DO FIRE AND INSECTS INTERACT IN EASTERN FORESTS?

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Abstract.—The increasing use of prescribed fire as a management strategy for manipulating forest-species composition generates questions regarding the effects on the arthropod community and the underlying processes in which arthropods play a dominant role, as well as its potential as a pest suppression strategy. Despite the apparent benefits of prescribed burning for manipulating stand composition and enhancing tree vigor, relatively little is known about how fire interacts with arthropod-dependent processes in eastern forest ecosystems. This paper reviews the evidence of direct and indirect interactions between forest arthropods and fire, and addresses the following questions: 1) are soil- and litter-dwelling arthropods irreparably harmed by burning? 2) does prescription burning alter plant susceptibility to insect herbivores? 3) can fire be used as a management strategy to suppress forest arthropod pests?

Although soil- and litter-dwelling arthropod abundance is affected by prescribed burning, arthropod diversity and richness are not. Litter arthropod evenness increases in response to burning, most likely due to reductions in mites and collembolans, the two dominant taxa. Fire-induced changes in foliar chemistry often are transient and may be species-specific. These changes are not fully predictable but could alter patterns of insect herbivory. Use of prescribed fire for pest suppression in managed forests has lagged behind that of other managed systems, and it has had limited use for pest suppression in deciduous forests of the Eastern United States. The highly clustered spatial distribution of acorn predators makes effective suppression through prescription burning problematic.

INTRODUCTION

Prescribed fire is increasingly used as an intermittent disturbance agent to mimic pre-settlement disturbance regimes. This management strategy is designed to encourage regeneration and stand development (Lorimer 1993). Prescribed fire combusts the leaf litter and can reduce total microbial and fungal biomass (Fritze et al. 1994). Burning can lead to increased soil pH and greater fluctuations in temperature and moisture, with subsequent loss of vegetation (Haimi et al. 2000). Burning suppresses vegetative competition and enhances light penetration to the forest floor. In oak-dominated forests of the Eastern United States, fire helps reduce invasive fire-sensitive maples (Arthur et al. 1998), and makes conditions more favorable for development and growth of oak seedlings (Reich et al. 1990; Adams and Rieske 2001). The increasing use of prescribed fire as a management strategy for manipulating forest-species composition generates questions regarding the effects on the arthropod community and on the underlying processes in which arthropods play a vital role.

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Insects and related arthropods are essential to forest ecosystem processes. Arthropods dominate forest soils and leaf litter, and play vital roles in litter decomposition, nutrient dynamics, soil development, and soil stability (Wood 1995). Arthropods contribute to decomposition of organic matter and soil development by reducing the size of organic particles, consequently accelerating fungal and bacterial decomposition (Metz and Dindal 1975). Arthropod fungivores also stimulate fungal growth by hyphal grazing, thereby influencing the balance between fungi and bacteria (Hanlon and Anderson 1979).

As herbivores, arthropods also play critical roles in ecosystem processes. Herbivores can function as seed predators, causing extensive, localized loss of regeneration in eastern oak forests (Drooz 1985). Acorn predators such as acorn weevils, sap beetles, and the acorn moth are primary and/or secondary pests (feeding and breeding in intact versus damaged seed), consuming acorn cotyledons and damaging radicles, or directly damaging germinated seedlings (Van Leeuwen 1952; Gibson 1964; Galford and Weiss-Cottrill 1991; Galford et al. 1988, 1995). Acorn predators are closely associated with soil and litter and as such may vector and/or create infection courts for potentially pathogenic microorganisms. Additionally, these arthropods are strongly affected by factors such as stand composition, litter quality and depth, and soil type and depth, which influence their local distribution and impact (Dindal 1990).

Defoliating herbivores alter net primary productivity, increasing nitrogen input and light penetration. Indirectly, defoliators can influence watershed characteristics and, through changes in resource availability, affect wildlife distribution patterns. Herbivore population outbreaks cause widespread mortality that can shift forest-stand composition and influence ecological succession (Drooz 1985). Insect herbivory is one of a suite of disturbance factors that have contributed to the development of today's forests. In addition to herbivore pressure, intermittent disturbances consisting of pathogens, anthropogenic activities, climactic pressures, and fire have influenced the formation and maintenance of forests of Eastern North America (Abrams 1992).

