FACTORS AFFECTING SELF-PRUNING IN NORTHERN RED OAK (*Quercus rubra L.*)

by

Stephanie M. Jenniges

A Thesis

Submitted in partial fulfillment of the requirements of the degree

MASTER OF SCIENCE

IN

NATURAL RESOURCES (FORESTRY)

College of Natural Resources

UNIVERSITY OF WISCONSIN

Stevens Point, WI

May 2006

APPROVED BY THE GRADUATE COMMITTEE OF:

Dr. Robert Rogers, Committee Chair
Professor of Forestry

Dr. Diane A. Caporale
Associate Professor of Biology

Dr. Christine Thomas
Professor of Resource Management

ABSTRACT

Northern red oak (*Quercus rubra L*) is an important timber species in the United States, and especially in Wisconsin, where the 1996 growing stock was over 2.7 billion cubic feet. Northern red oak is the highest valued timber in Wisconsin. Defects in stem quality lower timber value, but thinning and pruning regimes can be used to reduce these defects, at a cost. Northern red oak is a self-pruning species, and this characteristic may be used to reduce the cost of producing high-quality wood. The objectives of the study were to 1) determine how forest stand density affects tree characteristics and self-pruning in northern red oak, and 2) to recommend practices, which incorporate the regulation of stand density, to encourage self-pruning in northern red oak. Fifty trees were sampled from ten stands in northern and central Wisconsin. Data collected included stand density and density around the sample trees, dbh, total height, height, length, and diameter of the lowest living and dead branches, and crown area. Predictive models were developed to describe the tree characteristics. BA/acre was found to be a significant variable in the models for percent clear bole and rate of crown recession (two descriptors of self-pruning), but the models themselves were not good predictors.

A secondary study included in this research sought to determine the genetic make-up of the sample trees. Northern red oak and northern pin oak (*Quercus ellipsoidalis*) hybridize in the wild and both are located in Wisconsin. Northern pin oak is not a self-pruning species. Past studies have been unable to find a strong method for determining if a tree is a northern red

oak, a northern pin oak, or a hybrid of the two. For the purposes of the study, true northern red oak were required. The secondary study used RAPDs (Random Amplified Polymorphic DNA) in an attempt to first find a genetic marker to distinguish between the two species and then to determine if the sample trees were true northern red oak. Several primers were tested. The genetic study was inconclusive and more research is needed to find a distinct northern red oak genetic marker.

ACKNOWLEDGEMENTS

The completion of this research and thesis would not have been possible without the assistance and support of the many people who guided me along the way. Above all, I thank my advisor, Dr. Robert Rogers, for giving me the opportunity to participate in this project, and for sharing with me his extensive knowledge of oaks and statistical analysis.

I also extend my thanks to my other committee members. Dr. Diane Caporale taught me RAPD analysis and provided laboratory supplies and equipment. Dr. Christine Thomas provided added insights to the project and her time is greatly appreciated.

My summer research assistant, Michelle Pauly, was invaluable. She aided me in both field and laboratory work, as well as with data entry.

Many state and county foresters located stands for me to work in, and I owe them all great thanks. I especially thank Paul Fiene, Terry Strong, Paul Schultz, Bill Wengler, and Paul Lochner.

Funding for this research was provided by the University of Wisconsin-Stevens Point.

Lastly, I must thank all my family and friends who supported me along the way, especially my parents, John and Margaret. Without their encouragement, this work would not have been possible.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

CHAPTER 1

FACTORS AFFECTING SELF-PRUNING IN NORTHERN RED OAK

Introduction

Northern red oak (*Quercus rubra L.*) is an important timber species in the United States, and especially in Wisconsin. In 1996, the growing stock of northern red oak in the Northern Mixed Forest region of Wisconsin (Figure 1.1) was over one billion cubic feet (Wisconsin Department of Natural Resources 2000). In the Southern Broadleaf Forest region there was nearly 1.7 billion cubic feet of growing stock in 1996. Current stumpage rates (2004) for northern red oak range from $273.57 to $482.03/mbf[1] for veneer quality wood (Wisconsin Department of Natural Resources 2005). It is the highest valued timber in the state, making it an important economic species.

The range of the northern red oak extends from Nova Scotia to Ontario and from Minnesota to North Carolina (Figure 1.2). It grows in a wide variety of soils and topographic positions. Northern red oak is a moderately shade-intolerant species with a relatively slow-growing seedling stage (Johnson 1994). Once established, however, red oak is a moderate to fast-growing species, which makes it suitable for producing usable timber in a short period of time.

---

[1] Mbf (thousand board feet)-a board foot is a piece of sawn material measuring one inch by 12 inches by one foot.

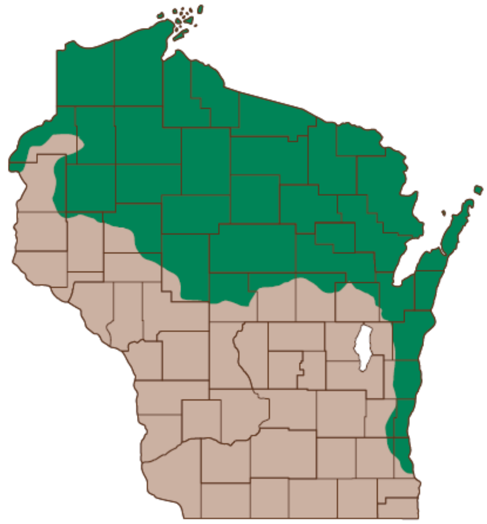


Figure 1.1 Northern Mixed Forest region of Wisconsin. (Wisconsin Department of Natural Resources 2000)

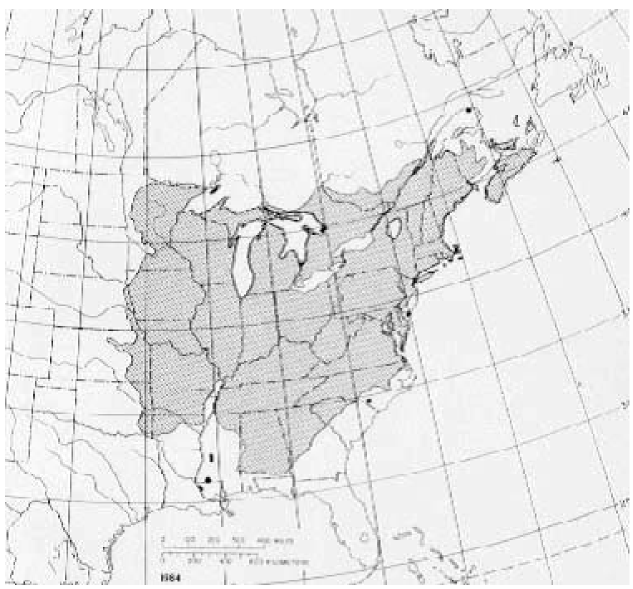


Figure 1.2 Native range of northern red oak (http://www.na.fs.fed.us/)

Defects in stem quality lower timber value. However, thinning and pruning regimes can be used to reduce these defects. On the other hand, costs of the regimes are often prohibitive. Northern red oak is considered to be a self-pruning[2] species. Therefore, one way to reduce costs of producing high-quality wood may be to use specific silvicultural methods designed specifically to encourage self-pruning in the northern red oak. This study examines the relationship between stand density and the self-pruning process in young northern red oak stands and describes tree characteristics related to timber quality.

Objectives

1. To determine relationships between forest stand density affects tree characteristics and self-pruning in northern red oak.

2. To recommend practices, which incorporate the regulation of stand density, to encourage self-pruning in northern red oak.

Literature Review

Northern red oak is a valuable timber species. One basis of value is wood quality. Others include the demand in the local area and the species of tree being harvested. Some indicators of wood quality include stem straightness, freedom from branches and overgrown knots, and no evidence of decay (Dale and Sonderman 1984). Of these indicators, branch related defects cause the most serious problems (Godman and Brooks 1971). An increase in defects means a decrease in timber value. In an attempt to

[2] Self-pruning-(also known as natural pruning) is the process of branch death and shedding caused by physical and biotic agents, such as shading, fungi, and wind, snow, or ice breakage (Helms 1998)

address this problem different thinning and pruning regimes have been tried. Smith (1962) suggests a period of “stem training” where high stand density is used to develop a branch-free stem of desired length, followed by thinning to promote crown expansion and increased diameter growth. Studies in the United States on the long-term effects of thinning and pruning on the quality of hardwoods indicate that, for most species, stand density affects tree quality. In a 6-year study by Sonderman (1984), defects/ft^2 surface area decreased with time for all stocking levels in most species tested (oak (*Quercus sp*.), yellow-poplar (*Liriodendron tulipifera*), aspen(*Populus sp.*), and maple (*Acer sp.*)). When all species were combined, there was a decrease of 61% in the control plots and 70% stocking plots. At the 30% stocking level the defects/ft^2 for oak was significantly greater than the other treatments ($p<0.13$). Sonderman’s study also looked at changes in crown ratio (ratio of live crown length to total tree height). The lower the crown ratio, the greater amount of clear wood a tree will have. The results showed a decrease in crown ratio for all species combined in all stocking levels, with the exception of the 30% stocking level. The additional growing space opened up by the increased thinning provides the extra light needed to promote the growth of branches lower in the crown thereby increasing the crown ratio.

A second study by Sonderman (1986) found similar results. Once again the number of defects/ft^2 were significantly greater in the 30% stocking plots for all species combined ($p<0.12$). The crown ratios increased for the

30 and 45 percent stocking levels over the 6 years, and remained approximately the same for the 60 percent and control plots.

In a third study by Sonderman (1985) stocking treatments of 30%, 50%, and 60% were used, with the 30% and 50% being the least effective in reducing the number of stem defects.

Other studies have looked, more specifically, at the effects of thinning on oak trees. Dale and Sonderman (1984) studied how thinning affects quality in young white oak stands. As with the studies on mixed hardwoods, they found that increased thinning leads to a greater number of limb-related defects. Stands with residual basal areas of 15 ft^2/acre after thinning had 0.244 live and dead limb defects per square foot of stem surface area, as compared to only 0.083 defects in stands with a residual basal area of 75 ft^2/acre. This trend is due to more, and larger, dead and live branches on the heavily thinned trees. Larger branches require longer drop-off time and leave larger defects on the stem. The study concluded that if stocking levels remain above 50%, tree quality is not seriously affected by thinning. A study on mixed-oak stem quality also found that light thinning (80-100% of full stocking) resulted in the greatest reduction in the number of defects per square foot, from .420 to .320, most likely due to self-pruning. (Sonderman and Rast 1988). Moreover, crown ratio was not affected by thinning, except in the light thinning treatment where crown ratio increased from 29.8 to 32.5. However, the authors caution that lengthier studies are needed to either substantiate or reject the results. Dwyer and Lowell (1988) found neither a difference in quality of oak lumber under different regimes of pruning nor a significant interaction between the thinning and pruning treatments, indicating that, under the conditions present in their study, pruning is not recommended as a method of increasing stem quality.

Although studies have related thinning and pruning regimes to stem defects, few look specifically at self-pruning. Shade-intolerant species are more likely to self-prune than shade-tolerant species (Toumey and Korstian 1937; Millington and Chaney 1973). Induction of self-pruning may be the result of several different factors. These factors include: reduced irradiances due to shading (Smith 1962; Millington and Chaney 1973), drought (Mahall and Wilson 1986), nutrient deficiency (Addicott and Lyon 1973), or a combination of factors. A laboratory study by Mahall and Wilson (1986) examined causes for self-pruning in *Ceanothus megacarpus* Nutt., a chaparral shrub. They concluded that drought and shading worked together to induce branch death. Their study was not able to determine if long-term shading alone would have been enough to cause the self-pruning. Mahall and Wilson (1986) also looked at the adaptive significance of self-pruning and concluded that self-pruning in the shrub would have a small, negative affect on net carbon gain, but would enhance water use efficiencies.

A study in Germany examined self-pruning in young oak stands and how it affects timber quality (Nutto 1998). Nutto found that diameter increment was negatively related to the dynamics of self-pruning (crown recession and height to lowest dead branch), while height growth was positively related. He concluded that a greater height increment would compensate for the negative affects of large diameter growth. Nutto (1998) also developed predictive models that calculate crown development measures for a given tree. Crown width, diameter of largest dead branch, and crown base can be determined by age, DBH, average radial growth, and average yearly height increment. All required measurements are common, making the models easy to use.

A study in southern Brazil by Nutto, Spathelf, and Rogers (2005) sought to analyze diameter growth and the relationship of natural pruning and morphological characteristics of Parana pine (*Araucaria angustifolia* Bertol.). The study concluded that natural pruning is mainly related to growing space, age, and site index. Since site index is difficult to manage, DBH, height, and age were examined in relation to growing space in order to produce models predicting maximum radial growth, height to the base of the crown, and height to the first dead branch. Natural pruning may be improved by keeping stands at a higher density, however rotation period increases because diameter growth slows. They recommended that, if the efficiency of natural pruning is insufficient to produce high quality timber in the desired time period, artificial pruning regimes may be necessary.

Another study of self-pruning in silver birch (*Betula pendula* Roth.) was conducted by Mäkinen et al (2003). One objective of their study was to develop a generalized linear variance component model for the self-pruning ratio (height of lowest dead branch divided by the height of the crown base).

They found that the self-pruning ratio was not related to stand characteristics, and only slightly related to stem diameter. The authors concluded that the rate of self-pruning progressed at a relatively constant rate for the trees in the study. Differences in self-pruning rate between stands indicated that not all factors affecting the rate were accounted for in the study.

Past studies indicate that manipulation of stand density will affect the rate of natural pruning. Although other factors may be involved, they are less easily manipulated. However, no such studies have been done on northern red oak, a valuable timber species in Wisconsin. The aims of this study are to determine the relationship between stand density and self-pruning, and develop models for production of high-quality timber for northern red oak.

Materials and Methods

Study Sites

I worked with Wisconsin state and county foresters to identify appropriate study sites. I developed several criteria that the sites needed to meet in order to be included in the study.

1. The site needed to be on public land in order to make access easier.
2. The site index for northern red oak had to be greater than 65. High site index was a requirement since the goal is to promote high quality trees. Sites with a low site index are less likely to produce these trees.
3. The age of northern red oak had to be 5-60 years old and they had to be in the dominant class of the stand. It is at the earlier ages that we have

the best opportunity to influence the growth of the trees to promote self-pruning.

4. Sample trees needed to be in the dominant class so they would not show repressed growth.
5. The sample trees had to have a yearly increment growth of ¼ inch since we wanted to work with trees that had the potential to produce high-quality wood.
6. The stand could have no recent disturbance. Trees growing in an area of recent disturbance will not yet show a response to the disturbance and could confound the data.

I was able to identify ten appropriate sites for this study (Appendix I, Figure 1.3). All ten study sites were located in the Northern Mixed Forest region of Wisconsin (Wisconsin Department of Natural Resources 2000). In 2000, approximately 36% of the forests in this region were government owned. 52% were owned privately (Figure 1.4). 8% of the Northern Mixed Forest region is oak-hickory forest type, consisting mostly of northern red oak, northern pin oak, white oak, red maple, big-tooth aspen, and eastern white pine. Northern red oak is also a characteristic species in the maple-basswood forest type that makes up 38% of the region (Figure 1.5).

The soils are mainly loams or silts, with portions being sandy and more infertile. Soil series descriptions are located in Appendix II. The total precipitation is approximately 35 inches per year and the average annual maximum and minimum temperatures are approximately 50 degrees and 30 degrees Fahrenheit, respectively. These data were provided by the weather stations located closest to the study sites (Appendix III).

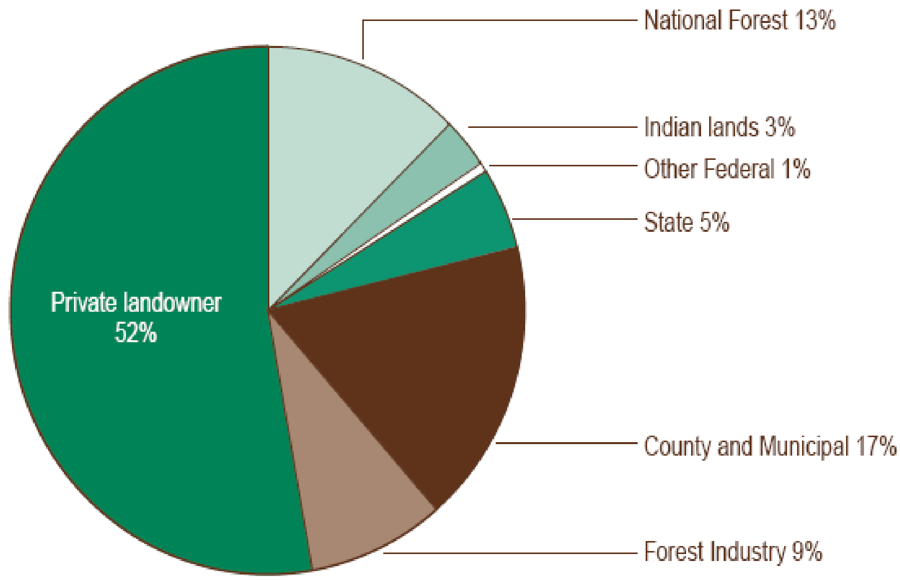


Figure 1.4 Forest ownership in the Northern Mixed Forest Region of Wisconsin in 2000. (Wisconsin Department of Natural Resources 2000)

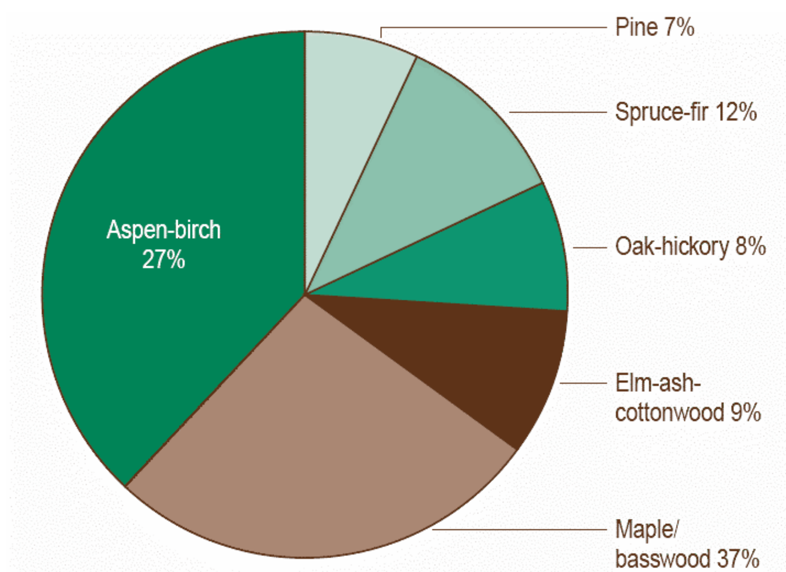


Figure 1.5 Forest composition in the Northern Mixed Forest Region of Wisconsin in 2000. (Wisconsin Department of Natural Resources 2000)

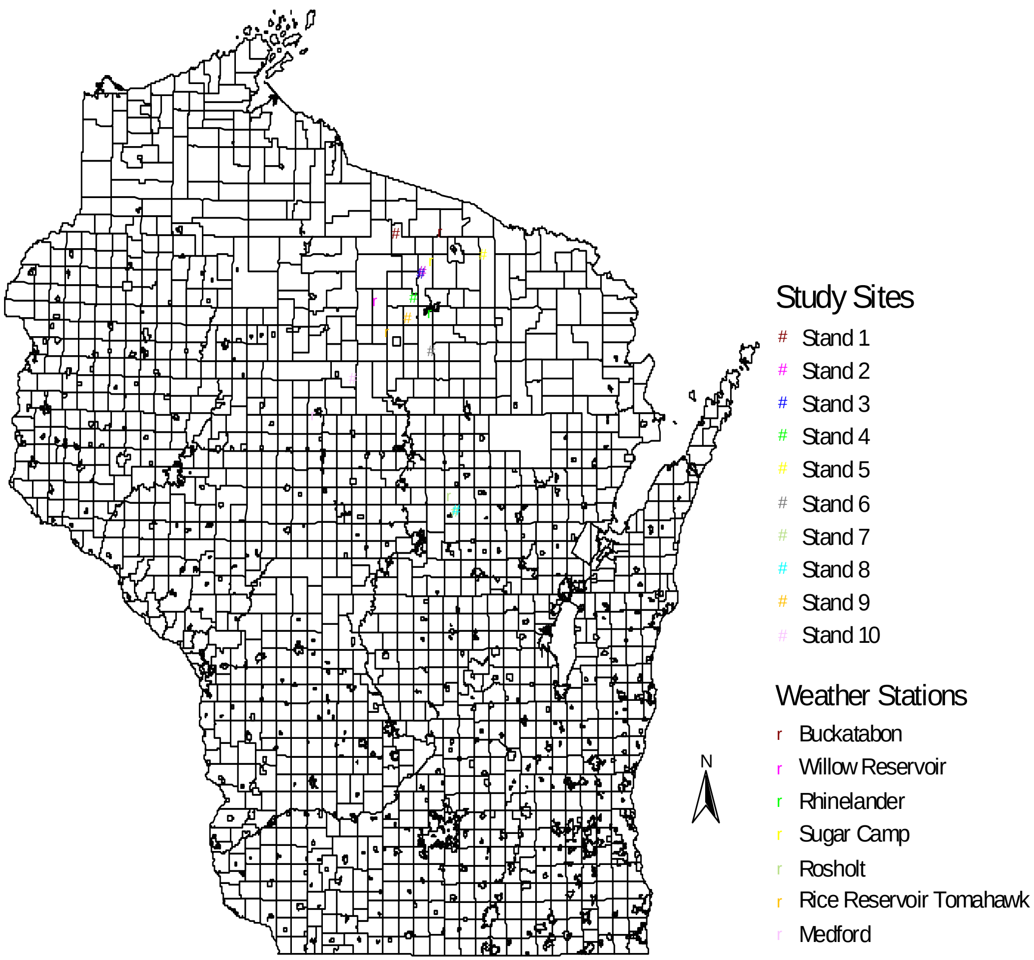


Figure 1.3 Study Site and Weather Station Locations

Study Site	Age	SI	Soil Type	Slopes
1	20	70	Sayner-Rubicon Complex	0-6% slopes
2	15	70	Keweenaw-Sayner Complex	15-30% slopes
3	19	70	Keweenaw-Sayner Complex	15-30% slopes
4	25	75	Padus-Pence Sandy loams	1-6% slopes
5	15	70	Sayner-Rubicon Complex	0-6% slopes
6	19	70	Padwood Sandy Loam	1-6% slopes
7	29	65	Oesterle Variant	
8	55	65	Oesterle Variant	
9	8	70	Sayner Loamy Sand	15-45% slopes
10	12	70	Withee Silt Loam	0-3% slopes

Table 1.1 Study site descriptions

Field Methods

I generated five random points for each stand along with five alternate points (Appendix I). When available, this was done using an ArcView shapefile and a random points generator. If a shapefile was not available, coordinates of the edges of the stand were obtained from an aerial photo, and random points were generated within the range. I verified these random points using aerial photos of the stand. My field assistant and I navigated to the points using a Garmin® GPSMap 76S. If the point was appropriate, that is, it was at least 50 ft. from the edge of the stand and in the proper forest type, it was used in the study. If not, an alternate point was used. We took density measurements using both variable and fixed radius plots. A point sample tally was taken using a Spiegel relaskop. A BAF of 10 was used. However, if the count was too small (less than 7) the tally was redone using a

BAF of 5. The fixed area tally was taken for an area of 1/20 acre. We used these measurements to describe density characteristics of the whole stand.

Then we located the sample trees. The sample tree for each point was the northern red oak closest to the point. Sample trees had to morphologically look like pure northern red oak, since we would not be able to genetically confirm it until later, in the laboratory. In addition, if the closest northern red oak was too old or did not display proper increment growth it was not used, and a new sample tree was located using the alternate points generated earlier. GPS Coordinates of the sample trees were recorded either in WTMs or UTMs, depending on how original coordinates of the stands were given (Appendix I). We determined age of the trees using an increment borer at 1 ft above ground level and used a caliper to measure dbh. Total height and height to lowest live and dead branches were measured using a Vertex III hypsometer and transponder (Haglöf, VertexIII). We measured the diameter of the lowest live branch using a caliper. If the lowest live branch was low enough its length was measured directly. However, if it was too high up to reach, the length was calculated using indirect measurements. The height of the branch at the stem was measured, along with the height at the tip of the branch. The measurements were subtracted. The extension of the branch was also measured. These values were then used in the equation:

$$branch\ length = \sqrt{(height\ difference)^2 + \ extension^2}.$$

For genetic analysis, we collected leaf samples from the lowest branch of the tree, if it was reachable. Only trees that contained reachable branches were included in the genetic portion of the study. Point sample and fixed area tallies were taken with the sample tree as the point to get density measurements around each individual tree.

