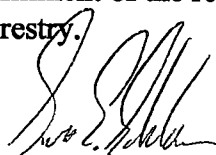


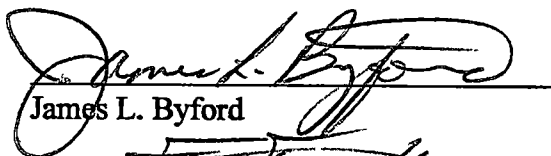
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I am submitting herewith a thesis written by Jason S. Maxedon entitled "Establishment of wildlife plantings using quality-improved seedlings in conjunction with the Tennessee Seed Zone System". I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Forestry.

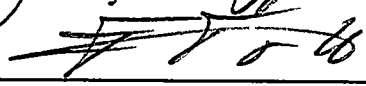


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**ESTABLISHMENT OF WILDLIFE PLANTINGS
USING QUALITY-IMPROVED SEEDLINGS IN
CONJUNCTION WITH THE TENNESSEE SEED
ZONE SYSTEM**

A Thesis

Presented for the

Master of Science

Degree

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Jason Shane Maxedon

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ABSTRACT

The feasibility of establishing locally adapted wildlife plantings using quality-improved seedlings in east Tennessee was studied on four different Tennessee Wildlife Resources Agency (TWRA) properties. Seeds of various mast producing species were collected over a two-year period (fall 1998-fall 1999) and were guided by the Tennessee Seed Zone System. Seeds were collected by individual mother trees.

Seven different species of oak (*Quercus* L.) were grown at the Georgia Forestry Commission's Flint River Nursery in 1998. The seedlings were grown by genetic family for one year to obtain optimal size. They were lifted and visually separated into three grades (cull, good, or premium). Approximately 60 percent of the seedlings were judged to be of acceptable quality for field plantings.

Data were collected on the seedlings to compare first-order lateral root (FOLR) number, height, and root collar diameter (RCD) among and within various oak species. Genetic differences in growth performance of nursery seedlings indicate that families can be selected for early competitiveness in the field based on overall mean nursery performance. Species adapted to more xeric sites, such as scarlet and southern red oaks, had fewer and smaller ranges in FOLR numbers than northern red and willow oak species from mesic or hydric sites, indicating species similarities in adaptability according to site characteristics. The strongest correlation between growth variables was represented by the association between seedling height and RCD except in northern red

oak. The strongest correlation for northern red oak was between FOLR and RCD. The positive correlations between RCD and other growth variables demonstrates that RCD could be a good indicator of FOLR number and height when visually selecting plantable seedlings. Some families had higher percentages of larger seedlings identifying specified mother trees that produce proportionally more high quality seedlings. At least 85 seedlings are needed to adequately represent growth characteristics of a family.

Wildlife plantings of different oak species were established in the winter of 2000. Nine mixed oak plantings were established on four different TWRA Wildlife Management Areas (WMA), leaving additional space for soft mast species to be planted in 2001. The plantings can eventually be thinned of low mast producers and poor growing trees to keep only the fastest growing, best mast producers. In addition to providing mast, these plantings can be developed into seed orchards to provide a source of locally adapted, genetically improved seed. Seedlings that exhibit the best overall masting and growth characteristics can be grafted into to seed orchards to further maximize growth potential, if grafting is an option.

In 1999, five different species of oaks and ten different species of soft mast were collected and planted at the Georgia Forestry Commissions Flint River Nursery. Collection of soft mast seed presented many difficulties and is very resource demanding. Collection procedures will help develop practical collection protocols for native soft mast species at an affordable cost.

The plantings in this study were generally established according to the Tennessee Seed Zones. A Geographical Information System (GIS) database was set up in

conjunction with the Tennessee Seed Zone System using ArcView® GIS (ESRI, Redlands, California). The locations of collection trees were transferred to TWRA GIS personnel. In the future, TWRA personnel will be able make seed collections from mother trees that have been identified as consistent mast producers and/or produce fast growing progenies.

TABLE OF CONTENTS

CHAPTER	PAGE
I. INTRODUCTION	1
II LITERATURE REVIEW	6
Importance of Oak Species to Wildlife	6
Natural Regeneration of Oak Species	7
Artificial Regeneration of Oak Species	8
Production of High-Quality Seedlings	9
Plantings Established for Wildlife	11
Mast and Wildlife	13
Utilization of Hard Mast	14
Utilization of Soft Mast	15
III. MATERIALS and METHODS	17
1998 Seed Collection	17
Seed Handling	19
Nursery Sowing	21
Fertilization Applications	21
Seedling Lifting and Grading	23
Seedling Measurements	23
Statistical Analyses	24
Plantation Establishment	25
1999 Seed Collection	25
Seed Handling and Planting	28
Fertilization Applications	30
GPS and GIS Information	32
IV. RESULTS	40
Species Differences	40
First-Order Lateral Root Number	40
Seedling Height	40
Root Collar Diameter	42
Rank of Growth Variables	42
Family Differences	42
Black Oak	42
FOLR	42
Seedling Height	45
Root Collar Diameter	45

TABLE OF CONTENTS (continued)

CHAPTER	PAGE
Chestnut Oak	45
FOLR	45
Seedling Height	45
Root Collar Diameter	45
Northern Red Oak	48
FOLR	48
Seedling Height	48
Root Collar Diameter	48
Scarlet Oak	48
FOLR	48
Seedling Height	48
Root Collar Diameter	52
Southern Red Oak	52
FOLR	52
Seedling Height	52
Root Collar Diameter	52
Willow Oak	52
FOLR	52
Seedling Height	54
Root Collar Diameter	54
White Oak	54
FOLR	54
Seedling Height	54
Root Collar Diameter	54
Grade Differences	57
FOLR	57
Seedling Height	57
Root Collar Diameter	57
Percentage Comparisons for Grades by Species and Family	60
Family Comparisons by Cluster	64
Correlations Among Seedling Growth Variables	69
Effects of Family Size on Variance Components	86
 V. DISCUSSION	 90
Species Differences	90
Family Differences	92
Grade Differences	93

TABLE OF CONTENTS (continued)

CHAPTER	PAGE
Correlations Between Growth Variables	93
Determination of Minimum Sample Size	95
Seed Collection Procedures	95
Seed Collection and Seed Orchard Establishment	97
Seed Zone System	99
VI. CONCLUSIONS	100
LITERATURE CITED	104
APPENDIX	114
VITA	119

LIST OF TABLES

TABLE	PAGE
3.1 Species and number of families within species represented in the Fall 1998 seed collection	20
3.2 Fertilizer applied at the Georgia Forestry Commission's Flint River Nursery for seedlings grown in 1998	22
3.3 Site information and post-planting maintenance for plantings in east Tennessee, 2000	26
3.4 Species and number of families within species represented in the Fall 1999 seed collection	29
3.5 Fertilizer applied at the Georgia Forestry Commission's Flint River Nursery for seedlings grown in 1999	31
3.6 Species list of abbreviations in conjunction with implementation of the Tennessee Seed Zone System (cf. Post 1998)	115
3.7 County abbreviations in conjunction with implementation of the Tennessee Seed Zone System (cf. Post 1998)	118
4.1 Means and associated standard errors for first-order lateral roots (FOLR), height (cm), and root collar diameter (RCD) (mm) for premium, good , and cull grade oak seedlings grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999	41
4.2 Ranges of first-order lateral roots (FOLR), height (cm), and root collar diameter (RCD) (mm) for premium, good, and cull grade oak seedlings grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999	41
4.3 Rank of species over premium, good, and cull grades for first-order lateral roots (FOLR), height (cm), and root collar diameter RCD (mm) (lowest rank associated with highest means) for oak seedlings grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999	43

LIST OF TABLES (continued)

TABLE	PAGE
4.4 Means and associated standard errors for first-order lateral roots (FOLR), height, and root collar diameter (RCD) for black oak genetic families grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999 . . .	44
4.5 Ranking of black oak genetic families based on number of first-order lateral roots (FOLR), height (cm), and root collar diameter (RCD) (mm) for seedlings grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999	46
4.6 Means and associated standard errors for first-order lateral roots (FOLR), height, and root collar diameter (RCD) for chestnut oak genetic families grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999	47
4.7 Ranking of chestnut oak genetic families based on number of first-order lateral roots (FOLR), height (cm), and root collar diameter (RCD) (mm) for seedlings grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999	47
4.8 Means and associated standard errors for first-order lateral roots (FOLR), height, and root collar diameter (RCD) for northern red oak genetic families grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999	49
4.9 Ranking of northern red oak genetic families based on number of first-order lateral roots (FOLR), height (cm), and root collar diameter (RCD) (mm) for seedlings grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999	49
4.10 Means and associated standard errors for first-order lateral roots (FOLR), height, and root collar diameter (RCD) for scarlet oak genetic families grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999	50
4.11 Ranking of scarlet oak genetic families based on number of first-order lateral roots (FOLR), height (cm), and root collar diameter (RCD) (mm) for seedlings grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999	51

LIST OF TABLES (continued)

TABLE	PAGE
4.12 Means and associated standard errors for first-order lateral roots (FOLR), height, and root collar diameter (RCD) for southern red oak genetic families grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999	53
4.13 Ranking of southern red oak genetic families based on number of first-order lateral roots (FOLR), height (cm), and root collar diameter (RCD) (mm) for seedlings grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999	53
4.14 Means and associated standard errors for first-order lateral roots (FOLR), height, and root collar diameter (RCD) for willow oak genetic families grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999	53
4.15 Ranking of willow oak genetic families based on number of first-order lateral roots (FOLR), height (cm), and root collar diameter (RCD) (mm) for seedlings grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999	55
4.16 Means and associated standard errors for first-order lateral roots (FOLR), height, and root collar diameter (RCD) for white oak genetic families grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999	55
4.17 Ranking of white oak genetic families based on number of first-order lateral roots (FOLR), height (cm), and root collar diameter (RCD) (mm) for seedlings grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999 ...	56
4.18 Means and associated standard errors (SE) for first-order lateral roots (FOLR) for each oak species over premium (grade 1), good (grade 2) , and cull (grade 3) grade seedlings grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999	58
4.19 Means and associated standard errors (SE) of height for each oak species over premium (grade 1), good (grade 2) , and cull (grade 3) grade seedlings grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999 ...	58

LIST OF TABLES (continued)

TABLE	PAGE
4.20 Means and associated standard errors (SE) of root collar diameter (RCD) for each oak species over premium (grade 1), good (grade 2) , and cull (grade 3) grade seedlings grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999	59
4.21 Number of observations and percent of seedlings in each oak species for premium (grade 1), good (grade 2), and cull (grade 3) grade seedlings grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999 ...	61
4.22 Number of observations and percent of seedlings in black oak families for premium (grade 1), good (grade 2), and cull (grade 3) grade seedlings grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999 ...	62
4.23 Number of observations and percent of seedlings in chestnut oak families for premium (grade 1), good (grade 2), and cull (grade 3) grade seedlings grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999	63
4.24 Number of observations and percent of seedlings in northern red oak families for premium (grade 1), good (grade 2), and cull (grade 3) grade seedlings grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999 ...	65
4.25 Number of observations and percent of seedlings in scarlet oak families for premium (grade 1), good (grade 2), and cull (grade 3) grade seedlings grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999 ...	66
4.26 Number of observations and percent of seedlings in southern red oak families for premium (grade 1), good (grade 2), and cull (grade 3) grade seedlings grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999 ...	67
4.27 Number of observations and percent of seedlings in willow oak families for premium (grade 1), good (grade 2), and cull (grade 3) grade seedlings grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999	67
4.28 Number of observations and percent of seedlings in white oak families for premium (grade 1), good (grade 2), and cull (grade 3) grade seedlings grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999 ...	68

LIST OF TABLES (continued)

TABLE	PAGE
4.29 Number of observations and percent of seedlings in clusters 1, 2, 3, and 4 for black oak families grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999	70
4.30 Number of observations and percent of seedlings in clusters 1, 2, 3, and 4 for chestnut oak families grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999	72
4.31 Number of observations and percent of seedlings in clusters 1, 2, 3, and 4 for northern red oak families grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999	74
4.32 Number of observations and percent of seedlings in clusters 1, 2, 3, and 4 for scarlet oak families grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999	76
4.33 Number of observations and percent of seedlings in clusters 1, 2, 3, and 4 for southern red oak families grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999	78
4.34 Number of observations and percent of seedlings in clusters 1, 2, 3, and 4 for willow oak families grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999	78
4.35 Number of observations and percent of seedlings in clusters 1, 2, 3, and 4 for white oak families grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999	81
4.36 Correlations among growth variables for each oak species grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999 without respect to seedling grades	84
4.37 Correlations among growth variables for premium (grade 1), good (grade 2), and cull (grade 3) grade oak seedlings grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999	85

LIST OF FIGURES

FIGURE	PAGE
3.1 Tennessee counties where seeds were collected in 1998 and 1999 and seedlings were distributed in 1999	18
3.2 Seed zone map for Tennessee based on temperature, precipitation, and elevation, developed using a geographic information system (from Post 1998)	33
3.3 Seed zone map for east Tennessee Counties from Post (1998) showing examples of tree locations in the 1999 collection using a geographic information system	34
3.4 Seed zone map for Blount County, Tennessee from Post (1998) showing examples of tree locations in the 1999 collection using a geographic information system	35
3.5 Seed zone map for Campbell County, Tennessee from Post (1998) showing examples of tree locations in the 1999 collection using a geographic information system	36
3.6 Seed zone map for Jefferson County, Tennessee from Post (1998) showing examples of tree locations in the 1999 collection using a geographic information system	37
3.7 Seed zone map for Greene County, Tennessee from Post (1998) showing examples of tree locations in the 1999 collection using a geographic information system	38
3.8 Seed zone map for Monroe County, Tennessee from Post (1998) showing examples of tree locations in the 1999 collection using a geographic information system	39
4.1 Clusters of the top 50 percent of seedlings in black oak genetic families grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999	71
4.2 Clusters of the top 50 percent of seedlings in chestnut oak genetic families grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999	73

LIST OF FIGURES (continued)

FIGURE	PAGE
4.3 Clusters of the top 50 percent of seedlings in northern red oak genetic families grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999	75
4.4 Clusters of the top 50 percent of seedlings in scarlet oak genetic families grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999	77
4.5 Clusters of the top 50 percent of seedlings in southern red oak genetic families grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999	79
4.6 Clusters of the top 50 percent of seedlings in willow oak genetic families grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999	80
4.7 Clusters of the top 50 percent of seedlings in white oak genetic families grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999	82
4.8. Relationship of standard error with sample size (frequency) for first-order lateral roots of seedlings grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999	87
4.9. Relationship of standard error with sample size (frequency) for height of seedlings grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999	88
4.10. Relationship of standard error with sample size (frequency) for root collar diameter of seedlings grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999	89

CHAPTER I.

INTRODUCTION

Mast is a general term that refers to seeds and fruits of plants and is associated with wildlife food sources. Mast is divided into two categories, “hard mast” and “soft mast”. “Hard mast” is the production of hard-shelled seeds, such as acorns (*Quercus* spp. L.) and hickory (*Carya* spp. Nutt.) nuts. “Soft mast” is the production of edible fleshy fruit that contains a seed or seeds, such as persimmon (*Diospyros* spp. L.) and plum (*Prunus* spp. L.).

Studies have shown that year-round foods are important to a large number of wildlife species (Van Dersal 1938, Martin *et al.* 1951, Goodrum *et al.* 1971). Mast has been found to be consumed in all seasons, but not necessarily from the same species. Therefore, it is preferable to manage for a diversity of mast producing species, so that different types of mast will be available throughout the year. Mast producers that collectively ripen throughout all seasons ensure that a variety of nutrients will be available to wildlife, and provide alternative food sources, should one species have a year of low production or mast failure. Additionally, mast diversity reduces the possibility of mast failure due to weather conditions and normal cyclic variations of different species.

Nutritional needs of wildlife change throughout the year in preparation for reproduction, migration, hibernation, and growth (Martin *et al.* 1951). Matching the

changing seasonal needs of wildlife can be possible by providing a diversity of mast producing species throughout the year (Goodrum *et al.* 1971). Nuts can provide carbohydrates and fats (King and McClure 1944, Goodrum 1961) and fleshy fruits provide carbohydrates, vitamins, and minerals, to help meet nutritional needs of wildlife (Short and Epps 1976). Wildlife managers often desire to have a variety of mast producing species on their management areas, because of the importance of hard and soft mast for many species of birds and mammals.

Recently there has been a growing interest for planting mast producing species to augment existing mast or broaden the selection of mast in a given area . When selecting species to plant, native species of a local seed source would be highly desirable because survival is ensured for many years. The term native is commonly used to refer to species that existed in an area prior to European settlement (Calfee 1999). There are many reasons for the preferential selection of a 'native' over a 'non-native' species such as the prevention of exotic invasions, maintenance of biodiversity, and the creation of more suitable habitat for native wildlife. Native species are usually better adapted to soils, climate, rainfall, pests, and soil microorganisms in their geographical range than exotic species or genotypes (Calfee 1999). According to the National Wildlife Federation (1997), native plants can support up to 50 times as many species of native wildlife as non-indigenous plants. Additionally, native trees often tolerate inclement weather better than non-native species (Sternberg 1996).

Several standard forest management options can be applied toward maximizing mast diversity and production. Timber harvest strategies, such as clear cut, group

selection, single tree selection, and prescribed fire are silvicultural techniques that affect mast diversity and production (McAninch *et al.* 1984). These silvicultural techniques may be economically applied on large tracts of forests where more intensive management techniques are needed to achieve desired composition of mast producing species. In certain cases, these management strategies can be augmented with practices such as soil scarification to better establish mast producing species (Stransky and Halls 1980).

Clearcutting is the timber cutting practice that significantly alters wildlife habitat, because it completely removes the tree component of forest habitat. Clearcutting sets succession to an early stage, disturbs soil conditions, and promotes growth of soft mast species (McAninch *et al.* 1984). Group selection initially decreases plant species diversity because small openings temporarily increase shade-intolerant plants and forage plants (Thomas 1979). Single tree selection can be used to preserve individual trees of species with high wildlife values, such as trees that seem to be good and consistent mast producers (McAninch *et al.* 1984). Fire has been found to increase fruit yield averages greater than areas that have been mechanically disturbed (Stransky and Halls 1980).

Some tracts of land may require species enrichment through artificial regeneration practices to achieve a forest composition of hard and soft mast producing species. Standard silvicultural methods as above may not be feasible, practical, or desirable. A benefit of artificial regeneration is the ability to choose specific species or a combination of species that will provide food and habitat for wildlife.

Species selected for planting should be based on mast richness and diversity and landowner objectives. Hard mast seedlings are grown by many nurseries. Although

many native soft mast species are in demand, most growers do not produce seedlings of these species (Calfee 1999). Many soft mast species are considered difficult to handle and grow, and good seed sources often are lacking (Calfee 1999). A few nurseries produce crops of native soft mast species, but often the seedlings are not grown to the size and quality desired by wildlife managers (Calfee 1999). Additionally, identity of seed source is not usually maintained.

One important factor to successful artificial regeneration is the correct selection of species and seed source for proper establishment and productivity of a site (cf. Zobel and Talbert 1984). If a seedling is not planted where it is most likely to survive and thrive, overall productivity will be reduced (Wakeley 1963), which could affect the amount of mast produced over time. Other problems associated with using a seed source not adapted to locality include: poor growth, vigor, and even stand failure, which can also affect the amount of mast produced. Nursery managers often grow seedlings from an unspecified seed source, which can be planted on sites that have a very different environment than the seed origin. According to Post (1998), some environmental factors that affect plant growth and reproduction include: growing season length, amount and seasonal patterns of precipitation, and minimum temperature.

Studies of various tree species have shown genetic variation in seedlings from different geographic sources when grown at the same location (cf. Zobel and Talbert 1984). Post (1998) noted a need for seed zone guidelines based on biological, climate, and geographic criteria for seed collections of species for which no or limited information exists on genetic variation and adaptability to non-native sites. When seed

zones guidelines are not followed in artificial regeneration, the local ecotypes can be contaminated with non-local genes (Wilson 1990). Development of a practical system for collecting seed and returning the resulting seedling to the appropriate seed zone will increase adaptability to local environments (Schubert and Pitcher 1973).

A seed zone system for Tennessee has been developed for use in conjunction with a Geographical Information System (Post 1998). The Tennessee Seed Zone System was created to guide seed and seedling movement within Tennessee to ensure local adaptation of woody species that have not been evaluated by genetic testing. The seed zones were based on the annual distribution of precipitation and minimum temperature over a 30-year period, elevation, and Bailey's Ecoregions. Seed zones for TWRA properties were defined under this system, thereby creating guidelines for seed collection and reforestation by TWRA managers.

This thesis research was conducted to determine the feasibility of using the Tennessee Seed Zone System to establish plantings with high quality seedlings of locally adapted mast species. There were four main objectives:

- (1) establish plantings for wildlife on TWRA properties with quality-improved seedlings to provide year-round mast production,
- (2) compare seedling characteristics within and among various oak species,
- (3) determine how many seedlings are needed to represent an adequate sample size for evaluation of genetic families for seedling quality, and
- (4) document seed collection procedures and establish a GIS database in conjunction with the Tennessee Seed Zone System.

CHAPTER II.

LITERATURE REVIEW

Importance of Oak Species to Wildlife

Quercus L. is the most important, abundant, and widely distributed genus of hardwood trees in the northern temperate zone (Van Dersal 1940). Within the hardwood forest of the eastern United States, oaks are important, dominant species. Oak trees provide many wildlife values, such as cover and food. Oak leaves stay on the tree longer than those of most other species and provide an important part of the winter diet for many species of wildlife such as the white-tailed deer (*Odocoileus virginianus*) (Shaw 1971, Harlow and Hooper 1971, Harlow *et al.* 1975). Leopold (1936) rated oaks as number one on a list of the most palatable browse plants for German deer (*Dama dama*). Correspondingly, management of wildlife habitat in hardwood forests should give high priority to oak regeneration to increase the feeding capacity for forest wildlife (Shaw 1971).

Oaks provide food for more wildlife species than any other genus of woody plants (Van Dersal 1938,1940, Martin *et al.* 1951, Goodrum *et al.* 1971, Shaw 1971, Schroeder and Vanglider 1997). Various parts of oak trees are consumed by 186 different species of birds and mammals, and the geographic distribution of many animals appears to coincide with the range of oak trees (Van Dersal 1940). Acorns are

particularly important for deer (*Odocoileus virginianus*), turkeys (*Meleagris gallopavo*), bears (*Ursus americanus*), and squirrels (*Sciurus spp.*). Non-game animals also feed on acorns (King and McClure 1944), such as bluejays (*Cyanocitta cristata*), crows (*Corvus brachyrhynchos*), titmouse (*Parus bicolor*), chickadee (*Parus carolinensis*), nuthatch (*Sitta spp.*), cranes (*Grus spp.*) and a large variety of rodents (Goodrum 1961).

Acorns are high in fat and carbohydrates, and contain calcium, protein, vitamins, phosphorus, and serve as a good food concentrate (Goodrum *et al.* 1971). Some animal species respond to the availability and quantity of this high-energy food (Goodrum *et al.* 1971, Harlow *et al.* 1975). Acorn crops may influence reproductive success, survival, and body condition in many species of wildlife.

