

DELAYED MORTALITY OF EASTERN HARDWOODS AFTER PRESCRIBED FIRE

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Abstract—The Southern Appalachian Mountain and the Ohio Hills sites of the National Fire and Fire Surrogate Study are located in hardwood dominated forests. Mortality of trees was anticipated the first year after burning but it continued for up to 4 years after burning, which was not expected. Survival analysis showed that the likelihood of mortality was related to prior tree health, size class, species, and first-order fire effects. Both sites were unmanaged and trees were likely stressed by competition. Burning provided additional stresses through cambial and crown damage which may have predisposed trees to death. This study indicated that monitoring only first-year effects of prescribed fires or wildfires does not provide an accurate assessment of fire impacts. Also, managers should consider tree health when making plans for prescribed burns.

INTRODUCTION

Several studies document the cellular necrosis of tree cambium and buds directly due to the heat of combustion (i.e., first-order fire effects) after fuel-reduction treatments. However, none has attempted to establish the interactions between fuel reduction and ecological processes. The National Fire and Fire Surrogate (NFFS) Study was established to compare ecological and economic impacts of prescribed fire and mechanical fuel-reduction treatments (Youngblood and others 2005). Thirteen independent study sites across the United States (eight in the West and five in the East) receive identical treatment (prescribed fire and mechanical fuel reduction treatments) and measurement protocols. All western sites are dominated by ponderosa pine (*Pinus ponderosa*). Eastern sites include hardwood-dominated sites in the Ohio Hill Country and Southern Appalachian Mountains of NC, a pine-hardwood site in the Piedmont of SC, a site dominated by longleaf pine (*P. palustris*) in AL, and a site dominated by slash pine (*P. elliotii*) in FL.

Two NFFS sites—the Southern Appalachian Mountain and Ohio Hills sites—are located in hardwood-dominated forests. Increased first-year post-treatment mortality of overstory trees (d.b.h.>4 cm) was expected in Southern Appalachian Mountain and Ohio Hills units that received prescribed fire. Not expected was that these units would display increased mortality in trees of most size classes for up to 4 years post-treatment. The causes of delayed mortality are unknown but are thought to be related to prior tree health, species related bark thickness, and first order fire effects. This study examines the relationship of fuel, fire behavior, and tree variables to delayed mortality of hardwoods.

METHODS

Study Sites

Both the Southern Appalachian and Ohio Hills study sites consist of three replicate blocks, with four fuel reduction treatments applied to a randomly chosen treatment unit within each block. The Ohio Hills NFFS site is located on the unglaciated Allegheny Plateau of southern Ohio. The climate of the region is cool, temperate with mean annual

precipitation of 1 024 mm and mean annual temperature of 11.3 °C (Sutherland and others 2003). The forests of the region developed between 1850 and 1900, after the cessation of cutting for the charcoal and iron industries (Sutherland and others 2003). The current canopy composition differs little from that recorded in the original land surveys of the early 1800s. The most abundant species in the current canopy were white oak (*Quercus alba*), chestnut oak (*Q. prinus*), hickories (*Carya* spp.), and black oak (*Q. velutina*); however, the midstory and understory are now dominated by species that have only in the last few decades become common in this community (e.g., sugar maple (*Acer saccharum*) red maple (*A. rubrum*), and yellow-poplar (*Liriodendron tulipifera*) (Yaussy and others 2003). Analysis of fire scars in stems of trees that were cut very near the NFFS experiment indicated that fires were frequent (return intervals of 4-8 years) from 1875 to 1930 (McEwan and others 2007). In contrast, few fires occurred after the onset of fire suppression activities in the mid 1920s (Hutchinson and others 2002). The Ohio Hills NFFS site is composed of three experimental blocks, with one each in the Raccoon Ecological Management Area, Zaleski State Forest, and Tar Hollow State Forest.

The Southern Appalachian NFFS site is located in the Green River Game Land in the Blue Ridge Physiographic Province, Polk County, North Carolina. The climate of the region is warm continental, with mean annual precipitation of 1,638 mm and mean annual temperature of 17.6 °C (Keenan, 1998). The forests of the study area were 80 to 120 years old, and no indication of past agriculture or recent fire was present, though the historical fire return interval prior to 1940 was approximately 10 years (Harmon 1982). The most abundant species in the canopy were northern red oak (*Q. rubra*), chestnut oak, white oak, black oak, pignut hickory (*Carya glabra*), mockernut hickory (*C. tomentosa*), and shortleaf pine (*Pinus echinata*). A relatively dense evergreen shrub assemblage was present in the understory of a majority of the study site, with mountain laurel (*Kalmia latifolia*) and rhododendron (*Rhododendron maximum*) the most common species.

