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Minimizing epicormic branch formation on Louisiana leading commercial bottomland red oaks

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MINIMIZING EPICORMIC BRANCH FORMATION ON LOUISIANA LEADING COMMERCIAL BOTTOMLAND RED OAKS

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Dedication

This project is dedicated to my mother Donna K. Culpepper of Dubberly, Louisiana.

You are my inspiration and biggest fan. You have always believed in me and pushed me to excel at every endeavor. Without you I could not have completed the data collection for this project.

From the thorns and thickets of Black Lake Bottom to the mosquito infested woods of the endless Tensas forest and 48 consecutive days of 103° F heat, you were there beside me through it all, helping carry or write down anything I needed. You never complained, just asked me when I needed help next or what else could you do? You also provided endless amounts of compassion and understanding while I was working on this project. Thank you for all that you have done for me throughout my life and know that you will always hold a special place in my heart.

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Abstract

The goal of this study was to isolate biological, natural, and silvicultural factors that encourage the production of epicormic branches on bottomland red oak saw-timber trees and to use this information to help landowners and forest managers reduce epicormic branches in stands dominated by bottomland red oaks. *Quercus nigra*, *Q. pagoda*, *Q. phellos*, and *Q. texana,* the most common commercial bottomland red oaks in Louisiana, were evaluated in this study. Both qualitative and quantitative variables were assessed in this study. The following attributes were collected from each sample tree and primary competitor: site class, basal area, crown class DBH, presence or absence of epicormic branches, soil series, flooding regime, total tree height, height to base of live crown, live crown ratio, localized disturbance, and distance to nearest competitor. A total of 768 trees were evaluated, of which 384 trees displayed epicormic branching and 384 were without epicormic branches. Sample trees of all four species were equally distributed across four crown classes (dominant, co-dominant, intermediate, and suppressed). Equal numbers of all four oak species were collected to maintain homogeneity within the dataset. Logistic and Poisson regressions were used to analyze the data. An α level of 0.1 was considered effective for significance in this exploratory research. Logistic regression analysis yielded three variables significant in relation to the probability of epicormic branch occurrence. Variables significantly affecting the probability of epicormic branch production were total height of the sample tree, distance from the sample tree to the primary competitor, and crown class of the primary competitor. The Poisson regression analysis was used to evaluate the number of epicormic branches a tree might produce. In this analysis dbh of the sample tree, crown class of the primary competitor, disturbance, flooding regime, and live crown ratio of

sample trees were significant variables correlated with the number of epicormic branches produced.

Tree, site, and environmental characteristics isolated as being important to epicormic branch production produced a means for evaluating the potential development of epicormic branches. These factors in concert provide the forester or land manager with a simple means of enhancing bottomland red oak value. The driving mechanism for sudden appearance of epicormic branches seems to be related to reduced tree vigor as affected by competition (or relative vigor based on relative height to competitors) and site stress factors. Taller trees with less competition from similar sized trees have a reduced probability of epicormic branches. Or stated in another way, trees with close competitors or nearly equal height are more likely to produce epicormic branches. Dominant trees have a reduced likelihood of developing epicormic branches if other stress factors are not at play. Intermediate and suppressed crown class trees should be removed during early thinnings of red oaks stands to avoid or reduce epicormic branch production. In concert, factors reducing competition and increasing tree vigor tend to reduce the probability of epicormic branch production on bottomland red oaks.

Introduction

The largest concentration of bottomland hardwoods in the United States occurs in the Lower Mississippi River Alluvial Valley, with the principal tracts being in Arkansas and Louisiana. These bottomlands hold some of the South's most economically important hardwood forests, which provide raw material for many of our nation's essential hardwood products and wildlife habitat.

Preventing the degradation of the wood value in crops trees is pivotal to the economic management of these timberlands (Meadows 1995). Many problems with reduced individual tree value can be resolved during silvicultural operations by the reduction or elimination of low quality trees throughout the rotation. However, a reduction in individual tree value can be increased during silvicultural operations if care is not taken to prevent the formation of epicormic branch production. The presence of epicormic branches greater than 9.53 mm (0.37") in diameter lead to inferior logs and considerably reduces value of the log and the wood. Epicormic branches are branches found along the main that develop from either adventitious buds or dormant buds that are formed or released during the life of the tree in response to several types of stimuli (Brown and Kormanik 1969).

The production of high quality sawlogs is often an important goal in bottomland hardwood management. A forest manager or land owner interested in producing high-value logs and lumber cannot afford to ignore the effect of epicormic branching. In many timber stands epicormic branching causes a great loss of valuable oak lumber. Any stem attribute change that results in a difference in log value deserves special attention of the forest manager and land owner (Dimov et al 2006). Because the grade of hardwood lumber is affected more by the number and distribution of knots rather than by the size of individual knots, even small defects

can substantially reduce log and lumber value. These defects caused by epicormic branches can affect the length and number of clear cuttings from a log, as well as the number of clear faces (Meadows and Burkhart 2001, Clatterbuck 2006). Five epicormic branches greater than 9.5 mm in diameter on a 4.9 m (16 foot) log is enough to cause a one-grade reduction in grade (Meadows and Burkhardt 2001). Meadows and Burkhardt (2001) found epicormic branching in *Quercus phellos* was severe enough to cause a one-grade reduction in 45% of the butt logs and 46% of the upper logs, while 7% of the butt logs were damaged enough to be downgraded two log grades. It is important for both landowners and forest managers to be aware of the potential loss of wood value from epicormic branching and where practical to manage stands to reduce the production of trees with epicormic branches.

The exact reasons for the formation of epicormic branches and the reason for the degree of formation are poorly understood. For many years researchers believed that epicormic branching was a function of a tree's response to changes in light conditions (Hedlund 1964, Meadows 1995, Schlaegel 1978, Smith 1965, Stubbs 1986). More epicormic branches seem to occur on the light exposed faces of border trees than on the sides facing the uncut stands (Meadows 1995, Stubbs 1986, Howell and Nix 2002, Putnam et al 1960). Sudden exposure of the bole to direct sunlight tends to encourage the profuse production of epicormic branches, especially on low-vigor trees of susceptible species (Meadows 1995, Sonderman and Rast 1988). Following a thinning, trees with high vigor and large dense crowns had fewer epicormic branches than low vigor trees with weak and sparse crowns (Meadows and Goelz 2002, Meadows et al 2006). Various types of stress may reduce vigor in individual trees and lead to the production of epicormic branches. Several researchers have noted that trees that are severely stressed are at a much higher risk of exhibiting epicormic branches than trees with high vigor

(Auchmoody 1972, Meadows and Goelz 2002, Clatterbuck 2006, Howell and Nix 2002, Jemison and Schumacher 1948, Stubbs 1986, Dimov et al 2006). However, a stand composed mostly of *Q. pagoda* exhibited little difference in epicormic branch production in regards to the stand opening, degree of release, or crown class (Stubbs 1986). Stubbs indicates that epicormic may not be a function of tree genetics and vigor alone. Epicormic branching along the boles of southern bottomland hardwood trees can never be eliminated, but the occurrence of these defect-causing branches can be minimized through careful forest management (Meadows 1995, Carpenter et al 1989). Partial cutting in mature hardwood stands often causes physical damage to residual stems through felling and skidding resulting in a decline in bole quality and subsequent loss of tree value.

Some scientists have recommended that to minimize the production of epicormic branches on residual trees, partial cuts should retain trees with large, healthy, fully developed crowns (McKnight 1958, Meadows et al 2006, Meadows and Stanturf 1997, and Nix 2006). The use of improvement cuttings and thinnings can prove to be a key in the maintenance of blemish free boles (Meadows and Goelz 2002).

Objectives

Epicormic branching literature has been primarily focused on what causes the proliferation of these branches, not which species of red oaks are most prone to developing epicormic branches. Most studies have concentrated on the production of epicormic branches after disturbance rather than analyzing trees already producing epicormic branches. The primary objective of this study was to produce a model for evaluating those factors leading to an increase in epicormic branch likelihood on standing trees, as a means of avoiding them through proactive management. A second objective was to examine and evaluate the number of epicormic branches a tree is likely to produce and evaluate the variables most closely associated with the increased numbers.

Materials and Methods

Bottomland red oak stands across the Lower Mississippi Alluvial Valley are very diverse and complex. I chose to study the presence of epicormic branches in the red oaks from these stands across a wide range of site and forest conditions to provide a more encompassing overview of factors and to make the prediction of epicormic branch production more universal, rather than regionally isolated. The diversity and complexity of these sites was enhanced by a variety of levels of management. Study sites were chosen to ensure a cross section of sites with differences in water regimes, geomorphology, soils, topography, species composition, and management objectives, disturbance levels, and to allow for differences in species composition and stand structure (Figure 1). The sites were also selected because they possess a wide range of species diversity with *Q. nigra, Q. texana, Q. pagoda,* and *Q. phellos* inhabiting a number of these sites. Tables 1 & 2 display a summary of each site used in the study.