Natural Regeneration of Oak Species

Mixed-oak forests on high-quality sites across the eastern United States often lack oak regeneration following conventional timber harvests (Trimble 1973, Crow 1988). A major factor contributing to this problem is the lack of advanced regeneration of desirable oak species (Lorimer 1992, Loftis 1990). A number of factors, including poor seed production, consumption of acorns, damage to seedlings by insects, animals, weather, site distribution, and poor seedling development under canopies are known to contribute to oak regeneration failures (Lorimer 1992). However, the interactions of all these factors on oak regeneration is still not well understood (Lorimer 1992).

Oak regeneration and management can be a paradox (McGee and Loftis 1986). Significant efforts have been expended to produce and maintain oaks on sites where oaks

are not a desired species or where oaks did not originally reside (McGee and Loftis 1986). In addition, regenerating oaks where oaks are the desired species has proven to be a difficult task (McGee and Loftis 1986).

Oak regeneration failures on good sites (site index 65 +) have been recognized as a widespread problem only in the last fifty years (Lorimer 1992). Oak stands on good sites clear cut after 1930 are now dominated by shade tolerant species of lesser value such as yellow-poplar (*Liriodendron tulipifera* L.), maples (*Acer rubrum* L. and *A. saccharum* M.), and hickories (*Carya* spp. Nutt.), while stands that originated prior to the 1930s on similar sites are usually dominated by oaks (Beck and Hooper 1986, Hix and Lorimer 1991, Abrams and Nowacki 1992).

Artificial Regeneration of Oak Species

Historically, artificial regeneration of oaks was conducted on old field sites for reforestation and for species conversion on timberlands (Pope 1992). More recently, artificial regeneration has been used to supplement natural regeneration prior to or following stand removal, to reforest disturbed lands, and to provide species diversity (Pope 1992).

Artificial regeneration of oak species has never been widely practiced in the United States (Russell 1971). A major reason is that natural regeneration has been abundant on cut-over areas and there was little need for planting or seeding (Russell 1971). Only limited success in planting oaks has been achieved due to faster growing vegetation overtopping seedlings that results in decreased light and seedling suppression

(Johnson 1976, McGee and Loftis 1986, Russell 1973).

Successful establishment of oak seedlings from planting requires appropriate planting procedures, acceptable seedling quality, and limited overstory and understory competition (Bowersox 1992). Conventional planting techniques have been successful in several regions. On cleared forested sites in central Tennessee, first-year survival of white, black, and northern red oaks is usually greater than 90 percent (Russell 1971). In the southern Appalachian region, survival after 2 years averaged 94 percent for six northern red oak plantings spanning a range of site indexes from 76 to 98 feet at age 50 years (Olson and Hooper 1968). However, planted oak seedlings of typical size and quality (i.e., eight inches to sixteen inches in height) usually have good early survival, but early growth is seldom more than a few inches per year (Olson and Hooper 1972, Russell 1971). There is considerable variability in size and root characteristics of oak seedlings that are available at any one time (Bowersox 1992). Planting small seedlings with low vigor often results in suppression by more competitive species (Russell 1971).

Production of High-Quality Seedlings

Planting failures can be partially attributed to the failure of commercial forest tree nurseries in providing nursery stock that can compete successfully in the field (cf. Clark *et al.* 2000). Because of variability in planting stock quality, many hardwood plantings do not grow vigorously or have good survival, especially several years after planting (Johnson 1981, Johnson *et al.* 1986, Wendel 1980). Nurseries typically establish their own procedures for growing seedlings. Recommendations have been

made to adjust nursery practices for production of large nursery stock that can quickly become established in the field (Johnson 1985, Kormanik *et al.* 1994a). However, recommendations vary for identification of superior seedlings (Johnson 1981, Ruehle and Kormanik 1986).

A number of studies have shown that nursery-grown seedlings with larger stems and/or root collar diameters have better survival and growth than smaller stock (Olson and Hooper 1972, Zaczek *et al.* 1997). Ruehle and Kormanik (1986) and Johnson (1989) have demonstrated that first-order lateral root number (FOLR), stem height, and root collar diameter are important factors for the successful establishment of planted oak seedlings. Seedlings with higher FOLR numbers have been found to perform better than those with lower numbers, both in nursery and under field conditions (Johnson 1976, Kormanik *et al.* 1989). Nursery seedlings with the highest FOLR numbers were generally the tallest after one growing season in the nursery (Kormanik *et al.* 1994b, Ruehle and Kormanik 1986) and in the field after 3 to 7 years (Kormanik *et al.* 1995, Thompson and Schultz 1995).

Recently, nursery practices have been developed that concentrate on adjusting fertilization and irrigation applications to produce high-quality oak seedlings (Kormanik *et al.* 1994a, Kormanik *et al.* 1994b). In addition, grading nursery stock has been shown to improve oak seedling field performance (Kormanik *et al.* 1995, Schultz and Thompson 1990). Seedlings have been graded by height (Johnson 1981), FOLR number, and root collar diameter (Kormanik *et al.* 1995, Schultz and Thompson 1990). Grading according to these characteristics are generally not heeded to by commercial nurseries, in

part because of the lack of field performance data for quality-graded seedlings (Lay 1999). Grading seedlings in a commercial nursery operation, in contrast, is generally not based on precise measurements, but on visual assessment of seedling size by relatively unskilled nursery workers (Lay 1999). The effects of visual grading on seedling quality, as defined by stem and root characteristics, has not been well documented.

Previous studies have been conducted to determine differences in size and quality of seedlings. Variation in size and quality of nursery stock has been partially attributed to differences in provenance and mother tree seed source (Buchsacher *et al.* 1991, Kreibel 1965). Field performance has been shown to be significantly influenced by provenances, stands, genetic families, and individual trees within families (Houston 1987, Kreibel *et al.* 1976, Schlarbaum and Bagley 1981).

Plantings Established for Wildlife

Most wildlife plantings have been associated with reforestation efforts on former bottomland hardwood sites (Haynes *et al.* 1988, Haynes *et al.* 1995, Twedt and Portwood 1997). Within the Mississippi Alluvial Valley, reforestation efforts on former bottomland hardwood sites (Savage *et al.* 1989, Newling 1990) are bolstered by U.S. Army Corps of Engineers mitigation, acquisition of public lands for wildlife management, and government incentives to private landowners, such as the Wetland Reserve Program (Twedt and Portwood 1997). Wildlife managers and foresters, however, have historically sought to increase the area of bottomland hardwood forest because of its value as wildlife habitat and for timber production (Twedt and Portwood

1997). Most wildlife managers consider oak the genera of choice for wildlife reforestation.

Green-tree reservoir establishment for wildlife may exceed more acreage than any other type of wildlife planting. Green-tree reservoirs are created by flooding timber stands in the dormant season to provide resting places and food for wintering waterfowl (McQuilkin and Musbach 1977). In terms of providing forage for waterfowl, the value of bottomland hardwood forests is directly related to the proportion and species composition of oaks within the forest (Allen 1987).

Studies have indicated that planting of 1-0 (1 year old) nursery stock or direct seeding can be effective on a variety of lower Mississippi Valley sites (Johnson 1983, Krinard and Kennedy 1987). Also, planting of some light-seeded species (soft mast) with particular value to target wildlife species has occurred on sites distant from mature trees (Allen 1990). Halls and Oefinger (1969) found it feasible to plant dogwood for improvement of wildlife habitat, especially where fruit-producing hardwoods are scarce.

Kramer *et al.* (1952) found that planted dogwoods grew well along the margins of southern pine forests and produced abundant fruit in forest openings (Halls and Alcaniz 1972). Therefore, it may be effectively spot-planted around southern forest openings to provide an abundant source of fall food for wild turkeys and woodland songbirds (Mitchell *et al.* 1988). Dogwood may also be planted in combination with other shrubs to establish woodland borders or develop corridors for game species such as white-tailed deer and wild turkey (Mitchell *et al.* 1988).

Successful establishment of wildlife food and cover plants is prerequisite to restoration of biological productivity to coal surface mines. Several reclamation demonstrations emphasizing wildlife habitat improvement have been conducted by the Tennessee Valley Authority (TVA) since 1963. Fowler and Adkisson (1980) established reclamation plantings for wildlife on TVA properties using 1-0 nursery stock seedlings. They planted a hard and soft mast mix to provide diversity, including sawtooth oak (*Quercus acutissima* L.), bear oak (*Quercus ilicifolia* L.), red maple (*Acer rubrum* L.), manchu cherry (*Prunus tomentosa* L.), autumn olive (*Elaeagnus umbellata* L.), and other species. They felt that the plantings would attract a diversity of wildlife species. However, no results were published on this study due to the reduction of TVA programs.

Mast and Wildlife

The importance of fruit as wildlife food is well known. Oak mast alone is used by many wildlife species and is available for up to 8 months (Van Dersal 1940, Goodrum *et al.* 1971). Certain species of wildlife are dependent on annual fruit production for survival, and data on fruit abundance is quite important (DeGange *et al.* 1989). However, enumeration of the number and size of fruiting plants is often limited to describing fruit-bearing potential and value to wildlife (DeGange *et al.* 1989).

Forests managed primarily for timber have the potential to sustain large wildlife populations, and management can be directed toward increasing the amount of fruit available (Martin *et al.* 1951). In addition to providing essential cover and nesting habitat for many wildlife species, the fruits, seeds, and foliage of woody plants also

furnish a large share of their food. Fruit variety is as important to wildlife as abundance. When a diversity of plants are present, fruits are likely to be available throughout much of the year and meet the nutritional needs of many wildlife species (Johnson and Landers 1978). A variety of mast species helps animals obtain a balanced diet, especially in the South where many forages are deficient during several months of the year (Harlow *et al.* 1975).

Mast richness and abundance are functions of site conditions, weather, and past land use (Edwards *et al.* 1992). Once mast-producing species are established, their inherent yield and periodicity will determine mast abundance. However, the relationship between mast richness and wildlife use is not exact. Each wildlife species may use several mast items during a particular season, depending on availability and individual preference. Harlow and Van Lear (1990) suggested that increases in mast diversity should be accompanied by increased wildlife diversity. Mast production varies considerably among tree species, among trees of the same species, and among years (Christisen and Kearby 1984); thus one must design a mast-production study with great care. To maximize the benefit to wildlife and minimize variations in mast availability, Edwards *et al.* (1992) suggest managing for both traditional (oaks) and buffer (soft mast) mast species in conjunction with maintaining species diversity.

Utilization of Hard Mast

The importance of hard mast as food for a variety of wildlife species has been well documented (Martin *et al.* 1951, Goodrum *et al.* 1971, Shaw 1971). Hard mast

includes fruits with dry or hard exteriors such achenes, nuts, samaras, cones, pods, seeds, and capsules (Martin *et al.* 1951). Hard mast furnishes a substantial and sustaining food for wildlife (Van Dersal 1940) that is high in carbohydrates and fats (King and McClure 1944, Goodrum 1961) and provides energy and nutrients to wildlife (Harlow *et al.* 1975).

Numerous factors affect hard mast production, including age of plant, size of plant, genetics of individual plant, climate, soil, competition for resources, and previous use by animals (Schupp 1990). The annual variation in yield of hard mast production for wildlife food makes it difficult to determine the provisions of stable or high production over large land units (Harlow *et al.* 1975). Consequently, management practices that provide for the greatest variety of food-producing hard mast plants will assure favorable conditions for the greatest variety of wild animals (Harlow *et al.* 1975).

Utilization of Soft Mast

Fleshy fruits or soft mast, rich in carbohydrates and vitamins, are especially important foods for wildlife (Short and Epps 1976). Fleshy fruits are usually products of woody plants and are generally available in late spring , summer, and fall (Martin *et al.* 1951). Some persistent species are available to wildlife during the winter months, such as persimmon (*Diospyros virginiana L.*) and hackberry (*Celtis occidentalis L.*). The widely distributed rose family (*Rosaceae L.*) provides a large proportion of important soft mast species, including blackberry (*Rubus spp.*), serviceberry (*Amelanchier arborea L.*), and hawthorn (*Crataegus spp. L.*) (Martin *et al.* 1951, Edwards *et al.* 1992). Additional soft mast species of wildlife importance are black cherry (*Prunus serotina E.*),

sassafras (*Sassafras albidum* M.), pawpaw (*Asimina triloba* L.), dogwood (*Cornus florida* L.), plum (*Prunus spp.*), red mulberry (*Morus rubra* L.), and carolina buckthorn (*Rhamnus caroliniana* L.) (Martin *et al.* 1951, Halls 1973).

Fruits of wild shrubs and vines are important food items in wildlife diets (Martin *et al.* 1951, Lay 1965). Studies have been conducted on fruit and seed production in pine plantations and fruit production in relation to site disturbance and preparation for wildlife (Lay 1966, Halls and Alcaniz 1968, Johnson and Landers 1978, Campo and Hurst 1980). However, few studies have been conducted on growing and planting seedlings of native species to produce soft mast for wildlife.

CHAPTER III.

MATERIALS AND METHODS

1998 Seed Collection

Open-pollinated progenies (genetic families) were collected from individual trees at five different locations in east Tennessee: Royal Blue WMA, Kyker Bottoms Wetland Refuge, Foothills WMA, Jefferson County Purchase Property, and Great Smoky Mountains National Park (Figure 3.1). University of Tennessee Tree Improvement and Tennessee Wildlife Resources Agency personnel selected the WMAs for the study. The criteria for selection were based on open areas for artificial regeneration.

Each area and proximal properties were surveyed in 1998 for collection trees. The goal was to locate 10 trees of an individual oak species for as many species as possible in each area. Binoculars were used to spot acorns in the tree canopy. Any oak tree producing an estimated 250 or more acorns was designated a potential collection tree. Final selections were made based on the ability to collect acorns from an individual tree without mixing with acorns from surrounding trees. Trees were collected from densely forested stands and open areas. Each collection tree was marked by an aluminum tag with an identification number attached to a ground stake at the base of each tree. The taxonomic identity of each tree was confirmed by using leaf, twig, bark, and fruit characteristics according to the National Audubon Society Field Guide to North

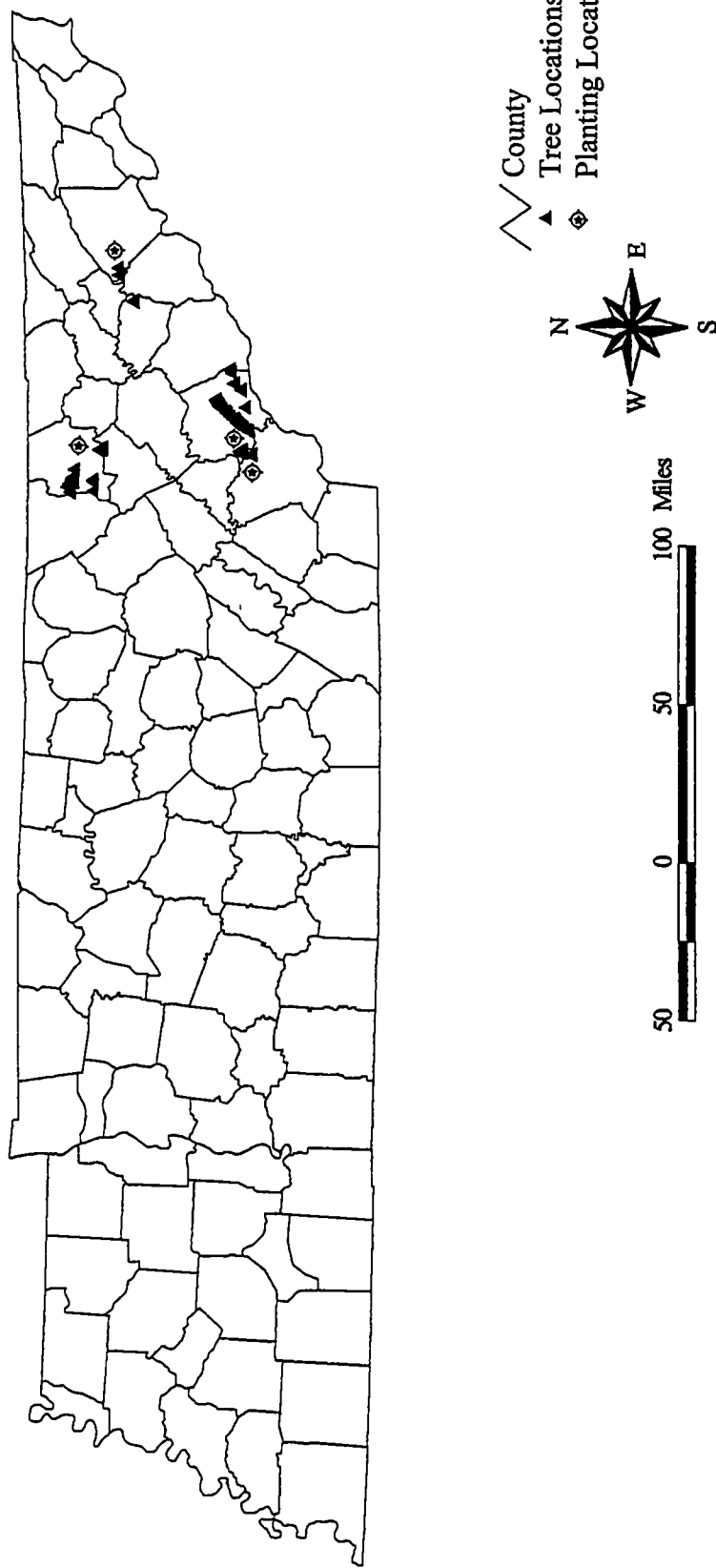


Figure 3.1. Tennessee Counties where seeds were collected in 1998 and 1999 and seedlings were distributed in 1999. Seed collection trees are marked by triangles. Main planting locations are marked with circled stars.

American Trees (Eastern region) (1998).

Black mesh nets were placed beneath some trees to facilitate the collection process. Under trees in the open, the nets were stretched out to the extent of the tree canopy. Nets were not placed under trees in areas that appeared to be heavily used by hunters or recreationists.

All acorns were collected by hand and placed in plastic bags. Each bag was labeled by family and a tag placed inside with the family name and collection date. Acorns from 69 trees were collected in the 1998 Fall (Table 3.1). In addition, family NAWO28 from the USDA Forest Service's Beech Creek Seed Orchard near Murphy, North Carolina was planted due to a shortage of white oak acorns. The mother tree for family NAWO28 was originally from Rockbridge County, Virginia on the Jefferson National Forest, Glenwood Ranger District.

Seed Handling

The acorns were tested for viability immediately after collection. The acorns were subjected to a flotation test for viability (Olson 1974), with the floating acorns discarded, and the sinking acorns retained for planting. The sinking acorns were stored in a plastic bag with the identification number and photographed by family for additional documentation.

The acorns were stored inside a refrigerated cooler at a temperature of 42 degrees Fahrenheit until time for sowing. The acorns were checked weekly for moisture content in the bag. If there was too much moisture, the acorns were moved to another bag.

Table 3.1. Species and number of families within species represented in the Fall 1998 seed collection.

Species	Number of families collected
Black Oak (<i>Quercus velutina</i> L.)	15
Chestnut Oak (<i>Quercus prinus</i> L.)	11
Northern Red Oak (<i>Quercus rubra</i> L.)	7
Post Oak (<i>Quercus stellata</i> L.)	1
Scarlet Oak (<i>Quercus coccinea</i> L.)	9
Southern Red Oak (<i>Quercus falcata</i> L.)	3
White Oak (<i>Quercus alba</i> L.)	13
Willow Oak (<i>Quercus phellos</i> L.)	10

Nursery Sowing

Approximately 13,150 acorns were sown in late November 1998 at the Georgia Forestry Commission's Flint River Nursery, located near Byromville, Georgia and grown according to protocols developed by the USDA Forest Service's Institute for Tree Root Biology (Kormanik *et al.* 1994). The nursery beds were treated with methyl bromide and fertilized prior to planting. Initial fertilizer applications prior to planting included one application of K-Mag ($K_2SO_4 \cdot MgSO_4$) at a rate of 200 lbs/acre of product and one application of zinc sulfate ($ZnSO_4$) at a rate of 25 lbs/acre of product, both were applied on November 10, 1998. There were 548 running bed feet of seed planted by hand at a density of six per square foot. Families were kept separate when sown in the nursery beds, with approximately four feet of empty bed space between each family to facilitate keeping the seedlings separate by family when lifting. The number of acorns available for each family varied widely.

Fertilization Applications

Fertilization regimes for the nursery beds are shown in Table 3.2. Ammonium nitrate (NH_4NO_3) was applied every 10 to 14 days at a rate of 45 lbs/acre of product in May, increasing to 150 lbs/acre of product by September. In early August, one application of K-Mag ($K_2SO_4 \cdot MgSO_4$) was applied at a rate of 250 lbs/acre of product. Fertilization applications ended on September 14, 1999.

Table 3.2. Fertilizer applied at the Georgia Forestry Commission's Flint River Nursery for seedlings grown in 1998. Rates are in pounds of product.

Nursery	Date Applied	Fertilizer applied	Rate applied
Georgia	11-10-98	$K_2SO_4 \cdot MgSO_4$	200 lbs/acre
Georgia	11-10-98	$ZnSO_4$	25 lbs/acre
Georgia	4-3-99	NH_4NO_3	45 lbs/acre
Georgia	5-24-99	NH_4NO_3	45 lbs/acre
Georgia	6-3-99	NH_4NO_3	150 lbs/acre
Georgia	6-14-99	NH_4NO_3	150 lbs/acre
Georgia	6-23-99	NH_4NO_3	150 lbs/acre
Georgia	7-2-99	NH_4NO_3	150 lbs/acre
Georgia	7-16-99	NH_4NO_3	150 lbs/acre
Georgia	7-26-99	NH_4NO_3	150 lbs/acre
Georgia	8-4-99	NH_4NO_3	150 lbs/acre
Georgia	8-4-99	$K_2SO_4 \cdot MgSO_4$	250 lbs/acre
Georgia	8-16-99	NH_4NO_3	150 lbs/acre
Georgia	8-27-99	NH_4NO_3	150 lbs/acre
Georgia	9-14-99	NH_4NO_3	150 lbs/acre

Seedling Lifting and Grading

In early February, the seedlings were undercut to 25-30 cm, lifted with a Fobra™ machine lifter, transported to Knoxville, and placed in cold storage. The seedlings were bundled and graded by family. Seedlings were visually separated into different grades, premium (grade 1), good (grade 2), and cull (grade 3) (*sensu* Clark *et al.* 2000). Only grade 1 and grade 2 seedlings were planted. Grade 3 seedlings were considered to be inferior in quality and culled. Two crews of three people each were formed to sort through the seedlings and separate them into grades for measuring. A few representative samples of medium grade seedlings in each family were used for a guide to determine premium and cull seedlings. The crews were instructed to consider FOLR number, seedling height, and RCD when visually grading seedlings.

Seedling Measurements

After the seedlings were sorted into grades, FOLR numbers were counted, and height and root collar diameters were measured. Height was measured to the nearest 0.5 cm using a meter stick. Root collar diameter (RCD) was measured 2.54 cm above the root collar using digital calipers. A first-order lateral root (FOLR) can be defined as a suberized lateral root stemming from the main taproot that is at least 1 mm in diameter (Kormanik 1994b). All measurements were recorded with a handheld polycorder® (Omnicdata International, Inc.). After evaluation, the seedlings were again placed in cold storage until sorting into different plantations.

