5-2001

Patterns of seed production in Table Mountain pine (Pinus pungens)

Ellen Ann Johnson Gray

To the Graduate Council:

I am submitting herewith a thesis written by Ellen Ann Johnson Gray entitled "Patterns of seed production in Table Mountain pine (Pinus pungens)." I have examined the final electronic 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.

John Rennie, Major Professor

We have read this thesis and recommend its acceptance:

Tom Waldrop, Sally Horn

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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J. Rennie

John Rennie, Major Professor

We have read this thesis
and recommend its acceptance:

Thomas A. Waldrop

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Accepted for the Council:

Anne Mayhew

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Dean of The Graduate School

PATTERNS OF SEED PRODUCTION IN TABLE MOUNTAIN PINE

(*Pinus pungens*)

A THESIS

PRESENTED FOR THE

MASTER OF SCIENCE

DEGREE

THE UNIVERSITY OF TENNESSEE, KNOXVILLE

ELLEN A. JOHNSON GRAY

MAY 2001

DEDICATION

This thesis is dedicated to the memory of my beloved father

Elmo Walter "Lucky" Johnson,

for his guidance, continuous encouragement, endless patience, infinite wisdom, and immeasurable love.

ACKNOWLEDGEMENTS

There are so many people I would like to thank for their involvement in this study. First I would like to thank my thesis committee, Dr. John Rennie, Tom Waldrop, and Dr. Sally Horn. Dr. Rennie, my major professor, a person who has the fortune of always being in a good mood, was very encouraging and provided many hours of guidance, support and help in data collection. Tom Waldrop not only served on my committee, he initiated my interest in Table Mountain pine research, encouraged me "not to worry", and provided me with funding and field help. Sally Horn was one of my favorite instructors in school and I have always admired her devotion to helping students and providing them with guidance and support in research studies.

I am grateful for the funding provided by the U.S.D.I., U.S.D.A. Forest Service Joint Fire Sciences Program, the Southern Research Station, U.S.D.A, and the SRS-4104 Disturbance and Management of Southern Pine Ecosystems. I must also thank Entomologist Jim Hanula and biological technician Mike Cody, both with the Southern Research Station in Athens, Georgia, for their tremendous help with cone collection. Also thanks to other personnel with the Southern Research Station and fellow graduate students who assisted me with data collection. Warm thanks to the staff of the Forestry, Wildlife and Fisheries Department, Martha, Susan, Lavetta, and Sharon for providing assistance with financial and transportation needs for this project. In addition, I would like to thank Ronnie Lintz and the foresters with the Nolichucky Ranger District for their warm welcome and assistance in identifying stands of Table Mountain pine on the Cherokee National Forest.

I want to thank my dear friends Vicky Christofi and Denise Harvey for all their love, support, mentoring, and constant words of encouragement when sanity was an issue. To my great friend Ammar who humored me during those long nights of writing and kept me up to date on APA. My years at the university have not only provided me with several other wonderful friendships, but have given me the opportunity to realize my potential and the ability to explore and experience other cultures. It has truly been one of the most rewarding experiences of my life.

I want to thank my mother, Barbara Johnson for being so proud and encouraging and for taking care of my laundry. Thanks to the best sisters in the whole world, Christine, Barbara, and Jill for all your love and support. A very special thanks to my children, Jeremy and Joshua, and my daughter-in-law Stephanie, for all your love, confidence, and patience in supporting my pursuit to learn. Finally to my grandchildren, Jasmine and Jaida, who make my life so meaningful and have brought me great joy.

ABSTRACT

The lack of regeneration in stands of Table Mountain pine (*Pinus pungens* Lamb.) in the Southern Appalachian Mountains is of concern, particularly to federal land managers. Efforts to regenerate Table Mountain pine stands with prescribed burning have been less successful than expected. Several factors that may play a key role in successful regeneration are currently being investigated. The purpose of this study was to determine if Table Mountain pine seed viability and availability varied with tree age, cone age, and season. Seeds were collected in four seasons from 2-5 year old cones of 5-76+ year old trees. Results indicate that for trees 11 years and older, cones collected in the winter had the highest number of seeds and that those seeds were most viable. Young stands of trees less than 10 years old had many seed, but viability was poor. The results of this study can used to identify stands with an adequate number of viable seed. Information from this study and corollary studies funded by the Joint Fire Sciences Program will be used to ensure successful regeneration of Table Mountain pine.

TABLE OF CONTENTS

INTRODUCTION 1
I. LITERATURE REVIEW 2
Evidence of Decline 2
The Role of Fire 4
Restoration with Prescribed Burning 6
Adaptations to Fire 7
Cone and Seed Production 8
II. STUDY AREAS 10
Criteria 10
Location and Description of Study Areas 11
Cherokee National Forest 12
Round Knob Road 12
Green Mountain Road/Horsehitch Gap 13
Meadow Creek Road 13
Chatahoochee National Forest 14
Sumter National Forest 15
Damascus Road 16
Brasstown Road 16
III.METHODS 17
Cone Collection 17
Seed Extraction 20
Seed Germination 20
Statistical Analysis 21
IV. RESULTS 22
Seed Availability 22
Percent Seed Viability 22
Number of Viable Seed Per Cone 25
Number of Cones By Tree Age Class 25
V. DISCUSSION 28
Seed Numbers and Viability 28
Tree Age Class 28
Cone Age 29
Season 30
Cones Per Tree 31
VI. CONCLUSION AND RECOMMENDATIONS 32
REFERENCES 33
APPENDIX 38
VITA 64