Figure 1. Map of Louisiana showing the approximate location of study sites. 1-Middle Fork Bayou, 2-Black Lake Bottom, 3-Jackson Bienville Wildlife Management Area, 4-Tensas River National Wildlife Refuge, 5-CLECO Bottom, 6-Cotile Lake, 7-Grande Cote National Wildlife Refuge, 8-Lake Ophelia National Wildlife Refuge, 9-Three Rivers Wildlife Management Area, 10-Spring Bayou Wildlife Management Area, 11-A. Wilbert's Sons, 12-Bayou Sorrel.

Table 1. Description of selected site and vegetation conditions for the north Louisiana study locations.

LOCATION	SOIL			SITE INDEX	SAMPLE SPECIES REPRESENTED BY SITE INDEX[1]	TIME ELLAPSED SINCE STAND DISTURBANCE	ASSOCIATED FOREST COVER[1]	FLOOD REGIME
	Series	Texture	Drainage Class					
Middle Fork Bottom (Claiborne Parish)	Ouachita Guyton	clayey-loam clayey-sand	poorly drained moderately drained	High	QUNI, QUPH, QUPA	≥ 20 yrs	QUNI,QUPA, QUPH, QUMI, QUOB, QULY, LIST, FRPE, CAOV, CACO, ULAM	flashy and local precipitation driven
Tensas River National Wildlife Refuge (Tensas & Madison Parishes)	Sharkey Newellton	fine clay heavy clay	poorly drained	High Medium/ low	QUTE QUTE	≤ 30 yrs	QUTE, QUPH, LIST, FRPE, FRPR, GLTR, GLAQ, ULAM, ULCR, CELA, CAAQ, PODE, ACRU	frequently flooded / inundated
Jackson / Bienville Wildlife Management Area (Jackson Parish)	Wrightsville Ouachita	silty-clay clayey-loam	poorly drained	low High	QUNI, QUPH, QUPA QUNI, QUPH, QUPA	≥ 20 yrs	QUNI, QUPH, QUPA, QUMI, QUMS, QUOB, QULY, PITA, NYBI LIST, FRPE, CAOV, CACO, ULAM	flashy and local precipitation driven, storm flow from cities of Grambling and Ruston, LA
Black lake Bottom (Bienville & Webster Parishes)	Bienville Guyton	sandy-loam clayey-sand	well-drained poorly drained	Medium /low High	QUPH, QUNI, QUPA QUPA, QUPH, QUNI	≤ 10 yrs	QUNI,QUPA, QUPH, QUMI, QUMS, QULY, QUOB, QULY, LIST, NYBI, FRPE, CAOV, CACO, CAAQ, ULAM, TADI	flashy and local precipitation driven; flats and sloughs may hold water for extended periods
CLECO Bottom (**(**Rapides Parish)	Kolin	loamy-clay	moderately-drained	High	QUNI, QUPH, QUPA	≥ 10 yrs	QUNI,QUPA, QUPH, QUMI, QUOB, LIST, FRPE, CAIL, CACO, ULAM, ACRU	flashy and local precipitation driven, discharge from power plant

[1]QUNI: *Quercus nigra*, QUPA: *Quercus pagoda*, QUTE: *Quercus texana*, QUPH: *Quercus phellos*, QUMI: *Quercus mississippiensis*, QUOB: *Quercus obtusa*, QULY: *Quercus lyrata*, LIST: *Liquidambar styraciflua*, FRPE: *Fraxinus pennsylvannica*, FRPR: *Fraxinus profunda*, CAOV: *Carya ovata*, CACO: *Carya cordiformis*, CAAQ: *Carya aquatica*, CAIL: *Carya illinoinensis*, ULAM: *Ulmus americana*, ULCR: *Ulmus crassifolia*, ACRU: *Acer rubrum* var *drummondii*, PITA: *Pinus taeda*, PODE: *Populus deltoides*, NYBI: *Nyssa biflora*, GLTR: *Gleditsia triacanthos*, GLAQ: *Gleditsia aquatica*, TADI: *Taxodium distichum*

Table 2. Description of selected site and vegetation conditions for the central and south Louisiana study locations

LOCATION	**SOIL**			**SITE INDEX**	**SAMPLE SPECIES REPRESENTED BY SITE INDEX**[1]	**TIME ELLAPSED SINCE STAND DISTURBANCE**	**ASSOCIATED FOREST COVER**[1]	**FLOOD REGIME**
	Series	**Texture**	**Drainage Class**					
A Wilberts Sons (Point Coupee Parish)	Sharkey Fausse	fine clay compacted clays	poorly drained poorly drained	High/low Medium	QUTE / QUNI QUTE	≥ 2 yrs	QUNI, QUPH, QUOB, QULY, LIST, FRPE, ULAM, FRPR QUTE, DIVI, TADI, CELA, ACRU, CAAQ	Frequent & prolonged flooding / inundation
Bayou Sorrel (Iberville Parish)	Fausse Gramercy	compacted clays silty clay	poorly drained	Medium High	QUTE QUTE	≥ 2yrs	PODE, QULY, LIST, FRPE, ULAM, FRPR, DIVI, TADI, CELA, ACRU, CAAQ, QUTE	Frequent & prolonged flooding / inundation
Lake Ophelia National Wildlife Refuge (Avoyelles Parish)	Sharkey	fine clay	poorly drained	Low	QUNI, QUPH, QUPA	≥ 15yrs	QUNI, QUPH, QUPA, QUMI, QUOB, QULY, LIST, FRPE, ULAM, CAIL, PLOC, QUMIC, CELA	Precipitation driven ponding, levees prevent river from directly flooding
Cotile Lake (Rapides Parish)	Perry	silty clay	poorly drained	Medium /low	QUPH, QUNI,QUPA	≥ 20 yrs	QUNI,QUPA, QUPH, QUMI, QUMS, QULY, QUOB, QULY, LIST, NYBI, FRPE, CAOV, CACO, CAOV, ULAM, ACRU	flashy and local precipitation driven; flats and sloughs may hold water for extended periods
3 Rivers Wildlife Management Area **(**Avoyelles Parish)	Dundee	loamy-clay	moderately-drained	High	QUNI, QUPH, QUPA	≥ 10 yrs	QUNI,QUPA, QUPH, QUMI, QUOB, LIST, FRPE, CAIL, CACO, ULAM, ACRU	Precipitation driven ponding, levees prevent river from directly flooding
Spring Bayou Wildlife mgt Area (Avoyelles Parish)	Latanier	Sandy/loamy clay	Moderately drained	High	QUNI, QUPH, QUPA	≥ 2 yrs	QUNI, QUPH, QUOB, QULY, QUTE, LIST, FRPE, ULAM, FRPR QUTE, DIVI, TADI, CELA, ACRU, CAIL	flashy and local precipitation driven
Grande Cote National wildlife Refuge (Rapides Parish)	Coushatta	calcareous clay	Moderate / well drained	medium	QUTE	≥ 2 yrs	QUNI, QUPH, QUPA, QUMI,QUTE, QUOB, QULY, LIST, FRPE, ULAM, CAIL, PLOC, QUMIC, CELA	flashy and local precipitation driven; flats and sloughs may hold water for extended periods

[1]QUNI: *Quercus nigra*, QUPA: *Quercus pagoda*, QUTE: *Quercus texana*, QUPH: *Quercus phellos*, QUMI: *Quercus mississippiensis*, QUOB: *Quercus obtusa*, QULY: *Quercus lyrata*, LIST: *Liquidambar styraciflua*, FRPE: *Fraxinus pennsylvannica*, FRPR: *Fraxinus profunda*, CAOV: *Carya ovata*, CACO: *Carya cordiformis*, CAAQ: *Carya aquatica*, CAIL: *Carya illinoinensis*, ULAM: *Ulmus americana*, ULCR: *Ulmus crassifolia*, ACRU: *Acer rubrum* var *drummondii*, PITA: *Pinus taeda*, PODE: *Populus deltoides*, NYBI: *Nyssa biflora*, GLTR: *Gleditsia triacanthos*, GLAQ: *Gleditsia aquatica*, TADI: *Taxodium distichum*

Matrix of Stand and Tree Characteristics

The trees for this study were selected using a matrix of selection criteria outlined below and shown in figure 2. The matrix was used to ensure a wide variety of conditions. A minimum of three trees per matrix cell was established to obtain a reasonable sample size. Separate but nearly identical matrices of site characteristics were selected for each species in both north and south Louisiana locations. The matrix variables selected for this study include: site class, basal area class, crown class, dbh class, and the presence and absence of epicormic branches. A total of 64 matrix combinations of characteristics were evaluated for each species.