Statistical Analyses

The data were analyzed using statistical packages available in SAS version 8 (SAS 1999). The statistical model used to analyze the data was a complete randomized design, with three treatment factors: grade, family and species. Means of height, RCD, and FOLR number for seedlings in each species, family within species, grade (premium, medium, and cull) and seedlings for all three grades combined were calculated. A mixed model analysis (PROC MIXED) was used to detect significant differences among species and families within species as well as grade differences. The least square difference (LSD) values of the family means were averaged to produce a single value for mean separation. Pearson correlation coefficients among growth variables for seedlings in all species and families within species were generated using PROC CORR. An error level of $\alpha = 0.05$ was chosen to indicate significant differences in all statistical procedures.

Number plots were used to determine the relationship of standard error with sample size. This relationship was used to determine how many seedlings in each family are needed for an adequate sample size. Additionally, a cluster analysis (PROC CLUSTER and TREE) was conducted on the top 50 percent of seedlings in each family to identify families that had a high proportion of seedlings with the largest growth characteristics. It was decided *a priori* to divide the seedlings up into four groups based on previous analyses with American chestnut seedlings (Schlarbaum, University of Tennessee unpublished data). A contingency table (PROC FREQ) was used to compare percentages in each grade by family and species.

Plantation Establishment

Plantings for wildlife were established on TWRA properties in early Spring, 2000 (Figure 3.1). Two sites were planted on Lick Creek WMA (BCF and HWCF), four sites on Royal Blue WMA (SQS, CGS, BBS, and BCS), two sites on Kyker Bottoms Wetland Refuge (WFS and BSFS), and one area on Chota WMA (CR). The planting sites generally consisted of old field sites with the exception of two sites on Royal Blue, which were old mine spoil sites (BBS and CGS). Site condition and preparation varied for each individual site prior to planting (Table 3.3). The plantings were guided by the Tennessee Seed Zone System (Post 1998), and species were selected based on whether they were native to the site.

Most plantings were designed to incorporate native soft mast species in the winter of 2001. Mixed oak species plantings varied for each site. Spacing for each site varied depending on seedling numbers and species to be planted in 2001. Half acre spaces were left on two sites to allow native warm season grasses to be planted for nesting cover and food for wildlife.

Gas powered hand augers with 6 inch drill bits were used to drill holes to a depth of 25 to 30 cm deep, and the seedlings were planted by hand. Plantings were then mapped and sprayed with a deer repellent, Deer Away[®], the same day of planting. A 30-day spraying schedule was developed and given to each individual manager.

1999 Seed Collection

To complete the wildlife plantings established by this study, hard and soft mast

Table 3.3. Site information and post-planting maintenance for plantings in east Tennessee, 2000.

Plantation Site	Species occupying site prior to planting	Site preparation	Date of planting	Post-planting site maintenance as of July 1, 2000
1. Hal Wise Carver Farm, Lick Creek WMA	Fescue (<i>Festuca arundinacea</i> L.)	Mowed to clear Fescue	2-24-2000	6 direct sprayings of deer repellent
2. Bible Cemetery Farm, Lick Creek WMA	Fescue (<i>Festuca arundinacea</i> L.)	Mowed to clear Fescue	1-14-2000	7 direct sprayings of deer repellent
3. Sand Query Site, Royal Blue WMA	Perennial grasses and weeds	Cleared with bulldozer	2-23-2000	6 direct sprayings of deer repellent
4. Carryville Grave Site, Royal Blue WMA	Fescue (<i>Festuca arundinacea</i> L.), perennial grasses, and weeds	None	2-26-2000	6 direct sprayings of deer repellent
5. Bear Branch Site, Royal Blue WMA	Fescue (<i>Festuca arundinacea</i> L.)	Cleared with bulldozer	2-23-2000	6 direct sprayings of deer repellent
6. Baptist Church Site, Royal Blue WMA	Perennial grasses and weeds	Cleared with bulldozer	2-22-2000	6 direct sprayings of deer repellent
7. Wheat Field, Kyker Bottoms Wetland Refuge	Winter Wheat (<i>Tritum aestivum</i> L.)	None	2-11-2000 2-25-2000	6 direct sprayings of deer repellent

Table 3.3. (Continued)

8. Broom sedge Field, Kyker Bottoms Wetland Refuge	Broom sedge and Fescue (<i>Festuca arundinacea</i> L.)	Mowed to clear grasses	2-11-2000	6 direct sprayings of deer repellent
9. Chota Ridge, Chota WMA	Clear-cut	Burned	2-25-2000	6 direct sprayings of deer repellent

seed was collected through the summer and fall of 1999. The seed were collected from seven different Tennessee Wildlife Resources Agency management areas in east Tennessee; Royal Blue WMA, Cove Creek WMA, Lick Creek WMA, Jefferson Co. Purchase Property, Chota WMA, Foothills WMA, and Kyker Bottoms Wetland Refuge. The species and collection areas, were selected by Tennessee Wildlife Resources Agency and Tennessee Tree Improvement personnel on the same basis as the acorn collection in 1998. A species list for soft mast species most important to wildlife in east Tennessee was developed by the TWRA area managers (Table 3.4). Seed collection procedures were the same as the 1998 collection. Thirty-nine hard mast and eighty-seven soft mast families were represented in the 1999 seed collection.

Seed Handling and Planting

The acorns were processed as in the 1998 collection. The soft mast seed were cleaned immediately after collection according to specifications found in the Seeds of Woody Plants in The United States (Schopmeyer 1974). All soft mast seed were cleaned by hand with the exception of black cherry. Pulp was completely removed, either floated off by submerging in water or removed by scrubbing the fruit over screens. The black cherry seed were cleaned with a commercial macerator (Dibvig Seed Cleaner™). This machine was used only on black cherry because of the fruit and seed size. Most other fruits collected were either too small or too large to use the machine for the cleaning process.

The seed lots were air dried in the greenhouse and stored under refrigeration (42°

Table 3.4. Species and number of families within species represented in the Fall 1999 seed collection.

Species	Number of families collected
Chestnut Oak (<i>Quercus prinus</i> L.)	12
Swamp Chestnut Oak (<i>Quercus michauxii</i> L.)	6
Swamp White Oak (<i>Quercus bicolor</i> L.)	1
White Oak (<i>Quercus alba</i> L.)	19
Willow Oak (<i>Quercus phellos</i> L.)	1
American Plum (<i>Prunus americana</i> L.)	3
Black Cherry (<i>Prunus serotina</i> L.)	12
Carolina Buckthorn (<i>Rhamnus caroliniana</i> L.)	10
Dogwood (<i>Cornus florida</i> L.)	10
Hackberry (<i>Celtis occidentalis</i> L.)	10
Hawthorn (<i>Crataegus</i> L.)	8
Pawpaw (<i>Asimina triloba</i> L.)	6
Persimmon (<i>Diospyros virginiana</i> L.)	17
Red Mulberry (<i>Morus rubra</i> L.)	2
Sassafras (<i>Sassafras albidum</i>)	9

F) until time for sowing. Each seed lot was checked weekly for moisture content in the bags. If too much moisture was apparent and mildew was imminent, the seed lot was placed in another bag.

The seeds were sown in late November 1999 at the Georgia Forestry Commission's Flint River Nursery and are being grown according to the USDA Forest Service's Institute for Tree Root Biology specifications (Kormanik *et al.* 1994a). The nursery beds were fertilized and treated with methyl bromide prior to planting. Initial fertilizer applications included one application of K-Mag ($K_2SO_4 \cdot MgSO_4$) at a rate of 400 lbs/acre of product, one application of zinc sulfate ($ZnSO_4$) at a rate of 25 lbs/acre of product, one application of dolomitic lime ($CaMg (SO_4)_2$) at a rate of 1,500 lbs/acre of product, and one application of gypsum ($CaSO_4 \cdot 2H_2O$) at a rate of 1,000 lbs/acre of product, all applications were applied on October 10, 1999. Families were sown separately as with the 1998 collection. The number of seed available for each species varied widely. There were approximately 43,896 acorns and 32,496 soft mast seeds sown, comprising 1,829 running bed feet of acorns and 1,354 running bed feet of soft mast seed planted at a density of 6 per square foot.

Fertilization Applications

Fertilization regimes for the nursery beds are shown in Table 3.5. Ammonium nitrate (NH_4NO_3) was applied twice in April at a rate of 45 lbs/acre of product, twice in May at a rate of 90 lbs/acre of product, increasing over the growing season to a rate 150 lbs/acre of product ending September. In mid July, one application of K-Mag ($K_2SO_4 \cdot$

Table 3.5. Fertilizer applied at the Georgia Forestry Commission's Flint River Nursery for seedlings grown in 1999. Rates are in pounds of product.

Nursery	Date Applied	Fertilizer applied	Rate applied
Georgia	10-10-99	$K_2SO_4 \cdot MgSO_4$	400 lbs/acre
Georgia	10-10-99	$CaMg (SO_4)_2$	1500 lbs/acre
Georgia	10-10-99	$CaSO_4 \cdot 2H_2O$	1000 lbs/acre
Georgia	10-10-99	$ZnSO_4$	25 lbs/acre
Georgia	4-6-00	NH_4NO_3	45 lbs/acre
Georgia	4-26-00	NH_4NO_3	45 lbs/acre
Georgia	5-05-00	NH_4NO_3	90 lbs/acre
Georgia	5-13-00	NH_4NO_3	90 lbs/acre
Georgia	5-25-00	NH_4NO_3	150 lbs/acre
Georgia	6-05-00	NH_4NO_3	150 lbs/acre
Georgia	6-15-00	NH_4NO_3	150 lbs/acre
Georgia	6-24-00	NH_4NO_3	150 lbs/acre
Georgia	7-6-00	NH_4NO_3	150 lbs/acre
Georgia	7-17-00	NH_4NO_3	150 lbs/acre
Georgia	7-19-00	$K_2SO_4 \cdot MgSO_4$	300 lbs/acre
Georgia	7-27-00	NH_4NO_3	150 lbs/acre
Georgia	8-7-00	NH_4NO_3	150 lbs/acre
Georgia	8-17-00	NH_4NO_3	150 lbs/acre
Georgia	8-28-00	NH_4NO_3	150 lbs/acre
Georgia	9-7-00	NH_4NO_3	150 lbs/acre
Georgia	9-18-00	NH_4NO_3	150 lbs/acre

MgSO₄) was applied at a rate of 250 lbs/acre of product. Fertilization applications will end around September 18, 2000.

GPS and GIS Information

A Trimble Geo Explorer II™ Global Positioning System unit was used to obtain geographic locations of all collection trees. The coordinates were downloaded into Pathfinder Office™ and differential correction was conducted on each location. The data were then transferred into ArcView® GIS (ESRI, Redlands, California). The coordinates were overlaid on the Tennessee Seed Zone System map (Post 1998) (Figure 3.2). Maps were generated for each county from which seed were collected (Figures 3.3, 3.4, 3.5, 3.6, 3.7, and 3.8). Information was recorded for each tree including collection area, x and y coordinates, tag identification, tree type, county, seed zone, species, tree number, property owner, contact person, collection years, seed quantity, latitude, longitude, elevation, notes about tree, and directions to tree (information on file, University of Tennessee Tree Improvement Program). This information was then transferred to the TWRA GIS personnel.

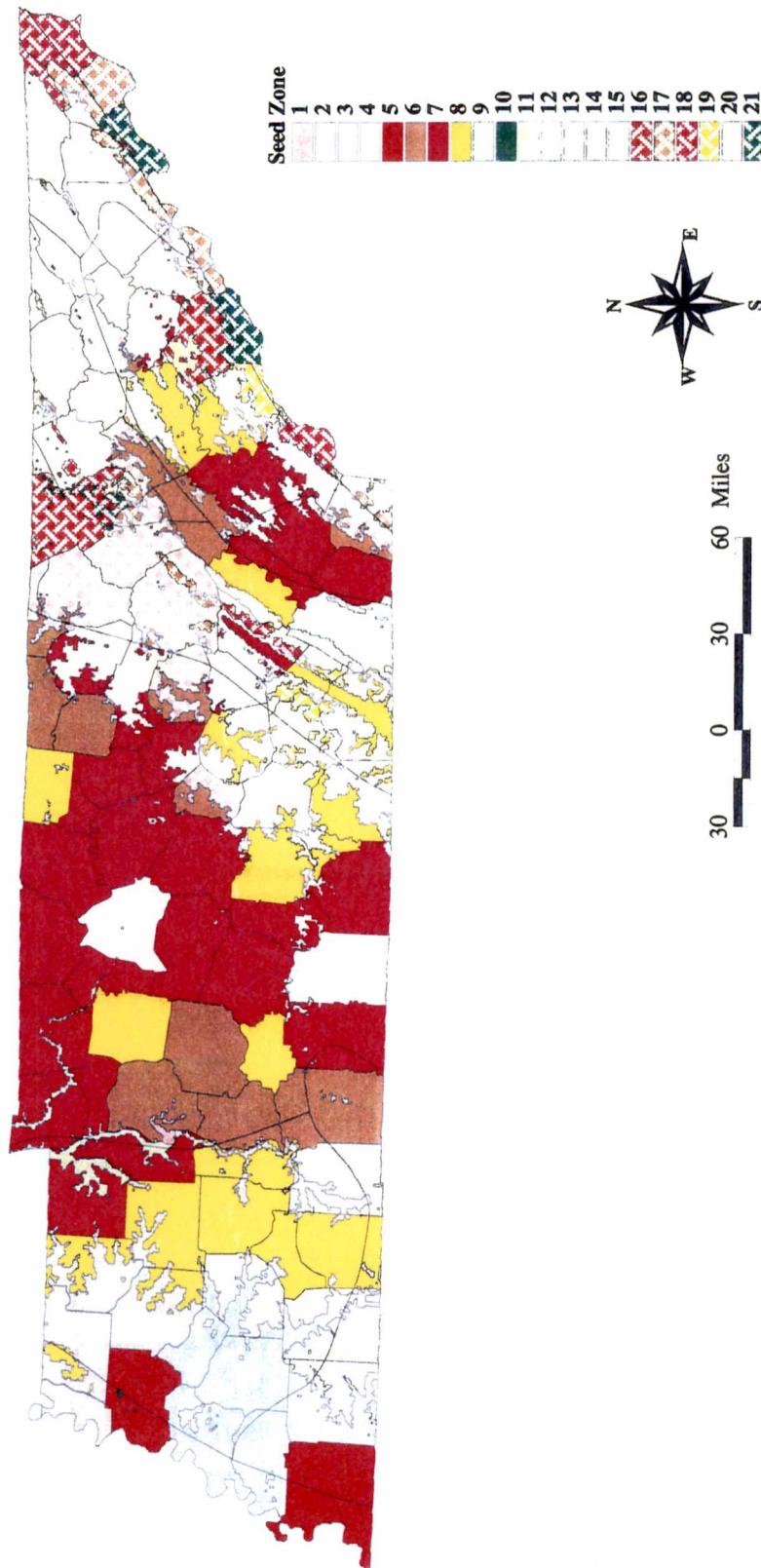


Figure 3.2. Seed zone map for Tennessee based on temperature, precipitation, and elevation, developed using a geographic information system (from Post 1998).

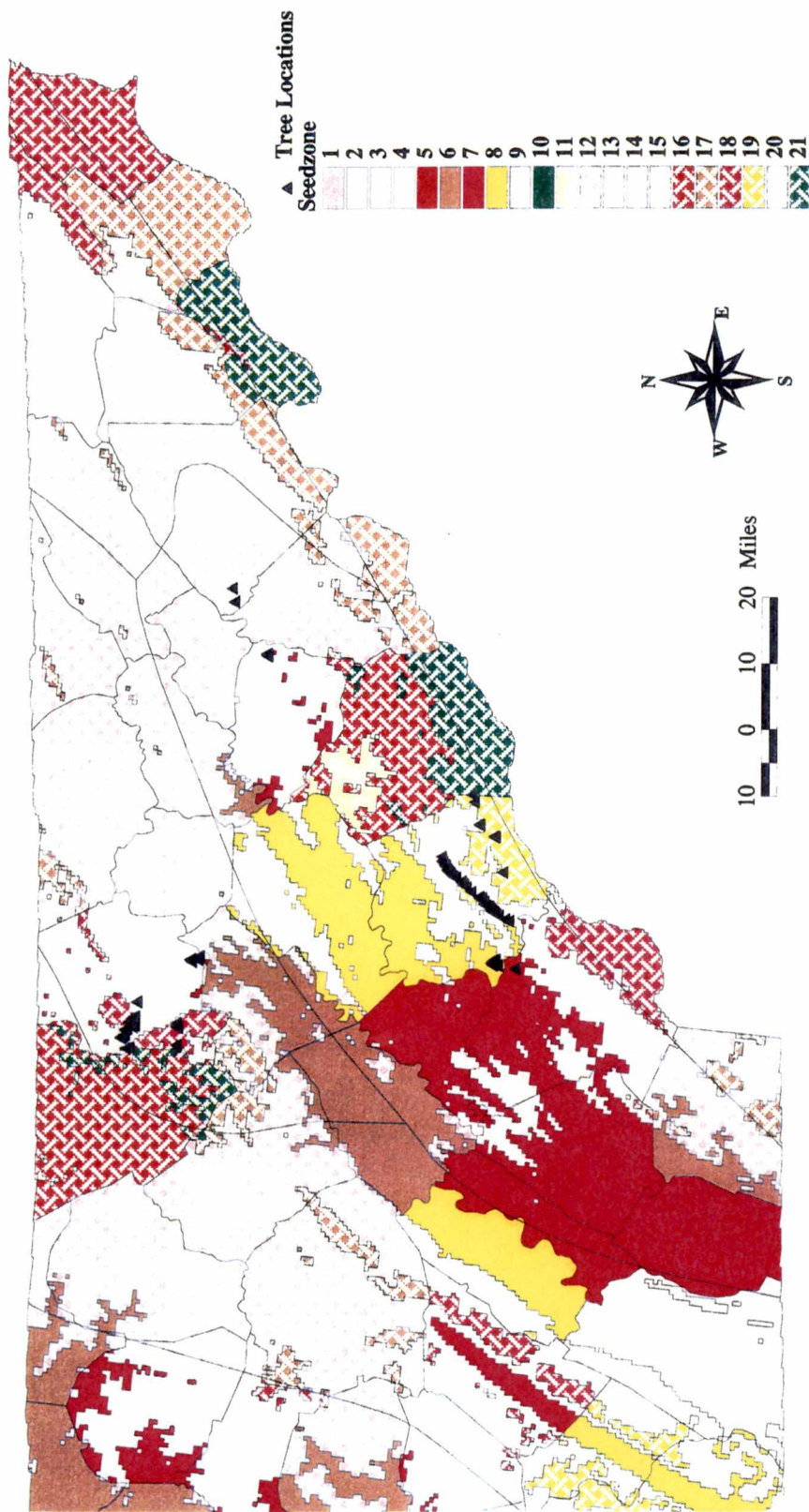


Figure 3.3. Seed zone map for east Tennessee Counties from Post (1998) showing examples of tree locations in the 1999 collection using a geographic information system.

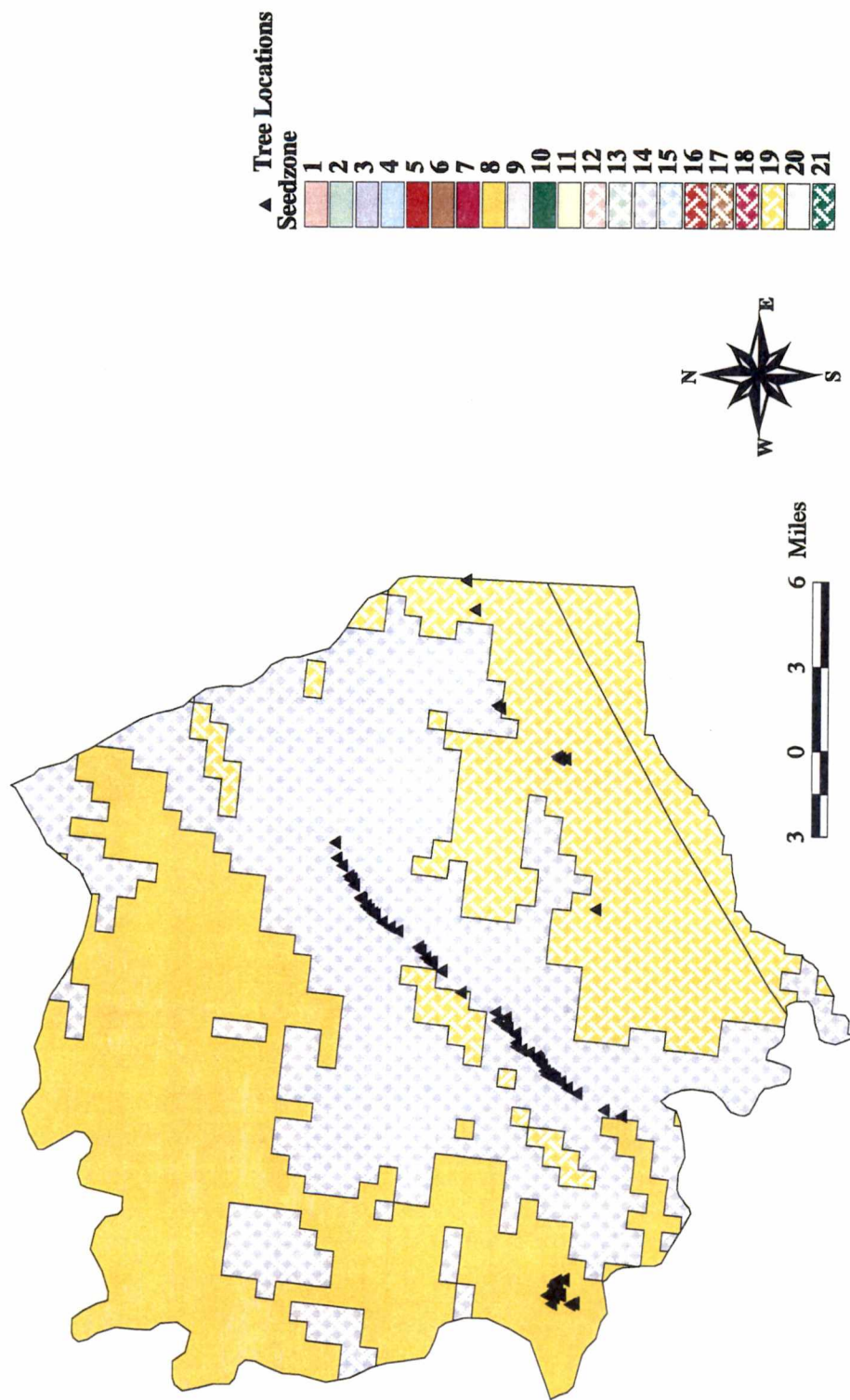


Figure 3.4. Seed zone map for Blount County, Tennessee from Post (1998) showing examples of tree locations in the 1999 collection using a geographic information system.

