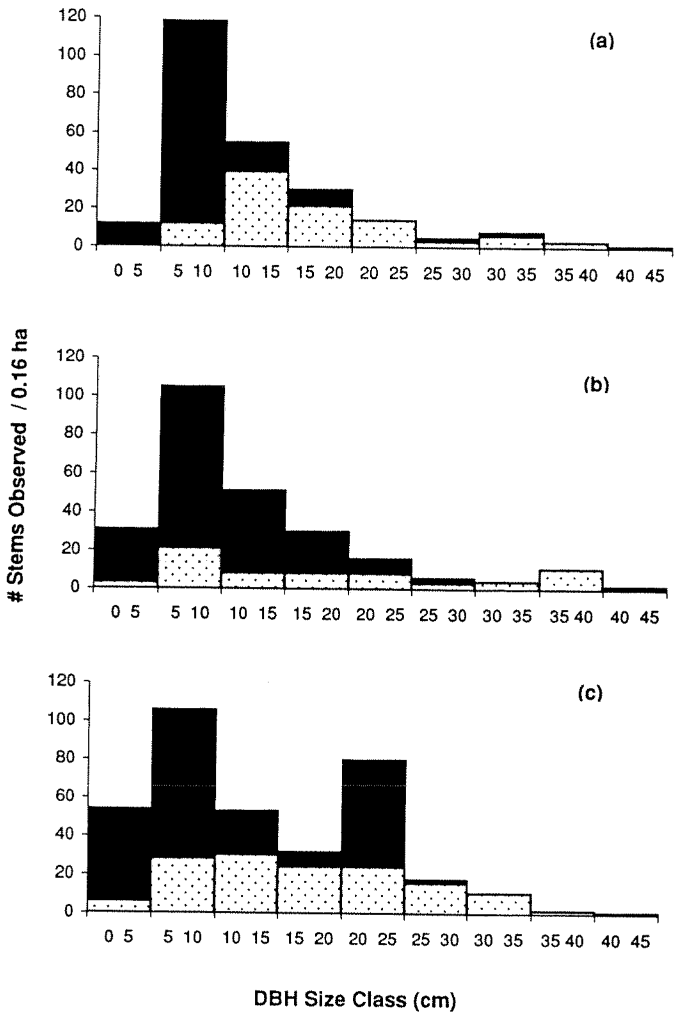

Fig. 2. Distribution of living [dotted] and fire-killed [black] canopy stems (all stems >2.5 cm DBH).

Post-burn mean understory densities were significantly greater than pre-burn values on all sites (Table 6). Mean ground layer cover was significantly reduced after all burns. Litter depth was significantly lower on all sites following burning whereas duff depth was not. Post-burn duff depth was significantly lower than pre-burn duff depth only on the GWWS fall burn site. Pine regeneration was observed following the GWWS fall burn (15 000 pitch pine seedlings/ha) and the PSGF burn (8000 table mountain pine seedlings/ha).

4. Discussion

Species composition of table mountain pine and pitch pine stands has changed in the past five to six decades because of the absence of fire. Table mountain pine and pitch pine remain overstory dominants but are lacking in midstory, understory, and ground layer strata. Instead, numerous hardwood species are present in these lower strata. Of the midstory species observed, 90, 100, and 74% were hardwoods on the GWWS fall burn, GWWS spring burn, and PSGF site, respectively. In addition, roughly 50% of understory species and 33% of ground layer species on each site were hardwoods. Significant hardwood components were also reported for midstory and understory strata of table mountain pine stands of the Chattahoochee National Forest, Georgia (Turrill et al., 1997; Waldrop and Brose, 1999), and for pitch pine stands of the Great Smoky Mountains National Park, Tennessee (Harrod et al., 1998) and the Nantahala National Forest, North Carolina (Elliott et al., 1999). Under current fire-suppressed conditions of a closed canopy and accumulated litter and duff, hardwood regeneration will continue whereas pine regeneration will not (Zobel, 1969; Williams et al., 1992; Williams, 1998) and hardwood species, most likely, will increase in dominance in all of these stands.

The species present in the midstories and understories of the sampled stands suggest how forest succession may change canopy dominance if fire is not returned to similar stands. Although species typically confined to lower forest strata, such as blackjack oak, sassafras, and blackgum, dominated the midstory, understory, and ground layer of each site, potential overstory species, such as chestnut oak, scarlet oak, and red maple were prevalent as well. These hardwood species may invade the overstory of each site as table mountain pine and pitch pine stems die-out in the continued absence of fire or following the cyclic southern pine bark beetle (*Dendroctonus frontalis*) infestations that are common to these forests (Kuykendall, 1978; Smith, 1991). Other authors predict similar changes in canopy species composition. Oaks and maples are predicted to invade pitch pine overstories of North Carolina (Waterman et al., 1995), central Pennsylvania (Nowacki and Abrams, 1992), and central and western New York (Seischab and Bernard, 1991). Sutherland et al. (1995) and (Williams and Johnson, 1990, 1992) predict chestnut oak and scarlet oak dominance of table mountain pine stands in Virginia in the continued absence of fire.