LIST OF TABLES

Table		Page
1.	Cone collection dates in Table Mountain pine stands on the Cherokee (CNF), Chattahoochee (ChNF), and Sumter (SNF) National Forests..	18
2.	Average number of seeds per cone by tree age class, season, and cone age in Table Mountain pine stands in the Cherokee, Sumter, and Chattahoochee National Forests..	23
3.	Average percent viability of seed by tree age class, season, and cone age in Table Mountain pine stands in the Cherokee, Sumter, and Chattahoochee National Forests..	24
4.	Average number of viable seed per cone by tree age class, season, and cone age in Table Mountain pine stands in the Cherokee, Sumter, and Chattahoochee National Forests..	26
5.	Average number of cones per tree in Table Mountain pine stands in the Cherokee, Sumter, and Chattahoochee National Forests..............	27
A-1.	Fall collection data on Table Mountain pine stands in the Cherokee, Sumter, and Chattahoochee National Forests..............................	39
A-2.	Winter collection data in Table Mountain pine stands in the Cherokee, Sumter, and Chattahoochee National Forests..............................	43
A-3.	Spring collection data in Table Mountain pine stands in the Cherokee, Sumter, and Chattahoochee National Forests..............................	47
A-4.	Summer collection data in Table Mountain pine stands in the Cherokee, Sumter, and Chattahoochee National Forests.................	51
A-5.	Data on trees selected from the Cherokee National Forest for a Table Mountain pine study...	55
A-6.	Data on trees selected from the Sumter and Chattahoochee National Forests for a Table Mountain pine study..................................	58

Table		Page

A-7. Analysis of variance for number of seeds per cone in Table Mountain pine stands in the Cherokee, Sumter, and Chattahoochee National Forests.......... 60

A-8. Analysis of variance for percent viability of seed in Table Mountain pine stands in the Cherokee, Sumter, and Chattahoochee National Forests.......... 61

A-9. Analysis of variance for number of viable seed per cone in Table Mountain pine stands in the Cherokee, Sumter, and Chattahoochee National Forests.......... 62

A-10. Analysis of variance for number of cones per tree in Table Mountain pine stands in the Cherokee, Sumter, and Chattahoochee National Forests.......... 63

INTRODUCTION

Researchers and practitioners have assumed that a seed source is always available in serotinous-coned species such as Table Mountain pine (*Pinus pungens*); however, little is known about the specific seed biology of Table Mountain pine (TMP). Table Mountain pine stands of the Southern Appalachians are fire-dependent. In the past, cultural burning practices and lightning-ignited fires provided the necessary disturbance for maintaining these stands. The implementation of fire suppression programs in the early twentieth century has resulted in a subsequent decline of TMP and a shift toward fire-intolerant species. Since the majority of Southern Appalachian TMP is located on public lands, federal agencies have joined together to regenerate TMP with prescribed burning. However, efforts to regenerate stands with prescribed burning have been less successful than expected (Waldrop & Brose 1999, Waldrop et al. 2000, Turrill et al. 2000).

The objective of this study was to determine if seed viability and availability vary with tree age, cone age, and season in Table Mountain pine. Also, differences in the number of cones per tree were to be evaluated. Information from this study may be used to identify stands with an adequate and viable seed source in addition to suggesting the most appropriate season for burning. This study was conducted in conjunction with corollary studies funded by the Joint Fire Sciences Program aimed at restoring Table Mountain pine communities (Brose et al. 2001, Ellis et al. 2001, Mohr et al. 2001, Randles et al. 2001, Waldrop et al. 2001).

I. Literature Review

Table Mountain pine was once considered a species of little economic value due to its poor lumber quality (Williams 1992), and very little effort was given to its scientific study. However, more recent research has shown that the importance of Table Mountain pine lies in its ecological value. Commonly occurring with pitch pine (*P. rigida*), these forest species provide adequate food and cover to a number of wildlife species (Mollenhauer 1939, Williams 1998). In addition, they increase landscape diversity, and protect areas within their natural range that are sensitive to erosion.

Table Mountain pine is a fire-dependent Appalachian endemic found primarily on exposed ridgetops and southwest-facing dry mountain slopes from central Pennsylvania to northern Georgia (Zobel 1969, Williams 1998). Also known as hickory pine, poverty pine, mountain pine, and prickly pine, this somewhat hardy species has the adaptive ability to resist drought and exposure, thus allowing it to occupy sites which are less conducive to regeneration by other species in this region (Racine 1966, Williams 1992, Zobel 1969, U.S.D.A. 1990).

Evidence of Decline

Evidence of declining populations of Table Mountain pine in the Southern Appalachians has been recognized (SAMAB 1996, Harmon 1982 and White 1987; in Williams 1998). This recognition has stimulated efforts to restore degraded stands, which are being replaced by hardwoods and loblolly pine (SAMAB 1996). In 1996, the

Southern Appalachian Assessment listed Table Mountain pine woodlands as one of thirty-one rare communities in the Southern Appalachian Mountains (SAMAB 1996), attributing its decline mainly to the lack of fire. According to SAMAB, a second factor contributing to the decline were outbreaks of southern pine beetle. Stands killed by southern pine beetle do not regenerate because the exposed mineral soil needed for germination, usually provided by fire, is not present (SAMAB 1996). The Great Smoky Mountains National Park Fire Management Plan states the species "appears" to be declining within park boundaries (NPS 1996).

