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

HEIGHT-DIAMETER EQUATIONS AND MORTALITY RATES
FOR THIRTEEN MIDWEST BOTTOMLAND HARDWOOD SPECIES

presented by Kenneth Colbert

a candidate for the degree of Master of Science

and hereby certify that in their opinion it is worthy of acceptance.

____

____

____

HEIGHT-DIAMETER EQUATIONS AND MORTALITY RATES FOR THIRTEEN MIDWEST BOTTOMLAND HARDWOOD SPECIES

A Thesis
presented to
the Faculty of the Graduate School
University of Missouri-Columbia

In Partial Fulfillment
of the Requirements for the Degree

Master of Science

---

by
KENNETH COLBERT

Dr. David Larsen, Thesis Supervisor

DECEMBER 1998

ACKNOWLEDGMENTS

Special thanks are extended to Dr. David Larsen, Dr. John Dwyer, Dr. Ernie Wiggers, and Dr. John Kabrick, all of the University of Missouri-Columbia, Larry Gnewikow of Amana Society Forestry, Wayne H. Fuhlbrugge of the Iowa Department of Natural Resources, the Iowa Department of Natural Resources, the Illinois Department of Natural Resources, the Missouri Department of Conservation, the USDA Forest Service, and to Tolicia Colbert, for their time, patience, and guidance in ensuring the completion of this project. Several individuals too numerous to thank contributed information that made this project possible. Heartfelt thanks are extended to all individuals who contributed in any way to this project. The content of this thesis is due to all named and unnamed individuals, however, any errors herein are the sole responsibility of the author.

LIST OF TABLES

LIST OF ILLUSTRATIONS

TABLE OF CONTENTS

INTRODUCTION

The 1993 flood in the central United States has sparked concern about tree mortality in the riparian forests in this region. The flood of 1993 was of such magnitude that it was at first believed to have been a 500-year event. Further examination of recorded meteorological events indicated that the flood of 1993 was a 100-year to 175-year event (Blackwell 1997). Three states which suffered the most crop damage, infrastructure damage, soil loss, and tree mortality due to the flood were Iowa, Missouri, and Illinois. In Davenport, Iowa, the flood was classified as at least a 100-year event. The Corps of Engineers classified the flood as at least a 100-year event in Kansas City, Missouri, and a 175-year event in St. Louis, Missouri.

The purpose of this study was to determine bottomland hardwood mortality in Midwest riparian species due to prolonged flooding during the growing season. Although the initial proposal for this research project included an inventory by species for mortality due to prolonged flooding during the growing season, the data garnered from the collection phase of the project also contributed to the development of height-diameter equations for 13 riparian tree species in the mid-western United States.

The data for this study was collected along major rivers in Missouri, Illinois, and Iowa. Riparian forest sites lay along the Missouri, Platte, Illinois, Iowa, Des Moines, Cedar, and Mississippi Rivers. The collaborating agencies that assisted with the data collection were the Missouri Department of Conservation, the Illinois Department of Natural Resources, the Iowa Department of Natural Resources, the USDA Forest Service, and Amana Society Forestry. Each agency involved in the research suggested potential sample sites. These sites were assessed, prioritized, and then scouted to ensure sampling of the 1993 flood range of the big rivers in the three states. This document is comprised of two papers, the first (Chapter 2), on height-diameter equations for thirteen bottomland hardwood species found in the mid-western United States. The second (Chapter 3), examines mortality rates of the same thirteen bottomland hardwood species due to a prolonged growing season flood.

HEIGHT-DIAMETER EQUATIONS FOR THIRTEEN
MIDWEST BOTTOMLAND HARDWOOD SPECIES

Introduction

Height-diameter equations are extremely useful for estimating vertical forest structure and predicting heights in diameter growth models. This chapter presents equations for Midwest bottomland hardwood species in big river riparian forests. The results of this study will allow natural resource managers working in wetland or riparian forest management, wetland or riparian forest restoration, and streambank stabilization to make more informed decisions. The height-diameter equations presented here will enable managers to predict heights of Midwest bottomland hardwood species in big river riparian forests when only diameters are measured. These equations will permit the efficient use of time, in addition to making data collection easier by measuring only one parameter, dbh (diameter at breast height).

Height-diameter equations are used for assessing tree volume (Larsen and Hann, 1987, Miner et al. 1988, Walters et al. 1985, Walters and Hann 1986), and to determine a tree's social position within a stand (Larsen 1994, Ritchie and Hann 1986). Its use in determining site index is a measure of stand productivity (Carmean et al. 1989, Hann and Scrivani 1987). Tree heights are time consuming and costly to measure accurately. In many samples they are either subsampled or not measured at all. In these cases, height-diameter equations are commonly used to predict tree height when heights are not measured. This chapter presents equations for predicting total height as a function of diameter at breast height (1.37 meters above ground) for the 13 species listed in Table 2A, all found in bottomland hardwood forests of Missouri, Iowa, and western Illinois.

Background

A number of equations have been used to predict tree height from the diameter of a tree species (Curtis 1967, Monserud 1975, Wykoff et al. 1982, Ek et al. 1984, Van Deusen & Biging 1985, and Larsen & Hann 1987). Larsen and Hann (1987) evaluated a number of equations and used Monserud's (1975) height-diameter equation for predicting heights of tree species in southwest Oregon. Monserud's equation is a flexible form that readily fits most height-diameter data sets. Monserud's equation also provides a starting point for further iterations, both linear and non-linear. The models presented in this chapter also uses Monserud's equation as a starting point in the development of the final model. Monserud's model form is:

$$H = 1.37 + \exp(b_0 + b_1 D^{b_2}) \qquad 2.1$$

where H is total tree height (m), 1.37 is breast height (m), D is diameter at breast height (cm), and b_x are regression coefficients. This equation has the logical features of height equaling breast height when D is zero. Additionally, the equation will approach an upper asymptote as b_2 becomes negative.

Methods

The data were collected along major rivers in Missouri, Illinois, and Iowa. Riparian forest sites lay along the Missouri, Platte, Illinois, Iowa, Des Moines, Cedar, and Mississippi Rivers. The collaborating agencies that assisted with the data collection were the Missouri Department of Conservation, the Illinois Department of Natural Resources,

Table 2A. Bottomland hardwood species list. Shown are the common names, scientific names, and species groups for analysis.

Common name	Scientific name	Species group
Box elder	*Acer negundo* L.	Acer negundo
Silver maple	*Acer saccharinum* L.	Acer saccharinum
Sycamore	*Platanus occidentalis* L.	Platanus occidentalis
Eastern cottonwood	*Populus deltoides* Bartr. ex Marsh.	Populus deltoides
Pin oak	*Querqus palustris* Muenchh.	Querqus palustris
Black willow	*Salix nigra* Marsh.	Salix nigra
American elm	*Ulmus americana* L.	Ulmus americana
Hackberry	*Celtis occidentalis* L.	Celtis spp.
Sugarberry	*Celtis laevigata* Willd.	Celtis spp.
Green ash	*Fraxinus pennsylvatica* Marsh.	Fraxinus spp.
White ash	*Fraxinus americana* L.	Fraxinus spp.
Red mulberry	*Morus rubra* L.	Morus spp.
White mulberry	*Morus alba* L.	Morus spp.

the Iowa Department of Natural Resources, the USDA Forest Service, and Amana Society Forestry. Each agency involved in the research suggested potential sample sites. These sites were assessed based on whether they were flooded in 1993 or not, prioritized by potential for plot locations (i.e., enough area to negate fringe effects, proximity to major stream, etc.), and then scouted to ensure adequate sampling of the 1993 flood range of the big rivers in the three states. Eight sites in Missouri, six sites in Illinois, and seven sites in Iowa were systematically sampled (Figure 2A). The data includes a wide range in heights and diameters for the 10 species groups (Table 2B).

The sample plots were designed to take into account spatial variation within sampled sites in terms of landform and distance from stream. The plot design resembles one-half of a wheel with five spokes. Plot center was located at least 30 meters from the river's edge, this allowed the plot to remain in riparian forest on the river side of the levee. Plot center was selected so that a 120-meter long transect could run approximately parallel to the stream. Each successive vector (spoke) contained two subplots (30 meters apart) on bearings 45 degrees greater than the previous vector bearing (Figure 2B). The plot covered an area 120 meters by 60 meters. The minimum area needed to establish a plot was approximately 100 by 130 meters.

The first subplot of any plot was permanently marked as plot center with painted rebar at the center of the first subplot. Also, at least two witness trees were marked with two horizontal bands of orange spray paint and aluminum tree tags. Each subplot consisted of a vegetative plot (1/1414 ha), a small-tree plot (1/198 ha), and a large-tree

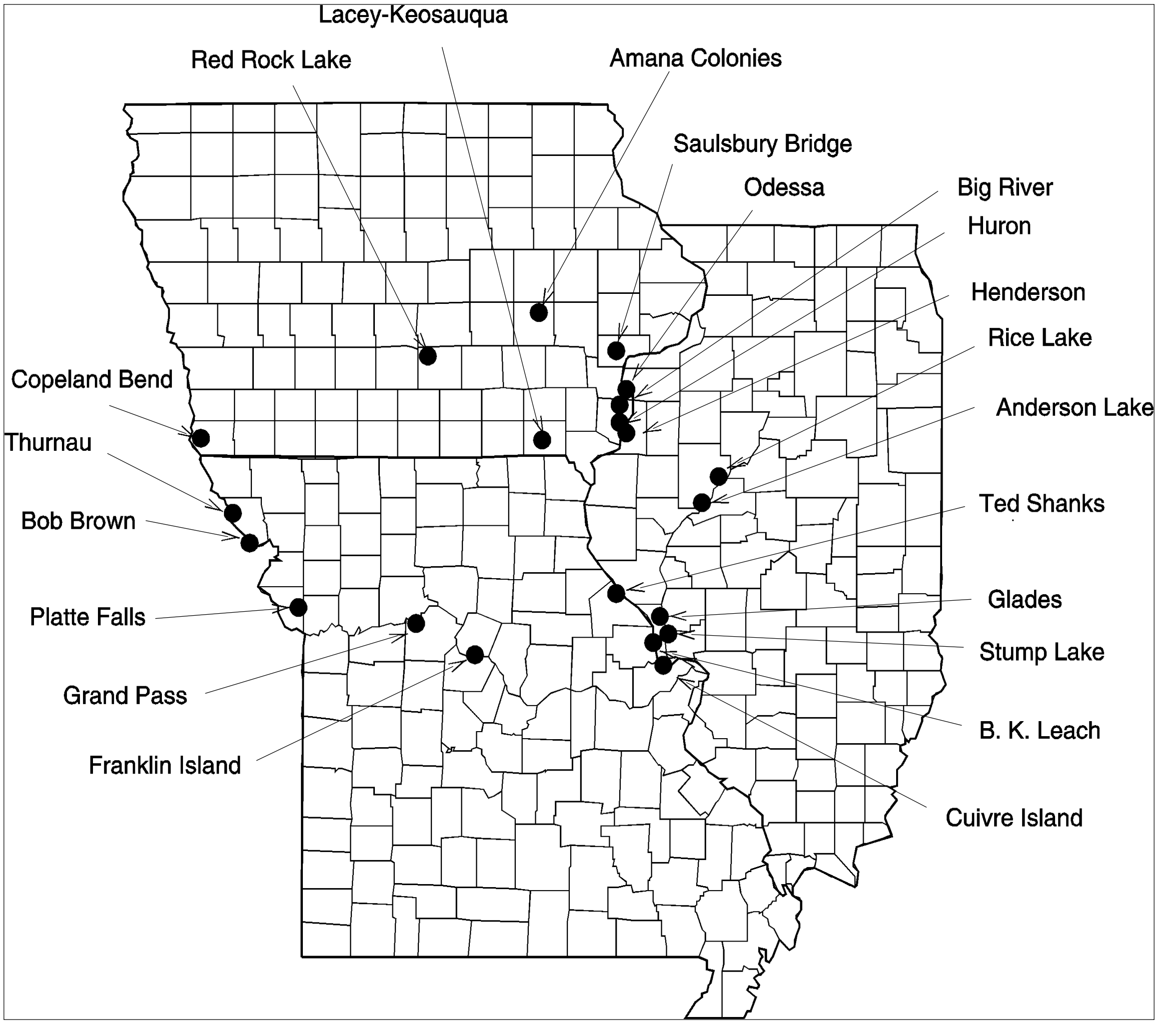

Figure 2A. Sample sites in Missouri, Iowa, and Illinois for both 1994 and 1995. Several sites contained multiple plots. A total of 45 plots were installed at the 21 sites.

Table 2B. Summary statistics for data used in this study. They include: averages, standard deviations, minimums, and maximums for dbh and height by species group.

		DBH (cm)				**Height** (m)			
Species Group	**# Obs.**	avg.	std.dev.	min.	max.	avg.	std.dev.	min.	max.
Acer negundo	248	19.6	12.3	1	56	11.7	5.5	2	25
A. saccharinum	1035	33.9	19.1	1	143	20.6	7.5	2	60
Plat. occi.	50	26.6	13.8	2	59	19	7.5	4	31
Popu. delt.	361	41.8	14.6	5	105	29.6	7.5	2	48
Quer. palu.	105	28.3	15.7	4	90	20.3	7.5	7	35
Salix nigra	155	21.2	15.8	1	62	14.8	7.5	2	36
Ulmu. amer.	462	14.8	9.2	1	64	11	7.5	2	30
Celtis spp.	70	14.5	11.5	1	50	10.3	7.5	2	26
Fraxinus spp.	226	23.5	15	1	65	16.1	7.5	2	44
Morus spp.	450	10.5	8.1	1	54	6.8	7.5	2	30

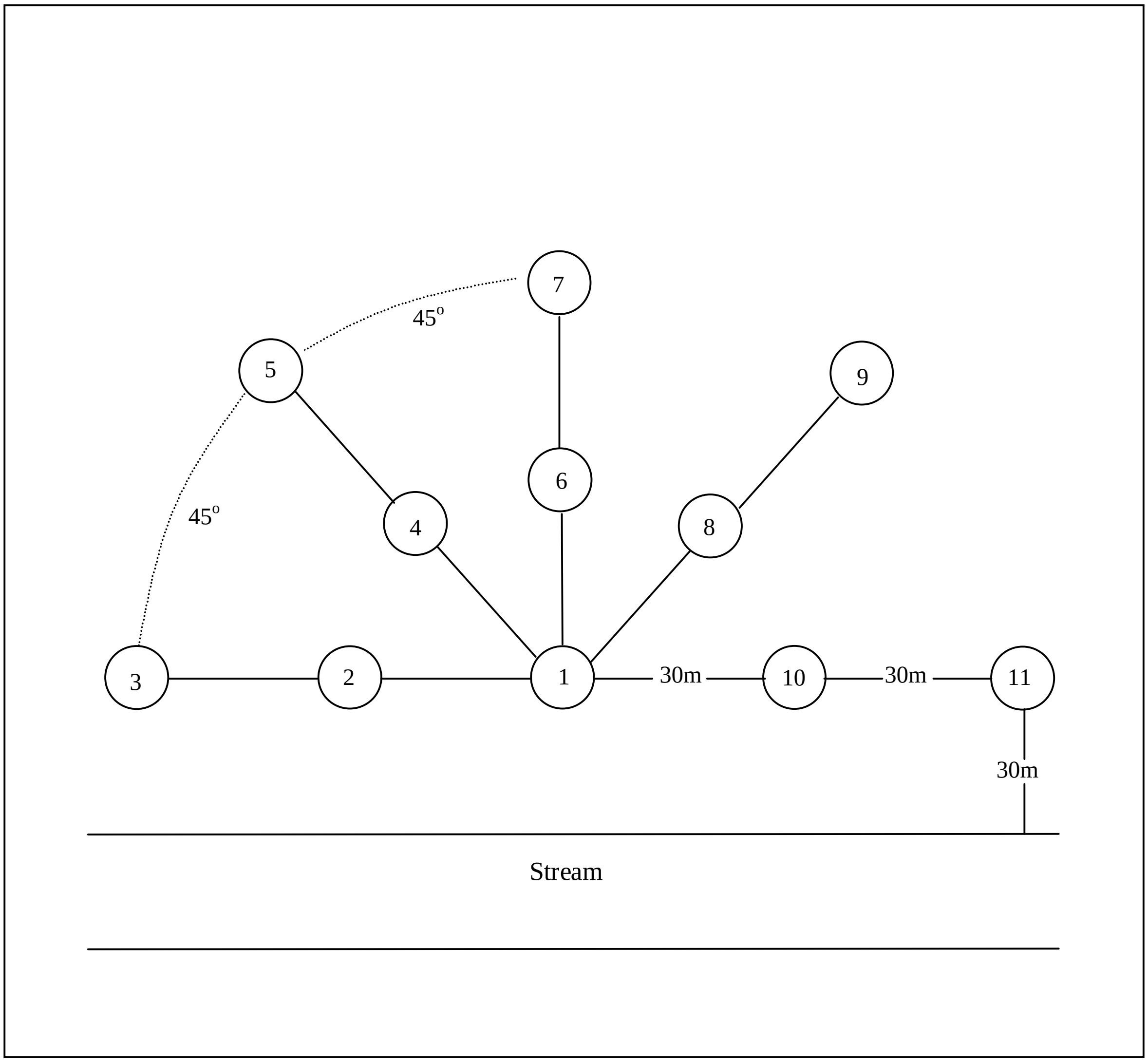

Figure 2B. Plot layout and distances between subplots. Spacing was ≥ 30 m from river and the subplots were 30 m along each vector (spoke). The vectors were 45^o apart.

plot (1/50 ha)(Figure 2C). In the vegetative plot, all vegetation less than dbh (1.37 meters) was measured to attain an average height by species and percent ground cover. All trees at least 1.37 meters in height and less than 15 centimeters at dbh were measured to determine species, dbh, height, crown ratio, crown condition, and damage in the small-tree plot. And finally, in the large-tree plot, all trees at least 1.37 meters tall and at least 15 centimeter at dbh were measured to obtain species, dbh, height, crown ratio, crown condition, and damage.