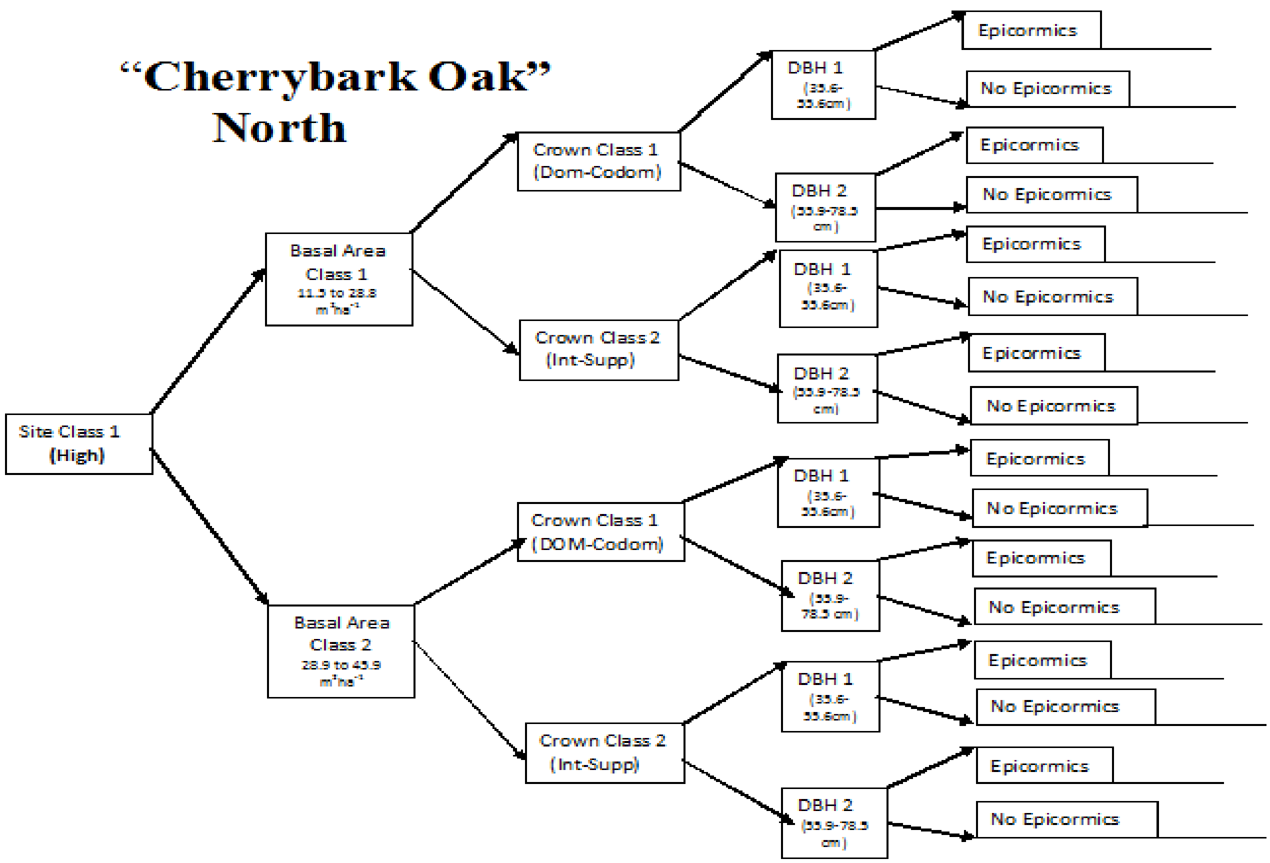

Figure 2. Typical tree selection matrix illustrating the sequence of established classes needed for the selection of each sample tree to be analyzed. The same general procedure was used on all sites, for all species.

For each study species, 3 trees of each combination of conditions were sampled making the total number of trees for each species 192. With all the matrix variable combinations and species, the potential total number of trees was 768. A description of each variable category is described below.

Region: North and south Louisiana were delineated as the two regions for the test areas to be located. Both of the regions possess large quantities of bottomland areas, but have very different alluvial settings. For convenience, south Louisiana was designated as those sites selected south of Alexandria, Louisiana and while north Louisiana sites included all those north of Alexandria. South Louisiana sites are borne from vast river alluvial plains with clayey sediments, while north Louisiana sites were chiefly composed of minor stream bottoms with coastal plain sediments.

Site Class: The next branch of the decision tree was the site class, which was divided into two categories, high and medium. Site information was assessed from soil surveys, NRCS Web Soil Survey, in areas where my data was collected. The Site class was determined by applying site indices provided by Baker and Broadfoot (1977) for species by soil combinations. Only high and medium site classes were used for this study because low site classes are not feasible for growing quality bottomland hardwoods. The study sites were chosen because of existing species composition and though offsite species occurred, most sampled trees were growing on the correct site. If species had a site index lower than 22.86 m (75 ft) in 50 yrs then they were put in the medium site class (1). If the site index was 23.16 m (76 ft) in 50 yrs or greater than the site was put in the high site class (2).

Basal Area Class: The third branch of the matrix was the basal area of tree stems surrounding the sample tree. The basal area of each circular sample plot was assessed and split into 2 classes, those from 11.5 to 28.8 m^2ha^{-1} (50-125 ft^2ac^{-1}representing basal area class 1) and those from 28.9

to 45.9 m^2ha^{-1} (126-200 ft^2ac^{-1}) basal area class 2. These basal area limits were arbitrarily developed for data collection, based on observations. . Areas less than 11.5 m^2ha^{-1} (50ft^2ac^{-1}) were considered under stocked, while areas with a basal area greater than 28.9 m^2ha^{-1} (126 ft^2ac^{-1}) are usually considered fully stocked or overstocked. Ideal bottomland hardwood basal areas lie between 261.4-479.2 m^2ha^{-1} (60-110 ft^2ac^{-}1) (Schlaegel 1978, Howell and Nix 2002).

The basal area was measured as follows: first, an 11.43 m (37.5ft) radius was measured in four directions from the sample tree and four pin flags were placed at these locations. This plot was used to represent the direct environment of each sample tree. Within this defined boundary Haglof Mantax® calipers with precision lasers were used to obtain the dbh (at 1.3 m height) of the plot and sample trees. Plot basal area was computed as the sum of the individual tree basal areas and then converted to per hectare and per acre values.

Crown Class: The fourth branch of the matrix was crown class, dominant or co-dominant and intermediate or suppressed. Crown class was defined either as crown class 1 (dominant and co-dominant) or crown class 2 (intermediate and suppressed) as developed by Meadows et al (2001). The crown class was also recorded for all sample trees and nearest primary competitor trees as one of the four crown classes (dominant, co-dominant, intermediate, or suppressed). Meadows et al 2001, crown class components included (1) the amount of direct sunlight received from above, with a point value assigned 0-10; (2) the amount of direct sunlight received from the sides, with a point value of 0-10; (3) crown balance, with a 1-4 point value; (4) relative crown size, with a point value of 1-4 based on the conditions present in the crown such as density, dieback, size, and shape. Each score was kept as a separate variable to determine the potential relationship to propensity to produce epicormic branches. The total points represented by these component parts were summed to determine crown classes in this study. Class was applied as

dominant (24-28pts), co-dominant (17-23 pts), intermediate (10-16 pts), or over-topped (2-9 pts) (Meadows et al 2001).

Diameter Class: The DBH was divided into two categories which are 35.6 to 55.6 cm (14-21.9 inches) and 55.9-78.5 cm (22-30.9 inches). Trees over 78.5cm (30.9 inches in diameter were not measured impractical for many saw mills to process, so are not generally favored in bottomland red oak management systems.

Presence of Epicormic Branches: For the fulfillment of the matrix, sampled trees with epicormic branches present were placed in epicormic branch category 1 or if epicormic branches were absent they were placed in category 2).

The presence or absence and number of epicormic branches on the sample tree were tallied as well. Only the butt log (first 5.3 m (17.3 ft) accounting for stump height was examined for epicormics because of measurement ease and value. Only the epicormic branches that were greater than 1 cm (0.38") in diameter were counted, as they are the threshold value for USFS log grading rules, which are followed by many hardwood lumber mills. Diameter of epicormics was checked by attaching a diameter template on the end of the 5.5 m (18 ft) height pole to slip around the branch. If epicormic clusters, multiple branches originating from a solitary bud or apparent bud group, were present on the bole of the sample trees they were counted as one epicormic branch unit.

Plot Delineation

From the matrix of selection criteria outlined, a modified strip sampling technique was used to locate sample trees within each sample site. Sampling strips remained at least 30 m inside tract boundaries to minimize edge effects. The sampling strips were at least 10 m from one another to reduce the probability of resampling an area. The sample tree was chosen randomly as long as it

fit the following criteria: was over 35.6 cm (14inches) in diameter, had at least 1 merchantable log, had a sound bole. The strip sample encompassed enough of the overall tract being assessed to fill as much of the sample matrix categories as possible. The area sampled for strip sampling was 10 % of the area, but was modified with additional strips when necessary to yield maximum site and tree matrix coverage.

Data Collection

Additional tree variables and site or stand characteristics measured, calculated, or categorized were: soil series, flooding regime, total tree height, height to base of live crown, live crown ratio (LCR), localized disturbance, and distance to nearest competitor (the nearest tree whose total height was equal to or greater than the midpoint of the crown of the sample tree). In addition, the following attributes were assessed for the nearest primary competitor: distance, species, DBH, direction, and crown class.

Flooding regime: Local micro topography at the selected tree was documented in regards to the flooding regime of the area. Flood regime was determined using water marks, sediment deposition, existing water, hydrophytic vegetation, and soil characteristics. From these observations the individual test tree's flooding regime was placed in the categories of well-drained, frequently flooded, and seasonally flooded. Well-drained areas were those that were in bottomland areas, but are only flooded during significant rain events. Frequently flooded areas were those that typically flood during flashy rain events and can remain flooded for typically only several days. Seasonally flooded areas remain flooded for weeks and months during the rainy season of the year and can have a relatively high level of flood water.

