OAK DECLINE ACROSS THE OZARK HIGHLANDS – FROM STAND TO LANDSCAPE AND REGIONAL SCALE PROCESSES

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Abstract—Oak decline has been a problem in forests of the Ozark Highlands (OzH) for decades. It has impacted upland oak-hickory forests, particularly species in the red oak group (*Quercus* section *Lobatae*) across the Ozark Highlands of Missouri, Arkansas, and Oklahoma. The oak decline complex is often described in terms of predisposing factors, inciting factors, and contributing factors. Drought is a common inciting factor in oak decline, while advanced tree age is considered a predisposing factor, and opportunistic organisms such as armillaria root fungi and wood boring insects are believed to contribute to the decline and demise of formerly stressed trees. Declining trees are initially indicated by foliage wilt and browning followed by progressive branch dieback. If crown dieback continues, trees can die. In this paper we synthesize four of our key research studies on oak decline, examining the occurrence, distribution, and characteristics of oak decline as it has impacted the OzH across space and time. Long-term climate forecasts for this region indicate decreasing precipitation and warming temperatures. Consequently, periodic droughts such as the widespread 2012 U.S. drought are expected to increase in frequency and intensity, and thereby exacerbate oak decline on millions of hectares of aging oak forests. Results from our research indicate that regular monitoring of forest conditions; increasing the proportion of species in the white oak relative to the red oak group; judicious application of prescribed fire; periodic thinning to favor species in the white oak group; and proactive harvest of aging red oak species anticipated to be at increased risk of mortality are methods that can help forest managers mitigate oak decline.

INTRODUCTION

Oak-hickory forests cover the largest area and contribute the greatest amount of biomass of any forest-type group in the Eastern United States (table 1). During the period 1856 to 1986, some 57 major oak mortality events were recorded across those forests (Millers and others 1989). The Ozark Highlands ecoregion (OzH) (McNab and Avers 1995, McNab and others 2005), located mainly in southern Missouri and northern Arkansas, contains some of the highest concentrations of oak with the mean basal area contributed by *Quercus* species estimated at 63percent (Oak and others 2015).

Widespread oak decline events of the OzH that began in 2000 have been particularly severe and continue today. Drought from 1998 through 2000 incited this oak decline episode. Drought has been the inciting factor for decline in the OzH in the past, and is most often cited as the predominant inciting factor for decline throughout the Southeastern United States (Millers and others 1989). Of the oak species, those in the red oak group (*Quercus* section *Lobatae*) are the most susceptible to decline while those in the white oak group (*Quercus* section *Quercus)* are relatively resilient during decline events (Fan and others 2012). The higher mortality of red oak species may be due in part to their high abundance on dry, rocky sites owing to widespread establishment on these areas following the extensive, exploitive logging of shortleaf pine in the early 1900s (Kabrick and others 2008). The past disturbance history of the Ozark Highlands has resulted in a disproportionate area of old forests that are susceptible to oak decline

Table 1—Biomass of Eastern U.S. forests by forest-type group. Oak dominated forests contribute 53 percent of the biomass of all of the forests in the eastern U.S. FIA assessment area (based on Oswalt et al. 2014)

Forest-Type Group	Biomass	Area
Oak-Hickory	39%	34%
Oak-Gum-Cypress	8%	6%
Oak-Pine	6%	7%
Total	**53%**	**47%**

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events. Nearly 60 percent of forests in this region are greater than 60 years old, an age cohort considered predisposed to oak decline. An additional 27 percent of OzH forests are between 40 and 60 years of age (Miles 2015). This situation assures that mortality associated with oak decline will be an important management issue for decades to come. Concern about the current and anticipated extent and severity of oak decline in the Ozark Highlands has prompted renewed collaborations, most notably the convergence of over 350 scientists, land managers, and landowners and the formation of the Upland Oak Ecology Symposium in 2002 (Spetich 2004b).

From a broader perspective, a recent paper on global drought and heat-induced tree mortality associated with climate change suggests that the composition and structure of forests worldwide may be altered by increases in heat and drought stress (Allen and others 2010). The authors suggest that some of the world's forests may already be responding to these changes in climate. Further, they conclude that if widespread tree mortality transpires there will be considerable impact to society and to the global ecosystem. Some climate models suggest that from 2000 to 2060 temperature in the OzH is expected to increase by about 3 degrees centigrade and precipitation is expected to decrease by at least 200 mm (McNab and others 2014), which will continue to predispose the OzH to future oak decline events.

