TIMBER PRODUCT VALUE LOSS DUE TO PRESCRIBED FIRE CAUSED INJURIES IN RED OAK TREES

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by

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The undersigned, appointed by the dean of the Graduate School, have examined the thesis entitled:

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a candidate for the degree of Master of Science, and hereby certify that, in their opinion, it is worthy of acceptance.

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TIMBER PRODUCT VALUE LOSS DUE TO PRESCRIBED FIRE CAUSED INJURIES IN RED OAK TREES

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ABSTRACT

Prescribed fire is used for a variety of land management tasks in sites containing merchantable sized red oak trees with sparse information on how it affects lumber product values. We analyzed how fire related injuries affect lumber volume and value in 88 red oak (*Quercus velutina, Q. rubra, and Q. coccinea*) lowest logs harvested from three sites in southern Missouri. Trees with varying degrees of external fire damage, time since fire, and diameter were harvested and milled into dimensional lumber. Lumber grade changes and volume losses due to fire related injuries were tracked on individual boards (n=1298, 18.3 cubic meters (7754 board feet)) and analyzed using the individual log as the unit of study. Observed volume and grade per board were compared to expected volume and grade (ignoring fire damage). Threshold values were identified regarding scar height and percent basal circumference injured, beyond which significant value losses occur. Annual percent value loss for different fire scar sizes was determined for the first fourteen years after fire damage occurred. Overall, value and volume losses due to fire damage were surprising low. If fire damage is less than 50 cm tall and/or 20 percent basal circumference injured, little value loss is expected. If these thresholds are exceeded, value loss is likely. Value loss is very low if trees are harvested within five after fire damage, regardless of scar size. These findings are applicable under these constraints: Time between fire damage and tree harvest is not greater than fourteen years, and trees are at least 20 cm diameter at breast height at time of fire damage.

Chapter 1

Introduction

Throughout the understood human history of the Missouri Ozarks, the interactions between humans, fire and their cultured ecosystems have swung like a pendulum. Native Americans wielded fire as a tool to manipulate their surroundings, manipulating the flora and fauna of their landscapes (Guyette and Cutter 1991, Black et al. 2006). Bringing their own fire culture and likely mimicking Native Americans, European settlers frequently set fire to the woodlands, savannas, and forests of southern Missouri to promote browse (herbaceous) material for their free roaming cattle and hogs permitted under the open range tradition of the Missouri Ozarks (Flader 2008). The timber resource was fully exploited by the end of the 1920s, and forestry professionals began to look toward cultivating a forest on the steep slopes and thin soils of the Ozark Mountains (Palmer 1991). The frequent fire culture was of great concern to forest managers (Guldin 2008). Technological advances after World War II led to effective and widespread fire suppression. The pendulum of human fire use swung away from frequent toward suppression. Late in the 20th century, scientific understanding of the complex interactions between fire and oak (*Quercus*) ecosystems began to be elucidated (Abrams 1992). Presently, in the Missouri Ozarks, and the eastern United States in general, the deliberate use of fire as a management tool (prescribed fire) has increased both in occurrence and acceptance (Hartman 2005, Nowacki and Abrams 2008) as an appropriate and effective land management tool.

Prescribed fire is the deliberate use of fire as a land management tool under specified conditions. It is employed in eastern oak ecosystems as a tool for natural community restoration, hazardous fuel reduction, and for silvicultural objectives (Burton 2011, Hartman 2005, Brose 1998, Pyne et al. 1996). In Missouri, prescribed fire is used to restore glades, savannas, and woodlands by decreasing the number of woody stems, creating forest canopy openings, and favoring fire tolerant tree and shade intolerant herbaceous species (personal communication Aaron Stevenson, Missouri Department of Conservation Fire Ecologist March 2012). Confidence that prescribed fire can meet these goals can be found in Ratajczak (2012) which demonstrated that the encroachment of woody stems decreased herbaceous volume and species diversity in sites across North America.

Mark Twain National Forest (MTNF) in southern Missouri offers a good example of this increasing fire use pendulum swing. Figure 1A shows a dramatic increase in the total acres prescribed burned on MTNF property from 1971 to 2012. In tandem, there is a steady increase in the area contained in an individual prescribed fire unit (Figure 1B). As land management agencies increasingly move toward landscape level management processes, prescribed fire will likely burn across ecological boundaries more frequently, including into stands of merchantable timber. Currently, there is a need for scientific knowledge regarding how prescribed fire affects timber product values in areas containing merchantable sized trees.

It is well documented that fire causes injuries to tree boles and can serve as entrance ways for wood degrading fungi and insects (Nelson et al. 1933, Berry and Beaton 1972, Shigo 1984, Gutsell and Johnson 1996, Brose and Van Lear 1999, Bova and Dickinson 2005). Recent studies in oak ecosystems have investigated fire scar characteristics (Smith and Sutherland 1999), landscape and fire intensity influences on fire scarring (Stevenson 2007), fire scar formation likelihood (McEwan et al. 2007), and relationships between fire scar formation, tree diameter, and growth rate (Guyette and Stambaugh 2004).

There have been no studies investigating fire-caused timber value loss measured in actual lumber products. Three studies found in the conducted literature review investigate closely related subject matters.

Burns (1955) measured scalable defect and cull on fire damaged small (average 12 in. diameter at breast height (DBH, measured on bole at 1.5 meter above ground)) red and white oak (*Quercus coccinea* Muenchh., *Q. velutina* Lam., and *Q. alba*) logs in southern Missouri. Cull and scalable defect due to fire was distinguished from non-fire related cull and scalable defect. Fire scars were classified as being either ‘open’, ‘healed’, or ‘hidden’. It was attempted to depict a relationship between fire scar classification and percent cull on the log. Findings include that cull was frequently associated with fire damage, and that too large amount of variability existed in the amount of decay present in fire scarred logs to accurately predict percent cull by scar type. Fire scar cull averaged six to twelve percent per log.

Loomis (1974) scaled and graded (USDA Forest Service 1965) logs with fire damage twice: 1) ignoring fire defect, 2) including fire related defects. Prediction equations were developed for: lumber value loss, volume loss, length scalable defect, and cross sectional area scalable defect. Predictor variables considered were: wound length, wound width, wound age, and DBH at time of injury. Wound length was found to be the best predictor variable for all dependent variables, followed by wound age, DBH at time of injury (except in the case of length scalable defect), and wound width. Seventy percent of lumber value loss was due to volume loss and 30% due to quality loss (log grade change).

Lastly, Guyette and others (2008) investigated prescribed fire effects on volume and log grade on three upland oak species (*Quercus coccinea, Q. velutina,* and *Q. alba*) in southern Missouri. Fire scar dimensions were measured and classified into different types. Logs were graded according to Rast et al. (1973) on fire damaged trees ignoring and accounting for fire caused scalable defect. The height of internal fire related defect (decay, scars, discoloration) was determined by analysis of multiple retained cross-sections from each tree. Only fire related defects from the previous six years were considered in analysis. Finding included models to predict total volume of log in defect (TDV) and percent of log in defect (PercDefect). Scar size and time since fire were predictor variables for TDV and predictor variables for PercDefect were scar size, time since fire, and DBH. Log grades change very little in this study, and the volume of decayed wood was surprisingly low.

This study assessed value loss due to fire in dimensional lumber products milled from fire damaged red oak (*Erythrobalanus*) trees in southern Missouri. The value loss of individual butt logs (lowest log) due to fire damage was determined by the summation of the expected (as if no fire damage occurred) and observed values of dimensional lumber products sawn per log. In southern Missouri red oak trees are harvested for a variety of products including railroad ties, dimensional lumber, blocking, pulp, and biomass. Dimensional lumber was used as the end product due to the fine scale valuation allowed.

Timber product value loss serves as one means of assessing the costs of using prescribed fire. As with all land management decisions, detailed information regarding costs and benefits of utilizing prescribed fire enable informed decision making. We developed and tested two hypotheses toward understanding timber product values losses due to prescribed fire in red oak trees:

Hypothesis 1: Timber product value loss of the butt log can be predicted by external fire scar size dimensions and tree size.

Hypothesis 2: The time between fire damage and harvesting (fire scar residence time) can be used to predict percent value loss per butt log.

Chapter 2

Methods

Site Description

Ninety trees were harvested from prescribed fire units and known wildfire prone areas at three Missouri Department of Conservation (MDC) Areas in southern Missouri: Peck Ranch Conservation Area (Carter Co.), Lead Mine Conservation Area (Dallas Co.), and Graves Mountain Conservation Area (Wayne Co.) (Figure 2). Species included were: black oak (*Q. velutina* Lam., n=58), northern red oak (*Q. rubra* L., n=20), and scarlet oak (*Q. coccinea* Muenchh., n=12) (Table 1). These species were grouped in the ‘red oak’ group economically because they are considered interchangeable with regards to dimensional lumber products (Hardwood Market Report 2011).

All trees were harvested from lands managed with prescribed fire except for fifteen trees at Lead Mine Conservation Area, which were located in an area with a known frequent wildfire history due to fire activity on adjacent private property. The management objective of prescribed fire use at all sites was to increase and maintain coverage of native forbs and grasses by reducing both the number of woody stems and leaf litter depths (personal communication, Aaron Stevenson MDC Fire Ecologist March 2012). Maximum time between prescribed fire damage and harvest (fire scar residence time) was fourteen years at Graves Mountain and Peck Ranch Conservation Areas, and nine years for Lead Mine Conservation Area.

All prescribed fire units in which harvesting occurred were in glade and woodland complexes that follow a three year prescribed fire interval management plan. The trees harvested from Lead Mine and Graves Mountain Conservation Areas were from stands of merchantable sized trees surrounding glades, and were included in the prescribed fire units for fire control purposes. The trees harvested from Peck Ranch Conservation Area were in woodland restoration units. All trees were harvested from areas that are considered MDC "Site Class 2" (personal communication, Steven LaVal MDC Resource Forester May 2012), defined as having a black oak site index of 55-64 (McQuilkin 1974).

Field sampling

Trees of varying merchantable size, log grade (Rast et al. 1973), time since fires, and severity of fire-caused injury (fire scar) were non-randomly selected for sampling. All trees were of merchantable sizes (≥23 cm (9 in.)) diameter at breast height (DBH, measured at 1.37 meters above ground) and exhibited external evidence of fire scarring. The tree selection process sought to represent a wide range of fire scar/tree size relationships, i.e., large trees with small and large fire scars, as well as small trees with small and large fire scars. External fire scars were identified by: occurring on the uphill side at the base of tree, being roughly triangular in shape, and being present on multiple trees in an area (Paulsell 1957, Gutsell and Johnson 1996, Guyette and Cutter 1991, Guyette and Stambaugh 2004). Tree locations were recorded using a hand held global positioning system (GPS) unit and described with regard to aspect and slope (degree, shape, position). Tree DBH and external fire injury dimensions: scar height (ScarH), scar width (ScarW), and scar depth (ScarD) of each tree were measured in the field (Figure 3). ScarW was measured at the widest point; ScarH from the base of the leaf litter to the top of the damaged area; and ScarD at the deepest point within the fire scar area. External fire damage was classified into five scar types corresponding to Guyette et al. (2008) (Figure 4): cat face (triangular in shape), oval, closed (vertical seam on bark surrounded by new bark growth), bark slough (multiple healed over areas spatially connected though not continuous), and basal or flutes (injury only present in exposed root flaring). In the case of ‘closed’ and ‘bark slough’, depth was not measurable and was recorded as 0.3 cm (.1 in.); all other scar types had dead cambium visible surrounded by encroaching new growth. This new growth which is growing over the dead cambium is referred to as ‘woundwood ribs’ by Smith and Sutherland (1999), defined as the thickened annual growth rings that eventually cover the wound. Local professional loggers were contracted to harvest and deliver the butt logs to a local mill. Each tree was cut as low as physically possible and cut to a 2.6 (n=14) or 3.2 (n=76) meter (8.5 or 10.5 feet) log. The logger was instructed to cut the upper portion of the bole (above butt log) into 2.6 meter (8.5 feet) logs down to a minimum 20.3 cm (8 in.) small end diameter (SED), that were considered economically viable given local markets. This number of ‘upper logs’ was recorded per tree sampled. The number of upper logs can be used to describe the economic value of the tree above the butt log. The lower end of each butt log was painted a unique color combination to facilitate log and board tracking through the study. A basal cross-section was retained from the top of each stump for fire scar analysis.

Laboratory

Basal cross-sections were sanded with progressively finer sand paper (80 to 600 grit) to reveal cellular detail of annual rings and fire scar injuries. Fire scars on cross-sections were identified by the presence of callus tissue, cambial injury, and wound wood ribs that cover the dead cambium (Smith and Sutherland 1999). Fire injury dates and tree ages were identified using standard dendrochronological methods (Stokes and Smiley 1996). Measurements made on each basal cross-section included: radius at time of each fire injury and at time of harvest (each an average of two measurements, pith to year of injury or harvest (outside bark)), and the length injured along the circumference of the section for each fire scar (scar arc) (Figure 5).

Milling and Grading

At the mill the SED was measured inside the bark of each butt log. Logs were then evaluated and assigned a factory-lumber log class using the hardwood log grading methods developed by Rast et al. (1973). Logs were graded ignoring the fire-caused defect to describe the amount of non-fire-related defects present. Scale deductions were calculated for sweep, crook, and non-fire-related rot. Rast et al.’s (1973) guidelines stipulate that logs are graded on the condition of their third (of four) worst face, under the assumption that the mill operator will always cut off the worst face in the first cut. Therefore, during the log grading process a white line was painted on the log indicating the worst face. This ensured that the log was milled consistent with the assigned log grade (which ignored fire scarring). The logs were sawn by a professional mill operator on a Baker Products, Inc. portable band sawmill, with a measured kerf of

0.2 cm (0.09 in.). The mill operator was instructed to ignore the fire-caused defect; cut off the log face indicated as the worst as the first; and to mill each log for the highest grade of 2.9 cm (1.125 in.) dimensional lumber as possible. Logs were milled down to a 10.2 cm (4 in.) square post (cant) which contained the pith. Lumber was cut to variable widths and wane was removed with an edger.

Each board was assigned a number as it came off the mill noting the tree and individual board number. All defects (discoloration, rot, char, missing wood) associated with fire injuries were marked on each board and cant with a wax marker. An observer was located at the front of the mill, adjacent to where the bandsaw blade cut into the wood, to view the fire damaged area as it was sawn and identify which defects in the lumber were spatially related to the external fire damage. This allowed for differentiation between areas of fire damage and lumber defects due to other causes (e.g., insect damage, branch knots, decay related to broken limbs).

A National Hardwood Lumber Association trained lumber grader assigned scale (board feet volume measurement) and lumber grade to each board according to NHLA grading rules (NHLA 2010). Cants were only evaluated in terms of volume, either sound or cull. All boards with fire-related defects were graded/scaled twice:

1) scaled/graded as observed, with fire-related defect incorporated in the assigned values; thus assigning actual volume and grade per board;
2) scaled/graded as if fire-related defect was not present; thus assigning expected volume and grade per board.

