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EFFECTS OF PRESCRIBED FIRE ON SOUTHERN APPALACHIAN ECOSYSTEMS

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ABSTRACT

The magnitude and duration of watershed responses to fire depends on the interactions among burn severity, post-fire precipitation intensity and duration, topography, soil characteristics, and vegetative recovery rate. The typical impact of fire is an immediate change in vegetative cover, forest floor surface, and chemical properties of the soil, followed by mid- and long-term changes in biological pools and nutrient cycling processes. Watershed scale studies were conducted on the effects of prescribed fire on nutrient and carbon cycling, water quality, and vegetation dynamics (regeneration, compositional changes, mortality, and diversity) in multiple forest types and among fire types (ignition source, intensity, and severity) in the southern Appalachian region. The fire types included: stand-replacement fires (simulated wildfire and cut-and-burn prescriptions); low-to-moderate intensity, understory fire prescriptions; and a wildfire in an old-growth deciduous forest. The ecosystems studied were xeric, low productivity pitch pine (*Pinus rigida*)/hardwood forests; dry, moderate productivity shortleaf (*P. echinata*)/Virginia pine (*P. virginiana*)/oak forests; and mesic, high productivity, mixed/hardwood (*Liriodendron tulipifera*/*Quercus rubra*) forests. With prescribed burning in the southern Appalachians, the forest floor humus layer remains largely intact, which mitigates surface erosion and off-site deposition of sediment. For the simulated wildfire in the pine/hardwoods, stream nitrate (NO_3-N) did not increase, most likely because the unburned riparian zone served to buffer fire effects. A fell-and-burn treatment in pine/hardwoods showed a significant elevated stream NO_3-N response (0.075 mg L^{-1}) for 30 weeks. No significant response in stream NO_3-N was measured following low-severity fire in dry, shortleaf pine forests or mesic, mixed/hardwoods forests. After stand replacement fires, vegetation composition and diversity were altered with more deciduous species and less evergreen shrub cover; and ground flora diversity and cover were significantly higher. After low-severity, understory fires, no significant change in overstory, midstory, or ground flora species diversity was found.

INTRODUCTION

For centuries, much of southern Appalachia was dominated by *Quercus* spp., *Castanea den*tata, and yellow pines (such as *Pinus rigida*, *P. echinata*, and *P. pungens*); all fire tolerant early successional species. Due to fire suppression efforts through the 1900s, oaks and pines are being replaced by later-successional, fire-sensitive species, such as *Acer rubrum*, *Pinus strobus*, and ericaceous shrubs. Low severity burning, such as prescribed fires, can promote a herbaceous flora (Elliott et al. 1999, Gilliam 1988, Hutchinson et al. 2005) increase plant available nutrients (Elliott et al. 2004), and thin-from-below over-crowded forests (Elliott and Vose 2005a). In the southern Appalachians, prescribed fires are used to reduce fuels, enhance diversity, and initiate regeneration of desirable species. This paper will highlight results from prescribed fire studies conducted by scientists at Coweeta Hydrologic Laboratory from 1989 to present. These studies use an ecosystem approach to examine the effects of fire on stream water quality, nutrient and carbon cycling, soil and soil water chemistry, and vegetation diversity, composition and structure.

METHODS

Watershed scale studies were conducted on the effects of prescribed fire on nutrient and carbon cycling, water quality, and vegetation dynamics (regeneration, compositional changes, mortality, and diversity) in multiple forest communities and among fire types (ignition source, intensity, and severity) in the southern Appalachian region (34°N, 84°W). The fire types included: stand-replacement fires (fell-and-burn prescriptions and simulated wildfire); low-to-moderate intensity, understory fire prescriptions; and a wildfire in an old-growth deciduous forest (Table 1). The ecosystems studied were xeric, low productivity pitch pine (*Pinus rigida*)/hardwood forests; dry, moderate productivity shortleaf (*P. echinata*)/Virginia pine (*P. virginiana*)/oak forests; and mesic, high productivity, mixed/hardwood (*Liriodendron tulipifera*/*Quercus rubra*) forests.

Table 1. Brief site descriptions of prescribed fire studies in the southern Appalachians.