In this paper, we synthesize four of our key OzH research studies on oak decline. These studies cover three spatial scales—stand, landscape, and region—examining past events and projecting conditions into the future. We examine the occurrence, distribution, and characteristics of oak decline as it has impacted the OzH across space and time, and we provide management suggestions aimed at mitigating future episodes of oak decline.

SITES

The Ozark Highlands ecological section contains over 12 million ha (30 million acres) and covers parts of southern Missouri, northern Arkansas, and a small portion of northeastern Oklahoma (McNab and Avers 1995, McNab and others 2005). The following field studies are based on data from Forest Inventory and Analysis (FIA) inventories (USDA Forest Service 2015) and other research plots across the OzH ecoregion in Missouri and Arkansas. These four studies cover three spatial scales: forest stand, landscape, and regional.

Stand Scale, Study 1:

The study site is a 32-ha area in an upland oak-hickory stand which was 74 years old in 2004 and located on a southwest facing slope with dry, rocky soil. The forest stand is dominated by oak (*Quercus* spp.) and hickory (*Carya* spp.) and was the center of a local patch of oak decline beginning in 2001. The site was undisturbed for more than 20 years prior to 2000 and had no deer browsing pressure on seedlings during the study.

Landscape Scale, Studies 2 and 3:

These two studies encompass a 427,660-ha area (1,056,771 acres) within the Ozark National Forest purchase boundaries and include three ranger districts: Bayou, Buffalo, and the Pleasant Hill (since the studies were completed, the Buffalo and Bayou ranger districts were combined to form the Big Piney ranger district). Dominant species are oak and hickory.

Regional Scale, Study 4:

This study included all forest within the OzH within Arkansas and Missouri that contained an oak component.

PROCEDURES

We examined dynamics of these forests at three spatial scales: forest stand (32 ha), intermediate landscape (428 thousand ha), and regional (12 million ha; the entire OzH across Arkansas and Missouri).

Stand Scale, Study 1 – regeneration:

In the winter of 2000, 24 overstory plots (0.16 ha) were established with 20 regeneration measurement plots (5.4 m^2) nested within each overstory plot (480 total regeneration plots). In the summer of 2000, trees < 5 cm diameter at breast height (dbh) were inventoried for all 480 regeneration plots. In the summer and early fall of 2000, standing trees were inventoried on all midstory (5- to 25-cm dbh trees) and overstory ($\geq$ 25-cm dbh trees) plots, and in the fall of 2001, 6 of the 24 overstory plots were remeasured. On March 12, 2004, prescribed fire was applied to one fourth of the site and encompassed 120 of the regeneration plots. Then in 2005 and again in 2008, all 480 regeneration plots were remeasured. Detailed methods of the study are described in Spetich (2004a, 2006, 2013, and 2014).

Landscape Scale, Study 2 – harvest methods:

The landscape disturbance model LANDIS PRO (He 2015) was used to simulate three harvest methods (clearcutting, thinning, and group-selection), and model long-term, landscape-scale effectiveness of treatments on oak decline mitigation 100 years into the future. During the simulated harvests, older red oaks were given priority for harvesting. Detailed study methods are described by Wang and others (2013).

Landscape Scale, Study 3 – prescribed fire:

The landscape disturbance model LANDIS (He and others 2005) was used to simulate the impact of two fire regimes on future oak decline risk 150 years into the future over a 427,660-ha area. Additional details on study methods are provided by Spetich and He (2008).

Regional Scale, Study 4 – drought:

Spatial and temporal trends of oak decline and mortality across the Ozark Highlands were assessed using FIA data (USDA Forest Service 2015) from 1999 to 2010. We used data from trees on 6,997 spatially referenced FIA plots across the Ozark Highlands of Arkansas and Missouri. On each 0.4-ha plot, trees > 11 cm dbh were measured and periodically remeasured from 1999 to 2010. For analysis, the tree species were divided into three groups: white oak group, red oak group, and a non-oak species group. The percentage of dead trees was calculated in terms of basal area. Cross-correlation analysis was used to examine the relationship of growing season Palmer drought severity index (PDSI) to oak mortality (Palmer 1965). Additional details about methodology are available in Fan and others (2012).

RESULTS AND DISCUSSION

Stand Scale, Study 1:

Within one year, 2000 to 2001, the number of standing dead trees more than doubled from 23 trees per hectare to 51 trees per hectare ($p = 0.029$) for northern red oak *Quercus rubra* (Spetich 2004a). However, many of these trees were below the main canopy. This understory mortality is likely due to the fact that this stand was in the stem exclusion phase of stand development (Oliver and Larson 1990), putting this cohort of trees in a highly competitive condition prior to drought and the subsequent stand decline. Understory mortality on oak decline sites has been noted in at least one other decline study (Heitzman and others 2007).