Statistical Analysis

Data were entered into a Microsoft Excel (Microsoft Excel 2002) spreadsheet (Appendix IV). Correlation coefficients were calculated to determine the strength of the linear association between several factors, and linear regressions to produce prediction models for different growth characteristics important to timber quality and self-pruning. Residual analyses were then performed on all models.

Results

A total of 50 trees were sampled from ten stands. Raw data and descriptive statistics for all the variables collected are located in Appendix V. The range in age of the sample trees was 53 years with a minimum of 8 and a maximum of 61. The mean age was 21.76. The height of the lowest live branch ranged from 1.16 m to 14.5 m with a mean of 4.877 m. The range of the height to the lowest dead branch was from 0.45 m to 12.5 m with a mean of 2.53 m. The basal area/acre (BA/acre) around the individual trees ranged from 40 sq. ft. to 180 sq. ft. with a mean of 87 sq. ft.

Correlation coefficients were calculated for all variables to examine possible relationships. Several pairs of variables showed strong correlations (r=0.7). Age had correlations with dbh and total height of 0.845 and 0.887, respectively. Dbh had a correlation with total height of 0.92. Total height was strongly correlated with the height of the lowest live branch (r=0.729) and the height of the lowest live branch was strongly correlated with the height of the lowest dead branch (r=0.728). Length of the lowest live branch had a strong correlation with the diameter of the lowest live branch (r=0.753). All correlation coefficients are found in Appendix V.

Predictive Models

Predictive equations were developed to describe certain characteristics related to individual trees and self-pruning. The descriptions of all variables are found in Table 1.2. The values of all equation coefficients and their significance, and the coefficient of determination (R^2) and standard error for the equation are found in Table 1.3.

Variable	Definition
A	Tree age (years)
BA	Basal area per acre around individual tree (m^2/acre)
CB	Percent clear bole (height to lowest dead branch/total height)
CR	Rate of crown recession (height to lowest live branch/age)
DG	Diameter growth of stem (cm/yr)
DLLB	Diameter of the lowest live branch (cm)
LLLB	Length of thelowest live branch (m)
H	Total tree height (m)
HI	Average yearly height increment (m/yr)
HLDB	Height of the lowest dead branch (m)
HLLB	Height of the lowest live branch (m)
RGI	Average radial growth increment (cm/yr)
SP	Self-pruning ratio (HLDB/HLLB)

Table 1.2 Description of variables used in prediction equations.

Dbh had a positive linear relationship to age (Figure 1.6). As age increases, the DBH increases at a constant rate. Examination of the residuals showed non-random pattern, indicating that the model is not in violation of any assumptions underlying regression analysis (Figure 1.7). The assumptions are that the random deviations are independent, normally distributed, and have a constant variance.

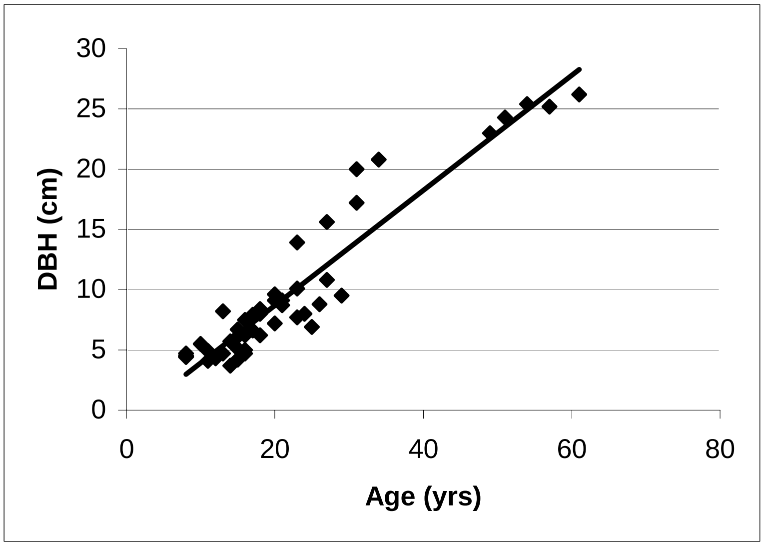


Figure 1.6 DBH as a function of age

[1] DBH = -0.83223 + 0.47717*A

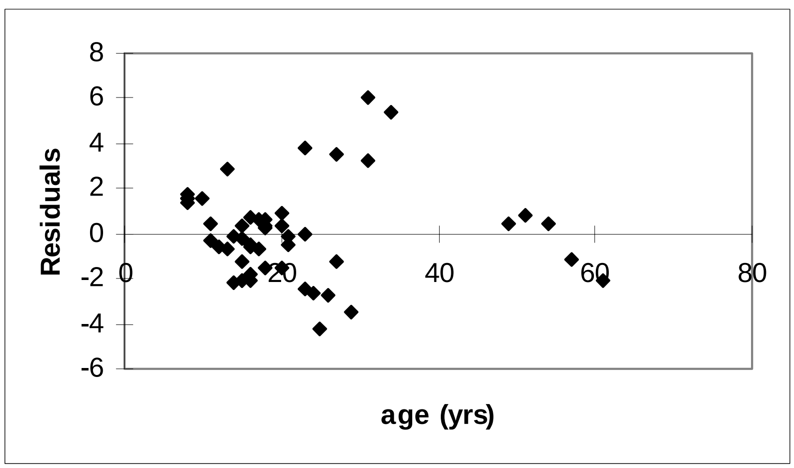


Figure 1.7 Residuals for equation [1] plotted against age.

The relationship between total tree height and DBH, as well as total tree height and age are shown in Figures 1.8 and 1.9, respectively.

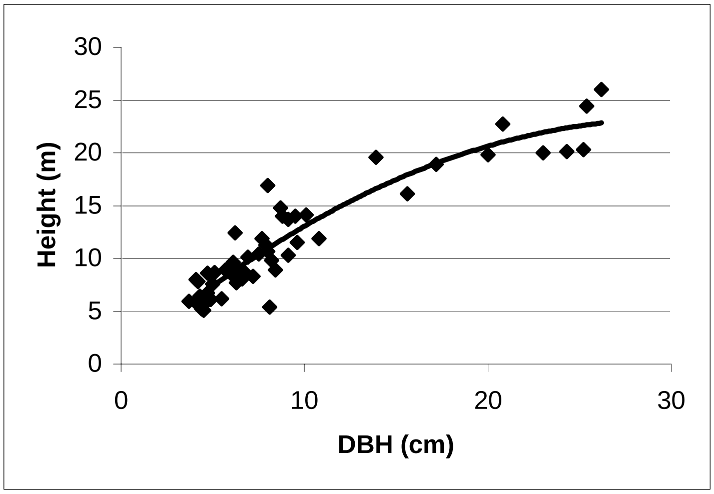


Figure 1.8 Total tree height as a function of DBH

[2] H = 0.47363 + 1.50782*DBH – 0.02499*DBH^2

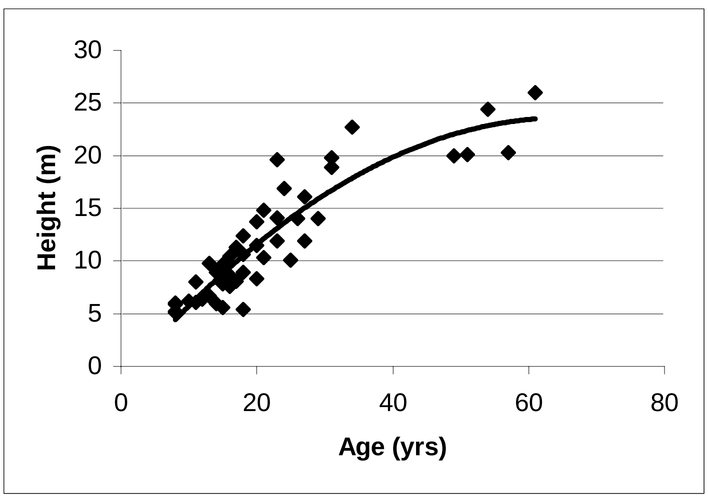


Figure 1.9 Total tree height as a function of age.

[3] H = -1.31108 + 0.761372*A – 0.00581*A^2

Both of these relationships are polynomic in nature, indicating that as the age and dbh of the tree increase, the height growth slows down. This is consistent with tree growth.

Residual analysis of both equations show a random pattern and indicates that the models do not violate statistical assumptions (Figure 1.10 and 1.11).

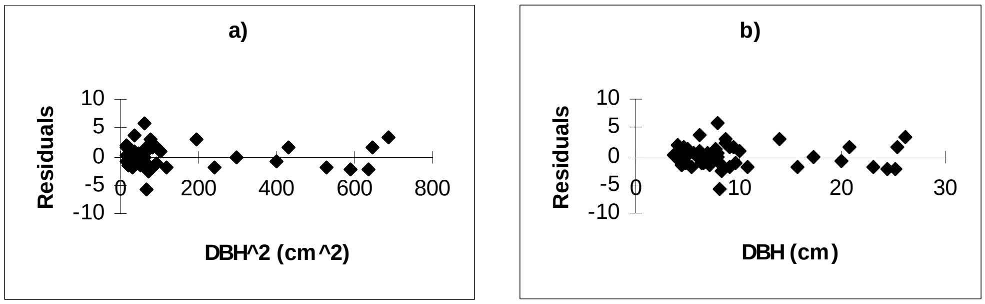


Figure 1.10 Residuals for model [2] plotted against DBH^2 (a) and DBH (b).

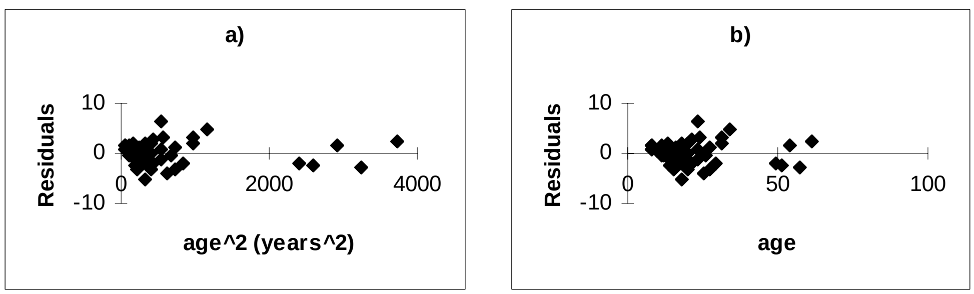


Figure 1.11 Residuals for model [3] plotted against age^2 (a) and age (b).

The height of the lowest live branch (crown base) can be described as a function of total height (Figure 1.12). The height of the lowest dead branch can be described as a function of the height of the lowest live branch (Figure 1.13). The location of the lowest dead branch is approximately half the height of the crown base.

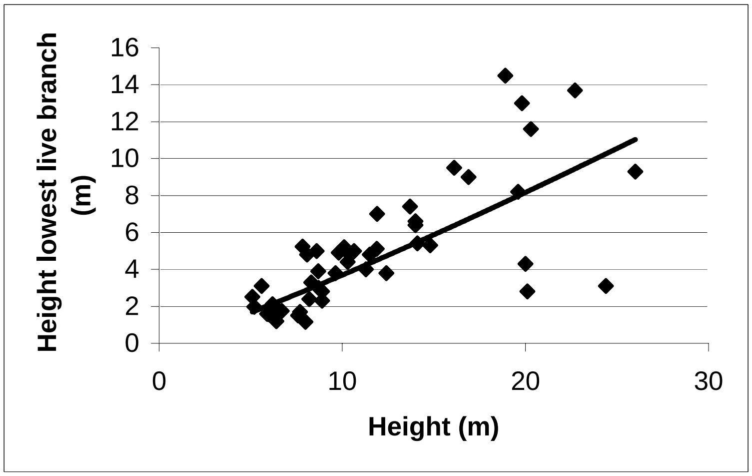


Figure 1.12 Height of the lowest live branch as a function of total tree height.

[4] HLLB = 0.2641*H$^{1.1454}$

Figure 1.13 Height of lowest dead branch as a function of height of lowest live branch.

[5] HLDB = 0.082937 + 0.499085*HLLB

Residual analysis of model 4 showed that assumptions for regression analysis were met (Figure 1.14). However, residual analysis of model 5 indicates that variance increases as the height of the lowest live branch increases (Figure 1.15). This is common for growth models. However, models developed using transformed data were still not able to eliminate this trend. (Figure 1.16)

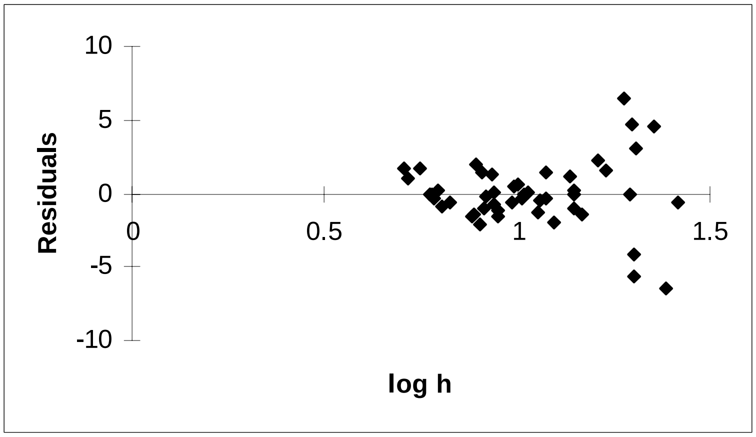


Figure 1.14 Residuals for model [4] plotted against logH.

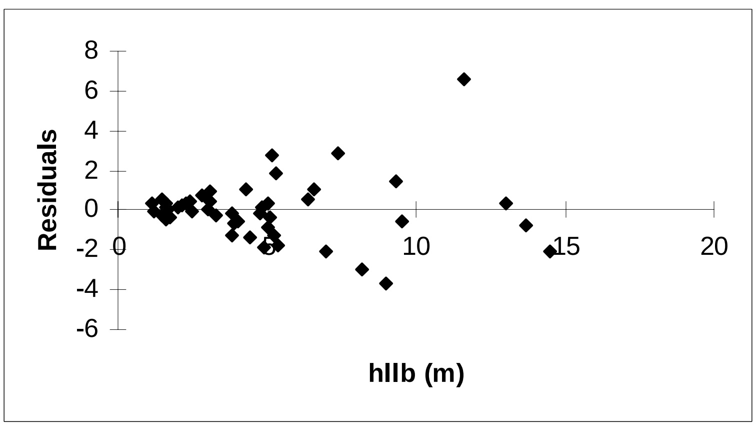


Figure 1.15 Residuals for model [5] plotted against height of the lowest live branch.

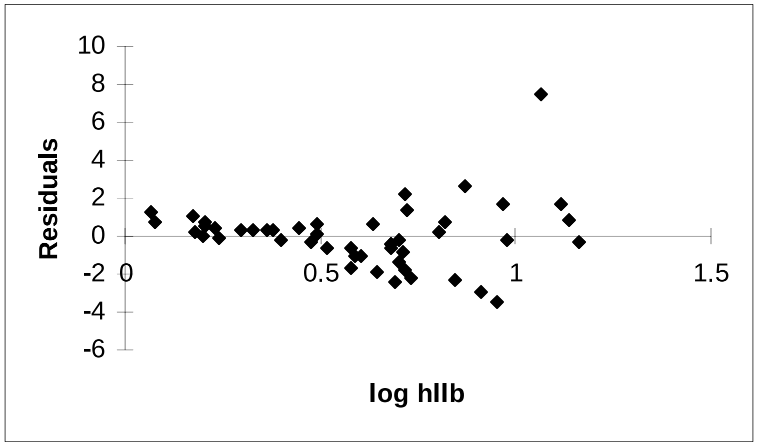


Figure 1.16 Residuals for model [5] plotted against the $\log_{10}$ of the height of the lowest live branch.

A study by Nutto, Spathelf, and Rogers (2005) found that the height of the lowest live branch could be described as a function of dbh, age, and total height. This relationship was examined using data from my study, and the following model was developed:

[6] HLLB = -0.496 – 0.166*A + 0.066*DBH + 0.714*H

The P-values for age and total tree height were significant at the P<0.05 level. However, the coefficients for the intercept and DBH were not significant, indicating that they explain very little of the variation in the height of the lowest live branch and therefore may be removed from the equation (Table 1.3). Residual analysis shows that, for all variables, as the Y increased, so did the variance, indicating that, for this study, the model does not meet the heterogeneity assumptions for regression analysis (Figure 1.17). Once again, data transformation did not improve the model.

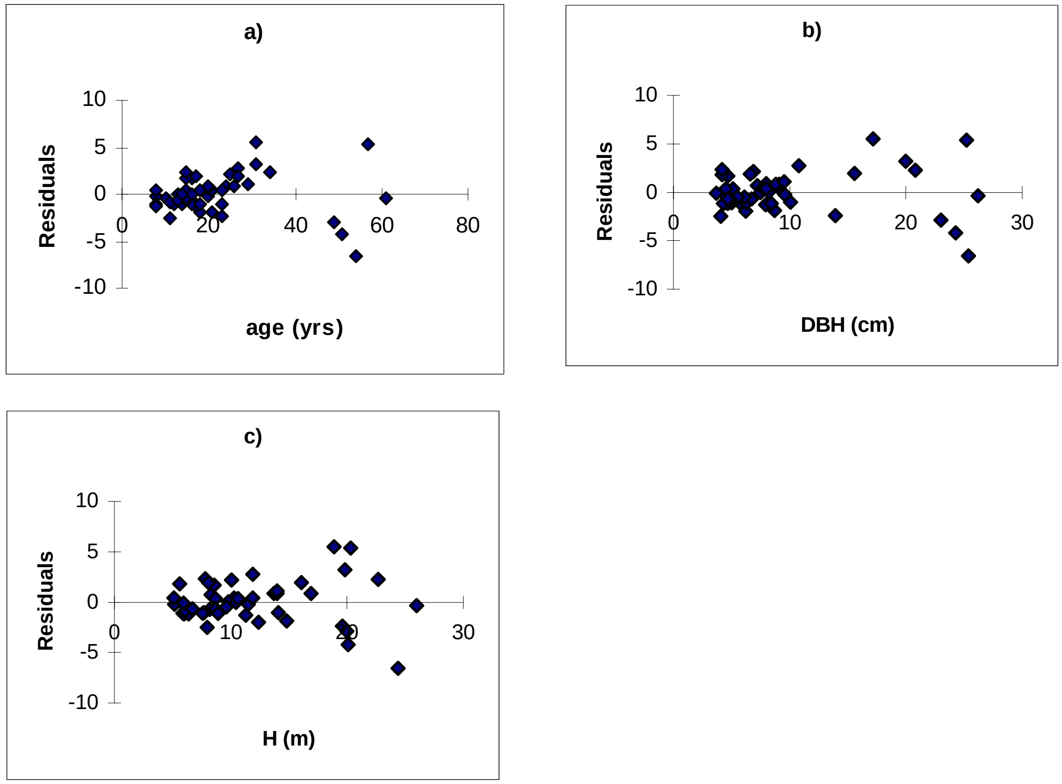


Figure 1.17 Residual analysis for model [6] plotted against age (a), DBH (b), and H (c).

Another study by Nutto (1998) described height to the lowest live and dead branches as functions of age, dbh, average radial increment, and average yearly height increment. These relationships were examined for this study and the following models were developed:

[7] HLLB = 3.409 – 0.289*A + 1.058*DBH + 9.236*HI – 17.176*RGI

[8] HLDB = - 0.483 + 0.084*A + 0.098*DBH + 0.050*HI + 0.695*RGI

Height of the lowest live branch was positively related to DBH and average yearly height increment, and negatively related to age and radial growth increment. Height of the lowest dead branch was positively related to all variables tested. Residual analyses of both models show that the assumptions underlying regression analysis are met. (Figures 1.18 and 1.19)

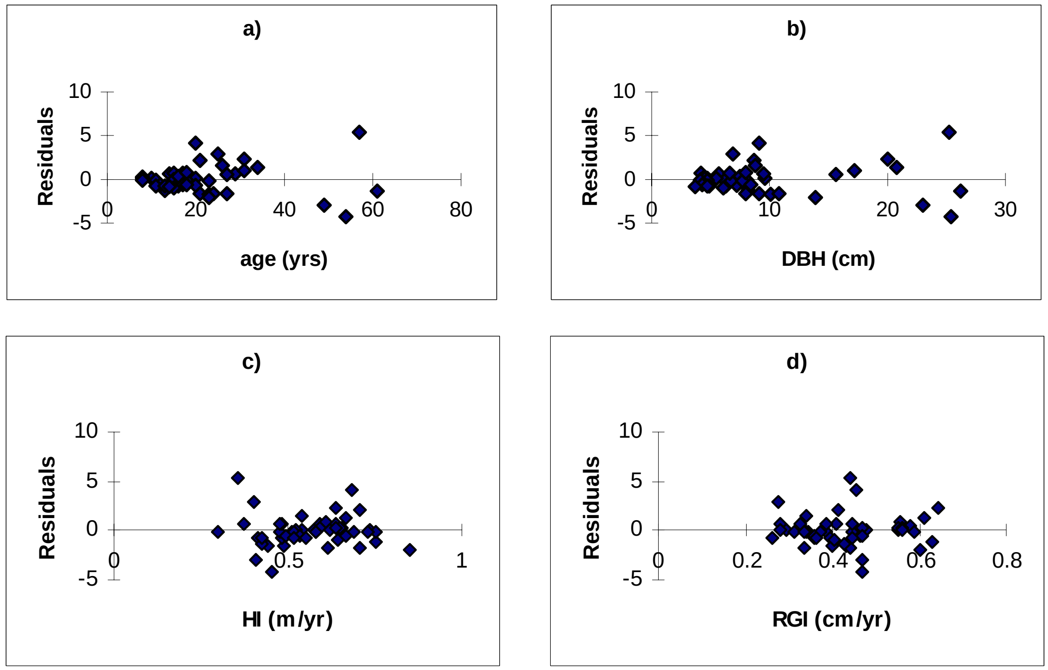


Figure 1.18 Residuals for model [7] plotted against age (a), DBH (b), HI (c), and RGI (d)

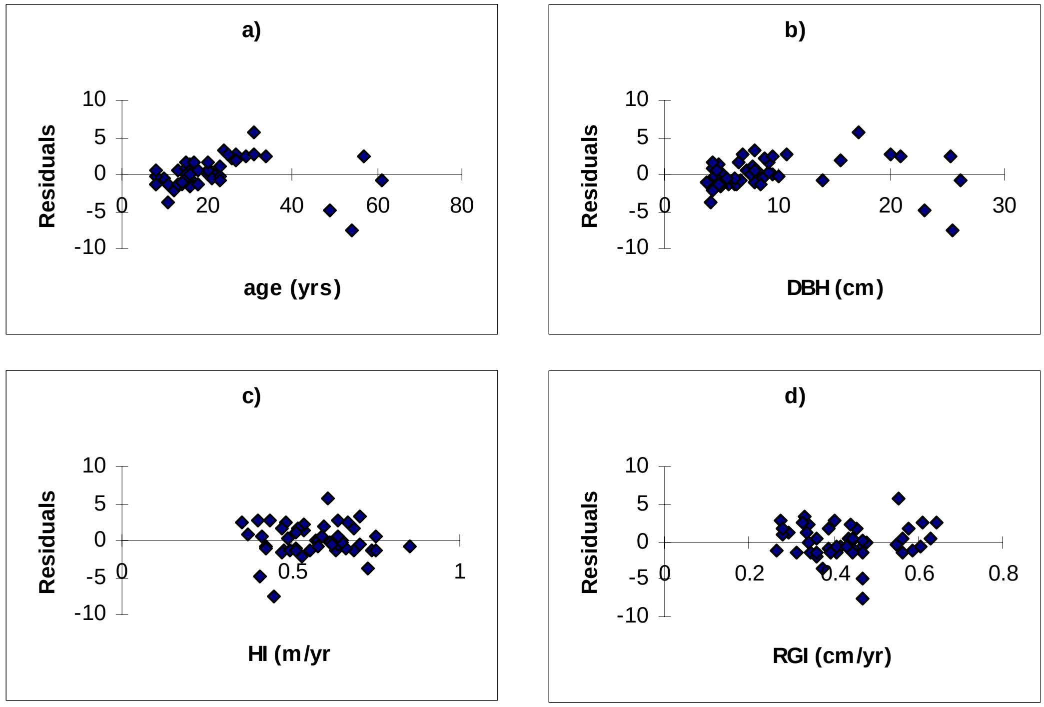


Figure 1.19 Residuals for model [8] plotted against age (a), DBH (b), HI (c), and RGI (d).

A strong predictive equation was developed for the length of the lowest live branch as it is related to the diameter of the branch (Figure 1.20).

Figure 1.20 Length of lowest live branch as a function of its diameter.

[9] $\mathbf{LLLB = 1.3159*DLLB^{0.8344}}$

A residual analysis of the logarithmic transformation of the model [9] shows non-random patterns (Figure 1.21).