Once tree species was determined, diameter at breast height was measured to the nearest one-half centimeter using a diameter tape. The height of an individual tree was measured to the nearest meter using the clinometer-tape method. After species, dbh, and height were determined, crown ratio and crown condition were determined and recorded. The crown ratio of a tree was taken as a percent of crown length to total tree length. Crown condition was determined as a percent of actual crown present to an ideal crown of a healthy tree of the same species in a Midwest riparian forest setting. Damage codes for each tree were designated as follows:

0 = no damage	10 = dead top
1 = debris damage	12 = fire damage
2 = water damage	13 = animal damage (deer, beaver, etc.)
3 = suppressed	14 = vine suppressed
4 = broken top	15 = diseased (cankers, galls, etc.)
5 = dead limbs	16 = wind damage
6 = rotting stem	95 = snag
7 = midseason mortality	96 = snag with cavities
9 = dead	

A data summary for the 10 species groups is given in Table 2B.

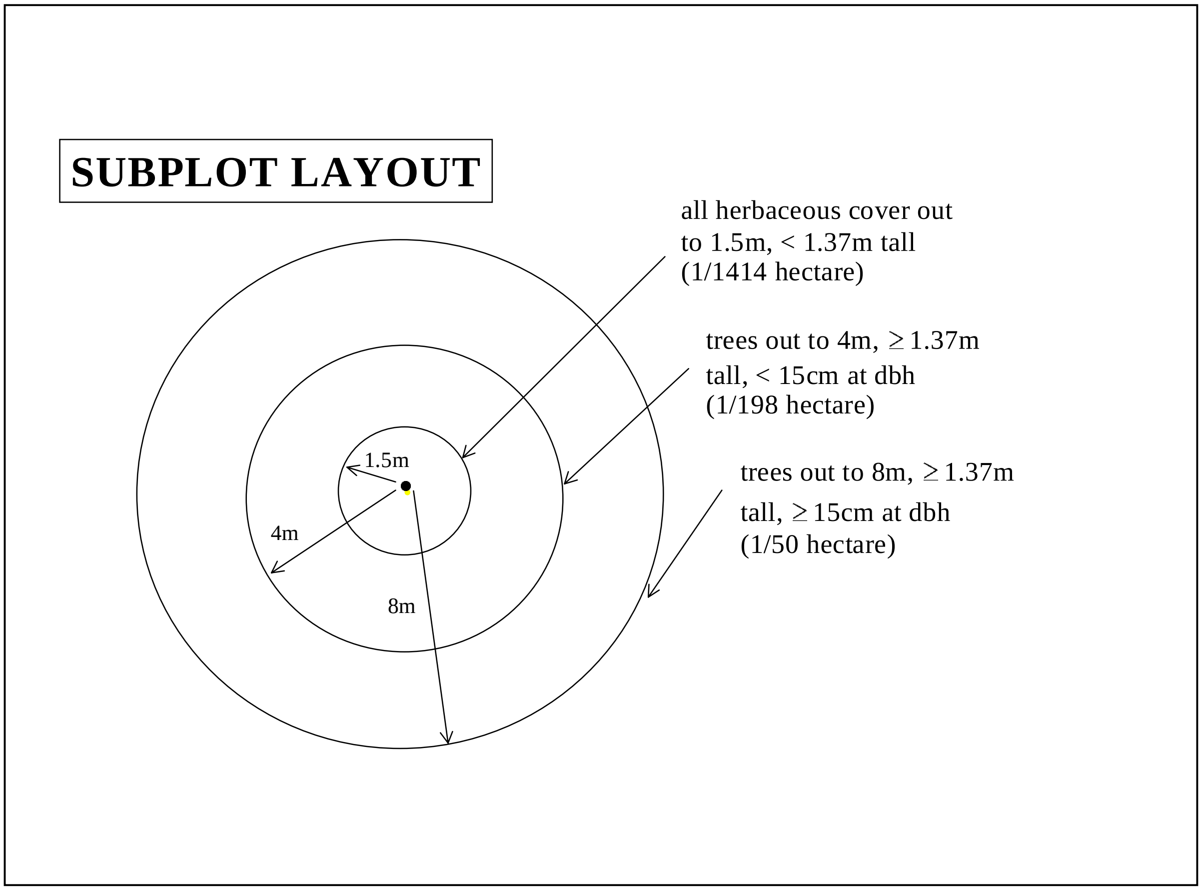

Figure 2C. Subplot layout showing areas, radii, and vegetation measured within subplots.

Results

Thirteen tree species were sampled, however, due to the similarity of species within the same genus and the lack of sample observations, *Celtis occidentalis* L. and *C. laevigata* Willd., *Fraxinus pennsylvatica* Marsh., and *F. americana* L., and *Morus rubra* L. and *M. alba* L. were grouped to produce the *Celtis* spp., *Fraxinus* spp., and *Morus* spp. groups respectively (Table 2A).

Equation 2.1 was transformed to linearize the equation, and b_2 was forced to - 0.2 which made the independent side of the equation linear. Larsen and Hann (1987) found -0.2 for b_2 to be a common parameter. The transformed equation was then fit with linear regression to the tree data, using the equation:

$$\ln(\text{height} - 1.37) = b_0 + b_1 D^{-0.2} \qquad 2.2$$

where D is diameter at breast height and b_0 and b_1 are regression coefficients. The values for b_0, b_1, and -0.2 were used as starting values for a non-linear fit of the equations to the species data sets. After running the linear and non-linear regressions on the data, it was found that of the ten species groups examined, correlation coefficients for three groups could not be improved because the data was not sufficient for non-linear regression. There was no way to solve the non-linear function, therefore, the regression coefficient b_2 was forced to –0.2 and used in the linear regression. The values from the transformed linear regression equation were used for the American elm (*Ulmus americana* L.), *Celtis* spp., and *Morus* spp. groups.

Species group coefficients are given in Table 2C along with the standard errors of the model fits and the pseudo non-linear adjusted R^2, which measures the proportion of the variation in tree height accounted for in the model, taking into account the number of independent variables (Neter & Wasserman 1974, and Zar 1996). The pseudo adjusted R^2 was calculated by applying the equation to the observed X values and calculating residuals. The sums of squares were calculated from these residuals in the normal way. Figures 2D-2M illustrate the model predictions by species across the range of observed data.

Discussion

The predicted shapes across the range of observed data for box elder (*Acer negundo* L.) and silver maple (*A. saccharinum* L.) depict a good fit and a tight pattern of observed data around the predicted height-diameter line. Although there were relatively few data points for the sycamore (*Platanus occidentalis* L.) species group, the sycamore group's observed data followed the predicted line quite well. Eastern cottonwood (*Populus deltoides* Bartr. ex Marsh.) did not exhibit as good a fit as the sycamore group, possibly due to other factors not accounted for such as tree physiology, site productivity, or general health of the stand. Pin oak (*Quercus palustris* Muenchh.) and black willow (*Salix nigra* Marsh.) both had comparatively few data observations, but while pin oak maintained a tight fit, black willow had more variance due to factors not accounted for. The American elm and *Celtis* spp. groups followed the predicted lines well, even though the *Celtis* spp. group had relatively few observations. *Fraxinus* spp. and *Morus* spp. both had tight patterns around their respective predicted lines. Although there were outliers

Table 2C. Models for estimating height of species found in riparian forests (b_0, b_1, and b_2 are coefficients for equation 2.1).

Species Group	**Parameter estimates**			**Root MSE**	**R^2 adjusted**
	b_0	b_1	b_2		
Acer negundo†	4.3862	-5.2031	-0.3217	2.9570	0.7144
A. saccharinum†	4.0415	-5.7366	-0.4858	4.3939	0.5780
Plat. occi.†	4.9715	-5.4871	-0.2986	3.6734	0.7339
Popu. delt.†	4.8069	-7.7305	-0.4475	5.6817	0.5256
Quer. palu.†	5.9483	-5.7029	-0.1953	3.3127	0.7571
Salix nigra†	7.7002	-8.1554	-0.1549	5.0823	0.7464
Ulmu. amer.*†	6.2662	-6.8222	-0.2000	2.8500	0.7154
Celtis spp.*†	6.6189	-7.5257	-0.2000	2.7737	0.8332
Fraxinus spp.†	5.5448	-6.2387	-0.2545	3.6148	0.8086
Morus spp.*†	5.3877	-5.9011	-0.2000	2.3150	0.6569

* Linear shown because non-linear not applicable. † P-value for all groups was zero.

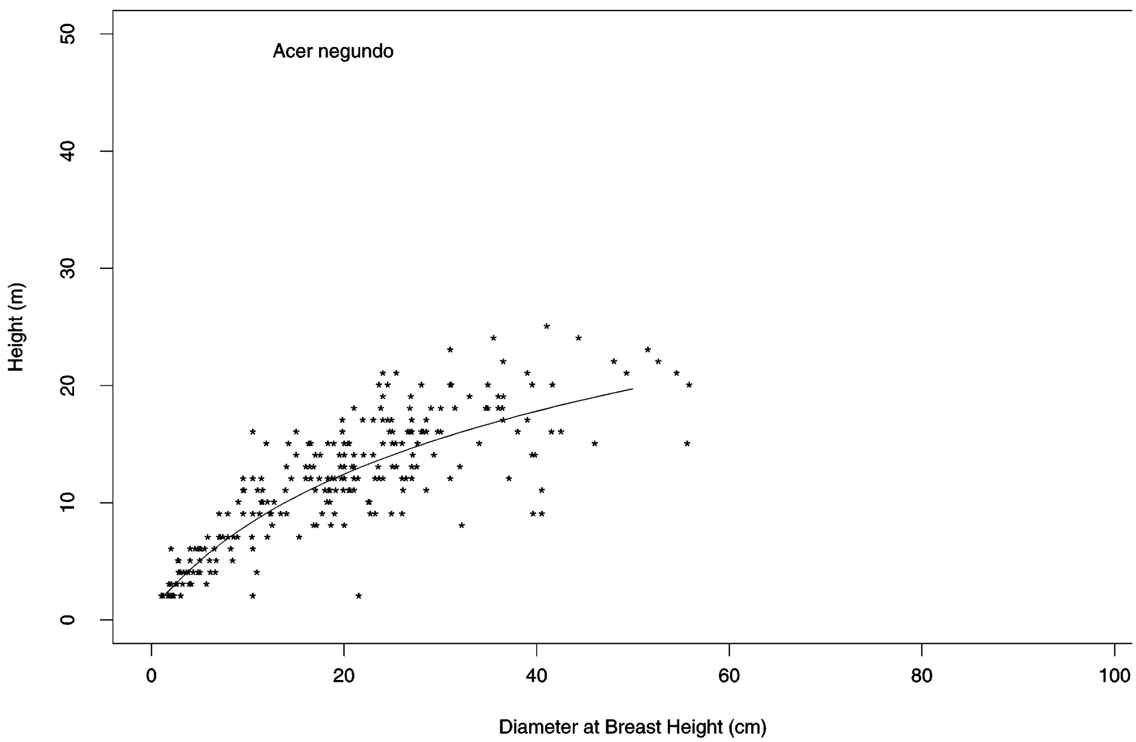

Figure 2D. Model predictions and observations for box elder.

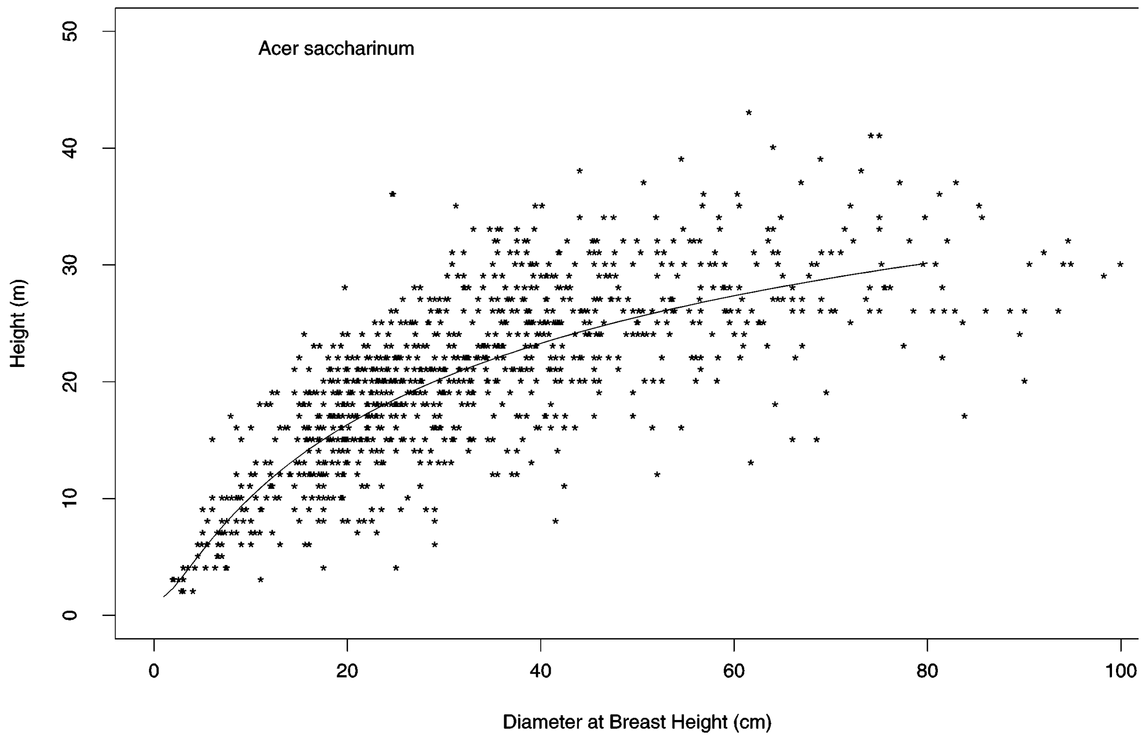

Figure 2E. Model prediction and observations for silver maple.

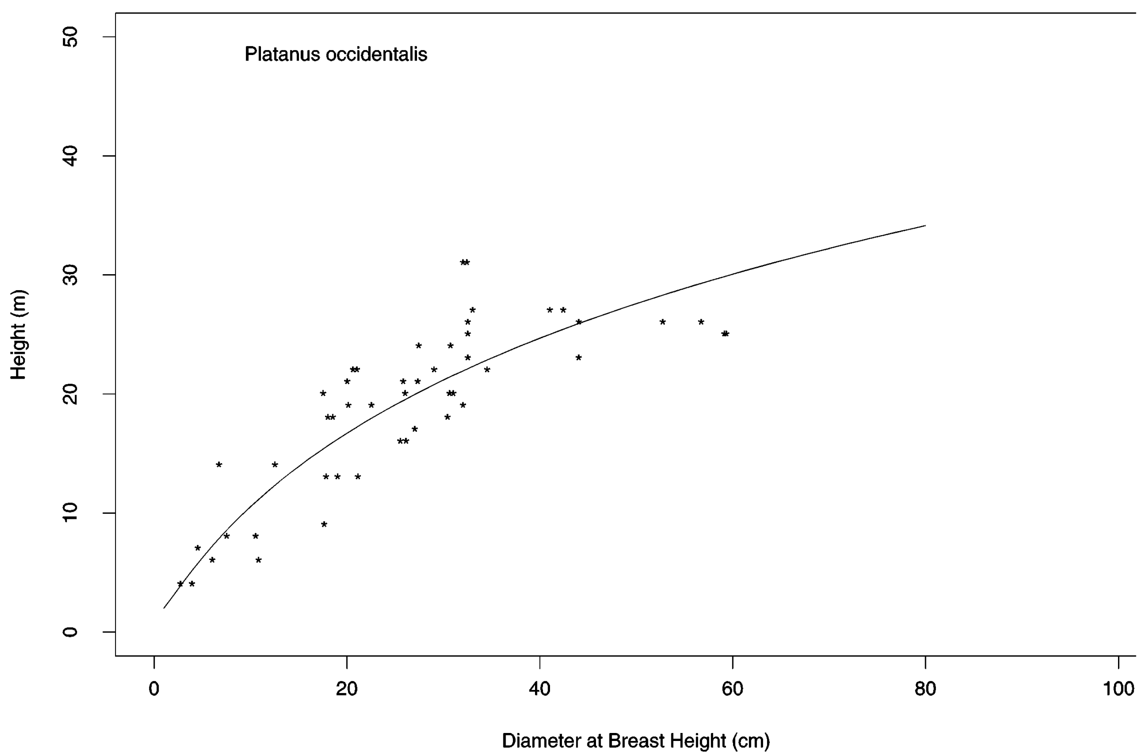

Figure 2F. Model predictions and observations for sycamore.