One year after the 2004 prescribed fire, northern red oak regeneration in the unburned area had greater probability of survival in all diameter classes compared to the burned area. However, by 2008 this relationship changed where survival probability in the burned area remained relatively stable over all regeneration diameter classes, while in the unburned area there was a decrease in survival probability across all regeneration basal stem diameter classes. This decrease is likely due to a greater amount of competing vegetation remaining in the unburned area. In the burned area, the number of regeneration trees was 28,587 per hectare, while in the unburned area it was 44,718 trees per hectare. By 2008, seedlings greater or equal to a 6-mm basal stem diameter in the burned area had greater survival probability than regeneration in the unburned area (fig. 1).

For white oak (*Quercus alba*), stem age (measured at the beginning of the study in 2000) was used to predict survival because basal diameter is not a useful predictor of regeneration survival for this species in the Ozarks due to its slow diameter growth rate at this stage of tree development (Spetich 2014). Survival probabilities of white oak regeneration remained relatively stable for all inventory years and stem age classes (1 to 15 years), and this is likely due to greater shade tolerance of white oak compared to northern red oak. In all cases, survival began to reach a maximum and level off at a stem age of 5 years with survival ranging from 74 to 78 percent at stem age 5, and 81 to 85 percent for stem age 15 (fig. 2). For detailed results of study 1, see Spetich (2004a, 2006, 2013, and 2014).

Landscape Scale Simulation, Study 2 – harvest methods:

By simulation year 100, on high risk sites, the three harvesting methods (clearcutting, thinning, and group-selection) reduced the percent of oak decline on the landscape by only three percent below that of doing nothing. On medium-risk sites, all three harvesting methods reduced the percent of oak decline on the landscape by 13 percent below that of doing nothing. However, the areas of potential oak decline decreased during the first five decades of simulation regardless of harvest method used, indicating that natural species dynamics and succession will also play a strong role in reducing the susceptibility of these forests to oak decline. For detailed results of study 2, see Wang and others (2013).

Landscape Scale Simulation, Study 3 – prescribed fire:

With prescribed fire administered on only half of the study area during the 150-year simulation period, all potential oak decline sites were reduced from covering 45 percent of the landscape at year 0, to 30 percent at year 150. By increasing prescribed fire to three times across the entire area during the 150-year period, all potential oak decline sites were reduced to only 20 percent of the landscape. High risk sites were reduced from 20 to 7 percent, medium risk sites from 15 to 7 percent, and low risk from 10 to 6 percent with three fires. The future impact of oak decline was alleviated as more frequent fire diminished red oak regeneration, thus shifting stand-level species dynamics. The result was a landscape with greater resistance to decline due to the replacement of red oak species with the more decline-resistant white oak species. For detailed results of study 3, see Spetich and He (2008).

Regional Scale, Study 4 – drought:

Beginning one year after the instigating drought, the proportion of dead basal area of white oak species remained relatively stable and was comparable to non-oak species from 1999 to 2010, with both white and non-oak averaging approximately 5 percent of dead basal area. The proportion of dead basal area was not significantly different than non-oak in at least eight of the twelve years. In fact, during three of the years in which dead basal area differed more than one standard error (1999, 2008, and 2009), white oak mortality was lower than non-oaks.

However, dead basal area of red oak was significantly greater than white oak and non-oaks from 2000 to 2010, starting at a low of 8 percent dead basal area in 1999 and increasing to approximately 15 percent of dead basal area by 2008. Cross-correlation analysis revealed a significant relationship between red oak mortality and growing season PDSI. This indicated a two- to three-year lag of mortality after single droughts and a cumulative impact of droughts of up to ten years. For additional details, see Fan and others (2012).

Recommendations for Forest Land Managers:

Harvesting mature stands without regard to species is not likely to fully mitigate oak decline on high risk sites. However, over time even low frequency of prescribed fires could significantly decrease the area of potential oak decline. Time for a measurable response resulting from prescribed burning is likely measured in decades, because the change is based on the growth and succession of forest tree species. Prior to burning, managers should assess oak regeneration for sufficient density to meet site specific management objectives and locate stands with white oaks that are at least five years old. White oaks are more resistant to oak decline than red oaks, and white oaks will be favored