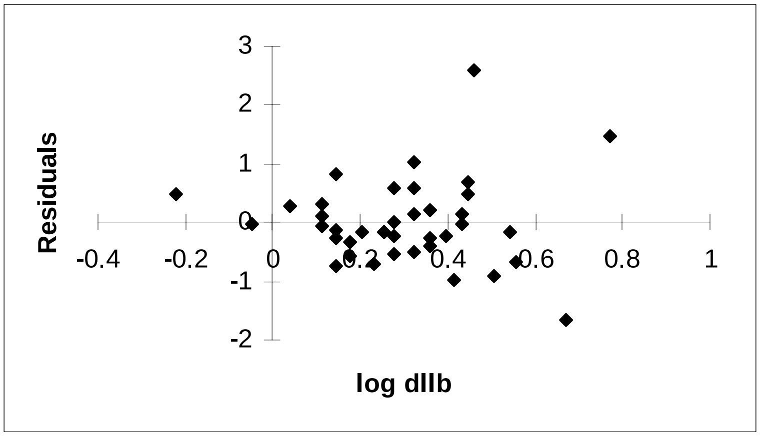


Figure 1.21 Residuals for model [9] plotted against log(DLLB).

The percent clear bole was examined in relation to the basal area per acre and age of the tree and the following predictive model was formed:

[10] CB = 0.079662 + 0.001033*BA + 0.002053A

The R^2 value for this model is 0.142, which is relatively low (Table 1.3). However, the coefficient for BA is significant at the $P<0.1$ level ($P=0.0864$), indicating that there is a weak, but significant, relationship between the percent clear bole and basal area per acre.

The rate of crown recession was also weakly related to the BA/acre around the individual trees (Figure 1.22). The R^2 value was 0.21 with a significant coefficient for BA ($P<0.0494$).

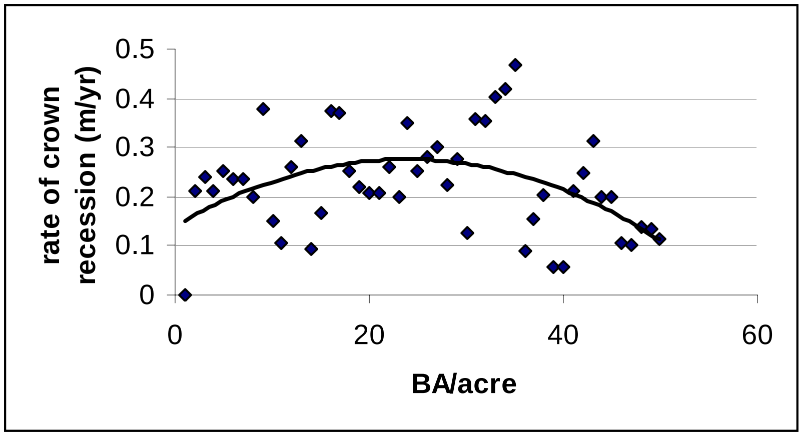


Figure 1.22 Rate of crown recession as a function of basal area per acre.

[11] CR = -0.01465 + 0.004199*BA – 0.000014*BA^2

Residual analysis of models [11] and [12] show no unusual non-random patterns (Figures 1.23 and 1.24).

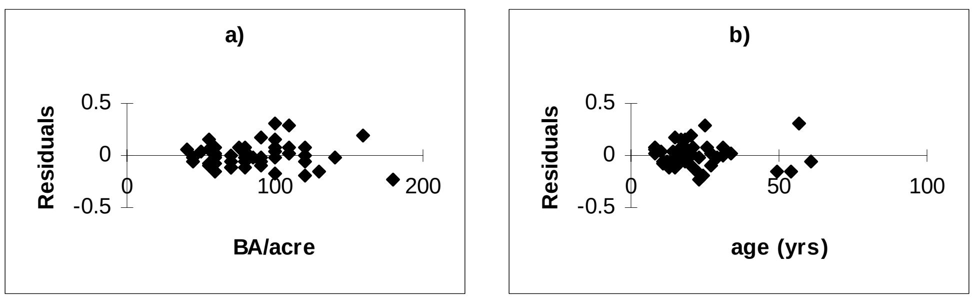


Figure 1.23 Residuals for model [10] plotted against BA (a) and age (b).

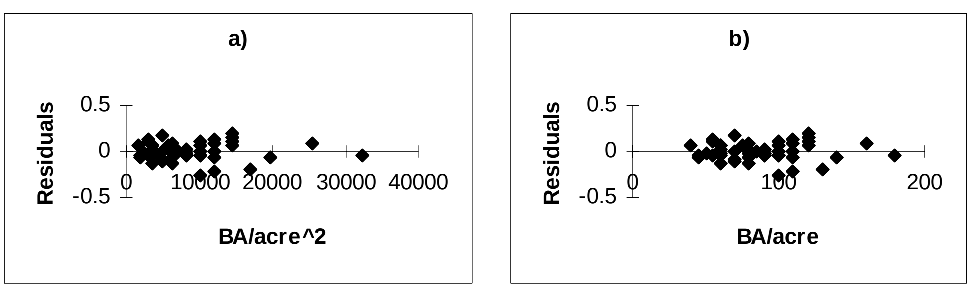


Figure 1.24 Residuals for model [11] plotted against BA^2 (a) and BA (b).

The study by Nutto, Spathelf, and Rogers (2005), found a model describing crown width as a function of DBH. The relationship was examined for this study, with the following model being developed:

[12] CW = 1.241 + 0.241*DBH – 0.0069*DBH^2

The R^2 value for the model is low ($R^2 = 0.136$), but the P-values for all variables are significant ($P<0.1$) indicating a weak, but significant, relationship between crown width and dbh (Table 1.3). The graph of the model and the residual analysis are found in Figure 1.25 and 1.26, respectively. The residual analysis shows that the model does not violate statistical assumptions.

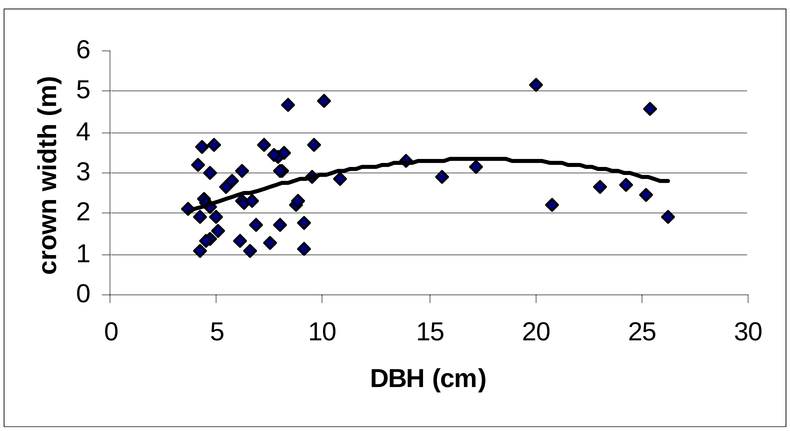


Figure 1.25 Crown width as a function of DBH.

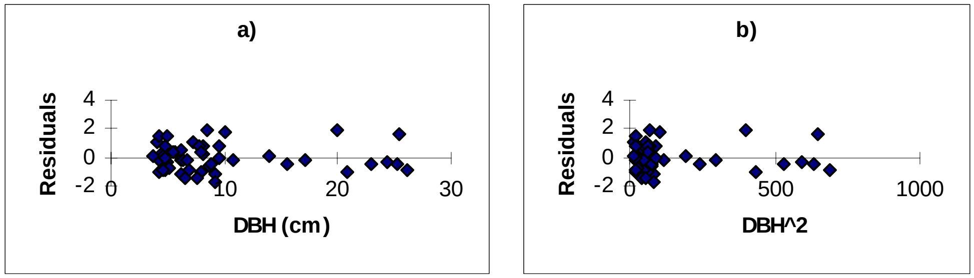


Figure 1.26 Residual for model [12] plotted against DBH (a) and DBH^2 (b).

Several other relationships pertaining to self-pruning characteristics were evaluated, and no strong relationships were found. The self-pruning ratio (height of lowest dead branch/height of lowest live branch) was insignificant in relation to BA/acre with P-values for BA and BA^2 being 0.731 and 0.712, respectively (Table 1.3). Likewise, diameter growth was found to be insignificantly linked to basal area/acre (P= 0.927).

[13] SP = 0.450007 + 0.002012*BA - .000011*BA^2

[14] DG = 0.429081 + 0.0000454*BA

Residual analysis for models [13] and [14] indicated that the assumptions underlying regression analysis were met (figures 1.27-1.28).

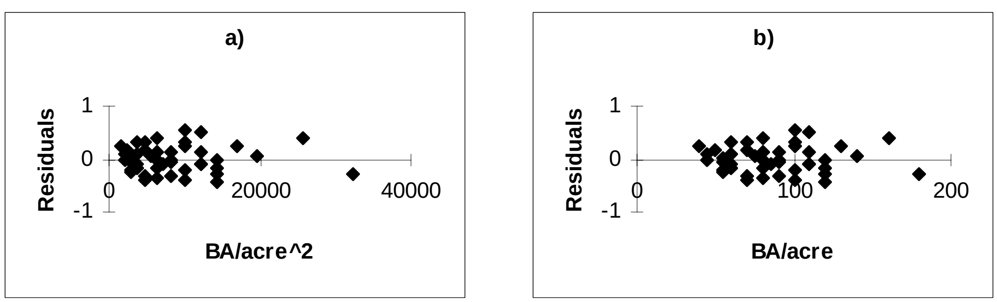


Figure 1.27 Residuals for model [13] plotted against BA^2 (a) and BA (b).

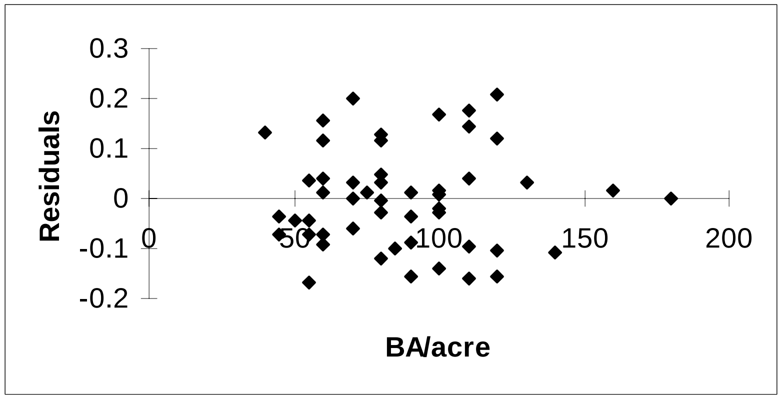


Figure 1.28 Residuals for model [14] plotted against BA.

Table 1.3 Models for predictive equations, the values of the coefficients and their P-values, and the standard error and R2 for the equation. Bold denotes statistically significant at the P<0.10 level.
†Indicates equations which have been logarithmically transformed for analysis purposes

MODEL	b_0		b_1		b_2		b_3		b_4		$S_{x.y}$	R^2
	Estimate	P-Value	Estimate	P-Value	Estimate	P-Value	Estimate	P-Value	Estimate	P-Value		
[1] $DBH = b_0 + b_1*A$	-0.833	0.168	**0.477**	**<.001**							2.112	0.893
[2] $H = b_0 + b_1*DBH + b_2*DBH^2$	0.474	0.712	**1.508**	**<.001**	**-0.025**	**<.01**					2.016	0.872
[3] $H = b_0 + b_1*A + b_2*A^2$	-1.311	0.386	**0.761**	**<.001**	**-0.00581**	**<.01**					2.329	0.829
[4] $\log(HLLB) = b_0 + b_1(\log H)$†	**-0.578**	**<.001**	**1.145**	**<.001**							0.186	0.594
[5] $HLDB = b_0 + b_1*HLLB$	0.0829	0.841	**0.499**	**<.001**							1.588	0.530
[6] $HLLB = b_0 + b_1*A + b_2*DBH + b_3*H$	-0.496	0.572	**-0.166**	**0.0339**	0.0665	0.714	**0.714**	**<.001**			2.177	0.598
[7] $HLLB = b_0 + b_1*A + b_2*DBH + b_3*HI + b_4*RGI$	3.409	0.436	-0.289	0.146	**1.058**	**0.015**	**9.236**	**0.037**	**-17.176**	**0.067**	2.317	0.520
[8] $HLDB = b_0 + b_1*A + b_2*DBH + b_3*HI + b_4*RGI$	-0.483	0.876	0.084	0.556	0.098	0.746	0.050	0.985	0.695	0.916	1.677	0.499
[9] $\log(LLLB) = b_0 + b_1(\log DLLB)$†	**0.119**	**<.001**	**0.834**	**<.001**							0.108	0.690
[10] $CB = b_0 + b_1*BA + b_2*A$	0.0796	0.136	**0.00103**	**0.0864**	0.002053	0.168					0.115	0.142
[11] $CR = b_0 + b_1*BA + b_2*BA^2$	-0.0147	0.882	**0.00420**	**0.0494**	-0.000014	0.172					0.00454	0.209
[12] $CW = b_0 + b_1*DBH + b_2*DBH^2$	**1.241**	**0.0418**	**0.241**	**0.0355**	**-0.0069**	**0.0755**					0.936	0.136
[13] $SP = b_0 + b_1*BA + b_2*BA^2$	0.450	0.109	0.00201	0.731	-0.000011	0.712					0.249	0.0032
[14] $DG = b_0 + b_1*BA$	**0.429**	**<.001**	0.000045	0.927							0.102	0.0002

Discussion

Many of the strong associations found in this study were expected. I expected that age would be strongly correlated with DBH and total tree height. The older the tree gets, the taller and wider its stem becomes. Likewise, it's reasonable to assume that total tree height and height to the lowest live branch will be correlated. Since northern red oak is a self-pruning species, as it ages it will begin losing its lower branches. However, some relationships that were expected to have strong correlations did not. I would have expected that BA/acre around each sample tree would be strongly related to the crown width of that tree because trees with lower density around them should take advantage of having more room to grow. However, the correlation coefficient for the relationship was low. The low value of the correlation coefficient indicates that the density around the individual trees is not strongly related to any of the other variables that were measured.

For forest managers, the ability to predict the height of the lowest live branch (crown base), height of the lowest dead branch (merchantable height), and diameter growth is useful for planning stand management strategies. I developed several models that predict the height of the crown base. If a forest manager wants to predict the height of the crown base given a certain age, model [3] may be used to first determine the total tree height. Once that is calculated, model [4] may be used to determine the height of the crown base. The merchantable height is also of great importance. Using the value of the height of the crown base from model [4] in model [5], the height of the lowest dead branch can be estimated. Nutto, Spathelf, and Rogers (2005) also developed a model to describe the merchantable height as a function of crown base in their study. These models ([4] and [6] may be used to determine the amount of clear wood that will be produced at a given rotation age. For example:

> If a forester has a stand of northern red oak that is 60 years of age, the predicted total height of each tree would be 43.68 m. Using this information and model [4], the height to the lowest live branch is predicted to be 19.976 m. Inserting this value into model [6] gives a height of the lowest dead branch (merchantable height) of 10.05 m.

The models may also be used to determine the rotation age necessary to produce a certain quantity of clear wood. It is up to the individual forest manager to decide at what rotation age and what amount of clear wood best meet their management goals. These equations allow for advanced prediction and planning.

Other models for predicting the height of the lowest live and dead branches show how these characteristics are related to average yearly height increment and average radial growth increment. Model [7] shows that the height of the lowest live branch is positively related to average yearly height increment and negatively related to radial growth increment. This means that as the rate at which the tree grows vertically increases, so does the height to the crown base. Tree height is, in part, related to site index, a factor not accounted for in this study. A higher site index would increase the rate of height growth, and therefore raise the height of the crown base. Nutto, Spathelf, and Rogers (2005) addressed this in their study. The negative relationship between the radial growth increment and height of the crown base indicates that, as DBH increases, the height of the lowest live branch decreases. This is consistent with the results of Nutto (1998). However, the height of the lowest dead branch was found to be positively related to both radial growth increment and yearly height increment. This means that as the diameter of the tree increases at a greater rate, the merchantable height increases. This is inconsistent with the results of Nutto (1998) who found that the height of the lowest dead branch is negatively related to radial growth increment, while it is positively related to yearly height increment. The P-values for all coefficients in model [8] are all high ($P>0.1$), indicating that they are not statistically significant at the $P<0.1$ level and that the model predictions are weak.

One aim of this study was to determine if density around the sample tree affects characteristics related to self-pruning and timber quality. Being able to manipulate stand characteristics would allow forest managers to produce higher quality timber. Models were developed to describe the percent clear bole, rate of crown recession, self-pruning ratio, and radial growth increment as functions of BA/acre. BA/acre was found to be a significant variable in the models for percent clear bole [10] and rate of crown recession [11], but the models themselves were not good predictors, with R^2 values of 0.142 and 0.209, respectively (Table 1.3). The inclusion of more factors into the models may create better predictors.

Mäkinen et al. (2003) found that the self-pruning ratio was not related to stand characteristics, such as density. They concluded that not all factors related to self-pruning were accounted for in their study. Variability between stand or regional characteristics were cited as possible factors that were missing. These could include weather-related variables such as amount of precipitation, or other factors such as soil. This current study also failed to find a relationship between the self-pruning ratio and stand characteristics. As with the Mäkinen et al. (2003) study, this study did not include weather or soil factors.

Sonderman (1984) found that a decrease in crown ratio was achieved by increasing stocking percentage (a measure of stand density). However, no such relationship was found here. The stocking percentage for this study ranged from 45% to 100%.

The relationships found provide useful information for forest managers interested in increasing the quality of timber produced in their stands. Future studies can look to verify the relationships found here and hopefully will be able to provide more models for the production of high-quality timber in northern red oak in Wisconsin.

Suggestions for Future Studies

Although it was determined that a minimum sample size of 50 trees was necessary, and this minimum was met, a larger sample size may have increased our confidence in the relationships found. However, due to the lack of young stands of northern red oak in Wisconsin, it was not possible to increase the sample size. County foresters from all over Wisconsin were contacted in order to locate young stands for the study. Several responded by saying they had many oak stands over the age of 75, but that younger stands were very limited. Oak regeneration has been a problem in Wisconsin over the last 50 years, and as a result there are not many young stands. FIA (Forest Inventory and Analysis) inventories from 1968 to 1996 show an approximately 200,000 acre decline in the 0-19 year stand age class of the oak-hickory forest type in Wisconsin (USDA Forest Service 2006). More studies need to be done to address the problem in sample size. This may be accomplished by expanding the study site range outside of the state of Wisconsin, were perhaps more young stands may be found.

A second problem encountered in the study was collecting all the data for every tree. A ladder was used to reach the lowest living and dead branches, making the height of the ladder a prohibiting factor. Some branches could not be reached, and the result was missing data for some of the sample trees, which resulted in smaller data sets for some of the variables. Nutto's study (1998) was done by following around logging operations. Doing so would have solved the problem of not being able to reach certain branches.

For future studies, sampling techniques need to be adjusted in order to be able to collect all data from all sample trees. This could be done by following Nutto's (1998) procedure, using longer ladders, or climbing the larger trees with ropes.

The study did provide useful models for predicting tree characteristics related to timber quality. Although several of the models were not good predictors of these characteristics, relationships were shown that may help forest managers devise management strategies for producing high quality timber. This study suggests areas deserve further attention, such as increasing sample size, having an even distribution of ages of sample trees, and alternative methods of collecting data so there are no gaps in the data sets.

CHAPTER 2
IDENTFICATION OF NORTHERN RED OAK

Introduction

Hybridization is the genetic crossing of two species or sub-species, and is a common occurrence in plants. Oaks are no exception. Two species of red oak are found in northern Wisconsin, which are the northern red oak (*Quercus rubra, L.)* and northern pin oak (*Quercus ellipsoidalis*) (Figure 2.1). Northern red oak is a valued timber species that drops its lower branches (called self-pruning). Northern pin oak does not self-prune, and has less valuable timber. Northern red oak and northern pin oak have been found to hybridize. Hybridization between the two species may affect self-pruning characteristics. The hybrids may show self-pruning characteristics intermediate to both species. Since the species of interest is the northern red oak, and the focus is on self-pruning, it is necessary to address this issue of hybridization. It is difficult to distinguish morphologically between northern red oak and its hybrids. Because little is known about the genetic sequences of northern red oak and northern pin oak, Random Amplified Polymorphic DNA (RAPD) fingerprinting was used to locate a genetic marker to distinguish between northern red oak, northern pin oak, and their hybrids. RAPDs does not require prior knowledge of the genome to find genetic differences among species or between individuals of the same species.

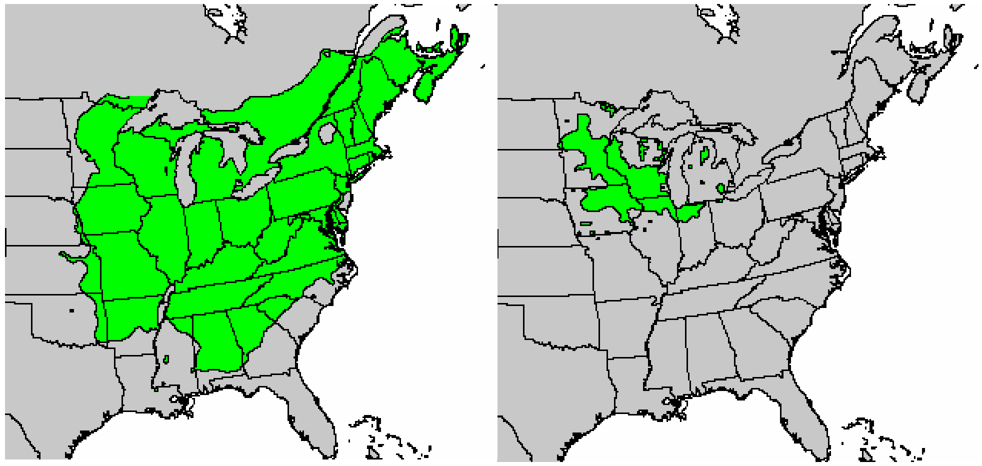


Figure 2.1 Range of northern red oak (left) and northern pin oak (right)

Objectives

1. To find a genetic marker using Random Amplified Polymorphic DNA (RAPD) fingerprinting to distinguish between northern red oak and northern red oak/northern pin oak hybrids.
2. To use the genetic marker to test sample trees, ensuring that they are not hybrids with northern pin oak.

Literature Review

In recent years, many studies have looked at oak genetics. These studies focus on genetically distinguishing between closely related species, as well as looking at hybridization between the species. Several studies have looked at northern red oak and northern pin oaks, and the hybrids between the two species. Jensen *et al.* (1993) looked at leaf characteristics and found a continuum between the characteristics of the northern red oak and northern pin oak. The study was done on the Apostle Islands, in northern Wisconsin. Observation on these islands had led scientists to believe that hybridization may be occurring between the northern pin oak located on the near shore islands, and northern red oak on the outer islands. Leaf samples were collected from several points in the Apostle islands to test this hypothesis. Eleven landmarks were located on each leaf and these landmarks were used to generate nine linear measures and three angular measures. Bristle tips were also counted. The results indicated that hybridization was occurring, although it was not possible to indicate the hybrid status of each individual tree.

In another study focusing on oak morphology, Tomlinson *et al.* (2000) determined that it is not possible to distinguish between northern red oak and hybrids using only whole tree characteristics, although identification of northern pin oak was possible. Sample mother trees were selected based on morphological characteristics. Samples used included northern red oak, northern pin oak, and those thought to be hybrids. Morphological analysis was done on the acorns, leaves, and seedlings of the mother trees. The results of the study showed two distinct groups of trees- northern pin oak, and northern red oak/hybrids. They were unable to distinguish the hybrids from pure northern red oaks.

Hokanson *et al.* (1993) studied isozyme variation in the oaks of the Apostle Islands. Isozymes are alternate forms of a particular protein. They found little variation in proteins between northern red oak and northern pin oak. The authors suggested that it could be due to past hybridization between the species.

Studies have been successful in genetically distinguishing between other species of oaks and their hybrids. Using microsatellite markers to study hybridization between *Q. lobata* and *Q. douglasii*, Craft *et al.* (2002) were able to successfully distinguish among the species and their hybrids. Microsatellites are stretches of DNA with repeated sequences of two, three, or four nucleotides (e.g., ACACACAC…, ACGACGACG…). The study found microsatellite sequences unique to each species, as well as some with different frequencies between the two species. Where most studies use phenotypes to place trees in groups and then genetically test them, the study by Craft *et al.* (2002) used the loci to place sample trees in species groups independent of their phenotypes. The results indicated that phenotypically intermediate trees were not necessarily hybrids. It also suggested that hybrids were not necessarily phenotypically intermediate.