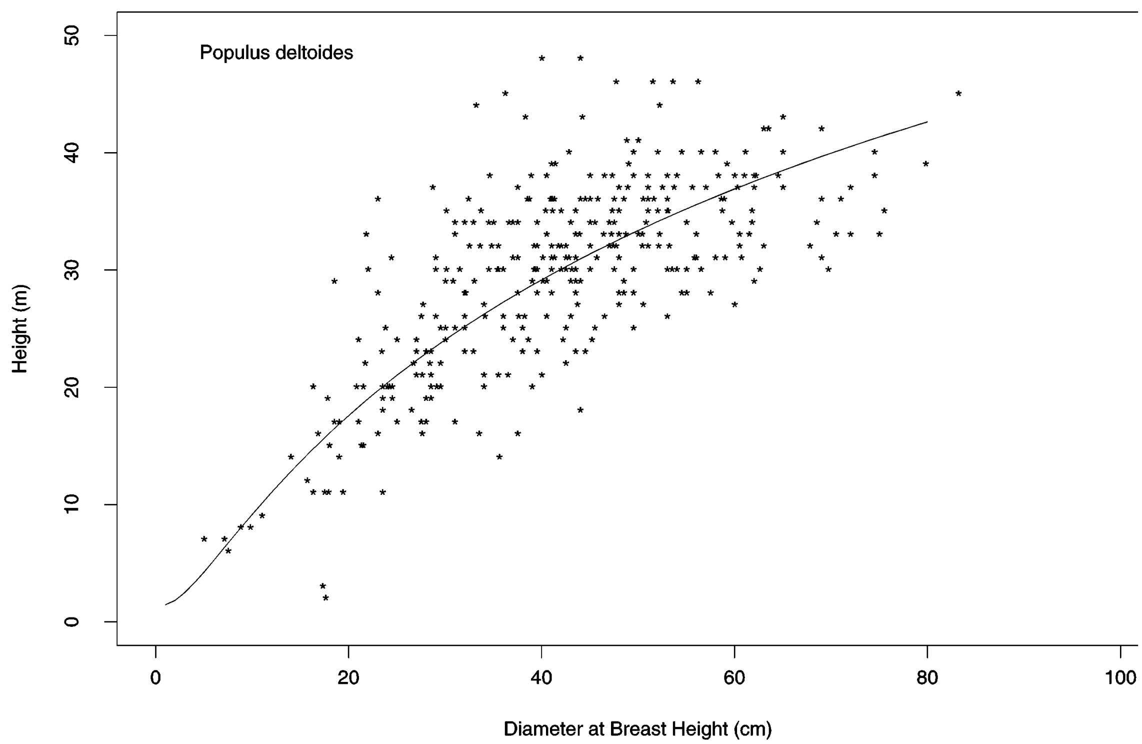

Figure 2G. Model predictions and observations for eastern cottonwood.

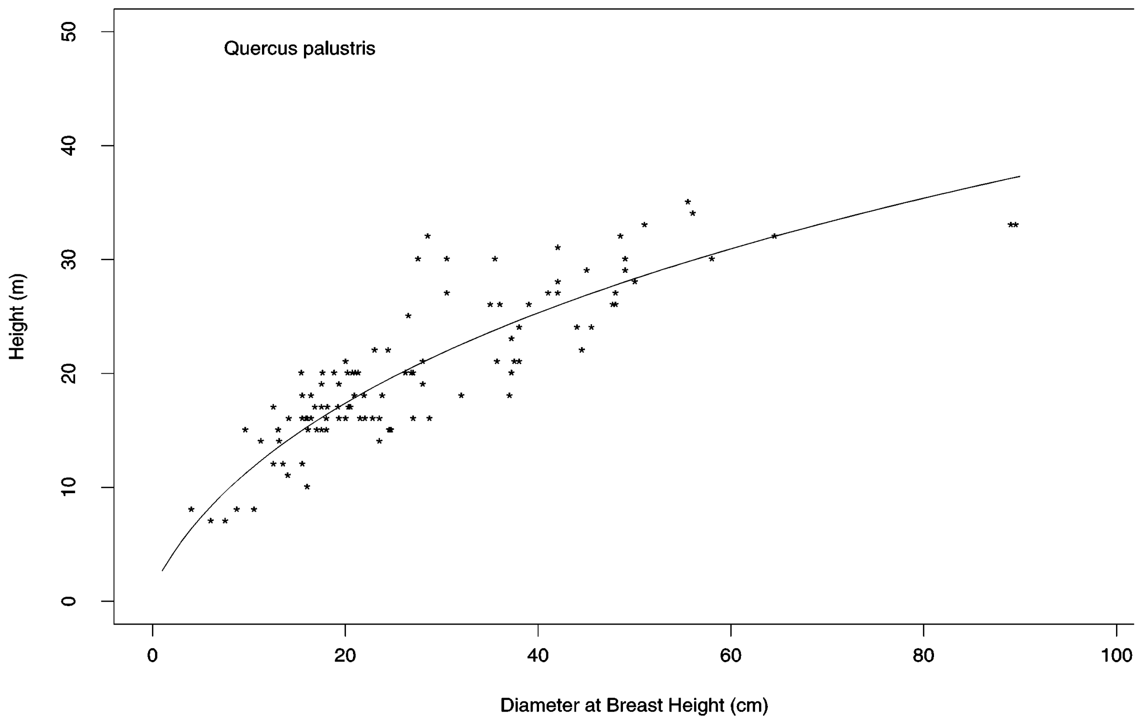

Figure 2H. Model predictions and observations for pin oak.

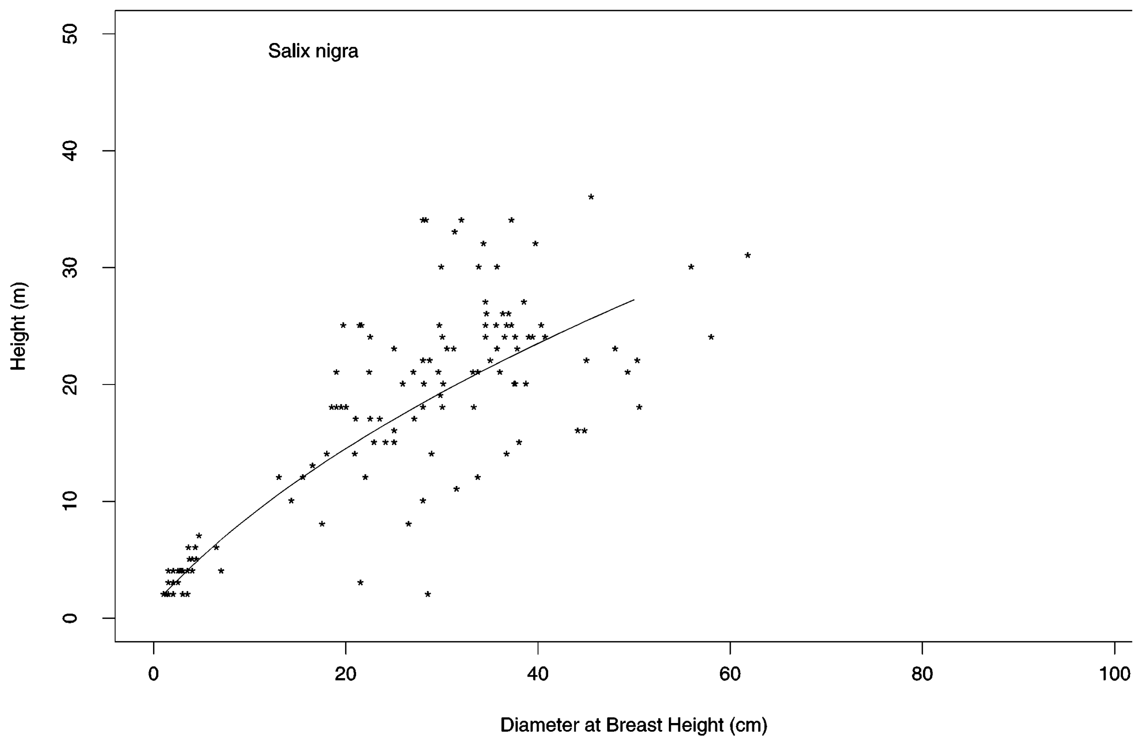

Figure 2I. Model predictions and observations for black willow.

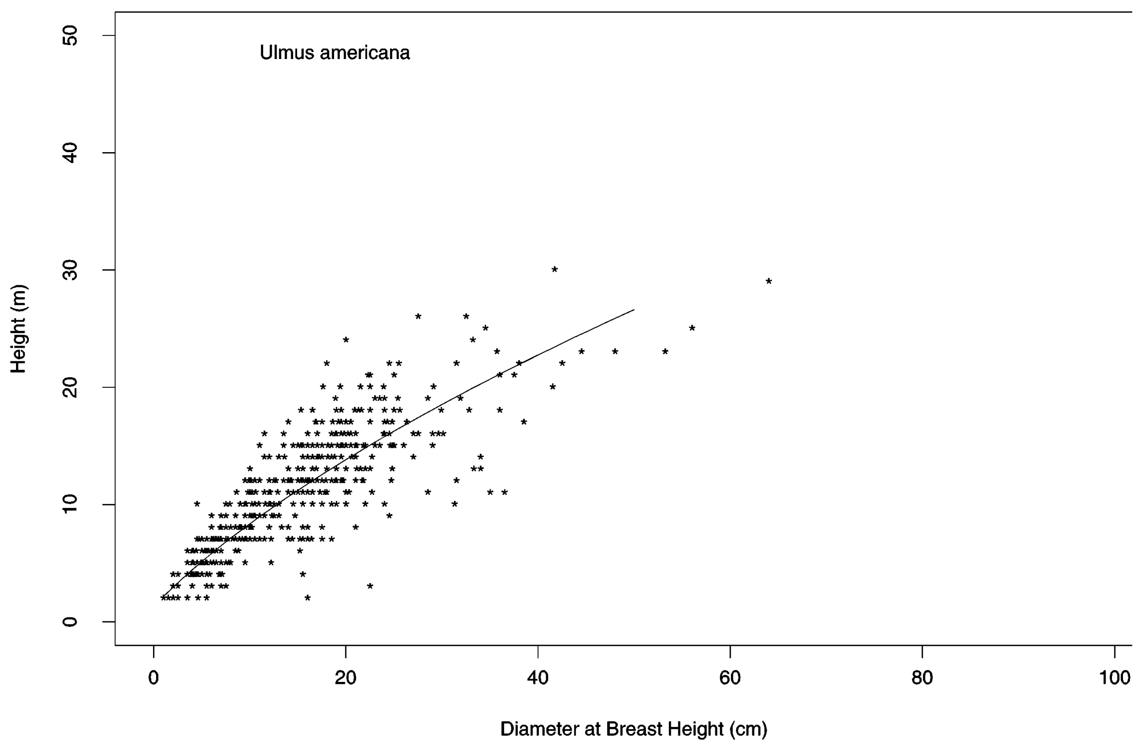

Figure 2J. Model predictions and observations for American elm.

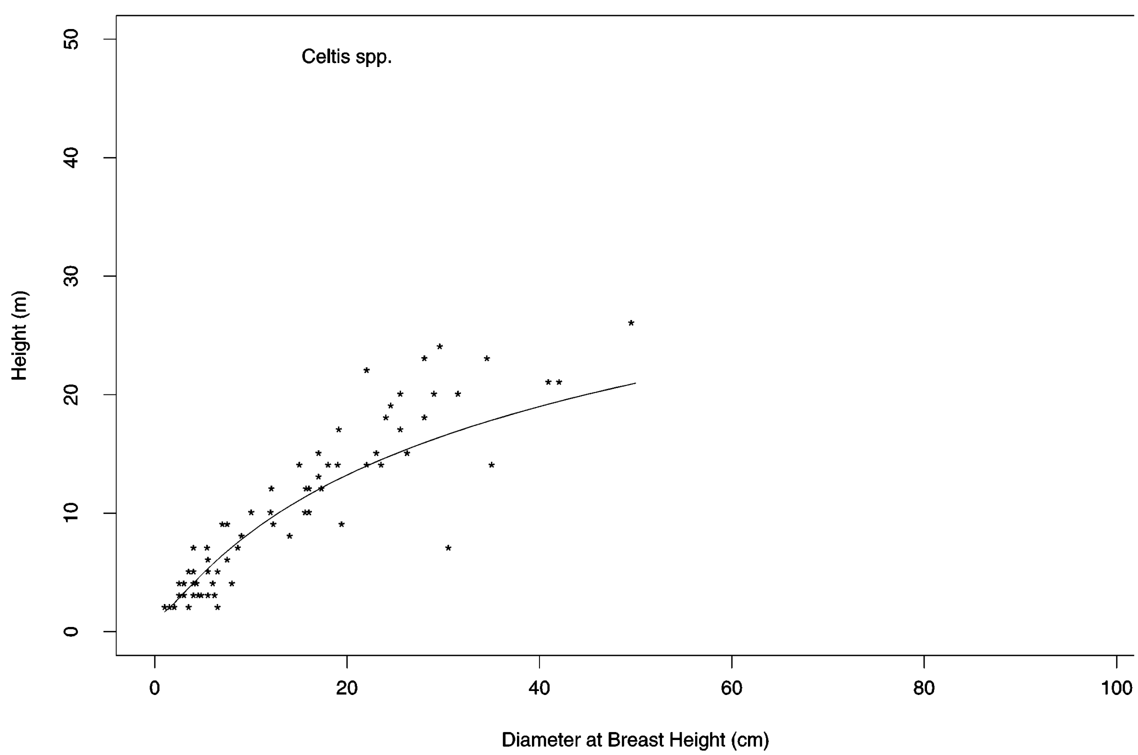

Figure 2K. Model predictions and observations for Celtis spp.

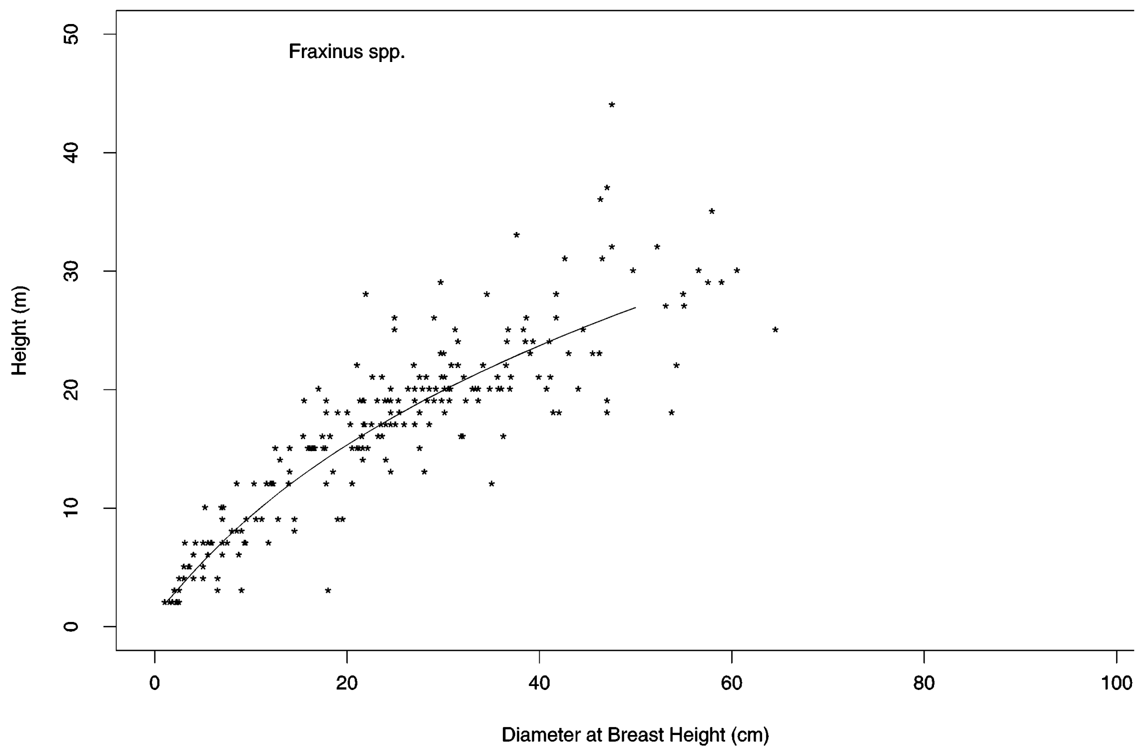

Figure 2L. Model predictions and observations for Fraxinus spp.