Results of a 1980 study conducted on the Meeting of the Pines Natural Area in south-central Pennsylvania indicated that oaks were dominating areas once occupied by pines, and that TMP stands were restricted to xeric, rocky, upper mountain slopes (Hunter and Swisher 1983). Another study conducted in TMP stands on Brush Mountain in southwestern Virginia concluded that a reduction in fire frequency following the acquisition of the land by the U.S.D.A. Forest Service, would lead to oak-dominated plant communities (Sutherland et al. 1995 as cited in SAMAB 1996).

Mollenhaurer (1939) attributed the scrubby appearance of TMP to limb cutting by the red squirrel, (*Tamiasciurus hudsonicus)*, a TMP seed consumer. A study conducted by Zobel in the mid-1960's confirmed that red squirrels were indeed responsible for gnawing off branches to get to the closed cones, but suggested that TMP seeds may serve as a reserve food. This damage resulted in a loss of seed supply affecting distribution and a reduction in growth, which decreased the competitive advantage of TMP relative to those species not being trimmed by squirrels (Zobel 1969).

In addition to southern pine beetle, other damaging agents which may cause the periodic demise of stands are the Table Mountain pine cone worm *Dioryctria yatesi*, a cone-boring insect (U.S.D.A. 1990) *Phaeolus schweinitzii*, which causes butt and root rot, and *Phellinus pini,* which causes heart rot in older or damaged trees (U.S.D.A. 1990).

THE ROLE OF FIRE

Prior to the early 1900's, Table Mountain pine stands were primarily maintained by pre-historic and historic cultural burnings (Van Lear and Waldrop 1989, Williams 1998, Turrill 1998). A recent study using macroscopic charcoal in soils on five National Forests throughout the Southern Appalachian region showed evidence of past fires in yellow pine communities (Turrill 1999). Continued burning by Native Americans and European settlers provided seedbeds suitable for regeneration. In the early twentieth century, destructive logging operations and slash burning increased fire frequency allowing pines to dominate upland forests (Turrill 1998, McIntyre 1929).

Lightning ignited fires played a small but integral part in shaping the landscape of the Southern Appalachians. In the Southern Appalachian region, lightning-ignited fires occur annually at an average of six lightning fires per one million acres (SAMAB 1996). More common on ridge tops and at higher elevations, these fires reinforced fire-adapted traits of southern pine communities (Turrill 1998).

The role of fire in maintaining the yellow pine ecosystems of the Southern Appalachians was altered in the early part of this century. The widely held view was that fire was a destructive event and had no place in forest ecosystems. Both Gifford Pinchot, the first Chief of the U.S.D.A. Forest Service, and naturalist John Muir held a different opinion. They recognized fire as a factor governing the distribution and character of forest growth that could play an important role in maintaining forest health and integrity. However, federal agencies adopted a fire suppression policy eliminating fire from public land and a policy to prohibit any burning in newly established National Forests. Ironically, this was seen as a method for preserving and maintaining ecosystems (Van Lear and Waldrop, 1989).

Fire is the critical element in maintaining populations of TMP as part of the landscape. Fire opens serotinous cones, exposes mineral soil by destroying litter, eliminates competing vegetation and thus provides sufficient light and water to pine seedlings. It may also minimize alleolopathic effects (Zobel 1969). In its absence, competition with shade tolerant hardwoods, low seed rain from serotinous cones, and poor seed bed conditions can limit TMP stands on some sites.

Zobel suggested that permanent self-maintaining stands exist on rock outcrops or shale slopes where hardwood species grow poorly (Zobel 1969). An ongoing study by Barden of a TMP population on Looking Glass Rock near Brevard, North Carolina, indicated that new TMP were recruited between 1887 and 1996 despite the absence of fire since 1889. However, environmental factors such as severe drought and an increase in temperature can have a negative effect on recruitment. High temperatures may increase the rate of opening of serotinous cones, but can reduce the production of viable seeds by desynchronizing the release of pollen with female strobilus receptivity, or by inhibiting germination. High temperatures also reduce seedling survival by reducing root growth. (Zobel 1969).

RESTORATION WITH PRESCRIBED BURNING

The fire history of the Southern Appalachians resulted in most forest vegetation adapting to fire and developing the ability to tolerate periodic fire to naturally regenerate. Prescribed fire mimics natural processes that have been at work for centuries in the Southern Appalachians. Major fires in the 1930's and 1950's brought about a realization of the need for prescribed burning to reduce the hazards of disastrous wildfires (Van Lear and Waldrop 1989). In an effort to enhance forest health and reduce fuel concentrations, the U.S. Department of Agriculture and U.S. Department of the Interior have established a national program to increase the use of prescribed fire as a management tool.

Previous studies on TMP regeneration suggested that high-intensity fires that remove the forest canopy and expose mineral soil would best serve to manage the stands (Zobel 1969, Sanders 1992). A 1999 study by Waldrop and Brose comparing fire intensity levels suggested medium-high intensity fires were successful in killing overstory trees and allowing abundant regeneration. Medium–intensity fires also have the advantage of being less dangerous and are easier to schedule due to a longer time available for burning (Waldrop and Brose 1998).

