REGENERATION DYNAMICS DURING OAK DECLINE WITH PRESCRIBED FIRE IN THE BOSTON MOUNTAINS OF ARKANSAS

Martin A. Spetich[1]

Abstract—Northern red oak (*Quercus rubra* L.) seedlings were inventoried in 2000 and again in 2005 to better understand survival of advance regeneration during oak decline. In 2000, basal stem diameter was measured and recorded for 861 individually tagged seedlings that were <5 cm d.b.h. By mid-2001, the stand containing these seedlings began to exhibit symptoms of severe oak decline. In 2004, a prescribed fire was applied to one-third of the study area. Based on logistic regression analysis, survival probability of northern red oak increased with increasing initial basal stem diameter and decreasing site index. In unburned areas, greatest mortality occurred on seedlings with basal stem diameters <7 mm. However, in burned areas, seedlings <12 mm exhibited the greatest mortality. This information can aid managers in developing prescriptions that help mitigate the impacts of oak decline by promoting practices that maximize oak regeneration to basal stem diameters >7 mm in areas not burned and to diameters >12 mm in areas to be burned.

INTRODUCTION

Drought is an inciting factor of oak decline (Manion 1991, Starkey and others 2004). A 3-year drought occurred across the Interior Highlands region of Arkansas and Missouri from 1998 to 2000. Through much of the Boston Mountain forests that were impacted by oak decline, this was coupled with stands of high tree density and mature trees, making these forests especially vulnerable to oak decline (Oak and others 2004). These and other factors led to an oak decline event across the Ozark Highlands in Arkansas and Missouri (Starkey and others 2004).

At the research site discussed in this paper, oak decline lasted through 2005 and altered snag (Spetich 2004a, 2006), overstory (Spetich 2006), and down-deadwood dynamics (Spetich 2007). However, regeneration dynamics have not been examined.

Fire was a once-frequent and important part of these ecosystems. However, during much of the past century, these once-frequent fires have been reduced to infrequent events (Guyette and Spetich 2003). Fire suppression has altered species dynamics of these upland hardwood forests (Spetich 2004b).

Understanding how to predict survival of oak (*Quercus* spp.) advance regeneration provides important information that managers can use to more effectively restore this valuable resource to the landscape. The objectives of this paper are to (1) identify predictors of survival of oak advance reproduction on a site with severe oak decline in burned and unburned areas, (2) provide survival models based on this information, and (3) develop management recommendations based on this information.

STUDY SITE

The study site is a 32-ha area in an upland oak-hickory (*Carya* spp.) stand that was approximately 75 years old in 2005. It is located in the Boston Mountains of Arkansas, part of the southern lobe of the central hardwood region (Merritt 1980). The Boston Mountains are the highest and most southern member of the Ozark Plateau Physiographic Province (Croneis 1930). They form a band 48 to 64 km wide and 320 km long from northcentral Arkansas westward into eastern Oklahoma. Elevations range from about 275 m in the valley bottoms to 760 m at the highest point. The plateau is sharply dissected. Most ridges are flat to gently rolling and generally are <0.8 km wide. Mountainsides are alternating steep simple slopes and gently sloping benches. Vegetation across much of the landscape is a forest matrix with nonforest inclusions.

More specifically, the study site is located in the northwestern corner of Pope County, approximately 3 km southeast of Sand Gap, AR. The stand is dominated by oak and hickory and has become the center of a local patch of oak decline. In August 2000, mean basal area for all standing trees was 25.9 m^2/ha, and there were 417 standing trees/ha. Of those standing trees 1.8 m^2/ha of basal area and 53 trees/ha were standing dead trees mostly in smaller diameter classes. Stocking was 88 percent.

METHODS

From 2000 to 2005, measurements were taken on 861 northern red oaks (*Q. rubra* L.) <5 cm d.b.h. These seedlings were individually tagged and monitored. The study site was located in an oak-hickory dominated stand in the Boston Mountains of northern Arkansas. For each seedling, we measured basal stem diameter in mm and tracked survival status.

A prescribed fire was applied to one-third of the study site on March 12, 2004. The fire burned an area that included 268 of the seedlings. Fire weather conditions during the fire were—relative humidity, 28 percent; wind from the northeast

[1] Research Forester, U.S. Department of Agriculture Forest Service, Southern Research Station, Hot Springs, AR.

at 2 to 6 km/hour; and ambient temperature averaged 21 °C. In 2005, we reinventoried all 861 seedlings for basal stem diameter and survival.