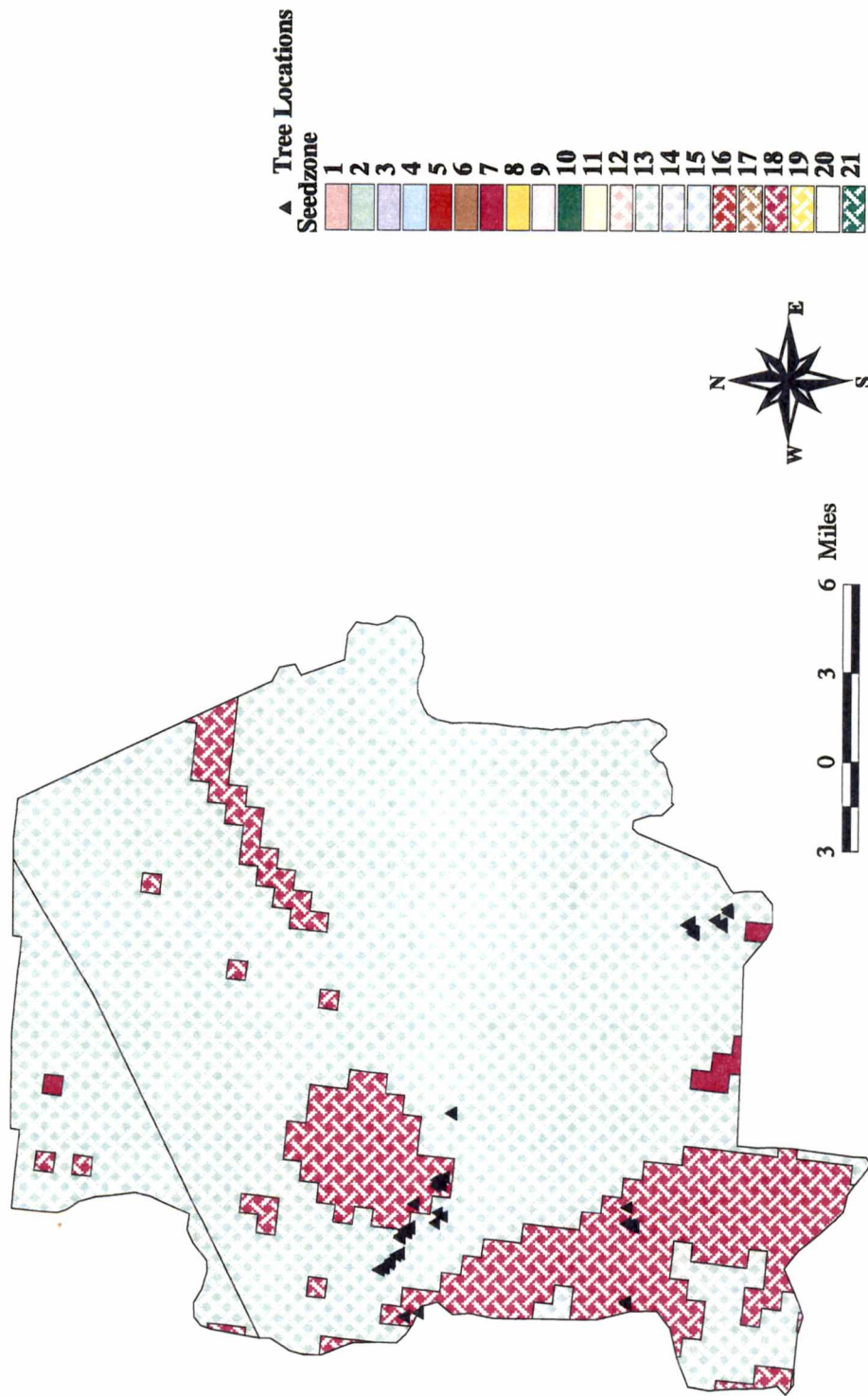


Figure 3.5. Seed zone map for Campbell County, Tennessee from Post (1998) showing examples of tree locations in the 1999 collection using a geographic information system.

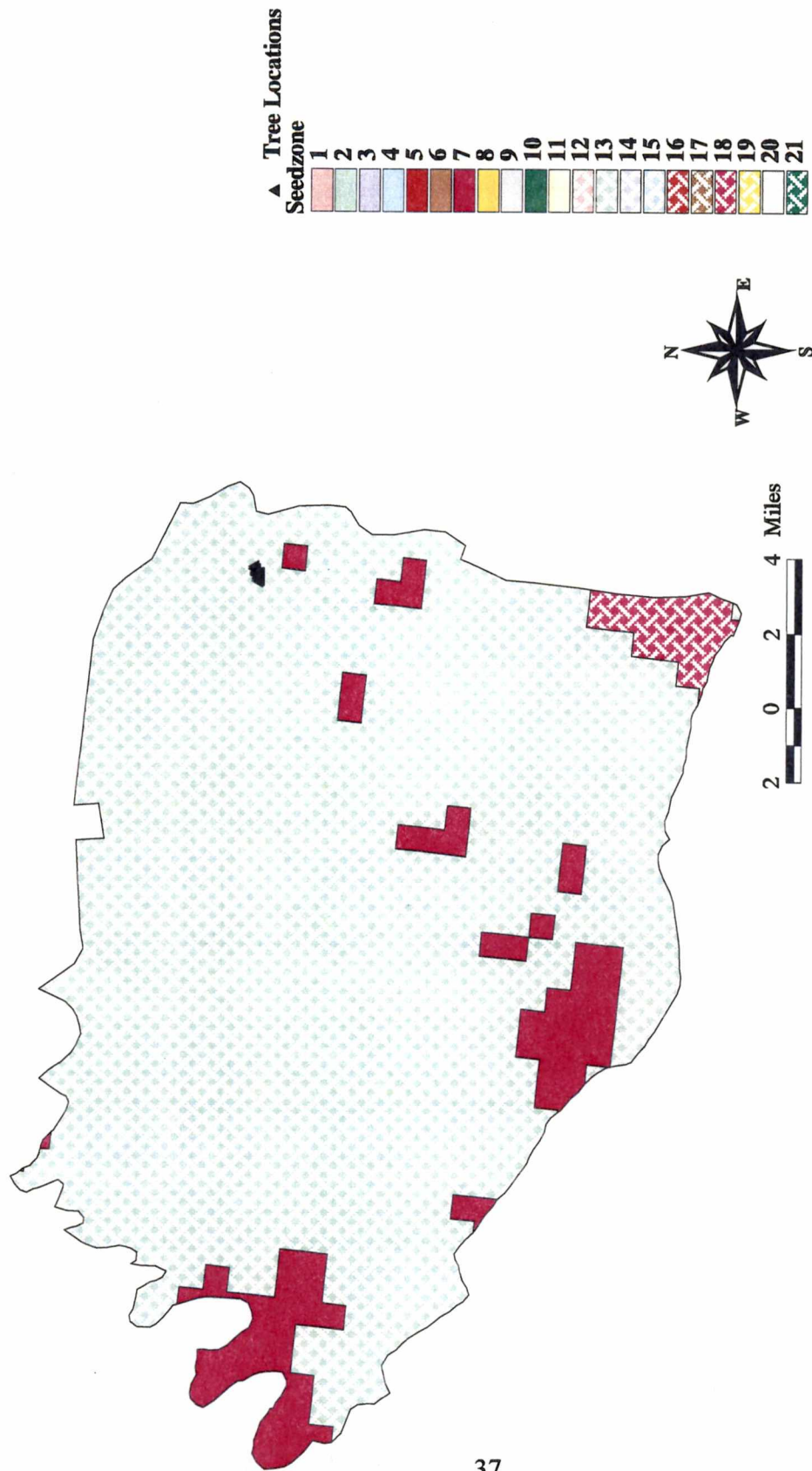


Figure 3.6. Seed zone map for Jefferson County, Tennessee from Post (1998) showing examples of tree locations in the 1999 collection using a geographic information system.

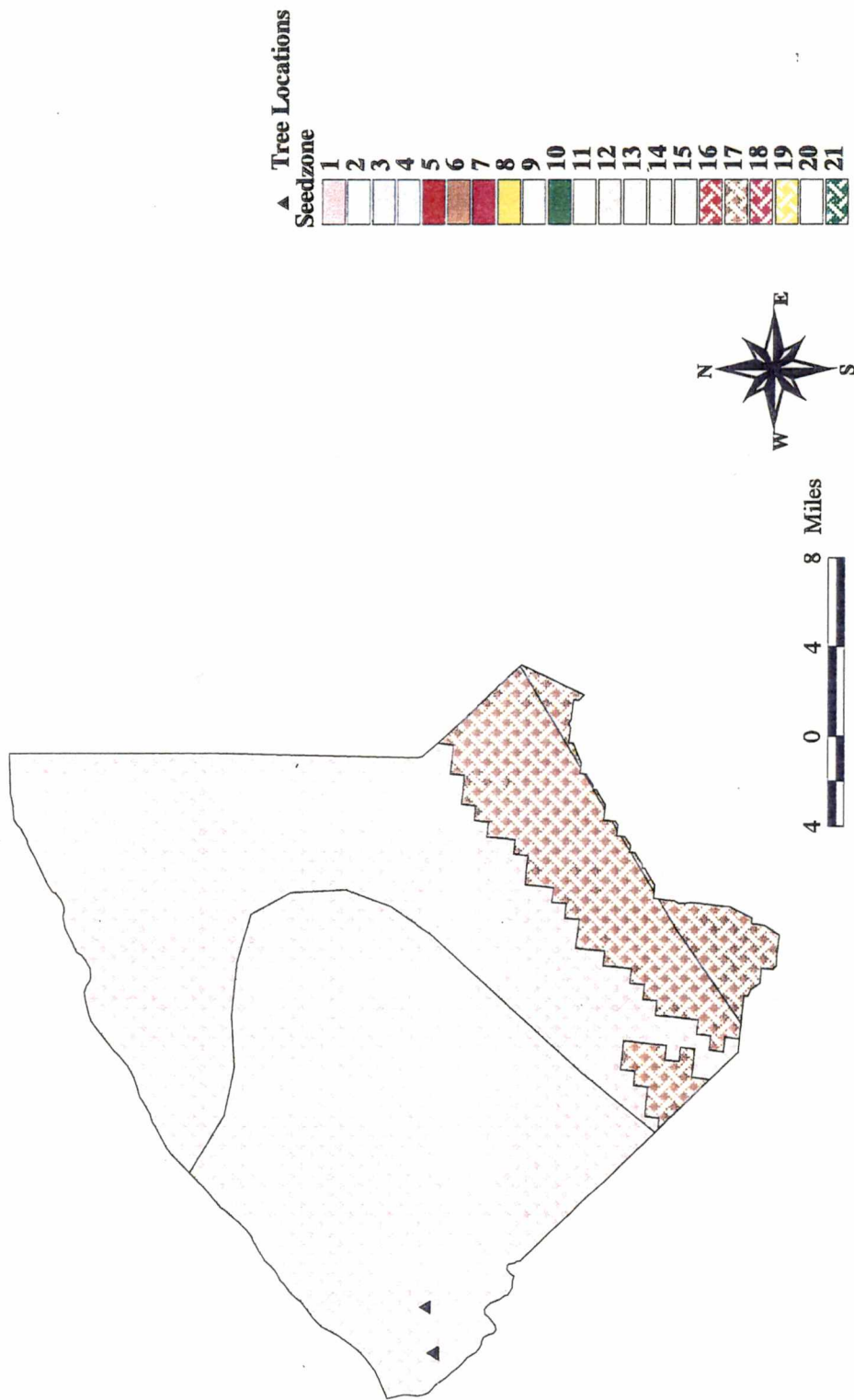


Figure 3.7. Seed zone map for Greene County, Tennessee from Post (1998) showing examples of tree locations in the 1999 collection using a geographic information system.

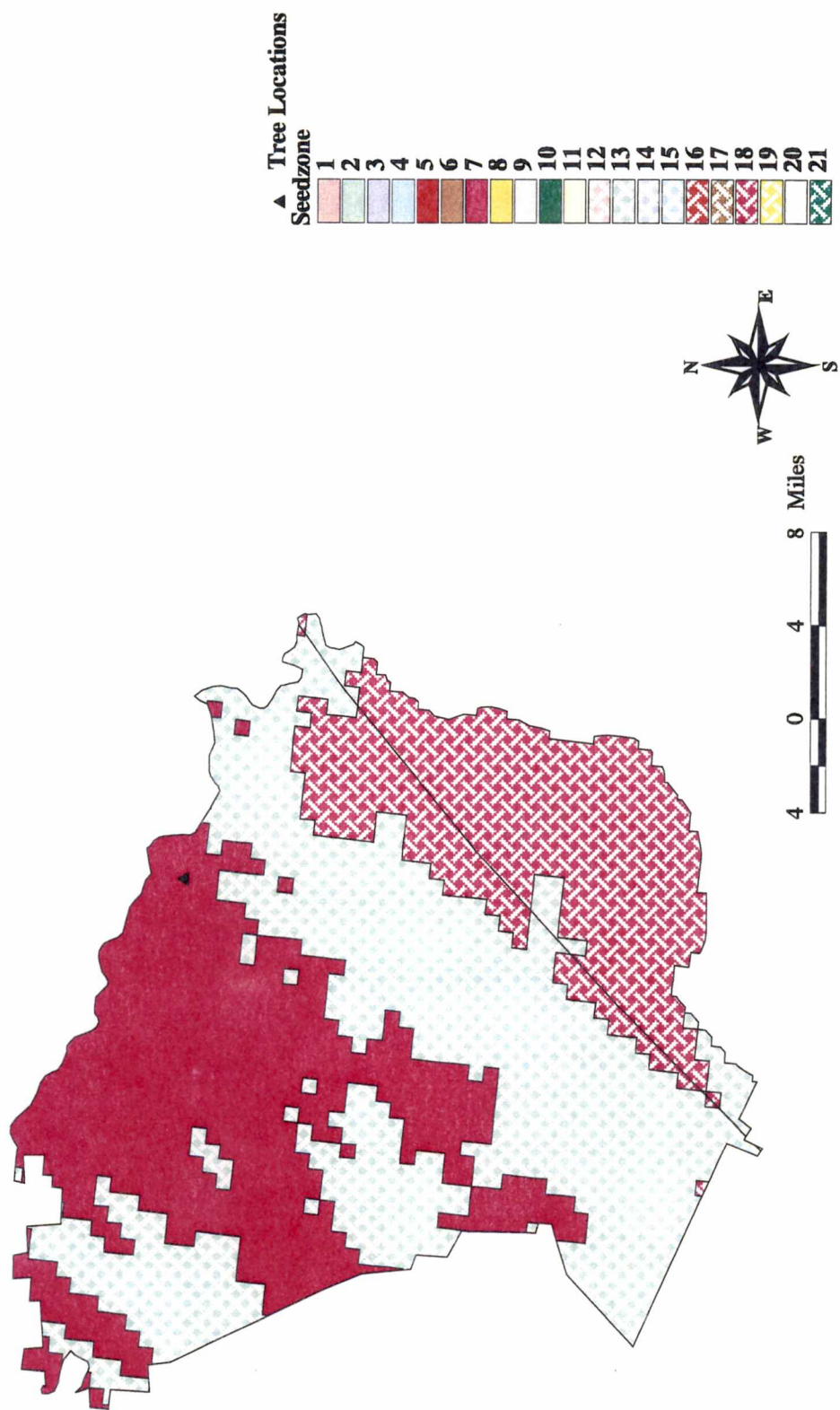


Figure 3.8. Seed zone map for Monroe County, Tennessee from Post (1998) showing examples of tree locations in the 1999 collection using a geographic information system.

CHAPTER IV.

RESULTS

Results of the data analyses will be presented in seven different sections:

1) species differences, 2) family differences, 3) differences within grade, 4) percentage comparisons for grades by species and family, 5) family comparisons by cluster, 6) correlations among seedling growth variables, and 7) effects of family size on variance components.

Species Differences

First-Order Lateral Root number. The average number of FOLR among species over all grades ranged from 9.9 in willow oaks to 2.0 in white oaks (Table 4.1). All means were statistically different except that black oak did not differ from either southern red oak or scarlet oak. Standard error was the greatest in willow oak (0.40) and the least in scarlet oak (0.19). Willow oak had the largest range of FOLR and white oak had the smallest range (Table 4.2).

Seedling Height. The average seedling height among species over all grades ranged from 72.4 cm in northern red oak to 23.6 cm in white oak (Table 4.1). Average heights for northern red oak and chestnut oak did not differ, nor did willow oak and southern red oak. In other species combinations, means were different. The standard

Table 4.1. Means and associated standard errors for first-order lateral roots (FOLR), height (cm), and root collar diameter (RCD) (mm) for premium, good , and cull grade oak seedlings grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999.

Species	No. Obs	FOLR no. (SE)	Height (SE)	RCD (SE)
Black Oak	626	4.2 (0.21)cd	55.1 (0.92)d	9.0 (0.12)c
Chestnut Oak	1,203	3.2 (0.23)e	70.5 (0.99)a	8.7 (0.13)cd
Northern Red Oak	927	6.5 (0.27)b	72.4 (1.23)a	9.6 (0.15)b
Scarlet Oak	1,998	3.9 (0.19)d	58.1 (0.77)c	8.6 (0.11)d
Southern Red Oak	640	4.9 (0.30)c	62.0 (1.22)b	8.1 (0.17)e
Willow Oak	175	9.9 (0.40)a	63.4 (1.71)b	10.6 (0.23)a
White Oak	472	2.0 (0.24)f	23.6 (1.03)e	7.1 (0.13)f

* Means followed by the same letter are not statistically different ($p < 0.05$)

** Average LSD: FOLR = 1.7, Height = 7.6, and RCD = 1.0

Table 4.2. Ranges of first-order lateral roots (FOLR), height (cm), and root collar diameter (RCD) (mm) for premium, good, and cull grade oak seedlings grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999.

Species	FOLR no.	Height	RCD
Black Oak	0-15	10.0-126.0	2.1-19.3
Chestnut Oak	0-24	7.0-162.0	2.7-17.2
Northern Red Oak	0-21	5.9-158.0	2.5-20.3
Scarlet Oak	0-22	5.0-144.0	1.2-18.5
Southern Red Oak	0-22	9.0-112.0	1.9-14.9
Willow Oak	1-27	25.0-111.0	3.5-19.5
White Oak	0-13	7.0-82.0	1.5-15.3

error was greatest in willow oak (1.71) and the least in scarlet oak (0.77). For seedling height, chestnut oak had the largest range and white oak had the smallest range of all species (Table 4.2).

Root Collar Diameter. The average RCD among species over all grades ranged from 10.6 mm in willow oaks to 7.1 mm in white oaks (Table 4.1). All means were statistically different except chestnut oak did not differ from either black oak or scarlet oak. The standard error was the greatest in willow oak (0.23) and the least in scarlet oak (0.11). For root collar diameter, northern red oak had the largest range and southern red oak had the smallest range of all species (Table 4.2).

Rank of Growth Variables. Growth variables were ranked by number with the lowest rank associated with the highest mean (most preferred for seedling quality) for each given characteristic. For example, willow oak exhibited a greater FOLR number per seedling than any other species (Table 4.1). Hence, willow oak was ranked first (Table 4.3). Furthermore, having the least number of FOLR per seedling, white oak was ranked seventh. Northern red oak and willow oak ranked first in height and RCD, respectively, whereas white oak ranked last in both characteristics.

Family Differences

Black Oak

FOLR. The average number of FOLRs among black oak families over all grades ranged from 5.6 in family BOCC3 to 3.1 in family BORB6 (Table 4.4). Family BOCM10 had the greatest standard error (0.90) and BORB9 had the smallest (0.52).

Table 4.3. Rank of species over premium, good, and cull grades for first-order lateral roots (FOLR), height (cm), and root collar diameter RCD (mm) (lowest rank associated with highest means) for oak seedlings grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999.

Species	FOLR no.	Height	RCD
Black Oak	4	6	3
Chestnut Oak	6	2	4
Northern Red Oak	2	1	2
Scarlet Oak	5	5	5
Southern Red Oak	3	4	6
Willow Oak	1	3	1
White Oak	7	7	7

Table 4.4. Means and associated standard errors for first-order lateral roots (FOLR), height, and root collar diameter (RCD) for black oak genetic families grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999.

Family	No. Obs	FOLR no. (SE)	Height in cm (SE)	RCD in mm (SE)
BOCC3	30	5.6 (0.68)a	58.7 (3.05)ab	8.8 (0.39)bc
BOCM10	18	5.1 (0.90)ab	41.3 (4.06)c	8.4 (0.51)c
BOCM4	23	4.1 (0.73)abc	62.7 (3.31)a	9.5 (0.41)ab
BOCM6	85	3.4 (0.56)bc	49.8 (2.38)b	8.5 (0.31)bc
BORB1	88	4.4 (0.57)abc	57.8 (2.42)ab	8.5 (0.32)bc
BORB5	28	4.2 (0.72)abc	56.7 (3.24)ab	9.2 (0.41)abc
BORB6	76	3.1 (0.58)c	61.3 (2.49)ab	9.9 (0.33)a
BORB7	48	4.6 (0.61)abc	47.1 (2.69)bc	9.1 (0.35)abc
BORB8	50	3.7 (0.61)bc	61.4 (2.65)ab	10.0 (0.34)a
BORB9	180	3.9 (0.52)abc	54.2 (2.16)b	8.4 (0.30)c

* Means followed by the same letter are not statistically different ($p < 0.05$)

** Average LSD: FOLR = 1.7, Height = 7.6, and RCD = 1.0

*** CC = Cades Cove, CM = Chilhowee Mountain, and RB = Royal Blue

Families are ranked based on the number of FOLRs in Table 4.5.

Seedling Height. The average seedling height among black oak families over all grades ranged from 62.7 cm for family BOCM4 to 41.3 cm for family BOCM10 (Table 4.4). The standard error was greatest in BOCM10 (4.06) and the least in BORB9 (2.16).

Root Collar Diameter. The average RCD among black oak families over all grades ranged from 10.0 mm in family BORB8 to 8.4 mm in families BOCM10 and BORB9 (Table 4.4). The standard error was greatest in BOCM10 (0.51) and the least in BORB9 (0.30).

Chestnut Oak

FOLR. The average number of FOLRs among chestnut oak families over all grades ranged from 4.9 in family COCM2 to 1.9 in family COCM6 (Table 4.6). Mean separations showing statistical differences between growth variable means for each family are denoted in the table by alphabetic representation. The standard error was greatest in COCM6 (0.80) and the least in COCM2 and COCM3 (0.50). Families are ranked based on the number of FOLRs in Table 4.7.

Seedling Height. The average seedling height among chestnut oak families over all grades ranged from 84.0 cm for family COCM3 to 56.5 cm for family COCM10 (Table 4.6). The standard error was the greatest in COCM6 (3.63) and the least in COCM3 (2.04).

Root Collar Diameter. The average RCD among chestnut oak families over all grades ranged from 9.5 mm in family COCM8 to 7.9 mm in families COCM1 and COCM10 (Table 4.6). The standard error was the greatest in COCM6 (0.45) and the

Table 4.5. Ranking of black oak genetic families based on number of first-order lateral roots (FOLR), height (cm), and root collar diameter (RCD) (mm) for seedlings grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999.

Family	FOLR no.	Height	RCD
BOCC3	1	4	6
BOCM10	2	10	9.5
BOCM4	6	1	3
BOCM6	9	8	7.5
BORB1	4	5	7.5
BORB5	5	6	4
BORB6	10	3	2
BORB7	3	9	5
BORB8	8	2	1
BORB9	7	7	9.5

* CC = Cades Cove, CM = Chilhowee Mountain, and RB = Royal Blue

Table 4.6. Means and associated standard errors for first-order lateral roots (FOLR), height, and root collar diameter (RCD) for chestnut oak genetic families grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999.