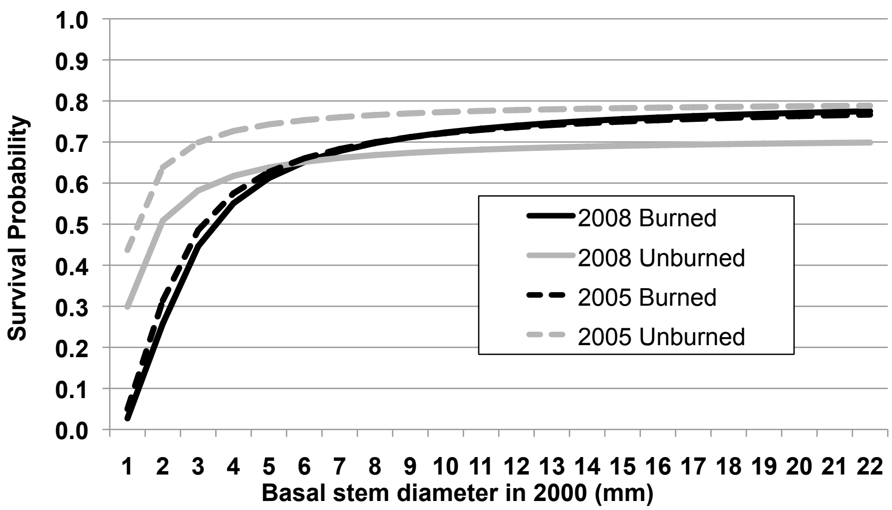

Figure 1—Study 1, oak regeneration. Red oak survival probability in the burned vs. unburned areas in 2005 and again in 2008.

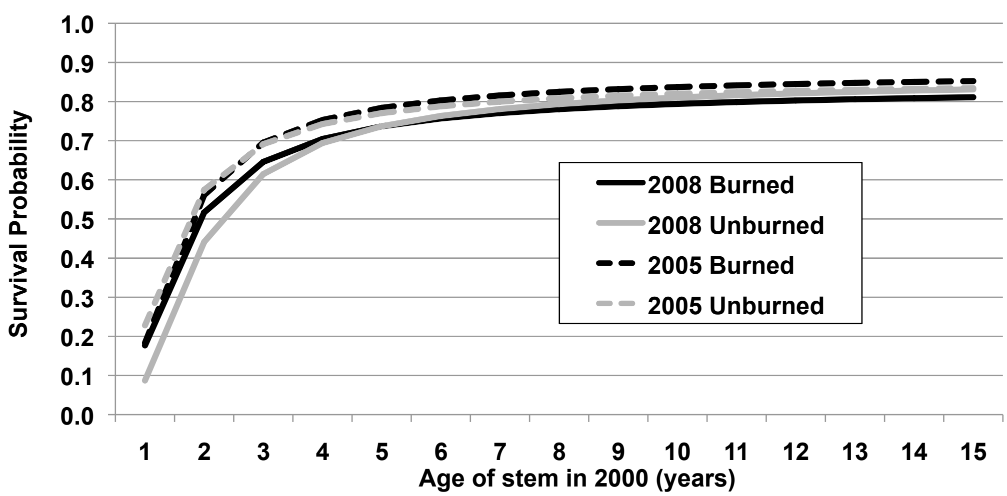

Figure 2—Study 1, oak regeneration. White oak survival probability in the burned vs. unburned areas in 2005 and again in 2008.

by prescribed burning in stands where white oak stems are mostly five years of age or older and red oaks are mostly smaller than 6 mm in basal diameter.

In light of a climate with increasing drought, increasing temperatures, and the lag time required for the impact of cumulative droughts on oak decline in the Ozarks to materialize, managers should consider proactive treatments for established oak stands. However, in study 2 above and in an applied harvesting study (Dwyer and others 2007), the mature stands that were harvested showed either modest or no impact on decline, so earlier intervention may be necessary, especially on high risk sites. In younger stands, this might be accomplished by harvesting red oak species on high risk sites before the trees reach a decline-susceptible age in order to help mitigate future oak decline effects. In high risk mature stands, it may be prudent to harvest most of the mature red oaks in a single treatment entry because sustaining red oaks through multiple thinning treatments is difficult on those sites. It is at maturity that red oak becomes most susceptible to oak decline (Manion 1991, Starkey and others 2004). Decline-resistant species like white oak could then be grown to rotation age while working to establish more white oak regeneration. The harvest of red oaks on decline-prone sites would likely be an intermediate harvest or a stand improvement harvest to address this forest health issue. Further, where there are limited resources, potential hot spots for oak decline can be identified through landscape-scale modeling [e.g., the LANDIS PRO model (He 2015)] so that limited forest management funding could be utilized most effectively.

Future studies should examine a combination of the above two methods by (a) using harvest methods to begin changing the overstory and understory species composition, and (b) applying prescribed fire to further encourage establishment and survival of decline-resistant species.

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