Nearest Primary Competitor: The nearest primary competitor tree to the sample tree was also documented in regards to DBH, species, direction, distance, and crown class. The nearest

primary competitor was defined as the nearest tree whose total height was equal to or greater than the midpoint of the crown of the sample tree. This definition was developed by the researcher to allow for a broad range of competitor trees to be analyzed throughout the study and aid in separating conflicting factors of competition such as size and distance. Height was used instead of diameter, since mixed species stands often have competitors of varying height to diameter ratios. While sample tree diameter is more affected by tree density, crown class is more affected by tree heights. All trees selected were of sufficient diameter to be harvested, but height varied substantially across species. Small trees, saplings, shrubs, and dead trees were not considered in this analysis. When two neighboring trees tied for primary competitor, the crown rating process was used and the highest rated tree was selected as the nearest competitor. Also instances of no "competitors" occurred in a number of tree sample plots (radius of 15m). When this anomaly occurred, the sample tree was abandoned and a new sample tree was selected, so that all trees in the data set were alike in having a nearest primary competitor. The importance of a primary competitor was emphasized in this research since in most forest settings primary competitors are present.

Disturbance: Any disturbances whether mechanical, climatic, or pathological that were observed at each test tree were recorded. Disturbances included logging damage, wind damage, pathogen, fire, ice, flooding, or abrasions from fallen neighbors. The disturbances were categorized as follows: thinning, bug gap, wind, lightning, or no disturbance. The time since the disturbance occurred was also estimated by visual indicators (debris, residual tops and stumps, scars and damage on trees).

Total Height, Height to Live Crown, LCR: The height of the tree was measured to the base of the live crown, and the total tree height was measured with a laser Suunto® clinometer. The LCR of each tree was measured to help assess tree vigor. The LCR was calculated as a percent (length of live crown/total tree height × 100).

Tree Ring Measurements: To assess the vigor of the test trees, increment cores were also taken from each individual tree. The cores were taken using a 36 volt drill with an attached borer chuck with a Haglof® increment borer. The cores were put into plastic core tubes and the tubes ends were sealed for transport. Slits were made in each core tube to allow for air circulation which allowed for efficient drying and reduced fungal growth. The tubes were placed in a dryer oven and allowed to dry for at least one week to insure optimal sanding quality. When sufficient drying was obtained, the cores were glued to wood core mounts and sanded to increase growth ring clarity. A Velmex® measuring stage and Winwedge® software were used to measure the width of each tree ring for the most recent ten years of each sample tree. The total 10 years growth (in cm) was used as the overall estimate of the current tree vigor. Only the full 10 year growth measurement was used, no partial year analyses were performed.

Data Analysis

Three Statistical Analysis System (SAS) programs were used to analyze data from this study. The logistic regression, GLM SELECT procedure, and Poisson regression were all used in this research and are described below. The collected data (Table 3) were divided into two types: categorical data (region, site, soil, water, disturbance, disturbance type, nearest primary competitor, crown class2, crown class1, and direction) and measurement data (DBH1, basal area1, live crown, total height, time since disturbance, distance from primary competitor, DBH2, live crown ratio, 10 year growth, epicormics, and basal area2). The following data were excluded

from evaluation in both data analyses because of selection criteria used: region, site, DBH1, and stand basal area (Table 3). This approach led to roughly equal representation of sample tree numbers under the data extremes, therefore, the variables were not random and the exclusion of these variables was necessary. The four tree species were grouped together and treated as one in the analysis for practical reasons (sufficient sample size). These species are commonly found growing together and rarely form large monocultures, however it must be realized that the individual species may respond somewhat differently. The intent of this research effort is to provide forest managers with a general model applicable bottomland red oaks. Thirty-two trees were removed from the data set because they had no primary competitor within the sample plot size of 0.04 hectares (1/10 acre). A total of 740 sample trees were used for the logistic regression, however only 369 trees were used for the Poisson regression. 369 trees were used in the Poisson regression because the Poisson regression requires count data and the data from trees without branches was therefore was excluded from the analysis.

The first goal of this study was to produce a model for evaluating the occurrence of epicormic branches. Logistic regression was chosen to predict the probability that a tree would produce epicormic branches because it was linear and allowed for the use of both numerical and categorical data. The Logistic regression allows for a probability that epicormic branches would not be produced on trees currently not exhibiting epicormic branching. The assumption is that trees growing under the same condition as sample trees would produce epicormic branches if the sample trees have epicormic branches and not produce sample branches under conditions of sample trees currently without epicormic branches. The resulting model is important to forest managers because it will allow them to evaluate the likelihood of future losses in tree value caused by epicormic branches. An α level equal to 0.10 was set for the Logistic regression. The

higher than typical α level (0.05) was set for this analysis because of the field setting (high variability) and the model being produced has never been attempted for bottomland red oaks. The increased alpha level provides a more inclusive model. The Logistic regression equation used for the analysis was as follows:

$\mathbf{p = e^{\beta}{}_{0}+\beta_{1}X_{1}\beta_{2}X_{2} \ldots +\beta^{n}X^{n} / 1 + e^{\beta}{}_{0}+\beta_{1}X_{1}+\beta_{2}X_{2} \ldots +\beta^{n}X^{n}}$, where p is the probability for the event to occur, X_1 is a predicting parameter, β_0 is the intercept, and β_1, β_2, β_3, and so on, are the regression coefficients.

The second goal of this study was to produce a model that could predict the number of epicormic branches that may occur on a tree. Poisson regression was selected as the method to analyze branch number data. The number of variables that had potential for use in the Poisson regression was very large, therefore, the variables to be used were evaluated with the GLM SELECT procedure of the general linear model in SAS. GLM SELECT unlike PROC GLM and PROC REG can be used with both categorical or Class variables and allows a variety of selection methods to be used. The α level was set at 0.10 for this analysis to be more inclusive in the selection process. The stepwise procedure functions as follows: The Stepwise method is a modified forward selection technique. If at a step of adding a variable to the model, the model is not significant, then the least significant of these variable effects is removed from the model and the algorithm proceeds to the next step. This ensures that no effect can be added to a model while some variable effect currently in the model is deemed non-significant. Three hundred and sixty nine sample trees were included in the Poisson regression analysis. All trees used for this analysis had epicormic branches at the time of sampling.

The data for this analysis was positively skewed potentially by the manner in which data was collected, the large amount of data and differences among the four tree species may have led

to this problem. Since the skew in data was positive, the natural logarithms of all the count data were used to better fit the variables included in the model.

The Poisson regression equation used was as follows: $\boldsymbol{\mu = e^{\beta}{}_0 + \beta_1 X_1 + \beta_2 X_2 \ldots + \beta^n X^n}$, where μ is the number of predicted branches, X_1 is the predicting parameter, β_0 is the intercept, and β_1, β_2, and so on, are the regression coefficients. Poisson regression was selected for this analysis because it allows for fitting to a linear model and describes the relationships between the independent variables and the dependent variables. The regression predicts the number of epicormic branches a tree will produce. The following variables were evaluated in the GLM SELECT analysis: class data (soil, water, disturbance, disturbance type, nearest primary competitor, crown class2, and direction) and count data (live crown, total height, time since disturbance, distance, DBH1, live crown ratio, ten year growth, and basal area; see Table 3).

Table 3. SAS variable names used in all the data analyses and their descriptions. All variables without units are class variables.

SAS Code Names	Actual Description	SAS Code Names	Actual Description
Region	North or south LA	Total height	Sample tree total height (m)
Soil	Soil series	Disturbance	Disturbance around sample tree
Site	Site index (high, medium-low)	Disturbance type	Disturbance type (silvicultural or natural)
Water	Flooding regime (well drained, frequently, seasonally)	Time since disturbance	Time since disturbance (yrs.)
DBH1	Sample tree DBH (cm)	Distance	Distance between sample tree and the nearest primary competitor (m)
Basal area1	Sample tree basal area (m)	Primary competitor	Primary competitor species
Crown class1	Sample tree crown class	DBH2	Primary competitor DBH (cm)
Epicormics	Sample tree epicormic #	Direction	Direction primary competitor was from sample tree (N,S,E,W,NE,NW.SE,SW)
Epi_prob	Sample tree epicormic presence, yes or no	Crown class2	Crown class of primary competitor
Live crown	Height to sample tree live crown (m)	Live Crown ratio	Live crown ratio of sample tree
Ten year growth	Sample tree ten year ring growth (cm)	Basal area2	Primary competitor basal area (m)

Results

Factors Influencing the Occurrence of Epicormic Branches: Logistic regression yielded three significant variables that were useful in predicting the likelihood of bottomland red oaks producing epicormic branches (Table 4). The crown class of the primary competitor was the most significant variable ($P < 0.0001$). Other significant variables included the distance from the sample tree to the primary competitor ($P < 0.02$) and sample tree height ($P < 0.09$) (Figures 3-5). All other variables were non-significant in predicting simple presence or absence of epicormic branches.

