INFLUENCE OF FIRE ON MAMMALS IN EASTERN OAK FORESTS

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Abstract.—With the exception of small mammals, little research has been conducted in eastern oak forests on the influence of fire on mammals. Several studies have documented little or no change in relative abundance or community measures for non-volant small mammals in eastern oak (*Quercus* spp.) forests following fires despite reductions in leaf litter, small woody debris, and changes in understory and midstory composition and structure. Other studies have documented short-term improvements in quantity and quality of forage for white-tailed deer (*Odocoileus virginianus*), but none has demonstrated changes in population parameters. For other mammal species there are no explicit studies and influences must be based on inferences from other research. We suggest that species that prefer partially open canopies, herbaceous understories, reduced midstories, or savannah habitats likely will prosper in the presence of fire. Fire has the potential to both recruit as well as eliminate den sites and cavity trees; burning regimes and fire intensity likely will determine outcomes. Species of high conservation concern, such as the Indiana bat (*Myotis sodalis*) and some subspecies of fox squirrels (*Sciurus niger*), should benefit from increased fire in these landscapes. An insidious consequence of continued preclusion of fire in oak systems is the loss of structure and the change in vegetative species composition to more fire-intolerant species.

INTRODUCTION

Fire has long been recognized as an important ecological driver and disturbance agent that shapes and maintains oak-dominated forest communities of eastern North America (Delcourt and Delcourt 1998; Frost 1998; Van Lear and Harlow 2002). Unlike other hardwood forest types, such as northern hardwoods and bottomland hardwoods, many oak-dominated types have relatively short fire return intervals (4 to 30 years) over most of the region (Frost 1998). A number of researchers have focused on concerns specifically related to the sustainability of oak forests (Clark 1993; Kellison 1993; Keyser et al. 1996; Brose et al. 1999; Brose et al. 2001), including those of the central hardwoods region (Van Lear et al. 2000; Sutherland and Hutchinson 2002).

Despite a number of studies on the effects of fire on wildlife in the Coastal Plain of the Southeastern United States, little work has been done on this subject in oak-dominated forests (Brennan et al. 1998; Lanham et al. 2002; Keyser et al. 2004), particularly as it relates to mammals (Keyser et al. 2001). Only several experiments have examined the response of non-volant small mammals, typically relative abundance and species richness at the stand level or smaller, to fire in the Eastern United States (Masters et al. 1998; Ford et al. 1999; Keyser et al. 2001; Kilpatrick et al. 2004). Incidental impacts of fire have been reported as well (Kirkland et al. 1996). Studies of economically important game species such as white-tailed deer (*Odocoileus virginianus*) have largely been confined to assessment of forage quality, availability, and use (Hallisey and Wood 1976; Wentworth 1986; Masters et al. 1993). Despite their high conservation status, fire impacts on nongame groups such as bats or charismatic mega-fauna such as black bears (*Ursus americanus*) have been examined only in conceptual, hypothetical approaches (Hamilton 1981; Carter et al. 2002). In this paper we review the literature relevant to fire effects on mammals in eastern oak forests. Our purpose is to draw meaningful inferences for species and species groups based on documented effects of prescribed fire or wildfire on habitat structure, and to discuss potential research directions to address current knowledge gaps. Fire or the lack thereof will continue to influence eastern oak forests and, in turn, the wildlife communities that depend on those forests for habitat (Kellison 1993; Brennan et al 1998). Accordingly, it is incumbent upon the natural resources community to work toward managing those outcomes to the benefit of sustainable wildlife populations.

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NON-VOLANT SMALL MAMMALS

Despite the paucity of data on fire impacts on most mammals in eastern oak forests of North America, non-volant small mammals have been perhaps the best studied due to their abundance, diverse assemblages, and ease of capture. In coniferous forests of Western North America and along the mixedwood-boreal transition zone where natural stand-replacing fires and intense site-preparation burns are more common, impacts of fire on non-volant small mammals can be significant via direct mortality (Tevis 1956) and through habitat modifications that alter and shape species assemblages (Crete et al. 1995; Sullivan and Boateng 1996; Monroe et al. 2004). Nonetheless, Crete et al. (1995) noted that a mosaic of stand seres created by landscape-level fires added to overall wildlife diversity, including that of non-volant small mammals.