Adaptations to Fire

The specific combination of fire frequency and intensity has brought about important morphological adaptations to fire in pine ecosystems. In general, major adaptations possessed by pines are thick bark, cone serotiny, rapid development and sprouting. Thick bark insulates the vascular tissue from low-intensity surface fires thereby making post-fire survivorship greater in large, more vigorous trees rather than in small or suppressed individuals. TMP is intermediate in bark thickness and fire resistance. Cone serotiny appears to be an adaptation to repeated fires. The serotinous cones of TMP aid in its persistence on sites where repeated fires maintain the maximum possible seed supply available (Zobel 1969). Serotiny differs from soil seedbanks in that the seeds persist only for the life of the parent. Serotiny, which occurs exclusively in conifers in the northern hemisphere, is common in woody species burned by crown fires at intervals of a decade or more (Bond and van Wilgen 1996). Epicormic sprouting is absent in TMP, and there are few basal buds, to which allow recovery of saplings after fire injury and animal damage. TMP does, however, occur on sites that are least favorable for rapid growth allowing it to out-compete other species for canopy space, minerals, and soil moisture. The ultimate size of Table Mountain pine on xeric sites is constrained less than that of other tree species, allowing the pine to continue to compete, which it could not do on more fertile sites where hardwoods dominate.

CONE AND SEED PRODUCTION

Research on cone and seed production is very limited. The first documented study of cone and seed production was in 1929 by McIntyre and focused on the location of maximum seed production on the cone. He suggested no relationship between length or weight of cone with seed viability. Information on this study is limited, but Barden (1979) also noted McIntyre's finding that seeds were retained in cones for many.

The cones of TMP are serotinous, and defined by Critchfield (1966) as cones that remain closed on a tree for one or more years after the seeds mature, but can open rapidly when high temperatures melt the resin, which seals cone scales. Serotiny is also defined as 'canopy seed storage' where some of the previous year's seed crop is retained when the current year's seed crop has matured (Keeley and Zedler 1998).

Cones of TMP are seen on trees of sapling size. The species has a minimum seed-bearing age of 5 years (U.S.D.A. 1990). Cone length, width, and length to width ratio appear to decrease significantly with elevation, but increase with latitude. Table Mountain pine has 2 to 5+ cones per whorl, with one flush of cones per year on the new growth of the branch (Barden 1979, Zobel 1969). A 1929 study by McIntyre found an average of 3.1 cones per whorl produced each year. Immature cones are deep green to brown. Mature cones are light brown and ripen in autumn of the second season (U.S.D.A. 1990). As cones age, the color changes from light brown to gray.

Depending on elevation, pollen release varies from early March to late April (Zobel 1969). Hybridization in TMP is restricted due to early pollen release as compared to other pine species. Cones ripen in autumn of the second season and open depending on the degree of serotiny. There is no innate dormancy in seeds of TMP (Schopmeyer 1974). Seeds of TMP are winged and triangular in shape. The high seed weight of TMP gives it the advantage of establishing seedlings quicker in dry regions (Zobel 1969). McIntyre (1929) indicated frosts, drought, and heavy rains exert a greater influence on flower initiation, cone growth, seed development, and viability than does tree age.

II. STUDY AREAS

CRITERIA

The first criterion in choosing stands for this study was that TMP be the main component of the stand. Second, several tree age classes ranging from 5 to 75+ years needed to be present. Finally, a sufficient number of closed cones ranging in ages from 2 to 5 years needed to be present on the trees of the various age classes. U.S.D.A. Forest Service personnel assisted in providing forest maps, TMP stand compartment maps, and stand data to facilitate the search for stands to meet the criteria for suitable study locations.

Several sample trees within each tree age class, 5-10, 11-25, 26-50, 51-75, and 76+ years were needed to represent trees across each age class. Tree age was determined by extracting increment cores at breast height (4.5 ft.) and counting the annual rings. Several stands in the Nolichucky Ranger District of the Cherokee National Forest (CNF) met the criterion for tree age classes ranging from 11 to 75+ years.

Additional stands on the Pickens Ranger District of the Sumter National Forest (SNF) and on the Tallulah Ranger District of the Chattahoochee National Forest (ChNF) were needed to provide trees 5 to 10 years of age. In young stands where tree diameter was too small for coring, trees were cut down to determine their age.

LOCATION AND DESCRIPTION OF STUDY AREAS

The Cherokee, Sumter, and Chattahoochee National Forests are in the Southern Appalachian region. These areas are included in the Blue Ridge, and Ridge and Valley physiographic provinces of the Southern Appalachian Mountains (Fenneman 1938).

Climate in the Southern Appalachian region is greatly influenced by topography and elevation. Climatic data from the nearest weather station to each study area were obtained. These data included averages for data from 1961 through 1990.

The nearest weather station to the Nolichucky Ranger District, CNF is the U.T. Tobacco Experiment Station in Greenville, Tennessee, elevation 924.9 ft. (281.6 m). Average annual temperature was 56.2 degrees F (13.4° C). January was the coolest month with an average temperature of 34.9 degrees F (1.6° C) and July was the warmest month with an average of 75.3 degrees F (24.1° C). The average annual precipitation was 42.1 in. (107.0 cm). Records indicated July to be the wettest month with an average rainfall of 4.9 in. (12.4 cm), and October to be the driest month with an average of 2.7 in. (6.73 cm) (Southeast Regional Climate Center 2000).