To mimic historic disturbance patterns, fire is being used as a management strategy in eastern deciduous forests. Despite the apparent benefits of prescribed burning, relatively little is known about how fire interacts with arthropod-dependent processes in eastern forest ecosystems. In this paper I review the evidence of direct and indirect interactions between forest arthropods and fire, and addresses the following questions: 1) are soil- and litter-dwelling arthropod populations irreparably harmed by burning? 2) does prescription burning alter plant susceptibility to insect herbivores? 3) can fire be used as a management strategy to suppress forest arthropod pests?

Are soil- and litter-dwelling arthropods irreparably harmed by burning?

Relatively large, highly mobile arthropods are unlikely to be negatively impacted by prescribed fire. Oak savanna arthropod communities in the Upper Midwest were unaffected by burning (Siemann et al. 1997). In central Ohio, prescribed burning had no negative effect on large predatory carabid beetles (Smith and Horn 2000), or on scavenging scarab beetles (Stanton et al. 2000). Similarly, in south-central Kentucky, prescribed fire had little effect on ground-dwelling arthropod abundance, richness, and diversity, but arthropod community evenness increased in response to a single-burn disturbance (Coleman and Rieske, unpublished).

For less mobile arthropods functioning on the forest floor, the direct effects of fire include immediate mortality and habitat destruction. Loss of these faunal groups to fire could potentially disrupt essential ecosystem functions. One year following a prescribed fire in hardwood forests of eastern Kentucky there was a reduction in total dry mass of soil- and litter-dwelling invertebrates (Kalisz and Powell 2000). The loss was attributed primarily to direct mortality of Coleopteran larvae, which serve several critical roles on the forest floor as predators, herbivores, and detritivores (Dindal 1990).

To examine the period of recovery needed to obtain pre-burn levels of arthropods following a prescribed fire regime using single- and multiple-burns, Coleman and Rieske (unpublished) monitored plots for two post-burn growing seasons. Mites (Acari) and springtails (Collembola) dominate at the soil/litter interface, and populations were devastated by both fire regimes. Mite abundance did not recover over the course of the study. Arthropod abundance was affected by the prescribed burns, but arthropod diversity and richness were not. Litter arthropod evenness increased as a consequence of burning, probably due to reductions in the two dominant taxa.

In addition to the direct effects of habitat loss and mortality, burning reduces the available resource base, resulting in bottom-up regulation of soil/ litter community dynamics. Fire also may indirectly affect arthropod communities by changing plant species composition and foliar accessibility (Mitchell 1990), and by altering plant phenology. Changes in flowering phenology could affect insect pollinators, pollination rates, and subsequent seed set, though there are no studies addressing this.

Does prescription burning alter plant susceptibility to insect herbivores?

Fire suppresses vegetative competition and increases soil nutrients (Reich et al. 1990), and enhances seedling vigor (Adams and Rieske 2001), which may reduce the negative effects of herbivory. Fire also may indirectly affect arthropod communities by changing plant-species composition and foliar characteristics. Combustion of the litter layer provides an influx of nutrients to the forest floor, which can influence plant foliar chemistry through changes in nutrient availability and light intensity (Reich et al. 1990; Kruger and Reich 1997; Arthur et al. 1998), potentially altering herbivore feeding patterns (Rieske 2002; Rieske et al. 2002; Adams and Rieske 2003).

Fire-induced changes in foliar chemistry are not fully predictable and may be species-specific. Reich et al. (1990) and Kruger and Reich (1997) found enhanced, though transient, leaf nitrogen levels in northern red oak seedlings. Similarly, chestnut oak seedlings sampled in the post-burn growing season had higher foliar nitrogen and water content following a wildfire than seedlings sampled from unburned sites (Rieske 2002). By contrast, Kruger and Reich (1997) found a transient elevation in red oak seedling foliar carbohydrates following an early spring, low-intensity surface fire, whereas chestnut oak seedlings from burned sites had transient declines in foliar carbohydrates, and higher initial tannin levels (Rieske 2002). Although it is possible that chestnut oak and northern red oak seedlings respond differently to fire with respect to foliar carbon levels, the differences in seedling response may be attributed to the timing and intensity of the fires. Regardless, fire-induced changes may not be detectable, due to the buffering capacity of mature trees (Rieske et al. 2002), spotty fire coverage over irregular terrain, or to the relatively cool nature of some prescribed burns (Adams and Rieske 2003).