In eastern oak forests, both natural and prescribed fires typically are of relative low intensity, are rarely stand replacing (Komarek 1974), and display site variability (Ford et al. 1999) at scales matching inherent variability of small mammal populations (Bowman et al. 2000). Consequently, negative impacts are not suspected in most cases. Orrock et al. (2000) noted that in some Appalachian habitats, small mammal species such as the southern red-backed vole (*Clethrionomys gapperi*) are specialized for mesic forest conditions and could be more fragmented and isolated by disturbance events. Results from both prescribed burning in the southern Appalachians of North Carolina (Ford et al. 1999) and a wildfire in the central Appalachians of Pennsylvania (Kirkland et al. 1996) suggest that small mammal abundance and species assemblages are not changed substantially by fire. Ford et al. (1999) noted that the abundance and assemblage patterns that existed prior to spring-burning persisted following burning with mesic-forest adapted species such as southern red-backed voles, smokey shrews (*Sorex fumeus*), and masked shrews (*S. cinereus*) more common in riparian areas and areas with abundant coarse woody debris in both burned and control stands. Moreover, data from Keyser et al. (2001) in central Virginia documented that the season of burn had little effect on non-volant small mammals with shrews (*Sorex longirostris, S. hoyi,* and *Blarina carolinensis*) and white-footed mice (*Peromyscus leucopus*) numbers not significantly different among oak shelterwood stands burned in the winter, spring, or summer, and unburned controls.

It is plausible that non-volant small mammals could be affected positively or negatively by fire in number of ways other than direct mortality. For example, on the Cumberland Plateau of Kentucky, prescribed fire in mixed mesophytic forests reduced the mass of soil invertebrates by approximately 35 percent (Kalisz and Powell 2000), which, in theory, could reduce available prey for Soricids. Conversely, Ahlgren (1966) observed that deer mice (*Peromyscus maniculatus*) responded positively to prescribed burning in Minnesota in part because fire consumption of the leaf litter and duff greatly increased seed exposure and, therefore, availability. Similar to forest floor structural changes observed in more intensive western fires, heavy reductions in leaf litter and downed coarse woody debris could negatively impact many non-volant small mammals in eastern oak forests. However, Kirkland et al. (1996) and Ford et al. (1999) observed virtually no change in coarse woody debris abundance following the low- to medium-intensity fires they studied. Additionally, substantial reductions in coarse woody debris following more intense fires in the region typically will be offset by overstory mortality and contributions to the future coarse woody debris pool (Regelbruggae and Smith 1994). Generally, though, data applicable to eastern oak forests are consistent with the findings of Kirkland et al. (1996) and Ford et al (1999) that ground-level vegetation change after one growing season following fire was less important than topo-edaphic factors of slope and aspect (Wentworth 1986, Hutchinson et al. 2005). Prescribed fire in eastern oak forests can be effective in reducing woody midstory stem density (Brose et al. 2001), creating structural conditions that do benefit both southern flying squirrels (*Glaucomys volans*; Bendel and Gates 1987) and fox squirrels (*Sciurus niger*; Edwards et al. 2003).

Although wholly unknown, behavioral changes in small mammals during or following fire might cause an increase in vulnerability to predation. Rowan et al. (2005) radio-tracked eastern chipmunks (*Tamias* *striatus*) following early spring fires in West Virginia on both burned and control plots. Despite fire intensities sufficient to consume most leaf litter, interrupt or modify the initial emergent patterns of herbaceous flora, and expose acorn caches, no difference was noted in mean home range size and habitat use between animals in the burned or control plots. Of the individuals captured and tagged within burned stands, none were observed leaving the burned areas or using adjacent unburned forest habitat that was in many cases less than 150 m away (Rowan et al. 2005). Home range overlap among conspecifics did not differ between burned and control plots, further suggesting minimal impact to eastern chipmunks.

