ROTATION LENGTH BASED ON A TIME SERIES ANALYSIS OF TIMBER DEGRADE CAUSED BY OAK BORERS

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Abstract—Recent outbreaks of red oak borer (*Enaphalodes rufulus* Haldeman) are causing unprecedented economic devaluation of red oak timber in many areas of the Ozarks in the Midwestern United States. Managers have few guidelines for coping with this problem in the long-term. Here we present a retrospective analysis of degrade in wood quality and value focused on cumulative degrade caused by oak borers over a period of approximately 80 years. This study is intended to provide managers with guidance on the temporal aspects of changes in wood quality as these are related to timber value and damage from oak borers. A dendrochronological determination of the cumulative number of dated xylem tunnels and wounds, basal area, and stand age was used to assess changes in timber value in a red oak stand. We sampled 31 black (*Quercus velutina* Lam.) and scarlet oaks (*Q. coccinea* Meunchh.) along two belt transects in a forest with observable red oak borer activity and canopy dieback near Bixby, Missouri in the Ozark Highlands. Cross-sections were taken along tree boles at one m intervals beginning at one m above the ground. Annual growth increments were cross-dated (Stokes and Smiley 1968) and tree stem initiation dates determined. We identified and determined the year of occurrence of 745 borer wounds on 137 cross sections. We used the cumulative frequency of dated injuries that occurred between 1925 and 2001 as a proxy for the amount of economic degrade that occurred throughout the life of the stand. The cumulative distribution of dated borer wounds and tunnels increased exponentially from the date of stand origin (circa 1925) with a dramatic pulse beginning about 1975. Based on data from this location, the earliest time of harvest for maximum value was about 1975 at a rotation length of about 60 years. After 1975 value either stayed the same or decreased depending on the difference in price between degraded and sound wood. The study provides a new and important approach to assessing temporal changes in red oak borer degrade caused by wood boring beetles.

INTRODUCTION

The numerous large tunnels (approximately 1 cm diameter x 20 cm long) resulting from red oak borer (*Enaphalodes rufulus* Haldeman) outbreaks (Solomon 1995) are causing unprecedented devaluation of red oak timber in many areas of the Ozarks in the Midwestern United States. Managers have few guidelines for coping with timber quality problems due to chronic insect damage (Gansner and Herrick 1982) and changing environmental and forest conditions (Muzika and Guyette 2004). In this paper we present a retrospective analysis focused on cumulative degrade caused by oak borers over a period of approximately 80 years. This analysis provides guidance on temporal aspects of wood quality, rotation age, and forest value due to damage from oak borers, thereby adding more information to the many considerations for optimal rotation length (Brazee and Newman 1999). Site productivity and red oak borer population dynamics vary greatly among sites and regions; therefore, this study's major contribution is to describe a means to assess the temporal dimension of red oak borer degrade in oak stands. We use dendrochronological methods to determine the cumulative number of defects from dated oak borer xylem tunnels and wounds, annual basal area increment at a given age, and stand age, and use these variables to assess changes in timber quality that influence optimum rotation age. The specific objective of this paper is to develop an equation that can be used to estimate the optimal rotation length for the best economic value considering only oak borer damage.

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METHODS

The study area was in the Mark Twain National Forest, near Bixby, Missouri, in the Ozark Highlands. Using two belt transects in a forest with observable red oak borer activity and canopy dieback, we sampled 31 oak trees, with approximately equal numbers from black oak (*Q. velutina* Lam.) and scarlet oak (*Q. coccinea* Meunchh.). Cross-sections were taken along potential saw logs at one m intervals beginning at one m above the ground. Annual growth increments were cross-dated (Stokes and Smiley 1968) and tree stem recruitment dates at 1 m in height. We identified and dated 745 borer wounds on 137 cross-sections. Injuries were identified as borer damage by wound configuration and characteristics (e.g. size, xylem wound shape, holes in bark, excelsior fibers), the presence of borer tunnels and tunnel stain traces, and the occurrence of live larvae in tunnels. Although all borer wounds can be dated, not all borer tunnels on a cross-section are datable. Tunnels constructed within the wood do not elicit a growth response from the dead heartwood or sapwood. However, every borer tunnel has an entrance wound and often an exit wound, and year of entrance and exit were determined when these wounds occurred on the sample cross-sections. Annual basal area increment (BAI) of the trees was estimated for each year by calculating basal area increment from the ring-widths of the trees. The BAI was used as a cumulative measurement of growth and increasing timber volume.