These two determinations allowed for a direct comparison between expected and actual volume and grade per board; volume only for cants.

The NHLA recognizes six different red oak lumber grades (in decreasing value): FAS, Select/1Face, 1 Common, 2 Common, 3A, and 3B (NHLA 2010). Lumber grade is dependent on board width, length, and the size, position, and number of clear and sound cuttings. Clear cuttings refer to the amount of surface area of a board that is clear of defect (i.e., rot, branch knots, insect damage), usually determined on the poorest side of the board. Sound cuttings refer to the surface area of a board that is sound though contains minor defects which affect the aesthetic, but not the structural integrity of the board (NHLA 2010). Varying amounts of defect are tolerated per grade, with the assumption that defects will be removed in later manufacturing processes. Volume was determined based on NHLA lumber scaling guidelines (NHLA 2010).

Chapter 3

Analysis

Measurements

Two samples were removed from the data set prior to analysis due to the inability to discern fire from non-fire related defect and determine date of fire damage due to rot. This resulted in a total of 88 trees from which 1,298 dimensional lumber products (1210 boards, 88 cants; 18.3 meter^3 total volume) were produced for analysis. All measurements were collected in English units (inches, board feet) and converted to metric (centimeters, cubic meters) using standard conversion factors (1 inch = 2.54 cm, 1 cubic meter = 423.77 board feet).

Lumber values from the Hardwood Market Report Southern Hardwoods Category (April 16, 2011) were assigned for each board (Table 2) dependent on observed and expected grade and volume. The Hardwood Market Report does not report values for the lowest lumber grade (3B) recognized by NHLA, therefore, this value was determined by personal communication with the only southern Missouri private lumber distributer found (at that time) who bought and sold this grade. The Hardwood Market Report does not report different grades of cants, subsequently only volume can change. All values were for rough green lumber, not stumpage. Expected and actual board/cant values and volumes were summed for each butt log.

This valuation process of grading and scaling each board allowed for the creation of the following variables for each butt log:

Expected log value (ELV):	the value expected if no fire damage occurred
Actual log value (ALV):	the actual value, included fire damage defects

Expected log scale (ELS): the volume of lumber that would have been generated by each log had the fire damage not occurred
Actual log scale (ALS): the observed volume of lumber, included fire damage causes volume loss
Percent value loss (PVL): 1- (ALV/ELV) Eq. 1
Percent scale loss (PSL): 1- (ALS/ELS) Eq. 2
Predicted log scale (PLS): expected log volume estimate using International Scale.

PLS was estimated ignoring fire defect and adjusted for non-fire-related scale deductions (Rast et al. 1973), using Proyield - a spreadsheet program for sawmill analysis (Govett et al. 2005). Proyield allows kerf size to be adjusted depending on mill specifications. Volume estimates were calculated using International Scale (by Proyield) and were based on SED inside bark measurement and log length.

Tree DBH was transformed to tree basal area (TBA) using the area geometric formula of a circle (π*(0.5*diameter)^2), where diameter equals DBH. For all fire scars on all samples, fire scar residence time (R-time) was calculated by subtracting the calendar year of fire injury from the year of harvest. Percent basal circumference injured (ScarArc%) was calculated for all fire scars by dividing the scar arc measurement by the basal circumference derived from the basal radius at the time of fire injury (basal circumference=basal diameter* π). To estimate DBH at time of fire injury (DBH_i) a taper equation (Taper1) for each tree was calculated by dividing DBH at time of harvest (DBH_h) by the basal cross section diameter. This quotient was then multiplied by the basal diameter at time of injury. A second taper equation (Taper2) described the diameter change from the SED of the butt log to the SED of the highest upper log (assumed 20.3 cm (8 in.)). This equation allowed for an estimation of the diameter of each upper log at any location of the length of the log. Summary statistics (mean, range, and standard deviation) were calculated for all external fire scar measurements, tree ages, DBH, PVL, and PSL. R statistical computing package (2008) was used for statistical summaries and regression/correlation analyses.

Stepwise regression was conducted to identify TBA as the strongest predictor variable for volume and value. Linear regression models were created to describe: ALS, ELS, ALV, ELV, and PLS.

Hypothesis I Analysis

PVL model- External fire scar and tree measurements only

We hypothesized that external fire scar size dimensions (ScarH, ScarW, and ScarD) and tree size (DBH at time of harvest) would be significant predictors of PVL. Correlation analysis identified significant ($p < .05$) PVL predictive fire scar and tree measurement variables. Frequency distributions of significant variables and PVL were viewed to observe statistical distributions. Scatterplots of PVL plotted against tree size and external scar dimension variables were assessed to examine statistical relationships. Trees with fire damage which occurred more than 30 years prior to harvest were excluded to maintain DBH at time of injury comparable amongst trees, as well as to consider only fire damage which occurred during the prescribed fire era in Missouri (Hartman 2005). This stratified data set is hereafter referred to as the *PVL data set*. Separate summary statistics were calculated for select *PVL data set* variables.

The product of the significant fire scar dimension variables scar height and scar depth was divided by tree size (TBA) to create interaction variable HDWA (Eq.1), an index value normalized by tree size.

HDWA= (ScarH*ScarD)/TBA Eq.3

Ordinary least squares linear regression was used to describe the relationship between HDWA and PVL. Three models were considered:

1) Zero value observations excluded and response variable not transformed.
2) Response variable zero value observations excluded and response variable transformed to its logit form (logit(PVL)), where:

   logit(PVL) = ln(PVL) – ln(1-PVL) Eq. 4

3) Untransformed and zero PVL values response variable observations included.

Whole tree bole value loss vs. butt log value loss

Seventy eight of the eighty eight trees analyzed had logs above the butt log retained by the logger, average 2.2 upper logs per tree (each log = 244 cm (96 in.)). The model predicting ELV allows for the value of each log above the butt log to be estimated using TBA which is calculated from DBH. This enabled value loss to be estimated for the whole tree bole, rather than the butt log only. DBH for each upper log was estimated by:

DBH first upper log = SED(butt log) – (Taper2*(137.16_1 (cm))) Eq. 5
DBH second upper log = SED(butt log) – (Taper2*(396.24_1 (cm))) Eq. 6
DBH third upper log = SED(butt log) – (Taper2*(655.32_1 (cm))) Eq. 7

DBH fourth upper log = SED(butt log) – (Taper2*(914.40_1 (cm))) Eq. 8

DBH fifth upper log = SED(butt log) - Taper2*(1173.48_1 (cm))) Eq. 9

[1] This is the estimated distance above the SED of the butt log corresponding to DBH on each upper log, 15.24 cm (6 in.) trim assumed per upper log.

VLDFS analysis

Most of the 88 trees analyzed had been damaged by multiple fires; either wildfires, prescribed fires, or both. This made associating fire damage characteristics of an individual fire scar (e.g., scar height, scar arc, residence time) to the PVL of an individual log not possible when only considering external fire scar measurements. Cross-sections retained from the stumps were visually inspected and ScarArc% for each fire scar per cross-section compared to determine if the fire damage associated with wood decay experienced by the log could be attributed to one value loss driving scar fire scar (VLDFS fire scar). Many trees were significantly more damaged by one fire event than others. Figure 6 shows the range of fire scar complexity in the 88 trees included in analysis. Six trees had only one fire scar (Fig.6A), therefore assigning value loss to a single fire event was simple. Some (Fig.6B) experienced fire damage early in life and successfully healed over the injury, and were then injured by fire again later in the tree's lifespan. No decay is associated with the early fire scar, and value loss can be attributed to the subsequent fire scar. Figure 6C depicts one large fire scar with substantially smaller fire scars from subsequent fires. In this case value loss is attributed to the large fire scar. Some were a combination of 6B and 6C, in which trees were scarred when small, healed over quickly and then one of several prescribed fire scars were dominant. Figure 6D shows a cross section recording 6 fire scars spanning most of its lifespan, an example of the type of fire scar history that is not included in the VLDFS data set.

Sixty-eight of the 88 trees included in analysis met the criteria to be assigned a VLDFS. These sixty-eight observations were further stratified to exclude those with VLDFS values greater than 30 years, and whose external fire damage was healed over; leaving 57 observations in the *VLDFS data set*. Separate summary statistics were calculated for select variables in the *VLDFS data set*. Scatterplots were created to inspect the relationship between PVL and ScarArc% and ScarH.

Fire scars on trees in which a VLDFS was identified could be classified into three groups based on when in the tree's life history they occurred: Before VLDFS, VLDFS, and After VLDFS. The average R-time and DBH (at time of fire injury) were determined for each of these classifications.

Hypothesis II Analysis

The *VLDFS data set* was analyzed in Hypothesis II analysis. We hypothesized that PVL is influenced by fire scar residence time (R-time). Based on findings in the results from Hypothesis 1 analysis, it was determined that PVL was strongly influenced by fire scar height (ScarH) and fire scar depth (ScarD). Possible relationships were explored between ScarD and R-time, under the assumption that ScarD is a function of tree growth and wood decay (e.g., Figure 3B) both governed by R-time. A significant ($p < .05$) logarithmic regression equation was developed predicting R-time considering ScarD as the predictor variable. Relationships were explored between R-time, ScarH, and PVL.

Chapter 4

Results and Discussion

Summary statistics

All trees sampled

For all trees harvested (n=90), DBH at time of harvest ranged from 24.1 – 62.9 cm (9.5 – 24.75 in.) average/standard deviation = 41.1/9.35 cm (16.2/3.68 in.). The frequency distribution of DBH at time of harvest appeared to be normally distributed (Figure 7). Species composition was skewed toward black oaks (65%) with trailing number of northern red (22%) and scarlet (13%) oaks. Butt log grades (ignoring fire defect) were distributed (Figure 8) as follows (in decreasing quality): F1: 17 logs, F2: 41 logs, F3: 26 logs, Local Use: 4 logs. Scar type distribution was as follows: Cat face: 56, Oval: 8, Closed: 10, Bark slough: 4, Basal or flutes: 10.

All trees included in analysis

Considering all trees included in analysis, 233 fire scars were recorded by 88 trees. DBH at time of injury ranged from .76 – 57.68 cm (.30 – 22.71 in.); average/standard deviation 30.15/14.17 cm (11.87/5.58 in.). Tree ages at harvest ranged from 43 to 180 years; average/standard deviation= 84.15/25.44 years. Fire scar heights ranged from 15.24 – 391.16 cm (6 -154 inches); average/standard deviation = 86.32/64.46 cm (33.98/25.38 in.); fire scar width ranged from 2.54 – 142.24 cm (1-56 in.); average/standard deviation = 50.11/32.33 cm (19.73/12.73 in.); and fire scar depths ranged from .30 – 37.8 cm (.1 – 14.9 in.); average/standard deviation = 6.8/6.14 cm (2.68/2.42 in.). ScarArc% ranged from 1.23 to 80.74%; average/standard deviation =

21.85/18.63. Fire scar residence time ranged from 1 – 153 years; average/standard deviation = 17.76/25.09.

PSL ranged from 0 – 61.70%; average/standard deviation = 3.91/8.84%. PVL ranged from 0 – 68.06%; average/standard deviation = 10.33/14.10%. The average value loss for the whole tree due to fire damage, opposed to just the butt log, decreased from 10.33 to 7.14%.

Table 3 lists summary statistics for important modeling values for *PVL* and *VLDFS data sets*.

Volume vs. value loss

Lumber grade changes accounted for value loss more than volume loss. Considering all lumber produced from the 88 trees (1210 boards, 88 cants) included in analysis, 2.42 percent of the volume was lost due to fire, compared to 9.44 percent value loss (234 boards or cants experienced value loss while only 79 experienced volume loss). Similarly, at the butt log level, 57 logs experienced value losses while only 37 experienced volume losses. Higher value grades (FAS, 1 Face/Select, 1 Common, and 2 Common) had actual volumes that were lower than the expected volumes. Low value grades (3A, 2 Common, 3B and cull) had actual volumes that were higher than the expected values (Figure 9). These differences between observed and expected volume per lumber grade are explained by the grade change occurrence of individual boards due to fire damage. Cants were not included in this figure because they were not categorized into different grades, but can only lose volume.

Volume and value models

Models were created to determine relationships and for graphic comparisons amongst different variables. All 88 trees included in analysis were considered in this analysis.

Expected log value (ELV) (Figure 10)

$ELV = .0389*(TBA) - 11.287$ Eq. 10

$r^2 = .8046$, $n=88$, $p < .001$

Actual log value (ALV)

$ALV = .0363*(TBA) - 11.792$ Eq. 11

$r^2 = .7471$, $n= 88$, $p < .001$

Expected log scale (ELS)

$ELS = .0001*(TBA) + .0035$ Eq.12

$r^2 = .7514$, $n= 88$, $p < .001$

Actual log scale (ALS)

$ALS = .0001*(TBA) - .0002$ Eq. 13

$r^2 = .7419$, $n= 88$, $p < .001$

Predicted log scale (PLS)

$PLS = .0002*(TBA) - .044$ Eq. 14

$r^2 = .9181$, $n=88$, $p < .001$

The regression equations 10 and 11 were plotted on one graph (Figure 11), allowing for comparison. Though quite similar, it is noteworthy that these equations suggest that larger trees lose more value than small trees. This is likely explained by the higher value expected in larger logs, therefore value loss is greater.

The regression equations 12, 13, and 14 were all also plotted on one graph (Figure 12). This allowed for consideration of the relative effects of fire damage versus scale estimation errors in common and widely used log volume estimating equations. It can be seen that the actual and expected scale equations were nearly identical, the slight difference accounted for by fire damage. International scale had considerably more error (compared to regression line for ELV), both for large and small trees, than the loss due to fire introduced.

Hypothesis I

PVL predictive model

This analysis only considered external tree and fire scar measurements made in the field, prior to tree being felled and cut into log lengths. Correlation analysis identified significant ($p < .05$) PVL predictive fire scar and tree measurement variables (Table 4). External fire scar width (ScarW) appeared to have no statistical relevance to PVL. It is likely that ScarW is a poor predictor because it changes rather quickly after fire scar formation. Woundwood ribs grow faster compared to other parts of the bole (Smith and Sutherland 1999), consequently this measurement will vary greatly depending on R-time. Fire scar height (ScarH) and depth (ScarD) are shown to be significant predictors of PVL. Previous studies have also found fire scar height to be the best predictor of quality or volume loss (Guyette et al. 2008, Loomis 1974, and Loomis and Paananen 1989). Loomis and Paananen (1989) found time since fire injury (R-time) to be an important predictor of value. It is logical that ScarD is related to R-time and this is explored closely below in Hypothesis II analysis.