Howard *et al.* (1997) worked with *Q. grisea* and *Q. gambelii* and found six 10-bp primers that provided 14 informative markers using RAPD analysis. With RAPDs, one short primer is used to amplify a section of DNA. It generates DNA fragments of different lengths that may be compared. Markers were considered informative if they were found in one isolated species and not the other. Seven hundred primers were tested to find these six that were informative. Other primers were rejected if they showed weak informative bands or amplified inconsistently.

Another study done by González-Rodríguez et al. (2004) used RAPD analysis to analyze the possibility of hybridization between two species of red oak in Mexico. A total of 131 10-bp primers were tested. Of these primers, 79 gave reproducible results. From the 711 fragments amplified, nine had significant differences in frequencies between the two species. Seven primers produced these nine fragments. None of the markers were completely diagnostic. However, the results did support the hypothesis of secondary contact between the two species of red oak.

These studies suggest that morphological comparisons are not sufficient enough to determine the species status of trees in areas of hybridization. Genetic analyses are needed combined with morphological analyses, to help distinguish among oak species.

Several types of DNA markers are used to study molecular genetics in population studies. These include restriction fragment length polymorphisms (RFLPs), microsatellite loci, and RAPD markers. All methods have limitations. RFLP analysis requires large quantities of DNA. Microsatellite loci and RAPD fingerprinting require small quantities of DNA, making them better options for the study. Fourteen microsatellite markers have been identified for northern red oak (Aldrich *et al*. 2002). Microsatellite loci would have been a viable option for this study, however RAPD fingerprinting was used instead. Weaknesses of RAPD fingerprinting include: 1) production of too many bands of varying intensities, 2) irreproducible results due to non-specific primer annealing, and 3) sensitivity to reaction conditions (Hadrys et al. 1992). However, an advantage to the RAPD procedure is that it does not require prior knowledge of the genome.

Materials and Methods

Leaves were obtained from three northern red oak in Missouri, a region where northern pin oak is not found. The samples were collected Three northern pin oak samples were collected from a high, dry, sandy site in Stevens Point, Wisconsin. Samples were placed in individual plastic bags, labeled, and kept in a freezer. These samples were used as control groups to find a genetic marker to distinguish between the two species and their hybrids.

DNA Isolation

DNA was isolated from the leaves of the northern pin oak and northern red oak controls, as well as from all sample trees in the study, using a Qiagen Plant Tissue DNA Extraction Kit, according to the manufacturer's suggestions. Buffer AE was preheated in a 65°C water bath. A portion of the leaf was cut up using a razor blade. Then liquid nitrogen was used to grind the leaf up into a fine powder with a mortar and pestle. A total of 400 µl of buffer AP1 was added to 20 mg of the sample, followed by 4 µl of RNase A. The solution was vortexed and then incubated for 10 min at 65°C. To ensure agitation, the tube was inverted three times during incubation. Samples were microfuged briefly and 130 µl of buffer AP2 was added, followed by vortexing and incubating on ice for 5 min. The sample was then added to a QIAshredder spin column and centrifuged at 12,000 rpm for 2 min. A total of 190 µl of buffer AP3 and 380 µl of 70% ethanol were added and pipette mixed. A 650 µl portion of the mixture was added to a DNeasy spin column and centrifuged for 1 min at 8,000 rpm. Flow-through was discarded. The remaining sample was added to the column and centrifuged for 1 min at 8,000 rpm. A total of 500 µl of buffer AW was added. It was then centrifuged at 8,000 rpm for 1 min. The flow-through was discarded and a 500 µl amount of buffer AW was added to the DNeasy column and centrifuged for 2 min at 12,000 rpm. The spin column was transferred to a screw cap tube and 30 µl of preheated buffer AE was added to the columns membrane. It was incubated at room temperature for 5 min and then centrifuged at 8,000 rpm for 1 min. The DNA was then quantified and stored at 4°C.

RAPD Amplification

The polymerase chain reaction was used to amplify DNA. Amplification reactions of 25 µl included 10-20 ng DNA (1 µl), 0.5 µl $MgCl_2$, 2.5 µl buffer, 2.5 µl each of 1 mM dATP, dCTP, dGTP, and dTTP, 1 µl of a 10 µM10-bp primer; 0.5 µl taq polymerase; and 8µl distilled H_2O. The mixture was run through a thermocycler set for one cycle for 3 min at 92°C, 1 min at 36°C, and 2 min at 72°C. This was followed by 45 cycles of

1 min at 94°C, 1 min at 36°C, and 2 min at 72°C (Howard et al. 1997). A total of 20 μl of each sample was taken and 4 μl of ethinium bromide was added. The samples were electrophoresed in a 3% agarose gel at 45V.

Samples of three northern pin oak and three northern red oak controls were used to screen primers for informative bands. The first primers screened were the six found to be informative by Howard *et al.* (1997)(111-6FAM, 285-6FAM, 290-6FAM, 438-6FAM, 471-6FAM, and 540-6FAM). Once an informative primer was found, the DNA samples from the study trees were tested. Samples were compared with a negative and positive control of both northern red oak and northern pin oak. The bands were analyzed and a determination was made as to the species of each study tree.

For the most informative primers, GeneScan analysis was used to get more quantitative results. The lengths of the informative bands were found and compared to the bands found in the sample trees.

Results

Seventeen primers were tested. Of these, two produced distinctive DNA fragments for northern red oak and northern pin oak, when observed in the agarose gel. The primers were 111-6FAM and 471-6FAM with the sequences, 5’ to 3’ of AGTAGACGGG and CCGACCGGAA, respectively. Primer 111-6FAM provided two distinctive DNA fragments - one for northern red oak and one for northern pin oak (Figure 2.1).

Primer 471-6FAM produced one distinctive DNA fragment for northern pin oak (Figure 2.2). Sample trees were tested. Several showed extra fragments, but none were in the same location as the northern pin oak band (Figure 2.3).

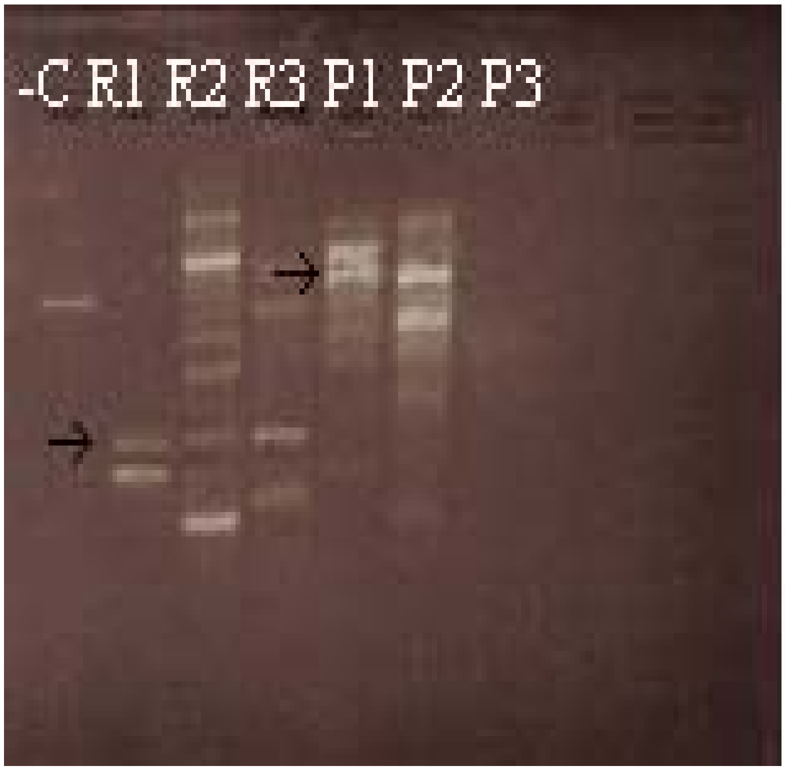


Figure 2.2 Primer 111 controls.

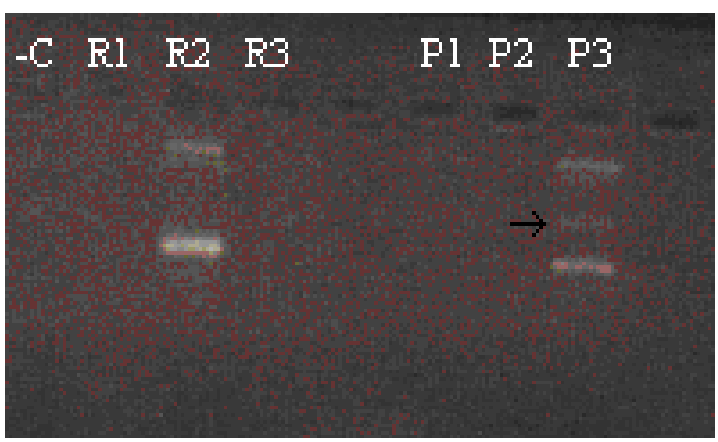


Figure 2.3 Primer 471 controls.

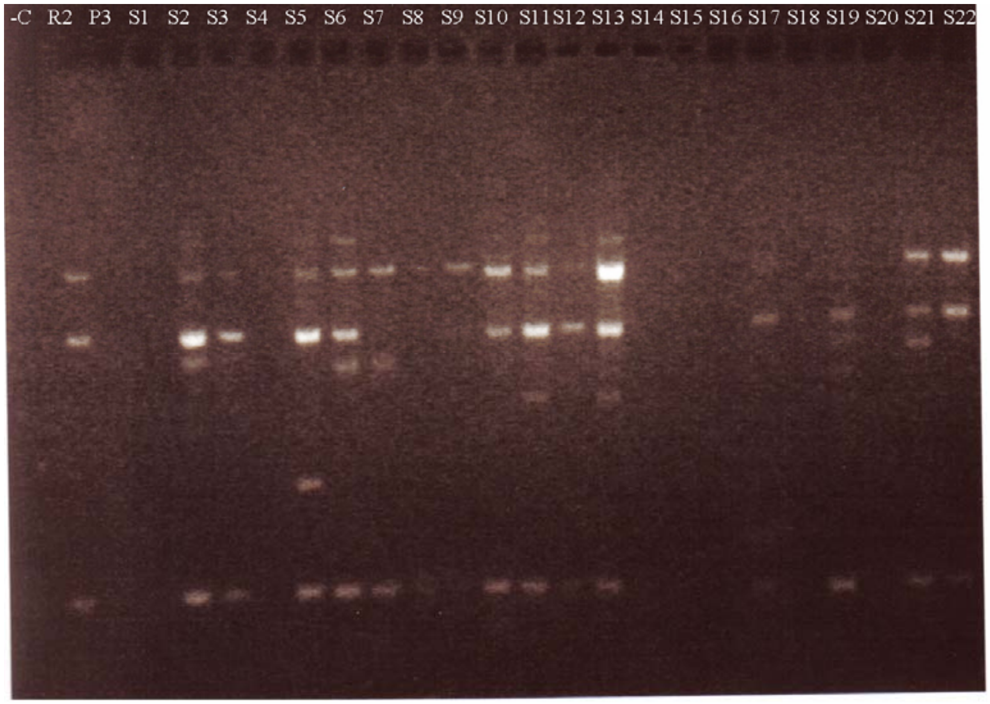


Figure 2.4 Primer 471 samples

Key:

-C = Negative Control

R = Northern red oak control

P = Northern pin oak control

S = Sample

Since both Primer 111-6FAM and Primer 471-6FAM showed distinctive DNA fragments in the agarose gel, they were tested using GeneScan analysis. Common fragments, found in at least three of six runs, for northern red oak for Primer 111-6FAM were lengths of 172, 193, 368, 403, and 466 bp (+/- 3 bp). Common DNA fragments, found in at least 3 of

5 runs, for northern pin oak were 376, 488, 605, 777, and 924 bp (+/- 3 bp). Table 2.1 indicates the number of samples out of 22 that contained various DNA fragments. Not all samples showed fragments.

NORTHERN RED OAK DNA FRAGMENT SIZES (BP)	PERCENTAGE OF PUTATIVE NORTHERN RED OAK SAMPLES CONTAINING DNA FRAGMENT
172	4.5
193	54.5
368	40.9
403	36.4
466	27.3
NORTHERN PIN OAK BAND LENGTHS (BP)	**PERCENTAGE OF PUTATIVE NORTHERN RED OAK SAMPLES CONTAINING DNA FRAGMENT**
376	27.3
488	40.9
605	31.8
777	36.4
924	22.7

Table 2.1 Percentage of sample trees containing identified common DNA fragment lengths for Primer 111-6FAM.

Primer 471-6FAM produced three bands that were common in all three northern red oak controls, with lengths 351, 375, and 405 bp. Table 2.2 gives the number of sample trees that showed the common DNA fragments. The northern pin oak fragment visible in the agarose gel was not detected in the GeneScan analysis.

NORTHERN RED OAK BAND LENGTHS	NUMBER OF SAMPLE TREES CONTAINING BAND
351	15
375	13
405	20

Table 2.2 Percentage of sample trees containing identified common DNA fragment lengths for Primer 471-FAM.

Other DNA fragments were found to be common among the sample trees for Primer 471-6FAM. These lengths were 80, 181, 225, and 878 bp. They were not detected in either the northern red oak or northern pin oak controls, which denotes intraspecific variation.

Discussion

When viewed in an agarose gel Primer 111-6FAM produced one unique DNA fragment common in the northern red oak controls and one unique fragment common in the northern pin oak controls. The northern red oak fragment may be used to verify that sample trees are northern red oak and absence of the northern pin oak fragment would help to verify that the sample trees are not northern pin oak hybrids. Further investigation using GeneScan analysis indicated that there were several DNA fragments common to either the northern red oak controls or the northern pin oak controls.

Analysis of the sample trees showed that many of them did not contain the distinctive northern red oak DNA fragments. Although they do not contain those fragments, it cannot be assumed that these trees are not northern red oak. It is possible that the fragments did not amplify enough to be visible. It is also possible that the DNA fragments observed in the northern red oak controls were specific to northern red oak in Missouri, and therefore would not show up in the Wisconsin sample trees, rendering them as possible distinct populations and not one gene pool. Northern red oak in Missouri hybridize with other species of red oak, so it is also possible that those markers are from the hybrid species, although the control trees were identified as northern red oak.

GeneScan analysis also showed that many of the sample trees contained one or more of the DNA fragments previously identified as unique to the northern pin oak controls. It could mean that the sample trees are either northern pin oak or hybrids of the two species. However, there are other possible explanations. The northern pin oak controls came from Wisconsin and the northern red oak controls came from Missouri. It may be that the DNA fragments identified as unique to northern pin oak may be found in red oak species in Wisconsin, but not Missouri. It is also possible that these fragments were found in the northern red oak controls, but did not amplify. More studies would need to be done to determine the reasons for these results. The studies should compare the DNA of northern red oak in Minnesota to those in Missouri.

Since the GeneScan results did not show any common northern pin oak DNA fragment, it was not possible to compare the sample trees to the northern pin oak controls. However, a large number of the sample trees did show the northern red oak fragments, confirming that they are, at least in part, northern red oak. The other common DNA fragments found in the sample trees could be bands specific to northern red oak found in Wisconsin, but not in Missouri.

Suggestions for Future Studies

There were several weaknesses in this study that should be addressed. First, there were only three northern red oak control samples and three northern pin oak control samples. Additional studies using a greater number of controls are recommended. The other studies cited contained sample sizes of near, or over, 100 trees. In addition, the controls for each species came from only one location. The northern red oak controls were collected from Missouri and the northern pin oak controls from central Wisconsin. This could mean that the similarities that were seen between the different control samples were unique intraspecific markers to those locations. Such markers may not be found in the trees located in the study sites. In addition, northern red oak does hybridize with other species in Missouri. Although the samples were phenotypically identified as northern red oak it is possible that the markers identified as unique to northern red oak were actually markers from some other species if the controls were hybrids.

The range of northern pin oak is enclosed in the range of northern red oak. This means that it was not possible to get control samples of northern pin oak for which we could be certain that the controls were not hybrids. Although steps were taken to be as confident as possible, there still is a possibility that one or more of the northern pin oak controls was a hybrid. Using controls from areas where previous studies have been done successfully on the hybridization of northern red oak and northern pin oak may help to increase the confidence that the northern pin oak controls are not hybrids.

Although the primers were informative in finding common bands in the sample trees and among each of the control groups, the results were not strong enough to confirm that the bands were unique to each particular species. Studies need to be done on samples from a wider area and in larger numbers to confirm that the common bands are not just part of the local genotype.

In addition, only a small number of primers were tested. Preliminary results using agarose gel indicated that informative primers may have been found, but further GeneScan Analysis proved this not to be true. It is possible that the primers were informative, but that the Gene Scan Analysis was unable to reproduce the results of the agarose gel due to non-specific primer annealing, or sensitivity to reaction conditions. Past oak studies have tested hundreds of primers in search of an informative primer that would distinguish between the oak species. It is possible that if more primers would have been tested, more informative primers would have been found. It is also possible that past hybridization of the two species has made genetic distinction of the two species by these methods improbable.

This study was a step in finding ways to distinguish between northern red oak and its hybrids, but many more studies are needed.

LITERATURE CITED

Addicott, F. T., and J. L. Lyon. 1973. Physiological ecology of abscission. P. 85-124 in Shedding of Plant Parts, T. T. Kozlowski, ed. Academic Press, New York.

Aldrich, Preston R., Charles H. Michler, Weilin Sun, and Jeanne Romero-Severson. 2002. Microsatellite markers for northern red oak (Fagaceae: *Quercus Rubra*). Molecular Ecology Notes. 2: 472-474.

Craft, Kathleen J., Mary V. Ashley, and Walter D. Koenig. 2002. Limited hybridization between *Quercus lobata* and *Quercus Douglasii* in a mixed stand in central coastal California. Am. J. of Botany. 89(11): 1792-8.

Dale, Martin E. and David L. Sonderman. 1984. Effect of thinning on growth and potential quality of young white oak crop trees. Broomall, PA, U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. Res. Pap. NE-539. 12p.

Dwyer, John P. and Kim E. Lowell. 1988. Long-term effects of thinning and pruning on the quality, quantity, and value of oak lumber. North. J. Appl. For. 5: 258-260.

Godman, Richard M. and David J. Brooks. 1971. Influence of stand density on stem quality in pole-size northern hardwoods. St. Paul, MN, U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. Res. Pap. NC-54. 7p.

González-Rodríguez, Antonio, Dulce M. Arias, Susana Valencia, and Ken Oyama. 2004. Morphological and RAPD analysis of hybridization between *Quercus affinis* and *Q. laurina* (Fagaceae), two Mexican red oaks. Am. J. of Botany. 91(3): 401-409.

Hadrys, H., M. Balick, and B. Schierwater. 1992. Applications of random amplified Polymorphic DNA (RAPD) in molecular ecology. Molecular Ecology. 1: 55-63.

Helms, John A., ed. 1998. Dictionary of Forestry. Bethesda MD: Society of American Foresters. 210p.

Hokanson, Stan C., J. G. Isebrands, Richard J. Jenson, and James F. Hancock. 1993. Isozyme variation in oaks of the Apostle Islands in Wisconsin: Genetic structure and levels of inbreeding in *Quercus rubra* and *Q. ellipsoidalis*. Am. J. of Botany. 80(11): 1349-1357.

Howard, Daniel J., Ralph W. Preszler, Joseph Williams, Sandra Fenchel, and William J. Boecklen. 1997. How discrete are Oak Species? Insights from a hybrid zone between *Quercus grisea* and *Quercus gambelii*. Evolution. 51(3): 747-755.

Jensen, Richard J., Stan C. Hokanson, J. G. Isebrands, and James F. Hancock. 1993. Morphometric variation in oaks of the Apostle Islands in Wisconsin: Evidence of hybridization between *Quercus rubra* and *Q. ellipsoidalis*. Am. J. of Botany. 80(11): 1358-1366.

Johnson, Paul S. 1994. Biology and Silviculture of Northern Red Oak in the North Central Region: a Synopsis. St. Paul, MN, U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. General Technical Report NC-173. 68p.

Mahall, B. E., and C. S. Wilson. 1986. Environmental induction and physiological consequences of natural pruning in the chaparral shrub *Ceanothus megacarpus*. Botanical Gazette. 147(1): 102-109.

Mäkinen, H., R. Ojansuu, and P. Niemistö. 2003. Predicting external branch characteristics of planted silver birch (*Betula pendula* Roth.) on the basis of routine stand and tree measurements. For. Sci. 49(2): 301-317.

Microsoft Excel 2002; Microsoft Corporation, 1985-2001.

Millington, W. F. and W. R. Chaney. 1973. Shedding of shoots and branches. P. 149-204 in Shedding of Plant Parts, T. T. Kozlowski, ed. Academic Press, New York.

Nutto, Leif. 1998. Neue perspektiven für die begründung und pflege von jungen eichenbeständen. Forstwissenschaftliche Fakultät der Albert-Ludwigs-Universität. Freiburg. 190p.

Nutto, L., P. Spathelf, and R. Rogers. 2005. Managing diameter growth and natural pruning of Parana pine, *Araucaria angustifolia* (Bert.) O Ktze., to produce high value timber. Ann. For. Sci. 62: 1-11.

Smith, D.M. 1962. The practice of silviculture, 7th Ed. John Wiley and Sons, Inc., New York. 578p.

Sonderman, David L. 1984. Quality response of 29-year-old, even-aged central hardwoods after thinning. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. Res. Pap. NE-546. 9p.

Sonderman, David L. 1985. Stand density-a factor affecting stem quality of young hardwoods. Broomall, PA; U.S Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. Res. Pap. NE-561. 8p.

Sonderman, David L. 1986. Changes in stem quality on young thinned hardwoods. Broomall, PA; U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. Res. Pap. NE-576. 9p.

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

Tomlinson, Patricia T., Richard J. Jenson, and James F. Hancock. 2000. Do whole tree characters indicate hybridization in red oak (*Quercus* Section *Lobatae*). Am. Midl. Nat. 143: 154-168.

Toumey, J. W., and C. F. Korstian. 1937. Foundations of silviculture upon an ecological basis. John Wiley and Sons, Inc., New York. 456p.

USDA Forest Service. 2005. Forest Inventory and Analysis National Program. http://www.fia.fs.fed.us/tools-data/data/. 30 Nov 2005.

Wisconsin Department of Natural Resources. "Wisconsin Forests at the Millennium". 2000. http://www.dnr.state.wi.us/org/land/forestry/Look/assessment/WIforestsAtMillennium.htm. 20 March 2003.

Wisconsin Department of Natural Resources. 2005. Sawtimber Values. http://www.dnr.state.wi.us/org/land/forestry/Private/Harvest/Curr_stumprt.htm. 30 Nov 2005.

APPENDIX I

RANDOM POINT AND SAMPLE TREE COORDINATES

Stand #	Point #	Coordinate System	Random Point Location		Sample Tree Location	
			Northing	Easting	Northing	Easting
1	1	WTM	541647	614359	541660	614350
	2	WTM	541325	614460	541311	614469
	3	WTM	540439	615080	540432	615089
	4	WTM	541115	616037	541105	616021
	5	WTM	541162	616225	541159	616233
2	1	WTM	557876	593741	557889	593713
	2	WTM	557975	593645	557967	593637
	3	WTM	558145	593600	558156	593587
	4	WTM	558020	593553	558031	593556
	5	WTM	557975	593519	557981	593520
3	1	WTM	558126	593153	558111	593157
	2	WTM	558286	593158	558312	593174
	3	WTM	558267	593089	558248	593102
	4	WTM	558318	593005	558321	592989
	5	WTM	558310	592950	558303	592949
4	1	WTM	552658	579326	552578	579365
	2	WTM	552472	579353	552473	579328
	3	WTM	552519	579318	552472	579312
	4	WTM	552367	579311	552370	579319
	5	WTM	552419	579299	552417	579339
5	1	UTM	0342784	5083429	0342790	5083434
	2	UTM	0342835	5083479	0342837	5083480
	3	UTM	0342754	5083483	0342756	5083475
	4	UTM	0342803	5083528	0342796	5083533
	5	UTM	0342784	5083591	0342778	5083587
6	1	UTM	0307238	5031878	0307238	5031978
	2	UTM	0307419	5032030	0307410	5032031
	3	UTM	0307419	5031961	0307403	5031961
	4	UTM	0307365	5031913	0307349	5031931
	5	UTM	0307339	5032101	0307339	5032101
7	1	UTM	0322821	4945688	0322810	4945706
	2	UTM	0322794	4945723	0322761	4945754
	3	UTM	0322766	4945743	0322757	4945698
	4	UTM	0322690	4945741	0322731	4945688
	5	UTM	0322704	4945769	0322704	4945769
8	1	UTM	0323631	4945878	0323621	4945875
	2	UTM	0323639	4945869	0323657	4945859
	3	UTM	0323663	4945850	0323624	4945895
	4	UTM	0323650	4945861	0323637	4945836
	5	UTM	0323650	4945858	0323606	4945857
9	1	UTM	0294549	5052684	0294544	5052868
	2	UTM	0294545	5052722	0294545	5052722
	3	UTM	0294567	5052789	0294532	5052717
	4	UTM	0294547	5052696	0294542	5052690
	5	UTM	0294551	5052693	0294556	5052677
10	1	UTM	0730444	5019808	0730411	5019808
	2	UTM	0730444	5019809	0730432	5019802
	3	UTM	0730447	5019803	0730453	5019804
	4	UTM	0730479	5019858	0730478	5019864
	5	UTM	0730432	5019913	0730429	5019912

APPENDIX II

USDA-NRCS OFFICIAL SOIL-SERIES DESCRIPTIONS[3]

---

[3] Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Official Soil Series Descriptions [Online WWW]. Available URL: "http://soils.usda.gov/soils/technical/classification/osd/index.html" [Accessed 7 Dec 2004].