Site index was determined by measuring age and height of 48 dominant or codominant northern red oak and/or white oak (*Q. alba* L.). Site indices for red oaks were converted to white oak site indices using a published conversion formula (Carmean and Hahn 1983). The average of the nearest two site index trees was used to determine site index for each area of regeneration trees. None of the site index trees were used more than once. Site index trees were generally located within 22 m or less of regeneration trees.

Logistic regression was used to model survival of northern red oak in both the burned and unburned areas. Results are expressed as the probability of survival of northern red oak advance regeneration. The versatility of logistic regression to analyze dichotomous data first gained recognition in the 1960s (Hosmer and Lemeshow 1989: vii). Since then, researchers have used this method to examine a range of data types including human health issues, the growth and survival of naturally regenerated trees (Lowell and others 1987), and dynamics of artificial regeneration of northern red oak (Spetich and others 2002).

To evaluate logistic regression model performance, we selected predictors with a *p*-value of 0.05 or less based on the chi-square distribution with one degree of freedom. We used the Hosmer-Lemeshow goodness-of-fit statistic (Hosmer and Lemeshow 1989: 140) to test the null hypothesis that the equation described the data. For Hosmer-Lemeshow goodness-of-fit, the null hypothesis was rejected for *p*-values of 0.05 or less (indicating a poor fit of the equation to our data). Consequently, it is important to note that predictor *p*-values of 0.05 or less have a different interpretation than the Hosmer-Lemeshow goodness-of-fit *p*-values of 0.05 or less.

RESULTS

Survival probability of northern red oak seedlings increased with increasing basal stem diameter and decreasing site index. The models are presented below:

Burned area, model 1:

$$PSb = 1/(1 + EXP(-(1.255-(0.178 * SI(m) * (1/BSD)))))$$

PSb = probability of survival in burned area
BSD = basal stem diameter in 2000, mm
SI = site index for white oak, m

Predictor [SI(*m*) * (1/BSD)] *p*-value = <0.001
Goodness-of-fit[2] (*p*-value) = 0.443

Unburned area, model 2:

$$PSu = 1/(1 + EXP(-(1.293 - (0.0675 * SI(m) * (1/BSD)))))$$

PSu = probability of survival in unburned area
BSD = basal stem diameter in 2000, mm
SI = site index for white oak, m

Predictor [SI(*m*) * (1/*BSD*)] *p*-value = 0.03
Goodness-of-fit[2] (*p*-value) = 0.418

[2]Goodness-of-fit—Based on the Hosmer-Lemeshow goodness-of-fit statistic, differences between estimated probabilities and observed responses are not significant. Small *p*-values designate a poor fit of the equation to the data while large values (>0.05) indicate a good fit.

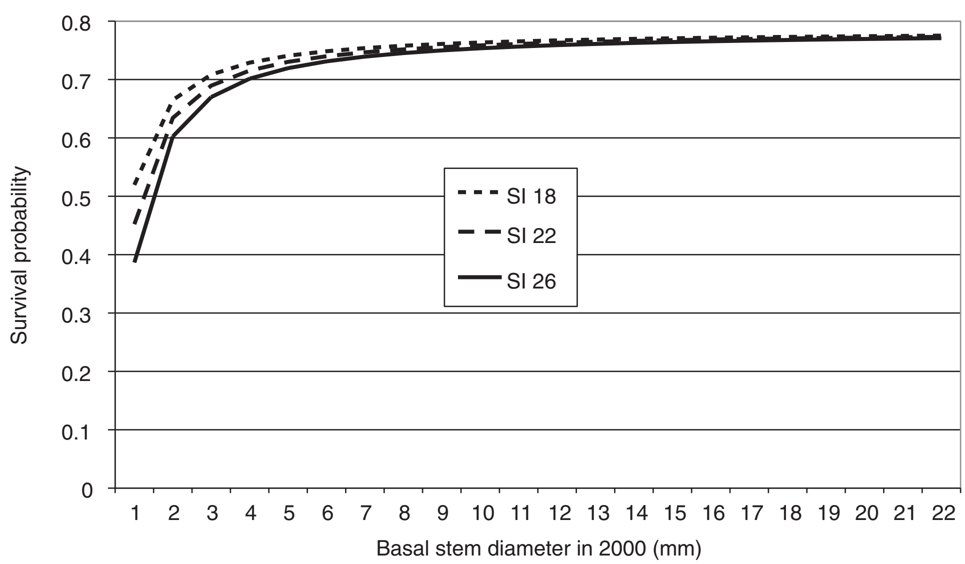

Figure 1—Survival of northern red oak advance regeneration in 2005 in unburned area, *n* = 539.