Family	No. Obs	FOLR no. (SE)	Height in cm (SE)	RCD in mm (SE)
COCC1	171	2.7 (0.53)bc	74.2 (2.22)b	9.2 (0.30)a
COCM1	190	2.0 (0.52)c	69.4 (2.14)b	7.9 (0.41)c
COCM10	57	2.0 (0.72)c	56.5 (3.06)c	7.9 (0.41)c
COCM2	325	4.9 (0.50)a	83.2 (2.05)a	9.0 (0.28)ab
COCM3	366	4.3 (0.50)ab	84.0 (2.04)a	8.1 (0.28)bc
COCM6	21	1.9 (0.80)c	57.5 (3.63)c	8.5 (0.45)ac
COCM8	73	4.2 (0.60)ab	68.7 (2.57)b	9.5 (0.34)a

* Means followed by the same letter are not statistically different ($p < 0.05$)

** Average LSD: FOLR = 1.7, Height = 7.6 , and RCD = 1.0

*** CC = Cades Cove and CM = Chilhowee Mountain

Table 4.7. Ranking of chestnut oak genetic families based on number of first-order lateral roots (FOLR), height (cm), and root collar diameter (RCD) (mm) for seedlings grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999.

Family	FOLR no.	Height	RCD
COCC1	4	3	2
COCM1	5.5	4	6.5
COCM10	5.5	7	6.5
COCM2	1	2	3
COCM3	2	1	5
COCM6	7	6	4
COCM8	3	5	1

* CC = Cades Cove and CM = Chilhowee Mountain

least in COCM2 and COCM3 (0.28).

Northern Red Oak

FOLR. The average number of FOLRs among northern red oak families over all grades ranged from 10.0 in family NROKB1 to 4.2 in family NRORB10 (Table 4.8).

The standard error was greatest in NROKB2 (1.18) and the least in NRORB10 (0.51).

Families are ranked based on the number of FOLRs in Table 4.9.

Seedling Height. The average seedling height among northern red oak families over all grades ranged from 84.5 cm for family NRORB3 to 55.3 cm for family NROCM3 (Table 4.8). The standard error was greatest in NROKB2 (5.66) and the least in NRORB10 (2.08).

Root Collar Diameter. The average RCD among northern red oak families over all grades ranged from 11.0 mm in families NROCM1 and NROKB1 to 8.3 mm in family NRORB4 (Table 4.8). The standard error was the greatest in NROKB2 (0.67) and the least in NRO RB10(0.29).

Scarlet Oak

FOLR. The average number of FOLRs among scarlet oak families over all grades ranged from 5.3 in family SCOCC4 to 2.8 in family SCOCC6 (Table 4.10). The standard error was greatest in SCOCM2 (0.58) and the least in SCOCC5, SCOCC6, and SCOCC7 (0.50). Families are ranked based on the number of FOLRs in Table 4.11.

Seedling Height. The average seedling height among scarlet oak families over all grades ranged from 65.5 cm for family SCOCC5 to 53.9 cm for family SCOCC8 (Table 4.10). The standard error was greatest in SCOCM2 (2.52) and the least in

Table 4.8. Means and associated standard errors for first-order lateral roots (FOLR), height, and root collar diameter (RCD) for northern red oak genetic families grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999.

Family	No. Obs	FOLR no. (SE)	Height in cm (SE)	RCD in mm (SE)
NROCM1	92	7.9 (0.56)b	79.1 (2.38)ab	11.0 (0.32)a
NROCM3	78	5.9 (0.60)cd	55.3 (2.64)e	10.8 (0.34)a
NROKB1	17	10.0 (0.79)a	76.9 (3.68)abc	11.0 (0.45)a
NROKB2	6	7.3 (1.18)bc	67.3 (5.66)d	9.3 (0.67)b
NRORB10	261	4.2 (0.51)d	73.2 (2.08)bc	8.5 (0.29)b
NRORB3	215	5.7 (0.52)cd	84.5 (2.16)a	8.7 (0.30)b
NRORB4	258	4.4 (0.64)d	70.8 (2.63)cd	8.3 (0.36)b

* Means followed by the same letter are not statistically different ($p < 0.05$)

** Average LSD: FOLR = 1.7, Height = 7.6 , and RCD = 1.0

*** CM = Chilhowee Mountain, KB = Kyker Bottom, and RB = Royal Blue

Table 4.9. Ranking of northern red oak genetic families based on number of first-order lateral roots (FOLR), height (cm), and root collar diameter (RCD) (mm) for seedlings grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999.

Family	FOLR no.	Height	RCD
NROCM1	2	2	1.5
NROCM3	4	7	3
NROKB1	1	3	1.5
NROKB2	3	6	4
NRORB10	7	4	6
NRORB3	5	1	5
NRORB4	6	5	7

* CM = Chilhowee Mountain, KB = Kyker Bottom, and RB = Royal Blue

Table 4.10. Means and associated standard errors for first-order lateral roots (FOLR), height, and root collar diameter (RCD) for scarlet oak genetic families grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999.

Family	No. Obs	FOLR no. (SE)	Height in cm (SE)	RCD in mm (SE)
SCOCC4	137	5.3 (0.54)a	61.8 (2.26)ab	9.5 (0.31)a
SCOCC5	423	3.7 (0.50)ab	65.5 (2.03)a	8.2 (0.28)bc
SCOCC6	474	2.8 (0.50)b	57.3 (2.02)bc	7.5 (0.28)c
SCOCC7	314	3.6 (0.50)ab	60.4 (2.06)abc	8.6 (0.29)ab
SCOCC8	190	3.9 (0.52)ab	53.9 (2.13)cd	9.0 (0.29)ab
SCOCC9	220	5.0 (0.52)a	48.1 (2.18)d	8.2 (0.30)bc
SCOCM2	68	4.0 (0.58)ab	55.3 (2.52)bcd	8.7 (0.33)a
SCORB2	172	3.6 (0.52)ab	62.5 (2.16)ab	9.2 (0.30)ab

* Means followed by the same letter are not statistically different ($p < 0.05$)

** Average LSD: FOLR = 1.7, Height = 7.6 , and RCD = 1.0

*** CC = Cades Cove, CM = Chilhowee Mountain, and RB = Royal Blue

Table 4.11. Ranking of scarlet oak genetic families based on number of first-order lateral roots (FOLR), height (cm), and root collar diameter (RCD) (mm) for seedlings grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999.

Family	FOLR no.	Height	RCD
SCOCC4	1	3	1
SCOCC5	5	1	6.5
SCOCC6	8	5	8
SCOCC7	6.5	4	5
SCOCC8	4	6	3
SCOCC9	2	8	6.5
SCOCM2	3	7	4
SCORB2	6.5	2	2

* CC = Cades Cove, CM = Chilhowee Mountain, and RB = Royal Blue

SCOCC6 (2.02).

Root Collar Diameter. The average RCD among scarlet oak families over all grades ranged from 9.5 mm in family SCOCC4 to 7.5 mm in family SCOCC6 (Table 4.8). The standard error was the greatest in SCOCM2 (0.33) and the least in SCOCC5 and SCOCC6 (0.28).

Southern Red Oak

FOLR. The average number of FOLRs among southern red oak families over all grades ranged from 5.4 in family SROCC2 to 4.3 in family SROCC1 (Table 4.12). The standard error was the greatest in SROCC2 (0.52) and the least in SROCC1 and SROCM4 (0.51). Families are ranked based on the number of FOLRs in Table 4.13.

Seedling Height. The average seedling height among southern red oak families over all grades ranged from 67.5 cm for family SROCM4 to 51.4 cm for family SROCC2 (Table 4.12). The standard error was the greatest in SROCC2 (2.16) and the least in SROCM4 (2.09).

Root Collar Diameter. The average RCD among southern red oak families over all grades ranged from 8.5 mm in family SROCC1 to 7.8 mm in family SROCC2 (Table 4.12). The standard error was the greatest in SROCC2 (0.30) and the least in SROCC1 and SROCM4 (0.29).

Willow Oak

FOLR. The average number of FOLRs among willow oak families over all grades ranged from 10.4 in family WLOJC1 to 9.5 in family WLOJC4 (Table 4.14). The standard error was the greatest in WLOJC4 (0.58) and the least in WLOJC1 (0.54).

Table 4.12. Means and associated standard errors for first-order lateral roots (FOLR), height, and root collar diameter (RCD) for southern red oak genetic families grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999.

Family	No. Obs	FOLR no. (SE)	Height in cm (SE)	RCD in mm (SE)
SROCC1	220	4.3 (0.51)a	67.3 (2.11)a	8.5 (0.29)a
SROCC2	181	5.4 (0.52)a	51.4 (2.16)b	7.8 (0.30)a
SROCM4	239	4.9 (0.51)a	67.5 (2.09)a	7.9 (0.29)a

* Means followed by the same letter are not statistically different ($p < 0.05$)

** Average LSD: FOLR = 1.7, Height = 7.6 , and RCD = 1.0

*** CC = Cades Cove and CM = Chilhowee Mountain

Table 4.13. Ranking of southern red oak genetic families based on number of first-order lateral roots (FOLR), height (cm), and root collar diameter (RCD) (mm) for seedlings grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999.

Family	FOLR no.	Height	RCD
SROCC1	3	2	1
SROCC2	1	3	3
SROCM4	2	1	2

* CC = Cades Cove and CM = Chilhowee Mountain

Table 4.14. Means and associated standard errors for first-order lateral roots (FOLR), height, and root collar diameter (RCD) for willow oak genetic families grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999.

Family	No. Obs	FOLR no. (SE)	Height in cm (SE)	RCD in mm (SE)
WLOJC1	114	10.4 (0.54)a	27.0 (2.53)b	10.4 (0.31)a
WLOJC4	61	9.5 (0.58)a	55.1 (2.53)a	10.8 (0.33)a

* Means followed by the same letter are not statistically different ($p < 0.05$)

** Average LSD: FOLR = 1.7, Height = 7.6 , and RCD = 1.0

*** JC = Jefferson County

Families are ranked based on the number of FOLRs in Table 4.15.

Seedling Height. The average seedling height among willow oak families over all grades ranged from 55.1 cm for family WLOJC4 to 27.0 cm for family WLOJC1 (Table 4.14). The standard error was the greatest in WLOJC1 and WLOJC4 (2.53).

Root Collar Diameter. The average RCD among willow oak families over all grades ranged from 10.8 mm in family WLOJC4 to 10.4 mm in family WLOJC1 (Table 4.14). The standard error was the greatest in WLOJC4 (0.33) and the least in WLOJC1 (0.31).

White Oak

FOLR. The average number of FOLRs among white oak families over all grades ranged from 3.7 in family WORB2 to 0.93 in family WORB8 (Table 4.16). The standard error was the greatest in WORB3 (0.77) and the least in WORB1 (0.58). Families are ranked based on the number of FOLRs in Table 4.17.

Seedling Height. The average seedling height among white oak families over all grades ranged from 32.0 cm for family WORB4 to 16.7 cm for family WORB9 (Table 4.16). The standard error was the greatest in NAWO28 (3.19) and the least in WORB1 (2.53).

Root Collar Diameter. The average RCD among white oak families over all grades ranged from 7.7 mm in family WORB9 to 6.4 mm in family WORB1 (Table 4.16). The standard error was the greatest in WORB3 (0.44) and the least in WORB1 (0.33).

Table 4.15. Ranking of willow oak genetic families based on number of first-order lateral roots (FOLR), height (cm), and root collar diameter (RCD) (mm) for seedlings grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999.

Family	FOLR no.	Height	RCD
WLOJC1	1	2	2
WLOJC4	2	1	1

* JC = Jefferson County

Table 4.16. Means and associated standard errors for first-order lateral roots (FOLR), height, and root collar diameter (RCD) for white oak genetic families grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999.

Family	No. Obs	FOLR no. (SE)	Height in cm (SE)	RCD in mm (SE)
NAWO28	75	1.9 (0.75)b	22.1 (3.19)bc	6.9 (0.42)ab
WORB1	62	1.1 (0.58)c	27.0 (2.53)ab	6.4 (0.33)b
WORB2	91	3.7 (0.59)a	23.7 (2.54)bc	7.5 (0.34)a
WORB3	41	2.5 (0.77)abc	20.8 (3.36)bc	6.8 (0.44)ab
WORB4	82	1.7 (0.62)c	32.0 (2.66)a	6.9 (0.35)ab
WORB6	44	0.96 (0.66)c	26.3 (2.90)ab	7.3 (0.37)ab
WORB8	44	0.93 (0.63)c	19.8 (2.76)bc	6.9 (0.36)ab
WORB9	33	3.5 (0.67)ab	16.7 (3.00)c	7.7 (0.38)a

* Means followed by the same letter are not statistically different ($p < 0.05$)

** Average LSD: FOLR = 1.7, Height = 7.6 , and RCD = 1.0

*** NA = Northern Appalachian and RB = Royal Blue

Table 4.17. Ranking of white oak genetic families based on number of first-order lateral roots (FOLR), height (cm), and root collar diameter (RCD) (mm) for seedlings grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999.

Family	FOLR no.	Height	RCD
NAWO28	4	5	5
WORB1	6	2	8
WORB2	1	4	2
WORB3	3	6	7
WORB4	5	1	5
WORB6	7	3	3
WORB8	8	7	5
WORB9	2	8	1

* NA = Northern Appalachian and RB = Royal Blue

Grade Differences

Tables 4.18, 4.19, and 4.20 present the mean differences and associated standard errors across seedling grades for FOLR, height, and RCD, respectively. The larger means for each seedling characteristic are associated with a higher quality seedling. The means for each seedling characteristic decreased as seedling grade decreased.

FOLR. The average number of FOLR among species for grade 1 ranged from 12.6 in willow oak to 3.8 in white oak (Table 4.18). The standard error was the greatest in willow oak (0.71) and the least in scarlet oak (0.33). The average number of FOLR among species for grade 2 ranged from 10.6 in willow oak to 1.4 in white oak. The standard error was the greatest in willow oak (0.68) and the least in scarlet oak (0.31). The average number of FOLR among species for grade 3 ranged from 6.6 in willow oak to 0.6 in southern red oak. The standard error was the greatest in willow oak (0.68) and the least in scarlet oak (0.32).

Seedling Height. The average seedling height among species for grade 1 ranged from 98.6 in northern red oak to 32.7 in white oak (Table 4.19). As with FOLR, standard error was the greatest in willow oak (3.07) and the least in scarlet oak (1.40). The average seedling height among species for grade 2 ranged from a high of 75.1 in northern red oak to a low of 21.9 in white oak. The standard error was the greatest in willow oak (2.89) and the least in scarlet oak (1.28). The average seedling height among species for grade 3 ranged from 50.0 in willow oak to 16.1 in white oak. The standard error was the greatest in willow oak (2.89) and the least in scarlet oak (1.31).

Root Collar Diameter. The average RCD among species for grade one ranged

Table 4.18. Means and associated standard errors (SE) for first-order lateral roots (FOLR) for each oak species over premium (grade 1), good (grade 2) , and cull (grade 3) grade seedlings grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999.

Species	Grade 1	Grade 2	Grade 3
Black Oak	6.6 (0.36)	4.3 (0.33)	1.7 (0.36)
Chestnut Oak	4.9 (0.40)	3.2 (0.35)	1.3 (0.41)
Northern Red Oak	9.9 (0.43)	6.3 (0.47)	3.2 (0.41)
Scarlet Oak	7.1 (0.33)	4.1 (0.31)	0.7 (0.32)
Southern Red Oak	8.8 (0.52)	5.1 (0.51)	0.6 (0.51)
Willow Oak	12.6 (0.71)	10.6 (0.68)	6.6 (0.68)
White Oak	3.8 (0.45)	1.4 (0.36)	0.92 (0.42)

Table 4.19. Means and associated standard errors (SE) of height for each oak species over premium (grade 1), good (grade 2) , and cull (grade 3) grade seedlings grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999.

Species	Grade 1	Grade 2	Grade 3
Black Oak	74.4 (1.62)	58.2 (1.41)	32.7 (1.57)
Chestnut Oak	96.9 (1.72)	71.7 (1.45)	42.8 (1.72)
Northern Red Oak	98.6 (1.88)	75.1 (2.03)	43.6 (1.76)
Scarlet Oak	82.9 (1.40)	70.0 (1.28)	30.4 (1.31)
Southern Red Oak	83.7 (2.16)	64.4 (2.08)	38.0 (2.12)
Willow Oak	77.1 (3.07)	63.2 (2.89)	50.0 (2.89)
White Oak	32.7 (2.05)	21.9 (1.54)	16.1 (1.82)

Table 4.20. Means and associated standard errors (SE) of root collar diameter (RCD) for each oak species over premium (grade 1), good (grade 2) , and cull (grade 3) grade seedlings grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999.

Species	Grade 1	Grade 2	Grade 3
Black Oak	10.8 (0.21)	9.2 (0.19)	7.1 (0.21)
Chestnut Oak	10.9 (0.23)	8.8 (0.20)	6.3 (0.23)
Northern Red Oak	12.1 (0.24)	9.9 (0.27)	7.0 (0.23)
Scarlet Oak	11.4 (0.19)	9.0 (0.18)	5.5 (0.18)
Southern Red Oak	10.8 (0.30)	8.2 (0.29)	5.2 (0.29)
Willow Oak	13.0 (0.40)	10.7 (0.39)	8.2 (0.39)
White Oak	8.6 (0.26)	7.1 (0.20)	5.5 (0.24)

from 13.0 in willow oak to 8.6 in white oak (Table 4.20). As with seedling height, standard error was the greatest in willow oak (0.40) and the least in scarlet oak (0.19). The average RCD among species for grade two ranged from 10.7 in willow oak to 7.1 in white oak. The standard error was the greatest in willow oak (0.39) and the least in scarlet oak (0.18). The average RCD among species for grade three ranged from 8.2 in willow oak to 5.5 in scarlet oak and white oak. The standard error was the greatest in willow oak (0.39) and the least in scarlet oak (0.18).

Percentage Comparisons for Grades by Species and Family

In grade 1, percentages ranged from 36.35 % in northern red oak to 13.98 % in white oak (Table 4.21). Grade 2 percentages ranged from 45.97 % in white oak to 27.08 in northern red oak. Grade 3 percentages ranged from 40.04 % in white oak to 31.41 in southern red oak. Grade 2 represented the largest number of seedlings at 2,402.

In black oak, grade 1 seedlings ranged from 34.78 % in family BOCM4 to 14.47 % in family BORB6 (Table 4.22). Grade 2 seedlings ranged from 77.78 % in family BOCM10 to 26.09 in family BOCM4. Grade 3 seedlings ranged from 47.73 % in family BORB1 to 0.00 % in family BOCM10.

In chestnut oak, grade 1 seedlings ranged from 32.00 % in family COCM2 to 9.52 in family COCM6 (Table 4.23). Grade 2 seedlings ranged from 73.68 % in family COCM10 to 26.77 % in family COCM2. Grade 3 seedlings ranged from 42.47 % in family COCM8 to 0.00 % in family COCM10.

In northern red oak, grade 1 seedlings ranged from 75.19 % in family NRORB4

Table 4.21. Number of observations and percent of seedlings in each oak species for premium (grade 1), good (grade 2), and cull (grade 3) grade seedlings grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999.

Species	Grade 1	Grade 2	Grade 3	Total
BO/# Obs Percent	135 21.57	252 40.26	239 38.18	626
CO/# Obs Percent	293 24.36	520 43.23	390 32.42	1,203
NRO/# Obs Percent	337 36.35	251 27.08	339 36.57	927
SCO/# Obs Percent	382 19.12	844 42.24	772 38.64	1,998
SRO/# Obs Percent	185 28.91	254 39.69	201 31.41	640
WLO/# Obs Percent	42 24.00	64 36.57	69 39.43	175
WO/# Obs Percent	66 13.98	217 45.97	189 40.04	472
Total	1,440 23.84	2,402 39.67	2,199 36.40	6,041 100.00

* BO = Black Oak, CO = Chestnut Oak, NRO = Northern Red Oak, SCO = Scarlet Oak, SRO = Southern Red Oak, WLO = Willow Oak, and WO = White Oak

Table 4.22. Number of observations and percent of seedlings in black oak families for premium (grade 1), good (grade 2), and cull (grade 3) grade seedlings grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999.

Family	Grade 1	Grade 2	Grade 3	Total
BOCC3/#Obs Percent	8 26.67	13 43.33	9 30.00	30
BOCM10/#Obs Percent	4 22.22	14 77.78	0 0.00	18
BOCM4/#Obs Percent	8 34.78	6 26.09	9 39.13	23
BOCM6/#Obs Percent	22 25.88	33 38.82	30 35.29	85
BORB1/#Obs Percent	13 14.77	33 37.50	42 47.73	88
BORB5/#Obs Percent	7 25.00	17 60.71	4 14.29	28
BORB6/#Obs Percent	11 14.47	32 42.11	33 43.42	76
BORB7/#Obs Percent	12 25.00	15 31.25	21 43.75	48
BORB8/#Obs Percent	13 26.00	18 36.00	19 38.00	50
BORB9/#Obs Percent	37 20.56	71 39.44	72 40.00	180
Total	135 21.57	252 40.26	239 38.18	626 100.00

* CC = Cades Cove, CM = Chilhowee Mountain, and RB = Royal Blue

Tale 4.23. Number of observations and percent of seedlings in chestnut oak families for premium (grade 1), good (grade 2), and cull (grade 3) grade seedlings grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999.

Family	Grade 1	Grade 2	Grade 3	Total
COCC1/#Obs Percent	32 18.71	107 62.57	32 18.71	171
COCM1/#Obs Percent	45 23.68	70 36.84	75 39.47	190
COCM10/#Obs Percent	15 26.32	42 73.68	0 0.00	57
COCM2/#Obs Percent	104 32.00	87 26.77	134 41.23	325
COCM3/#Obs Percent	88 24.04	165 45.08	113 30.87	366
COCM6/#Obs Percent	2 9.52	14 66.67	5 23.81	21
COCM8/#Obs Percent	7 9.59	35 47.95	31 42.47	73
Total	293 24.36	520 43.23	390 32.42	1,203 100.00

* CC= Cades Cove and CM = Chilhowee Mountain

to 6.41 in family NROCM3 (Table 4.24). Grade 2 seedlings ranged from 44.87 % in family NROCM3 to 0.00 in family NRORB4. Grade 3 seedlings ranged from 51.63 % in family NRORB3 to 24.81 % in family NRORB4.

In scarlet oak, grade 1 seedlings ranged from 27.37 % in family SCOCC8 to 14.98 in family SCOCC6 (Table 4.25). Grade 2 seedlings ranged from 56.93 % in family SCOCC4 to 38.30 % in family SCOCC5. Grade 3 seedlings ranged from 46.82 % in family SCOCC9 to 23.36 % in family SCOCC4.

In southern red oak, grade 1 seedlings ranged from 33.18 % in family SROCM4 to 20.44 in family SROCC2 (Table 4.26). Grade 2 seedlings ranged from 43.65 % in family SROCC2 to 35.98 % in family SROCM4. Grade 3 seedlings ranged from 35.91 % in family SROCC2 to 26.36 % in family SROCC1.

In willow oak, grade 1 seedlings ranged from 34.43 % in family WLOJC4 to 18.42 in family WLOJC1 (Table 4.27). Grade 2 seedlings ranged from 37.72 % in family WLOJC1 to 34.43 % in family WLOJC4. Grade 3 seedlings ranged from 43.86 % in family WLOJC1 to 31.15 % in family WLOJC4.