Site/study name	Fire Rx	Community	Burn	Timing	Area (ha)
Jacobs Branch (Knoepp & Swank 1993)	Stand replacement/ Fell and burn	Mid-elevation pine/hardwood	High intensity, moderate severity	September, 1990	6
Wine Spring (Vose et al. 1999)	Simulated wildfire	High elevation pine/hardwood	Moderate intensity, low severity	April, 1995	82
Joyce Kilmer (Clinton et al. 2003)	Wildfire	High-elevation, old-growth	Low-to moderate intensity, low severity	November, 1999	2400
Hickory Branch (Clinton et al. 2003	Stand replacement	Mid-elevation, pine/hardwood	Moderate intensity	March, 1999	365
Conasauga (Elliott & Vose 2005)	Understory	Low elevation, pine/hardwood	Low-to-moderate intensity, low severity	March, 2001	15
Mulberry (Elliott et al. 2004)	Understory	Low elevation, mesic hardwoods	Low-to-moderate intensity, low severity	March, 2000	10
Robin Branch Alarka Laurel (Vose et al. 2005)	Understory	High elevation, mesic hardwoods	Low intensity, low severity	March, 2001	~100
Uwharrie (Vose et al. 2005)	Understory	Piedmont; pine/hardwoods	Moderate intensity, low severity	March, 2003	240
Croatan	Understory	Coastal Plain; longleaf pine	Moderate intensity, low severity	January, 2005	160

Similar methods were used in the prescribed fire studies listed in Table 1. All vascular plants were measured in permanent plots using a nested plot design (trees 200 m^2, shrubs 25 m^2, and herbaceous layer 4 x 1.0 m^2) before and after the burn treatments. Vegetation was measured by layer: the overstory layer included all trees ≥5.0-cm diameter at breast height (DBH, 1.37 m above ground); the understory layer included all woody stems <5.0-cm DBH and ≥0.5 m height; the herb-layer included a percent cover estimate for woody stems <0.5-m height and all herbaceous species. In addition, woody stems <0.5-m height were be counted in each 5.0-m x 5.0-m subplot. Aboveground woody biomass was estimated on all permanent plots from measured-dbh using allometric equations developed by others for woody species in the southern Appalachians. Downed wood volume (large wood >7.6 cm diameter) was estimated by measuring total length and circumference, then volume was converted to mass using specific gravity estimates base on wood samples taken from each measured log (Vose and Swank 1993). Forest floor components were sampled using a 0.3 x 0.3 m wooden frame, material extracted from within the frame was separated into three components: small wood <7.6 cm diameter, litter (Oi), and a combined fermentation and humus component (Oe+Oa).

Soil solution was sampled by placing porous-cup lysimeters near the riparian zone of burn and control sites. Lysimeters were sampled weekly before and after treatment, and soil solution analyzed for total N, P, and C, and inorganic N, PO_4, and pH. The effects of fire treatments on stream solute concentrations were assessed by collecting pre-treatment and post-treatment grab samples on sections of the stream influenced by the burn and unburned stream sections (i.e., reference locations upstream of the burned area). Nutrient and carbon content of soil, soil water, stream water, forest floor, and vegetation samples were analyzed using protocols and methods developed at the Coweeta Hydrologic Laboratory (Deal et al. 1996).

RESULTS AND DISCUSSION

With prescribed burning in the southern Appalachians, the forest floor humus layer remains largely intact, which mitigates surface erosion and off-site deposition of sediment and nutrients (Vose et al. 2005, Elliott and Vose 2005). For the simulated wildfire in the pine/hardwoods, stream nitrate (NO_3-N) did not increase, most likely because the unburned riparian zone served to buffer fire effects (Vose et al. 1999). The fell-and-burn treatment in pine/hardwoods showed a significant elevated stream NO_3-N response (0.075 mg L^{-1}) for 30 weeks (Knoepp et al. 1993). No significant response in stream NO_3-N was found following low-severity fire in dry, shortleaf pine forests (Elliott and Vose 2005) or mesic, mixed/hardwoods forests (Clinton et al. 2003). Vose et al. (2005) compared the effects of low severity prescribed fire in Piedmont and southern Appalachian mountain streams. In streamwater, measured NO_3^--N was extremely low (<0.1 mg NO_3^--N L^{-1}) before and after burning. Both sites were burned in early spring and fires were confined to the understory and forest floor. There was generally no overstory mortality to prevent the rapid vegetation N uptake and immobilization of soil nutrients typical of the spring growth flush. Fires were of low enough intensity to prevent significant overland flow and movement of nutrients off-site via physical changes in hydrologic processes.