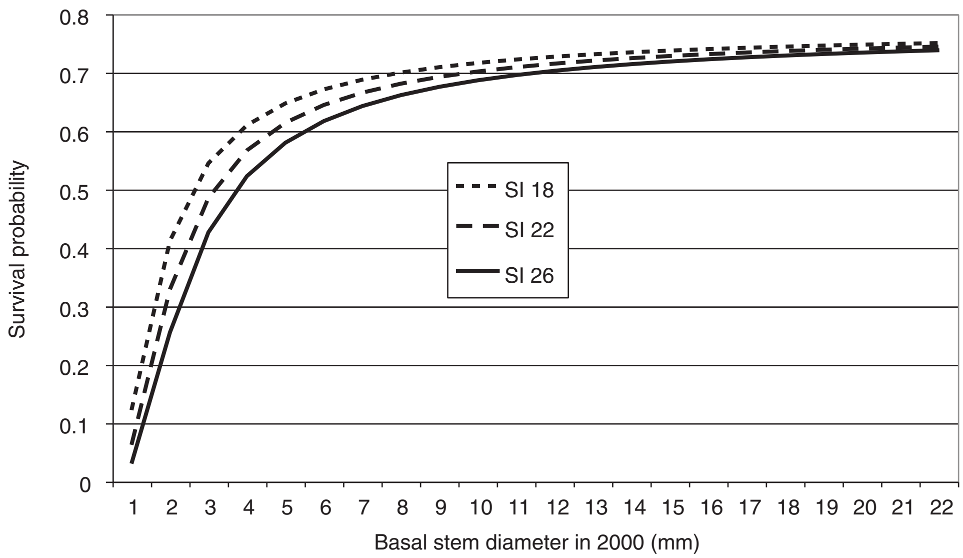

Figure 2—Survival of northern red oak advance regeneration in 2005 in the 2004 prescribed burn area, *n* = 268.

The relationship of survival, basal stem diameter, and site index is illustrated in figures 1 and 2. In both cases survival increased with increasing diameter and decreasing site index. For a given site index, northern red oak seedlings in the area receiving the 2004 prescribed fire had lower survival than seedlings of equal diameter in the unburned area (figs. 3 and 4).

DISCUSSION

A better understanding of regeneration dynamics on oak decline sites can help managers prepare prescriptions to help mitigate the impacts of oak decline and help restore a valuable species to the landscape. For seedlings with <7 mm basal stem diameter there was a greater difference in survival between the burned and unburned areas on the high site index site (fig. 4) compared to the low site index site (fig. 3). For seedlings with 1.0 mm basal stem diameter, survival probability in the burned areas was nearly zero (fig. 2) versus about 0.4 to 0.5 in the unburned area (fig. 1).

As basal stem diameter increased, survival probability increased. These results reinforce the importance of large basal stem diameter advance regeneration. In the unburned area, basal stem diameters of <7 mm rapidly decrease in survival probability with decreasing diameter (figs. 1, 3, and 4). However, on the site receiving the 2004 prescribed fire, basal stem diameters of <12 mm rapidly decrease in survival probability with decreasing diameter (figs. 2, 3, and 4). Beyond these benchmark diameters of 7 mm and 12 mm there were relatively small gains in survival with increasing diameter of natural regeneration.

The general relationship of increasing site index with a corresponding decrease in survival has been noted for underplanted northern red oak (Spetich and others 2002). A similar relationship exists for the relationship of decreasing dominance probability of natural regeneration with increasing site index (Loftis 1990, Sander and others 1984). Dominance probability has seedling survival incorporated into it.

Based on these results, on oak decline sites where fire is not a prescriptive option, managers should consider optimizing conditions to grow advance regeneration to basal stem diameters of >7 mm. Moreover, on areas where fire is a prescriptive option, managers should consider burning only after a significant proportion of advance oak regeneration reaches basal stem diameters of >12 mm in order to increase the probability of survival. Implementing these suggestions may help to mitigate northern red oak regeneration losses in the Boston Mountains during oak decline.

CONCLUSIONS

Because this is a long-term study with repeated fires, the results reported here are preliminary. Therefore, these results should be considered in the context of this single fire event. Results reinforce the importance of large basal stem diameter advance regeneration. In the unburned area, basal stem diameters of <7 mm rapidly decrease in survival probability with decreasing diameter. In the burned area, basal stem diameters <12 mm rapidly decrease in survival probability with decreasing diameter.