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Treatments and Experimental Design

Each of the three replicate blocks in each site is composed of four treatment units. At the Ohio Hills site, individual treatment units were 19-26 ha whereas in the Southern Appalachian site they were approximately 14 ha in size. A 50 by 50 m grid was established in each treatment unit, and ten sample plots of 0.10 ha were established randomly within each treatment unit.

Treatments were randomly allocated among treatment units at each site. Treatments consisted of prescribed fire, a mechanical treatment, the combination of prescribed fire and mechanical treatments, and an untreated control. In the Ohio Hills, the mechanical treatment involved thinning from below to a basal area comparable to that present prior to Euro-American settlement. This was a commercial thinning operation that reduced basal area from 27.0 to 20.9 m²/ha. At the Southern Appalachian site, the mechanical treatment was designed to create a vertical fuel break. Chainsaw crews removed all stems >1.8 m tall and <10.2 cm diameter at breast height (d.b.h.) as well as all mountain laurel and rhododendron stems, regardless of size. All detritus generated by the mechanical treatments was left on site in both areas.

Mechanical treatments were accomplished between September 2000 and April 2001 in Ohio and between December 2001 and February 2002 at the Southern Appalachian site. The prescribed fires were applied during March-April 2001 in the Ohio Hills and March 2003 at the Southern Appalachian site. These dormant-season fires consumed unconsolidated leaf litter and fine woody fuels while leaving the majority of the coarse woody fuels only charred. At the Southern Appalachian site, the fire prescription was also designed to kill ericaceous shrubs. Details of fire behavior are given by Iverson and others (2004) for the Ohio Hills and Tomcho (2004) for the Southern Appalachian site.

Measurements and Analysis

All treatment units were sampled during the pretreatment year, 2000 in the Ohio Hills and 2001 in the Southern Appalachians. Additional measurements were made in Ohio 1, 2, and 4 years after treatment. The Southern Appalachian site was measured 1 and 3 years after treatment. Numerous variables were measured at grid points and sample plots for many components of the NFFS study. Those used in this study included peak fire temperature, crown vigor, bark thickness, duration of heat, d.b.h., basal area, and dummy variables (0 or 1) for mortality, treatment, and species. Most variables were measured in accordance with standard protocols. Peak temperature and duration of heat were measured with thermocouples attached to dataloggers buried at each grid point. We measured a total of 6,941 trees at the two sites, and 546 of these trees died during the study. A survival analysis was conducted using the SAS[®] PHREG procedure with Cox regression and Stepwise procedures. This analysis produces the probability of survival given each measured condition for each variable.

RESULTS

Several variables proved to have significant relationships to hardwood mortality. The hazard function (table 1) provides a relative measure of the relationship of each variable to predicting mortality. A value of 1 indicates no change. The index for maximum temperature suggests that for each degree that fire temperature increases, there is a 0.3 percent increase in the probability of mortality each year. The probability of mortality decreases by 4.5 percent with each increase of bark thickness by 1 mm. The single most important predictor of mortality was crown vigor. The survival rate for healthy trees was 3.69 times the survival rate for trees of low vigor.

The relative contribution of individual variables in determining mortality varied over the 4-year sampling period. There was little difference between long-term mortality in OH and long-term mortality in NC (fig. 1). However, treatment did affect survival (fig. 2). The probability that a tree would die within 4 years was 5 percent in plots that had received the burn-only treatment and 7 percent if the plots had received the mechanical + burn treatment. Peak fire temperature also had an impact (fig. 3). Trees subjected to temperatures of 100 °C had a 96 percent chance to survive 4 years but trees subjected to 700 °C had an 80 percent chance to survive. Preburn tree vigor is a strong predictor of mortality (fig. 4). Healthy trees had a 95 percent chance of surviving 4 years after fire while trees with low vigor had less than a 73 percent chance. Exposure to increased heat for 20 minutes had slightly more impact on long-term survival than did exposure to increased heat for 1 minute (fig. 5). D.b.h. and bark thickness had predictable effects (fig. 6); small diameter trees with thin bark had a 92 percent rate of survival, whereas larger trees with thick bark had a 99 percent survival rate. With all other variables held constant, there were differences in survival rates among species (fig. 7). Oaks were less likely to survive 4 years than were maple, blackgum, and sourwood.