KEWEENAW SERIES

The Keweenaw series consists of very deep, well drained soils formed in sandy deposits typically on ground moraines and end moraines, but in some places are on drumlins and islands of till surrounded by outwash. These soils have moderate or moderately rapid permeability. Slopes range from 0 to 70 percent. Mean annual precipitation is about 29 inches, and mean annual temperature is about 43 degrees F.

TAXONOMIC CLASS: Sandy, mixed, frigid Alfic Haplorthods

TYPICAL PEDON: Keweenaw loamy sand - on a 5 percent west-facing slope under a hardwood forest. (Colors are for moist soil unless otherwise stated.)

Oa--0 to 1 inch; black (5YR 2.5/1) well decomposed forest material; extremely acid.

E--1 to 11 inches; reddish gray (5YR 5/2) loamy sand; weak fine and medium subangular blocky structure; very friable; many very fine to coarse roots; 3 percent gravel; extremely acid; clear irregular boundary. (0 to 10 inches thick)

Bhs--11 to 17 inches; dark reddish brown (5YR 3/3) loamy sand; moderate medium subangular blocky structure; firm; 75 percent weakly cemented ortstein; many very fine to coarse roots; 3 percent gravel; extremely acid; gradual irregular boundary. (0 to 10 inches thick)

Bs1--17 to 27 inches; dark brown (7.5YR 3/4) loamy sand; medium thin platy structure; friable and firm; 35 percent weakly cemented ortstein; ortstein occurs at tongues that extend to a depth of 60 inches; common very fine to medium roots; 8 percent gravel; extremely acid; clear irregular boundary.

Bs2--27 to 39 inches; brown (7.5YR 4/4) loamy sand; weak thin platy structure; very friable; few very fine and fine roots; 2 percent gravel; very strongly acid; clear smooth boundary. (Combined thickness of Bs horizons is 4 to 27 inches)

B/E--39 to 61 inches; reddish brown (5YR 4/4) fine sandy loam (Bt); common very fine and fine vesicular pores in peds; occupies about 70 percent of the horizon surrounded by weak brown (7.5YR 5/4) loamy sand (E); weak thin platy structure; friable; 2 percent gravel; very strongly acid; clear smooth boundary. (0 to 24 inches thick)

E and **Bt**--61 to 80 inches; reddish brown (5YR 4/3) loamy sand (E) and lamellae of brown(7.5YR 4/4) fine sandy loam and sandy loam (Bt); single grained; loose; lamellae are 1/8 to 2 inches in thickness with a total accumulation of 8 inches; 2 percent gravel; very strongly acid.

TYPE LOCATION: Keweenaw County, Michigan. 1 mile north of Thayer Lake; 2064 feet west and 1484 feet south of the northeast corner of sec. 29, T. 57 N., R. 31 W. Sherman Township. USGS Mohawk, MI topographic quadrangle; lat. 47 degrees 18 minutes 39.27 seconds N. and long. 88 degrees 15 minutes 59.57 seconds W., NAD83

RANGE IN CHARACTERISTICS: Solum thickness ranges from 30 to greater than 80 inches, and depth to the B/E horizon ranges from 14 to 39 inches. Some pedons contain fragments of sandstone in the solum, or contain fragments of crystalline rocks throughout. Cobble content ranges from 0 to 35 percent by volume in the surface layers, and from 0 to 15 percent by volume in the subsoil and substratum. Gravel content ranges from 0 to 25 throughout the soil. Typically stones cover from less than .01 percent of the surface to 0.1 percent of the surface.

Some pedons have an A horizon. The A horizon has hue of 5YR, 7.5YR, or 10YR; value of 2 or 3; and chroma of 1 or 2 or is neutral. It is loamy sand, loamy fine sand, or sandy loam, or gravelly or cobbly analogues of these textures. Reaction ranges from extremely acid to slightly acid.

The E horizon has hue of 5YR, 7.5YR, or 10YR; value of 4 to 6; and chroma of 2 or 3. It is loamy sand, loamy fine sand, or sandy loam, or gravelly or cobbly analogues of these textures. Reaction ranges from extremely acid to slightly acid.

The Bhs horizon has hue of 5YR or 7.5YR, value of 3, and chroma of 2 to 4. It is loamy sand, loamy fine sand, or gravelly or cobbly analogues of these textures. Reaction ranges from extremely acid to moderately acid.

The Bs1 horizon has hue of 2.5YR, 5YR, or 7.5YR; value of 3 to 5; and chroma of 3 to 6. It is loamy sand, loamy fine sand, or gravelly or cobbly analogues of these textures. Weakly cemented ortstein is in the Bhs and Bs1 horizons of some pedons. Reaction ranges from extremely acid to moderately acid.

The Bs2 horizon has hue of 5YR or 7.5YR, value of 4 or 5, and chroma of 4 to 6. It is sand, loamy sand, loamy fine sand, or gravelly or cobbly analogues of these textures. Reaction ranges from very strongly acid to slightly acid. In some pedons individual subhorizons of the Bhs or Bs horizons may be sandy loam, however, the 10 to 40 inch particle size control section averages to sandy.

The E part of the B/E horizon is in the form of coatings on the faces of peds of Bt part, but in the E and Bt horizon the two kinds of material are in alternate bands. In the E and Bt horizon, the Bt bands range from 1/8 to 2 inches thick and have a cumulative thickness of greater than 6 inches within a depth of 80 inches. Some pedons have E, Bt, or E/B horizons.

The E part of these horizons has hue of 2.5YR, 5YR, or 7.5YR; value of 5 or 6; and chroma of 2 to 6. It is sand, loamy sand, loamy fine sand, or gravelly or cobbly analogues of these textures. The Bt part has hue of 2.5YR, 5YR, or 7.5YR; value of 3 to 5; and chroma of 3 to 6. It is loamy sand, loamy fine sand, fine sandy loam, sandy loam, or gravelly or cobbly analogues of these textures. The clay content of the argillic horizon ranges from 8 to 15 percent. The B/E horizon exhibits some characteristics of a fragipan; it is firm when moist and hard when dry and has some brittleness. Reaction of the E/B, E and Bt, E, Bt, or B/E horizon ranges from very strongly acid to slightly acid.

Some pedons have a C horizon. The C horizon has hue of 2.5YR, 5YR, or 7.5YR; value of 4 to 6; and chroma of 3 to 6. The C horizon ranges from uniform loamy sand to water worked, interbedded sand and loamy sand that contains some bands or pockets of sandy loam. Gravelly or cobbly analogues of these textures are allowed. It ranges from strongly acid to slightly acid.

COMPETING SERIES: These are the Leelanau, Mancelona, and Melita and Southwells series. Leelanau and Mancelona soils contain free carbonates within depths of 60 inches and do not have hues of 2.5YR or 5YR in the substratum. Melita soils formed in 40 to 60 inches of sand and contain 18 to 35 percent clay in the argillic horizon. Southwells soils have hues yellower than 7.5YR in the lower part of the series control section.

GEOGRAPHIC SETTING: Keweenaw soils formed in sandy deposits typically on ground moraines and end moraines, but in some places are on drumlins and islands of till surrounded by outwash. Slopes range from 0 to 70 percent. Mean annual precipitation ranges from 26 to 33 inches, and the mean annual temperature from about 41 to 44 degrees F.

GEOGRAPHICALLY ASSOCIATED SOILS: These are the well drained Steuben and the moderately well drained Munising, and Yalmer soils with fragipans and the somewhat excessively drained Kalkaska soils, which do not have argillic horizons.

DRAINAGE AND PERMEABILITY: Well drained. Runoff is negligible to high, dependent on slope. Permeability is moderate or moderately rapid.

USE AND VEGETATION: Most of this soil is forested with the primary species being sugar maple, eastern hemlock, northern red oak, paper birch, red maple, quaking aspen, yellow birch, and balsam fir. Cleared areas are used for growing hay, potatoes, and small grains.

DISTRIBUTION AND EXTENT: Upper Peninsula of Michigan and northern Wisconsin. The series is of large extent.

MLRA OFFICE RESPONSIBLE: St. Paul, Minnesota.

SERIES ESTABLISHED: Alger County, Michigan, 1969.

REMARKS: Diagnostic horizons and features recognized in this pedon are:
albic horizon - 1 to 11 inches (E horizon);
spodic horizon - 11 to 39 inches (Bhs, Bs1, and Bs2 horizons)
argillic horizon - 39 to 61 inches (B/E horizon)
glossic horizon - 39 to 61 inches (B/E horizon).

The moderately well drained phase of this soil is no longer within the series concept.

Series type location moved because the original type location was altered due to building site development.

OESTERLE SERIES

The Oesterle series consists of very deep, somewhat poorly drained soils which are moderately deep to underlying sandy outwash. They formed dominantly in loamy alluvium underlain by sandy outwash on outwash plains, valley trains, stream terraces, glacial lake plains, and outwash areas on moraines. Permeability is moderate or moderately rapid in the loamy alluvium and rapid or very rapid in the sandy outwash. Slopes range from 0 to 3 percent. Mean annual precipitation is about 30 inches. Mean annual temperature is about 42 degrees F.

TAXONOMIC CLASS: Coarse-loamy, mixed, superactive, frigid Aquic Glossudalfs

TYPICAL PEDON: Oesterle sandy loam - on a 1 percent slope in a cultivated field at an elevation of about 1,045 feet. (Colors are for moist soil unless otherwise stated.)

Ap--0 to 7 inches; very dark brown (10YR 2/2) sandy loam, dark grayish brown (10YR 4/2) dry; weak very fine subangular blocky structure; friable; few fine roots; about 5 percent gravel; very strongly acid; abrupt smooth boundary. (5 to 10 inches thick)

E/B--7 to 11 inches; about 70 percent brown (10YR 5/3) sandy loam (E), very pale brown (10YR 7/3) dry; weak thick platy structure; friable; extends as tongues into yellowish brown (10YR 5/4) sandy loam (Bt); moderate very fine subangular blocky; friable; common faint dark yellowish brown (10YR 4/4) clay films on faces of peds; few fine prominent and distinct yellowish brown (10YR 5/8) masses of iron accumulation; about 5 percent gravel; very strongly acid; clear wavy boundary. (Glossic horizon - 2 to 30 inches thick.)

Bt1--11 to 16 inches; yellowish brown (10YR 5/4) sandy loam; weak medium subangular blocky structure; friable; common faint dark yellowish brown (10YR 4/4) clay films on faces of peds; many fine distinct light brownish gray (10YR 6/2) iron depletions and many fine prominent yellowish red (5YR 5/8) masses of iron accumulation; about 7 percent gravel; very strongly acid; clear wavy boundary.

Bt2--16 to 27 inches; yellowish brown (10YR 5/4) sandy loam; moderate medium subangular blocky structure; friable; common faint dark yellowish brown (10YR 4/4) clay films on faces of peds; many medium prominent yellowish red (5YR 5/8) masses of iron accumulation and many medium distinct light brownish gray (10YR 6/2) iron depletions; about 10 percent gravel; very strongly acid; gradual wavy boundary.

Bt3--27 to 31 inches; mixed light brownish gray (10YR 6/2) and yellowish red (5YR 5/8) sandy loam; weak medium subangular blocky structure; very friable; few distinct and prominent dark yellowish brown (10YR 4/4) clay films on faces of peds; the light brownish gray areas are iron depletions and the yellowish red areas are masses of iron accumulation; about 10 percent gravel; strongly acid; clear wavy boundary. (Combined thickness of the Bt horizons ranges from 4 to 25 inches)

2C--31 to 60 inches; yellowish brown (10YR 5/4) stratified sand and gravelly sand; single grain; loose; about 20 percent gravel; moderately acid.

TYPE LOCATION: Portage County, Wisconsin; about 1 1/2 miles west and 1 1/2 miles south of Rosholt; 500 feet east and 1,000 feet south of the northwest corner, sec. 31, T. 25 N., R. 10 E.

RANGE IN CHARACTERISTICS: Thickness of the loamy mantle and depth to sandy outwash range from 20 to 40 inches. The particle-size control section averages 7 to 17 percent clay and 50 percent or more, fine sand or coarser. Volume of rock fragments averages less than 35 percent in the particle size control section. Volume of gravel ranges from 0 to 35 percent in the loamy mantle but is typically less than 15 percent. The volume of gravel in the sandy outwash ranges from 3 to 50 percent as a weighted average, and from 0 to 60 percent in individual strata. Volume of cobbles ranges from 0 to 5 percent throughout. Reaction typically ranges from very strongly acid to slightly acid in the solum, but ranges to neutral in the upper part, where the soil is limed. Reaction ranges from strongly acid to slightly acid in the substratum. Redox features are throughout the solum below the Ap horizon. Redox depletions with chroma of 2 or less are in the upper 10 inches of the argillic horizon. Aquic conditions occur in the upper 10 inches of the argillic horizon for some time in most years.

The Ap horizon has value and chroma of 2 or 3. Uncultivated pedons have an A horizon 2 to 5 inches thick with hue of 10YR, value of 2 or 3 and chroma of 1 or 2. The Ap or A horizon is loam, sandy loam, fine sandy loam, or very fine sandy loam.

Some pedons have an E horizon with hue of 7.5YR or 10YR, value of 4 to 6, and chroma of 2 or 3. It typically is sandy loam, fine sandy loam, loam, or the gravelly analogs. Less typically, it is loamy sand, loamy coarse sand or the gravelly analogs.

Oesterle soils have a glossic horizon (E/B or B/E horizons, or both). The E part has color and texture like the E horizon described above. The Bt part has hue of 5YR, 7.5YR, or 10YR; value of 4 to 6; and chroma of 3 to 8. It is loam, fine sandy loam, sandy loam, or the gravelly analogs.

The Bt horizon has color and texture like the Bt part described above. Below the upper 10 inches of the argillic horizon, some pedons have a Btg horizon with dominant chroma of 2 or less.

Some pedons have a 2Bt or 2BC horizon with hue of 5YR, 7.5YR, or 10YR; value of 4 to 6; and chroma of 1 to 8. It is sand, coarse sand, loamy sand, loamy coarse sand, or the gravelly or very gravelly analogs.

The 2C horizon has color like the 2BC horizon described above. It is typically stratified sand, coarse sand, or the gravelly or very gravelly analogs. Some pedons have strata of loamy sand or loamy coarse sand or the gravelly or very gravelly analogs.

COMPETING SERIES: These are the Fallcreek, Hatley, Magnor, Magroc, and Plover series. Similar soils are the Halder, Ossmer, Poskin, and Scott Lake series. Fallcreek, Magnor, and Hatley soils do not have stratified sandy outwash within a depth of 40 inches. Magroc soils have a lithic contact with igneous or metamorphic bedrock at a depth of 40 to 60 inches. Plover soils have stratified loamy and sandy lacustrine deposits within a depth of 40 inches.. Halder soils are fine-loamy over sandy or sandy skeletal. Ossmer soils have a 12 to 40 inch thick silty mantle and are coarse-loamy over sandy or sandy-skeletal. Poskin soils are fine-silty over sandy or sandy-skeletal. Scott Lake soils do not have redox depletions in the upper 10 inches of the argillic horizon.

GEOGRAPHIC SETTING: Oesterle soils are on outwash plains, valley trains, stream terraces, glacial lake plains, and in outwash areas on moraines. Slopes range from 0 to 3 percent. These soils formed in loamy alluvium overlying sandy outwash. Mean annual precipitation ranges from 26 to 33 inches. Mean annual temperature ranges from 39 to 45 degrees F. The frost free period ranges from about 90 to 135 days. Elevation ranges from 700 to 1950 feet.

GEOGRAPHICALLY ASSOCIATED SOILS: These are the Minocqua, Rosholt and Scott Lake soils. The well drained Rosholt soils, the moderately well drained Scott Lake soils, and the poorly drained Minocqua soils form a drainage sequence with the Oesterle soils.

DRAINAGE AND PERMEABILITY: Somewhat poorly drained. Surface runoff is slow. Permeability is moderate or moderately rapid in the loamy alluvium and rapid or very rapid in the sandy outwash. Flooding is none to rare. These soils have an apparent seasonal high water table at a depth of 1 to 2.5 feet for 1 month or more per year at some time during the period October to June in 6 or more out of 10 years.

USE AND VEGETATION: Many areas are used for cropland or pastureland. Corn, small grain, and hay are the principal crops. Many areas are used for woodland. Native vegetation is mixed deciduous and coniferous forest. Eastern white pine, red maple, bigtooth aspen, paper birch, northern red oak, American hornbeam, white spruce, eastern hemlock, sugar maple, yellow birch, American elm, white ash, balsam fir, and quaking aspen are the major tree species.

DISTRIBUTION AND EXTENT: Central and northern Wisconsin. These soils are of moderate extent.

MLRA OFFICE RESPONSIBLE: St. Paul, Minnesota

SERIES ESTABLISHED: Portage County, Wisconsin, 1972.

REMARKS: Diagnostic horizons and features recognized in this pedon are: ochric epipedon - 0 to 11 inches (Ap, E part of E/B); glossic horizon - 7 to 11 inches (E/B); argillic horizon - 11 to 31 inches (Bt1, Bt2, Bt3); aquic feature - redox depletions with chroma of 2 or less and aquic conditions in the upper 10 inches of the argillic horizon.

ADDITIONAL DATA: Soil Interpretation Record - WI0276. For NSSL data on an Oesterle pedon, refer to soil survey sample number S82WI-017-003.

PADWOOD SERIES

The Padwood series consists of very deep moderately well drained soils in outwash-veneered areas of outwash terraces and glacial lake plains. They formed dominantly in moderately deep, loamy alluvium underlain by sandy outwash which is underlain in turn by stratified lacustrine deposits. Permeability is moderate in the loamy alluvium, moderately rapid to very rapid in the sandy outwash, and moderately slow in the stratified loamy and sandy substratum. Slope ranges from 0 to 15 percent. Mean annual precipitation is about 30 inches. Mean annual temperature is about 42 degrees F.

TAXONOMIC CLASS: Coarse-loamy, mixed, superactive, frigid Alfic Oxyaquic Haplorthods

TYPICAL PEDON: Padwood sandy loam - on a convex, southwest facing slope of 2 percent in a mixed hardwood forest on a glacial lake basin at an elevation of about 1,540 feet. (Colors are for moist soil unless otherwise stated.)

A--0 to 4 inches; very dark gray (10YR 3/1) sandy loam, gray (10YR 5/1) dry; moderate fine granular structure; friable; many fine roots; about 3 percent gravel and 2 percent cobbles; strongly acid; abrupt wavy boundary. (0 to 5 inches thick)

E--4 to 5 inches; brown (7.5YR 5/2) sandy loam, pinkish gray (7.5YR 7.2) dry; weak thin platy structure; very friable; many fine roots; many distinct very dark gray (10YR 3/1) worm casts; about 2 percent gravel and 2 percent cobbles; strongly acid; abrupt broken boundary. (0 to 6 inches thick)

Bs1--5 to 7 inches; dark reddish brown (5YR 3/4) sandy loam; weak very fine subangular blocky structure; very friable; many fine roots; few prominent very dark gray (10YR 3/1) worm casts; about 8 percent gravel and 2 percent cobbles; strongly acid; abrupt broken boundary.

Bs2--7 to 15 inches; dark brown (7.5YR 4/4) sandy loam; weak fine subangular blocky structure; very friable; many fine roots; about 7 percent gravel and 2 percent cobbles; strongly acid; clear wavy boundary. (Combined thickness of the Bs horizon ranges from 6 to 20 inches)

E/B--15 to 27 inches; 70 percent brown (7.5YR 5/3) gravelly sandy loam (E), pink (7.5YR 7/3) dry; weak medium platy structure; friable; surrounds remnants of dark brown (7.5YR 4/4) gravelly sandy loam (Bt); moderate fine subangular blocky structure; friable; common distinct dark reddish brown (5YR 3/4) clay films on faces of peds; common fine roots; about 14 percent gravel and 2 percent cobbles; strongly acid; abrupt wavy boundary. (Glossic horizon - 6 to 20 inches thick)

2Bt--27 to 36 inches; strong brown (7.5YR 4/6) gravelly loamy sand; weak fine subangular blocky structure; very friable; few fine roots; many prominent dark reddish brown (5YR 3/4) clay bridges between mineral grains; about 21 percent gravel and 3 percent cobbles; strongly acid; abrupt wavy boundary. (0 to 11 inches thick)

2C--36 to 50 inches; light yellowish brown (10YR 6/4) fine sand; single grain; loose; few medium prominent strong brown (7.5YR 5/6) masses of iron accumulation; less than 1 percent gravel; moderately acid; abrupt wavy boundary. (6 to 30 inches thick)

3C--50 to 70 inches; stratified layers of brown (10YR 5/3) very fine sandy loam and yellowish brown (10YR 5/4) very fine sand with a few thin strata of strong brown (7.5YR 5/6) fine sand and brown (10YR 4/3) silt loam; massive; friable; breaks to weak thick to thin plates along depositional strata; common fine prominent yellowish red (5YR 4/6) and common medium prominent yellowish brown (10YR 5/6) masses of iron accumulation; moderately acid.

TYPE LOCATION: Lincoln County, Wisconsin; about 7 miles east of Tomahawk; 1,290 feet west and 2,440 feet south of the northeast corner of sec. 24, T. 35 N., R. 7 E.; USGS Woodboro, WI quad.; lat. 45 degrees, 30', 10" N., long. 89 degrees, 33', 13" W.

RANGE IN CHARACTERISTICS: Depth to the base of the argillic horizon, thickness of the loamy mantle, and depth to sandy outwash all range from 24 to 40 inches. Depth to the stratified lacustrine deposits ranges from 40 to 60 inches. Volume of rock fragments averages less than 35 percent in the particle-size control section. Volume of gravel ranges from 0 to 35 percent in the loamy mantle but typically is less than 15 percent in the upper part. The volume of gravel in the sandy outwash ranges from 3 to 50 percent as a weighted average, and from 0 to 60 percent in individual strata. Volume of cobbles ranges from 0 to 5 percent in the loamy mantle and in the sandy outwash. Rock fragments typically are absent in the lacustrine material. Reaction typically ranges from very strongly acid to moderately acid in the upper part of the solum but ranges to neutral in the Ap horizon, where the soil is limed. Reaction ranges from strongly acid to slightly acid below the spodic horizon. Redox accumulations are below the spodic horizon but within 40 inches. Saturation occurs within 40 inches at some time in most years.

The A horizon has hue of 5YR, 7.5YR, or 10YR; value of 2 or 3; and chroma of 1 or 2. Cultivated pedons have an Ap horizon with hue of 5YR, 7.5YR, or 10YR; value of 3 or 4; and chroma of 2 or 3.

The E horizon has hue of 5YR, 7.5YR, or 10YR; value of 4 to 6; and chroma of 2 or 3. Colors of 4/3 and 5/3 have value dry of 7 or more. It is sandy loam, fine sandy loam, loam, or the gravelly analogs. It is present in at least 50 percent of each pedon.

Some pedons have a Bhs horizon less than 3 inches thick with hue of 2.5YR, 5YR, or 7.5YR and value and chroma of 2 or 3. It is sandy loam, fine sandy loam, loam, or the gravelly analogs.

The Bs horizon has hue of 5YR, value of 3 to 6, and chroma of 4 to 6 or hue of 7.5YR, value of 3 to 5, and chroma of 4. It has textures like the Bhs horizon above.

Some pedons have an E' horizon with color and texture like the E horizon described above except in some pedons it is loamy sand or gravelly loamy sand.

Padwood soils have a glossic horizon (E/B or B/E horizons, or both). The E' part has color and texture like the E' horizon described above. The Bt part has hue of 5YR, 7.5YR, or 10YR; value of 4 or 5; and chroma of 4 to 6. It is sandy loam, fine sandy loam, loam, or the gravelly analogs.

Some pedons have a Bt horizon with color and texture like the Bt part described above. The argillic material averages 8 to 17 percent clay.

The 2Bt horizon has hue of 5YR, 7.5YR, or 10YR and value and chroma of 4 to 6. It is loamy sand, loamy fine sand, sand, fine sand, or the gravelly or very gravelly analogs.

Some pedons have a 2BC horizon with color and texture like the 2Bt horizon described above.