Figure 13 shows the frequency distribution for all significant predictor variables (ScarH, ScarD, HDWA) and response variable PVL. All are heavily skewed toward low values. Eighteen of forty-nine PVL observations considered in the PVL model were zero values. Because PVL is a probability (percent) variable (between 0 and 1 when in decimal form) and due to the considerable number of zero response variables (which can exhibit excessive influence in linear regression models), three models were considered and evaluated.

1) Excluding zero values and no PVL transformation:
   $PVL= .0379 + (.1242*HDWA)$ Eq. 15
   $r^2= .68, n=31, p < .001$

2) Excluding zero values and logit transformed:
   $logitPVL= -1.2263 + (.3526*HDWA)$ Eq. 16
   $r^2= .57, n=31, p < .001$, where:
   $logit(PVL)= \ln(PVL) – (\ln(1- PVL))$

3) No transformation/including zero values:
   $PVL= 0.0051 + (0.135*HDWA)$ Eq. 17
   $r^2= .71, n=49, p < .001$
   (Figure14)

Models were compared and Eq. 17 was chosen as the best model. This model was chosen because it considered the highest sample size (n=49 vs. n=31) and experienced the least amount of data manipulation. The model appears to explain a large amount (71%) of the variance in PVL at a statistically significant p value.

A field reference table (Table 5) was developed using Eq.17 to estimate PVL of fire-damaged butt logs. This table estimates percent value loss to date (at time of measurement). This table was developed using the midpoint value between DBH size class (e.g., 26.5 cm for the 25 cm column) and the regression coefficients from Eq.17. This table represents a snap shot in time view of PVL as it relates to external fire scar dimensions and tree size, at time of harvest. This table requires that external fire scar dimensions ScarH and ScarD be measureable. There is a period of time, approximately one to two years, that bark is still covering the dead cambium; therefore external fire scar dimensions are not measureable. For this reason this table is most appropriate for use on trees with fire scar residence times of at least 3 years. This is consistent with what Loomis (1973) suggested for an appropriate time period after fire to assess fire damage to hardwood trees.

Fire Scar Height and Percent Circumference Injured Thresholds

By coupling PVL to one fire event per log, the *VLDFS data set* allowed for identifying change points and relationships in the data that would not be possible otherwise. Thresholds were identified relating to scar height and percent circumference injured: 50 cm (~20 in.) for scar height and 20 percent for ScarArc% (Figures 15 and 16). PVL sharply increases after about 50 cm for scar height. Eighty three trees with any value loss had fire scar heights greater than 50 cm and ninety four percent had ScarArc% values greater than 20 percent.

Fifty of the fifty seven VLDFS data set trees had multiple fire scars recorded on the analyzed cross-sections. These fire scars can be classified as either: Before

VLDFS, VLDFS, or After VLDFS, depending on when in the tree's life history the fire scar was recorded. Table 6 summarizes average DBH (at time of fire injury) and R-time for each of these groups. Considering the After VLDFS group of fire scars (e.g., Figure 6C), sixty five fire scars on thirty eight trees were removed in the milling process, and discarded in the slab pile (Figure 17). The average R-time for these discarded fire scars was 3.81 years, and the average DBH (at time of fire injury) was 38.71 (cm). Regarding the Before VLDFS group of fire scars, twenty seven fire scars were effectively compartmentalized (*sensu* Shigo 1984) when the tree was relatively small (average DBH (at time of fire injury) = 17.6 cm, average R-time = 45.55 years. Any associated lumber defect is contained within the square cant (e.g., 6B). .

Guyette et. al (2008), Loomis (1974) and Crosby (1977) all suggest that there is a time period in a tree's development when fire defects are more likely to lead to value loss. These studies all suggest that injuries to small trees are frequently quickly healed over; and that trees that are very large when injured are likely not far from harvest time and defect is likely contained to the outer portion of the log and discarded in the slab pile. The findings listed in Table 6 support this concept. Tree size for injuries which were healed over without resulting in value loss tended to be smaller, and tree size for injuries whose defects were removed in the milling process tended to be larger.

Hypothesis II

A significant ($p < .05$) logarithmic regression equation was developed predicting ScarD considering R-time (of the VLDFS) as the predictor variable.

$$\log(\text{ScarD}) = .12383 + .09376*(\text{R-time}) \qquad \text{Eq. 18}$$

$$\text{multiple } r^2 = .551,\ p < .001$$

Figure 18 graphically represents the exponential form: $ScarD = e^{(.12383 + .09376*(R\text{-}time))}$. This equation shows a significant relationship between ScarD (an important PVL model variable) and R-time.

Armed with this understanding, models were explored predicting PVL considering only ScarH and R-time. Ultimately a linear model with interactive variables was selected to predict PVL utilizing ScarH and R-time as independent variables (*VLDFS data set*).

$$PVL= -4.059508 + (.64145*(ScarH)) + (.1893*(R\text{-}time)) + (.006035*(ScarH*R\text{-}time)) \qquad \text{Eq.19}$$

multiple $r^2 = .5149$, n=57, model $p < .001$

ScarH	p <	.001
R-time	p =	.002
ScarH*R-time	p =	.067

Line graphs were made using this model to described R-time effect on fire scars of varying heights (Figure 19). The range of scar heights (≥40 and ≤ 175 cm), and R-time (≤14 years) used in this figure represent the range of scar heights and R-time well represented in the VLDFS data set. Seven fire scar heights higher than 175 cm were observed, though the range between those scar heights was greater than those lower than 175 cm. The slope of each line becomes steeper as scar height increases. The dotted line in Figure 19 is that of the average scar height in the entire data set analyzed (n=88): 86 cm. For this scar height, the annual value loss is .7084%. Annual value loss for each fire scar height used in Figure 18 was determined and listed in Table 7. A line graph was constructed depicting annual percent value loss to the butt log predicted by fire scar height (cm) (Figure 20). This model can be used in conjunction with Table 4, or independently. If scar height is measurable (1-2 years post fire), this model can be used to predict value loss at some point in the future (i.e., end of stand rotation or scheduled harvest re-entry point). If the fire damage has been present long enough to gain a measurable fire scar depth, then Table 5 can be used first, and the annual rate of value loss can then be applied to predict the additional value loss at a point in time in the future (within fourteen years fire scar residence time).

Chapter 5

Conclusions

General conclusions

1. Timber product value loss in dimensional lumber products can be reliably estimated though external fire scar and tree size measurements.
2. Volume loss has less impact on timber product value loss than lumber grade change.
3. Timber product value loss can be predicted for different fire scar residency times at varying fire scar heights.
4. Small fire scars (less than 50 cm fire scar height and less than 20% percent basal circumference injured) typically lead to little or no product value loss. Beyond these threshold values timber product value loss can be expected.
5. Fire damage sustained on trees either small or large are frequently successfully compartmentalized or removed in milling process. Trees harvested within 5 years of fire damage typically experience little to no value loss, regardless of fire scar dimensions. Trees damaged at intermediate sizes (i.e., pole size class) may be most susceptible to value losses.

Product considerations

We measured the changes in values of a single but important oak product (i.e., dimensional lumber) due to fire damage. Changes in values to other products are likely different depending on multiple factors such as market values and log defects. For example, railroad ties, a common regional product derived from oaks, could undergo different lumber product devaluation given the same tree and fire scar dimensions. Minor injuries such as small amounts of insect damage or small fire scars likely cause little devaluation in railroad ties but change grades of lumber. Alternatively, compartmentalized injuries in the center of the tree can preclude a log from producing a tie, but if milled into dimensional lumber little value loss will be realized.

The valuation of prescribed fire effects on the economics of forests and woodlands have many dimensions. This study focused on the devaluation of dimensional lumber products from fire scarred red oaks, but there are other important components that should be considered when judging prescribed fire effects on the economic value of timber. These include: the density of scarred trees, the species scarred, and perhaps of most economic significance (in terms of timber products), changes in forest stand structure and species composition.

PVL Model

The model developed for estimating value loss of the butt log up to time of harvest is best suited for use on red oak trees that have an open scar face with fire damage residence times of fourteen years or less. Closed scars can result from very recent injuries that were quickly compartmentalized (i.e., minor wound and decay) or from old extensive fire damage that was healed over with extensive rot and decay under the surface. In cases of closed scars other methods for assessing the degree of decay (e.g., sounding bole with a hammer) may be more useful than this model.

It was insightful to watch apparently heavily damaged logs be milled into dimensional lumber. The process of milling round logs into rectangular dimensional lumber removes significant portions of fire damage in two ways: 1) milling of a log is limited by the small end diameter (dashed white line in Figure 17), which is smaller than the basal diameter because of log taper, and 2) the ‘slabbing’ process (white square, Figure 17) which removes the rounded outer section of the log can also remove a significant portion of defect, particularly of recent occurrence.

Management implications regarding fire scar residence time

Figure 18 allows for a land manager to predict the value loss of the butt log out to some point in the future (within 14 years after fire damage occurance). This will be a very useful reference to help determine if a tree should be cut either very soon, or if it can wait until a planned timber sale, or if might be best not to harvest at all.

Management implications regarding fire scar height, circumference, and residence time

Figures 15 and 16 offer valuable insights regarding the use of fire as a management tool in areas also managed for timber product values. Research has shown that fires often do not damage oak trees at all (McEwan et al. 2007, Brose and Van Lear 1999). Brose and Van Lear (1999) found that efforts toward minimizing logging slash built up at the base of residual trees in a shelterwood silvicultural system can significantly reduce bole damage due to fire. These efforts include directional felling (so not to leave tree tops in the immediate area of residual trees) and manually moving logging slash. Therefore, fire scar size can be minimized through relatively minor efforts. This study demonstrates that when a red oak is damaged by fire, certain amounts of damage can be tolerated and lead to little or no product devaluation. Trees exhibiting fire scars that are smaller than 50 cm (20 in.) tall and that have less than 20 percent of the basal circumference injured experienced minimal product value losses.

Study scope

Like all studies, this study has limited data through which the results must be viewed. Timber product values were only measured on red oak sawlogs (factory lumber grades F1 – Local use). Higher value products such as stave or veneer would likely have different results. The unit of study was the individual butt log. Value losses cannot be extrapolated to a spatial extent, i.e. hectares. Fire scar residence time was effectively limited to 14 years; only two samples with higher fire scar residence times were included in either PVL models (Eq.s 17 and 18). Future work could strengthen these findings through increasing the sample set, both in sample size and longer R-time.

Table 1. Site and sample information

	Peck Ranch CA	Lead Mine CA	Graves Mtn. CA
No. trees	30	28	32
Rx fire residence time* (years)	2-14	4-9	1-14
Tree diameters (cm) mean (range)	36 (25-56)	41 (25-64)	46 (30-54)
Tree ages (years)	78 (53-152)	80 (43-180)	94 (68-117)
No. prescribed fire years	4	3	4
No. wildfire years	2	24	4
Subsection and Land Type Association (LTA)**	Current River Hills Ecological Subsection, Eminence Igneous Glade/Oak Forest Knobs LTA	Osage River Hills Subsection, Niangua River Oak Woodland/Forest Breaks LTA	St. Francois Knobs and Basins Subsection, St. Francois Igneous Glade/Oak Forest Knobs LTA

* fire scar residence time is time lapse between fire damage occurrence and harvest

**(Nigh and schroeder 2002)

Table 2. Expected and observed lumber values for dimensional lumber products per 2.36 cubic meters (one thousand board feet) for rough green lumber (Hardwood Market Report, April 16 2011).

FAS	1 Face/Select	1 Common	2 Common	3A	CANT	3B	Cull
$880	$870	$560	$450	$375	$330	$82.50*	$0

*personal communication (4/21/2012) Jeff Davis, Master's Craft Flooring Company lumber distributer (West Plains, MO.)

Table 3. Summary statistics for important PVL predictor variables in the PVL and VLDFS data sets.

	Number of observations	Range	Average	Standard Deviation
PVL data set (Hypothesis I)				
DBH_h (cm)	49	25.91 - 57.91	40.85	8.53
PVL (%)	49	0 - 68.06	10.07	14.45
ScarH (cm)	49	15.24 - 391.16	97.04	76.46
ScarD (cm)	49	2.54 - 10.50	3	2.03
All fire scars on 49 trees				
R-time (years)	122	1 - 29	6.81	5.08
VLDFS data set (Hypothesis II)				
log measurements				
DBH_h (cm)	57	25.91 - 62.23	41.88	9.22
PVL (%)	57	0 - 49.57	8.56	11.49
ScarH (cm)	57	17.68 - 391.16	94.84	73.37
VLDFS fire scar measurement				
R-time (years)	57	2 - 14	8.82	4.36
DBH_i (cm)	57	15.82 - 50.37	33.14	9.77
All fire scars on 57 trees				
R-time (years)	148	1 - 123	13.36	21.52
DBH_i (cm)	148	1.37 - 57.69	32.96	13.41

DBH_h= Diameter at breast height (DBH) at time of harvest; PVL = percent value loss to red oak butt log due to fire damage; ScarH = fire scar height; ScarD = fire scar depth; R-time = time lapse between fire damage occurrence and tree harvest.

Table 4. Pearson's correlation coefficients (*r*) for percent value loss (PVL), DBH and external fire scar measurements (inches); p-values in parenthesis.

	DBH	Scar width	Scar height	Scar depth	HxD	HDWA
PVL	-.146 (.317)	.028 (.844)	.522 (<.001)	.670 (<.001)	.806 (<.001)	.840 (<.001)

DBH= tree diameter at 1.5 meter height, HxD = scar height * scar depth, HDWA = (scar height * scar depth) / tree basal area (cm^2); p-values in parenthesis. Tree basal area is calculated as: $\pi*(DBH*.5)^2$.

Table 5. Percent value loss (PVL) in timber product values to butt logs from trees with different fire scar dimensions (left column, HxD= fire scar height*fire scar depth) and diameter at breast height (DBH) measured at 1.37 meters above ground level (cm) (top row); due to fire damage. Tabled values developed using Equation 17: PVL= 0.0051 + (0.135*HDWA), where HDWA = (scar height*scar depth)/tree basal area (derived from diameter at breast height).