In white oak, grade 1 seedlings ranged from 29.03 % in family WORB1 to 4.88 in family WORB4 (Table 4.28). Grade 2 seedlings ranged from 89.33 % in family NAWO28 to 27.27 % in family WORB8. Grade 3 seedlings ranged from 63.41 % in family WORB4 to 0.00 % in family NAWO28.

Family Comparisons by Cluster

The cluster analysis divided the seedlings into four clusters as planned *a priori*.

Table 4.24. Number of observations and percent of seedlings in northern red oak families for premium (grade 1), good (grade 2), and cull (grade 3) grade seedlings grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999.

Family	Grade 1	Grade 2	Grade 3	Total
NROCM1/#Obs Percent	17 18.48	35 38.04	40 43.48	92
NROCM3/#Obs Percent	5 6.41	35 44.87	38 48.72	78
NROKB1/#Obs Percent	7 41.18	5 29.41	5 29.41	17
NROKB2/#Obs Percent	3 50.00	1 16.67	2 33.33	6
NRORB10/#Obs Percent	83 31.80	99 37.93	79 30.27	261
NRORB3/#Obs Percent	28 13.02	76 35.35	111 51.63	215
NRORB4/#Obs Percent	194 75.19	0 0.00	64 24.81	258
Total	337 36.35	251 27.08	339 36.57	927 100.00

* Grades 1 and 2 were combined in family NRORB4

** CM = Chilhowee Mountain, KB = Kyker Bottom, and RB = Royal Blue

Table 4.25. Number of observations and percent of seedlings in scarlet oak families for premium (grade 1), good (grade 2), and cull (grade 3) grade seedlings grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999.

Family	Grade 1	Grade 2	Grade 3	Total
SCOCC4/#Obs Percent	27 19.71	78 56.93	32 23.36	137
SCOCC5/#Obs Percent	83 19.62	162 38.30	178 42.08	423
SCOCC6/#Obs Percent	71 14.98	202 42.62	201 42.41	474
SCOCC7/#Obs Percent	72 22.93	132 42.04	110 35.03	314
SCOCC8/#Obs Percent	52 27.37	73 38.42	65 34.21	190
SCOCC9/#Obs Percent	22 10.00	95 43.18	103 46.82	220
SCOCM2/#Obs Percent	12 17.65	32 47.06	24 35.29	68
SCORB2/#Obs Percent	43 25.00	70 40.70	59 34.30	172
Total	382 19.12	844 42.24	772 38.64	1,998 100.00

* CC = Cades Cove, CM = Chilhowee Mountain, and RB = Royal Blue

Table 4.26. Number of observations and percent of seedlings in southern red oak families for premium (grade 1), good (grade 2), and cull (grade 3) grade seedlings grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999.

Family	Grade 1	Grade 2	Grade 3	Total
SROCC1/#Obs	73	89	58	220
Percent	33.18	40.45	26.36	
SROCC2/#Obs	37	79	65	181
Percent	20.44	43.65	35.91	
SROCM4/#Obs	75	86	78	239
Percent	31.38	35.98	32.64	
Total	185	254	201	640
	28.91	36.96	31.41	100.00

* CC = Cades Cove and CM = Chilhowee Mountain

Table 4.27. Number of observations and percent of seedlings in willow oak families for premium (grade 1), good (grade 2), and cull (grade 3) grade seedlings grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999. .

Family	Grade 1	Grade 2	Grade 3	Total
WLOJC1/#Obs	21	43	50	114
Percent	18.42	37.72	43.86	
WLOJC4/#Obs	21	21	19	61
Percent	34.43	34.43	31.15	
Total	42	64	69	175
	24.00	36.57	39.43	100.00

* JC = Jefferson County

Table 4.28. Number of observations and percent of seedlings in white oak families for premium (grade 1), good (grade 2), and cull (grade 3) grade seedlings grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999.

Family	Grade 1	Grade 2	Grade 3	Total
NAWO28/#Obs Percent	8 10.67	67 89.33	0 0.00	75
WORB1/#Obs Percent	18 29.03	19 30.65	25 40.32	62
WORB2/#Obs Percent	6 6.59	34 37.36	51 56.04	91
WORB3/#Obs Percent	8 19.51	33 80.49	0 0.00	41
WORB4/#Obs Percent	4 4.88	26 31.71	52 63.41	82
WORB6/#Obs Percent	4 9.09	16 36.36	24 54.55	44
WORB8/#Obs Percent	11 25.00	12 27.27	21 47.73	44
WORB9/#Obs Percent	7 21.21	10 30.30	16 48.48	33
Total	66 13.98	217 45.97	189 40.04	472 100.00

* NA = Northern Appalachian and RB = Royal Blue

Cluster one (cube) represents seedlings with the smallest growth characteristics and cluster four represents seedlings with the best overall growth characteristics, with clusters two and three representing seedlings of intermediate quality (Figure 4.1). In black oak, cluster one contained 0 - 62.50 % seedlings in each family, cluster two contained from 0 - 50 %, cluster three contained 0 - 30 %, and cluster four 4.17 - 100 % (Table 4.29 and Figure 4.1). In chestnut oak, cluster one and two contained 0 - 100 % seedlings in each family, cluster three contained 0 - 18.75 %, and cluster four contained 0 - 12.50 % (Table 4.30 and Figure 4.2). In northern red oak, cluster one contained 10 - 80 % seedlings in each family, cluster two 0 - 55.77 %, cluster three 0 - 20.00 % and cluster four ranged from 7.02 - 70 % (Table 4.31 and Figure 4.3). In scarlet oak, cluster one contained 0 - 15 % seedlings in each family, cluster two 44.44 - 68.48 %, cluster three 3.45 - 30.94 %, and cluster four contained 9.76 - 42.22 % (Table 4.32 and Figure 4.4). In southern red oak, cluster one contained 24.49 - 47.62 % seedlings in each family, cluster two 9.52 - 33.67 %, cluster three 15.31 - 42.86 %, and cluster four contained 0 - 26.53 % (Table 4.33 and Figure 4.5). In willow oak, cluster one contained 50.00 - 62.07 % seedlings in each family, cluster two 10.00 - 10.34 %, cluster three 10.34 - 30.00 %, and cluster four contained 10.00 - 17.24 % (Table 4.34 and Figure 4.6). In white oak, cluster one contained 33.33 - 100.00 % seedlings in each family, cluster two 0 - 66.67 %, cluster three 0 - 50.00 %, and cluster four contained from 0 - 25 % (Table 4.35 and Figure 4.7).

Correlations Among Seedling Growth Variables

The strongest correlations of seedling characteristics in all species, except

Table 4.29. Number of observations and percent of seedlings in clusters 1, 2, 3, and 4 for black oak families grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999.

Family	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Total
BOCC3/#Obs	2	6	0	5	13
Percent	15.38	46.15	0.00	38.46	
BOCM10/#Obs	0	0	0	1	1
Percent	0.00	0.00	0.00	100.00	
BOCM4/#Obs	2	3	3	2	10
Percent	20.00	30.00	30.00	20.00	
BOCM6/#Obs	11	5	3	1	20
Percent	55.00	25.00	15.00	5.00	
BORB1/#Obs	10	14	2	2	28
Percent	35.71	50.00	7.14	7.14	
BORB5/#Obs	7	5	2	2	16
Percent	43.75	31.25	12.50	12.50	
BORB6/#Obs	15	6	2	1	24
Percent	62.50	25.00	8.33	4.17	
BORB7/#Obs	9	4	0	4	17
Percent	52.94	23.53	0.00	23.53	
BORB8/#Obs	9	4	6	1	20
Percent	45.00	20.00	30.00	5.00	
BORB9/#Obs	22	25	8	3	58
Percent	37.93	43.10	13.79	5.17	
Total	87	72	26	22	207
	42.03	34.78	12.56	10.63	100.00

* CC = Cades Cove, CM = Chilhowee Mountain, and RB= Royal Blue

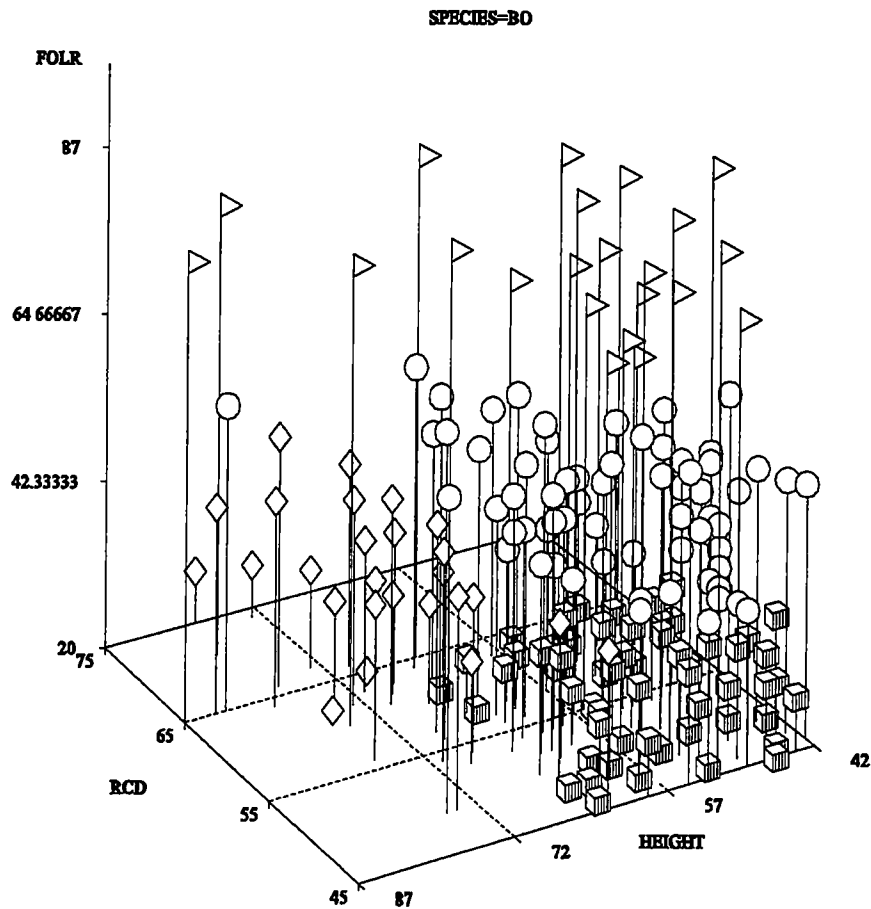


Figure 4.1. Clusters of the top 50 percent of seedlings in black oak genetic families grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999. Clusters 1, 2, 3, and 4 are represented, respectively, by a cube, balloon, diamond, and flag.

Table 4.30. Number of observations and percent of seedlings in clusters 1, 2, 3, and 4 for chestnut oak families grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999.

Family	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Total
COCC1/#Obs	32	13	1	6	52
Percent	61.54	25.00	1.92	11.54	
COCM1/#Obs	22	3	2	1	28
Percent	78.57	10.71	7.14	3.57	
COCM10/#Obs	7	0	0	0	7
Percent	100.00	0.00	0.00	0.00	
COCM2/#Obs	77	12	15	13	117
Percent	65.81	10.26	12.82	11.11	
COCM3/#Obs	76	12	24	16	128
Percent	59.38	9.38	18.75	12.50	
COCM6/#Obs	0	1	0	0	1
Percent	0.00	100.00	0.00	0.00	
COCM8/#Obs	7	5	1	1	14
Percent	50.00	35.71	7.14	7.14	
Total	221	46	43	37	347
	63.69	13.26	12.39	10.66	100.00

* CC = Cades Cove and CM = Chilhowee Mountain

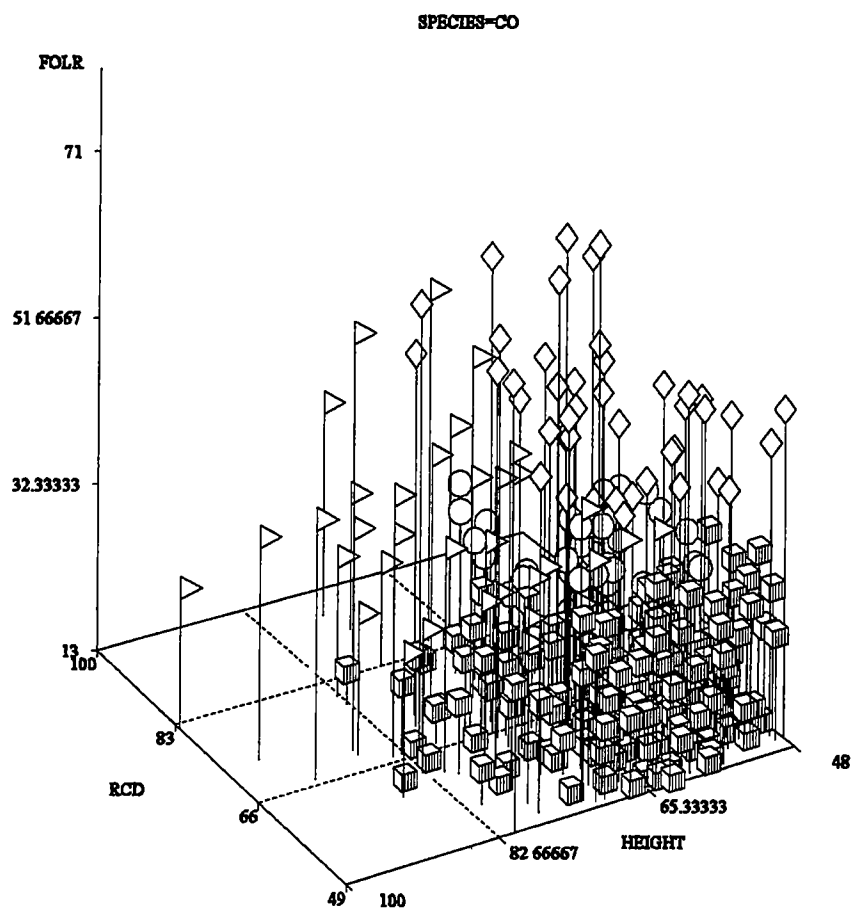


Figure 4.2. Clusters of the top 50 percent of seedlings in chestnut oak genetic families grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999. Clusters 1, 2, 3, and 4 are represented, respectively, by a cube, balloon, diamond, and flag.

Table 4.31. Number of observations and percent of seedlings in clusters 1, 2, 3, and 4 for northern red oak families grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999.

Family	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Total
NROCM1/#Obs	18	3	5	16	42
Percent	42.86	7.14	11.90	38.10	
NROCM3/#Obs	4	0	0	1	5
Percent	80.00	0.00	0.00	20.00	
NROKB1/#Obs	1	0	2	7	10
Percent	10.00	0.00	20.00	70.00	
NROKB2/#Obs	1	0	0	2	3
Percent	33.33	0.00	0.00	66.67	
NRORB10/#Obs	39	29	6	16	90
Percent	43.33	32.22	6.67	17.78	
NRORB3/#Obs	17	29	7	4	57
Percent	29.82	50.88	12.28	7.02	
NRORB4/#Obs	22	58	13	11	104
Percent	21.15	55.77	12.50	10.58	
Total	102	119	33	57	311
	32.80	55.77	12.50	18.33	100.00

* CM = Chilhowee Mountain, KB = Kyker Bottom, and RB = Royal Blue

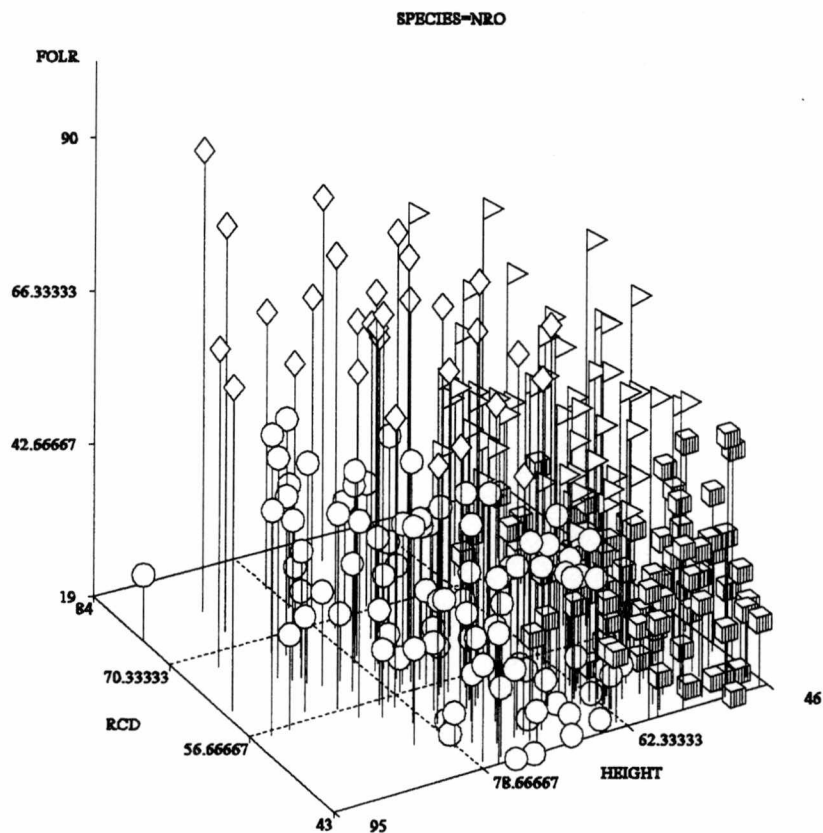


Figure 4.3. Clusters of the top 50 percent of seedlings in northern red oak genetic families grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999. Clusters 1, 2, 3, and 4 are represented, respectively, by a cube, balloon, diamond, and flag.

Table 4.32. Number of observations and percent of seedlings in clusters 1, 2, 3, and 4 for scarlet oak families grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999.

Family	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Total
SCOCC4/#Obs Percent	12 15.00	40 50.00	13 16.25	15 18.75	80
SCOCC5/#Obs Percent	12 7.02	91 53.22	45 26.32	23 13.45	171
SCOCC6/#Obs Percent	0 0.00	78 64.46	20 16.53	23 19.01	121
SCOCC7/#Obs Percent	7 5.04	71 51.08	43 30.94	18 12.95	139
SCOCC8/#Obs Percent	5 5.43	63 68.48	13 14.13	11 11.96	92
SCOCC9/#Obs Percent	3 6.67	20 44.44	3 6.67	19 42.22	45
SCOCM2/#Obs Percent	3 10.34	17 58.62	1 3.45	8 27.59	29
SCORB2/#Obs Percent	4 4.88	55 67.07	15 18.29	8 9.76	82
Total	46 6.06	435 57.31	153 20.16	125 16.47	759 100.00

* CC = Cades Cove, CM = Chilhowee Mountain, and RB = Royal Blue

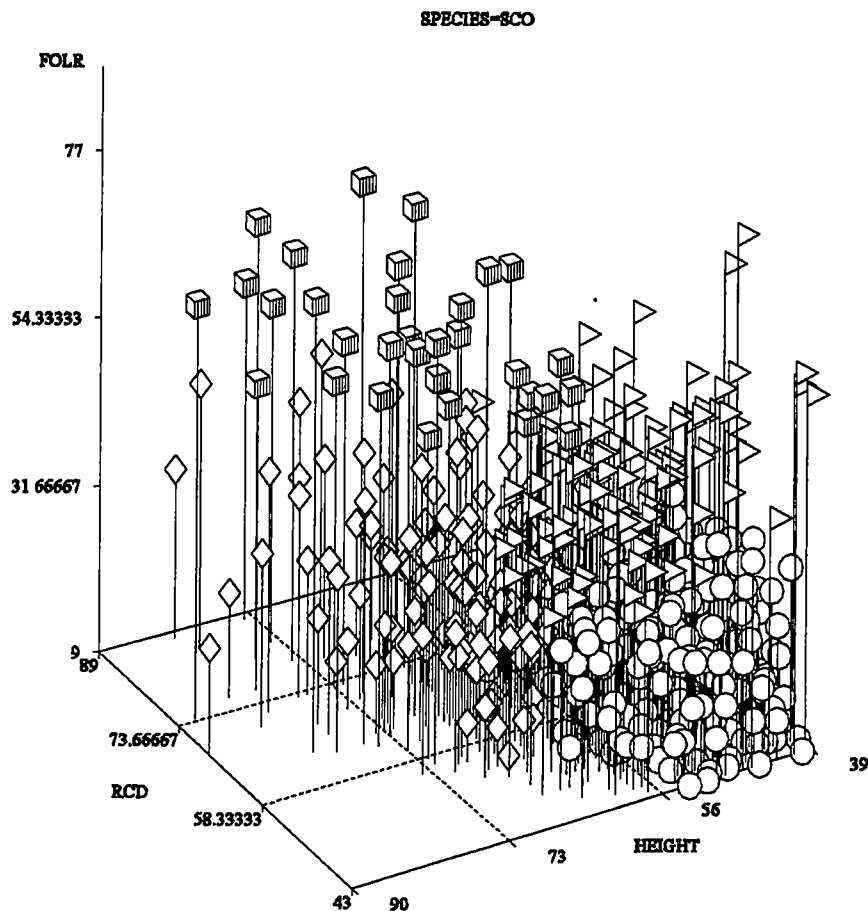


Figure 4.4. Clusters of the top 50 percent of seedlings in scarlet oak genetic families grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999. Clusters 1, 2, 3, and 4 are represented, respectively, by a cube, balloon, diamond, and flag.

Table 4.33. Number of observations and percent of seedlings in clusters 1, 2, 3, and 4 for southern red oak families grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999.

Family	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Total
SROCC1/#Obs	24	33	15	26	98
Percent	24.49	33.67	15.31	26.53	
SROCC2/#Obs	20	4	18	0	42
Percent	47.62	9.52	42.86	0.00	
SROCM4/#Obs	36	27	17	11	91
Percent	39.56	29.67	18.68	12.09	
Total	80	64	50	37	231
	34.63	27.71	21.65	16.02	100.00

* CC = Cades Cove and CM = Chilhowee Mountain

Table 4.34. Number of observations and percent of seedlings in clusters 1, 2, 3, and 4 for willow oak families grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999.