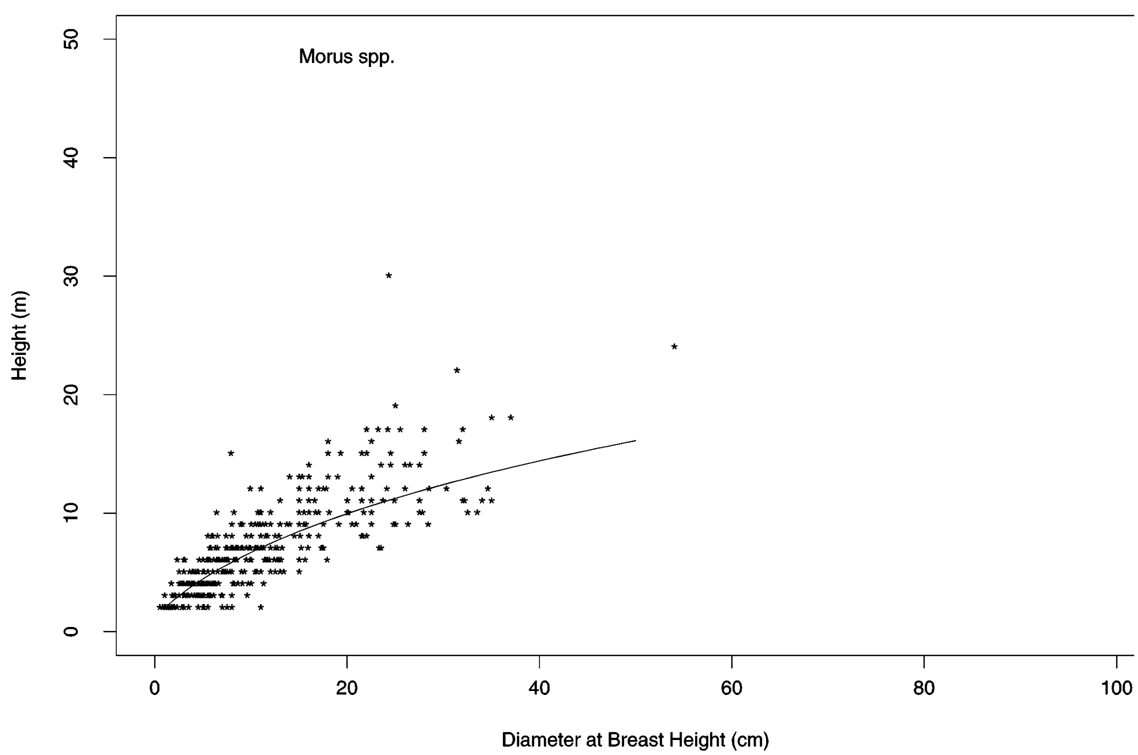

Figure 2M. Model predictions and observations for Morus spp.

present in the observations of both species groups, the predicted lines of both groups tended to be conservative.

The described procedure produced height-diameter equations that are consistent with biological growth patterns for each species. When plotted over the observed data, the models predict the general trend of observations well. Figure 2N summarizes the model predictions for the 10 species groups. The estimated coefficients were consistent, in sign and magnitude, with the work of other authors (Curtis 1967, Monserud 1975, Wykoff et al. 1982, Ek et al. 1984, Van Deusen & Biging 1985, and Larsen & Hann 1987) on other species. Interestingly, the species with the largest stature at large diameters also had the largest early heights at small diameters, with the exception of eastern cottonwood, which had the least stature at small diameter, but the largest stature at large diameter. This deviation is due to the accelerated growth rate associated with eastern cottonwood relative to other species and the lateral growth instead of vertical growth eastern cottonwood exhibits during the earlier stages of its life cycle. Although there were outliers present, and the data had been collected immediately following a major flood event, these factors did not appear to greatly affect either the linear or non-linear regression lines of any of the 10 species groups under consideration.

Conclusion

The equations presented in this paper are useful in forest inventory applications when heights have not been measured but are desired to estimate forest structure. These models and coefficients can be used for inventory compilations in Midwest bottomland

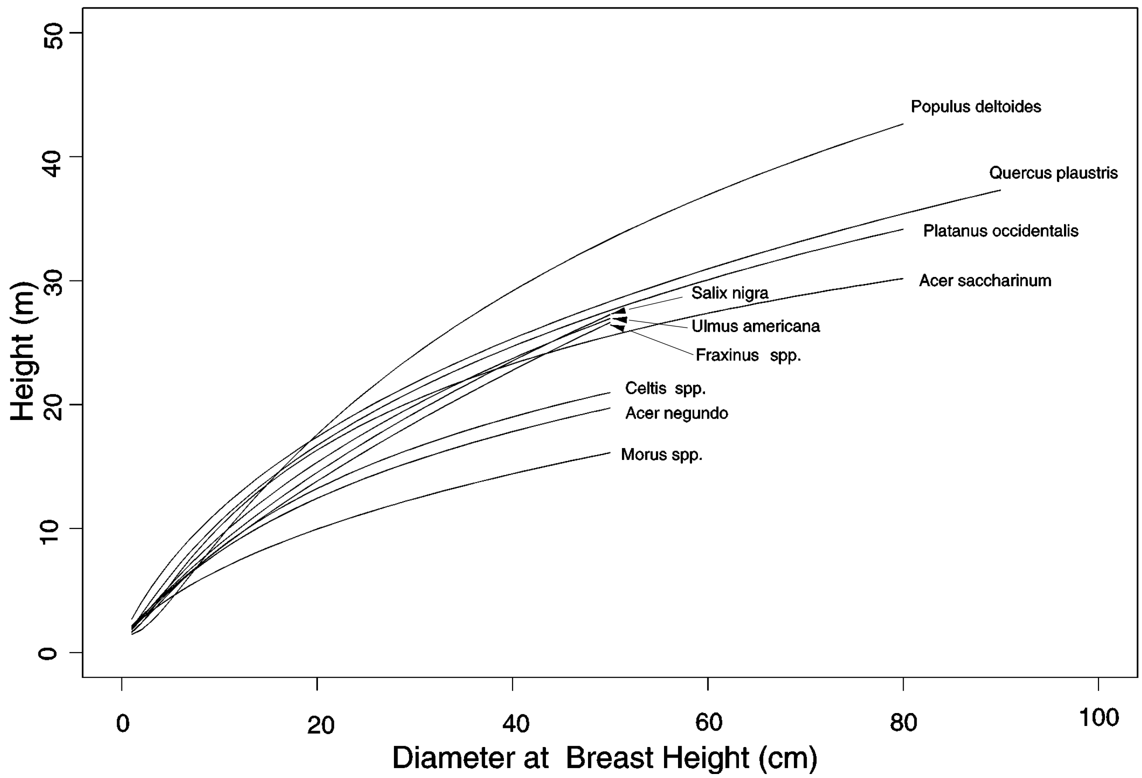

Figure 2N. Summary of model predictions for the 10 species groups.

hardwood forests located in riparian corridors. They are also useful when developing height-diameter models for Missouri, Iowa, and Illinois to be used in the *Forest Vegetation Simulator*. They can also be used in growth projection models to predict height based on diameter at breast height. The model form used produced logical and accurate results for the thirteen tree species (10 species groups) present in riparian forest in northern Missouri, southern Iowa, and western Illinois.

Natural resource managers working in riparian corridor, watershed, wetland, and streambank conservation projects will find these equations useful in predicting potential vertical forest structure and potential forest growth. The measurement of only one parameter (dbh) will also enable natural resource managers to complete projects in a timely manner, as well as decrease the amount of input needed to complete the task.

BOTTOMLAND HARDWOOD MORTALITY DUE

TO A PROLONGED GROWING SEASON FLOOD.

Introduction

The 1993 flood in the central United States was of such extreme duration and depth that it was classified as a 100-year to 175-year event by the Corps of Engineers (Blackwell 1997). The river began to exceed flood stages in late April and early May and continued until early September. According to a report produced by the US Army Corps of Engineers (1994), "A rare combination of meteorological patterns produced a convergence zone over the upper Midwest between the warm, moist air from the Gulf of Mexico, and the cooler, drier air from Canada. This weather pattern stalled in the area until the end of July, causing unusually heavy precipitation. The ground was already saturated, the result of a wet fall in 1992 and spring 1993 snowmelt, ...the additional rain went directly into runoff." Additionally, during peak flood stage, the water covered most or all of the flood plains of the Missouri, Mississippi, and their tributaries in the central United States. Natural resource managers have expressed concern regarding the effects a six-month flood would have on tree mortality rates in riparian forests, particularly, how mortality rates differ by tree species.

The purpose of this study was to determine bottomland hardwood mortality in Midwest riparian species due to prolonged flooding during the growing season. This study quantified tree mortality by species, region, and tree size for 13 tree species found in riparian forests on the river side of the levee system, in the Midwest.

The objective of this study was to examine the differences in mortality rates exhibited by bottomland hardwood tree species commonly found in Missouri, Iowa, and Illinois. After these mortality rates have been determined, natural resource managers will use this information to aid the decision-making process of what tree species to plant in areas susceptible to growing season floods. As very few existing permanent plots were found within flood-prone riparian forests, a sampling system was designed to gather data from the areas most affected by the flood of 1993 within the three states. A clustered fixed-area plot design was adopted in lieu of one large fixed-area plot to take into account landform microsite variability within these sites (Kabrick et al. 1998).

This chapter presents general mortality rates, and spatial variability within plots, as well as mortality equations for estimating the probability of tree survival as a function of diameter at breast height (dbh at 1.37 meters above ground) for 13 species (Table 3A), all found in bottomland hardwood forests of northern Missouri, southern Iowa, and western Illinois.

Background

Mortality of trees occurs in bottomland forests for several different reasons. A tree can die from senescence, competition from other vegetation, insect damage, disease, environmental factors (high winds, drought, freezing, etc.), and physical injuries as a result of harvesting, floating log abrasion or snow and ice storms. Catastrophic events such as tornadoes, hurricanes, and floods can also result in tree mortality. This chapter will focus on tree mortality due to prolonged flooding during the growing season of 1993.

Table 3A. Bottomland hardwood species list. Shown are the common names, scientific names, and species groups for analysis.

Common name	Scientific name	Species Group
Box elder	*Acer negundo* L.	Acer negundo
Silver maple	*Acer saccharinum* L.	Acer saccharinum
Sycamore	*Platanus occidentalis* L.	Platanus occidentalis
Eastern cottonwood	*Populus deltoides* Bartr. ex Marsh.	Populus deltoides
Pin oak	*Quercus palustris* Muenchh.	Querqus palustris
Black willow	*Salix nigra* Marsh.	Salix nigra
American elm	*Ulmus americana* L.	Ulmus americana
Hackberry	*Celtis occidentalis* L.	Celtis spp.
Sugarberry	*Celtis laevigata* Willd.	Celtis spp.
Green ash	*Fraxinus pennsylvatica* Marsh.	Fraxinus spp.
White ash	*Fraxinus americana* L.	Fraxinus spp.
Red mulberry	*Morus rubra* L.	Morus spp.
White mulberry	*Morus alba* L.	Morus spp.

Different tree species vary widely in their tolerance to flooding. Throughout this discussion, the terms tolerant, moderately tolerant, weakly tolerant, and intolerant will be used to define relative flood tolerance of the 13 species being considered. Tolerant will be used to describe species in groups that are able to survive and grow on sites in which the soil is saturated or flooded for long, indefinite periods during the growing season; moderately tolerant will describe species in groups that are able to survive saturated or flooded soils for several months during the growing season, but mortality is high if flooding persists or re-occurs consecutively for several years; weakly tolerant describes species in groups that are able to survive saturated or flooded soils for relatively short periods of a few days to a few weeks during the growing season, but mortality is high if flooding persist for longer periods; and intolerant will describe species in groups that are not able to survive even short periods of soil saturation or flooding during the growing season (Gill 1970, McKnight et al. 1980, Sykes et al. 1994).

The respiration of bottomland hardwoods is less active during the dormant season, allowing bottomland hardwoods to tolerate a dormant-season flood and exhibit little or no adverse effects with the exception of some physical damage from floating debris. Most bottomland hardwood species can also survive an early- or mid-season flood of relatively short duration during the growing season provided they do not experience a second flood in the same growing season. Under average flood disturbance conditions, the probability of mortality would be expected to be small (typically 2-7 %). If a tree is fully submerged during the growing season it can lose its foliage, however, the tree will produce new foliage if the flood duration is short. If flood conditions persist, the tree can die as a result of the prolonged flood due to inability of the submerged tree to respire. If the area receives a second flood later in the same growing season which once more submerges the tree, the tree will again lose its foliage, and generally, the tree will not produce foliage a third time in the same growing season. In this situation, the tree will undergo extreme stress and die unless the respiration cost is alleviated by the production of new foliage. Therefore, the probability that a tree will survive through the dormant season and into the next growing season to produce new foliage is dependent on the health and vigor of the tree after flooding has abated.

Tree size in bottomland hardwood ecosystems is an important predictor of survival. A tree of greater than average stand height for any given stand will possess a greater than average amount of foliage above water during flood conditions (Hall and Smith 1955, Hosner 1960). Not only does this decrease the probability of mortality due to flooding, it also gives the tree a competitive advantage over associated vegetation when vying for sunlight, the driving force in the photosynthetic process, as well as allowing the tree’s respiration process to function. The height of bottomland hardwoods is directly related to diameter, in general, greater tree diameter leads to greater tree height. However, height-diameter relationships vary among all tree species (Colbert and Larsen 1998). A tree with a dbh greater than the average stand dbh, will usually have a height greater than the average stand height, which increases the chances of that tree surviving a flood. The more foliage that remains above water, the greater the probability of survival.

Yin (1993) conducted an ordination analysis in the bottomland hardwood forests between river miles 30 and 80 of the Upper Mississippi River. He found that when ordination vectors that correlated with the flood disturbance gradient and the soil moisture gradient variables were used, pin oak (*Querqus palustris* Muenchh.) was found on sites that had the second lowest flood disturbance gradient value and the lowest soil moisture gradient among the 13 hardwood species. American elm (*Ulmus americana* L.) had the lowest flood disturbance gradient value but the highest soil moisture gradient value. Sugarberry *(Celtis laevigata* Willd.) appeared on sites with the second lowest soil moisture gradient value and a slightly higher flood disturbance gradient value than pin oak. Hackberry (*Celtis occidentalis* L.), green ash (*Fraxinus pennsylvatica* Marsh.), white ash (*F. americana* L.), sycamore (*Platanus occidentalis* L.), box elder (*Acer negundo* L.), silver maple (*A. saccharinum* L.), red mulberry (*Morus rubra* L.), white mulberry (*M. alba* L.), eastern cottonwood (*Populus deltoides* Bartr. ex Marsh.), and black willow (*Salix nigra* Marsh.) were all found on sites with relatively high flood disturbance and soil moisture gradient values. When comparing the last ten species, green ash appeared on sites with relatively lower flood disturbance and soil moisture gradient values, while black willow occupied sites with the highest flood disturbance and soil moisture gradient values. Black willow also had the highest flood disturbance gradient value of the 13 bottomland hardwood species under consideration. Yin's results parallel the findings in this paper in as far as species' tolerance to prolonged flooding is concerned. Yin's findings also show that different landform microsites favor different tree species.

Several mortality models have been developed to model mortality factors in stands not experiencing unusual or catastrophic events. Although these models predict the probability of mortality, their primary focus is “normal” or competition mortality. The model presented in this chapter focuses on estimating the probability of mortality of Midwest bottomland hardwoods due to a specific prolonged flood. Mortality models have been developed based on the empirical analyses of large data sets (Hamilton 1986), or if adequate data was lacking, mortality was determined by subjective judgment (Hegyi 1974). Other authors have extended the use of logistic regression analysis to predict growth and mortality simultaneously, using a single probabilistic function (Lowell and Mitchell 1987). Hamilton and Edwards (1976) published procedures for developing and testing models that predict the probability of individual tree mortality. Hamilton (1986) later developed a mortality model that reflected the impact of thinning on mortality rates. The logistic equation:

$$\text{Logit}(y) = b_0 + b_1\,dbh \qquad 3.1$$

or

$$y = \frac{e^{b_0+b_1 dbh}}{1-e^{b_0+b_1 dbh}} \qquad 3.2$$

where y is the dependent variable measured as a binary variable(dead 1, alive 0), was used to determine the probability of mortality of the 13 species. Tree size is expressed as diameter at breast height (*dbh*) in centimeters, b_0 and b_1 are regression coefficients estimated from the data. This equation can be used to estimate the probability of mortality by tree size for each of the 13 species in the study. Subplots closest to the river will be compared to those further away to test the hypothesis that mortality rates differ with distance from the river.

Methods

This study examines general mortality rates, spatial variability of mortality rates, and predicted mortality rates through logistic regression equations to estimate the probability of mortality based on the independent variable, diameter at breast height (dbh).

The Missouri Department of Conservation, the Iowa Department of Natural Resources, and the Illinois Department of Conservation collectively worked with the USDA Forest Service to study the effects of the 1993 flood (as these states were the most severely affected by the flood). Missouri took the lead in implementing the study. The data was collected along major rivers in Missouri, Illinois, and Iowa. Riparian forests identified as sample sites lay along the Missouri, Platte, Illinois, Iowa, Des Moines, Cedar, and Mississippi Rivers. Each state agency involved in the research suggested potential sample sites. These sites were assessed based on whether they were flooded in 1993 or not, then ranked by potential for plot locations (i.e., area enough to negate fringe effects, proximity to major stream, etc.), and prioritized to ensure sampling of the largest extent of the flooded region in the three states. Eight sites in Missouri, six sites in Illinois, and seven sites in Iowa were sampled with a number of plots at each site yielding a total of 50 plots (Figure 3A).