The 2C horizon has hue of 5YR, 7.5YR, or 10YR; value of 4 to 6; and chroma of 3 to 6. It has more than 85 percent sand and is fine sand, sand, coarse sand, or the gravelly or very gravelly analogs. Stratification is common in many pedons.

The 3C horizon has hue of 5YR 7.5YR, 10YR, 2.5Y, or 5Y; value of 4 to 6; and chroma of 1 to 6. It is stratified dominantly with silt, silt loam, very fine sandy loam, loamy very fine sand, or very fine sand, but thin strata of silty clay loam, loam, sandy loam, fine sandy loam, loamy fine sand, and fine or medium sand are in most pedons.

COMPETING SERIES: These are the Annalake, Goodwit, Newood, Peavy, Sarwet, Shoepac, and Tipler series. A related soil is the Padwet series. Annalake, Goodwit, Newood, and Sarwet soils do not have more than 85 percent sand (sandy outwash) in the series control section. Peavy soils do not have a glossic horizon. Shoepac soils have 18 to 30 percent clay in the argillic horizon. Tipler and Padwet soils have more than 85 percent sand throughout the lower part of the series control section.

GEOGRAPHIC SETTING: Padwood soils are in outwash-veneered areas of stream terraces and glacial lake plains. They formed dominantly in loamy alluvium and in the underlying sandy outwash which is underlain in turn by stratified loamy and sandy lacustrine deposits. Slope gradients range from 0 to 15 percent. Mean annual precipitation ranges from 28 to 33 inches. Mean annual temperature ranges from 39 to 45 degrees F. The frost free period ranges from about 90 to 120 days. Elevation ranges from 700 to 1900 feet.

GEOGRAPHICALLY ASSOCIATED SOILS: These are the Minocqua, Padus, Tipler, Worcester, and Worwood soils. The somewhat poorly drained Worwood soils are in a drainage sequence with the Padwood soils. The well drained Padus soils, the moderately well drained Tipler soils, the somewhat poorly drained Worcester soils, and the poorly drained and very poorly drained Minocqua soils form a drainage sequence in nearby areas where the substratum is sand and gravel to depths of more than 60 inches.

DRAINAGE AND PERMEABILITY: Moderately well drained. Surface runoff is slow or medium. Permeability is moderate in the loamy mantle, moderately rapid to very rapid in the sandy outwash, and moderately slow in the stratified loamy and sandy lacustrine material. Padwood soils have a perched seasonal high water table at a depth of 2.5 to 3.5 feet at some time during the period of October to May for 1 month or more per year in 6 or more out of 10 years.

USE AND VEGETATION: Most areas are in woodland. Native vegetation is sugar maple, red maple, northern red oak, American basswood, eastern hemlock, and white ash. A few areas have been cleared and are used for cropland. Common crops are corn, small grain, and hay. Some areas are used for growing potatoes.

DISTRIBUTION AND EXTENT: Northern Wisconsin. These soils are of minor extent.

MLRA OFFICE RESPONSIBLE: St. Paul, Minnesota.

SERIES ESTABLISHED: Lincoln County, Wisconsin, 1993.

REMARKS: Diagnostic horizons and features recognized in this pedon are: ochric epipedon - 0 to 5 inches (A, E); albic horizon - 4 to 5 inches (E); spodic horizon - 5 to 15 inches (Bs1, Bs2); glossic horizon - 15 to 27 inches (E/B); argillic horizon - 27 to 36 inches (2Bt); oxyaquic feature - redox accumulations and saturation below the spodic horizon but within 40 inches for 1 month or more per year in most years.

ADDITIONAL DATA: Soil Interpretation Record - WI0214. Refer to soil survey sample number S91WI-069-188 for NSSL data on the typical pedon.

PADUS SERIES

The Padus series consists of very deep well drained soils which are moderately deep to stratified sandy outwash. These soils formed mostly in loamy alluvium and are underlain by stratified sandy outwash on glacial lake plains, outwash plains, stream terraces, eskers, kames, and moraines. Permeability is moderate or moderately rapid in the loamy mantle and rapid or very rapid in the sandy outwash. Slopes range from 0 to 45 percent. Mean annual precipitation is about 30 inches. Mean annual temperature is about 42 degrees F.

TAXONOMIC CLASS: Coarse-loamy, mixed, superactive, frigid Alfic Haplorthods

TYPICAL PEDON: Padus sandy loam - on a convex southeast facing 3 percent slope in a woodland at an elevation of about 1490 feet. (Colors are for moist soil unless otherwise stated.)

A--0 to 2 inches; dark brown (7.5YR 3/2) sandy loam, gray (N 5/0) dry; moderate medium and fine granular structure; friable; many very fine and fine and few medium and coarse roots; very strongly acid; abrupt wavy boundary. (0 to 4 inches thick)

E--2 to 3 inches; pinkish gray (7.5YR 6/2) sandy loam, pinkish gray (7.5YR 7/2) dry; weak medium subangular blocky structure; very friable; many very fine and fine and few medium and coarse roots; very strongly acid; abrupt broken boundary. (0 to 5 inches thick)

Bs1--3 to 8 inches; dark brown (7.5YR 3/4) sandy loam; moderate medium subangular blocky structure; friable; common very fine and fine and few medium and coarse roots; very strongly acid; abrupt wavy boundary.

Bs2--8 to 19 inches; brown (7.5YR 4/4) sandy loam; moderate medium subangular blocky structure; friable; common very fine and fine and few medium and coarse roots; very strongly acid; clear wavy boundary. (Combined thickness of the Bs horizons range from 4 to 25 inches.)

E/B--19 to 26 inches; about 85 percent brown (10YR 5/3) sandy loam (E'), very pale brown (10YR 7/3)) dry; weak very thick platy structure; friable; surrounds remnants of brown (7.5YR 4/4) sandy loam (Bt); moderate medium subangular blocky structure; friable; few fine roots; very strongly acid; gradual wavy boundary. (0 to 15 inches thick)

B/E--26 to 38 inches; about 80 percent brown (7.5YR 4/4) sandy loam (Bt); moderate medium and coarse subangular blocky structure; friable; few faint dark brown (7.5YR 3/4) clay films on faces of peds; penetrated by tongues of brown (10YR 5/3) sandy loam (E'), pink (7.5YR 7/3) dry; moderate fine subangular blocky structure; friable; about 12 percent gravel; very strongly acid; abrupt wavy boundary. (0 to 15 inches thick)

2C--38 to 60 inches; yellowish brown (10YR 5/4) stratified sand and gravelly coarse sand; single grain; loose; about 20 percent gravel; slightly acid.

TYPE LOCATION: Florence County, Wisconsin; about 5 miles southwest of Fence; 150 feet north and 2100 feet west of the southeast corner, sec. 30, T. 38N., R. 16 E.

RANGE IN CHARACTERISTICS: (Unless otherwise stated, thickness and depth are measured from the top of the mineral soil.) Thickness of the loamy deposits and depth to sandy outwash range from 24 to 40 inches. Volume of rock fragments averages less than 35 percent in the particle size control section. Volume of gravel ranges from 0 to 35 percent but is typically less than 15 percent in the loamy mantle. Volume of gravel averages from 3 to 50 percent in the sandy outwash but ranges from 3 to 60 percent in individual strata. Volume of cobbles ranges from 0 to 5 percent throughout. Stones are on the surface in some areas and a stony phase is recognized. Reaction typically ranges from very strongly acid to moderately acid in the upper part of the solum but it ranges to neutral in the Ap horizon, where the soil is limed. Reaction ranges from very strongly acid to slightly acid below the spodic horizon.

Some pedons have an O horizon with hue of 7.5YR or 10YR or the hue is neutral. Value is 2 or 3 and chroma is 0 to 2.

The A horizon has hue of 5YR, 7.5YR, or 10YR; value of 2 to 3; and chroma of 1 or 2. Cultivated pedons have an Ap horizon with hue of 5YR, 7.5YR, or 10YR; value of 3 or 4; and chroma of 2 or 3. The A or Ap horizon is sandy loam, fine sandy loam, or loam.

The E horizon has hue of 5YR, 7.5YR, or 10YR; value of 4 to 6; and chroma of 2 or 3. It typically is sandy loam, fine sandy loam, or loam but in some pedons it is loamy sand.

Some pedons have a Bhs horizon, less than 3 inches thick, with hue of 5YR or 7.5YR and value and chroma of 2 to 3. It is sandy loam, fine sandy loam, or loam.

The Bs horizon has hue of 5YR, value of 3 to 6, and chroma of 4 to 6 or hue of 7.5YR, value of 3 to 5, and chroma of 4. It has textures like the Bhs horizon above.

Some pedons have an E' horizon with hue of 5YR, 7.5YR, or 10YR; value of 4 to 6; and chroma of 2 or 3. Typically, it is sandy loam, fine sandy loam, loam or the gravelly analogs but in some pedons it is loamy sand or the gravelly analog.

Padus soils have a glossic horizon (E/B or B/E horizons, or both). The E' part has colors and textures like the E' horizon above. The Bt part has hue of 5YR, 7.5YR, or 10YR; value of 4 or 5; and chroma of 4 or 6. It is sandy loam, fine sandy loam, loam, or the gravelly analogs.

Some pedons have a Bt horizon with colors and textures like the Bt part described above.

Some pedons have a 2Bt or 2BC horizon with hue of 5YR, 7.5YR, or 10YR and value and chroma 4 to 6. It is sand, loamy sand, or the gravelly or very gravelly analogs.

The 2C horizon has hue of 5YR, 7.5YR, or 10YR; value of 4 to 6 and chroma of 3 to 6. It is stratified sand, coarse sand, or the gravelly, or very gravelly analogs.

COMPETING SERIES: These are the Goodman, Mequithy, Newot, Padwet, and Sarona series. The Oconto series is similar. Mequithy soils have a lithic contact at 20 to 40 inches. Goodman soils have a 12 to 40 inch silty mantle and do not have stratified sand and gravel within 40 inches. Newot, and Sarona soils do not have stratified sand and gravel within 40 inches. Padwet soils have redoxymorphic features in the control section.

GEOGRAPHIC SETTING: Padus soils are on glacial lake plains, outwash plains, stream terraces, eskers, kames, and moraines. They formed mostly in loamy alluvial deposits underlain by stratified sandy outwash. Slope gradients range from 0 to 45 percent. Mean annual precipitation ranges from 28 to 33 inches. Mean annual temperature ranges from 39 to 45 degrees F. The frost free period ranges from about 90 to 135 days. Elevation ranges from 700 to 19500 feet.

GEOGRAPHICALLY ASSOCIATED SOILS: These are the Minocqua, Padwet, Padwood, Pence, Worcester, and Worwood soils. The moderately well drained Padwet soils, the somewhat poorly drained Worcester soils, and the poorly drained and very poorly drained Minocqua soils form a drainage sequence with the Padus soils. The moderately well drained Padwood soils and the somewhat poorly drained Worwood soils from a drainage sequence in nearby areas where the substratum is stratified sandy and loamy deposits at depths of 40 to 60 inches. The well drained Pence soils are nearby where the loamy deposits are thinner over the sandy and gravelly outwash.

DRAINAGE AND PERMEABILITY: Well drained. Surface runoff is slow to very rapid. Permeability is moderate or moderately rapid in the loamy mantle and rapid or very rapid in the sandy outwash.

USE AND VEGETATION: Most areas are in woodland. Native vegetation is mostly sugar maple, red maple, northern red oak, American basswood, white ash, and eastern hemlock but bigtooth aspen, red pine, and eastern white pine are in some stands. Some areas have been cleared and are used for cropland. Common crops are corn, small grain, and hay. Some areas are used for growing potatoes.

DISTRIBUTION AND EXTENT: Northern Wisconsin and the Upper Peninsula of Michigan. These soils are of large extent.

MLRA OFFICE RESPONSIBLE: St. Paul, Minnesota

SERIES ESTABLISHED: Oconto County, Wisconsin, 1985.

REMARKS: Diagnostic horizons and features recognized in this pedon are:
ochric epipedon - 0 to 3 inches (A,E);
albic horizon - 2 to 3 inches (E);
spodic horizon - 3 to 19 inches (Bs1, Bs2);
glossic horizon - 19 to 38 inches (E/B, B/E);
argillic horizon - 26 to 38 inches (B/E).

ADDITIONAL DATA: Soil Interpretation Record - WI0015; WI0396 (STONY).

PENCE SERIES

The Pence series consists of very deep somewhat excessively drained soils which are shallow to stratified sandy outwash. They formed in a thin mantle of loamy alluvium or eolian deposits and in the underlying stratified sand or stratified sandy outwash on glacial lake plains, outwash terraces, outwash plains, eskers, and kames within moraines. Permeability is moderate or moderately rapid in the loamy part of the solum; moderately rapid to very rapid in the sandy part of the solum; and rapid or very rapid in the substratum. Slopes range from 0 to 45 percent. Mean annual precipitation is about 30 inches. Mean annual temperature is about 42 degrees F.

TAXONOMIC CLASS: Sandy, mixed, frigid Typic Haplorthods

TYPICAL PEDON: Pence sandy loam - on a northwest-facing slope of 11 percent in an abandoned pasture at an elevation of about 1,675 feet. (Colors are for moist soil unless otherwise stated.)

A--0 to 3 inches; dark reddish brown (5YR 3/2) sandy loam, reddish gray (5YR 5/2) dry; weak fine subangular blocky structure; very friable; many roots; common white (5YR 8/1) sand grains; about 10 percent gravel; moderately acid; abrupt smooth boundary. (0 to 4 inches thick)

E--3 to 8 inches; brown (7.5YR 4/2) sandy loam, pinkish gray (7.5YR 7/2) dry; weak fine subangular blocky structure; very friable; many roots; about 10 percent gravel; strongly acid; clear wavy boundary. (0 to 5 inches thick)

Bs1--8 to 11 inches; dark reddish brown (5YR 3/4) gravelly sandy loam; weak medium subangular blocky structure; very friable; common roots; about 15 percent gravel; moderately acid; clear wavy boundary.

Bs2--11 to 15 inches; reddish brown (5YR 4/4) gravelly sandy loam; weak fine and medium subangular blocky structure; common roots; very friable; about 15 percent gravel; strongly acid; clear wavy boundary. (Combined thickness of the Bs horizons is 4 to 19 inches.)

2BC--15 to 21 inches; yellowish red (5YR 4/6), yellowish red (5YR 5/6) gravelly coarse sand; weak coarse subangular blocky structure; very friable; few roots; about 25 percent gravel; strongly acid; clear wavy boundary. (0 to 13 inches thick)

2C--21 to 60 inches; stratified yellowish red (5YR 5/6) and reddish yellow (5YR 6/6) gravelly coarse sand; with thin strata of light reddish brown (5YR 6/4) coarse sand and sand; single grain; loose; about 25 percent gravel; strongly acid.

TYPE LOCATION: Oneida County, Wisconsin; about 3/4 of a mile east of Three Lakes; 200 feet east and 380 feet north of the southwest corner, sec. 5, T. 38 N., R. 11 E.

RANGE IN CHARACTERISTICS: Solum thickness ranges from 18 to 36 inches. Thickness of the loamy mantle is 10 to 20 inches. Volume of rock fragments averages less than 35 percent in the particle-size control section. Volume of gravel ranges from 0 to 35 percent in the loamy mantle. Volume of gravel ranges from 15 to 35 percent in the sandy outwash as a weighted average but ranges from 0 to 65 percent in individual strata. Volume of cobbles ranges from 0 to 10 percent throughout. Some areas have boulders on the surface and a bouldery phase is recognized. Reaction typically ranges from very strongly acid to moderately acid in the upper part of the solum, but ranges to neutral in the Ap horizon, where the soil is limed. Reaction ranges from very strongly acid to slightly acid in the lower part of the solum and from strongly acid to slightly acid in the substratum.

The A horizon has hue of 5YR, 7.5YR, or 10YR, or has neutral hue; value of 2 to 3; and chroma of 0 to 2. Some pedons have an Ap horizon with hue of 5YR, 7.5YR, or 10YR; value of 3 or 4; and chroma of 1 to 3. Uncoated sand grains are common in the Ap or A horizon. The A or Ap is typically sandy loam, fine sandy loam, or loam but in some places it is loamy sand.

The E horizon has hue of 5YR, 7.5YR, or 10YR; value of 4 to 6; and chroma of 2 or 3. Colors of 4/3 and 5/3 have value dry of 7 or more. The E horizon is typically sandy loam, but the range includes loam, fine sandy loam, or loamy sand.

Some pedons have a Bhs horizon less than 3 inches thick. It has hue of 5YR or 7.5YR, value of 2 to 3, and chroma of 1 to 3. It is sandy loam, fine sandy loam, loam, or the gravelly analogs.

The Bs horizon has hue of 5YR, value of 3 to 6, and chroma of 4 to 6 or hue of 7.5YR, value of 3 to 5, and chroma of 4. It has texture like the Bhs horizon above.

Some pedons have a 2Bs horizon with color like the Bs horizon described above. It is loamy sand, loamy coarse sand or the gravelly analogues of these textures.

The 2BC horizon has hue of 5YR to 10YR, value of 4 to 6, and chroma of 6 to 8. It is sand, coarse sand, loamy sand, loamy coarse sand, loamy fine sand, or the gravelly analogs. Some pedons have strata which are very gravelly or extremely gravelly analogs of these textures and some have strata of gravel.

The 2C horizon has hue of 5YR, 7.5YR, or 10YR; value of 4 to 6; and chroma of 3 to 6. Typically, it is stratified with layers of sand or coarse sand, or the gravelly, very gravelly, or extremely gravelly analogs. Some pedons have strata of gravel.

COMPETING SERIES: These are the Deerton, Furlong, Kalkaska, Liminga, McMillan, Omega, and Springlake series. Deerton and Furlong have a lithic contact within 40 inches. Kalkaska, Liminga, and Omega soils have sandy textures throught the profile. McMillan soils have less than 15 percent coarse fragments throught the profile. Springlake soils have free carbonates within the series control section.

GEOGRAPHIC SETTING: These soils are on glacial lake plains, outwash terraces, outwash plains, eskers, and kames with in moraines. Slope gradients range from 0 to 45 percent. Pence soils formed in a thin mantle of loamy alluvium or eolian deposits and in the underlying sand or stratified sandy outwash. Mean annual temperature ranges from 36 to 45 degrees F. Mean annual precipitation ranges from 28 to 33 inches. The frost free period ranges from about 70 to 135 days. Elevation ranges from 600 to 2000 feet

GEOGRAPHICALLY ASSOCIATED SOILS: These are the Manitowish, Padus, Sayner, Tipler(T), Vilas, Worcester, and Wormet(T) soils. The moderately well drained Manitowish soils and the somewhat poorly drained Wormet soils form a drainage sequence with Pence soils. The well drained Padus soils, the moderately well drained Tipler soils, and the somewhat poorly drained Worcester soils form a drainage sequence in nearby areas where the loamy mantle is 20 to 40 inches thick. The excessively drained Sayner and Vilas soils are on landscape positions similar to those of Pence soils where the loamy mantle is absent.

DRAINAGE AND PERMEABILITY: Somewhat excessively drained. Surface runoff is slow to rapid. Permeability is moderate or moderately rapid in the loamy part of the solum; moderately rapid to very rapid in the sandy part of the solum; and rapid or very rapid in the substratum.

USE AND VEGETATION: Most areas remain in woodland. Forest vegetation is mixed coniferous and deciduous forest. Timber stands are mostly sugar maple, paper birch, red maple, American basswood, northern red oak, white ash, eastern hemlock, and eastern white pine. Red pine, aspen, balsam, and yellow birch are also in some stands. Some areas are used for cropland or pastureland. Common crops are corn, small grains, and hay.

DISTRIBUTION AND EXTENT: Northern Wisconsin and the Upper Peninsula of Michigan. The series is of large extent.

MLRA OFFICE RESPONSIBLE: St. Paul, Minnesota.

SERIES ESTABLISHED: Bayfield County, Wisconsin, 1958.

REMARKS: Diagnostic horizons recognized in the pedon are:
ochric epipedon - 0 to 8 inches (A, E);
albic horizon - 3 to 8 inches (E);
spodic horizon - 8 to 15 inches (Bs1, Bs2).

ADDITIONAL DATA: Soil Interpretation Record - WI0179; WI0552 (Bouldery).

RUBICON SERIES

The Rubicon series consists of very deep, excessively drained soils formed in sandy deposits on disintegration, ground, end and kame moraines, lake plains, outwash plains, stream terraces, beach ridges, and sand dunes. These soils have rapid permeability. Slopes range from 0 to 70 percent. Mean annual precipitation is about 30 inches, and mean annual temperature is about 43 degrees F.

TAXONOMIC CLASS: Sandy, mixed, frigid Entic Haplorthods

TYPICAL PEDON: Rubicon sand - on a 3 percent convex south-facing slope in a red pine plantation at an elevation of 859 feet. (Colors are for moist soil unless otherwise stated).

A--0 to 1 inch; black (10YR 2/1) sand, flecked with light brownish gray (10YR 6/2),dark gray (10YR 4/1) dry; weak fine granular structure; very friable; common roots; very strongly acid; abrupt smooth boundary. (0 to 3 inches thick).

E--1 to 6 inches; light brownish gray (10YR 6/2) sand; very weak medium granular structure; very friable; common roots; very strongly acid; clear smooth boundary. (1 to 7 inches thick)

Bs1--6 to 10 inches; brown (7.5YR 4/4) sand; weak medium granular structure; very friable; many roots; common (about 15 percent) distinct cracked coatings on sand grains; moderately acid; clear wavy boundary.

Bs2--10 to 18 inches; dark yellowish brown (10YR 4/4) sand; weak coarse granular structure; very friable; common roots; common (about 15 percent) faint cracked coatings on sand grains; moderately acid; clear irregular boundary. (4 to 32 inches thick).

BC--18 to 36 inches; yellowish brown (10YR 5/6) sand; very weak coarse subangular blocky structure; very friable; moderately acid; chunks of ortstein occur at depths of 18 to 24 inches and represent about 15 percent of the surface area of the horizon exposed; chunks are 4 to 6 inches in diameter; colors are yellowish brown (10YR 5/6) representing 60 percent of the mass and dark reddish brown (5YR 3/4) and pale brown (10YR 6/3) representing the remaining colors; massive; few roots; weakly to strongly cemented; moderately acid; clear irregular boundary. (0 to 20 inches thick)

C--36 to 60 inches; light yellowish brown (10YR 6/4) sand with some coarse sand in upper portion; single grain; loose; slightly acid.

TYPE LOCATION: Cheboygan County, Michigan; about 5 miles northeast of Afton; 300 feet north and 2440 feet east of the southwest corner, sec. 5, T. 35 N., R. 1 W. USGS Legrand, MI 7.5 minute topographic quadrangle; lat. 45 degrees 26 minutes 13.6 seconds N. and long. 84 degrees 27 minutes 39.9 seconds W., east part of Koehler Township.

RANGE IN CHARACTERISTICS: The thickness of the solum ranges from 20 to 50 inches. Coarse fragments range from 0 to 15 percent throughout the pedon. Calcareous substratum phases are recognized.

The A and Ap horizons have hue of 10YR, 7.5YR, 5YR, or is neutral; value of 2 to 4; and chroma of 0 to 3. The A or Ap horizon is sand or loamy sand. Reaction ranges from very strongly acid to moderately acid.

The E horizon has hue of 10YR, 7.5YR, or 5YR; value of 4 to 7; and chroma of 1 to 3. The E horizon is sand or loamy sand. Reaction ranges from very strongly acid to moderately acid.

The Bs1 horizon has hue of 7.5YR, or 5YR; value of 3 or 4; and chroma of 2 to 4. Values and chromas of 2 and 3 do not occur together.

The Bs2 horizon has hue of 10YR, 7.5YR, or 5YR; value of 4 or 5 and chroma of 3 to 8.

Reaction of the Bs horizons ranges from very strongly acid to moderately acid.

The BC horizon has hue of 10YR, 7.5YR, or 5YR; value of 4 to 6; and chroma of 3 to 8. The amount of ortstein occurring in the Bs and BC horizons range from 0 to 20 percent. Reaction ranges from very strongly acid to moderately acid.

The C horizon has hue of 10YR, 7.5YR, or 5YR; value of 4 to 7; and chroma of 3 to 8. It is medium or coarse sand. Thin color bands are in some pedons. The reaction ranges from very strongly acid to neutral.

COMPETING SERIES: These are the Duel, East Lake, Hartwick, Ishpeming, Karlin, Kiva, Rousseau, Sayner, Sultz (T), and Vilas series. Closely related soils are the Fernlake and Missisquoi soils. Duel soils are underlain by limestone bedrock. East Lake soils are underlain by gravelly sand within the control section. Hartwick soils have one or more horizons that average 15 to 35 percent gravel within the series control section. Ishpeming soils have igneous bedrock at a depth of 20 to 40 inches. Karlin soils have loamy fine sand, fine sandy loam or sandy loam in the 10 to 40 inch control section. Kiva soils have stratified coarse sand and gravel at depths ranging from 10 to 24 inches. Rousseau soils developed in fine sands. Sayner soils contain more gravel in the lower part of the profile. Sultz (T) soils are stratified with loamy, or loamy and sandy material in the lower part of the series control section. Vilas soils have loamy sand textures in the Bs horizon. The closely related Fernlake and Missisquoi soils have isotic mineralogy. In addition, the Fernlake soils are underlain with loamy sand and the Missisquoi soils have more gravel in the substratum.