In general, vegetation is responsive to prescribed fire in the southern Appalachians, but the magnitude of response depends on numerous factors (e.g., timing, fuel load, topography, and fire characteristics). After stand replacement fires in pine/hardwoods, vegetation composition and diversity were altered with more deciduous species and less evergreen shrub cover; and ground flora diversity and cover were significantly higher (Elliott et al. 1999; Clinton and Vose 2000). In contrast, after low-severity, understory fires in pine/hardwoods, no significant change in overstory, midstory, or ground flora species diversity was recorded. The vegetation layer most responsive to dormant season, prescribed fire is the understory and small size class trees. Even for low intensity fires in mesic forests mortality of small woody stems does occur (Figure 1); and rapid recruitment from spouting stems can alter species composition (Figure 2) (Elliott et al. 2004; Elliott and Vose 2005). In low-to-moderate intensity fire, species richness and diversity of the herbaceous layer were not affected; however, abundance (i.e., percent cover, density, or biomass) can increase due to a short term pulse of available nutrients, primarily nitrogen.

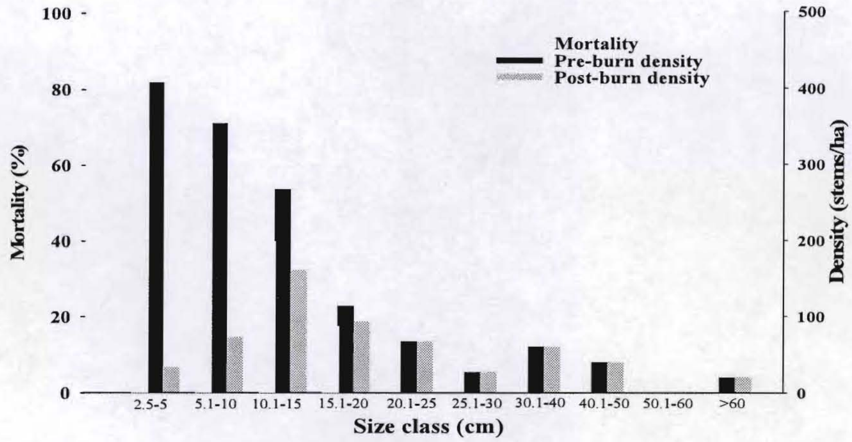

Figure 1. Overstory percent mortality and pre-burn and post-burn stem density from a low-intensity, dormant season fire (taken from Elliott et al. 2004).

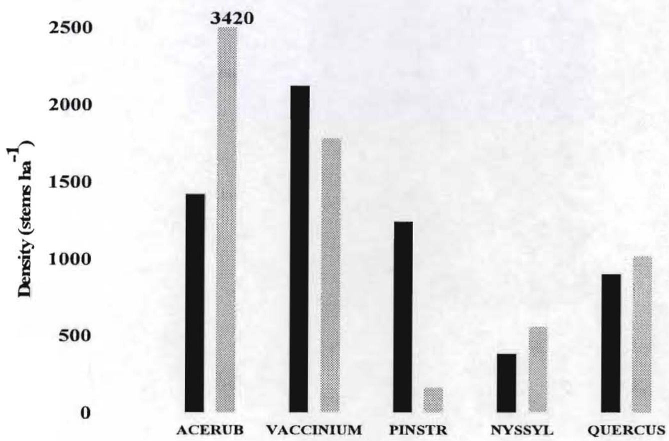

Figure 2. Mean density of abundant midstory species before and 2 years after understory, prescribed fire in dry forest communities in the Conasauga River Watershed (adapted from Elliott and Vose 2005). Species codes: ACERUB = Acer rubrum; VACCINIUM = Vaccinium arboretum, Vaccinium corymbosum, and Vaccinium vacillans; PINSTR = Pinus strobus; NYSSYL = Nyssa sylvatica; and QUERCUS = Q. alba, Q. coccinea, Q. velutina, Q. rubra, Q. prinus.

SUMMARY AND CONCLUSIONS

Prescribed fires in the southern Appalachians can be successful in reducing undesirable midstory species such as *P. strobus* and evergreen shrubs, with little to no affect on sediment and nutrient transport to streams. Maintaining an intact forest floor and promoting rapid vegetation recovery is critical to minimizing the magnitude and duration of sediment transport (surface erosion), sediment delivery (suspended solids) and subsequent water quality responses.

Fire managers can influence the effects of prescribed fire on water quality and other ecosystem properties (e.g., soil nutrient loss, vegetation recovery) by limiting fire severity, limiting fire size, and avoiding burning on steep slopes. Understanding the effects of fire on southern Appalachian ecosystems is complex, because of the long period of fire exclusion and variation in and among ecosystems in terms of community composition and structure, fuel quality and quantity, climate, soil properties, and topography. If additional fire treatments or a combination of treatments are considered such as altering season, intensity and frequency of burns; thinning overstory trees and midstory shrubs followed by fire; and planting desirable species, then watershed scale research will be required to evaluate the impacts on ecosystem resources.

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