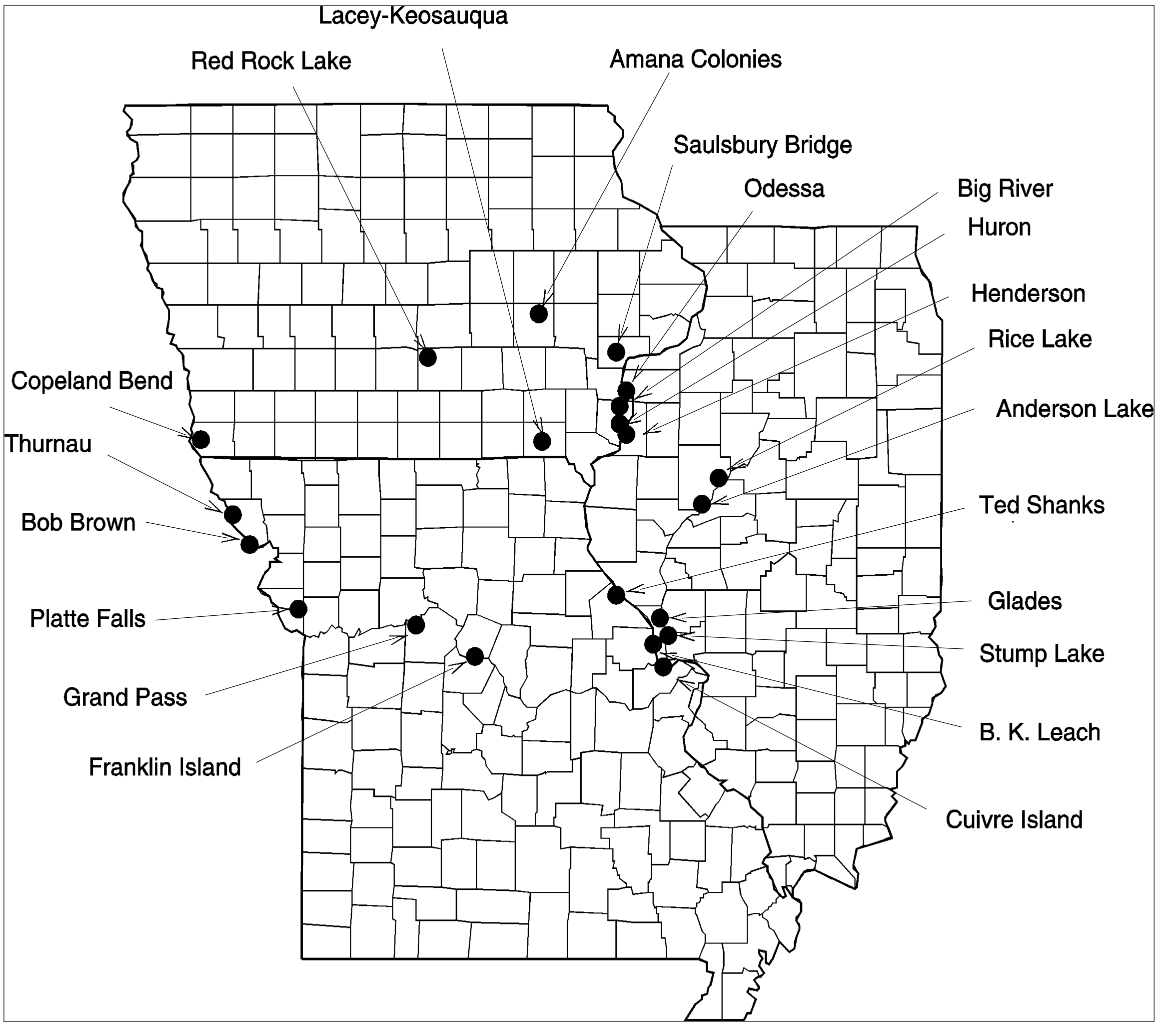

Figure 3A. Sample sites in Missouri, Iowa, and Illinois for both 1994 and 1995. Several sites contained multiple plots. A total of 45 plots were installed at the 21 sites.

The sample plots were designed to take into account spatial variation, as affected by distance from the stream, within the sampled plot. The plot design resembles one-half of a wheel with five spokes. Plot center was located at least 30 meters from the river's edge which allowed the plot to remain in the riparian forest. Plot center was selected so that a 120-meter long transect could run approximately parallel to the stream. Each successive spoke of the wheel contained two subplots (30 meters apart) on bearings 45 degrees greater than the previous vector (spoke) bearing (Figure 3B). The plot covers an area of 120 meters by 60 meters. The minimum area needed to establish a plot was approximately 100 meters by 130 meters.

The first subplot of any plot was permanently marked as plot center with painted rebar at the center of the first subplot. Also, at least two witness trees were marked with two horizontal bands of orange spray paint and aluminum tree tags. Each subplot consisted of a vegetative plot (1/1414 ha), a small-tree plot (1/198 ha), and a large-tree plot (1/50 ha)(Figure 3C). In the vegetative plot, all vegetation less than dbh (1.37 meters) was measured to attain an average height by species and percent ground cover. All trees at least 1.37 meters in height and less than 15 centimeters at dbh were measured to determine species, dbh, height, crown ratio, crown condition, and damage in the small-tree plot. And finally, in the large-tree plot, all trees at least 1.37 meters tall and at least 15 centimeter at dbh were measured to obtain species, dbh, height, crown ratio, crown condition, and damage.

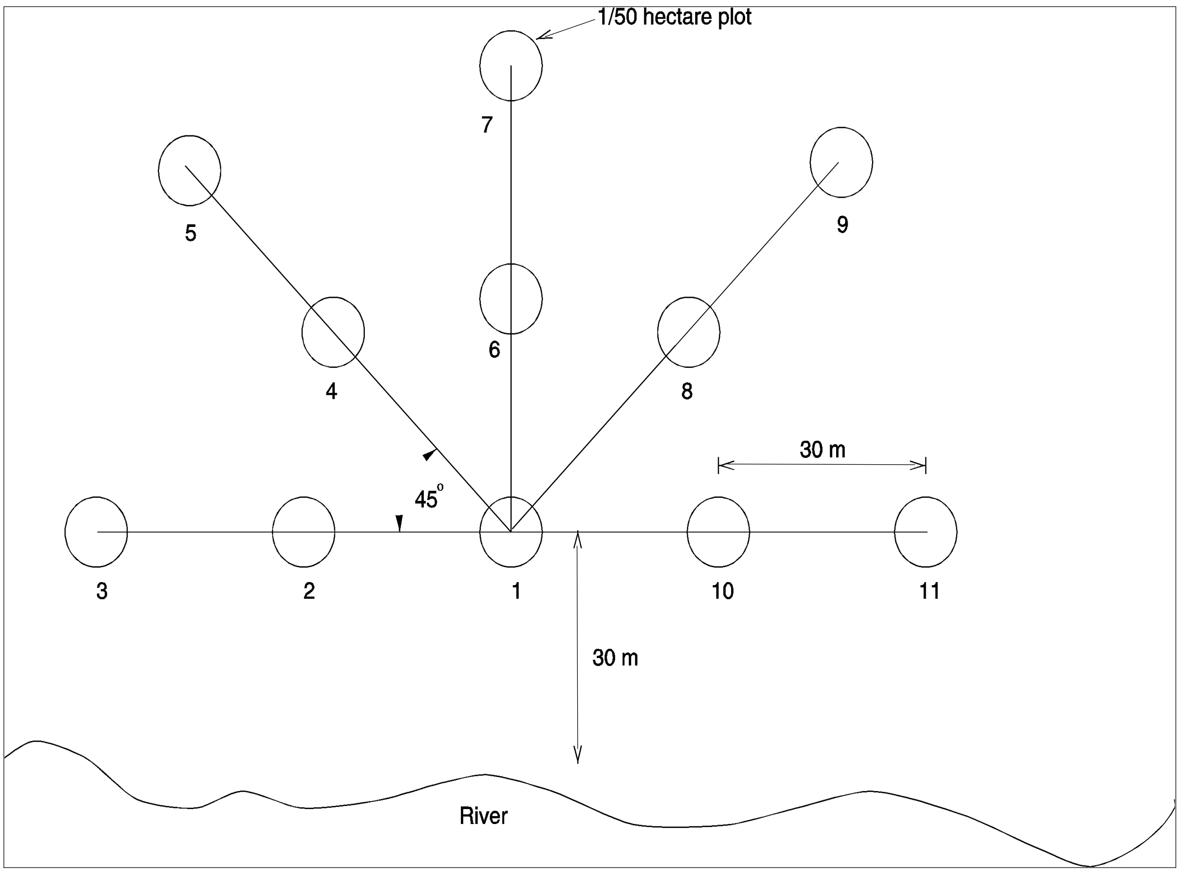

Figure 3B. Plot layout and distances between subplots. Spacing was ≥ 30 m from river and the subplots were 30 m along each vector (spoke). The vectors were 45° apart.

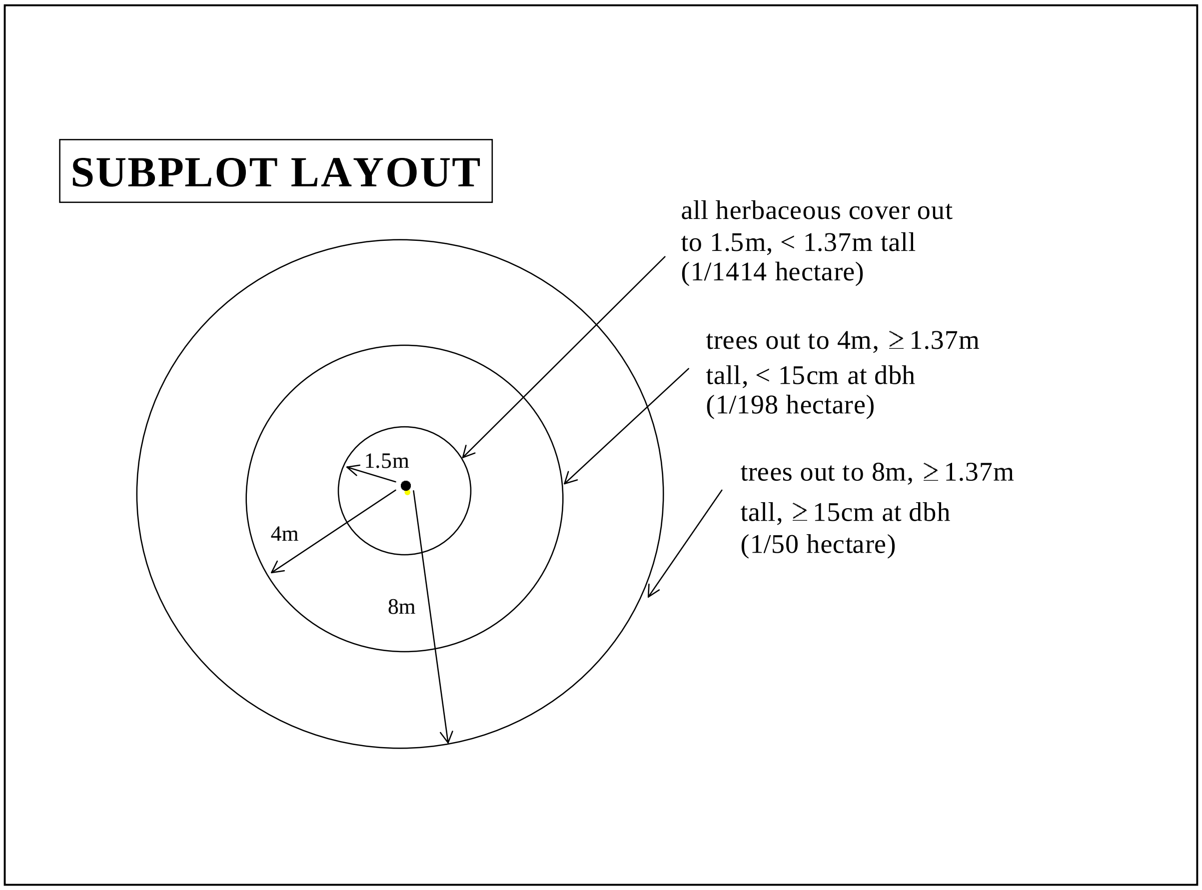

Figure 3C. **Subplot layout** showing areas, radii, and vegetation measured within subplots.

Once tree species was determined, diameter at breast height was measured to the nearest one-half centimeter using a diameter tape. The height of an individual tree was measured to the nearest meter using the clinometer-tape method. After species, dbh, and height were determined, crown ratio and crown condition were determined and recorded. The crown ratio of a tree was taken as a percent of crown length to total tree length. Crown condition was determined as a percent of actual crown present to an ideal crown of a healthy tree of the same species. Damage codes for each tree were designated as follows:

0 = no damage	10 = dead top
1 = debris damage	12 = fire damage
2 = water damage	13 = animal damage (deer, beaver, etc.)
3 = suppressed	14 = vine suppressed
4 = broken top	15 = (diseased (cankers, galls, etc.)
5 = dead limbs	16 = wind damage
6 = rotting stem	95 = snag
7 = midseason mortality	96 = snag with cavities
9 = dead	

Previous year tree mortality was determined if a tree appeared to have died but retained sound bark and many fine twigs, yet, had no leaves in the current growing season. Snags and snags with cavities were recorded, these were considered to have died before the 1993 flood and were not included in the data when developing the mortality model.

Thirteen of the tree species were sampled in sufficient number to allow estimation of the mortality equation parameters, however, due to the similarity of species within the same genus, *Celtis occidentalis* L. and *C. laevigata* Willd., *Fraxinus pennsylvatica*

Marsh. and *F. americana* L., and *Morus rubra* L. and *M. alba* L. were grouped to produce the *Celtis* spp., *Fraxinus* spp., and *Morus* spp. groups respectively (Table 3A).

Results

General mortality rates were calculated for the base data set and categorized by state, year, and species. There was some reason to expect differential mortality within the landform microsites of the plot area due to the fact that subplots 1, 2, 3, 10, and 11 are closer to the stream and are more likely to be located in an area subjected to scouring. The plots were examined with respect to distance from the river for differential mortality and showed no significant difference. Mortality rates seemed to be strongly size-dependent (diameter) (Table 3B). Logistic regression analysis was used to estimate the probability of mortality for the 13 Midwest riparian tree species after prolonged flooding has occurred during the growing season.

The total mean mortality rate for the 10 species groups was 32.9% (Table 3B). The *Celtis* spp. group had the highest mortality with 84%, followed by pin oak at 57%, while black willow and sycamore had the lowest (9% and 7% respectively). *Celtis* spp. and pin oak did not do well in riparian systems during prolonged growing season floods, even though the average dbh for pin oak was 34.4 cm.

Graphical analysis was conducted to determine if there was increased mortality of species by state or by year. Mortality for pin oak, American elm, box elder, silver maple, eastern cottonwood, and black willow was higher in Missouri than either Iowa or Illinois

Table 3B. Data summary for 10 species groups showing the total number of observations, range of diameters, and percent mortality in descending order.

Species	**Number**				**DBH (cm)**		
Group	Total	Dead	Live	**%Mort.**	mean	min.	max.
Celtis spp.	466	393	73	84	14.2	4	29
Querc. palu.	253	145	108	57	34.4	4	89
Morus spp.	690	226	464	32	9.5	0.5	31.6
Ulmus amer.	680	212	468	31	16.2	1	64
Acer negu.	362	102	260	28	16.2	1.7	55.8
Acer sacrnm.	1466	398	1068	27	35.3	1.9	98.2
Fraxinus spp.	280	48	232	17	24.8	1	60.5
Populus delt.	415	50	365	12	43.1	17.8	79.8
Salix nigra	180	17	163	9	17.8	1	61.8
Plat. occi.	56	4	52	7	26.4	4.5	59.3

(Figure 3D). The general stream and flood flows were in a southerly direction, therefore, the location of Missouri in relation to the other two states, and in Missouri's position relative to the flood of 1993 would account for the increased mortality of these species in Missouri.

When pin oak, *Fraxinus* spp., eastern cottonwood, black willow, and sycamore were examined by year (Missouri and Illinois were sampled in 1994,and Iowa was sampled in 1995), the analysis showed a definite lag-effect taking place (Figure 3E). This would indicate that the prolonged flood had critically damaged the pin oak, *Fraxinus* spp., eastern cottonwood, black willow, and sycamore species groups, and the effects were not readily apparent the first year after the flood, but became more apparent the second year post-flood.