The Highlands, North Carolina weather station, elevation 3,799 ft. (1158 m) was nearest to the study area in the Chattahoochee National Forest. From 1961 to 1990, the average annual temperature was 51.8 degrees F (11.0° C). The warmest month was July with an average of 68.1 degrees F (20.1° C), and January was the coolest month with an average temperature of 33.9 degrees F (1.1° C). Average annual precipitation was 83.8 in. (212.8 cm). Records indicated March to be the wettest month with an average rainfall of

8.2 in. (20.9 cm), and April to be the driest month with an average of 6.2 in. (15.7 cm) (Southeast Regional Climate Center 2000).

The Walhalla, South Carolina weather station, elevation 980.0 ft. (298.7 m) was nearest to the study area in the Sumter National Forest. From 1961 to 1990, the average annual temperature was 58.9 degrees F (14.9° C). The warmest month was July with an average of 76.3 degrees F (24.6° C), and January was the coolest month with an average temperature of 40.0 degrees F (4.4° C). Average annual precipitation was 61.6 in. (156.4 cm). Records indicated March to be the wettest month with an average rainfall of 6.5 in. (16.6 cm), and October was the driest month with an average of 4.4 in. (11.3 cm) (Southeast Regional Climate Center 2000).

CHEROKEE NATIONAL FOREST

Data were collected from three locations within the Nolichucky Ranger District of the CNF. All three locations contained stands adjacent to U.S.D.A. Forest Service roads. Round Knob Road and Green Mountain Road/Horsehitch Gap are in Greene County, Tennessee. The third location, Meadow Creek Road, is in Cocke County, Tennessee.

Round Knob Road

Round Knob Road (Forest Route 88) is southeast of Greenville, Tennessee and in the vicinity of Caney Creek and Jennings Creek in the northern portion of the Cherokee National Forest. The sampling location (36° 5' 15" N, 82° 41' 20" W) had an average elevation of 2625 ft. (800 m). Round Knob is in the Bald Mountains of the Southern Appalachian range. The geology is of the Unicoi and Hampton formations. Soils are Ramsey stony loam, very steep phase. They are weathered from quartzite, slate, shale, sandstone, and other acid metamorphic rocks. They are predominantly on plateaus and upper slopes of mountains. Runoff is medium to rapid, and permeability is rapid. Depth to bedrock ranges from 6 in. (15 cm) to 2 ft. (61 cm) (United States Department of Agriculture Natural Resource Conservation Service: Soil Survey Division 2001).

Green Mountain Road/Horsehitch Gap

Green Mountain Road (Forest Route 98) is south of Greenville, Tennessee in the northern portion of the Cherokee National Forest. It runs along Green Mountain, which is part of the Bald Mountains of the Southern Appalachian range. The sampling location (36° 1' 55" N, 82° 46' 10" W) had an average elevation of 2400 ft. (731 m). The geology of the location is of the Ocoee Supergroup and Unicoi formations. The soils at this location are Ramsey stoney loam, very steep phase. They are similar in character to those at the Round Knob Road location (United States Department of Agriculture Natural Resource Conservation Service: Soil Survey Division 2001).

Meadow Creek Road

Meadow Creek Road (Forest Route 142) is east of Newport, Tennessee and also in the northern portion of the Cherokee National Forest. It is in the Meadow Creek

Mountains of the Southern Appalachian range and north of the French Broad River. The sampling location (35° 58' 20" N, 82° 58' 10" W) had an average elevation of 2625 ft (800 m). Geology of this location is of the Erwin and Hampton formations. Soils are rough mountainous land, Ramsey soil material. These soils consist of very shallow, somewhat excessively drained soils on uplands with depths from zero to 1.5 ft. (45 cm). Small areas of rock outcrop of quartzite, conglomerate and sandstone are common, especially on steep and very steep backslopes. Soils of this series are very acidic and produce forests of slow growths and poor yields (United States Department of Agriculture Natural Resource Conservation Service: Soil Survey Division 2001).

CHATAHOOCHEE NATIONAL FOREST

This location is on Sarah Creek Road (Forest Route 155) in the Warwoman Wildlife Management on the Tallulah Ranger District Area east of Clayton, Georgia in Rabun County, Georgia. The sampling location (34° 55' 30" N, 83° 16' 50" W) had an average elevation of 2120 ft. (646 m) The geology of this location is Blue Ridge and Piedmont crystalline rock derived from metagawacke/mica schist and aluminous schist. Soils are of the Saluda and Evard fine loamy series. Saluda soils are shallow, well-drained, and moderately permeable soils formed in weathered granite, gneiss, or schist. Saluda soils are generally on narrow crests and steep slopes of the Appalachian Mountains at elevations ranging from 1,500 to 5,000 feet (457.2 m to 1,524.0 m). The Evard fine loamy series consists of very deep, well-drained soils that formed in residuum that may be affected by soil creep in the upper part of the profile. It is weathered from felsic to mafic, igneous and high-grade metamorphic rocks such as granite, hornblende gneiss, mica gneiss, and schist. Evard soils are on narrow to medium ridgetops and irregular or convex slopes in the Southern Appalachian Mountains (United States Department of Agriculture Natural Resource Conservation Service: Soil Survey Division, 2001).