The probability of epicormic branches occurring on a tree was similar for bottomland red oaks which had either dominant or co-dominant trees as their nearest primary competitors, but the probability of producing epicormic branches declined substantially as the crown class of the nearest primary competitor changed to intermediate for all distance and tree height combinations. The small amount of data that was collected for intermediate competitors is believed to have skewed the data, resulting in a significant difference in branching probability and was therefore removed from all resulting data. The decline in probability of epicormic branch occurrence was greatest as crown class of the primary competitor changed from the co-dominant to the intermediate crown class. The intermediate crown class had very little available data to test, so we speculate that this was the cause of the large difference in probabilities of epicormic branch occurrence. Since the test results seemed to be greatly skewed by the lack of testable data, the intermediate results were discarded from the results and deemed unusable for practical forestry application. Occurrence of epicormic branches were predicted to increase for trees that had suppressed trees as their nearest competitor. Within competitor crown classes both height of the

sample tree and distance to the nearest primary competitor influenced the probability of a selected tree having epicormic branches.

As sample tree height increased the probability of epicormic branching decreased by nearly 25% across all competitor crown classes. As the distance to the nearest primary competitor increased the probability of the sample tree having epicormic branches also declined. As the distance to the nearest competitor increased from 0 to 15 m the chance a tree having epicormic branches decreased approximately 10% across all competitor crown classes. Regardless of the primary competitor's crown class, the pattern of decline in probability of a tree having epicormic branches was the same.

Tree vigor effects on epicormic branch production as related to radial growth were evaluated in the logistic regression, but tree vigor as assessed by the last ten years of radial growth (surrogate for vigor) was non-significant.

Table 4. Logistic Regression results evaluating statistical parameters for epicormic branching as affected by primary competitor crown class, distance from competitor, and sample tree height.

Effect[1]	DF	Wald Chi-Square	Pr > ChiSq
CClass	3	20.57	0.0001
T_Height	1	2.96	0.085
Distance	1	5.48	0.019

[1]CClass = Competitor crown class, T_height = Sample tree height, Distance = Distance to nearest competitor

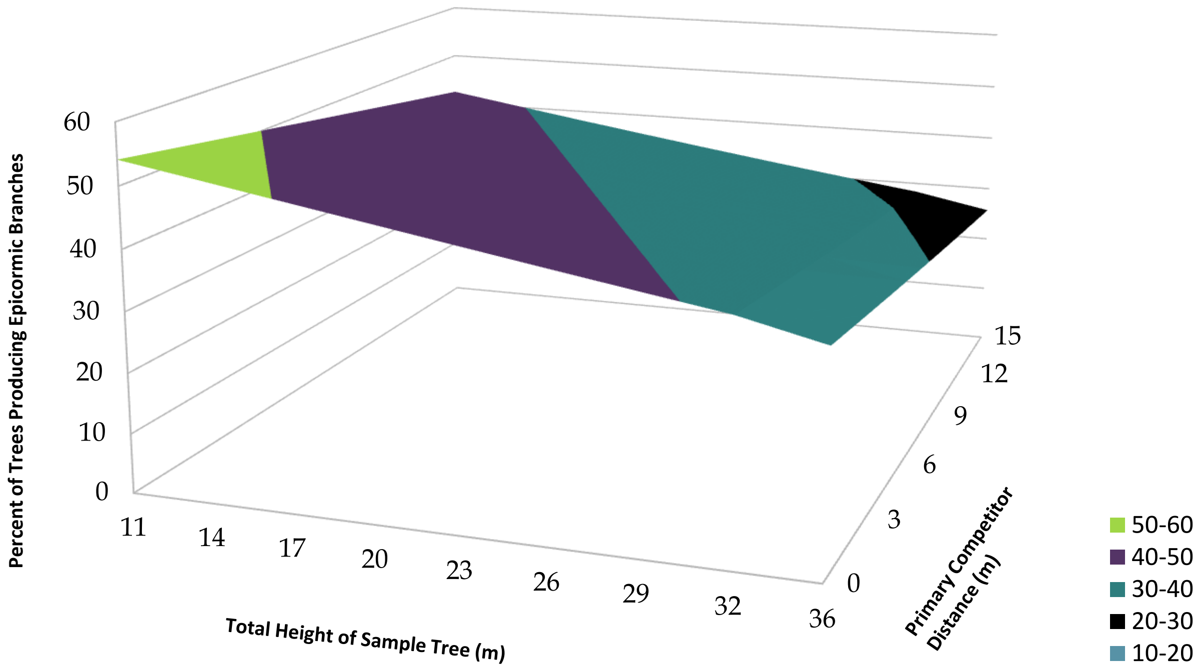

Figure 3. The probabilities for an 11-32m tall bottomland red oak to exhibit epicormic branching at a 0-15m distance when the primary competitor is in a dominant crown class.

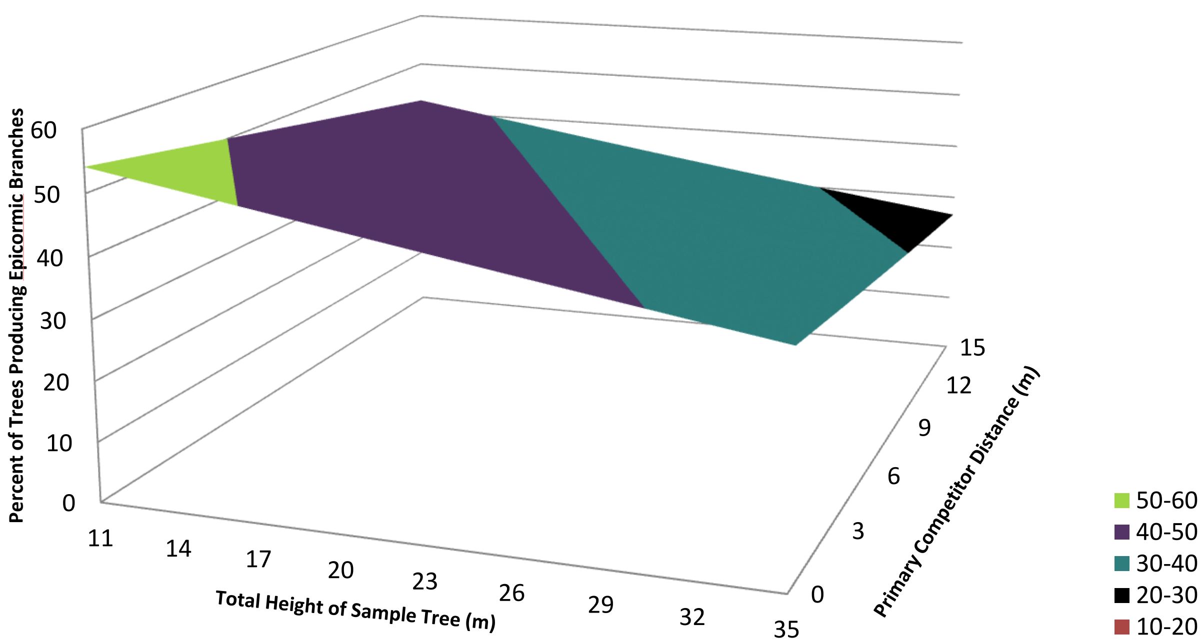

Figure 4. The probabilities for an 11-32m tall bottomland red oak to exhibit epicormic branching at a 0-15m distance when the primary competitor is in a co-dominant crown class.