The prescribed burns applied in this study were ineffective at opening the forest canopy. Even though all three burns significantly reduced canopy basal area and canopy density, stems over 20 cm DBH were not killed and stand overstories remained fairly intact. Similar to the results of Elliott et al. (in press), overstory red maple were top-killed by the GWWS spring burn. Accordingly, importance of pitch pine increased in the overstory following the GWWS spring burn. The importance of table mountain pine increased after the PSGF burn as the importance of scarlet oak, chestnut oak, and sourwood decreased. Numerous fire-intolerant, midstory blackjack oak, sassafras, and white pine were top-killed by the fire and contributed to the significant reductions in canopy basal area and canopy density.

Sprouting of top-killed overstory, midstory, and understory hardwoods doubled the density of understory stems following all three burns and increased the importance of hardwoods in post-burn understories. McGee et al. (1995) demonstrated that such post-burn increases in understory density persist for more than 12 years in mid-seral oak forests of New York. The hardwoods that sprouted, blackgum, sassafras, and sourwood, are confined typically to the midstory. However, red maple, a potential canopy dominant, sprouted following the PSGF burn. Since red maple is shade-tolerant, its sprouts likely will survive competition from post-burn sprouts of mountain laurel and other hardwoods (Waterman et al., 1995; Ducey et al., 1996). Waldrop et al. (1992) showed that post-burn increases in red maple are difficult to control and persist even after 43 years of annual winter burning on the Atlantic Coastal Plain.

Post-burn decreases in canopy species richness on all sites were most likely due to losses of fire-intolerant midstory species (blackjack oak, sassafras, red maple, white pine, etc.). Elliott et al. (in press) reported similar post-burn reductions in canopy species richness. Increases in understory species richness were due to the numerous hardwood sprouts that grew into the understory layer. Similarly, sprouts of tree, shrub, and some herbaceous species (blueberry and huckleberry) increased species richness of the ground layer following the GWWS fall and GWWS spring burns.

The pine regeneration that occurred following the GWWS fall burn and the PSGF spring burn may be sufficient to regenerate the stand. However, many of the observed seedlings are not likely to survive since neither fire fully opened the forest canopy nor lessened competing vegetation. Previous studies concluded that canopy removal and exposure of mineral soil were necessary for table mountain pine and pitch pine regeneration (U.S.D.A. Forest Service, 1965; Sanders, 1992; Williams and Johnson, 1992). Indeed, following the 1986 Bote Mountain Wildfire in the Great Smoky Mountains National Park, Tennessee, Sanders (1992) observed the greatest proportion of table mountain pine seedlings in high and moderate intensity burn areas where the forest canopy was opened and mineral soil was exposed. It appears that complete exposure of mineral soil, however, is not as critical to table mountain and pitch pine regeneration as once believed. In a recent study by Waldrop and Brose (1999), roots of table mountain pine seedlings penetrated duff layers up to 7.5 cm deep to reach mineral soil. Further studies comparing (1) survival rates of pine seedlings that germinate of duff to those that germinate on mineral soil and (2) survival rates of pine seedlings under varying degrees of canopy cover, are needed.

5. Conclusion

Long-standing fire suppression practices over the past five to six decades have resulted in closed canopy conditions in table mountain pine and pitch pine forests that encourage hardwood regeneration and preclude pine regeneration. When single prescribed fires were applied to three such stands, the overstory remained closed, the midstory opened slightly, and the understory became more dense. Many, if not all, pine seedlings that established following these fires were unlikely to survive due to shading and competition from remaining canopy vegetation and understory hardwood sprouts. Prescribed fires to restore table mountain pine and pitch pine forests must open the understory, as well as the overstory, of these forests. In order to reduce hardwood sprouting, prescribed burns should consume a significant portion of litter and duff and, in turn, expose regenerative basal buds of hardwoods to lethal temperatures. Recommendations as to the fire intensity or firing method necessary to reach these goals cannot be made on the basis of initial post-burn results from single prescribed burns. Studies employing repeated prescribed burning and canopy and understory reductions and removals are needed. Such treatments may be necessary to regenerate degraded table mountain pine and pitch pine stands.

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