BATS

Carter et al. (2002) provideed the most complete review of the relationship between fire and bats in eastern oak forests. Depending on the fire severity and fire susceptibility of tree species present, fire in eastern oak forest can both produce as well as consume standing snags that could be used as day-roosts by several bats species in the region (Starker 1934; Wendell and Smith 1986; Moorman et al. 1999a,b; Abrams 2000). The endangered Indiana bat (*Myotis sodalis*) and the northern bat (*M. septentrionalis*) predominately use snags as day-roosts from spring through early fall (Menzel et al. 2001; Owen et al. 2002). Whereas little brown bats do roost in snags (Fenton and Barclay 1980), that species' use is far less due in part to the availability of human structures as well as the overall change in forest condition, i.e., fewer large cavity trees and standing snags than in pre-settlement forests (Whitaker and Hamilton 1998). Although bats could be subject to direct mortality from the combustion of an occupied day-roost, especially one containing non-volant young in a maternity roost, most bats are capable of escaping a snag in advance of its consumption by fire. For bats that day-roost in foliage of live trees, e.g., hoary bats (*Lasiurus cinereus*) and eastern red bats (*L. borealis*), direct impacts probably result from temporary disturbance and displacement due to smoke (Rodrigue et al. 2001). Nonetheless, as nonhibernating migratory species, eastern red bats have been observed day-roosting in leaf and pine needle litter in upland pine-hardwood forests of South Carolina and Arkansas where they were disturbed as winter burning occurred (Saugey et al. 1998; Moorman et al. 1999a,b). It is possible that eastern red bats might be unable to flee advancing fire if in a state of torpor while ground-roosting.

Realistically, however, species that depend on snags probably benefit from a net addition of snags in burned stands in a region where it is believed that snag abundance is below that needed for many wildlife species (Carey 1983). For example, Wentworth (1986) noted that midstory tree mortality was pronounced on variable winter burns in the southern Appalachians, conditions that likely produce a net gain of day-roosts highly suitable for northern bats (Owen et al. 2002). Still, there are virtually no data on the net gain or loss or longevity and useful to bats of larger snags following fire in eastern oak forests. Lastly, Carter et al. (2002) noted that bats wintering in caves and mines might be subject to negative impacts from smoke in areas where air-flow into caves or mines occurs. However, few instances of this have been documented and none with recorded bat mortalities (D. Krusac, USDA Forest Service, pers. commun.).

Relative to all other mammalian taxa in the eastern oak forest, knowledge gaps in Indiana bat habitat management in conjunction with fire probably are the most critical to address. Maternity roost habitat of Indiana bats often is characterized by stands with numerous snags and relatively low overstory canopy cover (Kurta 2004), indicative of conditions following flood events in bottomland forest habitats in the Midwest (Carter and Feldhamer 2005) or following moderate to severe fires in upland habitats in the Appalachians (Beverly and Gumbert 2004). Although less demanding of particular thermal conditions (i.e., warm temperatures and direct solar radiation) helpful for the growth and development of juvenile bats, male Indiana bats also readily use day-roosts in snags created following prescribed burning on the Cumberland Plateau of Kentucky (J. MacGregor, Kentucky Wildlife and Fisheries Resources Commission, pers. commun.). Similarly, we have documented two male Indiana bats day-roosting in burned forest habitats in the Allegheny Mountains of West Virginia where diameter-limit harvests followed by early spring wildfire produced open conditions (20 to 50 percent canopy cover) and copious small to medium snags (< 40 cm d.b.h.) with large amounts of exfoliating bark. At that same site, Beverly and Gumbert (2004) described an Indiana bat maternity roost occurring in a small fire-killed red maple (*Acer rubrum*) snag (31 cm d.b.h.). This roost occurred at an elevation of 917 m where conditions were considered too cool during the growing season to support maternity activity (Brack et al. 2002). Because that roost was near a known winter hibernacula (< 1,000 m) and several male roosts in fire-killed sugar maple (*A. saccharum*) and red maple (unpublished), it has been hypothesized that Indiana bats in the Appalachians probably formed transitory maternity roosts within a shifting mosaic of habitats that may have followed disturbances such as fire across the landscape (T. Carter, Southern Illinois University, pers. commun.).