Scar Size	**DBH**											
HxD	**25**	**28**	**31**	**34**	**37**	**40**	**43**	**46**	**49**	**52**	**55**	**58**
0	0	0	0	0	0	0	0	0	0	0	0	0
65	2	2	2	1	1	1	1	1	1	1	1	1
194	6	5	4	3	3	3	2	2	2	2	2	1
323	9	8	6	5	5	4	4	3	3	3	2	2
452	13	10	9	7	6	5	5	4	4	3	3	3
581	16	13	11	9	8	7	6	5	5	4	4	3
710	20	16	13	11	9	8	7	6	6	5	5	4
839	24	19	16	13	11	10	8	7	7	6	5	5
968	27	22	18	15	13	11	10	8	7	7	6	5
1097	31	25	20	17	14	12	11	9	8	7	7	6
1226	34	27	22	19	16	14	12	10	9	8	7	7
1355	38	30	25	21	18	15	13	12	10	9	8	7
1484	41	33	27	23	19	16	14	13	11	10	9	8
1613	45	36	29	24	21	18	16	14	12	11	10	9
1742	48	39	32	26	22	19	17	15	13	12	10	9
1871	52	42	34	28	24	21	18	16	14	12	11	10
2000	56	44	36	30	26	22	19	17	15	13	12	11
2129	59	47	39	32	27	23	20	18	16	14	13	11
2258	63	50	41	34	29	25	22	19	17	15	13	12
2387	66	53	43	36	30	26	23	20	18	16	14	13
2516	70	56	46	38	32	28	24	21	19	17	15	13
2645	73	59	48	40	34	29	25	22	19	17	16	14
2774	77	61	50	42	35	30	26	23	20	18	16	15
2903	80	64	52	44	37	32	28	24	21	19	17	15
3032	84	67	55	46	39	33	29	25	22	20	18	16
3161	87	70	57	48	40	34	30	26	23	21	18	17

Table 6. Fire scar information of VLDFS data set.

	Before VLDFS	VLDFS	After VLDFS
Number of fire scars	27	57	65
Average DBHi (cm)	17.6	33.4	38.71
Average fire scar residence time (years)	45.55	8.82	3.81

VLDFS= value loss driving fire scar, single event to which value loss (if any) is attributed

DBHi = calculated tree diameter at 1.5 meter above ground level, at time of injury

Table 7. Annual percent value loss of red oak butt logs for different fire scar heights

ScarH	PVL_a
50 cm	0.49%
75 cm	0.64%
100 cm	0.79%
125 cm	0.94%
150 cm	1.09%
175 cm	1.25%

ScarH= fire scar height

PVL_a= percent value loss per year of fire scar residence time

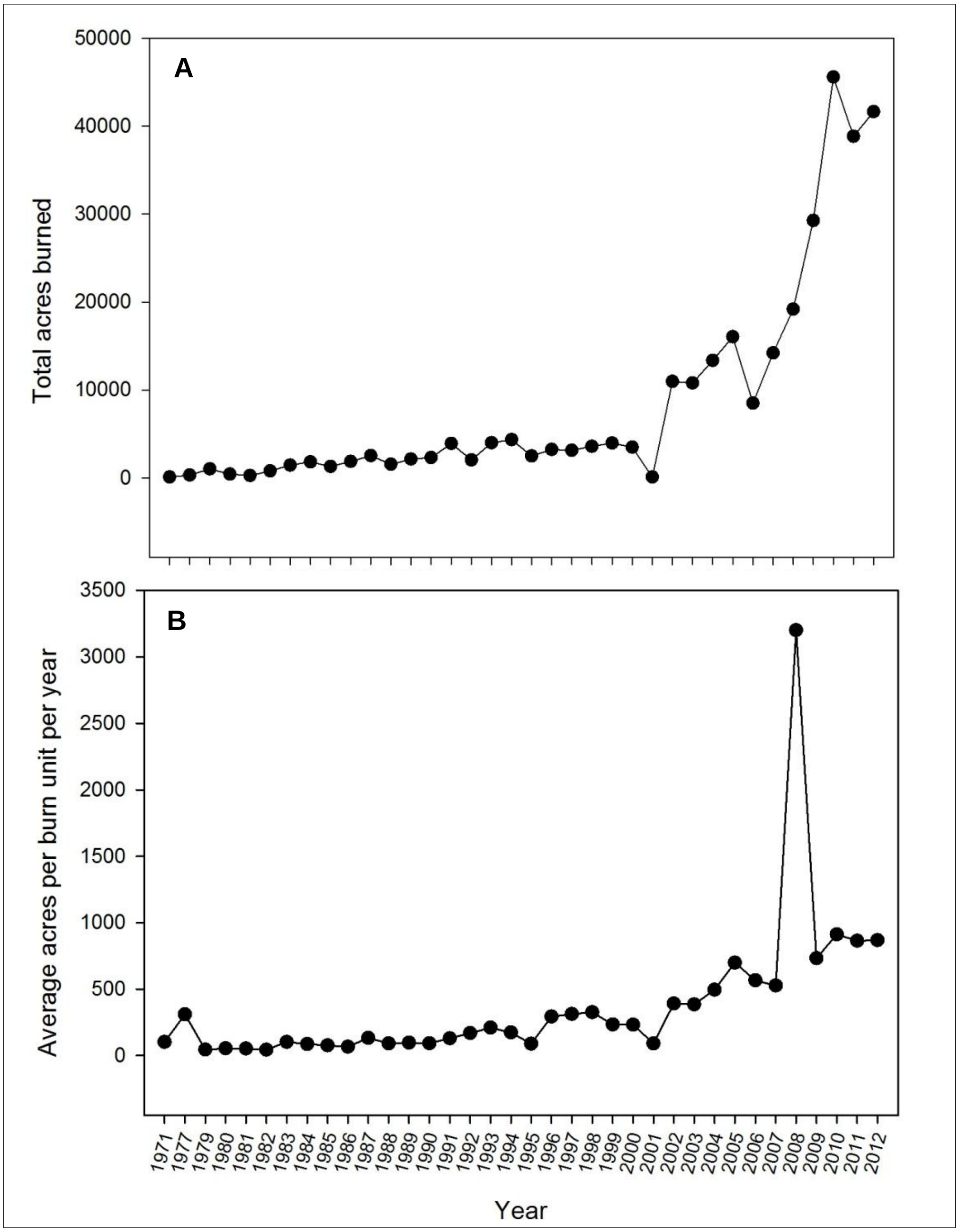

Figure 1. Total annual acres burned (A) as prescribed fire and average size of burn unit (B) each year from 1971 to 2012 on Mark Twain National Forest (MTNF). Data supplied by MTNF.

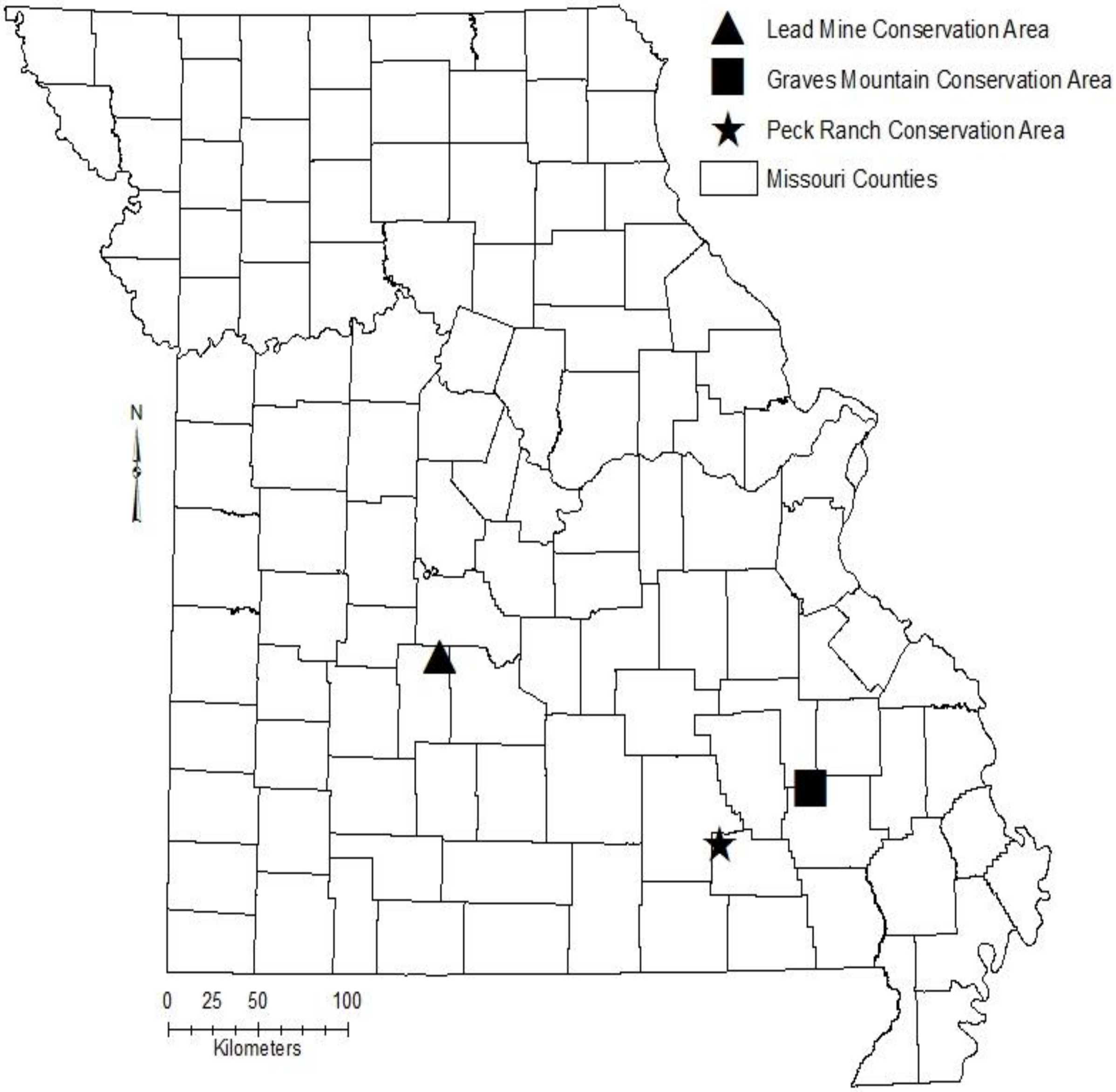

Figure 2. Map of Missouri with Missouri Department of Conservation Areas from which trees were sampled.

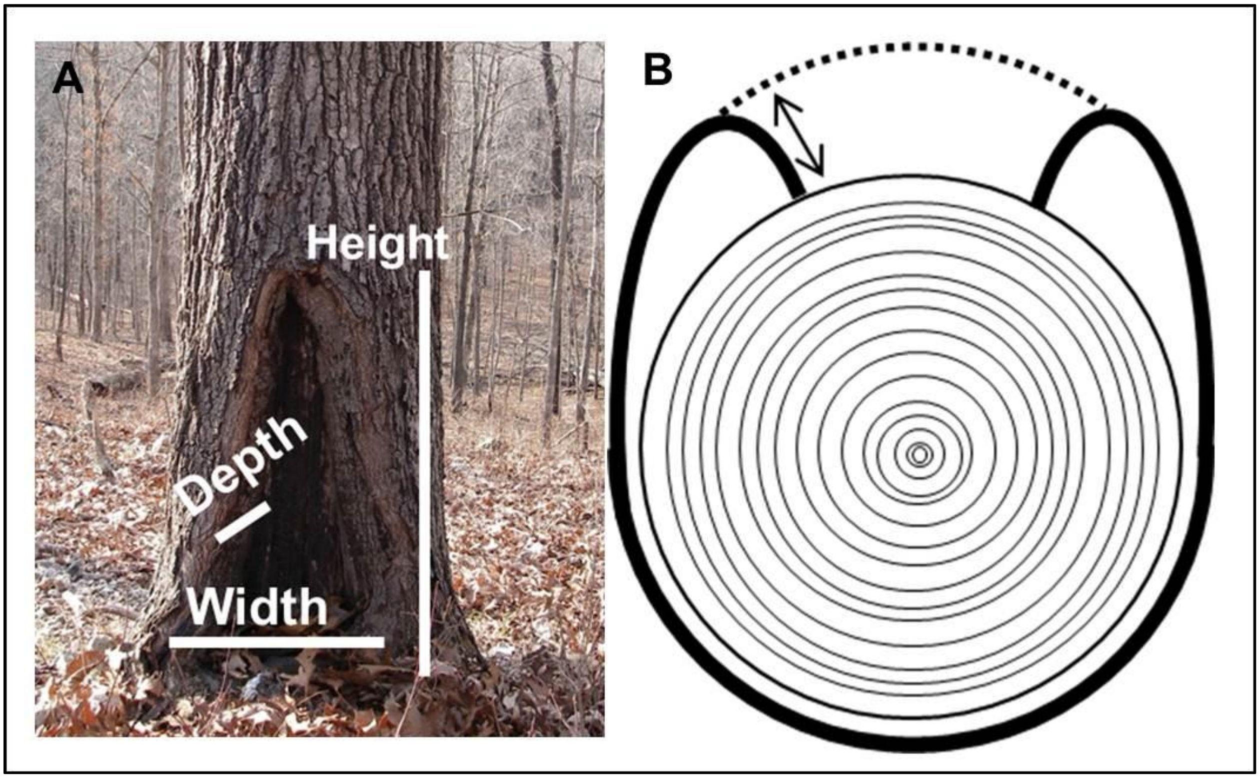

Figure 3. External scar measurements (A) measured in the field. B is a cross-sectional view of fire scar depth measurement.

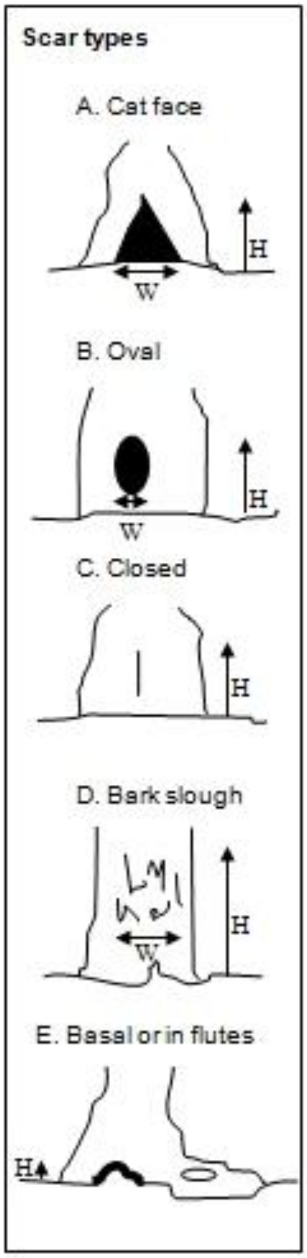

Figure 4. Illustration of external fire scar classifications.