The topography of most plots showed no signs of scouring except in cases where the levee was closer than 500 meters to the stream. Plots located in areas where there was ample space between the levee and the river, in excess of 500 meters, or on an island in the river, showed no signs of scouring. It was observed that, the closer the levee was to the river, the greater the water turbulence during flooding. Evidence of scouring was generally observed streamside, or in close proximity to the stream, with scouring occurring less as distance from the stream increased. However, when the sample plots were examined for mortality in relation to distance from the river (Table 3C), river plots (subplots 1, 2, 3, 10, & 11) versus back plots (subplots 4, 5, 6, 7, 8, & 9), there were

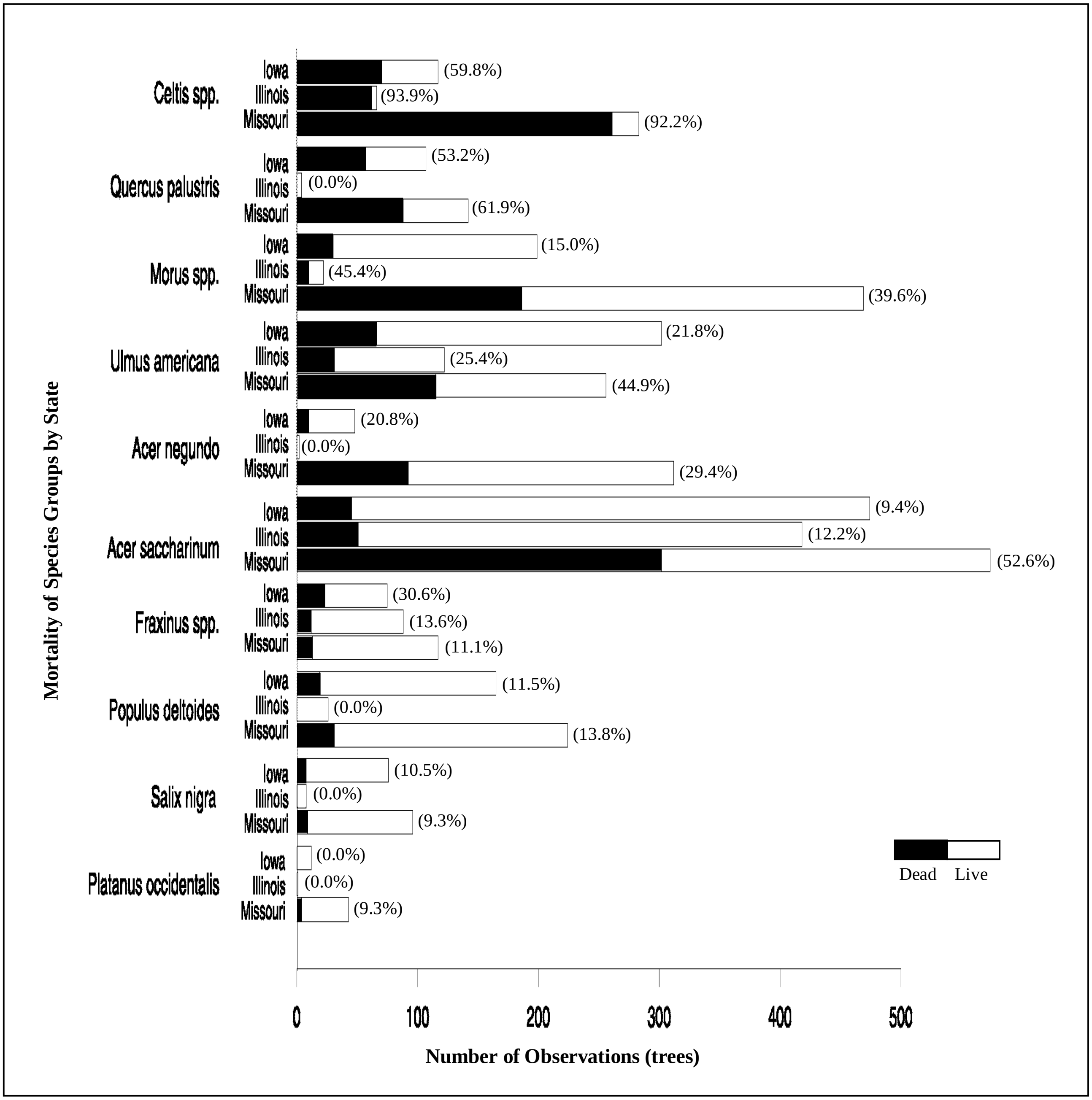

Figure 3D. Number of sample trees and mortality by species group and state. Bar length indicates the total number of trees for the species group. The dark portion of the bar indicates the number of dead trees for the species group. Species groups listed in descending order of mortality (percent mortality in parentheses).

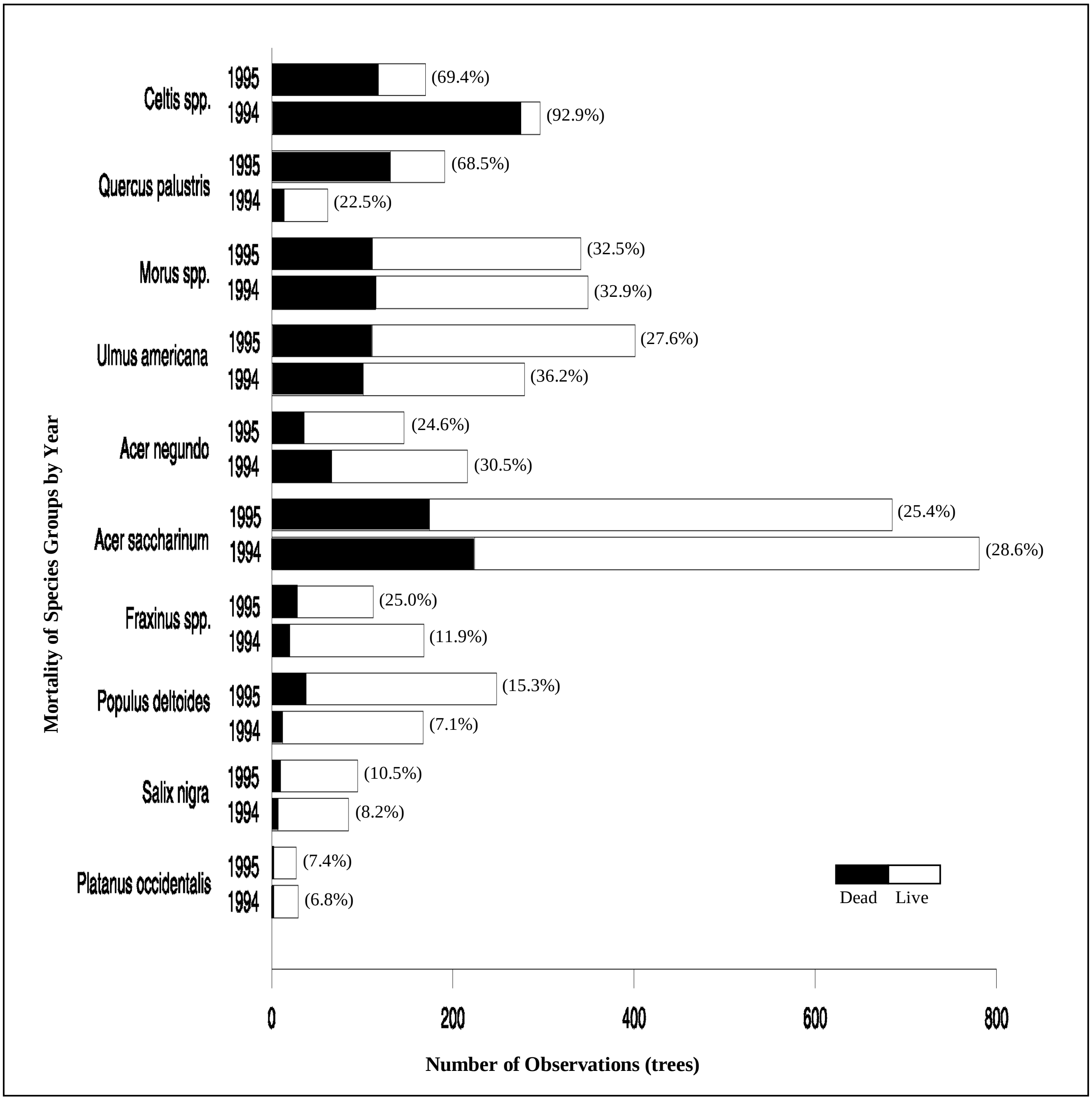

Figure 3E. Number of sample trees and mortality by species group and year. Bar length indicates the total number of trees for the species group. The dark portion of the bar indicates the number of dead trees for the species group. Species groups listed in descending order of mortality (percent mortality in parentheses).

Table 3C - Percent mortality of trees in relation to river by year and total.

Relation to river	Year	%Mort.	# Dead trees	# Live trees
River plots	1995	32	433	901
Back plots	1995	31	477	1081
River plots	1994	35	477	882
Back plots	1994	37	605	1013
River plots	Total	34	910	1783
Back plots	Total	34	1082	2094

minor differences between sampling years, but there was no difference in the total mortality rate.

The logistic regression equations display consistent results for most species. For most species, mortality rates were quite high for individuals having diameters less than 30 cm. However, these species exhibited very low mortality rates for trees with diameters greater than 30 cm. The reasons behind this trend may be that larger trees ($\geq$30 cm dbh) have greater energy reserves, as well as greater potential for the intake of CO_2 through stomatal openings and the transport of O_2 to the roots, where the majority of O_2 is utilized in the tree. A smaller tree may not have the energy reserve or possess sufficient crown ratio or crown condition as a result of its position below the overstory. All species exhibited a decreased mortality rate for the larger diameter trees relative to species, and, a declining mortality rate as diameter increased (Figures 3F-3O). Two species groups differed from the general trend, the pin oak group and the *Celtis* spp. group exhibited much higher mortality rates for all size trees, additionally, the pin oak group had an almost straight-line relationship between mortality and size. The sycamore group also showed a fairly constant relationship as well, although it had the lowest mortality rate of the species being considered. Except for the *Celtis* spp. and pin oak groups, the remaining eight species groups show a consistent range between large and small diameter classes where the mortality rate dropped drastically. Table 3D lists the coefficients and standard errors for the 10 species groups. The sycamore group coefficients exhibited the largest standard errors which probably resulted from the sample size (56 trees for this group).

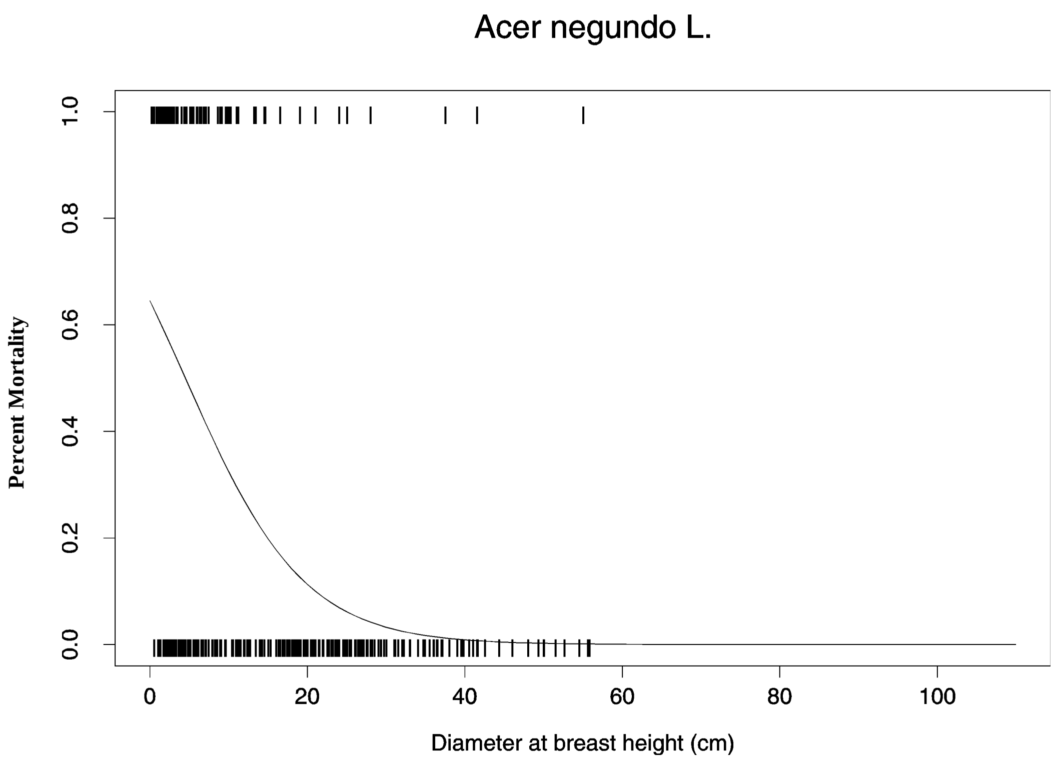

Figure 3F. Model predictions and observations for box elder. The vertical lines at the top and bottom of the graph are the observed data. 1.0 data represent dead trees, and 0.0 data are live trees. The horizontal is mortality predictions by diameter.

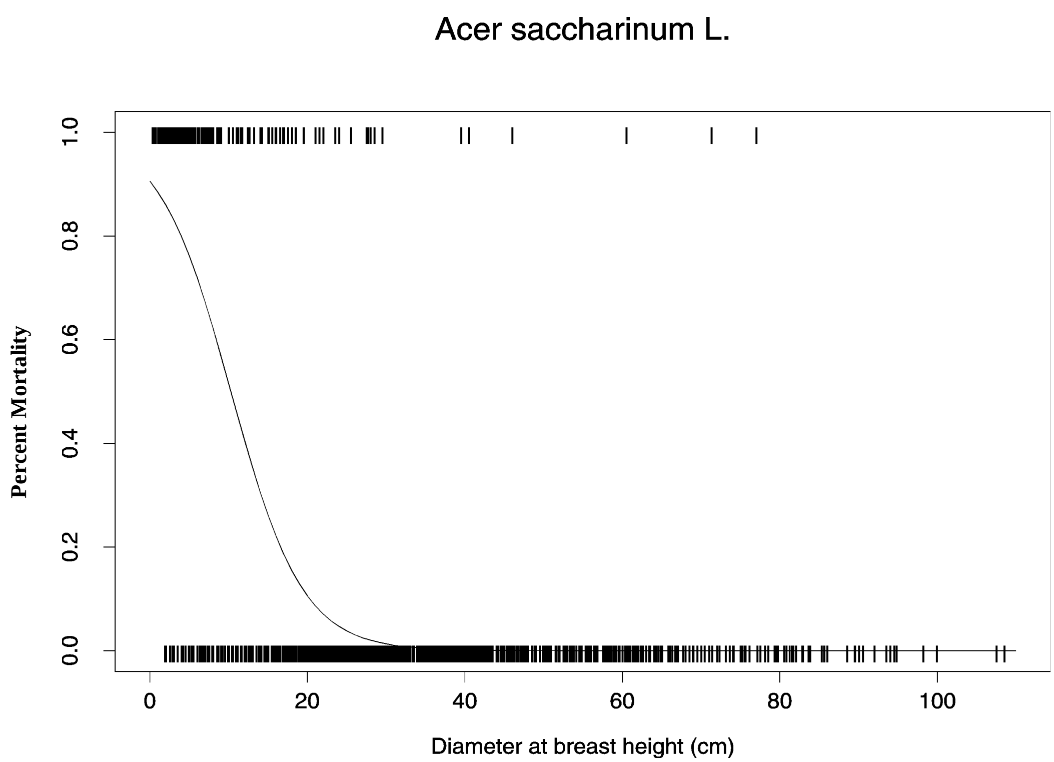

Figure 3G. Model predictions and observations for silver maple The vertical lines at the top and bottom of the graph are the observed data. 1.0 data represent dead trees, and 0.0 data are live trees. The horizontal is mortality predictions by diameter.

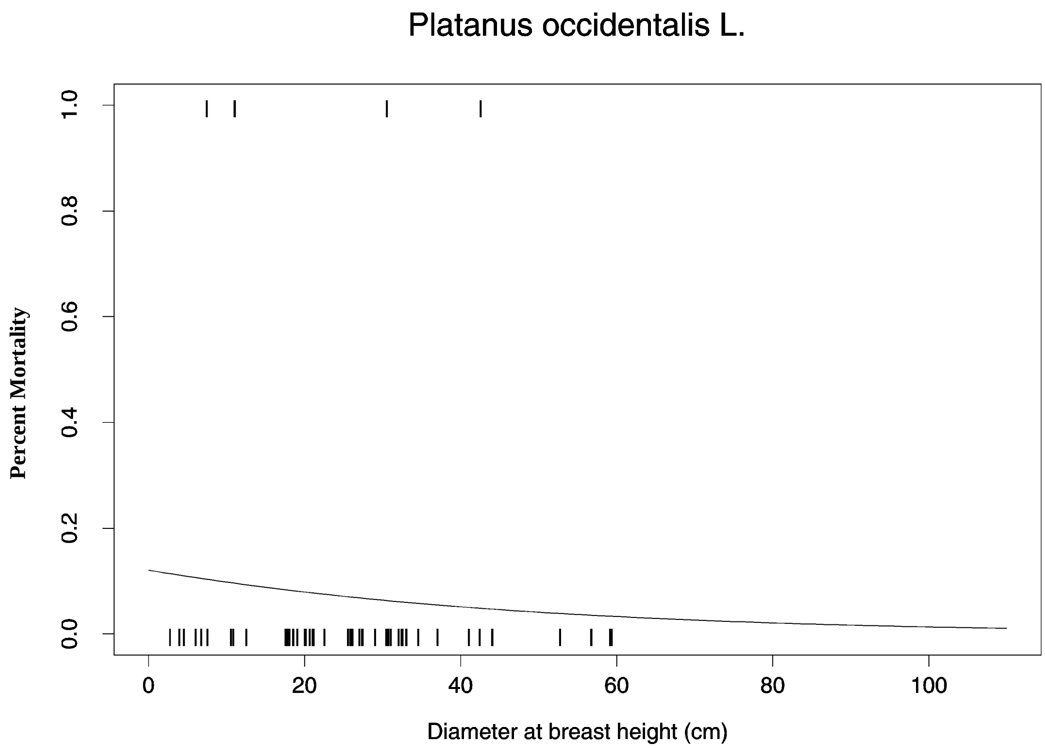

Figure 3H. Model predictions and observations for sycamore. The vertical lines at the top and bottom of the graph are the observed data. 1.0 data represent dead trees, and 0.0 data are live trees. The horizontal is mortality predictions by diameter.