Fire effects on the structure of bat foraging habitat and fire impacts to bat prey resources are largely unknown (Carter et al. 2002). Menzel et al. (2005) and Ford et al. (2005) both hypothesized that forest management activities that decreased stem density and or created canopy gaps and openings would benefit several bat species in the east that are adapted to foraging in less cluttered conditions, e.g., big brown bat (*Eptesicus fuscus*) and hoary bat. If they are correct, prescribed fire could be a useful tool for enhancing foraging habitat for both species by creating a more complex canopy structure through mortality of individual canopy stems.

WHITE-TAILED DEER

Stransky and Harlow (1981) provided a thorough review of the literature regarding deer habitat and fire. Because there were few studies at that time directly examining deer and fire relationships, theirs was a thorough review of work on forage, including that for livestock, and fire effects on vegetation in order to draw inferences relating to the likely effect of fire on deer habitat. Stransky and Harlow concluded that winter burns increased forage crude protein and phosphorous (P) content; increased the number of woody plant stems; increased the coverage of grasses, forbs, and legumes; and reduced soft mast production. Most of these effects were short term (1 to 3 years). Infrequent growing season burns had similar effects except that woody stems were reduced. However, frequent summer burns would eventually eliminate woody stems and lead to domination of the site by grasses and fire-adapted forbs. These structural changes were established empirically for pine forest systems by the long-term (43 years) experiment conducted by Waldrop et al. (1992).

Wood (1988) and Wentworth (1986) each documented limited responses of vegetation to burning, albeit generally consistent with the foregoing summary of Stransky and Harlow (1981). Both studies were conducted in closed-canopy mature forests. Hurst et al. (1980) and Masters et al. (1993) conducted experiments in which they documented three- and sevenfold increases in forage production. The opening of canopies in both studies was critical to these responses with fire modifying plant communities released by canopy disturbance. Working in a scrub oak community in the Appalachians, Hallisey and Wood (1976) found that crude protein, P, and amount of forage generally were increased by fire. In another experiment, Brennan et al. (1998) precluded fire from a previously burned stand and reported a dramatic decrease in herbaceous cover largely due to encroachment by fire-intolerant woody vegetation. With the exception of Wentworth's (1986) and Hallisey and Wood's (1976) studies, all of the work cited was conducted in pine or pine-hardwood systems.

Two studies (Hobbs and Spowart 1984 and Main and Richardson 2002), neither conducted in eastern hardwoods, empirically documented behavioral changes (habitat use and foraging, respectively) of ungulates in response to fire. Main and Richardson (2002) deployed infrared triggered cameras in areas that had been burned 6, 24, and 48 months previously to document use by white-tailed deer. They reported differences between the 48- and 24-month postburn sites as well as between the 48- and 6-month postburn sites, with use by deer 3 to 4 times greater in the more recently burned sites. They concluded that deer were attracted to the availability of better forage in the more recently burned areas. Hobbs and Spowart (1984) reported only modest improvements in site-level forage quality, but substantial improvements to actual diets of both mountain sheep (*Ovis canadensis*) and mule deer (*Odocoileus hemionus*) on burned versus unburned sites in Colorado. They determined that due to selective foraging, these ruminants were able to increase both CP and in vitro digestible organic matter by 100 to 400 percent. They contend that studies that look only at plant responses underestimate the impact of burns on overall diet quality.

From the foregoing discussion it seems clear that where some canopy disturbance is present, fire alters forage quality and quantity, deer behavior, and likely deer diets. Unfortunately, no study has linked any population parameter to fire in a conclusive manner. Johnson et al. (1992) documented subtle, short-term improvements in white-tailed deer body mass and condition after a single large (18,200 ha) wildfire in the Coastal Plain of North Carolina. However, cause-and-effect data for fecundity, growth, and survival for deer on burned habitats are lacking. Given the degree to which white-tailed deer herds exceed cultural carrying capacity (society's tolerance threshold for a species) despite being below biological carrying capacity throughout much of this region (Keyser et al., in press), would suggest that ample nutrition is available to support large and healthy populations in the absence of fire-enhanced habitats.

An insidious impact of fire suppression on deer habitat in the region is the possible loss of oak mast through a marked reduction of the oak component in these forests. Mast is an important and preferred food source for deer (Harlow and Hooper 1972; Osborne et al. 1992; Wentworth et al. 1992), one that is widespread and often available in association with excellent cover. It is difficult to predict the impact of a large-scale loss of this resource on regional deer populations, but it is potentially profound. This would be especially true in landscapes that are heavily forested and lack agronomic forages that could easily offset the loss of high energy and highly palatable forage provided by acorns.