The timing and accumulation of timber quality defects can be estimated over the life of a stand of oak trees from dated borer tunnels and injuries. The cumulative frequency of dated injuries that occurred between 1925 and 2001 is used as a proxy for the amount of degrade that occurred in timber throughout the life of the stand. We developed the assumption that all red oak borer tunnels and injuries reduce the value of timber. We used hypothetical levels of price reduction at three levels for degraded timber. We use the difference in price between timber that has no borer injury and the percent of this price for timber with varying levels of degrade. Admittedly, there are many variables we have not included in this analysis since the objective was to determine optimal rotation length based solely on timber quality degrade by oak borers. For example, the price differential for degraded and non-degraded timber which affects optimum rotation age would vary through time. This variability, although interesting, is difficult to document and we do not address this in our analysis. Additional value may be gained when the stand regenerated or when ingrowth can occur. We did not address these factors due to the limited nature of our study.

We developed an equation for estimating rotation age and tracking value in the stand based on (1) the cumulative amount of wood increasing in the harvest trees each year, (2) the cumulative degrade to this wood by oak borers, and (3) the difference between the value of degraded timber and undamaged timber. This price differential (a constant) determines the magnitude of difference in annual value estimates while the two time series variables (BAI and borer degrade) operate in opposing directions. We developed the equation both theoretically (using known relationships among variables) and empirically by testing the equation against known conditions. We assumed a linear relationship between economic value and the number of oak borer tunnels and wounds.

The output of the derived equation was calculated for three scenarios of market value. We used three levels of market price reduction (as percent of wood that is free of degrade): 25 percent, 50 percent, and 75 percent. The optimal rotation length was determined by the difference in value between degraded lumber versus non-degraded lumber and the rate of degrade accumulation.

RESULTS AND DISCUSSION

The cumulative distribution of dated borer wounds (fig. 1) and tunnels increased generally in an exponential form from the date of stand origin (circa 1925). During the last 20 years of the trees lives major borer damage occurred with increasing frequency in 1982, 1986, 1996, 1998, and 2000. Beginning about 1975 the rate increases from about 3 wounds per year to 23 wounds per year for all cross-sections in the sample. Whether this increase is due to the biology and population dynamics of the red oak borer or to environment factors or both is not known, but this rate precedes abrupt decreases in timber value as predicted below.

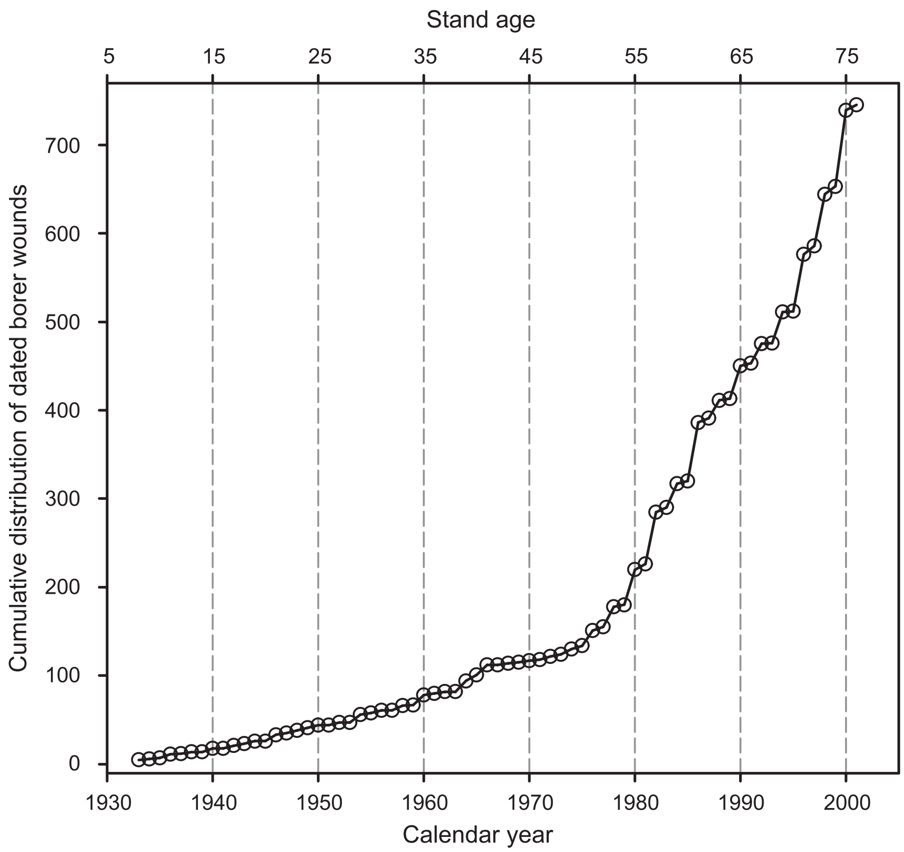

Figure 1—The cumulative distribution of dated borer wounds and tunnels determined from cross sections of 31 red oak trees sampled at 1-m intervals along 10 m of bole. The rate of borer wounding began increasing about 1975.