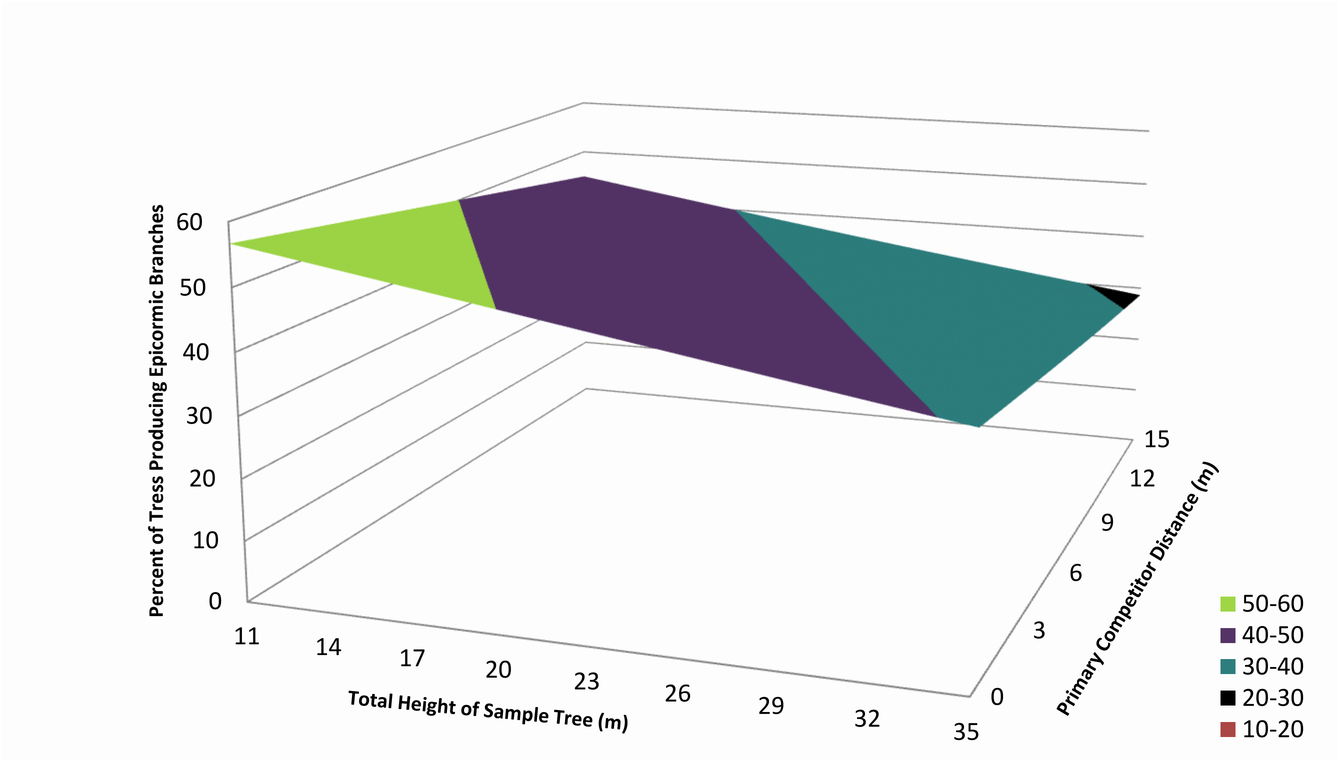

Figure 5. The probabilities for an 11-32m tall bottomland red oak to exhibit epicormic branching at a 0-15m distance when the primary competitor is in a suppressed crown class.

Factors Influencing the Number of Epicormic Branches Produced: Not only is it important to be able to predict the likelihood of epicormic branch occurrence in bottomland red oaks, it is also important to determine how many epicormic branches might be produced. The number of epicormic branches produced potentially reveals more information on the propensity of trees to produce epicormic branches and may help determine associated factors in their environment. All species were grouped together to produce a more universal model for epicormic branch production in bottomland red oaks.

Poisson regression was selected to predict the number of epicormic branches a tree might produce. Poisson regression was used because it the best model for situation where the dependent variable is a count or rate variable. However, the Poisson regression procedure cannot be used to evaluate the most highly correlated and most efficient variables that should be

included in model, therefore, GLM SELECT a SAS procedure, was used for variable selection to reduce the number of variables considered for inclusion in a Poisson regression prediction analysis. GLM SELECT yielded disturbance type, flooding regime, sample tree basal area, sample tree height, and a sample tree basal area by sample tree height interaction term as having the highest correlation with the number of epicormic branches a tree would produce (Table 5).

Sample trees with greater than "zero" epicormic branches were examined in the analysis. Three Poisson models were evaluated and ranked by their AIC (Akaike's Information Criteria). AIC is a statistic that reflects the appropriateness of a model by using covariance and the number of variables in a model to balance the trade-off between lack of fit and a penalty term. AIC is commonly used to evaluate the goodness of fit of multiple models. The smaller the AIC number the better the goodness of fit criterion. Model 1 included the number of epicormic branches as the dependent variable and the measured and class variables as the independent variables without log transformation of any variables. Model 2 included the log of the numbers of epicormic branches as the dependent variable and untransformed measured and class variables as the independent variables. Finally, Model 3 used the log of the number of epicormic branches as the dependent variable and the log of the measured and class variables as the independent variables. Though there are methods other than AIC for analyzing the best fit for the data this one was chosen for its simplicity. Of the three tested Poisson regression models, Model 1, with number of epicormic branches as the dependent variable and the measured and class variables as the independent variables, had the lowest AIC. Although the difference is AIC for the three models were not great enough to reflect any real differences in model performance, Model 1 was also selected as the best model for prediction of epicormic branch numbers, because it does not require transformation of variables and the inherit problems that are encountered in interpreting

the results after such transformations (Table 6). Model 1 included flooding type, disturbance type, sample tree cross-sectional area (tree basal area), sample tree height and a sample tree cross-sectional area by sample tree height interaction term as the significant predictor variables. Trees exhibiting four to ten branches offered somewhat better prediction, but variation was wide on either side of the 1:1 line (Figure 7). The Poisson regression tended to over predict at low levels of branch production and under predict at high levels of branch production. Trees without epicormic branches could not be used in the model because the large numbers of zero values are not allowed in Poisson regression. The lack of zero values may have altered intercept and thus slope and probably reduced the fit of the model.

Table 5. GLM SELECT model using stepwise selection showing the selected significant factors in epicormic branching.

Effect[1] Step Entered	Number Effects In	Number Parms In	Pr > F
0 Intercept	1	1	1.0
1 TTBA	2	2	<.0001
2 D_type	3	6	0.002
3 T_Height	4	7	0.011
4 Water	5	10	0.004
5 T_Height×TTBA	6	11	0.028

[1]**Water**(FF)=frequently flooded,(PF)=periodically flooded,(SF)=seasonally flooded,(WD)=well drained; **D_type = disturbance type where** (bg)=bug gap, (light)=lightning, (nothing=)no thinning, (thin)=thinning,(w)=wind; **TTBA**= sample tree basal area; **T_height**=total height of sample tree

Table 6. General Poisson regression model statistics of selected significant parameters for predicting the number of epicormic branches.

Parameter		DF	Estimate	Standard Error	Wald 95% Confidence Limits		Wald Chi-Square	Pr > ChiSq
Intercept		1	3.4848	0.1749	3.1419	3.8277	396.77	<0.0001
Water	FF	1	0.2559	0.0918	0.0760	0.4359	7.77	0.0053
Water	PF	1	0.1475	0.0468	0.0558	0.2392	9.93	0.0016
Water	SF	1	0.3489	0.0512	0.2485	0.4493	46.38	<0.0001
Water	WD	0	0.0000	0.0000	0.0000	0.0000	.	.
D_type	bg	1	0.3119	0.0869	0.1416	0.4822	12.89	0.0003
D_type	light	1	0.4816	0.1621	0.1640	0.7992	8.83	0.0030
D_type	nothin	1	-0.1916	0.0458	-0.2814	-0.1018	17.48	<0.0001
D_type	thin	1	-0.2304	0.0448	-0.3183	-0.1425	26.40	<0.0001
D_type	w	0	0.0000	0.0000	0.0000	0.0000	.	.
TTBA		1	-0.3186	0.0710	-0.4577	-0.1795	20.15	<0.0001
T_Height		1	-0.0147	0.0028	-0.0202	-0.0093	28.05	<0.0001
TTBA*T_Height		1	0.0029	0.0010	0.0009	0.0049	8.02	0.0046

[1]**Water in drainage class where** (FF)=frequently flooded,(PF)=periodically flooded,(SF)=seasonally flooded,(WD)=well drained; **D_type is disturbance where** (bg)=bug gap, (light)=lightning, (nothing=)no thinning, (thin)=thinning,(w)=wind; **TTBA**= sample tree basal area; **T_height**=total height of sample tree

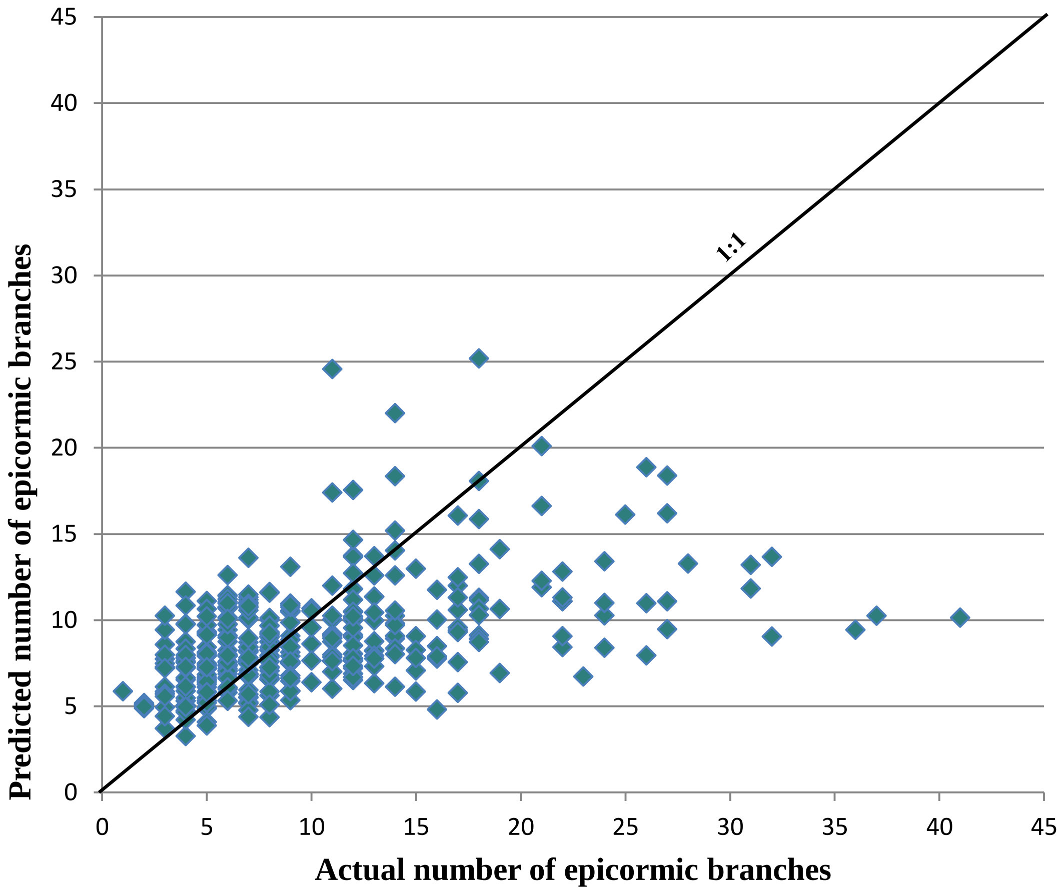

Figure 6. Actual number of epicormic branches against the predicted number of epicormic branches as predicted using Poisson regression.