GEOGRAPHIC SETTING: Rubicon soils are on outwash and lake plains, stream terraces, and moraines and to a lesser extent on old beach ridges and sand dunes along the Great Lakes. Slopes range from 0 to 70 percent. The mean annual precipitation is 27 to 34 inches, and annual temperature is about 40 to 47 degrees F.

GEOGRAPHICALLY ASSOCIATED SOILS: Croswell, Au Gres, and Roscommon soils form a common drainage sequence with Rubicon. Kalkaska, Grayling, and Montcalm soils are common well drained to excessively drained associates in similar landscape positions.

DRAINAGE AND PERMEABILITY: Excessively drained. Surface runoff is negligible to low, dependent on slope. Permeability is rapid.

USE AND VEGETATION: The majority of this soil is forested, including pine plantations. Some areas are idle cropland or in pasture. Only a very small proportion is used for small grains and hay crops. The native vegetation and present natural vegetation is dominantly red pine and quaking aspen with some eastern white pine and jack pine. Ground cover consists of blueberries, wintergreen, sweet fern, and bracken fern.

DISTRIBUTION AND EXTENT: Northern half of lower Michigan, Upper Michigan, and northern Wisconsin. The series is of large extent.

MLRA OFFICE RESPONSIBLE: St. Paul, Minnesota

SERIES ESTABLISHED: Ontonagon County, Michigan, 1922.

REMARKS: Diagnostic horizons and features recognized in this pedon are: albic horizon - the zone from 1 to 6 inches (E horizon); spodic horizon - the zone from 6 to 18 inches (Bs1 and Bs2 horizons). The Bs2 qualifies on the basis of cracked coatings.

The dark subsoil and banded subsoil phases (that have 1/16 to 1/4 inch bands of loamy sand at depths of 40 to 60 inches) are no longer within the series concept.

Burned and severely burned phases are recognized.

SAYNER SERIES

The Sayner series consists of very deep, excessively drained soils formed in stratified sand and gravel on outwash terraces, outwash plains, old beaches, kames, eskers, and other glaciofluvial areas within moraines. Permeability is moderately rapid or rapid in the solum and rapid or very rapid in the substratum. Slopes range from 0 to 60 percent. Mean annual precipitation is about 30 inches. Mean annual temperature is about 42 degrees F.

TAXONOMIC CLASS: Sandy, mixed, frigid Entic Haplorthods

TYPICAL PEDON: Sayner loamy sand - on a northeast-facing slope of 18 percent in a forested area at an elevation of 1606 feet. (Colors are for moist soil unless otherwise stated.)

A--0 to 2 inches; black (N 2/0) loamy sand, dark brown (7.5YR 3/2) dry; weak medium granular structure; very friable; many fine roots; few charcoal fragments; many uncoated sand grains; about 3 percent gravel; strongly acid; abrupt wavy boundary. (0 to 4 inches thick.)

E--2 to 4 inches; brown (7.5YR 4/2) loamy sand, pinkish gray (7.5YR 6/2) dry; weak fine subangular blocky structure; very friable; many fine roots; about 3 percent gravel; moderately acid; abrupt wavy boundary. (0 to 5 inches thick.)

Bs1--4 to 7 inches; dark reddish brown (5YR 3/4) loamy sand; weak medium subangular blocky structure; very friable; many fine roots; about 5 percent gravel; moderately acid; clear wavy boundary.

Bs2--7 to 14 inches; reddish brown (5YR 4/4) sand; weak medium subangular blocky structure; very friable; common fine roots; about 10 percent gravel; moderately acid; clear wavy boundary. (combined thickness of the Bs horizons is 5 to 24 inches)

BC--14 to 22 inches; strong brown (7.5YR 4/6) gravelly sand; single grain; loose; slightly coherent in places; few fine roots; about 25 percent gravel; slightly acid; clear wavy boundary. (0 to 14 inches thick)

C1--22 to 38 inches; strong brown (7.5YR 5/6) stratified gravelly coarse sand and coarse sand; single grain; loose; about 17 percent gravel as an average; slightly acid; gradual wavy boundary.

C2--38 to 60 inches; light yellowish brown (10YR 6/4) and brownish yellow (10YR 6/6) stratified coarse sand and gravelly coarse sand; single grain; loose; about 12 percent gravel as an average; slightly acid.

TYPE LOCATION: Oneida County, Wisconsin; about 3.25 miles south of Hazelhurst; 450 feet south and 1380 feet west of the northeast corner of sec. 27, T. 38 N., R. 6 E.

RANGE IN CHARACTERISTICS: Solum thickness ranges from 12 to 36 inches. Total volume of rock fragments averages less than 35 percent in the particle-size and series control section. Volume of gravel ranges from 0 to 35 percent in the solum and 15 to 35 percent in the substratum. Volume of cobbles ranges from 0 to 10 percent throughout. Reaction ranges from very strongly acid to moderately acid in the upper part of the solum and from strongly acid to slightly acid below the spodic horizon.

The A horizon has hue of 5YR, 7.5YR, or 10YR or it is neutral in hue. Value is 2 to 3 and chroma is 0 to 2. It is loamy sand or sand.

The E horizon has hue of 5YR, 7.5YR, or 10YR; value of 4 to 6; and chroma of 2 or 3. It is loamy sand or sand.

The Bs horizon has hue of 5YR, value of 3 to 6, and chroma of 4 to 6 or hue of 7.5YR, value of 3 to 5, and chroma of 4 to 6. It is typically loamy sand, sand, loamy coarse sand, or coarse sand, but in some pedons it is the gravelly analogs.

The BC horizon has hue of 5YR, 7.5YR, or 10YR and value and chroma of 4 to 6. It is loamy sand, loamy coarse sand, sand, coarse sand or the gravelly analogs. BC horizons with spodic colors have pH greater than 5.9 or have organic carbon content less than 0.6 percent.

The C horizon has colors like the BC horizon. It is more than 90 percent sand. Stratification is common. Individual strata are sand or coarse sand or the gravelly, very gravelly or extremely gravelly analogs. Some pedons have thin strata of gravel.

COMPETING SERIES: These are the Duel, East Lake, Hartwick, Ishpeming, Karlin, Kiva, Rousseau, Rubicon, Sultz(T), and Vilas series. Duel and Ishpeming soils have a lithic contact at a depth of 20 to 40 inches. East Lake and Hartwick soils have free carbonates within 40 inches. Karlin soils have a mantle of sandy loam, fine sandy loam, or loamy fine sand in the upper part of the series control section and have less than 15 percent rock fragments. Kiva soils have a 10 to 20 inch loamy mantle and have free carbonates within 40 inches. Rousseau soils have more than 50 percent fine sand and no rock fragments in the series control section. Rubicon and Vilas soils have less than 15 percent rock fragments throughout the series control section. Sultz (T) soils have stratified loamy, or loamy and sandy, strata in the lower part of the series control section and average less than 90 percent sand there.

GEOGRAPHIC SETTING: These soils are on nearly level to very steep areas of outwash terraces, outwash plains, old beaches, kames, eskers, and other glaciofluvial areas within moraines. Slope gradients range from 0 to 60 percent. Slopes are complex in many places. Sayner soils formed in stratified or unsorted sandy and gravelly outwash. Mean annual precipitation ranges from 28 to 33 inches. Mean annual temperature range from 39 to 45 degrees F. The frost free period ranges from about 90 to 135 days. Elevation ranges from 680 to 1950 feet.

GEOGRAPHICALLY ASSOCIATED SOILS: These are the Croswell, Pence, Rubicon, and Vilas soils all of which occur on similar landscape positions. Croswell Rubicon and Vilas soils are in areas where there is less gravel in the soil. Pence soils are in areas where there is a 10 to 20 inch loamy mantle.

DRAINAGE AND PERMEABILITY: Excessively drained. Runoff ranges from very slow to rapid. Permeability is moderately rapid or rapid in the solum and rapid or very rapid in the substratum.

USE AND VEGETATION: Most areas are in woodland. Only a small amount of this soil is in cropland. Native vegetation is coniferous and deciduous forest with red pine, eastern white pine, jack pine, northern red oak, red maple, paper birch, balsam fir, and quaking aspen predominating.

DISTRIBUTION AND EXTENT: Northern Wisconsin and the Upper Peninsula of Michigan. This series is of large extent.

MLRA OFFICE RESPONSIBLE: St. Paul, Minnesota.

SERIES ESTABLISHED: Vilas County, Wisconsin, 1985.

REMARKS: Diagnostic horizons and features are: ochric epipedon - 0 to 4 inches (A, E); albic horizon - 2 to 4 inches (E); spodic horizon - 4 to 14 inches (Bs1, Bs2).

ADDITIONAL DATA: Soil Interpretation Record - WI0334.

WITHEE SERIES

The Withee series consists of very deep, somewhat poorly drained soils formed in loess or silty alluvium and in the underlying loamy till on ground moraines. Permeability is moderate in the silty mantle and moderately slow in the till. Slopes range from 0 to 6 percent. Mean annual precipitation is about 30 inches. Mean annual air temperature is about 42 degrees F.

TAXONOMIC CLASS: Fine-loamy, mixed, superactive, frigid Aquic Glossudalfs

TYPICAL PEDON: Withee silt loam - on a plane, west facing 2 percent slope in a cultivated field at an elevation of 1,205 feet. (Colors are for moist soil unless otherwise stated.)

Ap--0 to 9 inches; dark grayish brown (10YR 4/2) silt loam, light brownish gray (10YR 6/2) dry; moderate medium subangular blocky structure; friable; common fine roots; neutral; abrupt smooth boundary. (6 to 9 inches thick)

E--9 to 14 inches; brown (10YR 5/3) silt loam, very pale brown (10YR 7/3) dry; weak medium subangular blocky structure; friable; common fine roots; common medium prominent brownish yellow (10YR 6/8) and few fine prominent reddish yellow (7.5YR 6/8) masses of iron accumulation; few fine faint light brownish gray (10YR 6/2) iron depletions; neutral; clear wavy boundary. (2 to 10 inches thick)

E/B--14 to 18 inches; about 70 percent pale brown (10YR 6/3) silt loam (E), very pale brown (10YR 7/3) dry; weak medium subangular blocky structure; friable; extends as tongues into and surrounds remnants of light yellowish brown (10YR 6/4) silt loam (Bt); moderate fine and medium subangular blocky structure; friable; few fine roots; few fine faint and distinct light brownish gray (10YR 6/2) iron depletions; common medium prominent reddish yellow (7.5YR 6/8) and few medium distinct brownish yellow (10YR 6/6) masses of iron accumulation; very strongly acid; clear irregular boundary.

B/E--18 to 24 inches; 60 percent light brown (7.5YR 6/4) silt loam (Bt); moderate medium subangular blocky structure; friable; few faint brown (7.5YR 5/4) clay films on faces of peds; penetrated by tongues of pale brown (10YR 6/3) silt loam (E), very pale brown (10YR 7/3) dry; weak medium subangular blocky structure; friable; few fine roots; few fine prominent and faint light brownish gray (10YR 6/2) iron depletions; common medium distinct and prominent reddish yellow (7.5YR 6/8) and few medium prominent and distinct brownish yellow (10YR 6/6) masses of iron accumulation; very strongly acid; clear wavy boundary. (Glossic horizon - 2 to 30 inches thick)

2Bt1--24 to 34 inches; reddish brown (5YR 5/3) loam; moderate medium subangular blocky structure; friable; common faint reddish brown (5YR 4/3) clay films on faces of peds; few faint pale brown (10YR 6/3) clean silt and sand grains coating faces of some peds; common medium faint reddish gray (5YR 5/2) iron depletions and many coarse prominent brownish yellow (10YR 6/6) masses of iron accumulation; about 3 percent gravel; very strongly acid; abrupt wavy boundary.

2Bt2--34 to 47 inches; reddish brown (5YR 4/4) loam; moderate medium subangular blocky structure; firm; common faint reddish brown (5YR 4/3) clay films on faces of peds; few pale brown (10YR 6/3) clean silt and sand grains coating faces of some peds; few medium distinct yellowish red (5YR 5/8) masses of iron accumulation; about 3 percent gravel; very strongly acid; gradual wavy boundary. (Combined thickness of the 2Bt horizons ranges from 5 to 40 inches)

2C--47 to 60 inches; reddish brown (5YR 4/4) loam; massive; firm; about 3 percent gravel; very strongly acid.

TYPE LOCATION: Clark County, Wisconsin; about 5 miles east and 0.5 miles south of Christie; 5 feet south and 620 feet west of the northeast corner, sec. 21, T. 25 N., R. 1 W.

RANGE IN CHARACTERISTICS: Thickness of the silty mantle and depth to till range from 12 to 36 inches. Depth to the base of the argillic horizon is more than 40 inches. Free carbonates are absent to a depth of 80 inches or more. The content of clay averages 18 to 25 percent in the particle size control section and the content of fine sand or coarser averages 15 to 65 percent. Volume of rock fragments averages less than 15 percent in the silty mantle and less than 35 percent in the till. Volume of gravel ranges from 0 to 10 percent in the silty mantle and from 3 to 35 percent in the till. Volume of cobbles ranges from 0 to 5 percent in the silty mantle and from 0 to 10 percent in the till. Reaction typically ranges from very strongly acid to moderately acid throughout the soil, but ranges to neutral in the upper part, where the soil is limed. Redox concentrations are typically throughout the pedon below the Ap or A horizon. Redox depletions, with chroma of 2 or less, are in the upper 10 inches of the argillic horizon and aquic conditions occur there at some time in most years.

The Ap horizon has value of 3 or 4 and chroma of 2 or 3. Uncultivated pedons have an A horizon with hue of 10YR, value of 2 or 3, and chroma of 1 or 2.

The E horizon has hue of 7.5YR or 10YR, value of 4 to 7, and chroma of 2 or 3. Colors of 4/3 or 5/3 have value dry of 7 or more. The E horizon is silt loam or

silt.
Withee soils have a glossic horizon. Horizonation has a wide range depending on the thickness of the silty mantle and the degree to which eluviation has occurred. Therefore these can be E/B, B/E, 2E/B, or 2B/E horizons singly or in combination, with or without a Bt horizon.

The E part of the E/B or B/E horizon has color and texture like the E horizon described above. The Bt part has hue of 7.5YR or 10YR, value of 4 to 6, and chroma of 3 to 6.

Some pedons have a Bt horizon with color and texture like the Bt part described above. Some pedons have a Btg horizon, with dominant chroma of 2, below the upper 10 inches of the argillic horizon.

The 2E part of the 2E/B or 2B/E horizon has hue of 5YR, 7.5YR, or 10YR; value of 4 to 6; and chroma of 2 or 3. It is loam, sandy clay loam, or the gravelly analogs. Colors of 4/3 or 5/3 have value dry of 7 or more.

The 2Bt part of the 2E/B or 2B/E horizon has hue of 5YR, 7.5YR, or 10YR; value of 3 to 5; and chroma of 3 to 6. Value and chroma of 3 do not occur together. It is loam, sandy clay loam, clay loam, or the gravelly analogs.

The 2Bt horizon has color like the 2Bt part described above. It is typically loam, sandy clay loam, clay loam or the gravelly analogs at least in the upper part, but grades to sandy loam or gravelly sandy loam in the lower part in some pedons. Bulk density ranges from 1.6 to 1.85 g/cm3.

Some pedons have a 2BC horizon with colors and textures like the 2C horizon described below.

The 2C horizon has hue of 5YR or 7.5YR, value of 3 to 5, and chroma of 4 to 6. It is fine sandy loam, sandy loam, loam, sandy clay loam, clay loam, or the gravelly analogs. Bulk density ranges from 1.7 to 1.95 g/cm3.

COMPETING SERIES: These are the Alstad, Kert, Meadland, Milladore, Nary, Point, and Rietbrock series.
Alstad soils have secondary carbonates within the series control section.
Kert soils have a paralithic contact within a depth of 20 to 40 inches.
Meadland and Point soils do not have a 12 to 36 inch mantle with more than 50 percent silt.
Milladore soils
Rietbrock soils have a lithic contact at a depth of 40 to 60 inches.

GEOGRAPHIC SETTING:
Parent material: Formed in loess or silty alluvium and in the underlying loamy till of Early Wisconsinan Age.

Landform: Flats, toeslopes, and footslopes on ground moraines.
Slope: 0 to 6 percent.
Elevation: 800 to 1950 feet.
Mean annual air temperature: 39 to 45 degrees F.
Mean annual precipitation: 28 to 33 inches
Frost-free days: 120 to 135 days.

GEOGRAPHICALLY ASSOCIATED SOILS: These are the Loyal and Marshfield soils. The moderately well drained Loyal soils and the poorly drained Marshfield soils form a drainage sequence with Withee soils. Loyal soils are on higher or more sloping landscape positions that are generally convex in shape. Marshfield soils are in depressions and drainageways.

DRAINAGE AND PERMEABILITY: Somewhat poorly drained. Surface runoff islow. Permeability is moderate in the silty mantle; and moderately slow in the till. These soils have a perched seasonal high water table at a depth of 1 to 2.5 feet for 1 month or more per year at some time during the period October to June in normal years.

USE AND VEGETATION: Most areas of this soil are used for cropland. Common crops are corn, small grain, and hay. Some areas are used for pastureland. Some areas remain in woodland. Native vegetation is deciduous forest. Common trees are red maple, sugar maple, northern red oak, American basswood, yellow birch, and white ash.

DISTRIBUTION AND EXTENT: North-central Wisconsin. LRR K and MLRA 90B. This soil is of large extent.

MLRA OFFICE RESPONSIBLE: St. Paul, Minnesota

SERIES ESTABLISHED: Wood County, Wisconsin, 1971.

REMARKS: The difference between Withee and Milladore soils is unclear. More study is needed to see if the Milladore series should be combined with the Withee series or redefined.

Diagnostic horizons and features recognized in this pedon are: Particle size control section - the zone from 18 to 38 inches.
Ochric epipedon - the zone from 0 to 18 inches (Ap, E, E/B)
Albic horizon - the zone from 9 to 18 inches (E, E part of the E/B).
Glossic horizon - the zone from 14 to 24 inches (E/B, B/E).
Argillic horizon - the zone from 18 to 47 inches (B/E, 2Bt1, 2Bt2).
Redoximorphic concentrations - oxidized color features in the zone from 9 to 47 inches.
Redoximorphic depletions - depleted color features in the zone from 9 to 34

inches.
Lithologic discontinuity - at the upper boundary of the 2Bt1 at 24 inches.

Aquic conditions in the upper 10 inches of the argillic horizon.

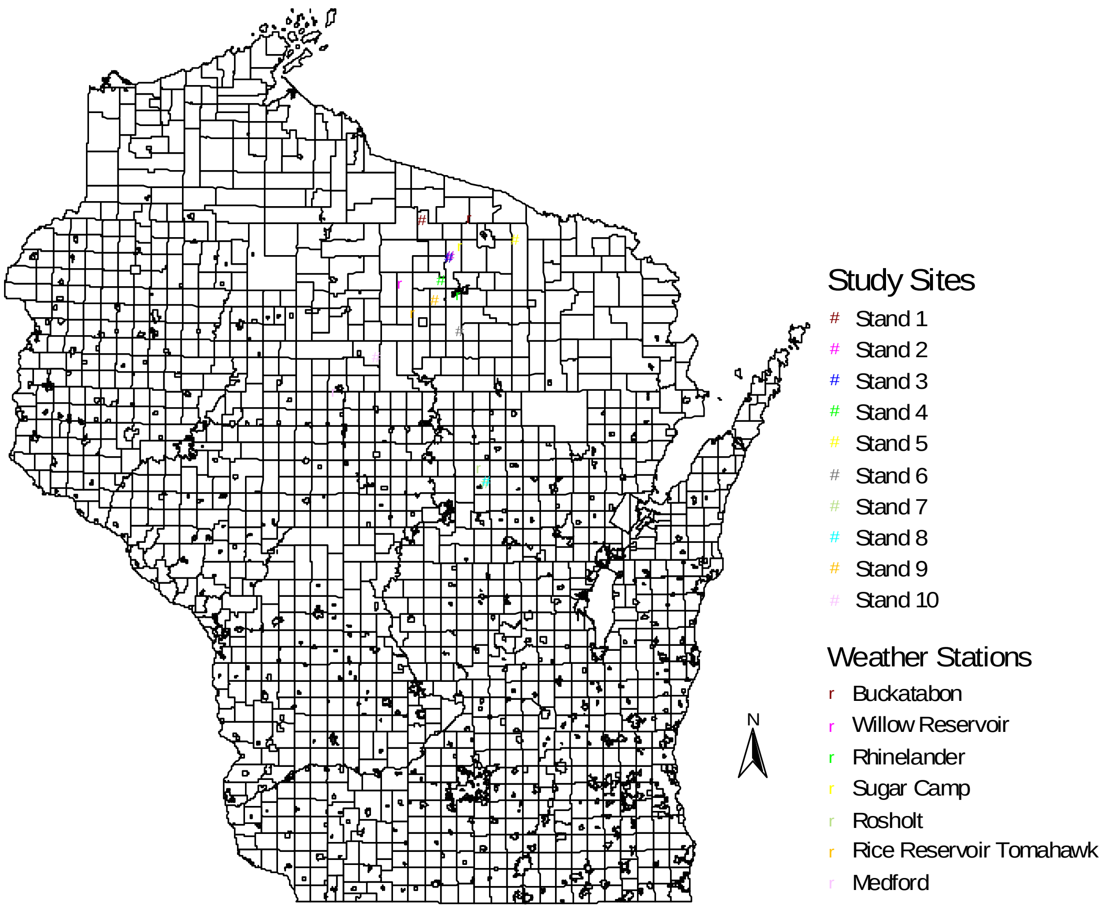
ADDITIONAL DATA - Former Soil Interpretation Record - WI0253.

APPENDIX III

CLIMATE DATA[4]

[4] State Climatology Office, Atmospheric and Oceanic Sciences Department at the University of Wisconsin-Madison. Historical Climate Data [Online WWW]. Available URL: "http://www.aos.wisc.edu/%7Esco/" [Accessed 7 Dec 2004].