OTHER SPECIES

As is the case with deer, small mammals, and bat communities, little work has been done on fire effects on other mammal species that are associated with eastern oak forests. Both Hamilton (1981) and Weaver (2000) discussed fire influences on black bear but were confined to inferring effects on habitat because of a lack of published data. They concluded that periodic use of fire could be positive in terms of enhancing soft mast production and maintaining herbaceous plant communities. Fire can be important in both the formation and destruction of den trees, though we are unaware of any work that documents optimum regimes for recruitment and/or maintenance of cavity trees in such areas. In the Appalachians, bears frequently rely on accumulations of large woody debris for ground dens (Quince 2002), which also can be eliminated by fire. Thus, fire can have both positive and negative effects on availability of dens. Where fires provide broken canopies and more diverse midstory and understory development, particularly as it relates to soft mast and herbaceous vegetation, fire likely would result in positive changes in habitat quality. On the other hand, to the extent that fire negatively affects mast production, it may negatively effect habitat quality. We do not believe that fires intense or frequent enough to induce such changes are likely to be the norm in most eastern oak systems.

Much of the foregoing discussion about black bear denning habitat likely is applicable to raccoons (*Procyon lotor*). Owen (2003) documented use of both ground dens and tree cavities by raccoons in the central Appalachians, though maternity dens were almost exclusively in tree cavities. Thus, burning frequencies and intensities that maintain adequate snags appear to be important for this species. Although conducted in the Coastal Plain, Jones et al. (2004) documented a reduction in use of forests burned the previous year versus unburned stands by raccoons. It is difficult to infer how this might apply to upland hardwood systems. As with black bears, fire effects that enhance soft or hard mast production likely would increase raccoon use (Owen 2003).

We are aware of no literature that deals specifically with responses of gray (*Sciurus carolinensis*) or fox squirrels to fire, a circumstance that has not changed since Kirkpatrick and Mosby (1981) reviewed the literature. Although we are in agreement with them that fire is unlikely to positively affect gray squirrel habitat, it may have important implications for conservation of rare or threatened subspecies of fox squirrels. Fox squirrels prefer more open stand structure and greater understory development (Edwards et al. 2003), conditions that could be created through prescribed burning.

Elk (*Cervus elaphus*) may benefit from the increased use of fire in eastern forests due to their preference for herbaceous understories. Masters et al. (1997) reported increased use of burned areas by elk in a pine hardwood system in the Ouachita Mountains where herbaceous cover had been developed by repeated fires. Elk rely on a wide variety of forages, but grasses and forbs dominate elk diets on a year-round basis and in most habitats (Boyd 1978). Most elk restoration efforts in the Eastern United States focus on release sites with adequate herbaceous habitats (McClafferty and Parkhurst 2001). As interest in restoration of elk increases in eastern states and as elk populations expand in Pennsylvania, Kentucky, North Carolina, and Tennessee, managers should consider the role of fire in developing oak savannah habitats.

SUMMARY AND CONCLUSIONS

The state of our current understanding of fire effects on mammals in the oak forests of Eastern North America remains largely based on inference from work conducted in other regions or on indirect effects of fire on various habitat components. On the basis of these studies, it is apparent that fire can have a beneficial impact on habitat quality for a number of species of mammals. Were fire to be applied on a broad enough scale, these habitat enhancements could reasonably be expected to have a positive effect on population parameters as well. It is unclear in today's social and political climate that land managers will apply fire at such a scale. Conversely, it could be expected that on a localized scale fire could have a significant impact on local populations of mammals, either behaviorally or numerically. Thus, individual landowners or managers interested in enhancing habitat for deer could use prescribed fire as a tool.

However, the continued exclusion of fire from most landscapes in eastern oak forests may have serious implications for the continued presence of oaks as a major component of regional forests. It is this scenario that likely will have broader impacts on mammalian communities of the region going forward. Current trends in forest communities suggest that oaks will be a diminishing part of our future forests. Such a change could have a deleterious effect on numerous species of wildlife.

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