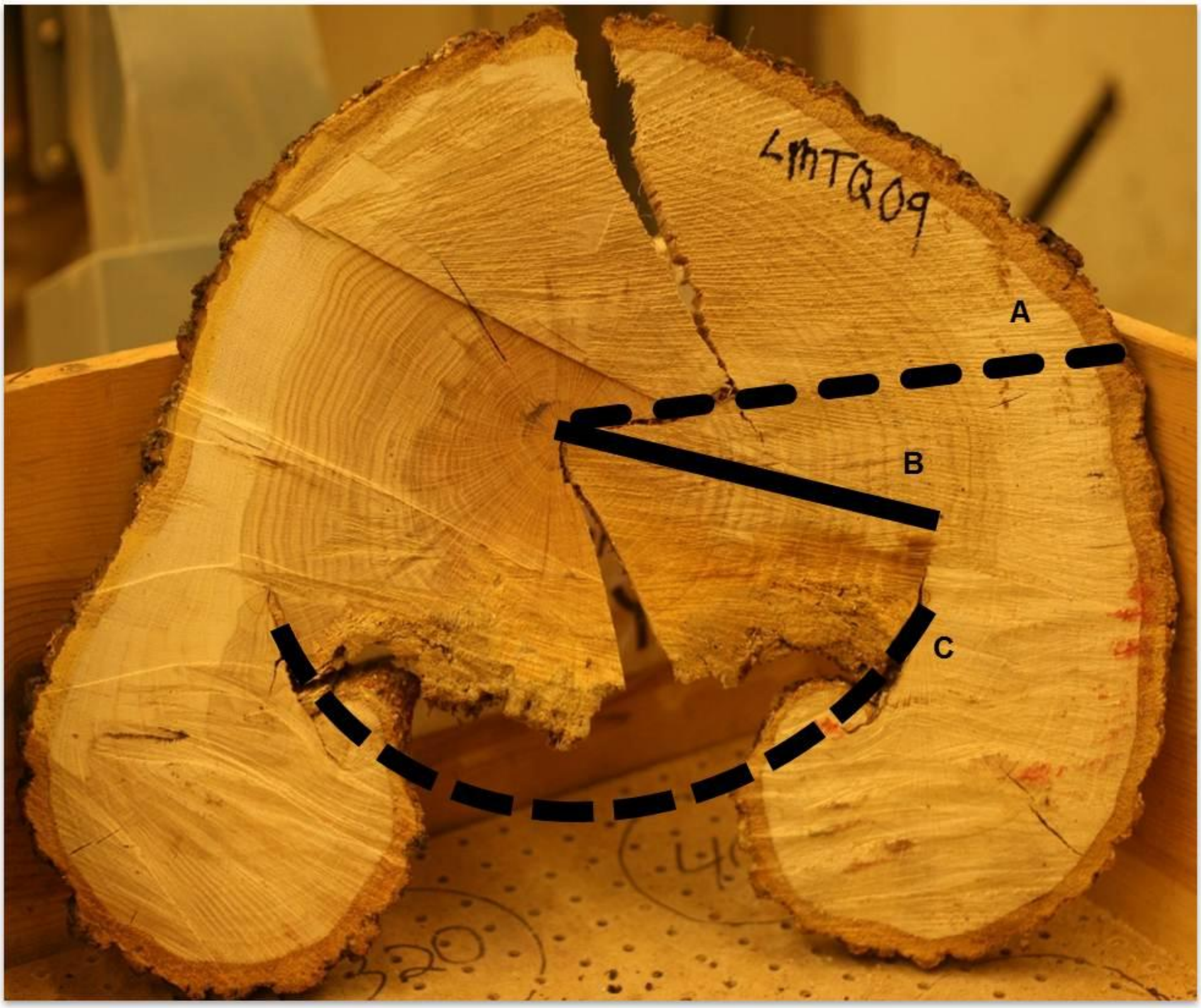

Figure 5. Fire scar measurements made on basal cross-sections retained from the top of the stump of all sampled trees. Line A is the radius at time of harvest; Line B is the radius at time of injury; and Line C is the length of the basal circumference injured. All recorded measurements were the average of two measurements.

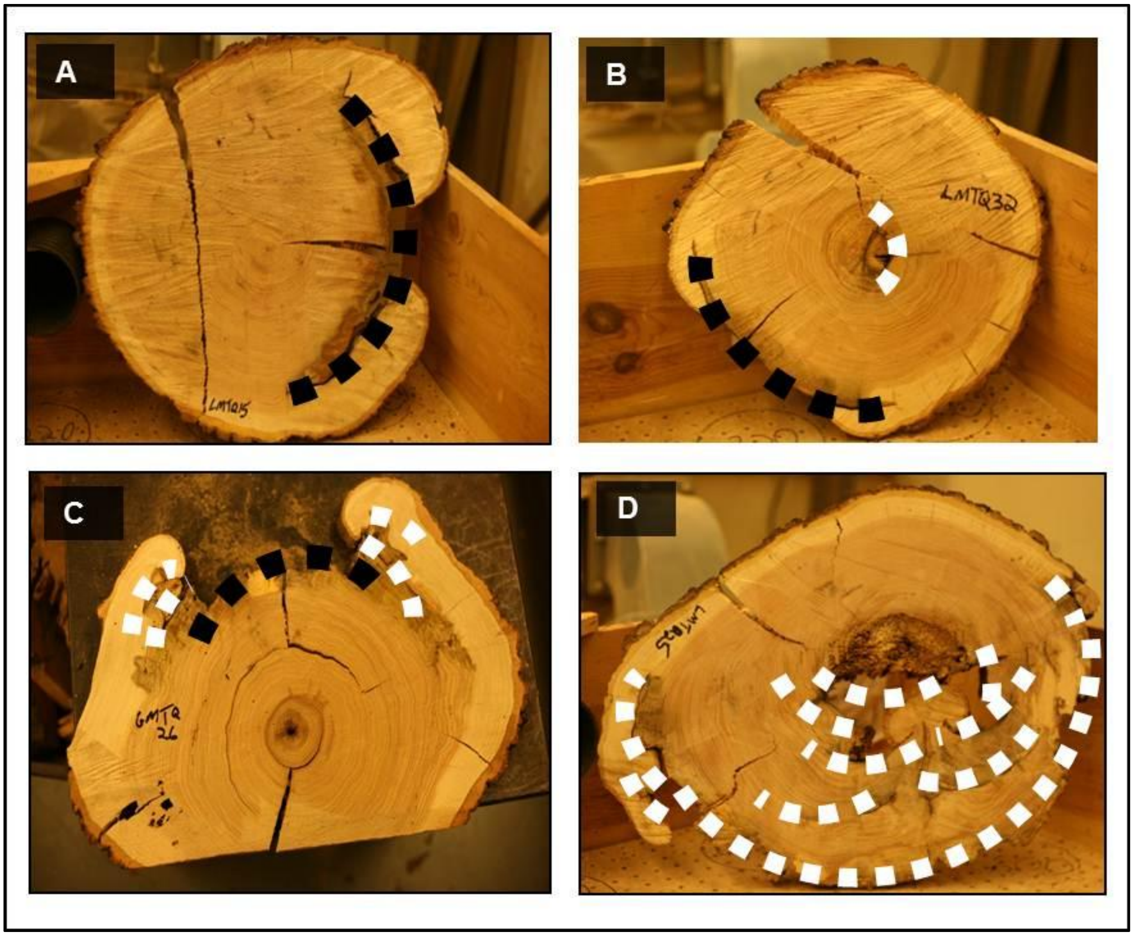

Figure 6. Examples of individual tree fire histories recorded on basal cross-sections. All cross-sections with multiple fire scars were inspected for the possibility of attributing decay and fire related defect present in the butt log to a single fire scar. This value loss driving fire scar (VLDFS) was determined based on the relative percent circumference scarred and basal diameter at time of injury. Fire scars are labeled with dotted lines, VLDFS fire scar(s) in black. A: 1 fire scar; B: 2 fire scars; C: 3 fire scars; and D: 6 fire scars. VLDFS was not determined for D because fire related defect was prevalent for most of the tree's lifespan.

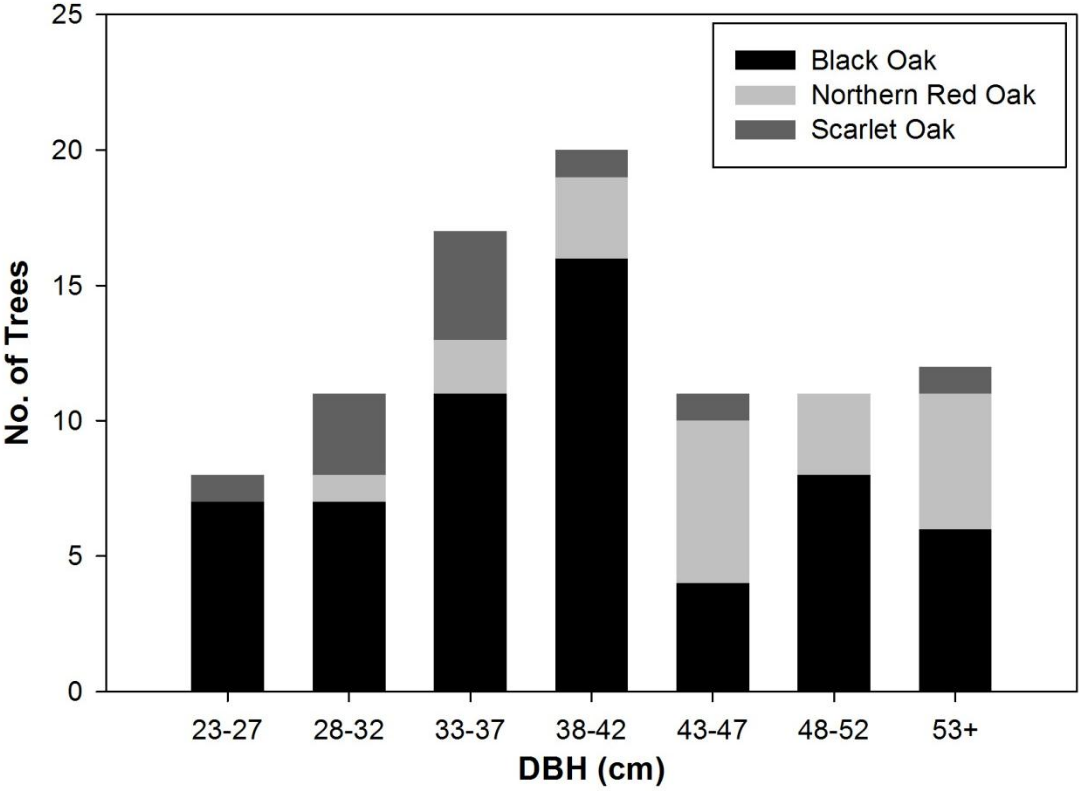

Figure 7. Species and diameter frequency distribution for all trees sampled.

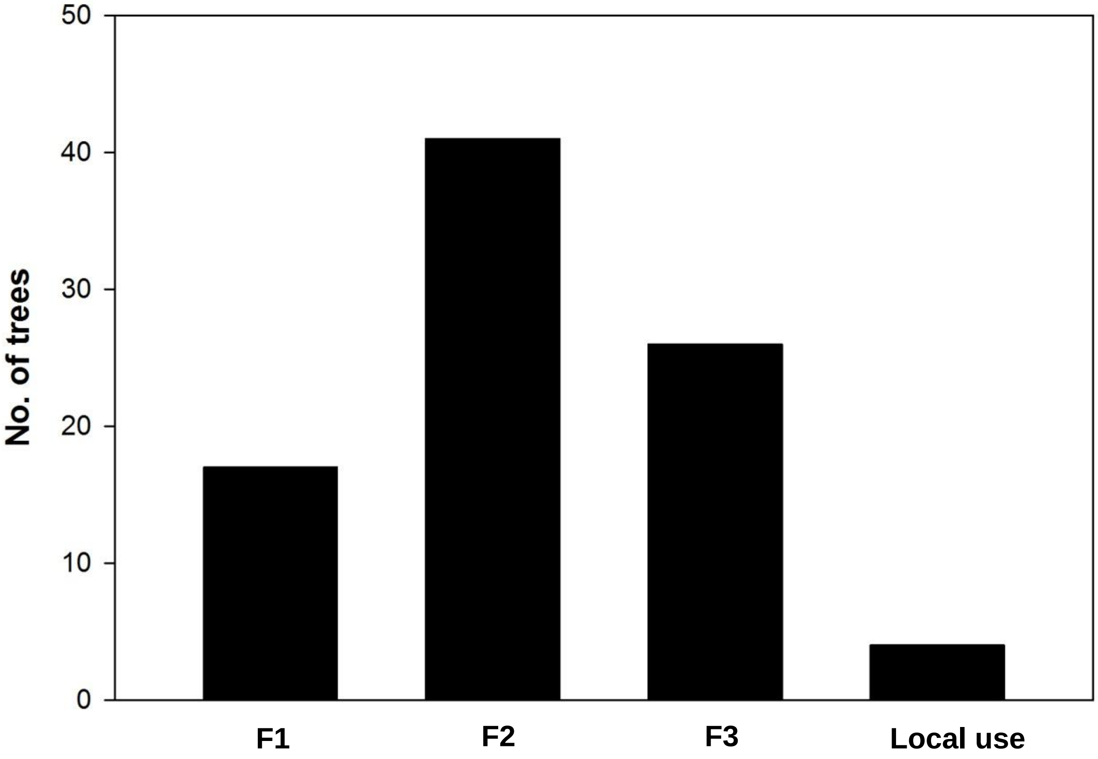

Figure 8. Frequency distribution of different log grades (Rast 1973) ignoring fire damage in descending order of value.

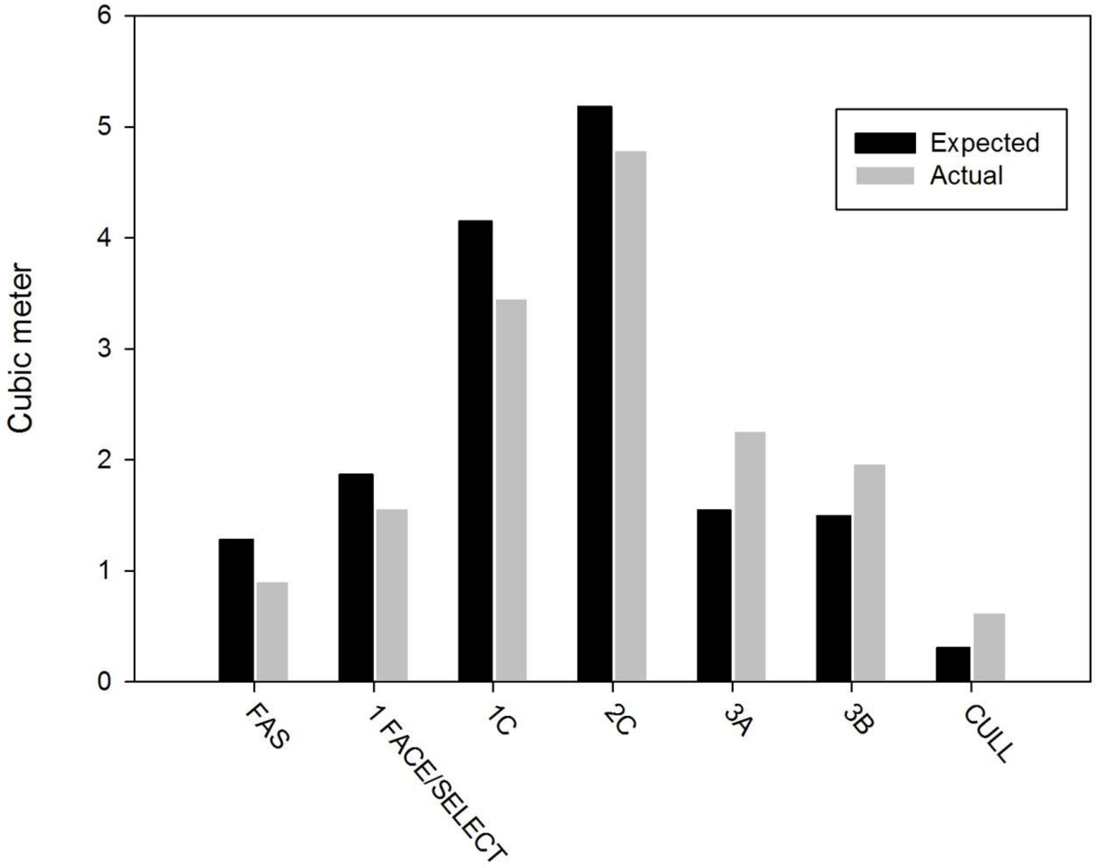

Figure 9. Expected and actual volume per lumber grade in descending order, considering all 1298 dimensional lumber products from 88 trees analyzed. 18.3 m^3 of lumber expected total volume.