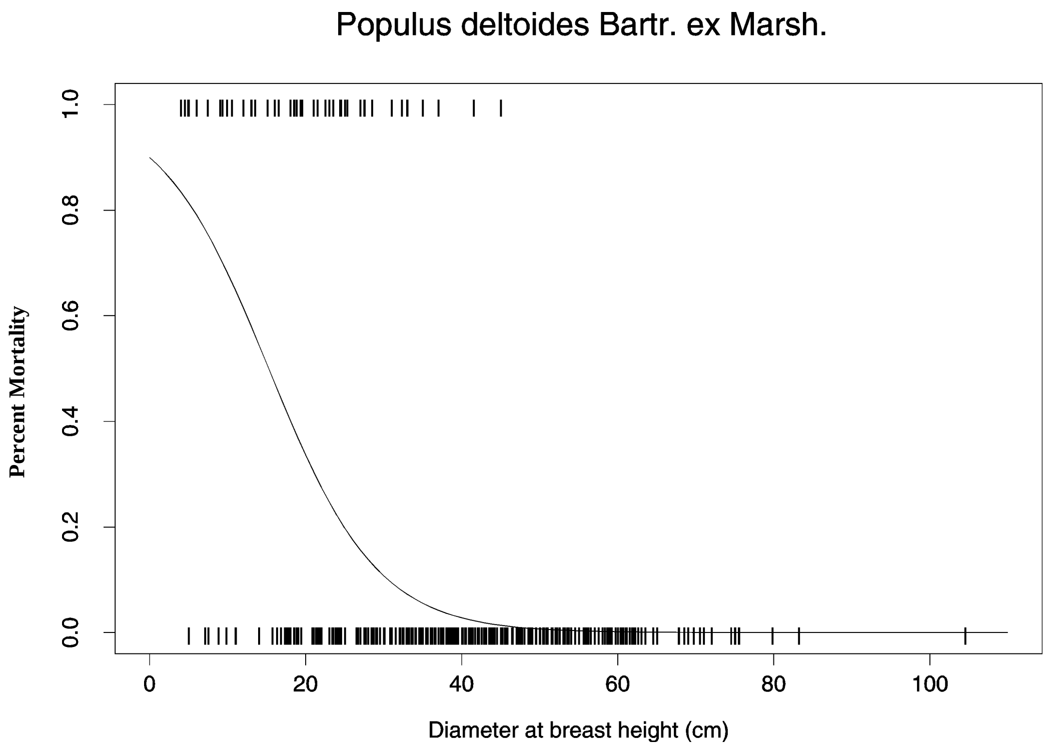

Figure 3I. Model predictions and observations for eastern cottonwood. The vertical lines at the top and bottom of the graph are the observed data. 1.0 data represent dead trees, and 0.0 data are live trees. The horizontal is mortality predictions by diameter.

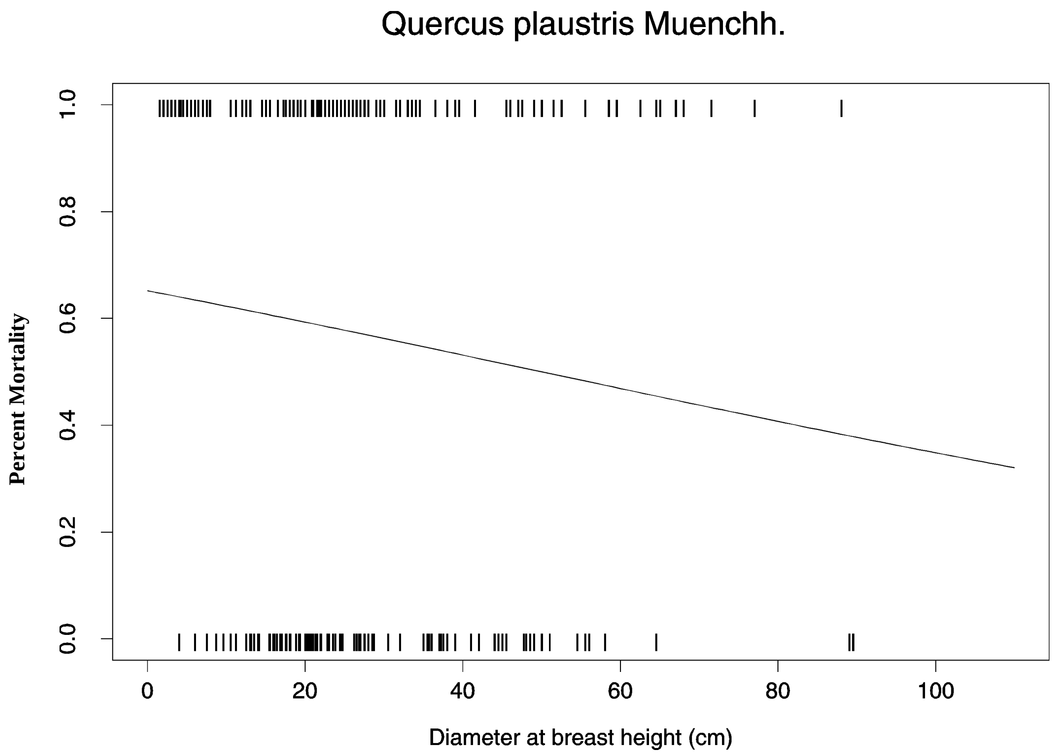

Figure 3J. Model predictions and observations for pin oak. The vertical lines at the top and bottom of the graph are the observed data. 1.0 data represent dead trees, and 0.0 data are live trees. The horizontal is mortality predictions by diameter.

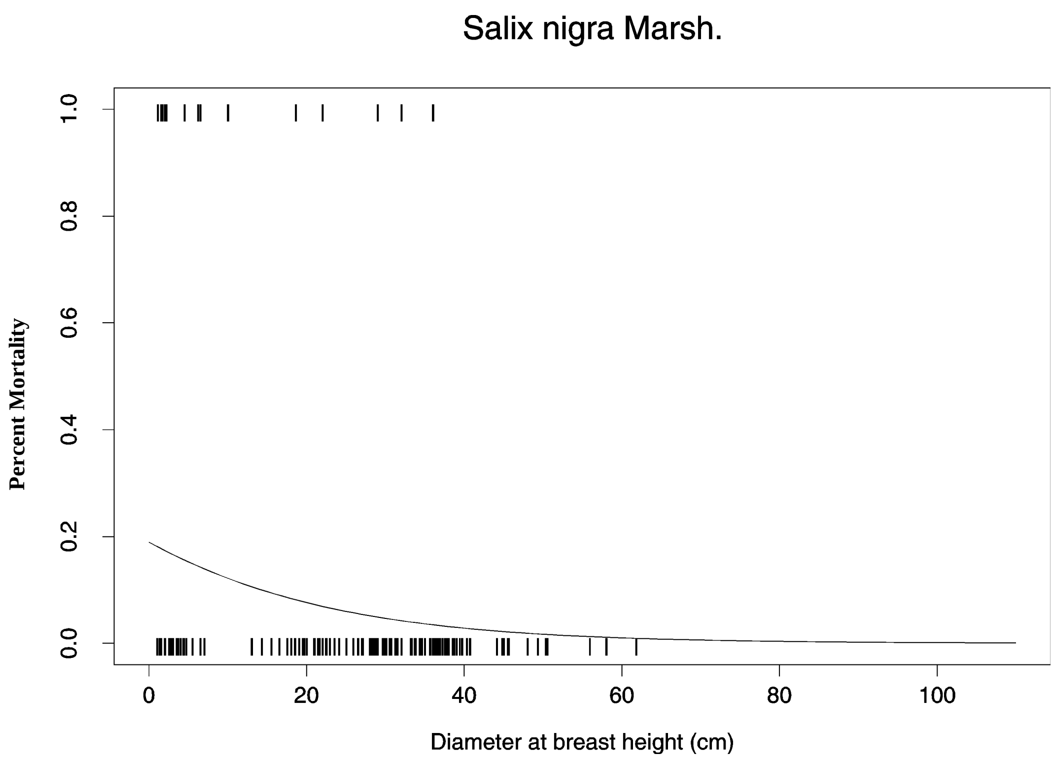

Figure 3K. Model predictions and observations for black willow. The vertical lines at the top and bottom of the graph are the observed data. 1.0 data represent dead trees, and 0.0 data are live trees. The horizontal is mortality predictions by diameter.

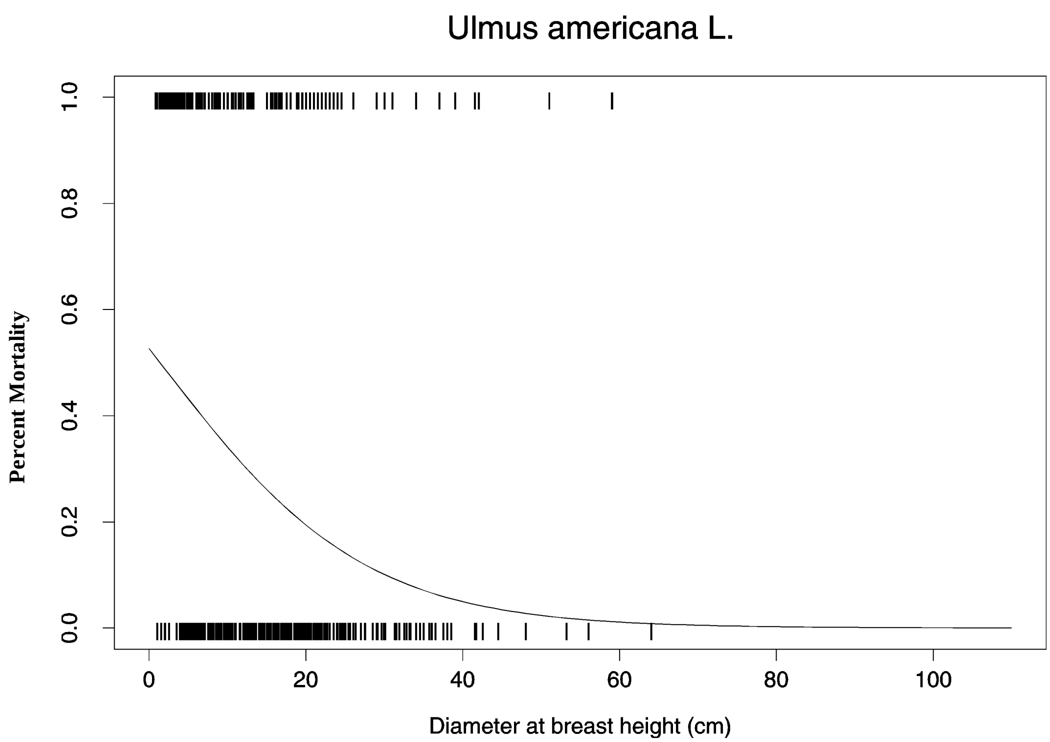

Figure 3L. Model predictions and observations for American elm. The vertical lines at the top and bottom of the graph are the observed data. 1.0 data represent dead trees, and 0.0 data are live trees. The horizontal is mortality predictions by diameter.

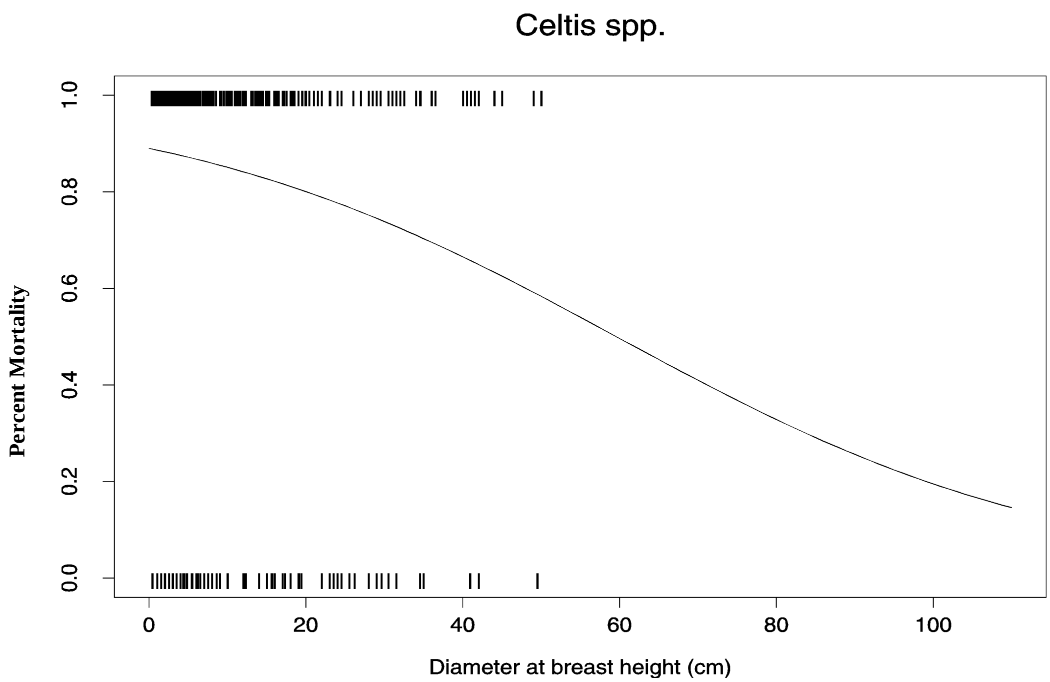

Figure 3M. Model predictions and observations for hackberry. The vertical lines at the top and bottom of the graph are the observed data. 1.0 data represent dead trees, and 0.0 data are live trees. The horizontal is mortality predictions by diameter.

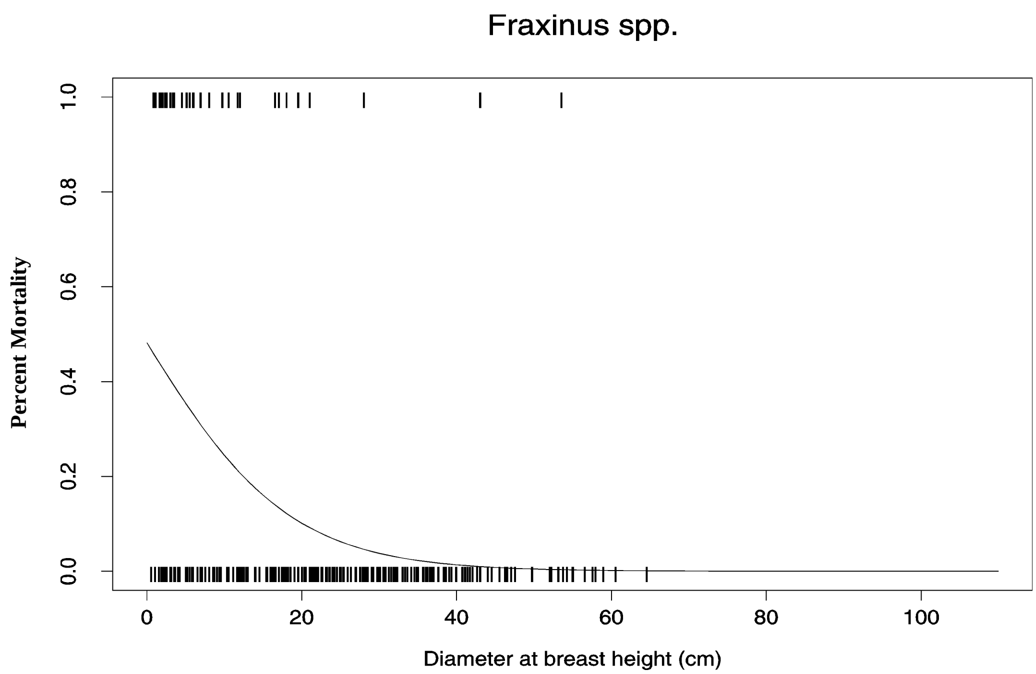

Figure 3N. Model predictions and observations for ash. The vertical lines at the top and bottom of the graph are the observed data. 1.0 data represent dead trees, and 0.0 data are live trees. The horizontal is mortality predictions by diameter.