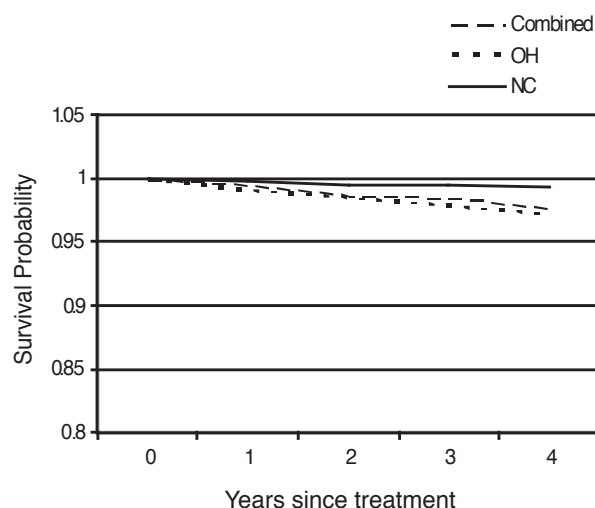


Figure 1—Differences in the survival probability of hardwoods after prescribed fires at the Southern Appalachian and Ohio NFFS sites.

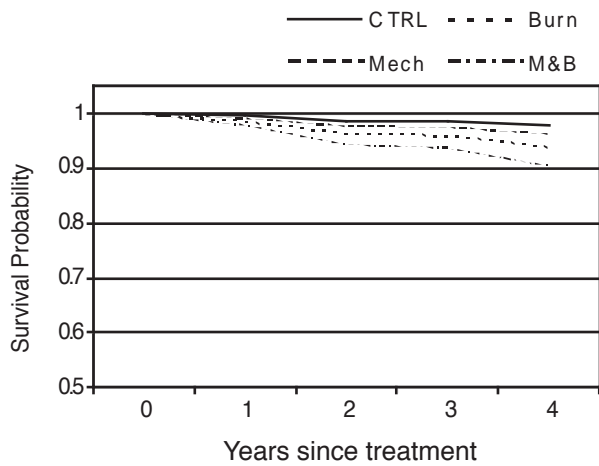


Figure 2—Differences in the survival probability of hardwoods by fuel reduction treatment at the Southern Appalachian and Ohio NFFS sites.

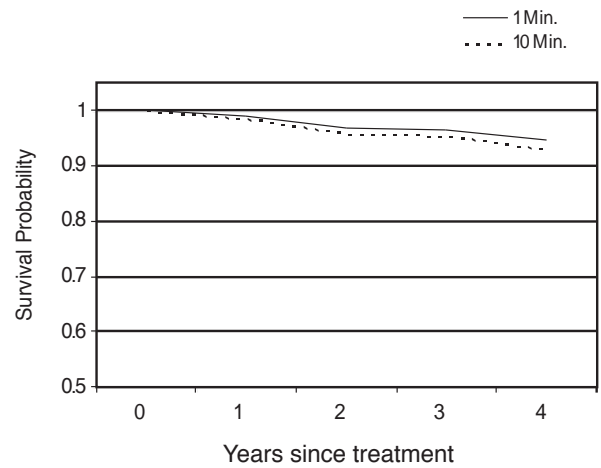


Figure 5—Differences in the survival probability of hardwoods by duration of exposure to heat at the Southern Appalachian and Ohio NFFS sites.

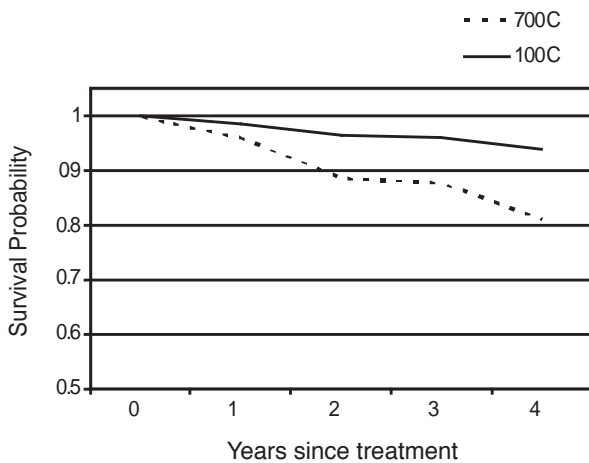


Figure 3—Differences in the survival probability of hardwoods by peak fire temperature at the Southern Appalachian and Ohio NFFS sites.