Discussion

Studies of epicormic branching and their causes have produced mixed results. Some researchers have indicated that the proliferation of epicormic branches can be induced by low vigor of the tree (Brown and Kormanik 1969, Harmer 1992, Lockhart et al 2006, Meadows 1995, Nix 2006, and Stubbs 1986). Meadows et al (2006) indicated that low vigor trees could be characterized as those with small crowns or severely unbalanced crowns with sparse foliage and that those trees regularly produce many epicormic branches. They also indicated that high vigor trees with large, well-shaped, full crowns were unlikely to produce epicormic branches. Conversely, Harmer (1992) found that crown size and crown vigor were not related to post treatment epicormic branch development. Devine and Harrington (2006) followed the development of epicormic branches in suppressed Oregon white oaks for five years after a release cutting. They removed trees greater than 10 cm in diameter around the white oaks from a radius equal to one-half the height of the subject trees (half-release) and equal to the full height of the subject trees (full-release). In their study the number of post treatment epicormic branches was not related to either crown size or crown die-back, but epicormic branch formation in suppressed trees were stimulated as a result of tree release and crown die-back. Even though epicormics were stimulated by release, the number of epicormic branches formed after release was fewer than the number present before release in both treatments. The average number of new epicormic branches produced under the full-release treatment was under five on the butt log. The variation in results in these studies could be related to the common use of a single species evaluation, the use of stands dominated by trees of similar ages and similar sized trees, or that many such studies have been performed in relatively young stands.

The current study is unique in that it includes four bottomland red oak species and tests them together, since bottomland red oaks rarely occur in monoculture stands. The grouped species approach was used to produce a general model for *Q. nigra, Q. pagoda, Q. phellos,* and *Q. texana*.

In the current study, recent diameter growth (latest 10 year growth) did not appear to affect the probability of trees having epicormic branches, however, sample tree height, relative crown class of the nearest primary competitor and distance to the nearest primary competitor were related to the probability of epicormic branching and all may affect or be related to tree vigor. Dimov et al (2006) found that *Q. pagoda* trees in dominant or co-dominant crown classes had fewer epicormic branches after logging than did trees in the intermediate and suppressed crown classes. Meadows et al (2006b) found similar results six years after thinning for *Q. nigra* and *Q. texana* in a mixed bottomland hardwood stand that was thinned by reducing stocking to 47 percent. The remaining oaks were primarily dominant and co-dominant trees. Lockhart et al (2006) found that thinning had little effect on the production of epicormic branches in the dominant and co-dominant crown classes of *Q. pagoda.* The results of these studies confirm the similarity among species in this response to thinning. `Lockhart et al (2006) and Dimov et al (2006) studies along with the current study suggest that relative tree vigor, especially as established by relative height of the tree and its competitors, may play a significant role in the susceptibility of a tree to produce epicormic branches. The assumption at the outset of this study was that the condition of tree boles in current stands should indicate the general conditions under which epicormic branches have formed and provide insight into the conditions that will affect their future production. That assumption seems to follow from these results, but might not be true if disturbance was very recent.

The results from the current study show the probability of epicormic branching can be as high as 60% with common occurrences in the 50+ percentile (Figures 4-6.) Meadows (1995) found that 13% of the value of willow oak lumber in a final stand harvest was lost due to the presence of epicormic branches on trees. Since trees that produce epicormic branches yield a loss in potential profit, the presence of epicormic branches should not be ignored during intermediate stand treatments. When trees are to be removed from a stand, those found to have high probabilities of producing epicormic branches should be removed from managed stands instead of removing trees less likely to produce epicormic branches. The release from competition has often been thought to increase production of epicormic branches and some have indicated stresses, such as increased light or temperature may have influenced the production of epicormic branches. However, Wignall and Browning (1988) and Harmer (1992) showed that increased light did not seem to directly influence epicormic branch production. Both sets of researcher indicated that epicormic shoot emergence is not stimulated by increased exposure to light in thinned stands. In the current study, height of the sample tree, distance to the primary competitor and the competitors crown class significantly affected the probability of epicormic branch production on sample trees. Increasing size (height) and reduced competition from similar sized trees (increased distance to trees of similar height) reduced the probability of epicormic branch presence. Dimov et al (2008) found that trees taller than sample trees that were within a distance of 2.4 times the mean crown radius had the greatest impact on tree vigor. In the current study, increasing distance from a competitor decreased the probability of a tree having epicormic branches, but the species of the competitor did not significantly affect the likelihood of epicormic branch presence. Since the bottomland red oaks studied were lumped together in this study, the species of competitor may deserve further evaluation. A special way of defining the

nearest competitor was used by limiting them to trees of at least half the height of the sample tree. Competitors of similar size to the sample tree seem to have greater effect on the probability of sample trees producing epicormic branches. However, we did not evaluate other competitors directly.

This study showed that epicormic branching was independent of the species of primary competitor. This is an important concept since the use of mixed species "trainer trees" is commonly suggested for maintaining clean boles on valuable red oaks. In the past, it was believed that a certain component of species diversity must be kept in order to maintain clean boles on valuable red oaks (Auchmoody 1972, Harmer 1992, Hedlund 1964, Howell and Nix 2002, Jemison and Schumacher 1948, McKnight 1958, Schlaegal 1978, Skilling 1957). Evaluating the relative height of trainer trees may be important in avoiding increased production of epicormic branches. Future thinnings should concentrate on the removal of nearest competitors based on relative height..

Flooding regimes were found to affect the number of epicormic branches produced. Bottomland red oak species found growing offsite should not be favored in a profitable forest setting. Species such as *Q. nigra* and *Q. pagoda* growing on frequently flooded sites, and *Q. phellos* growing on inundated sites should not be favored due to their lowered vigor on more frequently flooded sites. The vigor of these trees, which tend to be intermediate and suppressed trees on these sites, is reduced resulting in an increased chance of producing epicormic branches.

Even a few epicormic branches can reduce the lumber value significantly. The number of branches present may influence the log grade, which in turn affects the monetary value of the tree. As few as five epicormic branches somewhat evenly distributed on a 4.88 m (16 ft) log is enough to cause a grade reduction (Meadows 1995). The Poisson regression model developed in

this study was used to evaluate the number of epicormic branches a tree will form. Even though the model suffers from an imperfect fit it helps to interpret conditions affecting relative number of epicormics that might be expected.

Ten year radial growth was used as a variable in both the Logistic regression and GLM select procedure. The GLM select procedure found the 10 year radial growth to be insignificant and in turn it was not used in the Poisson regression. Nicolini et al (2001), noticed that slowed cambial activity in suppressed *Fagus sylvatica* led to enhanced production of epicormic branches. However, within the genus *Quercus*, there has been little research to quantify the effects of slowed cambial activity on the proliferation of epicormic branches. The current study used 10 year radial growth as a potential factor related to epicormic branch production. Both analyses failed to see a significant radial growth or basal area growth component in relation to the production of epicormic branches This may indicate that vigor related factors other than radial growth are more highly correlated to epicormic branching. Though 10 year radial growth measurements failed to yield substantial effect, other measures of tree vigor should be explored for potential effects on epicormic branch production. As trees mature, the vigor of the individual tree begins to decline. A highly merchantable tree can have declining vigor without showing any physical attributes of the decline. This study points toward tree height or relative tree height as perhaps stronger components in the relationship to tree vigor and epicormic branch production. This effect may vary with tree crown class. Taller sample trees, at least trees taller on a relative basis compared to their nearest primary competitors, tend to be less likely to produce epicormic branches.

Conclusions

The ability to predict the potential for occurrence of epicormic branching on bottomland red oaks increases the ability of forest managers to produce superior quality and high value timber of desirable species.

Epicormic branches are interesting and perplexing phenomena that are still poorly understood. The biological process for a tree producing epicormic branches can be explained in detail, but the driving mechanism for their sudden appearance has been somewhat elusive. The current study indicates that vigor (as assessed by relative height) of the individual tree and its primary competitor plays a key role in the presence and number of branches. Vigor is also influenced by competition relationships with the nearest primary competitor (trees nearly as tall as the subject tree) and by environmental factors such as the flooding regime and natural disturbances as seen in the results of both the presence and number of epicormic branches.