Study Site and Weather Station Locations



Stand	Weather Station
1	Buckatabon
2	Willow Reservoir
3	Willow Reservoir
4	Rhinelander
5	Sugar Camp
6	Rice Reservoir
7	Rosholt
8	Rosholt
9	Rice Reservoir
10	Medford

Station: 471155 BUCKATABON, WI

Base Temp °F	Median	Shortest	10%	90%	Longest
32	136	94	107	151	156
30	144	112	123	159	171
28	157	126	136	173	194
24	184	141	162	203	212
20	201	166	181	220	234
16	216	189	204	240	253

Precipitation Summary

1971-2000 NCDC Normals

Element	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
Precip (in)	1.36	0.95	1.66	2.14	3.14	3.58	3.82	3.89	3.70	2.64	2.15	1.34	30.37

Station: 475255 MEDFORD 1 SW, WI

Temperature Summary

1971-2000 NCDC Normals

Element	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN

Element	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
Precip (in)	1.18	0.91	1.84	2.51	3.16	4.44	3.97	4.68	4.50	2.60	2.13	1.28	33.20
Max °F	19.8	26.2	36.9	52.3	66.4	74.3	78.6	76.5	67.3	54.9	37.8	24.4	51.3
Min °F	-0.5	5.0	18.3	31.6	43.6	52.6	57.3	55.5	46.2	34.8	22.1	7.1	31.1
Mean °F	9.7	15.6	27.6	42.0	55.0	63.5	68.0	66.0	56.8	44.9	30.0	15.8	41.2
HDD base 65	1718	1384	1159	691	339	111	38	67	261	625	1051	1527	8971
CDD base 65	0	0	0	0	28	65	129	97	13	0	0	0	332

Precipitation Summary
Length of Growing Season (Days)
Derived from 1971-2000 Averages

Station: 477113 RHINELANDER WATER WORKS, WI

Temperature Summary

1971-2000 NCDC Normals

Element	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
Max °F	21.4	27.7	38.3	52.6	66.8	74.4	78.6	76.2	66.9	54.6	37.9	25.3	51.7
Min °F	-0.2	4.4	15.8	29.1	41.2	50.6	55.7	53.9	44.9	34.1	21.6	7.2	29.9
Mean °F	10.6	16.1	27.1	40.9	54.0	62.5	67.2	65.1	55.9	44.4	29.8	16.3	40.8
HDD base 65	1688	1371	1176	725	367	128	50	83	283	640	1057	1512	9080
CDD base 65	0	0	0	0	25	52	117	83	11	0	0	0	288

Precipitation Summary

1971-2000 NCDC Normals

Element	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
Precip (in)	1.24	0.87	1.60	2.38	3.36	3.93	4.04	4.35	4.11	2.65	2.05	1.32	31.90

Length of Growing Season (Days)
Derived from 1971-2000 Averages

Base Temp °F	Median	Shortest	10%	90%	Longest
32	125	98	105	145	156
30	139	98	126	159	169
28	157	133	137	176	183
24	186	139	163	211	227
20	206	176	187	219	249
16	217	189	201	238	261

Station: 477140 RICE RESERVOIR, WI

Precipitation Summary
1971-2000 NCDC Normals

Element	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
Precip (in)	1.18	0.86	1.94	2.59	3.32	4.16	4.06	3.94	4.60	2.57	2.36	1.29	32.87

Station: 477349 ROSHOLT 9 NNE, WI

Temperature Summary
1971-2000 NCDC Normals

Element	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
Max °F	21.7	27.5	38.7	54.1	67.7	76.3	80.2	77.5	68.8	57.2	40.1	26.4	53.0
Min °F	0.2	5.2	17.0	30.0	41.8	50.6	55.4	53.2	44.1	33.4	21.0	7.4	29.9
Mean °F	11.0	16.4	27.9	42.1	54.8	63.5	67.8	65.4	56.5	45.3	30.6	16.9	41.5
HDD base 65	1677	1362	1153	689	343	103	36	77	264	611	1034	1492	8841
CDD base 65	0	0	0	0	26	57	123	87	7	0	0	0	300

Precipitation Summary
1971-2000 NCDC Normals

Element	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
Precip (in)	1.12	0.94	1.77	2.92	3.67	3.70	3.92	4.55	3.83	2.54	2.34	1.36	32.66

Length of Growing Season (Days)
Derived from 1971-2000 Averages

Base Temp °F	Median	Shortest	10%	90%	Longest
32	126	85	95	146	151
30	136	97	102	152	157
28	153	102	128	168	191

24	177	130	153	204	214
20	205	140	175	218	220
16	218	167	184	246	259

Station: 478288 SUGAR CAMP, WI

Precipitation Summary

1971-2000 NCDC Normals

Element	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
Precip (in)	1.21	0.84	1.70	2.25	3.46	3.95	3.89	4.32	3.97	2.65	2.05	1.31	31.60

Station: 479236 WILLOW RESERVOIR, WI

Temperature Summary

1971-2000 NCDC Normals

Element	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
Max °F	18.9	25.4	35.5	49.7	64.3	72.1	76.4	74.4	65.2	52.9	36.4	23.6	49.6
Min °F	-2.7	1.6	13.3	27.4	39.8	49.7	54.5	51.9	43.5	33.4	20.9	5.6	28.2
Mean °F	8.1	13.5	24.4	38.6	52.1	60.9	65.5	63.2	54.4	43.2	28.7	14.6	38.9
HDD base 65	1765	1441	1258	793	419	162	64	121	328	677	1090	1563	9681
CDD base 65	0	0	0	0	17	39	78	63	8	0	0	0	205

Precipitation Summary

1971-2000 NCDC Normals

Element	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
Precip (in)	1.09	0.80	1.56	2.21	3.16	3.93	3.90	4.31	4.09	2.51	2.02	1.11	30.69

Length of Growing Season (Days)
Derived from 1971-2000 Averages

Base Temp °F	Median	Shortest	10%	90%	Longest
32	113	73	97	141	157
30	130	97	103	151	177
28	147	97	121	176	199
24	167	125	137	197	218
20	198	163	170	223	239
16	215	189	196	241	250

APPENDIX IV

RAW DATA

Stand ID	Tree ID	age	dbh	tot. h	hllb	lllb	dllb	sdllb
1	1	18	6.2	12.40	3.80	1.64	1.3	5.2
	2	20	9.6	11.50	4.80	2.45	2.3	6.2
	3	21	9.1	10.30	4.40	3.31	2.7	6.3
	4	21	8.7	14.80	5.30	3.04	2.3	6.4
	5	23	10.1	14.10	5.40	6.17	5.9	7.8
2	1	17	7.9	11.30	4.00	3.5	3.5	6.4
	2	14	5.7	8.90	2.80	2.82	2.1	4.6
	3	13	8.2	9.80	4.90	2.18	1.8	5.2
	4	16	6.2	8.20	2.40	1.92	1.9	5.7
	5	16	6.3	7.70	1.70	2.59	3.2	5.1
3	1	27	10.8	11.90	7.00	1.55	1.7	6.6
	2	18	8.1	5.40	-	-	-	-
	3	16	4.7	8.60	5.00	2.22	1.9	2.8
	4	16	5.0	7.60	1.50	0.67	0.6	4.8
	5	20	7.2	8.30	3.30	2.77	2.5	5.8
4	1	24	8.0	16.90	9.00	2.15	2.1	5.4
	2	20	9.1	13.70	7.40	2.70	1.4	5.6
	3	26	8.8	14.00	6.60	3.04	3.6	6.4
	4	29	9.5	14.00	6.40	3.92	2.8	5.9
	5	25	6.9	10.10	5.20	2.57	2.3	5.0
5	1	15	4.2	5.61	3.10	2.2	1.8	3.8
	2	15	5.1	8.69	3.90	1.67	1.1	3.7
	3	15	6.7	8.71	3.00	3.24	2.1	5.8
	4	15	4.2	7.84	5.23	2.02	1.3	3.4
	5	15	6.1	9.63	3.80	5.89	2.9	4.8
6	1	17	6.6	8.08	4.80	2.47	1.9	5.1
	2	16	7.5	10.44	4.79	1.84	1.3	5.9
	3	23	7.7	11.89	5.12	3.13	2.7	6.7
	4	18	8.0	10.64	5.00	3.73	2.8	6.7
	5	18	8.4	8.90	2.30	3.68	2.1	7.8
7	1	23	13.9	19.60	8.20	11.50	-	-
	2	27	15.6	16.10	9.50	5.02	-	-
	3	34	20.8	22.70	13.70	-	-	-
	4	31	20.0	19.80	13.00	6.95	-	-
	5	31	17.2	18.90	14.50	4.66	-	-
8	1	49	23.0	20.00	4.30	1.04	-	-
	2	61	26.2	26.00	9.30	1.05	-	-
	3	57	25.2	20.30	11.60	0.81	-	-
	4	54	25.4	24.40	3.10	1.40	-	-
	5	51	24.3	20.10	2.80	2.95	-	-
9	1	10	5.5	6.20	2.12	2.60	4.7	2.1
	2	8	4.4	5.20	1.98	1.74	1.4	4.3
	3	8	4.5	5.10	2.51	1.42	1.5	4.3
	4	8	4.5	5.90	1.60	2.12	2.6	4.2
	5	8	4.7	6.00	1.60	1.67	1.5	4.6
10	1	11	4.1	8.00	1.16	0.96	0.9	4.3
	2	12	4.3	6.40	1.20	1.12	1.4	4.5
	3	11	4.9	6.10	1.51	1.98	1.6	4.6
	4	13	4.7	6.70	1.75	3.06	1.9	4.1
	5	14	3.7	5.96	1.58	1.61	1.4	3.7

hllb=height of lowest live branch (m), lllb=length of lowest live branch (m)
dllb=dia. lowest live branch (cm), sdllb=stem dia. at lowest live branch (cm)

Stand ID	Tree ID	hldb (h)	lldb (m)	dldb (cm)	sdldb (cm)
1	1	1.80	0.86	1.9	6.5
	2	2.60	2.46	4.4	8.9
	3	0.89	0.10	1.6	9.2
	4	4.60	1.60	1.1	7.1
	5	1.03	2.18	1.9	10.4
2	1	1.50	3.22	1.9	8.3
	2	2.20	0.98	1.8	4.9
	3	0.64	0.72	0.7	8.7
	4	1.70	1.79	2.1	6.3
	5	1.02	1.12	2.1	6.6
3	1	1.50	0.78	1.4	10.5
	2	2.07	1.59	1.1	1.4
	3	1.70	0.63	1.1	4.9
	4	1.40	0.05	1.3	4.9
	5	1.50	0.64	2.1	6.6
4	1	0.92	0.01	0.4	8.6
	2	6.60	1.62	2.5	6.5
	3	4.40	1.96	3.0	7.4
	4	3.80	0.12	1.3	7.6
	5	5.40	0.14	1.1	4.9
5	1	2.10	0.38	0.4	3.9
	2	1.40	1.52	1.0	5.1
	3	1.59	1.48	1.4	6.4
	4	1.40	0.10	0.4	4.2
	5	0.71	0.92	0.7	6.7
6	1	2.60	3.59	2.0	6.1
	2	2.30	1.88	1.5	7.5
	3	2.30	1.28	1.5	7.1
	4	2.90	3.85	2.6	7.6
	5	1.60	2.85	2.6	7.8
7	1	1.23	0.02	1.5	14.4
	2	4.30	0.51	3.4	13.8
	3	6.20	1.92	-	-
	4	6.90	2.36	-	-
	5	5.20	0.13	3.2	15.8
8	1	3.30	1.25	-	-
	2	6.20	0.93	-	-
	3	12.50	0.73	-	-
	4	2.60	1.64	-	-
	5		-	-	-
9	1	1.42	1.64	1.7	5.2
	2	1.24	0.92	1.8	4.3
	3	1.30	1.40	1.1	4.5
	4	1.20	1.66	1.4	4.7
	5	1.01	0.60	1.0	4.9
10	1	1.01	0.88	0.9	4.7
	2	0.58	0.01	0.2	5.3
	3	0.53	0.22	0.7	4.4
	4	0.57	0.40	0.6	5.2
	5	0.45	0.59	0.7	3.8

hldb=height of lowest dead branch, lldb=length of lowest dead branchdldb=dia. of lowest dead branch, sdldb=stem dia. at lowest dead branch

Stand ID	Tree ID	N	S	E	W	Crown area (m^2)	crown dia. (m)
1	1	0.39	3.06	0.55	0.66	4.26	2.33
	2	1.33	2.31	2.47	1.25	10.64	3.68
	3	2.04	0.37	0.61	0.51	2.45	1.76
	4	0.00	3.31	0.65	0.48	3.87	2.22
	5	1.85	1.98	5.68	0.00	17.76	4.76
2	1	1.09	2.88	0.03	2.75	8.95	3.38
	2	0.00	2.76	1.95	0.90	6.18	2.80
	3	1.10	1.95	1.87	2.09	9.65	3.50
	4	0.80	2.47	2.29	0.51	7.23	3.04
	5	2.40	0.00	0.00	2.14	4.05	2.27
3	1	2.90	0.70	1.43	0.65	6.33	2.84
	2	2.07	1.59	1.06	1.36	7.26	3.04
	3	0.20	0.35	2.19	0.00	1.47	1.37
	4	0.24	1.20	1.18	1.17	2.82	1.90
	5	2.12	0.61	3.79	0.87	10.72	3.70
4	1	0.77	0.84	0.4	1.42	2.31	1.72
	2	1.30	0.00	0.2	0.74	0.99	1.12
	3	1.41	0.54	1.43	1.22	4.15	2.3
	4	4.92	0.39	0.00	0.50	6.637	2.90
	5	1.87	0.46	0.51	0.64	2.38	1.74
5	1	1.74	0.57	0.20	1.28	2.82	1.90
	2	0.47	1.45	0.49	0.77	1.99	1.59
	3	0.74	0.58	1.75	1.52	4.14	2.30
	4	0.00	0.86	0.79	0.51	0.92	1.08
	5	0.63	0.52	1.47	0.00	1.35	1.31
6	1	0.63	0.62	0.59	0.31	0.91	1.08
	2	0.51	0.90	0.87	0.27	1.28	1.28
	3	1.56	2.53	0.64	2.17	9.35	3.45
	4	1.70	0.99	1.56	1.88	7.38	3.06
	5	3.78	0.77	1.11	3.68	17.13	4.67
7	1	1.17	1.24	3.32	0.90	8.63	3.32
	2	0.47	1.98	2.69	0.69	6.67	2.92
	3	0.39	2.46	0.66	0.95	3.91	2.23
	4	0.70	4.65	2.73	2.20	20.75	5.14
	5	1.26	1.47	2.43	1.11	7.72	3.14
8	1	0.44	2.27	0.67	1.94	5.56	2.66
	2	0.59	1.94	0.63	0.68	2.90	1.92
	3	1.12	0.93	0.69	2.22	4.83	2.48
	4	1.70	2.67	1.92	2.87	16.47	4.58
	5	1.81	0.62	1.02	1.99	5.81	2.72
9	1	1.39	1.16	1.51	1.28	5.60	2.67
	2	1.74	1.17	1.38	0.46	4.43	2.38
	3	0.52	0.67	1.42	0.00	1.34	1.30
	4	1.85	0.89	0.55	1.19	3.94	2.24
	5	0.00	2.22	1.16	0.94	3.66	2.16
10	1	1.96	1.53	1.07	1.80	7.94	3.18
	2	1.16	2.59	2.20	1.36	10.49	3.66
	3	2.33	1.98	1.61	1.48	10.75	3.70
	4	0.00	3.34	1.13	1.50	7.00	2.98
	5	2.08	0.70	1.07	0.37	3.50	2.11

Stand ID	Tree ID	Individual Tree Density Fixed	Point Sample BAF	Point Sample count	trees/acre	BA/acre
1	1	59	10	9	1180	90
	2	78	10	8	1560	80
	3	68	10	7	1360	70
	4	75	10	10	1500	100
	5	47	10	18	940	180
2	1	90	10	8	1800	80
	2	95	10	10	1900	100
	3	62	10	7	1240	70
	4	74	10	5	1480	50
	5	75	5	9	1500	45
3	1	49	10	9	980	90
	2	55	10	10	1100	100
	3	59	10	10	1180	100
	4	60	10	8	1200	80
	5	84	10	6	1680	60
4	1	40	10	12	800	120
	2	43	10	16	860	160
	3	42	10	11	840	110
	4	14	10	14	280	140
	5	39	10	11	780	110
5	1	61	10	9	1220	90
	2	97	10	6	1940	60
	3	46	10	9	920	90
	4	70	10	12	1400	120
	5	74	10	8	1480	80
6	1	52	5	11	1040	55
	2	63	5	11	1260	55
	3	21	5	17	420	85
	4	56	5	15	1120	75
	5	29	5	14	580	70
7	1	19	10	10	380	100
	2	20	10	11	400	110
	3	17	10	11	340	110
	4	13	10	12	260	120
	5	29	10	12	580	120
8	1	24	10	13	480	130
	2	11	10	8	220	80
	3	18	10	10	360	100
	4	8	10	6	160	60
	5	9	10	11	180	110
9	1	18	10	8	360	80
	2	12	10	6	240	60
	3	19	10	8	380	80
	4	18	10	4	360	40
	5	11	10	6	220	60
10	1	9	10	7	180	70
	2	10	5	9	200	45
	3	16	5	12	320	60
	4	20	5	11	400	55
	5	18	5	11	360	55

		Stand Density				
Stand ID	Tree ID	Fixed	Point Sample		trees/acre	ba/acre
			BAF	Count		
1	1	74	10	9	1160	108
	2	99	10	10		
	3	51	10	8		
	4	38	10	11		
	5	28	10	16		
2	1	106	10	9	1212	88
	2	28	10	8		
	3	75	10	9		
	4	60	10	10		
	5	34	10	8		
3	1	71	10	5	1092	84
	2	23	10	7		
	3	34	10	7		
	4	41	10	10		
	5	104	10	13		
4	1	36	10	14	656	126
	2	67	10	9		
	3	11	10	8		
	4	25	10	13		
	5	25	10	11		
5	1	64	10	9	1372	90
	2	78	10	10		
	3	36	10	9		
	4	72	10	7		
	5	93	10	10		
6	1	52	5	11	984	65
	2	48	5	14		
	3	33	5	13		
	4	84	5	13		
	5	29	5	14		
7	1	30	10	10	220	94
	2	4	10	10		
	3	18	10	8		
	4	13	10	11		
	5	29	10	12		
8	1	26	10	13	284	104
	2	12	10	9		
	3	13	10	10		
	4	12	10	9		
	5	8	10	11		
9	1	17	10	7	344	64
	2	12	10	6		
	3	8	10	6		
	4	34	10	6		
	5	15	10	7		
10	1	9	10	7	300	79
	2	15	10	6		
	3	17	5	11		
	4	18	5	8		
	5	16	10	17		

APPENDIX V

DATA SUMMARY

Descriptive Statistics

age (yrs)		*DBH (cm)*	
Mean	21.76	Mean	9.55
Standard Deviation	12.69	Standard Deviation	6.40
Minimum	8	Minimum	3.70
Maximum	61	Maximum	26.20
Count	50	Count	50

Tot. Height (m)		*Height lowest live branch (m)*	
Mean	11.59	Mean	4.88
Standard Deviation	5.51	Standard Deviation	3.32
Minimum	5.1	Minimum	1.16
Maximum	26	Maximum	14.5
Count	50	Count	49

Length lowest live branch (m)		*diameter lowest live branch (cm)*	
Mean	2.81	Mean	2.17
Standard Deviation	1.87	Standard Deviation	1.02
Minimum	0.67	Minimum	0.60
Maximum	11.50	Maximum	5.90
Count	48	Count	39

stem diameter at lowest live branch (cm)		*height lowest dead branch (m)*	
Mean	5.17	Mean	2.53
Standard Deviation	1.26	Standard Deviation	2.27
Minimum	2.10	Minimum	0.45
Maximum	7.80	Maximum	12.50
Count	39	Count	49

length lowest dead branch (m)		*diameter lowest dead branch (cm)*	
Mean	1.19	Mean	1.56
Standard Deviation	0.95	Standard Deviation	0.89
Minimum	0.01	Minimum	0.20
Maximum	3.85	Maximum	4.40
Count	49	Count	43

stem diameter at lowest dead branch (cm)		*Crown area (m^2)*	
Mean	6.826976744	Mean	6.184888288
Standard Deviation	2.871544743	Standard Deviation	4.560981752
Minimum	1.36	Minimum	0.907624986
Maximum	15.8	Maximum	20.74988779
Count	43	Count	50

Crown width (m)		*trees/acre (individual tree)*	
Mean	2.6308	Mean	838.4
Standard Deviation	0.986512286	Standard Deviation	535.2526011
Minimum	1.075	Minimum	160
Maximum	5.14	Maximum	1940
Count	50	Count	50

BA/acre (individual tree)	
Mean	87.2
Standard Deviation	29.93462264
Minimum	40
Maximum	180
Count	50

stem diameter at lowest live branch (cm)		*height lowest dead branch (m)*	
Mean	5.169230769	Mean	2.52877551
Standard Error	0.201685002	Standard Error	0.32411426
Median	5.1	Median	1.6
Mode	6.4	Mode	2.6
Standard Deviation	1.259522434	Standard Deviation	2.268799823
Sample Variance	1.586396761	Sample Variance	5.147452636
Kurtosis	0.041561851	Kurtosis	6.779382363
Skewness	-0.076995039	Skewness	2.268536918
Range	5.7	Range	12.05
Minimum	2.1	Minimum	0.45
Maximum	7.8	Maximum	12.5
Sum	201.6	Sum	123.91
Count	39	Count	49
Confidence Level(95.0%)	0.408289955	Confidence Level(95.0%)	0.651675016

length lowest dead branch (m)		*diameter lowest dead branch (cm)*	
Mean	1.188367347	Mean	1.559534884
Standard Error	0.135683047	Standard Error	0.135096026
Median	0.93	Median	1.4
Mode	0.92	Mode	1.1
Standard Deviation	0.949781328	Standard Deviation	0.885883883
Sample Variance	0.902084571	Sample Variance	0.784790255
Kurtosis	0.612109475	Kurtosis	1.415552678
Skewness	0.923384087	Skewness	1.024964835
Range	3.841	Range	4.2
Minimum	0.009	Minimum	0.2
Maximum	3.85	Maximum	4.4
Sum	58.23	Sum	67.06
Count	49	Count	43
Confidence Level(95.0%)	0.27280889	Confidence Level(95.0%)	0.272634904

stem diameter at lowest dead branch (cm)		*Crown area (m^2)*	
Mean	6.826976744	Mean	6.184888288
Standard Error	0.437906468	Standard Error	0.645020225
Median	6.5	Median	5.193833668
Mode	4.9	Mode	2.820382057
Standard Deviation	2.871544743	Standard Deviation	4.560981752
Sample Variance	8.245769214	Sample Variance	20.80255454
Kurtosis	2.389246321	Kurtosis	1.949609988
Skewness	1.350495789	Skewness	1.382740281
Range	14.44	Range	19.84226281
Minimum	1.36	Minimum	0.907624986
Maximum	15.8	Maximum	20.74988779
Sum	293.56	Sum	309.2444144
Count	43	Count	50
Confidence Level(95.0%)	0.88373131	Confidence Level(95.0%)	1.296215886

Crown width (m)		*trees/acre (individual tree)*	
Mean	2.6308	Mean	838.4
Standard Error	0.139513905	Standard Error	75.69614877
Median	2.57	Median	820
Mode	1.895	Mode	360
Standard Deviation	0.986512286	Standard Deviation	535.2526011
Sample Variance	0.97320649	Sample Variance	286495.3469
Kurtosis	0.010473418	Kurtosis	-1.127784847
Skewness	0.518122237	Skewness	0.385593547
Range	4.065	Range	1780
Minimum	1.075	Minimum	160
Maximum	5.14	Maximum	1940
Sum	131.54	Sum	41920
Count	50	Count	50
Confidence Level(95.0%)	0.280363519	Confidence Level(95.0%)	152.1170139

BA/acre (individual tree)	
Mean	87.2
Standard Error	4.233394932
Median	80
Mode	80
Standard Deviation	29.93462264
Sample Variance	896.0816327
Kurtosis	0.849782078
Skewness	0.822380102
Range	140
Minimum	40
Maximum	180
Sum	4360
Count	50
Confidence Level(95.0%)	8.507320465

Correlation Coefficients

	age (yrs)	*DBH (cm)*	*Tot. Height (m)*	*hllb*	*lllb*	*dllb*	*sdllb*
age (yrs)	1						
DBH (cm)	0.945209	1					
Tot. Height (m)	0.887777	0.920085	1				
hllb	0.537699	0.62009	0.729372	1			
lllb	-0.00873	0.138275	0.277078	0.400985	1		
dllb	0.314996	0.453485	0.327983	0.21101	0.752786	1	
sdllb	0.628104	0.819425	0.637707	0.412426	0.486163	0.325152	1
hldb	0.695799	0.694841	0.641331	0.728089	0.013324	0.059056	0.276754
lldb	-0.00501	0.080983	0.04317	0.005565	0.071245	0.35367	0.435859
dldb	0.423877	0.592069	0.411509	0.387733	0.235057	0.324135	0.507539
sdldb	0.683957	0.907499	0.845896	0.802589	0.67781	0.471717	0.794107
Crown area	0.163798	0.274245	0.228889	0.077574	0.358423	0.397904	0.516162
Crown diameter	0.168274	0.274598	0.219676	0.051274	0.329497	0.377935	0.47831
trees/acre (ind tree)	-0.32156	-0.38785	-0.3054	-0.15325	-0.02409	0.065545	0.17561
BA/acre (ind tree)	0.360647	0.347009	0.475755	0.562518	0.359123	0.367402	0.276076
trees/acre (stand)	-0.35563	-0.4604	-0.38684	-0.25833	-0.04265	0.112428	0.322312
ba/acre (stand)	0.499741	0.384224	0.55285	0.423112	0.129131	0.184139	0.267478

	hldb	*lldb*	*dldb*	*sdldb*	*crown area*	*Crown diameter*
age (yrs)						
DBH (cm)						
Tot. Height (m)						
hllb						
lllb						
dllb						
sdllb						
hldb	1					
lldb	0.109121	1				
dldb	0.500795	0.478606	1			
sdldb	0.283078	-0.02915	0.515196	1		
Crown area	-0.00727	0.260943	0.281741	0.321456	1	
Crown diameter	-0.0221	0.207167	0.28482	0.32469	0.977179	1
trees/acre (ind tree)	-0.22355	0.195178	0.143228	-0.03422	-0.21937	-0.23599
BA/acre (ind tree)	0.433201	-0.05769	0.170452	0.345079	0.083194	0.040108
trees/acre (stand)	-0.32099	0.197009	0.00467	-0.12726	-0.15563	-0.18742
ba/acre (stand)	0.426946	-0.2413	0.145348	0.279905	-0.03752	-0.0424

	trees/acre	BA/acre	trees/acre	ba/acre
age (yrs)				
DBH (cm)				
Tot. Height (m)				
hllb				
lllb				
dllb				
sdllb				
hldb				
lldb				
dldb				
sdldb				
Crown area				
Crown diameter				
trees/acre (ind tree)	1			
BA/acre (ind tree)	-0.06639	1		
trees/acre (stand)	0.883637	-0.03168	1	
ba/acre (stand)	0.093874	0.641984	0.025976	1