SUMTER NATIONAL FOREST

Data were collected from two locations within the Andrew Pickens Ranger District of the SNF. Both locations contain stands adjacent to Forest Service roads. Brasstown Road (Forest Route 748) and Damascus Road (Forest Route 753) are both within Oconee County. Stand characteristics did not vary significantly. Both locations are south of South Carolina State Highway 76.

The geology of the two locations was Blue Ridge and Brevard Belts. Soils were of the Walhalla and Edneytown series. The Walhalla series consists of very deep, well-drained, moderately permeable soils that formed in residuum from granite, gneiss, or schist. Walhalla soils are on narrow ridgetops and side slopes adjacent to drainageways in the Southern Appalachian Mountains. The Edneytown series consists of very deep, well-drained, moderately permeable soils that formed in loamy material weathered from gneiss, granite, or schist rock. They are on ridgetops and side slopes adjacent to drainageways of the Southern Appalachian Mountains. Edneytown soils are on narrow to medium ridgetops and irregular or convex slopes in the Southern Appalachian

Mountains. (United States Department of Agriculture Natural Resource Conservation Service: Soil Survey Division 2001).

Damascus Road

This location lies between Battle Creek and Brasstown Creek. Coordinates are 34° 42' 45" N, 83° 16' 15" W); the elevation is 1580 ft (481 m).

Brasstown Road

This location is southeast of the Damascus Road location and north of Longnose Mountain. Coordinates are (34° 43' 15" N, 83° 19' 10" W); the elevation is 1510 ft (460 m).

III. Methods

Cone Collection

Cone collection took place in four consecutive seasons, beginning in the fall of 1999 and ending in summer of 2000. Cone collection representing each season was dependent on temperature and weather conditions rather than the actual month (Table 1). Winter collection was postponed until the end of February as a result of icy conditions on roads thereby preventing the use of the bucket truck. One collection was made from each location during each season. Fall months included September, October and November. Subsequent collections for the remaining seasons, winter, spring, and summer included three months for each season (Table A-1, A-2, A-3, A-4).

Sample trees in the Cherokee National Forest locations were marked, numbered, and tagged for easy identification throughout the study. Notation was made of tree age at breast height, diameter at breast height, and the number of cones per tree. Sixty-six trees were chosen from the three locations in CNF (Table A-5). Twenty trees were selected from the Round Knob Road location ranging in age at breast height from 15 to 98 years. Twenty-three trees were selected from both the Green Mountain Road/Horsehitch Gap location and the Meadow Creek Road location, ranging in age at breast height from 18 to 135 years and 16 to 148 years respectively.

Data collection for the Sumter and Chattahoochee National Forest locations began in November. A total of forty sample trees ranging in age from 5 to 12 years at breast height was chosen from the Sumter and Chattahoochee National Forests (Table A-6).

Table 1. Cone collection dates for a study in Table Mountain pine stands on the Cherokee (CNF), Chattahoochee (ChNF), and Sumter (SNF) National Forests.

Season	CNF	ChNF/SNF
Fall	Oct. 20-21	Nov. 5-6
Winter	Feb. 23-24	Mar. 3-4
Spring	May 17-18	June 17-18
Summer	July 5-6	July 21-22

Data were collected from approximately ten trees for each season. Sample trees at these locations were too small in diameter to core for age; therefore, it was necessary to cut the trees down to determine tree age. Thirteen trees were selected from both the Damascus Road and Brasstown Road locations. Fourteen trees were chosen from the Sarah Creek Road location. Notation was made of tree age at breast height, diameter at breast height, and number of cones per tree. Access to cones for the younger stands in the Sumter and Chattahoochee National Forests locations was achieved once trees were cut down.

An aerial lift truck with a 55 ft. boom, provided by the U.S.D.A. Forest Service, Southern Research Station, was used for cone collection at the Cherokee National Forest locations. Research Entomologist James Hanula and biological technician Michael Cody, with the Southern Research Station, assisted in cone collection while conducting a separate study on coneworm damage. In October when cone collection began, there was evidence of *Dioryctria yatesi* (TMP coneworm) infestation in sample trees located on the Cherokee National Forest. Holes left by burrowing could be seen on the outside of the closed cones. As the worm burrows into the cone, the cone changes from bright green to a deep purple resembling a bruise. Slicing the cone in half allowed viewing of the worm.

A total of 264 cones was expected each season from the 66 sample trees. However, coneworm infestations reduced the success of finding sound cones. Collections included only 232 cones (88%) in the fall, 206 cones (78%) in the winter, 185 cones (70%) in the spring, and 160 cones (61%) in the summer. Each collection produced increasing evidence of coneworm infestation. There was no sign of coneworm damage in the young sample trees on the Sumter and Chattahoochee National Forests.

This study focused on closed cones 2 to 5 years old. To ensure accuracy, cone age for this study was determined by color, position of whorl on branch, and time of year. In addition, no cones were sampled from broken branches. TMP cones are sessile, heavy, and armed with thick pointed spines. Leather gloves were used for cone removal. One cone representing each cone age was collected from each tree for a possible total of four cones per tree per season. If possible, cones from the same whorl or branch were taken to represent each season. Once removed from the branch, each cone was placed in a separate paper bag. Tree number, cone age, and location were recorded on the bag.