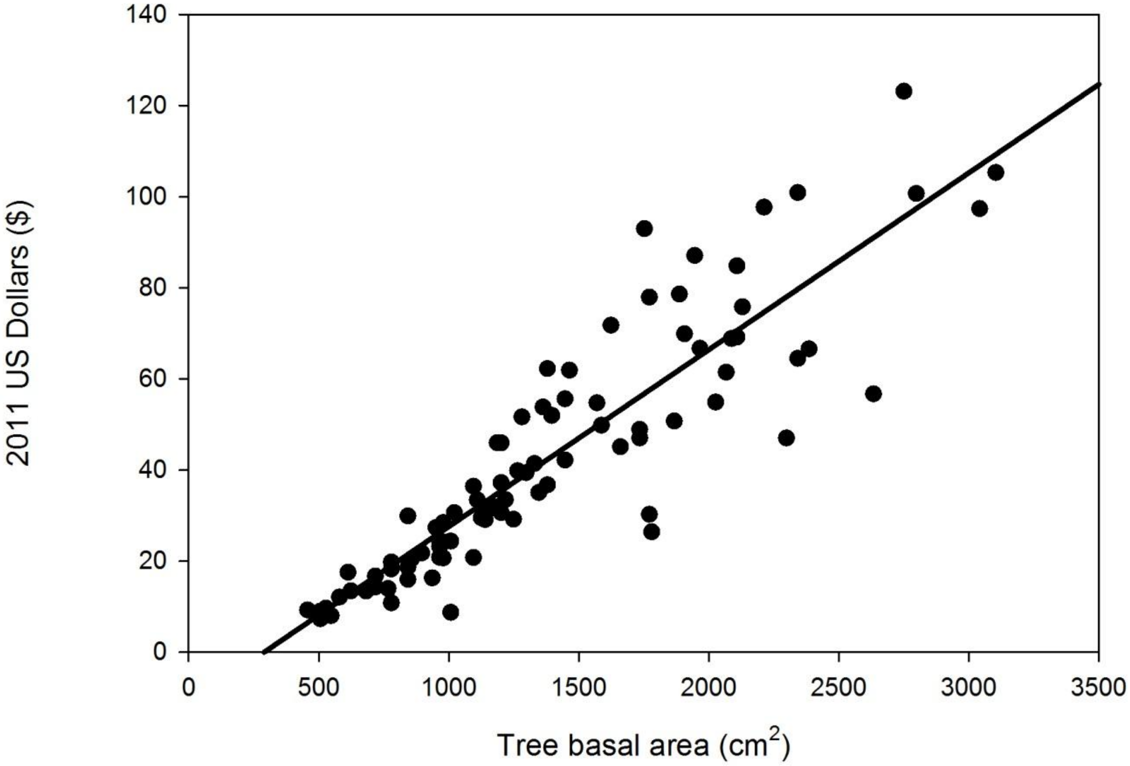

Figure 10. Scatterplot of expected butt log value (ELV) and individual tree basal area (TBA) with linear regression line (Eq. 10).

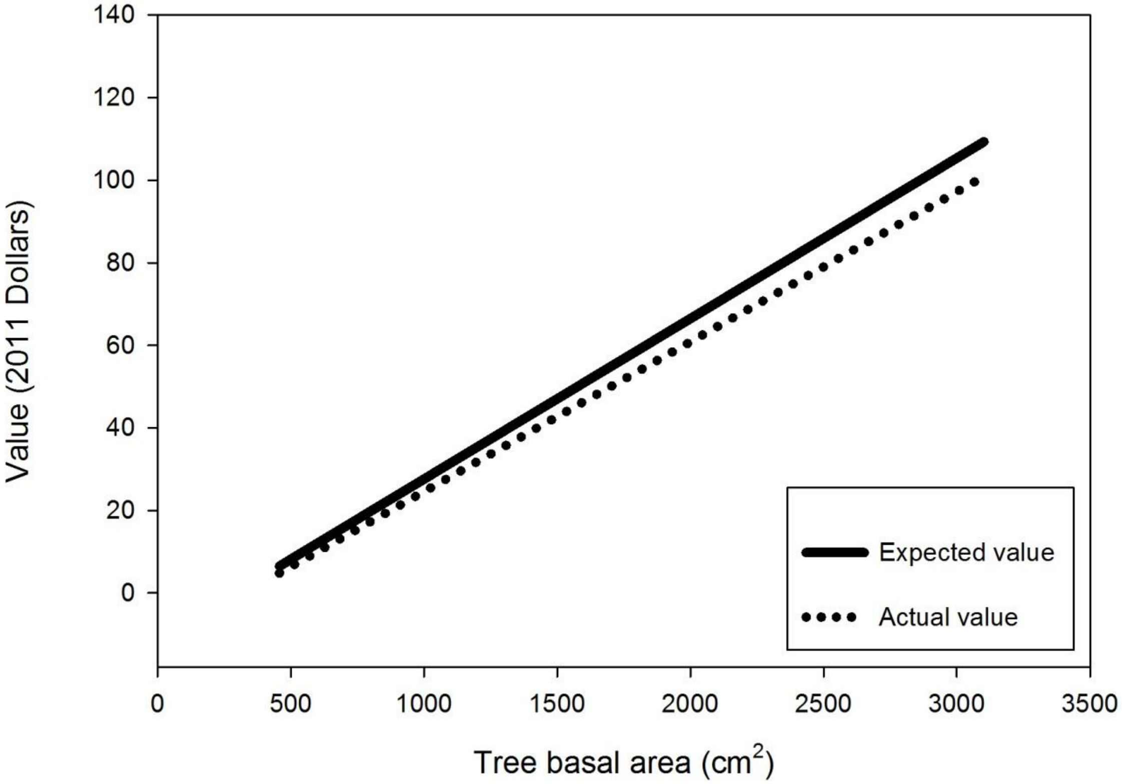

Figure 11. Regression lines for Equations 10 and 11, depicting actual and expected value predicted by tree basal area (cm2)

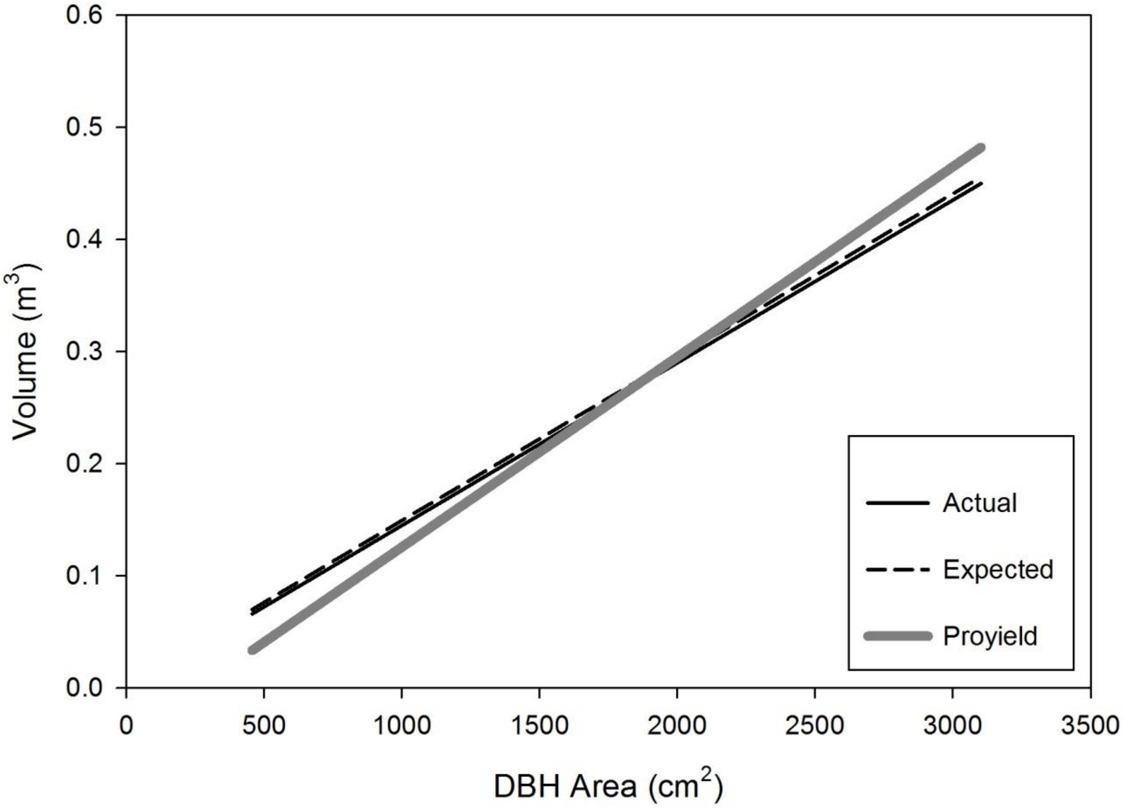

Figure 12. Regression lines for Equations 12, 13, and 14, depicting predicted actual, expected, and Proyield volume as predicted by tree basal area.

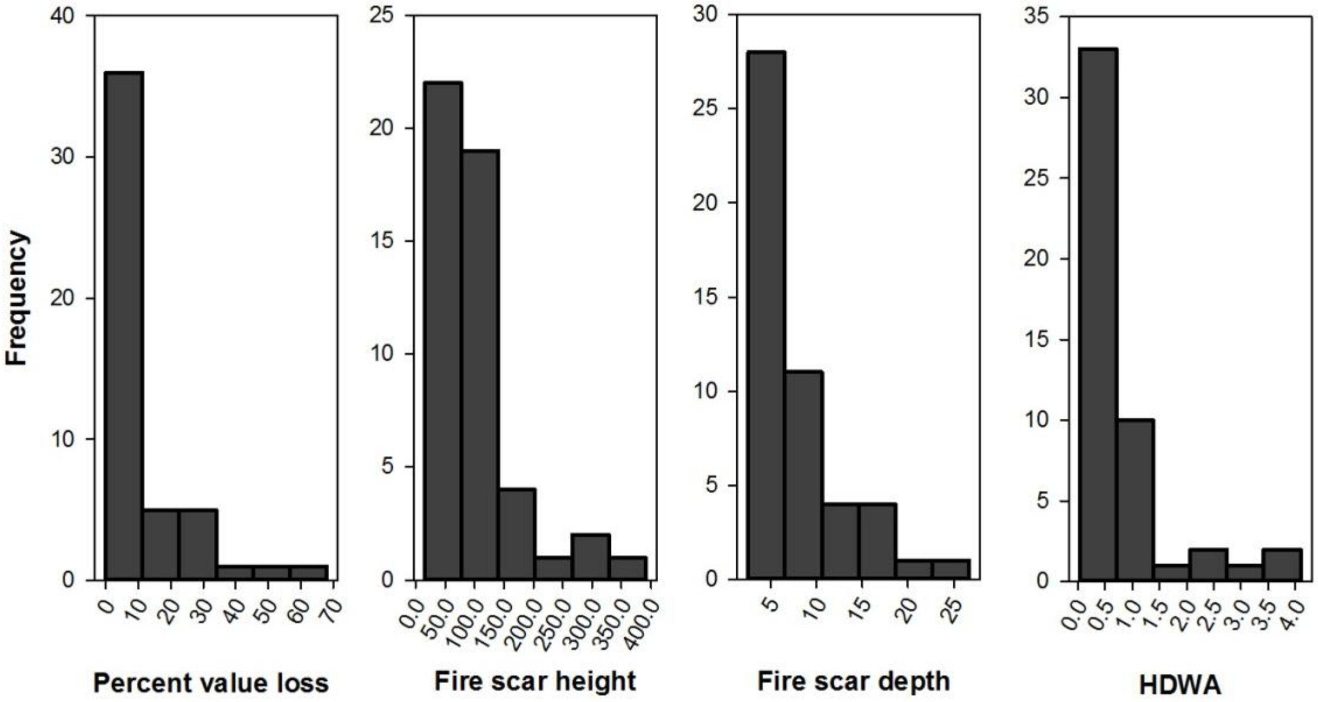

Figure 13. Frequency distribution for predicted variable (percent value loss), and predictor variables: fire scar height (cm), fire scar depth (cm), and HDWA ((scar height*scar depth)/tree basal area), all significant (p< .05).