By comparing estimates of timber degrade (cumulative red oak borer wounds) with stand growth (BAI) we can determine an optimum rotation age for timber value based on different scenarios of likely market value (fig. 2). Timber value estimated from the accumulation of both borer tunnels and increasing basal area of the stand is described by the equation:

$$TV(\%) = PCBAI * \{[(100\text{-}CBORER) + (pd * CBORER)]/100\} \quad (1)$$

where

TV(%) = percent timber value compared to undamaged timber
PCBAI = the cumulative percent increase in basal area
CBORER = cumulative percent borer damage
pd = degraded timber price/non-degrade price

Based on the first abrupt decline in annual estimates of relative value, these scenarios yielded a difference in rotation length of 16 years (table 1). If there is no difference in market value for timber with and without defect (e.g. firewood) then rotation length and value will not be different (Scenario 100%, fig. 2).

CONCLUSIONS

Cumulative indices of red oak borer degrade indicate that stand devaluation often begins one to two or more decades before typical rotation lengths of 65 to 85 years. Also, this devaluation often goes unnoticed until cutting begins. In these stands, once the rate of red oak borer activity increases (in 1975 in this study), increase in stand volume does not offset devaluation due to borer damage under most price scenarios.

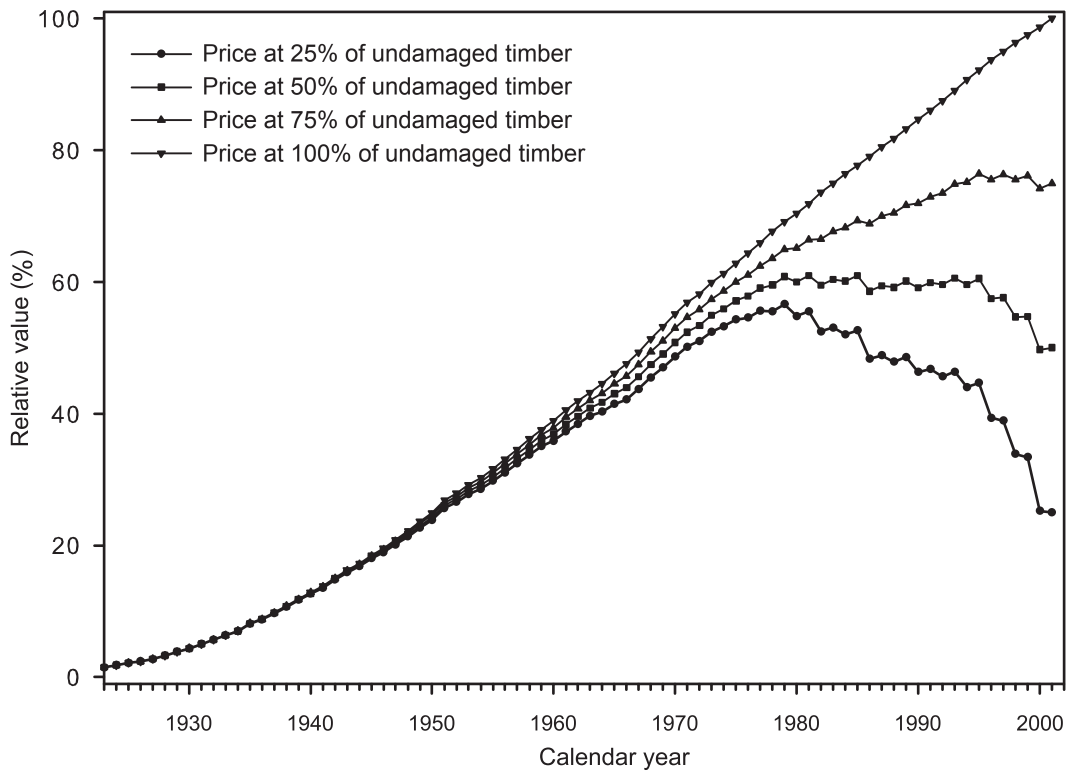

Figure 2—Plots of relative timber value at four levels of time-constant price differential between borer degraded and nondegraded timber. Rotation ages are based on the first abrupt decline in annual estimates of relative value.

Table 1—Rotation age versus market price reduction due to oak borer degrade in a red oak stand

Scenario	Residual value [a]	Harvest date [b]	Constant period [c]	Optimum rotation [d]
75% value reduction	25%	1979	1979-1980	54 years
50% value reduction	50%	1980	1980-1994	55 years
25% value reduction	75%	1995	1994-1999	70 years

[a] Residual value represents degraded timber value divided by non-degraded timber value and multiplied by 100.
[b] Optimum harvest date is defined as the calendar year of increasing value.
[c] Constant period refers to the period when timber value remains the same despite increasing BAI.
[d] Optimum rotation is the length of the rotation based on tree age.

In even aged, low site index red oak stands, where borer outbreaks and populations are high, short rotation intervals of less than 60 years may be optimum if timber quality is a consideration. The optimum rotation length for forests with severely degraded timber quality was 54 years. This study underscores the need to consider insect damage in infested forests when determining optimal rotation length.

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