SEED EXTRACTION

Following cone collection for each season, bags were placed one layer thick in a drying oven for a minimum of 12 hours at 60° C to allow cones to open. Following heating, bags were removed and stored at room temperature. Seed extraction was achieved by turning the cone upside down and knocking it on a hard surface. Seeds were collected and seed wings removed. Seeds were then counted, placed in small envelopes, and labeled for identification.

SEED GERMINATION

To determine seed viability, a sample of two-thirds of the total number of seeds extracted from each cone was selected for the germination test. For cones containing fewer than three seeds, one seed was selected. The selected seeds from each cone were placed in a covered 100x15 mm plastic Petri dish lined with a 9.0 cm diameter, course filter paper moistened with deionized water. Petri dishes were labeled, sealed with two inch parafilm to prevent moisture loss, and placed in an incubator and held at a constant temperature of 25° C for 14 days. After 14 days, dishes were removed and opened. Seeds were considered viable if any growth could be seen.

Statistical Analysis

Each cone collected represented one observation. The total number of seeds extracted from each cone, the number of seeds selected for germination tests, and the number of viable seeds were entered into a SAS file. Percent viability was the number of viable seeds divided by the total number of seeds tested times 100. The number of viable seed per cone was estimated by multiplying the number of seed extracted by percent viability divided by 100.

The total number of seeds extracted from each cone, percent viability per cone, and the number of viable seed per cone were then analyzed with ANOVA using the General Linear Methods procedure in SAS (SAS Institute 1997). Variables tested were tree age-classes, seasons, and cone ages, and interactions among these variables. After data were analyzed with ANOVA, means were obtained for tree age-classes, seasons, and cone ages, and tested using Duncan's Multiple-Range test. Cones per tree were also analyzed by tree age class with ANOVA (GLM, SAS, SAS Institute 1997). Means by tree age-class were calculated and tested using Duncan's Multiple Range test. All statistical analyses were conducted using a 95% confidence level.

IV. Results

Seed Availability

ANOVA showed significance in the number of seeds extracted from a cone by season and also by cone age (Table 2, A-7). The analysis produced no significance in the interactions of tree age class, cone age, and season. The average number of seeds per cone generally decreased with tree age class. Duncan's multiple range test identified two overlapping groups for tree age class: (1) 11-25 years, 5-10 years and 26-50 years; (2) 26-50 years, 51-75 years and 76+ years. The average number of seeds extracted per cone was significantly higher for the winter and fall collections than for the spring and summer collections. Extraction numbers by cone age indicated that seeds were significantly more numerous in 3, 4, and 5 year old cones than in 2 year old cones.

Percent Seed Viability

Seed viability was significantly associated with tree age classes, seasons, and cone ages (Table 3, A-8). The analysis produced no significance in the interactions of tree age class, cone age, and season. Seed viability was highest for the 76+ years tree age class at 38.6% and lowest for the 5 –10 year tree age class at 8.8%. For the 5-10 year tree age class, seed viability was significantly lower than the other classes. Seed viability for winter and spring collections was significantly higher than viability for fall and summer collections. Viability of seeds collected in the summer was significantly lower than that of the other three seasons. Four and 5 year cones did not vary significantly, but were

Table 2. Average number seeds per cone by tree age class, season, and cone age in Table Mountain pine stands in the Cherokee, Sumter, and Chattahoochee National Forests.

Tree Age Class	Mean[1]
5 - 10 years	46.0a,b
11 – 25 years	51.9a
26 - 50 years	43.5a,b
51 - 75 years	41.5b
76+ years	37.9b

Season	Mean[1]
Fall	45.9a
Winter	49.8a
Spring	39.2b
Summer	37.5b

Cone Age	Mean[1]
2 years	38.2b
3 years	46.0a
4 years	47.3a
5 years	47.0a

[1] Means within each group followed by the same letter do not differ at alpha=.05

Table 3. Average percent viability of seed by tree age class, season, and cone age in Table Mountain pine stands in the Cherokee, Sumter, and Chattahoochee National Forests.

Tree Age Class	Mean[1]
5- 10 years	8.8%b
11 - 25 years	33.3%a
26 - 50 years	32.7%a
51 - 75 years	32.9%a
76+ years	38.6%a

Season	Mean[1]
Fall	28.1%b
Winter	40.0%a
Spring	35.4%a
Summer	21.2%c

Cone Age	Mean[1]
2 years	27.3%b
3 years	27.6%b
4 years	38.5%a
5 years	36.7%a

[1] Means within each group followed by the same letter do not differ at alpha=.05

significantly more viable than 3 and 2 year old cones. Viability for 3 and 2 year old cones did not vary significantly. Four and 5 year cones did not vary significantly, but were significantly more viable than 3 and 2 year old cones. Viability for 3 and 2 year old cones did not vary significantly.

Number of Viable Seed Per Cone

ANOVA showed significance in the number of viable seeds per cone by tree age class, season and also by cone age (Table 4, A-9). The analysis produced no significance in the interactions of tree age class, cone age, and season. The number of viable seeds per cone did not differ significantly in trees 11 to 76+ years but was very low for the 5 to 10 year tree age class. The largest number of viable seed was from cones collected in the winter season. The number of viable seed from the summer collection was significantly lower than the other seasons. Fall and spring collections did not differ significantly. The number of viable seeds from the 4 and 5 year old cones did not differ, but was significantly higher than the 2 and 3 year old cones.

