The Role of Fire in Shaping the Structure and Function of Forest Ecosystems in the Southern Appalachians

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Abstract

Forest ecosystems in the southern Appalachians are the consequence of a long history of natural and human disturbances. Fire regimes have progressed from a long period of low intensity native American burning, a short period of intense fires for land clearing and post-logging after European settlement, a century of fire exclusion and reforestation of abandoned agricultural land, and contemporary land management activities that include prescribed burning. The structure and function of current day forests – increases in fire intolerant species, decreases in fire tolerant species, increased susceptibility to insect outbreaks – suggest that fire exclusion may have had an important role in initiating the successional trajectory. Land managers need tools to create, enhance, and maintain desired ecosystem conditions such as healthy and sustainable forests. Studies in the southern Appalachians indicate that these ecosystems have maintained characteristics of resistance and resiliency that promote positive responses to prescribed burning. For example, low intensity and severity fires generally have had a positive effect on plant diversity and nutrient availability, and no negative effects on water quality. Impacts on overstory species composition will require a long-term perspective; however, it is likely that aggressive treatments such as repeated burns, perhaps in combination with selective thinning and planting, will be required to alter the current successional trajectory.

Introduction

The contemporary structure and function of southern Appalachian ecosystem represents the cumulative influences of centuries of disturbances of varying intensity, frequency, and spatial extent. Prior to European settlement, native Americans used a variety of techniques to manipulate the landscape to improve hunting, gathering, and farming (Yarnell 1998). Historical accounts of the region suggest that fire was one of the techniques used to open the forests for hunting and encourage growth of desirable understory species for food and medicinal purposes (Van Lear and Waldrop 1989). Frequent fires would encourage the creation and maintenance of ecosystems (species, pools, and processes) that tolerate or require fire. For example, early descriptions of pine/hardwood communities suggest that many were maintained in open pine-hardwood-grass savannahs with frequent fire (DeVivo 1971). Further and even more significant disturbances occurred with European settlement in the late 1800's and early 1900's, including widespread logging, land clearing, mining, and large-scale fire (Yarnell 1998). Although the disturbance regime of early settlers was short-lived (i.e., ~50 years of intensive land use change), the severity and spatial extent had a major influence on current day forests. In the 20^{th} century, regional-scale changes in the species composition across Appalachian forests have resulted from the combined effects of reforestation of abandoned agricultural land, effective fire suppression (Brose et al. 2001), and the loss of American chestnut. On many sites, the reduction in fire frequency and loss of a major canopy species has been advanced as the primary factor facilitating the invasion of shade-tolerant and fire-intolerant hardwoods (e.g., red maple (*Acer rubrum*), sourwood (*Oxydendrum arboreum*), blackgum (*Nyssa sylvatica*)) and white pine to the overstory (Elliott et al. 1999; Elliott and Vose, in review). Further changes in vegetation composition are demonstrated by poor oak and yellow pine regeneration, and an increased reproduction of fire-sensitive species, especially red maple and blackgum (Elliott et al. 1999). Ericaceous species, *Rhododendron maximum* and *Kalmia latifolia*, have also expanded their range (Dobbs 1998), both species currently occupying mid-slope positions where prior to fire suppression *R. maximum* was more restricted to areas immediately adjacent to stream channels and *K. latifolia* was more restricted to xeric ridges. These impenetrable thickets of ericaceous species now often dominate midstories and understories and prevent desirable pine and oak regeneration from becoming established. Research suggests that management intervention will be required to alter the trajectory of forest development in the absence of fire (Smith 1991) or other disturbances that favor fire-tolerant species.