Family	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Total
WLOJC1/#Obs	18	3	3	5	29
Percent	62.07	10.34	10.34	17.24	
WLOJC4/#Obs	5	1	3	1	10
Percent	50.00	10.00	30.00	10.00	
Total	23	4	6	6	39
	58.97	10.26	15.38	15.38	100.00

* JC = Jefferson County

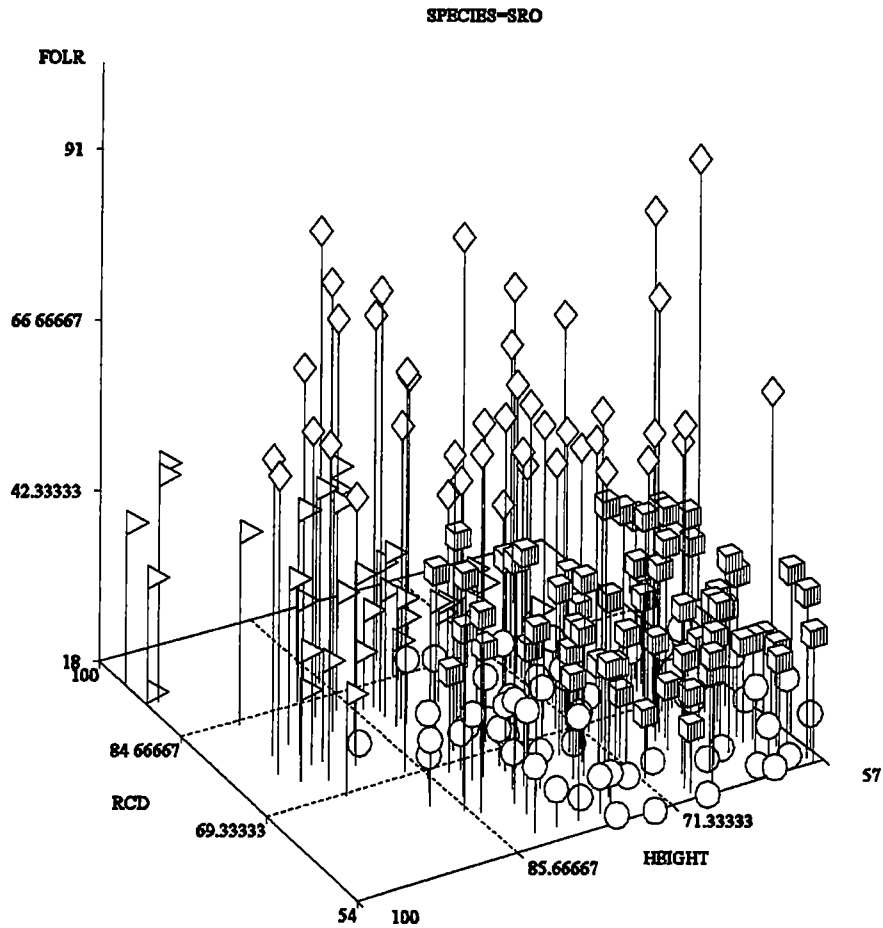


Figure 4.5. Clusters of the top 50 percent of seedlings in southern red oak genetic families grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999. Clusters 1, 2, 3, and 4 are represented, respectively, by a cube, balloon, diamond, and flag.

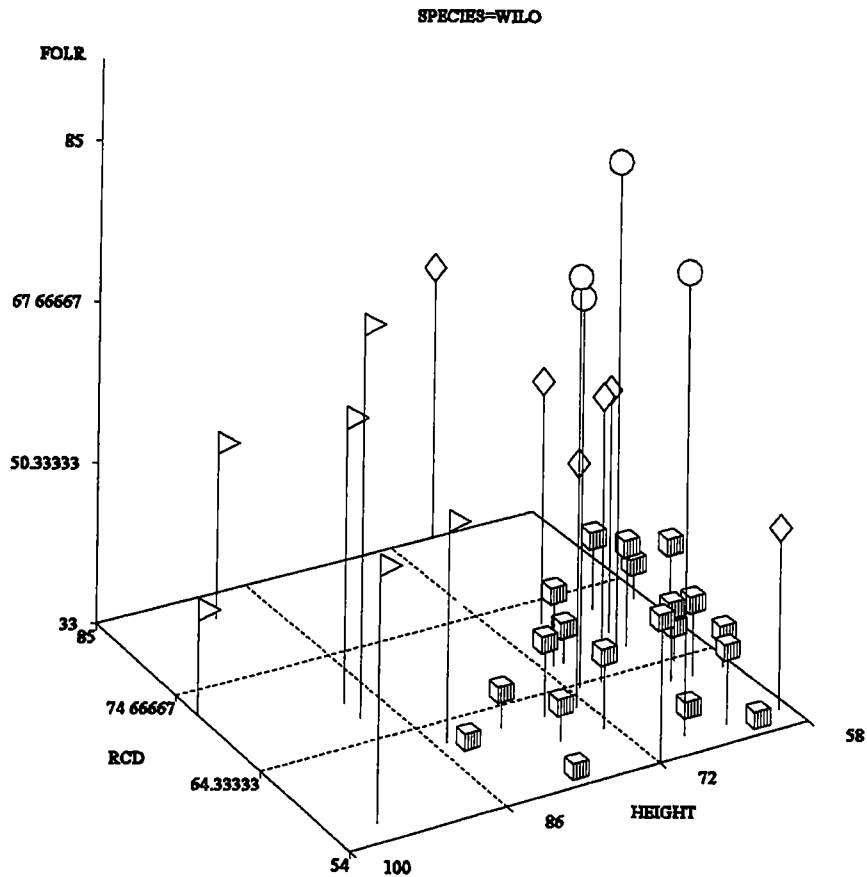


Figure 4.6. Clusters of the top 50 percent of seedlings in willow oak genetic families grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999. Clusters 1, 2, 3, and 4 are represented, respectively, by a cube, balloon, diamond, and flag.

Table 4.35. Number of observations and percent of seedlings in clusters 1, 2, 3, and 4 for white oak families grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999.

Family	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Total
NAWO28/#Obs	22	0	5	2	29
Percent	75.86	0.00	17.24	6.90	
WORB1/#Obs	11	6	1	1	19
Percent	57.89	31.58	5.26	5.26	
WORB2/#Obs	12	3	6	3	24
Percent	50.00	12.50	25.00	12.50	
WORB3/#Obs	5	1	3	3	12
Percent	41.67	8.33	25.00	25.00	
WORB4/#Obs	7	4	0	3	14
Percent	50.00	28.57	0.00	21.43	
WORB6/#Obs	2	4	0	0	6
Percent	33.33	66.67	0.00	0.00	
WORB8/#Obs	9	0	0	0	9
Percent	100.00	0.00	0.00	0.00	
WORB9/#Obs	2	0	2	0	4
Percent	50.00	0.00	50.00	0.00	
Total	70	18	17	12	117
	59.83	15.38	14.53	10.26	100.00

* NA = Northern Appalachian and RB = Royal Blue

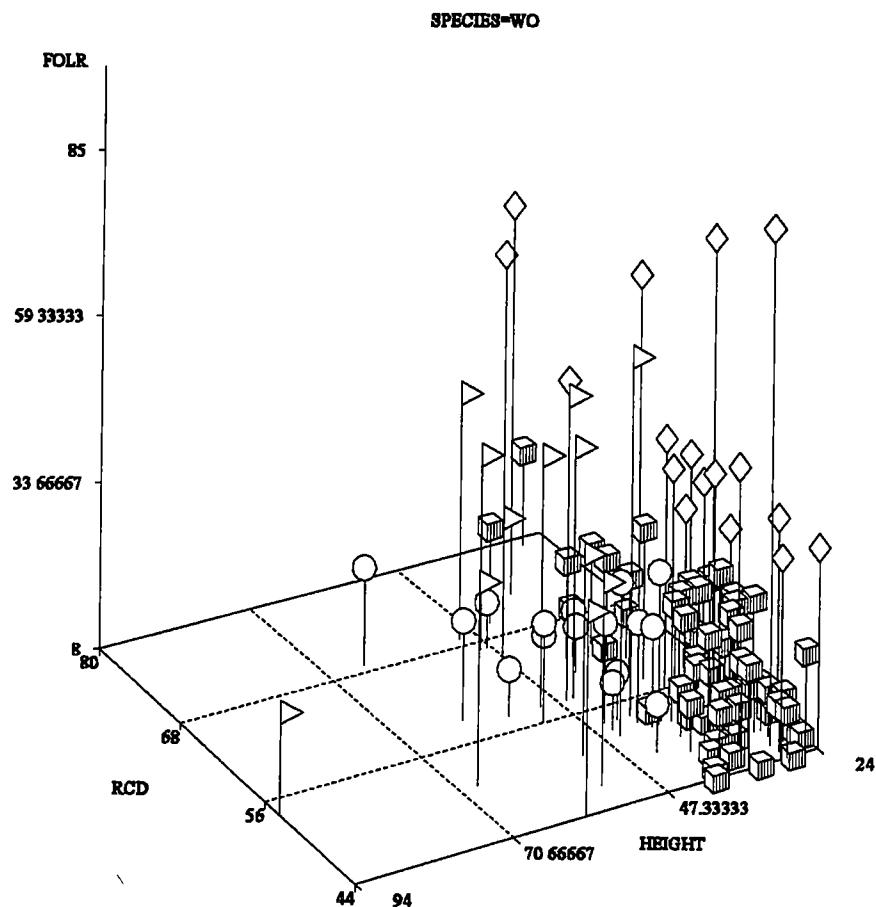


Figure 4.7. Clusters of the top 50 percent of seedlings in white oak genetic families grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999. Clusters 1, 2, 3, and 4 are represented, respectively, by a cube, balloon, diamond, and flag.

northern red oak were between seedling height and RCD (Table 4.36). This association was strongest (*sensu* Davis 1971) in southern red oak ($r = 0.84$) and very strong for black oak and scarlet oak. Chestnut oak and willow oak exhibited a stronger association between seedling height and RCD than white oak. In contrast, the strongest correlation in northern red oak was between FOLR and RCD ($r = 0.72$). Only one correlation, FOLR-height for white oak, had a relative low association.

Correlations among the seedling characteristics differed when compared by grade within species. Black oak exhibited a relative strong association between seedling height and RCD in all three grades (Table 4.37). Chestnut oak exhibited a relatively low association between FOLR and RCD and FOLR and height in grade one, a relative low association between FOLR and height in grade two, and a relative strong association between FOLR and height in grade three. Northern red oak exhibited a relative strong association between FOLR and RCD in all three grades. Scarlet oak exhibited a relative moderate association between height and RCD in grade one, and a moderate association between FOLR and RCD in grades two and three. Southern red oak exhibited a moderate association between height and RCD for grade one, a moderate association between FOLR and RCD in grade two, and a strong association between height and RCD in grade three. Willow oak exhibited a moderate association between FOLR and RCD in grade one, proved to be non-significant in grade two, and a moderate association between height and RCD in grade three. White oak exhibited low to moderate associations between FOLR and RCD in all three grades (Table 4.37).

Table 4.36. Correlations among growth variables for each oak species grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999 without respect to seedling grades.

Species	FOLR-RCD	FOLR-Height	Height-RCD
Black Oak	0.59	0.59	0.75
Chestnut Oak	0.43	0.47	0.67
Northern Red Oak	0.72	0.60	0.66
Scarlet Oak	0.73	0.65	0.81
Southern Red Oak	0.73	0.64	0.84
Willow Oak	0.52	0.38	0.54
White Oak	0.43	0.22	0.49

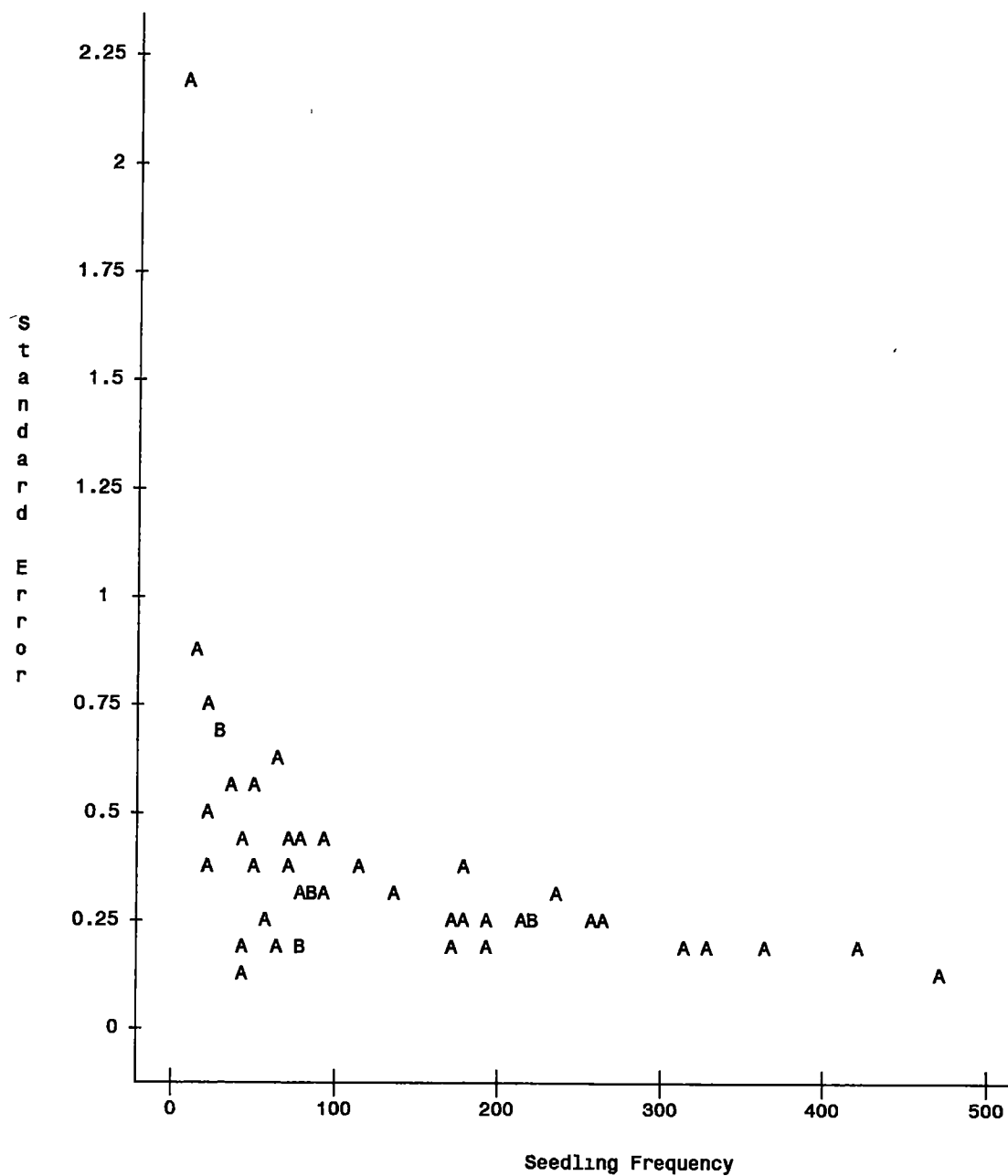
Table 4.37. Correlations among growth variables for premium (grade 1), good (grade 2), and cull (grade 3) grade oak seedlings grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999.

Species/Grade	FOLR-RCD	FOLR-Height	Height-RCD
Black Oak/1	0.37	0.11*	0.45
Black Oak/2	0.27	0.19	0.37
Black Oak/3	0.31	0.31	0.56
Chestnut Oak/1	0.29	0.29	0.23
Chestnut Oak/2	0.21	0.24	0.14
Chestnut Oak/3	0.41	0.52	0.49
Northern Red Oak/1	0.56	0.38	0.48
Northern Red Oak/2	0.55	0.05*	-0.10*
Northern Red Oak/3	0.57	0.36	0.40
Scarlet Oak/1	0.33	0.15	0.47
Scarlet Oak/2	0.43	0.15	0.25
Scarlet Oak/3	0.47	0.21	0.47
Southern Red Oak/1	0.23	0.04*	0.41
Southern Red Oak/2	0.45	0.23	0.44
Southern Red Oak/3	0.53	0.31	0.61
Willow Oak/1	0.44	0.17*	-0.11*
Willow Oak/2	-0.05*	-0.18*	0.07*
Willow Oak/3	0.27	0.34	0.45
White Oak/1	0.44	-0.06*	0.37
White Oak/2	0.29	0.12*	0.16
White Oak/3	0.31	0.02*	0.31

* Non-significant correlations ($p < 0.05$).

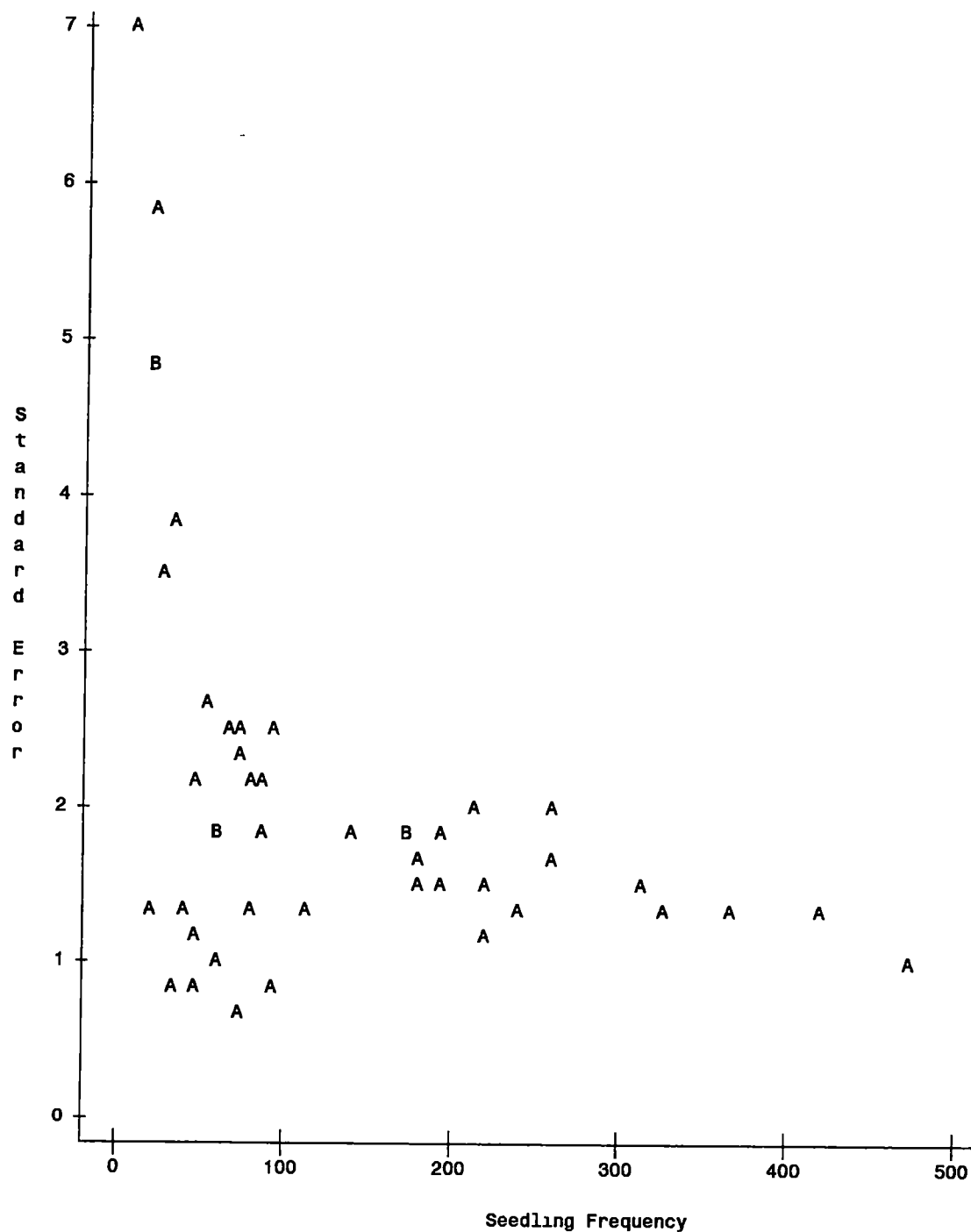
Effects of Family Size on Variance Components

The standard error of family means was found to decrease as sample size increases. Plots were constructed to display the relationship between FOLR (Figure 4.8), height (Figure 4.9), and RCD (Figure 4.10) and standard error, respectively. As seen in Figures 4.8, 4.9 and 4.10, standard errors decreased rapidly as sample size increased from 85 to 100 seedlings. There was no statistical benefit from an increased sample size greater than 100. Between 85 and 100 seedlings represent an adequate sample size to represent variation within a family over all species.



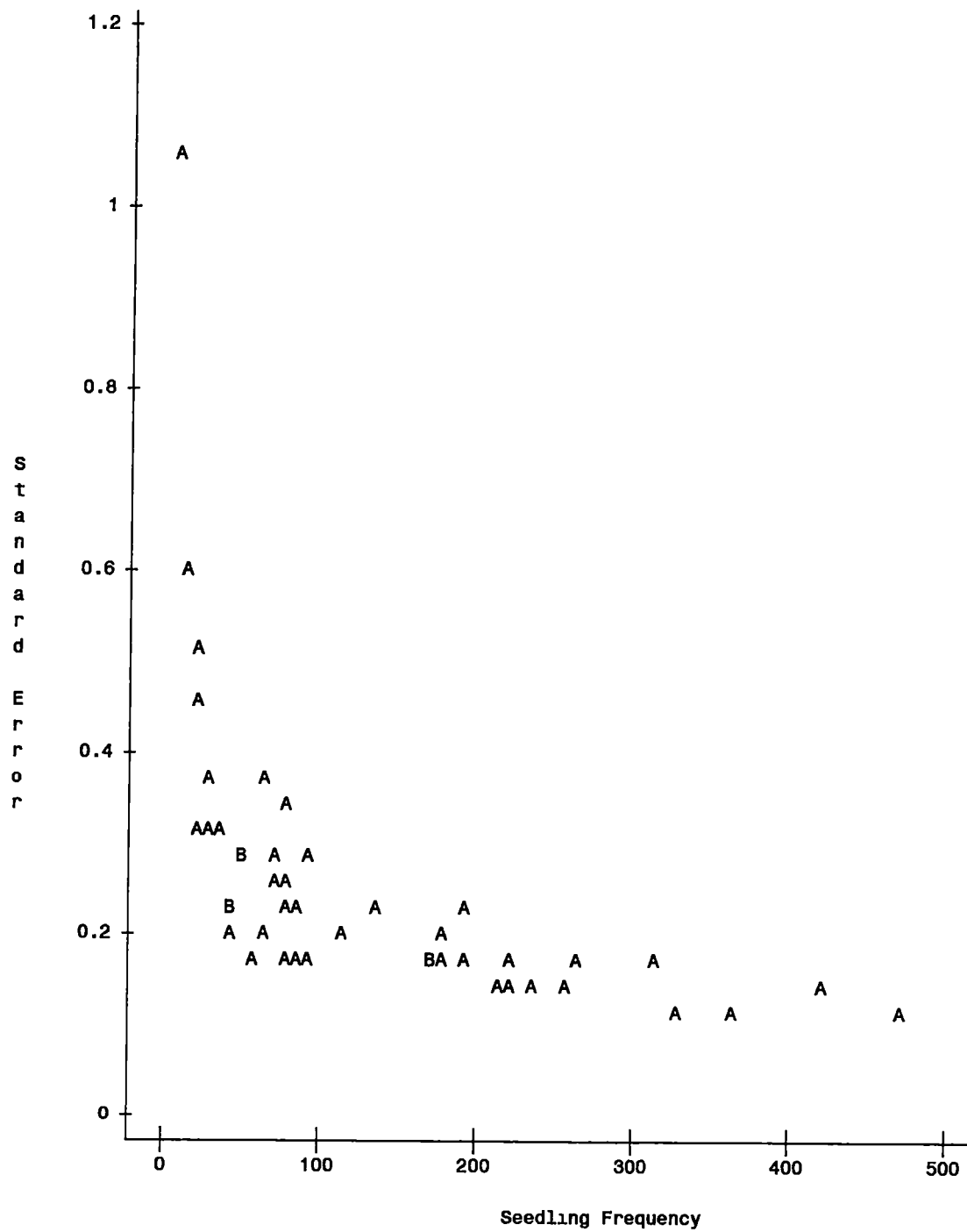
Legend: A = 1 family, B = 2 families

Figure 4.8. Relationship of standard error with sample size (frequency) for first-order lateral roots of seedlings grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999.