RECOMMENDATIONS

Prior to burning, assess oak regeneration and diameter distribution. Burn if oak regeneration is sufficiently established to meet management goals and if oak is well represented across diameter classes. If oak regeneration exists mainly in smaller diameter classes, postpone burning until regeneration is more evenly distributed.

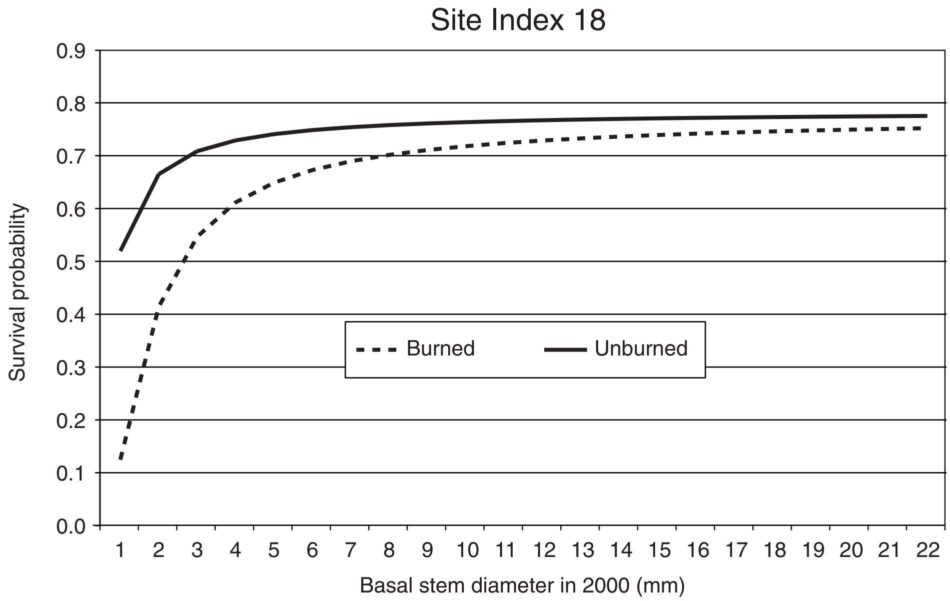

Figure 3—Advance regeneration on site index 18 m for white oak: survival of northern red oak advance regeneration in 2005.

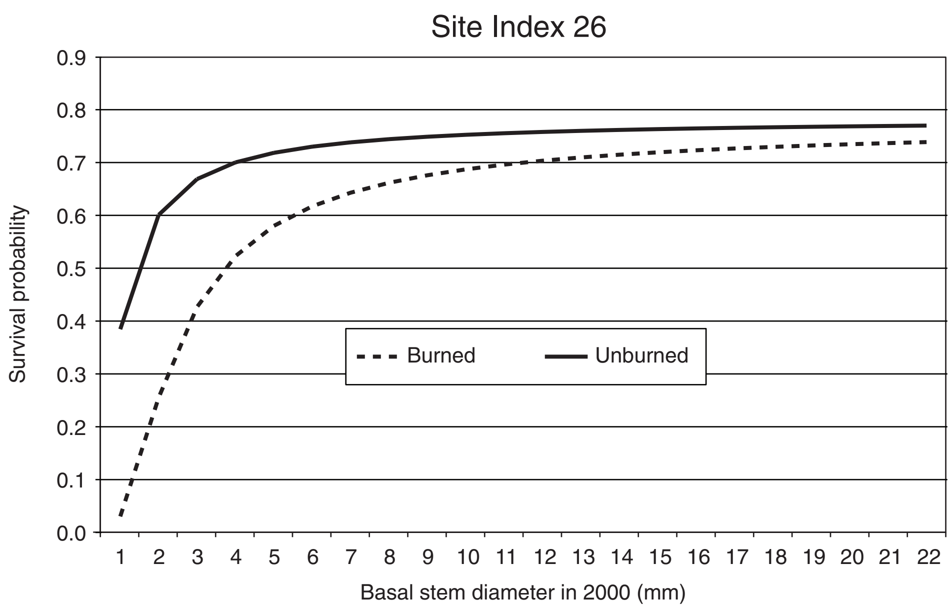

Figure 4—Advance regeneration on site index 26 m for white oak: survival of northern red oak advance regeneration in 2005.

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