Prescribed Fire in the Southern Appalachians

In the southern Appalachians, prescribed fire has primarily been used as a tool to reduce fuel loads, and secondarily to restore ecosystem structure and function. One of the challenges for land managers is determine how (i.e., when, where, how, how often?) to return fire to these ecosystems after (1) nearly a decade of exclusion, (2) the more recent southern pine beetle (SPB) mortality enhanced fuel loads in pine/hardwood stands, and (3) increased wildland-urban interface conflicts due to rapid population growth in the region. For example, higher fuel loads due to long periods of fire exclusion and SPB related overstory mortality have the potential to increase fire intensity and severity beyond those observed under more frequent burning regimes. At the extremes, fires of high intensity and severity can have a greater effect on ecosystem structure and function than clear-cutting or other intensive management practices (Vose and Swank 1993, Vose 2000). With the increased use of fire for silvicultural (fuel reduction and site preparation) and ecological (ecosystem restoration) objectives on public and private land, managers need to understand both short- and long-term effects on the whole system and consider the role of fire in ecosystem health and sustainability. In the last decade, impacts of prescribed burning in pine/hardwood and mixed hardwood stands in the southern Appalachians have been investigated with long-term (ongoing), multi-investigator, ecosystem approaches (Swift et al. 1993, Vose et al. 1994, 1997, 1999, Elliott et al. 1999, Vose 2000). These studies have examined several burn prescriptions; fell and burn in pine/hardwood stands, restoration burning of degraded pine/hardwood stands, and understory burning in mixed hardwood stands.

Effects on Ecosystem Structure and Function

To understand the impacts of prescribed fire on ecosystem structure and function, we have focused on quantifying fire effects on species composition and size class distribution (i.e., "structure") and nutrient cycling processes (i.e., "function"). A clear pattern that emerges from these studies is the role of fire intensity severity and timing in regulating ecosystem responses (Clinton et al. 1998). For example, the most severe fires result from felling the vegetation prior to burning. One of the objectives of the "fell and burn" treatment is to reduce logging slash to facilitate planting and reduce competition from mountain laurel. Felled vegetation is allowed to cure for several months prior to burning to increase fire intensity and biomass consumption. A consequence of these large reductions in fuel load is a corresponding large loss of total site nitrogen (N) pools. In studies examining total ecosystem N losses, the fell and burn treatments lost from 190 to 480 kg ha^{-1} and averaged ~300 kg ha^{-1} (Vose and Swank 1993). By comparison, prescribed fires in stands that have not been "felled" prior to burning have considerably less N loss. For example, in a pine/hardwood restoration burn, total ecosystem N losses were < 100 kg ha^{-1} (Vose et al. 1999). In both cases, fires increased understory diversity (Clinton et al. 1993, Elliott et al. 1999) and provided short-term increases in nutrient availability (Knoepp and Swank 1993); however, quantifying effects on overstory species composition and structure will require longer term measurements. In terms of water quality, we have found very little impact on either stream N or sediment (Clinton et al. 2003, Elliott and Vose, in review). Patterns of stream N loss suggest that responses are minimal and short-term. This is especially true when burns are conducted in the spring just prior leaf expansion and where unburned riparian zones buffer the movement of sediment and nutrients to streams.

Recommendations and Conclusions

The reintroduction of fire into southern Appalachian ecosystems must be done with a clear vision of desired future conditions and with an understanding of the historical disturbance regimes that have shaped contemporary ecosystem structure and function. Expansion of fire-intolerant species, decreases in fire-tolerant species, and increased susceptibility to insects and disease (i.e., southern pine beetle) are clear indicators of changes in ecosystem structure and function due to altered disturbance regimes. Land managers need tools to enhance, restore, and maintain forests that are healthy and sustainable. Due to the historical importance of fire in shaping southern Appalachian ecosystems, prescribed fire could (and perhaps, should) be one of those management tools. Results from ecosystem studies suggest that southern Appalachian ecosystems retain many characteristics of resilience and resistance to fire. Even after nearly a century of fire exclusion, prescribed fires in degraded stands (excluding those that have been fell and burned) result in very little ecosystem nutrient loss or increased erosion. In our studies, fires have had many positive benefits such as increased short-term nutrient availability (Knoepp and Swank 1993) and increased understory diversity. Long-term effects on overstory stand structure are difficult to predict; however it is unlikely that a single fire will be sufficient to alter the current course of stand development. Instead, these forest ecosystems may require multiple burns – perhaps in conjunction with other management activities such as thinning or planting desired species – to alter the current successional pathway in a meaningful way.

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