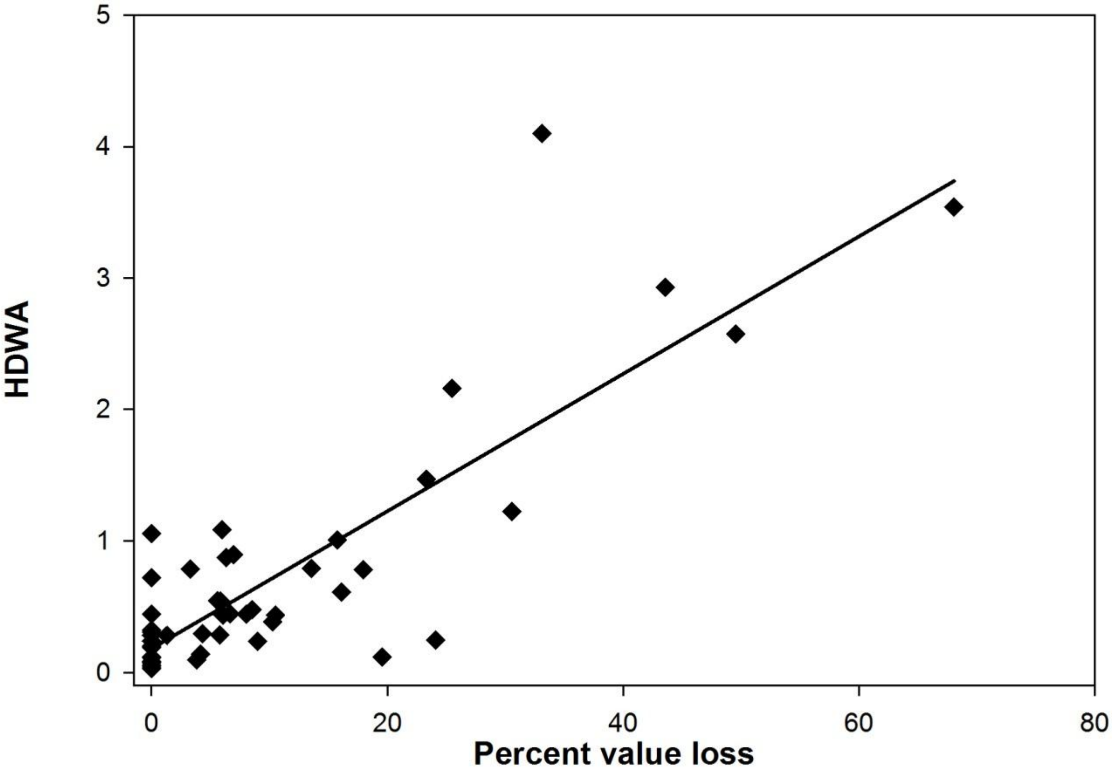

Figure 14. Scatterplot and regression line (Equation 17) of HDWA ((scar height*scar depth)/tree basal area) and percent value loss

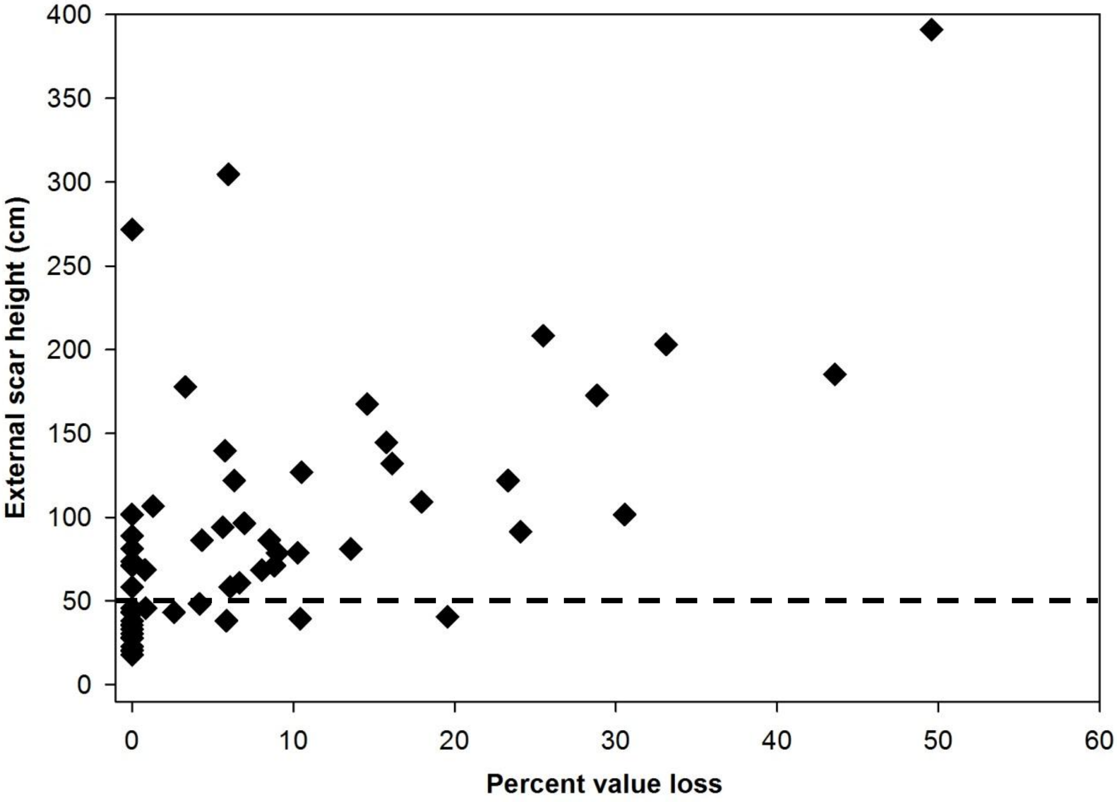

Figure 15. Scatterplot of percent value loss and external scar height (cm). Dotted line indicates the suggested threshold value for fire scar height (50cm), beyond which butt log value loss is expected.

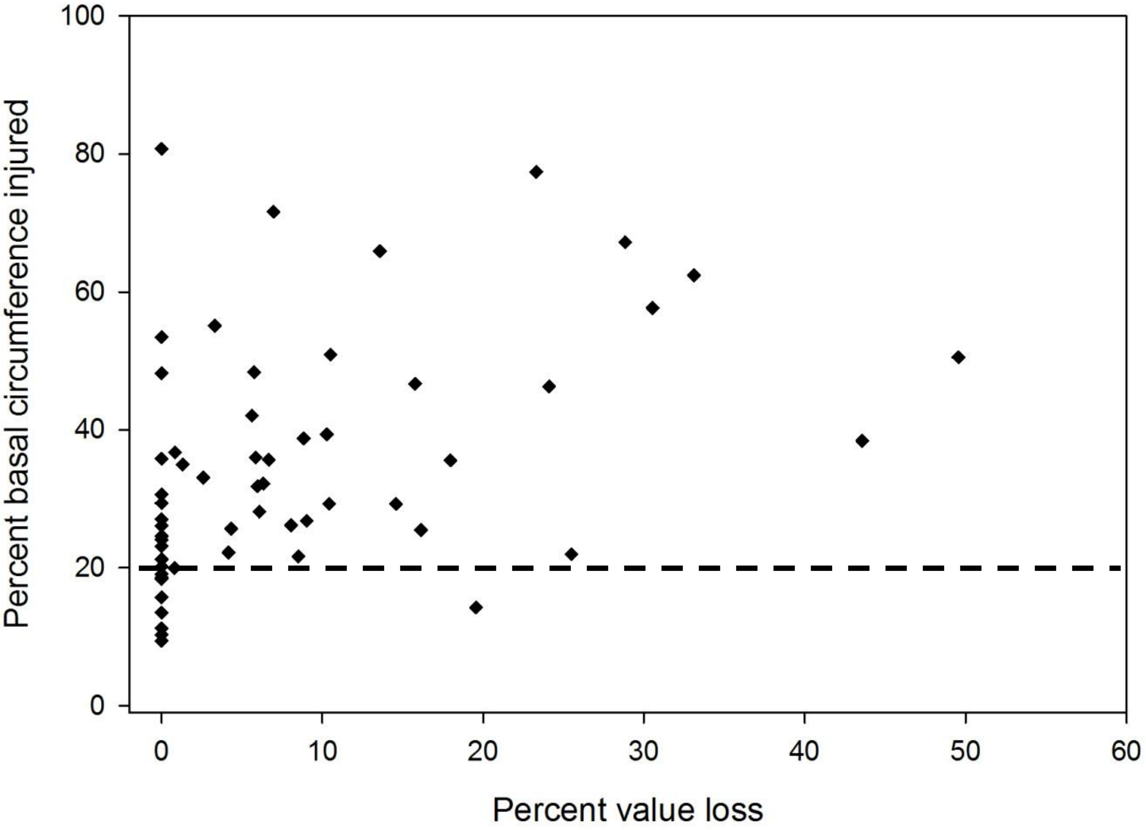

Figure 16. Scatterplot of percent value loss and percent basal circumference injured. Dotted line represents the suggested threshold value for percent basal circumference injured (about 20%), beyond which butt log value loss is expected.

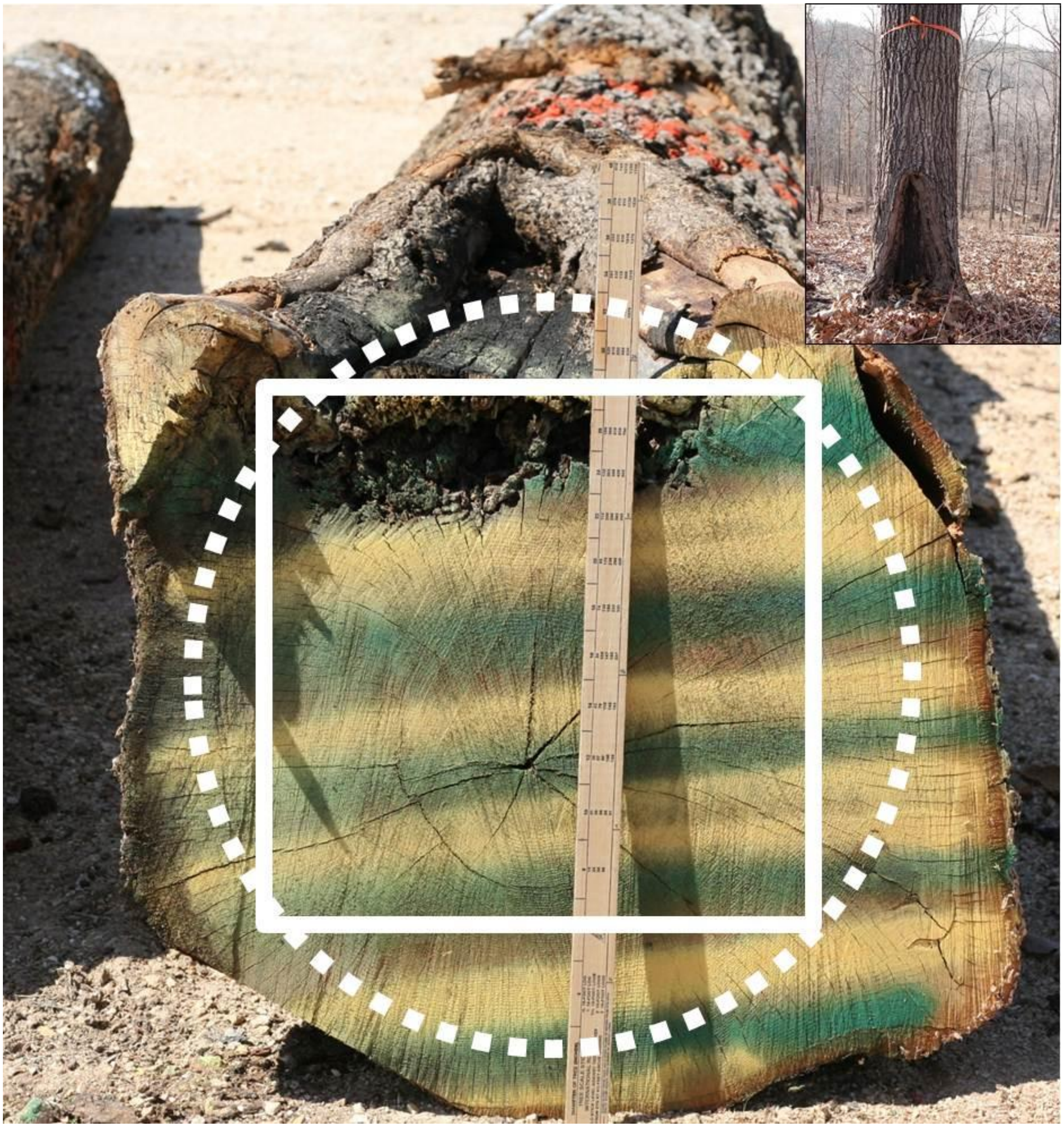

Figure 17. View of base of butt log. Dotted circle approximates the small end diameter, solid square represents the portion of the round log that is utilized when manufacturing rectangular dimensional lumber. Inset (top right) shows the tree prior to cutting.

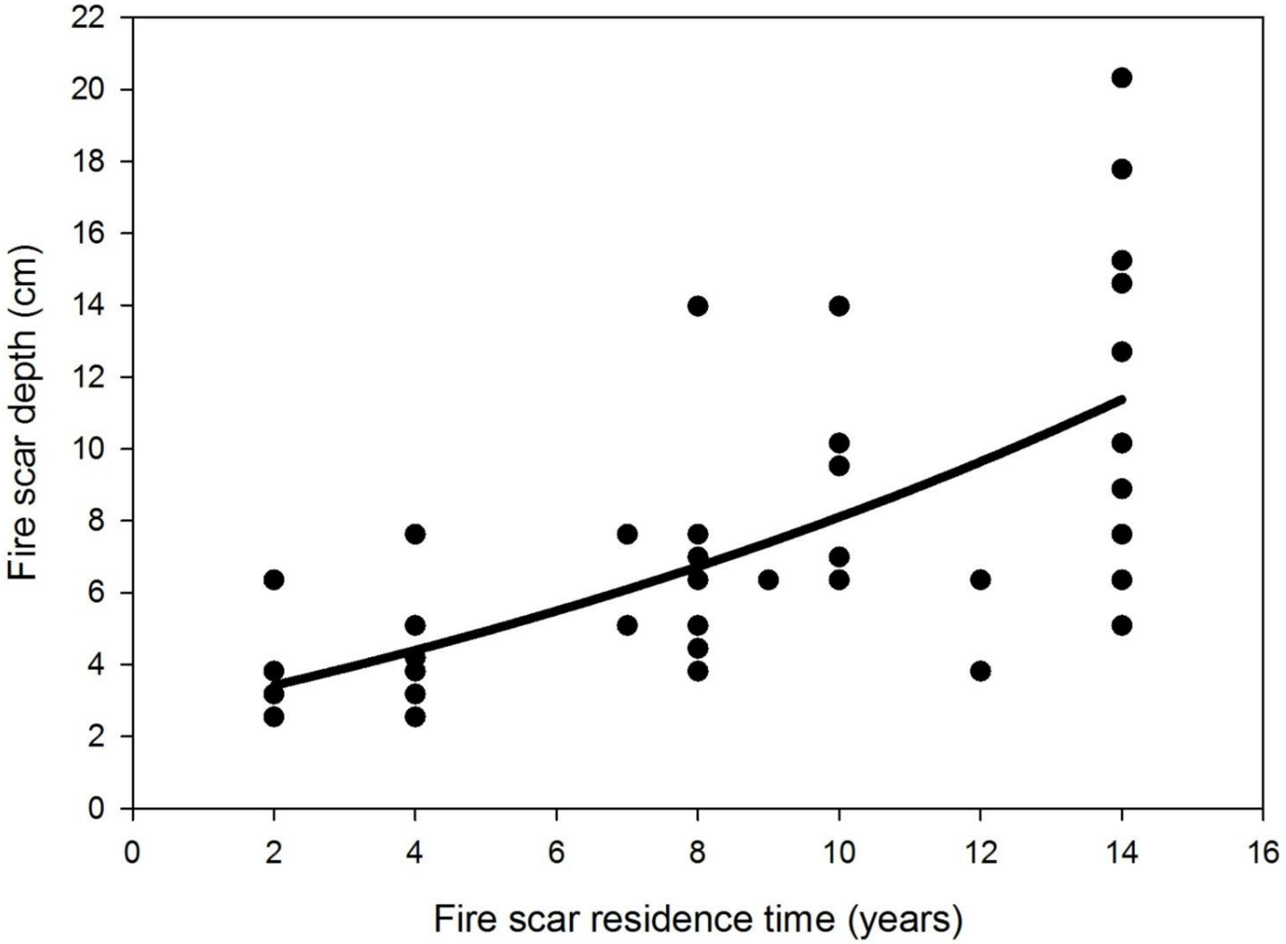

Figure 18. Scatterplot of fire scar depth (ScarD) and fire scar residence time (R-time). Exponential regression line equation: ScarD = $e^{(.12383 + (.09376*(R\text{-}time))}$; $r^2 = .551$, $p < .001$.