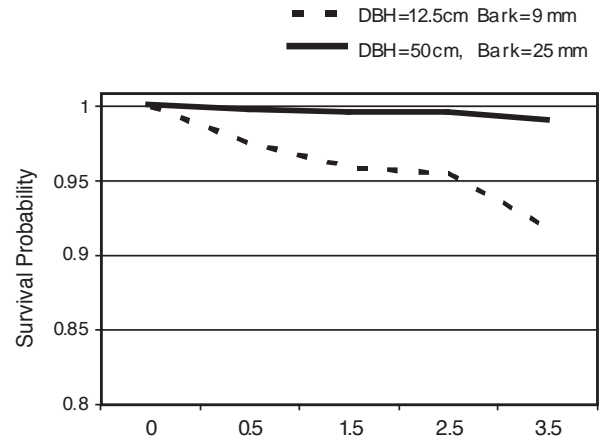


Figure 6—Differences in the survival probability of hardwoods by dbh and bark thickness at the Southern Appalachian and Ohio NFFS sites.

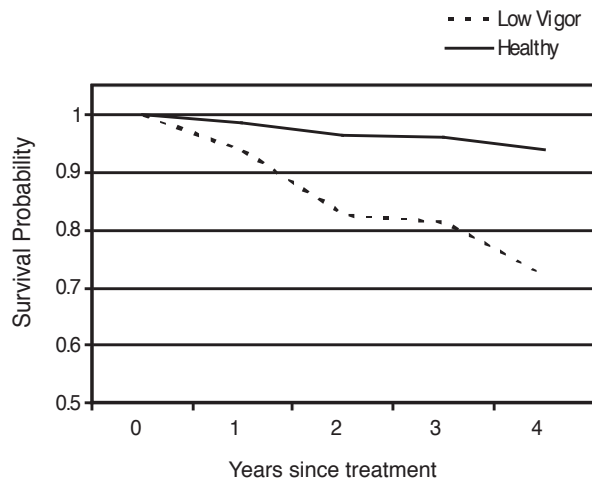


Figure 4—Differences in the survival probability of hardwoods by pre-burn tree vigor class at the Southern Appalachian and Ohio NFFS sites.

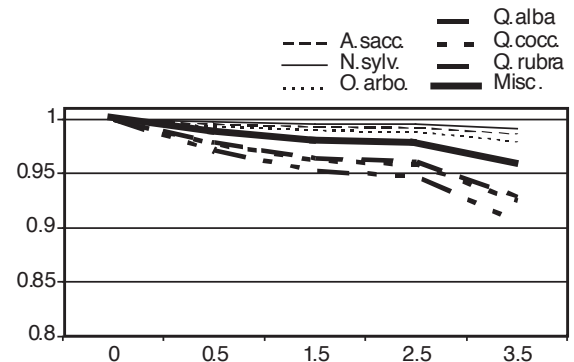


Figure 7—Differences in the survival probability of hardwoods by tree species at the Southern Appalachian and Ohio NFFS sites.

The probability of survival for any given tree is a function of all of the variables shown here and likely many more. If a tree is subjected to more than one of these variables, survival probability decreases dramatically. For example, a small tree has an 8 percent chance of dying in 4 years; that same tree has a 23 percent chance of dying if it also has low vigor. If the tree is subjected to 700 °C for 20 minutes, its chance of dying would increase to 88 percent.

CONCLUSIONS

In this study, mortality of hardwood species was observed for up to 4 years after prescribed burning at two study sites of the National Fire and Fire Surrogate Study. The pattern of mortality was similar at both sites, suggesting that conclusions drawn in earlier reports may have been premature. A number of variables were related to mortality but the most important ones were the peak temperature of the fire, the duration of exposure of each tree to flames, preburn tree vigor, and bark thickness. These variables were tested separately but they probably interact with each other and with a large number of variables not measured. Secondary agents of decline may be pathogens such as *Phytophthora* and *Armillaria*, root diseases present at both sites but not a component of this study. Microsite differences may play a role in the decline if burning dries the soil by increasing sunlight and decreasing forest floor depth (Waldrop and others 2002). Both sites were unmanaged and trees were likely stressed by competition. Burning provided additional stresses through cambial and crown damage which may have predisposed trees to death. Additional research is needed to fully understand the full complex of biotic and abiotic variables that contribute to hardwood mortality after fire.

ACKNOWLEDGMENT

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