Legend: A = 1 Family, B = 2 families

Figure 4.9. Relationship of standard error with sample size (frequency) for height of seedlings grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999.



Legend: A = 1 Family, B = 2 Families

Figure 4.10. Relationship of standard error with sample size (frequency) for root collar diameter of seedlings grown at the Flint River Nursery, Byromville, Georgia in 1998 and 1999.

CHAPTER V.

DISCUSSION

Species Differences

There was substantial variation in seedling characteristics among species.

Kormanik *et al.* (1994b) found that seedlings of species adapted to more xeric sites, such as scarlet and southern red oaks, had fewer and smaller ranges in FOLR numbers than species from mesic sites. The reduced number of FOLR was associated with overall smaller RCDs and shorter height. Seedlings of species typically found on moist bottomlands or seasonally hydric sites had better developed lateral root systems. The results of this study generally indicated site-specific growth patterns among oak species similar to those reported by Kormanik *et al.* (1994b), although there were some differences.

Northern red oak and willow oak, mesic and hydric species respectively, both ranked high in FOLR number and RCD and generally exhibited high means for seedling characteristics. Northern red oak had the greatest mean height of all species measured. Willow oak exhibited the largest number of FOLR and the largest RCD. Two xeric species, chestnut oak and scarlet oak, had relatively few numbers of FOLR. Scarlet oak had a low mean number of FOLR, short height, and small RCD. Chestnut oak also had few roots, but exhibited good height growth and RCD. The large size of the chestnut

acorns may have contributed to these observations as shown in northern red oak by Kormanik *et al.* (1999). The relatively low numbers of FOLR and concentration of food reserves in the taproot may be a characteristic that allows the seedlings to survive on shallow, dry, rocky soils where lateral roots would tend to dessicate.

Kormanik *et al.* (1994b) found that black oak seedlings had relatively high numbers of FOLR. Similar results were not found in this study. Black oak family means for FOLR were similar to means from two other xeric species, southern red oak and scarlet oak. This discrepancy could be due to collection of acorns from a more xeric site than in the Kormanik *et al.* (1994b) study. Black oak acorns collected for this study were from relatively dry upland sites and had fewer numbers of FOLR. In addition, Kormanik *et al.* (1994b) found relatively few FOLR in southern red oak, although, the FOLR number was relatively high in this study. This could be due to collection of seed from different geographic locations or possibly root counting bias between the studies. Alternatively, the southern red oak collected for this study may be from a more mesic type site than the seed used by Kormanik *et al.* (1994b).

In this study, white oak exhibited the smallest mean growth characteristics of all species. Growth of the white oak seedlings was affected by late germination due to planting the acorns too deep and mildew in the growth season. Overall, white oak seedlings exhibited uncharacteristically poor growth and did not reflect growth patterns shown by the other species. Therefore, it is difficult to discern whether the white oak seedlots exhibited mesic or xeric characteristics.

Family Differences

The variation in FOLR, height, and RCD among families of northern red and white oaks observed in this study concurs with differences found in previous studies (Kriebel 1965, Ruehle and Kormanik 1986, Kormanik *et al.* 1989, Buchschacher *et al.* 1991, Lay 1999). Family differences, however, have not been previously documented in scarlet, chestnut, and black oaks. Genetic variation in chestnut oak has been observed by the Tennessee Valley Authority, but only in internal documents (S.E. Schlarbaum, University of Tennessee personal communication).

The family means for each growth characteristic demonstrated the need for seedlings to be grown by family until the breeding value of the mother tree is established (Lay 1999). As the seedlots were not sown in an experimental design in the nursery, the genetic and environmental components of family differences can not be separated. However, previous studies have shown genetic differences among families in northern red oak seedlings (Ruehle and Kormanik 1986, Kriebel *et al.* 1988, Kormanik *et al.* 1989). Within the same species, some families came from mother trees within a short distance of each and had means that were very similar, indicating possible relatedness (Lay 1999).

Bigger seedlings will be more competitive in the field when competing with natural regeneration (Kormanik *et al.* 1995). The cluster analyses can be used to select families that have the highest proportion of seedlings that represent the overall best (largest) seedling characteristics for each species. Over time, mother trees that consistently produce a high proportion of superior offspring will be identified by nursery

testing.

Grade Differences

The results of this study are consistent with those of Kormanik *et al.* (1995) and Clark *et al.* (2000) and indicate that plantable oak stock can be divided into different grades of quality. The premium and good grades in this study meet recommendations for identifying high-quality nursery stock (Johnson 1981, Kormanik *et al.* 1994b, Thompson and Schultz 1989, Clark *et al.* 2000). However, the premium grade seedlings grew larger in the nursery and initially have a better chance of competing species when planted in the field (Kormanik *et al.* 1995, Clark *et al.* 2000).

In a visual grading and quality study of northern red oak seedlings, Clark *et al.* (2000) found that approximately 18% of the seedlings were premium, 18% were good, and 64% were culls. Similarities in grade percentages were not detected in this study. For all species measured, approximately 60% of the seedlings were rated as good and approximately 40% as culls. Differences with the Clark *et al.* study (2000) are probably due to graders classifying lower quality seedlings as good seedlings, thereby causing higher percentages of acceptable seedlings. The statistical analyses showing differences across seedling grades illustrated that visual grading, based on pre-measured sorting criteria (FOLR, height, and RCD) was justifiable.

Correlations Between Growth Variables

For all species, the strongest correlation between growth variables was

represented by the association between seedling height and RCD, except in northern red oak. All other relationships were either very strong, substantial, or moderate (*sensu* Davis 1971). Ruehle and Kormanik (1986) found a strong correlation between FOLR and height in a northern red oak study. However, both in Lay (1999) and this study, the strongest correlations were between FOLR number and RCD for northern red oak. This difference could be due to seed source or differences in determining FOLR numbers between the two groups of scientists.

In general, the very strong to moderate correlations between growth characteristics indicate that as one characteristic increases in size or number, other characteristics correspondingly increase, except where a certain threshold has been met with FOLR (Kormanik et al 1994b). Remaley (1998) stated this strong association is important for selecting quality seedlings on a commercial scale in nursery operations. Nursery operations do not have enough time to count FOLR numbers and measure seedling characteristics when handling thousands of seedlings. The positive correlations between RCD and other growth variables demonstrates that RCD could be a good indicator of root mass (Johnson 1989) and height (Olson and Hooper 1972) when visually selecting plantable seedlings. However, not every seedling with tall height and large RCD will have high numbers of FOLR. Therefore, when selecting quality seedlings, emphasis should not be based solely on one seedling characteristic, but on a combination of attributes.

Determination of Minimum Sample Size

The relationship between standard error and sample size was used to determine the sample size needed to adequately represent the variation within a family. This study found that a minimum of 85 seedlings are needed to obtain a representative sample of growth characteristics in a family, regardless of species. Kormanik (pers. comm. to S.E. Schlarbaum) regarded 200 seedlings as a minimum to accurately portray family variation. Based on research, fewer seedlings will have to be measured to draw accurate estimates of family means in future studies.

Seed Collection Procedures

The response of TWRA wildlife managers to the question of what different mast producing trees should be propagated at the beginning of this study was interesting. The majority of managers thought of wildlife foods in terms of heavy seeded, hard mast species, e.g., oaks (*Quercus* L.) and hickories (*Carya* Nutt.). This attitude probably reflected knowledge of the oak component loss on upland sites. Another factor could be the lack of availability of soft mast species from state nurseries, particularly species that mature in late spring and summer.

Problems associated with seed procurement and handling of soft mast species may contribute to the lack of availability of native soft mast species in state nurseries. Marketing, propagation, and production practices greatly influence the availability of nursery crops (Calfee 1999). Although many native trees are in demand, growers are reluctant to produce native species (Calfee 1999). Collections are slow because most

seed is collected by hand, either picked from the tree or ground. Additionally, there are few seed orchards of soft mast species, as tree improvement efforts on these species has been limited except for black cherry.

In this study, collection trees were visited at least twice a week when it appeared that seed was near ripening stage. Soft mast tends to ripen quickly, and if collection is not done in a timely manner, wildlife will consume much of the fruit while still on the tree. Consumption from animals was a major concern in this study. From a commercial nursery standpoint, it would be prohibitively expensive to collect and process seed of soft mast species from local natively occurring seed sources. A commercial nursery would have difficulty in being able to sell the resulting seedlings at a profit.

Fruit is collected in the majority of soft mast species, but generally only seeds are sown in the nursery; therefore it is necessary to extract the seeds from fruit pulp. The extraction processes can include macerating, de-pulping, drying, separation, and cleaning to achieve maximum production of clean seed having high viability (Stein *et al.* 1974). Long hours were spent in this study cleaning and properly drying seed to maintain viability. After seeds are dried, they must be properly stored (Holmes and Buszewicz 1958). Storage methods vary by species, mainly or exclusively dealing with temperature (Willan 1985). Through this study, collection procedures will help develop practical collection protocols for native soft mast species at an affordable cost until seed orchards are developed.

Without seed orchards, seeds are generally collected from the ground under trees in natural or urban settings. The collector has no way of knowing when peak seed fall

begins, if collection trees are not periodically observed. When seed has been left on the ground, it is susceptible to further consumption by insects and squirrels. In this study, oak seedlots from Chota WMA were collected late in the 1999 collection season (approximately two months after peak seed fall). Most of the acorns had germinating radicles, but a proportion of the pericarps were somewhat withered. The acorns were tested by a flotation test and only viable seed was planted. However, a visual inspection of the Chota seedlots in late June, 2000 generally showed poor germination (<60%). In contrast, the majority of oak seedlots that were collected earlier in 1999 exhibited good germination (>80%). Remaley (1998) suggests that loss of seed viability is due to factors such as selective consumption if collected late in the season. The reduced viability in the Chota seedlots may be reflecting selective consumption of acorns with little insect damage by squirrels and other animals. Further studies are needed to ascertain the relationship of viability to consumption in seed collections from natural stands.

Seed Collection and Seed Orchard Establishment

A record of mast production for individual trees was initiated in this study that will eventually make future collection processes easier. By recording the geographic coordinates of each tree, TWRA personnel can return to evaluate production and collect mast. Over time, this documentation will identify consistent, heavy producers, as found in oak seed orchards (Schlarbaum *et al.* 1998). Mother tree selection based on mast records and nursery performance of their progeny will identify trees that need to be selected for future mast collections. Seed orchards can be formed from grafts of these

mother trees (if the species can be readily grafted) to produce genetically improved seed for nursery growth. Unfortunately, the genetics of flowering/fruiting is poorly understood for most species, so the seed may or may not show improvement for mast production.

Production of genetically improved seed of species that do not graft well can be accomplished by converting the plantations into seedling seed orchards. The plantations established in this study were planted according to experimental designs and are essentially progeny tests. They can be eventually thinned to produce seedling seed orchards based initially on mast characteristics, and followed by growth characteristics. With protection from animals, these areas can be used to provide genetically improved seed for further reforestation. In addition, the trees in the seedling seed orchards that exhibit the best overall mast and growth characteristics can be grafted to construct seed orchards to further maximize growth potential, if grafting is feasible.

If conversion of a plantation to a seed orchard is desired, complete removal of some species will have to occur to avoid hybrid seedlots (Palmer 1948). For example, a seed orchard of a species from the white oak (*Leucobalanus* L.) and red oak (*Erythrobalanus* L.) subgenera, respectively, could be developed in the same planting. However, leaving two *Erythrobalanus* species, e.g., scarlet and northern red oak, in the seed orchard would have the potential to generate a proportion of hybrid seed.

Seed Zone System

Mast production areas will be useful for managers in the same seed zones to establish their management area with species that are locally adapted to that area. The resulting seedlings should survive and thrive well in their seed zone. The composition of plantings in this study were generally established according to the Tennessee Seed Zone System. All data on the trees were transferred to TWRA GIS personnel. The data was imported from Excel files into ArcView® and transferred to TWRA with no difficulty. This will allow TWRA personnel to collect seed from mother that exhibit the best masting characteristics over time.

CHAPTER VI.

CONCLUSIONS

This thesis research was conducted to investigate the process of enacting the Tennessee Seed Zone System by establishing plantings with high-quality locally adapted seedlings of different mast producing species. Nine different plantings on four different management areas were established for wildlife on Tennessee Wildlife Resources Agency properties using quality-improved seedlings of mixed oak species from local seed sources. Some plantings were established with spacing left for soft mast species to be planted in 2001. The plantations will eventually contain a mixture of mast species to provide mast throughout the year. Two of the plantings were established with 1 to 2 acre openings for native warm season grasses. These openings in conjunction with the trees provide a wildlife oasis of food and habitat.

Establishing the plantings according to the Tennessee Seed Zone System was not difficult because documentation and seed handling procedures were followed. To facilitate this process records associated with collection trees were transferred to TWRA personnel as an Arc View® GIS database. However, if managers do not separate and record seed by collection tree, difficulties may arise associated with seed zones.

This study generally found site-specific growth patterns among oak species. Species adapted to more xeric sites, such as chestnut, scarlet and southern red oaks, had

fewer and smaller ranges in FOLR numbers than species from mesic sites. The difference in FOLR numbers in black and northern red oaks suggest that natural selection along moisture regimes has an influence on FOLR number regardless of species. Black and southern red oak seedlings from mesic sites probably should not be planted on xeric sites until further studies on the effects of site on root systems are completed. Therefore, careful documentation of site condition needs to be made when collecting seed and when planning for a reforestation project, not only species should be matched with each site, but seedlots within a species should be classified by site. Further studies need to be conducted on individual species and their site adaptability by genotype.

For all species measured, approximately 60% of the seedlings were rated as good and approximately 40% as culls. Differences in cull percentages in northern red oak between this study and Lay *et al.* (1999) may be due to graders classifying cull seedlings as acceptable for planting, causing higher percentages of acceptable seedlings. However, the differences in cull percentages in the other species may be real and not due to a bias. The strongest correlation between growth variables was represented by the association between seedling height and RCD, except in northern red oak where correlations were strongest between FOLR and RCD. Thus, RCD may be used as an indicator when selecting high-quality seedlings in commercial nursery operations, as it indirectly selects for FOLR number and height.

The family mean ranges for each growth characteristic demonstrates the need for seedlings to be grown by family until breeding value of the mother tree is established. Families with superior growth characteristics and FOLR number in the nursery can be

selected over time. A cluster analysis, as conducted here, can be used to select certain families that have the highest proportion of seedlings representing the overall best (largest) characteristics.

Family performance will be able to be evaluated more efficiently in the future. A minimum of 85 seedlings were found to be needed to obtain a representative sample of growth characteristics in a family, regardless of species. Evaluation of less seedlings will allow for evaluation of more families in less time.

Collection procedures were slow and expensive because most seed was collected by hand from natural stands of trees, as there are no seed orchards. The GPS coordinates of selected soft mast trees will help to develop affordable collection strategies for native soft mast species. Seed orchard construction will be predicted on nursery performance and consistency of seedling production. Seed orchards may be constructed by grafts from original collection trees (if the species can be grafted) and from the plantations to make collections faster and easier at lower collection costs.

Plantings in this study were generally established according to the Tennessee Seed Zone System. As the trees become reproductively mature, natural regeneration from seeds coming from the plantings should have good survival and adaptability. Using the seed zone system for future collection and distribution of seedlings from species where zones have not been delineated by genetic testing will likely increase the adaptability of the resulting seedlings and their eventual progeny to local planting sites.

The TWRA plantings are a new and unique approach to providing mast for wildlife species. No other plantings have been established with-high quality seedlings of

known genetic stock for wildlife purposes. The plantings will serve a dual purpose by providing mixed mast for wildlife, information on genetic variability of mast of growth characteristics for a number of species and eventually serve as a source of genetically improved seed, if converted into a seedling seed orchards. Additionally, the plantings will provide study areas that will relate how a concentration of mixed mast species will influence wildlife population and composition dynamics.

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LITERATURE CITED

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APPENDIX

Table 3.6. Species list of abbreviations in conjunction with implementation of the Tennessee Seed Zone System (cf. Post 1998).

Scientific Name	Common Name	Abbreviation
Conifers		
<i>Taxodium distichum</i> L.	Baldcypress	CYP
<i>Tsuga canadensis</i> L.	Eastern Hemlock	HEM
<i>Picea</i> L.	Spruce	SPR
<i>Juniperous virginiana</i> L.	Eastern Red Cedar	ERC
<i>Pinus Strobus</i> L.	Eastern White Pine	EWP
<i>Pinus taeda</i> L.	Loblolly Pine	LLP
<i>Pinus echinata</i> M.	Shortleaf Pine	SLP
<i>Pinus virginiana</i> M.	Virginia Pine	VP
<i>Pinus rigida</i> M.	Pitch Pine	PP
<i>Pinus sylvestris</i> L.	Scotch Pine	SP
Hardwoods		
<i>Quercus alba</i> L.	White Oak	WO
<i>Quercus bicolor</i> L.	Swamp White Oak	SWO
<i>Quercus coccinea</i> L.	Scarlet Oak	SCO
<i>Quercus rubra</i> L.	Northern Red Oak	NRO
<i>Quercus nuttallii</i> L.	Nuttall Oak	NO
<i>Quercus shumardii</i> L.	Shumard Oak	SO
<i>Quercus michauxii</i> L.	Swamp Chestnut Oak	SWCO
<i>Quercus nigra</i> L.	Water Oak	WTO
<i>Quercus falcata</i> var. <i>pagodifolia</i> L.	Cherrybark Oak	CBO
<i>Quercus palustris</i> L.	Pin Oak	PO
<i>Quercus phellos</i> L.	Willow Oak	WLO
<i>Quercus lyrata</i> L.	Overcup Oak	OCO
<i>Quercus acuttisima</i> L.	Sawtooth Oak	STO
<i>Quercus velutina</i> L.	Black Oak	BO
<i>Quercus prinus</i> L.	Chestnut Oak	CO
<i>Quercus falcata</i> L.	Southern Red Oak	SRO
<i>Quercus stellata</i> L.	Post Oak	PTO
<i>Carya aquatica</i> M.	Pecan	PEC
<i>Carya laciniosa</i> M.	Shellbark Hickory	SBH
<i>Diospyros virginiana</i> L.	Persimmon	PER
<i>Acer saccharum</i> M.	Sugar Maple	SUM
<i>Acer rubrum</i> L.	Red Maple	RDM
<i>Acer negundo</i> L.	Boxelder	BEL
<i>Fagus grandifolia</i> E.	American Beech	AMB
<i>Liquidambar styraciflua</i> L.	Sweetgum	SWG

Table 3.6. (Continued)

Scientific Name	Common Name	Abbreviation
<i>Nyssa sylvatica</i> M.	Blackgum	BKG
<i>Fraxinus americana</i> L.	White Ash	WHA
<i>Fraxinus pennsylvanica</i> M.	Green Ash	GRA
<i>Platanus occidentalis</i> L.	American Sycamore	ASY
<i>Populus deltoides</i> B.	Eastern Cottonwood	ECW
<i>Tilia americana</i> L.	American Basswood	ABW
<i>Liriodendron tulipifera</i>	Yellow-Poplar	YP
<i>Magnolia grandiflora</i> L.	Southern Magnolia	SMG
<i>Magnolia virginiana</i> L.	Sweetbay	SWB
<i>Salix nigra</i> M.	Black Willow	BKW
<i>Salix babylonica</i> L.	Weeping Willow	WW
<i>Juglans nigra</i> L.	Black Walnut	BWN
<i>Prunus serotina</i> E.	Black Cherry	BC
<i>Prunus americana</i> L.	American Plum	AP
<i>Ulmus americana</i> L.	American Elm	AE
<i>Betula nigra</i> L.	River Birch	RBR
<i>Celtis occidentalis</i> L.	Hackberry	HBV
<i>Robinia pseudoacacia</i> L.	Black Locust	BLC
<i>Sassafras albidum</i> N.	Sassafras	SAS
<i>Cornus florida</i> L.	Flowering Dogwood	FDW
<i>Ilex opaca</i> A.	American Holly	AMH
<i>Elaeagnus angustifolia</i> L.	Russian Olive	RUO
<i>Paulownia tomentosa</i> T.	Royal Paulownia	PAU
<i>Malus angustifolia</i> M.	Southern Crab Apple	SCA
<i>Crataegus phaenopyrum</i> L.	Hawthorn	HT
<i>Asimina triloba</i> L.	Paw Paw	PAW
<i>Morus Rubra</i> L.	Red Mulberry	RM
<i>Rhamnus cathartica</i> L.	Carolina Buckthorn	CB

Table 3.7. County abbreviations in conjunction with implementation of the Tennessee Seed Zone System (cf. Post 1998).

County	Abbrev.	County	Abbrev.
Anderson	A1	Henderson	H8
Bedford	B1	Henry	H9
Benton	B2	Hickman	H10
Bledsoe	B3	Houston	H11
Blount	B4	Humphreys	H12
Bradley	B5	Jackson	J1
Campbell	C1	Jefferson	J2
Cannon	C2	Johnson	J3
Carroll	C3	Knox	K1
Carter	C4	Lake	L1
Cheatham	C5	Lauderdale	L2
Chester	C6	Lawrence	L3
Claiborne	C7	Lewis	L4
Clay	C8	Lincoln	L5
Cocke	C9	Loudon	L6
Coffee	C10	Macon	M1
Crockett	C11	Madison	M2
Cumberland	C12	Marion	M3
Davidson	D1	Marshall	M4
DeKalb	D2	Maury	M5
Decatur	D3	McMinn	M6
Dickson	D4	McNairy	M7
Dyer	D5	Meigs	M8
Fayette	F1	Monroe	M9
Fentress	F2	Montgomery	M10
Franklin	F3	Moore	M11
Gibson	G1	Morgan	M12
Giles	G2	Obion	O1
Grainger	G3	Overton	O2
Greene	G4	Perry	P1
Grundy	G5	Pickett	P2
Hamblen	H1	Polk	P3
Hamilton	H2	Putnam	P4
Hancock	H3	Rhea	R1
Hardeman	H4	Roane	R2
Hardin	H5	Robertson	R3
Hawkins	H6	Rutherford	R4
Haywood	H7	Scott	S1

Table 3.7 (Continued)

County	Abbrev.	County	Abbrev.
Sequatchie	S2	Union	U2
Sevier	S3	Van Buren	V1
Shelby	S4	Warren	W1
Smith	S5	Washington	W2
Stewart	S6	Wayne	W3
Sullivan	S7	Weakley	W4
Sumner	S8	White	W5
Tipton	T1	Williamson	W6
Trousdale	T2	Wilson	W7
Unicoi	U1		

VITA

Jason Shane Maxedon was born on June 29, 1974 in Jackson, Tennessee. He graduated from Dyer County High School in Newbern, Tennessee in May of 1992. In the fall of that same year, he entered Dyersburg State Community College. He graduated with a Associate of Science degree in Biology and Forestry in May 1995. Jason then entered school at The University of Tennessee at Martin, where he graduated in May of 1997 with a Bachelor of Science degree in Wildlife Biology.

In the fall of 1997, he started work for The University of Tennessee Agricultural Extension Service as a County Extension Agent in McNairy county. In August of 1998, Jason entered The University of Tennessee at Knoxville Graduate Program and began work towards a Master of Science degree in Forestry. In August 2000, Jason accepted a wildlife manager position with Tennessee Wildlife Resources Agency as the west Tennessee Wetlands Forester.