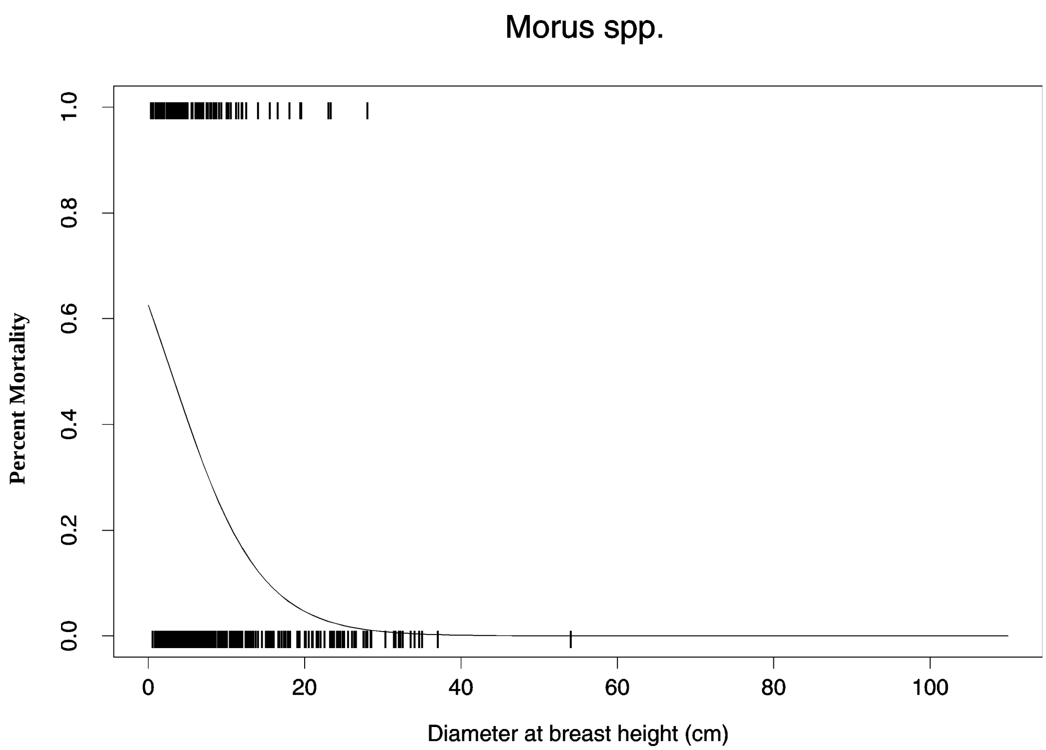

Figure 3O. Model predictions and observations for mulberry. The vertical lines at the top and bottom of the graph are the observed data. 1.0 data represent dead trees, and 0.0 data are live trees. The horizontal is mortality predictions by diameter.

Table 3D - Coefficients and standard errors for 10 species groups.

Species Group	b_0	Std Error	b_1	Std Error
Celtis spp.	2.0908	(0.1885)	-0.0350	(0.0106)
Quercus palustris	0.6270	(0.2377)	-0.0125	(0.0075)
Morus spp.	0.5153	(0.1492)	-0.1770	(0.0211)
Ulmus americana	0.0378	(0.1485)	-0.0746	(0.0114)
Acer negundo	0.5988	(0.2005)	-0.1329	(0.0176)
Acer saccharinum	2.2607	(0.1556)	-0.2197	(0.0120)
Fraxinus spp.	-0.0719	(0.2546)	-0.1053	(0.0191)
Populus deltoides	2.1930	(0.4757)	-0.1435	(0.0187)
Salix nigra	-1.4556	(0.3483)	-0.0516	(0.0204)
Platanus occidentalis	-1.9872	(1.0745)	-0.0232	(0.0406)

Discussion

The mortality rate observed after the flood of 1993 on the large rivers in the Midwest were substantially higher than would be expected in the same forest in a year without flooding during the growing season. The relative mortality rates increased from 4 to 25 times the mortality rates expected in a year without a growing season flood. On average, about one-third of the trees in these riparian forests were killed. However, total bottomland hardwood mortality will not be known for at least five years post-flood (Loucks 1987).Additionally, large differences were observed in both species response and response of trees of different sizes. Of the tree species common in these riparian forests, the *Celtis* spp. group and the pin oak group experienced much higher average mortality rates than the other species being considered.

Species differences in mortality rate are indicators of species tolerance to a particular flooding event. Tree tolerance to flooding in the literature usually refers to winter, spring or early summer floods of short duration (usually one to four weeks in length.) Interestingly, the species group with the highest mortality in this prolonged growing season flood, the *Celtis* spp. group (the majority of which was *Celtis occidentalis*), is considered moderately tolerant (Sykes et al. 1994). In fact, five of the six species groups with the highest mortality rate are considered moderately tolerant. The only other species group considered moderately tolerant, sycamore, had the lowest mortality rate. The sole tolerant species group, black willow, had the second lowest mortality rate. Eastern cottonwood and *Fraxinus* spp., both considered moderately tolerant to weakly tolerant, had the third and fourth lowest mortality rates, respectively.

Morus spp., which is considered weakly tolerant to intolerant, had the third highest mortality rate. It seems that of the 10 species groups considered, only sycamore, black willow, and *Morus* spp. follow the norm for flood tolerance according to McKnight et al. (1980). These results seem to exemplify the belief that only sycamore and black willow are flood tolerant during a growing season flood.

The hypothesis that distance from the river was a factor in the rate of mortality was not supported by the data. Most sampled sites, exhibited little or no scouring effects due to flooding, therefore, scouring was not a contributing factor to tree mortality due to flooding. When plots were examined by two classes, those nearest the river and those furthest from the river, no difference in the average mortality rate could be detected. Either 30 meters is not a great enough distance to significantly affect back plots compared to river plots, or, distance from the river is not a factor as long as any subplot is located on the river side of the levee.

The differential mortality rate as related to tree size is most easily summarized with the logistic regression equations. The equations produced should be considered descriptive of the mortality rates for the two-year period following the 1993 flood as opposed to predictions of future mortality rates. The equations indicate that, for most species, trees less than 30 cm in diameter died at much higher rates than those greater than 30 cm (see Figures 3F-3O). Box elder and silver maple both showed drastic reductions in the probability of mortality when dbh reached 30 cm or greater. The sycamore group had a low probability of mortality for all diameters at breast height, and only slightly higher probabilities for small diameter trees. Eastern cottonwood also exhibited a drastic reduction in the probability of mortality once the tree had attained a diameter of at least 30 cm. The pin oak group exhibited a generally high and consistent-with-size probability of mortality (35 to 60%). The black willow group exhibited similar probabilities of mortality as those of the sycamore group. American elm followed the general pattern of a drastic reduction in the probability of mortality once tree girth reached 30 cm at breast height. The *Celtis* spp. group had approximately a 60% probability of mortality regardless of tree size. The largest dbh measured of the *Celtis* spp. group was 50 cm, and as dbh decreased, the probability of mortality increased. The *Fraxinus* spp. and *Morus* spp. groups both followed the general trend of probability of mortality reductions once dbh reached 30 cm.

Conclusion

Average mortality rates in riparian forest along major rivers of the Midwest following the 1993 flood increased between 4 and 25 times those expected in these forests. In most of these forests approximately one-third of the trees died. These results did differ by species and size. Most species groups exhibited a higher mortality rate in small diameter trees (<30 cm). Two species groups (*Celtis* spp. and pin oak) did not follow this pattern and exhibited consistently high mortality over a wide range of diameters. Assuming this study is representative of Midwest bottomland hardwood forests in riparian areas, 32.9 % of the riparian forest experienced mortality due to the prolonged growing season flood of 1993. Mortality rates of the 10 species groups can be grouped into five categories: *Celtis* spp. and pin oak (84% and 57% respectively), *Morus* spp. and American elm (32% and 31%), box elder and silver maple (28% and 27%), *Fraxinus* spp. and eastern cottonwood (17% and 12%), and black willow and sycamore (9% and 7%).

The hypothesis that mortality rates differed with distance from the river was tested and we were unable to determine a significant difference between subplots closest to the river and those further away. While landform microsites have been shown to affect species establishment and survival, little difference was found in this study, possibly due to the location of the plots (river side of the levee). Landform microsites did not affect species survival in this study.

Logistic regression was used to determine the effect of tree size on mortality rate, while assuming that trees of all species under consideration were fairly vigorous. Diameter (dbh) seemed to be the most useful predictor of mortality. Small trees were either under water or did not possess sufficient crown ratio or have good crown condition to compensate for the roots inability to retrieve O_2 due to inundation. Trees with a dbh less than 30 cm tended to have a very high probability of mortality, while trees with a dbh greater than 30 cm had a very low probability of mortality.

Flood disturbance plays a unique role in forest stand dynamics. Floods tend to remove susceptible individuals, species groups or size groups from a forest while leaving the remaining trees relatively undisturbed. Timing and duration seem to be major factors affecting the intensity and result of flood disturbance in Midwest riparian forests along the big rivers in Missouri, Iowa, and Illinois.

SUMMARY

The height-diameter chapter presents a set of height-diameter equations for 13 Midwest riparian tree species in the central United States. The equations presented in this section are useful in forest inventory applications when heights have not been measured but are desired to estimate forest structure. The models and coefficients from the height-diameter section can be used for inventory compilations in Midwest bottomland hardwood forests located in riparian corridors. They can also be used in growth projection models to predict height based on diameter at breast height. The model form used produced reasonable results for the 13 forest tree species present in riparian corridors in northern Missouri, southern Iowa, and western Illinois. Natural resource managers working in riparian corridor, watershed, wetland, and streambank conservation projects can use these equations to predict potential vertical forest structure and potential forest growth.

The chapter dealing with bottomland hardwood mortality due to a prolonged growing season flood, focused on concern expressed as to the effect on tree mortality in riparian forests in the Midwest. The data from Missouri, Iowa, and Illinois was collected in areas that were submerged by that flood. The data indicates that certain species widely regarded as tolerant of flooding by biologists did not survive as well as was expected. In general, small diameter trees (< 30 cm) had very high probabilities of mortality and trees greater than 30 cm had relatively low probabilities of mortality.

Average mortality rates in riparian forest along major rivers of the Midwest following the 1993 flood increased between 4 and 25 times those expected in these forests. In most of these forests approximately one-third of the trees died. These results did differ by species and size. Most species groups exhibited a high mortality rate in small diameter trees. Two species groups (*Celtis* spp. and pin oak) did not follow this pattern and exhibited consistently high mortality over a wide range of diameters. Assuming this study is representative of Midwest bottomland hardwood forests in riparian zones, 32.9 % of the riparian forest experienced mortality due to this prolonged growing season flood. Mortality rates of the 10 species groups can be grouped into five categories: *Celtis* spp. and pin oak (84% and 57% respectively), *Morus* spp. and American elm (32% and 31%), box elder and silver maple (28% and 27%), *Fraxinus* spp. and eastern cottonwood (17% and 12%), and black willow and sycamore (9% and 7%).

The hypothesis that mortality rates differed with distance from the river was tested and no significant difference was found between subplots closest to the river and those further away. While landform microsites have been shown to affect species establishment and survival, little difference was found in this study. Floods tend to remove individuals, species groups, or size groups relatively intolerant to prolonged flooding during the growing season from a forest, while leaving the remaining trees relatively undisturbed.

REFERENCE LIST

Blackwell, P. 1997. Personal communication. US Army Corps of Engineers, Emergency Management. Little Rock District Office, Little Rock, AR.

Carmean, W.H., J.T. Hahn, and R.D. Jacobs. 1989. Site index curves for forest tree species in the Eastern United States. USDA For. Serv. Gen. Tech. Rep. NC-128. 142p.

Colbert, K. and D.R. Larsen. 1998. *Height-diameter equations for thirteen Mid-west bottomland hardwood species.* Northern Journal of Applied Forestry (submitted).

Curtis, R.O. 1967. Height-diameter and height-diameter-age equations for second growth Douglas-fir. Forest Science 13:365-375.

Ek, A.R., E.T. Birdsall and R.J. Spear. 1984. A simple model for estimating total and merchantable tree heights. USDA For. Serv. Res. Note NC-309. 5p.

Gill, C.J. 1970. *The flooding tolerance of woody species - a review*. Forestry Abstracts 31(4):671-688.

Hall, T.F., and G.E. Smith. 1955. Effects of flooding on woody plants, West Sandy Dewatering Project, Kentucky Reservoir. J. For. 53:281-285.

Hamilton, Jr., D.A. 1986. *A logistic model of mortality in thinned and unthinned mixed conifer stands of Northern Idaho*. Forest Science. 32:4 pp. 989-1000.

Hamilton, Jr., D.A. and B.M. Edwards. 1976. *Modeling the probability of individual tree Mortality*. Intermountain Forest and Range Experiment Station. USDA Forest Service Research Paper INT-185. 22p.

Hann, D.W. and J.A. Scrivani. 1987. Dominant-height-growth and site-index equations for Douglas-fir and ponderosa pine in southwest Oregon. Oregon State University, Forest Research Laboratory, Corvallis,Oregon. Research Bulletin 59. 36p.

Hegyi, F. 1974. <u>Growth models for tree and stand simulation</u> (J. Fries,ed.*): A simulation model for managing jack pine stands.* Royal College of Forest Resources Notes 30, Stockholm. pp. 74-90.

Hosner, J.G. 1960. Relative tolerance to complete inundation of fourteen bottomland tree species. For. Sci. 6(3):246-251.

Kabrick, J., D.R. Larsen, and R.D. Hammer. 1998. Landform Microsites as strata for sampling and interpreting herbaceous plant distributions in riparian ecosystems. American Midland Naturalist (submitted).

Larsen, D.R. 1994. Adaptable stand dynamics model integrating site-specific growth for innovative silvicultural prescriptions. For. Ecol. Manage. 69:245-257.

Larsen, D.R. and D.W. Hann. 1987. Height-diameter equations for seventeen tree species in southwest Oregon. Forest Research Laboratory, Oregon State University, Corvallis. Research Paper 49. 16p.

Loucks, W.L. 1987. Flood-tolerant trees. J. For. 85(3):36-40.

Lowell, K.E. and R.J. Mitchell. 1987. *Modeling growth and mortality probabilistically using logistic regression*. Presented at the IUFRO Forest Growth Modeling and Prediction Conference. Minneapolis, MN. August24-28,1987. pp. 708-715.

McKnight, J.S., D.D. Hook, O.G. Langdon, and R.L. Johnson. 1980. Flood tolerance and related characteristics of trees of the bottomland hardwood forests of the southern United States. Reprinted from *Wetlands of Bottomland Hardwood Forests*. Proceedings of a Workshop on Bottomland Hardwood Forest Wetlands of the Southeast. United States held at Lake Lanier, GA. June 1-5. 1980. pp. 29-69.

Miner, C.L., N.R. Walters, and M.L. Belli. 1988. A guide to the TWIGS program for the North Central United States. USDA For. Serv. Gen. Tech. Rep. NC-125. 105p.

Monserud, R. 1975. Methodology for simulating Wisconsin northern hardwood stand dynamics. Ph.D. dissertation. University of Wisconsin, Madison. 156p. [University Microfilm Number 7602496].

Neter, J. and W. Wasserman. 1974. Applied linear statistical models. Richard D. Irwin, Inc. Homewood, Illinois. 842p.

Ritchie, M.W. and D.W. Hann. 1986. Development of a tree height growth model for Douglas-fir. Forest Ecology and Management. 15:135-145.

Sykes, K.J., A.W. Perkey, and R.S. Palone. 1994. *Crop tree management in riparian zones*. USDA Forest Service, Northeastern Area, State & Private Forestry, 180 Canfield Street, Morgantown, WV 26505, Available on the world wide web at *http://www.fsl.wvnet.edu/frm/watershed/riparian.html*.

US Army Corps of Engineers. 1994. North Central Division. The great flood of 1993 post-flood report. Upper Mississippi River and Lower Missouri River Basins. Main Report. 60p.

Van Deusen, P.C., and G.S. Biging. 1985. Development of a tree height growth model for Douglas-fir. Forest Ecology and Management 15:135-145.

Walters, D.K. and D.W. Hann. 1986. Predicting merchantable volume in cubic feet to a variable top and in Scribner board feet to a 6-inch top for six major conifers of southwest Oregon. Forest Research Laboratory, Oregon State University, Corvallis, Oregon. Research Bulletin 52. 107p.

Walters, D.K., D.W. Hann, and M.A. Clyde. 1985. Equations and tables predicting gross total stem volumes in cubic feet for six major conifers of southwest Oregon. Forest Research Laboratory, Oregon State University, Corvallis, Oregon. Research Bulletin 50. 36p.

Wykoff, W.R., C.L. Crookston, and A.R. Stage. 1982, User's guide to the Stand Prognosis Model. USDA Forest Service, Intermountain Forest and Range Experiment Station, Ogden, Utah. General Technical Report INT-133. 122p.

Yin, Yao. 1993. An ordination analysis of plant species association and plant species-habitat relationships in bottomland hardwood forests between river miles 30 and 80 of the Upper *Mississippi River*. Report by the Missouri Department of Conservation in Cape Girardeau, Missouri, for the U.S. Fish and Wildlife Service. Environmental Management Technical Center. Onalaska, Wisconsin. EMTC 93-SO__. 41 p.

Zar, J.H. 1996. Biostatistical analysis: third edition. Prentice-Hall. Upper Saddle River, New Jersey. 662p.