To assess the extent to which fire interacts with seedling herbivory, Adams and Rieske (2001) assessed mammalian and arthropod herbivore pressure on white oak seedling growth and vigor in burned forests in Kentucky. They found that herbivory is a measurable force impacting white oak seedlings but that prescribed fire did not affect herbivore pressure. They also found that the mammalian component of the herbivore complex had a greater impact on white oak seedling growth than the arthropod component.

Can fire be used as a management strategy to suppress forest arthropod pests?

Fire has been used extensively in agricultural, prairie, and rangeland ecosystems to manipulate vegetative composition and alter host plant quantity and quality, thereby directly or indirectly manipulating arthropod pest populations (Miller 1979). Successful suppression using fire requires that the pest be spatially and temporally vulnerable to fire-induced mortality (i.e., in the soil at the appropriate time), and that the fire itself does minimal damage to the standing crop of trees. Use of prescribed fire for pest suppression in managed forests has lagged behind that of other managed systems and has focused primarily on boreal forests (Mitchell 1990; Brennan and Hermann 1994; McCullough et al. 1998). The intricate link between fire and bark beetles as episodic disturbance agents in coniferous systems is now widely accepted, and recognition of this relationship gives land managers the opportunity to minimize harmful outcomes of these interactions.

Prescription burning has had limited use as a pest suppression strategy in deciduous forests of the Eastern United States (Brennan and Hermann 1994; McCullough et al. 1998). Historically, forest tracts in Massachusetts were burned to kill overwintering egg masses and clusters of feeding caterpillars as part of early attempts to eradicate the gypsy moth, *Lymantria dispar*, with mixed success (Doane and McManus 1981). More recently, prescribed fire was used to suppress populations of pear thrips, *Taeniothrips inconsequens*, in northern sugar maple stands. In addition to the direct mortality to overwintering thrips populations, fall burning seems to disrupt the phenological synchrony between emerging thrips and sugar maple bud expansion that is critical to the success of these insects (Brose and McCormick 1992). Attempts to reduce acorn mortality caused by the acorn weevil, *Conotrachelus posticatus*, and associated acorn predators using prescribed fire in eastern oak forests have met with some success (Wright 1986; Roccardi et al. 2004; Rieske, unpublished). The highly clustered spatial distribution of these seed feeders makes effective suppression and effective sampling problematic.

CONCLUSIONS

Although large, highly mobile arthropods appear to escape the negative effects of fire, the smaller, less mobile arthropods that are critical to decomposition processes are unable to escape. Arthropod abundance at the soil/litter interface can be severely reduced by burning, while effects on diversity, richness, and evenness are less marked. The use of repetitive prescribed fire to encourage regeneration and enhance stand development should be based on a schedule to allow appropriate time for leaf litter habitats to return to pre-burn conditions, and allow for resurgence of the arthropod community.

Fire-induced changes in oak foliar chemistry include increases in foliar nitrogen, carbohydrates, and defensive compounds, which can influence herbivore feeding patterns. Many of these changes are transient and not fully predictable; they may be species-specific and depend on the timing and intensity of the fire. Herbivory is a measurable force on oak seedlings, and mammalian herbivory has a greater impact on seedling vigor than arthropod herbivory.

Prescribed fire has limited use for pest suppression in deciduous forests of the Eastern United States. Pest vulnerability, both spatially and temporally, and the highly clustered spatial distribution of many pests makes effective suppression through prescription burning challenging and unpredictable. Although direct suppression of selected herbivores with prescribed fire is possible, prescription burning may be more viable as a means of enhancing forest health and redirecting succession, thereby reducing stand susceptibility to herbivore outbreaks.

Additional research is needed to fully understand the dynamics of insect-fire interactions in eastern oak forests. We lack a complete understanding of the effects of fire on the critical arthropod-driven processes in the soil/litter interface. More work is needed on fire-induced changes in herbivore pressure and herbivore susceptibility of important forest tree species.

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