Based on the results of this study, a forest manager about to thin a stand can select trees of superior bottomland red oak leave trees and reduce the chance they will produce epicormic branches that will reduce the value of the leave trees. The forest manager should apply the following guiding principles to help ensure minimization of epicormic branch formation on the selected leave trees. First select only leave trees adapted to the site conditions, those of high quality with regard to form and canopy dominance. Once a desired stocking level has been set, trees in intermediate and suppressed crown classes should be removed to favor dominant and co-dominant trees of superior form and crown condition. When dominant and co-dominant trees are in close proximity choose the taller tree to leave, if form and quality are similar. Shorter trees in close proximity to the selected leave trees (distance less than 10 m) should be removed when these competing trees are exceeding the height of the lower crown of the leave tree. The removal

of trees that are not tolerant of site conditions (off-site species) should be a priority in profitable stand maintenance.

Based on the results of this study a forester or land manager can make better decisions on how the leave trees will respond with epicormic branching. Having a set of guiding principles to help reduce the occurrence and numbers of epicormic branches that a leave tree may produce after a thinning gives the land manger more control over future log quality and potential profits.

Literature Cited

Auchmoody, L., 1972. Epicormic branching: seasonal change, influence of fertilization and frequency of occurence in uncut stands. USDA Forest Service Resource Paper NE-228: 1–8.

Baker, J.B., Broadfoot, W.M., 1977. A practical field method of site evaluation for eight important southern hardwoods. General Technical Report-SO-14. New Orleans, LA, US Department of Agriculture, Forest Service, Southern Forest Experiment Station. 31 pp.

Brown, C.L., Kormanik, P.P., 1969. Origin and development of epicormic branches in sweetgum. USDA Forest Service, Research Paper SE-54. Southeastern Forest Experiment Station, Asheville, NC. 17 p.

Carpenter, R.D., Sonderman, D.L., Rast, E.D., Jones, M.J., 1989. Defects in hardwood timber. Agricultural Handbook No. 678. USDA Forest Service, Northeastern Forest Experiment Station, Delaware, OH. 88 p.

Clatterbuck, W.K., 2006. Logging damage to residual trees following commercial harvesting to different overstory retention levels in a mature hardwood stand in Tennessee. In: Connor, K.F., ed. Proceedings of the 13th Biennial Southern Silviculture Research Conference. General Technical Report-SRS-92. Asheville, NC: US Department of Agriculture, Forest Service, Southern Research Station. 591-594.

Devine, W. D., and C. A., Harrington. 2006. Changes in Oregon white oak (*Quercus garryana* Dougl. ex Hook.) following release from overtopping conifers. Trees 20:747-756.

Dimov, L.D., Stelzer, E., Wharton, K., Meadows, J.S., Chambers, J.L., Ribbeck, K., Moser, E.B., 2006. Effects of thinning intensity and crown class on cherrybark oak epicormic branching five years after treatment. In: Connor, K.F., ed. Proceedings of the 13th Biennial Southern Silviculture Research Conference. General Technical Report-SRS-92. Asheville, NC: US Department of Agriculture, Forest Service, Southern Research Station. 606-610.

Harmer, R., 1992. Do dominant oaks have few epicormic branches? Forestry Commission Research Division, Research Information Note 223, 4 p.

Hedlund, A., 1964. Epicormic branching in north Louisiana delta. USDA For. Serv. Res. Note S-O-8: 1–3.

Howell, M.P., Nix, L.E., 2002. Early thinning in bottomland hardwoods. In: Gen. Tech. Rep. SRS-48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 196-200.

Jemison, G.M., Schumacher, F. X., 1948. Epicormic branching in old-growth Appalachian hardwoods. Journal of Forestry 46 (4) 252-255.

Lockhart, B.R., Michalek, A. J., Lowe, M.W., 2006. Epicormic branching in red oak crop trees five years after thinning and fertilizer application in a bottomland hardwood stand. In: Connor, K.F., ed. Proceedings of the 13th Biennial Southern Silviculture Research Conference. General Technical Report-SRS-92. Asheville, NC: US Department of Agriculture, Forest Service, Southern Research Station.595-598

McKnight, J. S., 1958. Thinning stands of water oaks. In Proceedings, Seventh Annual Forestry Symposium. p. 46-50. Louisiana State University, School of Forestry, Baton Rouge.

Meadows, James S., Burkhardt, E.C., Johnson, Robert L., Hodges, John D., 2001. A numerical rating system for crown classes of southern hardwoods. Southern Journal of Applied Forestry. 25(4): 154-158.

Meadows, J.S., 1995. Epicormic branches and lumber grade of bottomland oak. In Proceedings of the 23rd Annual Hardwood Symposium Conference, Advances in hardwood utilization: following profitability from the woods through rough dimension, Cashiers, NC, Memphis, TN: National Hardwood Lumber Association. 19-25.

Meadows, J.S., Burkhardt, E.C., 2001. Epicormic branches affect lumber grade and value in willow oak. Southern Journal of Applied Forestry. 25 (3): 136-141.

Meadows, J.S., Goelz, J.C.G., 2002. Fourth-year effects of thinning on growth and epicormic branching in a red oak-sweetgum stand on a minor stream bottom site in 32 West-central Alabama. General Technical Report-SRS-48. Asheville, NC: US Department of Agriculture, Forest Service, Southern Research Station. 201-208.

Meadows, J.S., Leininger, T.D., Nebeker, T.E., 2006. Thinning to improve growth and bole quality in an *Inonotus hispidus*-infected, red oak-sweetgum stand in the Mississippi Delta: sixth-year results. In: Connor, K.F., ed. Proceedings of the 13th Biennial Southern Silviculture Research Conference. General Technical Report-SRS-92. Asheville, NC: US Department of Agriculture, Forest Service, Southern Research Station. 640 p.

Meadows, J.S. and Skojac, D.A., 2006. Third-year growth and bole-quality responses to thinning in a late-rotation red oak-sweetgum stand in east Texas. From Connor, K. F., ed. 2006. Proceedings of the 13th Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS–92. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 640 p.

Meadows, J.S. and Stanturf, J.A., 1997. Silvicultural systems for southern bottomland hardwood forests. Forest Ecology and Management 90:127-140.

Nicoloni, E., Chanson, B. and Bonne, F., 2001. Stem growth and epicormic branch formation on understory beech trees *Fagus sylvatica* L. Annals of Botany 87: 737–750.

Nix, L.E., 2006. Crop trees and quality in bottomland hardwoods ten years after an early thinning in a young sprout-origin stand in South Carolina. In: Connor, K.F., ed. Proceedings of the 13th Biennial Southern Silviculture Research Conference. General Technical Report-SRS-92. Asheville, NC: US Department of Agriculture, Forest Service, Southern Research Station. 620-627.

Putnam, J.A., Fumival. G.M.,McKnight, J.S., 1960. Management and inventory of southern hardwoods. Agric. Handb. No.181. U.S. Dept. of Agriculture. Washington, DC, 102 pp.

Schlaegel, Bryce E., 1978. Growth and yield of natural hardwood stands; concepts, practices, and problems. In Proceedings, Second Symposium on Southeastern Hardwoods, April 20-22, 1977, Dothan, Alabama. p. 120-129. Southeastern Area, State and Private Forestry, Atlanta, GA.

Skilling, D.D., 1957. Is the epicormic branching associated with hardwood pruning wounds influenced by tree crown class? Tech. Notes No. 510. USDA Forest Service. Lake States Forest Experiment Station. St. Paul, MN, 2 p.

Smith, H. C., 1965. Effects of clearcut openings on quality of hardwood border trees. Journal of Forestry: 63 (12) 933-937.

Sonderman, D. L.; Rast, E. D., 1988. Effect of thinning on mixed oak stem quality. Res. Pap. NE-618. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 6 p.

Stubbs, J., 1986. Hardwood epicormic branching-small knots but large losses. Southern Journal of Applied Forestry: 10 (4) 217-220.

Wignall, T.A., Browning G., 1988. The effects of stand thinning and artificial shading on epicormic bud emergence in pedunculate oak (*Quercus robur* L.). Forestry 61: 45–59.

Vita

Denton William Culpepper was born in Minden, Louisiana May 8, 1986. He grew up in this small rural community as the son of a timber contractor / surveyor and a homemaker. Denton graduated from Lakeside High School in 2004 with honors and immediately enrolled in Louisiana Tech University. While at LA Tech, Denton double majored in Forestry and Wildlife Conservation and obtained three minors in Plant Science, Biology, and Environmental Science. As a student at LA Tech, Denton served as President of the Wildlife Club, Forestry Club, and Xi Sigma Pi. He was also honored as the 2008 LFA Forestry Student of the Year and as a LA Tech Who's Who in 2009. He graduated in the spring of 2009 with the honors of Magna cum Laude. Denton spent the summers of 2008-2009 as an intern with the USFWS at Tensas River National Wildlife Refuge performing duties as a forester. Denton has been a student at LSU since the fall of 2009 and is presently a candidate for the degree of Master of Science in Forest Ecology. Denton is married to Savanna Pace Culpepper of Boyce, LA, who currently is a 3rd year Veterinary Student at LSU. Denton is currently employed by Mississippi River Trust as a Field Biologist/Forester and works out of Baton Rouge, LA.