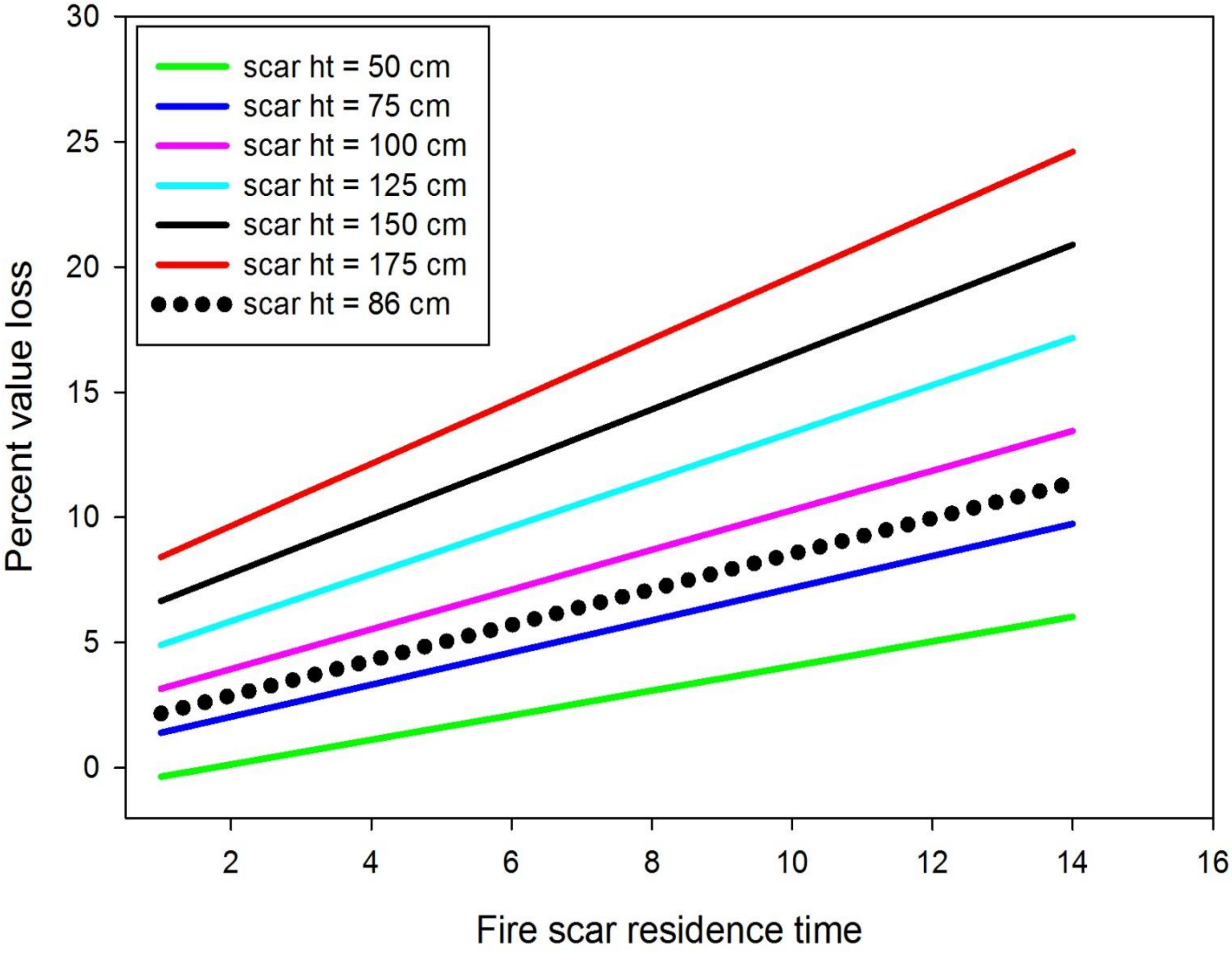

Figure 19. Line graph depicting percent value loss at different fire scar residence times for different fire scar heights. The dotted line represents the average fire scar height for all trees sampled. Lines were developed using Equation 18.

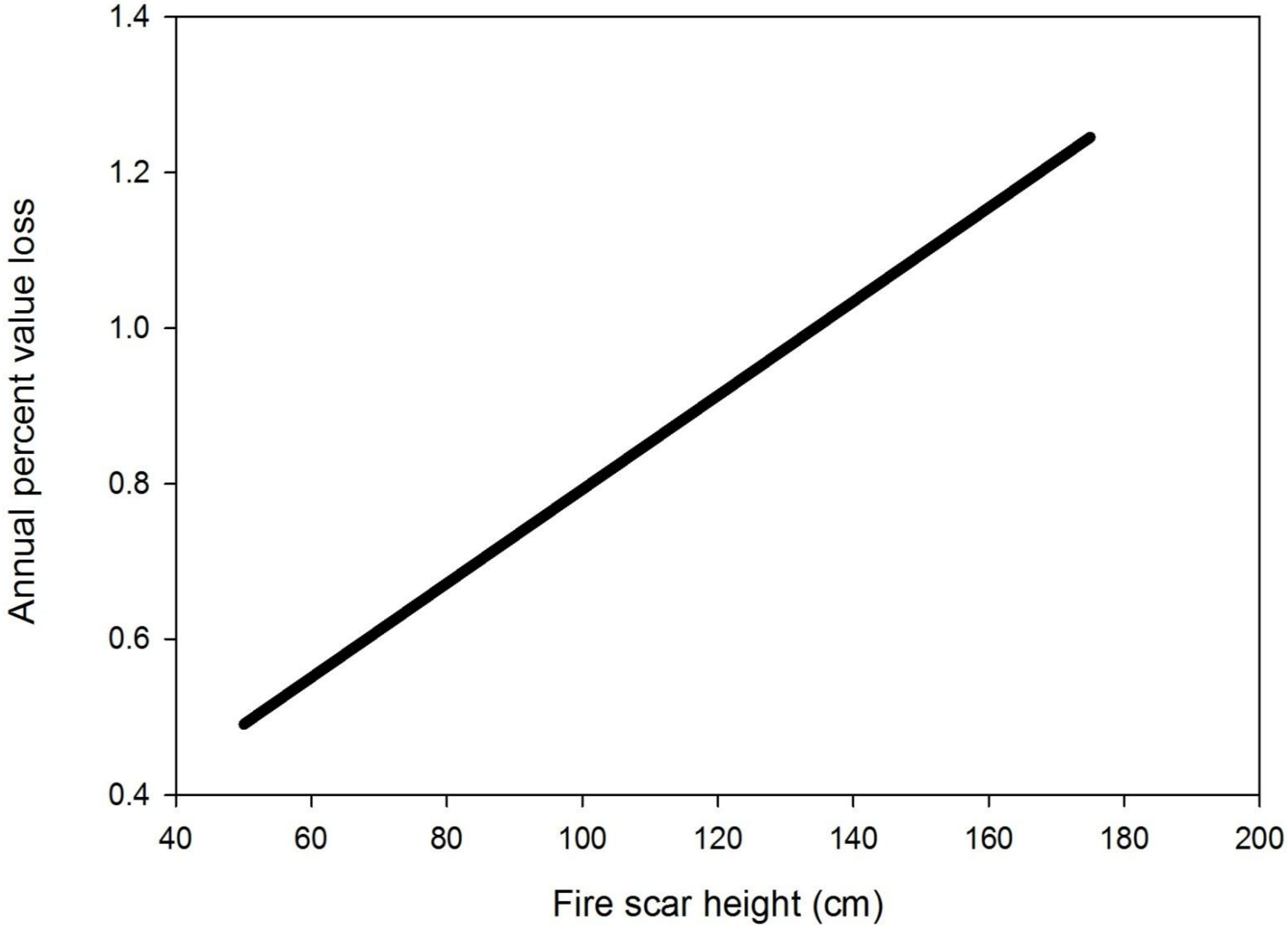

Figure 20. Line graph depicting change in annual percent value loss caused by increasing fire scar height.

REFERENCES

Abrams, M.D. 1992. Fire and the development of oak forests. Bioscience 42(5): 346-353.

Berry, F.H. and J.A. Beaton. 1972. Decay in oak in the central hardwood region. Res.Pap. NE-242. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 11 p.

Black, B.A., Ruffner, C.M., Abrams, M.D. 2006. Native American influences on the forest composition of the Allegheny Plateau, northwest Pennsylvania. Canadian Journal of Forest Research 36: 1266-1275.

Bova, A.S. and M.B. Dickinson. 2005. Linking surface-fire behavior, stem heating, and tissue necrosis. Canadian Journal of Forest Research 35:814-822.

Brose, P. and D. Van Lear. 1998. Prescribed fire effects on hardwood advance regeneration in mixed hardwood stands. Southern Journal of Applied Forestry 22:138-142.

Brose, P. and D. Van Lear, 1999. Effects of seasonal prescribed fires on residual overstory trees in oak-dominated shelterwood stands. Southern Journal of Applied Forestry 23(2): 88-93.

Burns, P.Y. 1955. Fire scars and decay in Missouri oaks. Bulletin 642. Columbia, MO: University of Missouri, College of Agriculture, Agricultural Experiment Station: 8 p.

Burton J., S. Hallgren, S. Fuhlendorf, and D. Leslie. 2011. Understory response to varying fire frequencies after 20 years of prescribed burning in an upland oak forest. Plant Ecology 212:1513–1525.

Crosby, J.S. 1977. A guide to the appraisal of: wildfire damages, benefits, and resource values protected. Research Paper NC-142, North Central Forest Experiment Station, Forest Service, U.S. Department of Agriculture, St. Paul, MN. 43 pp.

Flader, S. L. 2008. Missouri’s Pioneer: a half century of sustainable forestry. Pioneer Forest: A half century of sustainable uneven-aged forest management in the Missouri Ozarks. GTR-SRS-108.

Govett, R., R. Dramm, S. Bowe, and T. Mace. 2005. Proyied-Sawmill Yield Analysis Spreadsheet.

Guldin, J.M. A history of forest management in the Ozark Mountains. Pioneer Forest: A half century of sustainable uneven-aged forest management in the Missouri Ozarks. GTR-SRS-108.

Gutsell, S.L., and E.A. Johnson. 1996. How fire scars are formed: coupling a disturbance process to its ecological effect. Canadian Journal of Forest Research 26:166-174.

Guyette, R.P., and B.E. Cutter. 1991. Tree-ring analysis of fire history of a post-oak savanna in the Missouri Ozarks. Natural Areas Journal 11:93-99.

Guyette, R.P., and M.C. Stambaugh. 2004. Post-oak fire scars as a function of diameter, growth, and tree age. Forest Ecology and Management 198:183-192.

Guyette, R.P., M.C. Stambaugh, A. Stevenson, and R. Muzika, R. 2008. Prescribed fire effects on the wood quality of oak (Quercus species) and shortleaf pine (Pinus echinata). Final report prepared for the Missouri Department of Conservation. 115 p.

Hardwood Market Report. April 16, 2011. Memphis, TN. Vol:LXXXIX, Number 16.

Hartman, G.W. 2005. Forest land management guide: use of prescribed fire. Jefferson City, Mo. Missouri Department of Conservation.9 p.

Loomis, R.M. 1974. Predicting the losses in sawtimber volume and quality from fire in oak-hickory forests. Res. Pap. NC-104. St. Paul, MN. U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station.

McEwan, R.W., T.F. Hutchinson, R.D. Ford, and B.C. McCarthy. 2007. An experimental evaluation of fire history reconstruction using dendrochronology in white oak (Quercus alba). Canadian Journal of Forest Research 37:806-816.

McQuilkin, R.A. 1974. Site index prediction table for black, scarlet, and white oaks in southeastern Missouri. Res. Pap. NC-108. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Experiment Station 8 p.

National Hardwood Lumber Association (NHLA). 2010. Rules for the Measurement and Inspection of Hardwood and Cypress. 104p.

Nelson, R., L. Sims, and M. Abell. 1933. Basal fire wounds on some southern Appalachian hardwoods. Journal of Forestry 31:829-837.

Nigh, T. A. and W.A. Schroeder. 2002. Atlas of Missouri Ecoregions. Jefferson City, MO. Missouri Department of Conservation.212 p.

Nowacki, G.J., and Abrams, M.D.. 2008. The demise of fire and the mesophication of forests in the eastern United States. BioScience 58(2): 123-138.

Palmer, B. 1991. Missouri forests-their history, values and management. Jefferson City, MO: Missouri Department of Conservation. 24 p.

Paulsell, L.K. 1957. Effects of burning an Ozark hardwood timberland.College of Agriculture, University of Missouri, Columbia, Res. Bull.No. 640.

Pyne, S., P. Andrews, and R. Laven. 1996. Introduction to wildland fire. New York, NY: John Wiley & Sons.769 p.

R Development Core Team (2008). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.

Rast, E.D., D.L. Sonderman, and G.L. Gammon. 1973. A Guide to Hardwood Log Grading. Gen. Tech. Rep. NE-1. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 32 p.

Ratajczak, Z., J.B. Nippert, and S.L. Collins. 2012. Woody encroachment decreases diversity across North American grasslands and savannas. Ecology 93:697–703.

Shigo, A.L. 1984. Compartmentalization: a conceptual framework for understanding how trees grow and defend themselves. Annual Review of Phytopathology 22: 189-214.

Smith, K.T., and E.K. Sutherland.1999. Fire-scar formation and compartmentalization in oak. Canadian Journal of Forest Research 29:166-171.

Stevenson, A. 2007.Effects of prescribed burning in Missouri Ozark upland forests. M.S. thesis, University of Missouri-Columbia.260 p.

Stokes, M.A. and T.L. Smiley. 1996. Introduction to tree-ring dating. University of Arizona Press.73 pp.

USDA Forest Service. 1965. A guide to hardwood log grading, 50 p. Northeast. For. Exp. Stn., Upper Darby, Pa.