Number of Cones By Tree Age Class

ANOVA showed significance in the number of cones per tree by tree age class. Each tree age class was significantly different from the other except for the 51 to 75 and the 76+ year tree age class. Cones increased in number with tree age (Table 5, A-10).

Table 4. Average number of viable seed per cone by tree age class, season, and cone age in Table Mountain pine stands in the Cherokee, Sumter, and Chattahoochee National Forests.

Tree Age Class	Mean[1]
5- 10 years	5.6b
11 - 25 years	21.0a
26 - 50 years	17.4a
51 - 75 years	17.0a
76+ years	16.8a

Season	Mean[1]
Fall	16.1b
Winter	23.3a
Spring	14.8b,c
Summer	11.2c

Cone Age	Mean[1]
2 years	13.1b
3 years	13.7b
4 years	23.0a
5 years	19.8a

[1] Means within each group followed by the same letter do not differ at alpha=.05

Table 5. Average number of cones per tree by tree age class in Table Mountain pine stands in the Cherokee, Sumter, and Chattahoochee National Forests.

Tree Age Class	Mean[1]
5- 10 years	5.3d
11 - 25 years	24.6c
26 - 50 years	49.1b
51 - 75 years	67.1a
76+ years	76.3a

[1] Means within each group followed by the same letter do not differ at alpha=.05

V. DISCUSSION

Lack of regeneration following prescribed fire in the fire dependent Table Mountain pine stands led to several questions. In addition to current research on stand replacement fire, several recent studies are examining other factors such as seedbed habitat, mycorrhizal associations, and disturbance history through dendrochronology. The questions focused on in this study were, "Can stands with an adequate and viable seed source be identified?" and "Are there differences in seed numbers and viability as a result of tree age, cone age, and/or the season in which the seeds were collected and germinated?"

SEED NUMBERS AND VIABILITY

Tree Age Class

McIntyre (1929) reported that Table Mountain pine averaged 49.6 seeds per cone with an average viability of 81%. McIntyre (1929) was the only published report with which to compare the results from the current study. There was no significant difference in the number of seeds per cone from trees 5 to 76+ years old (Table A-7). However, seeds did decrease in number as tree age increased beginning with the 11 year old trees. This trend was interrupted by the 5-10 year old trees whose seed numbers exceed those trees 26 to 76+ years old (Table 2). Trees in the 5 to 10 year old age class were located farther south in latitude than the 11-76+ age class trees, and may have produced differences as a result of soil and climate. McIntyre (1929) found that both drought and heavy precipitation could have a greater influence on cone and seed development than age of tree.

Although trees of all age classes produced an adequate number of seeds; there was a very significant drop in percent seed viability and the number of viable seeds per cone in trees 5 to 10 years (Tables 3 and 4). As stated earlier, location may be a factor. This could also be a response to fire intervals in the past. Studies have shown that prior to acquisition by the U.S. Forest Service, fires occurred approximately every 10 to 12 years in some areas of the Southern Appalachians (Harmon 1982, Sutherland et al. 1993). Although seed numbers in the 5 to 10 year age class are adequate, low viability in this age class may result in poor regeneration if very young stands are burned too frequently. However, periodic fires are necessary to reduce the establishment of hardwoods which out-compete young seedlings.

Cone Age

The trend for number of seeds per cone and for viability was the same, with 2 year old cones ranking significantly lower in both categories (Tables 2, 3, 4). Seeds from 3 year old cones were also significantly lower in percent viability and the number of viable seeds per cone than seeds from the 4 and 5 year old cones (Tables 2, 3, 4).

This was probably the result of differences in pollenation and other factors in the respective years of cone development. These effects could not be separated because the cones in this study were collected in the same year; that is, two year old cones were initiated in 1998, three year old cones in 1997, and so forth. To separate the effect of cone age from the effect of year would require a multi-year study. This study does suggest, however, that viability does not decrease with time.

A seed study on jack pine (*P. banksiana*), another serotinous coned species, found a significant drop in seed quality from 3 year old cones and concluded that constant moisture content is a more important factor in maintaining viability than temperature (Schantz-Hansen 1941). Barden (1979) stated that seeds can remain viable in cones up to 11 years. Barden also found that about 40% of the 2 year old seeds are released each year as a strategy for maintaining the population in the absence of fire. Similar to TMP, jack pine cones remain on the tree for several years and open irregularly to liberate a few seeds at a time (Schantz-Hansen 1941).

Season

Cones collected in winter and fall produced a significantly higher number of seeds than cones from the spring and summer collections. Percent viability was highest in seeds from the winter collection, but not significantly different from spring. The lowest percent viability and the number of viable seeds per cone, occurred in seeds in the summer months. This suggests that although cones ripen in autumn of the second season, seed viability may not peak until winter. Mature cones generally turn brown; however, cone color alone may not be sufficient evidence for maturity. To avoid collecting immature seeds, the manual of *Seeds of Woody Plants of North America* (1992) suggests checking ripeness in a small sample of cones from individual trees. A mature seed has a firm white or cream-colored endosperm and a yellow to white embryo that nearly fills the endosperm cavity

The delayed effects of severe drought can cause reduced production of viable seed. In addition, high temperatures can cause premature opening of serotinous cones. It also reduces the production of viable seeds by desynchronizing pollen release and female strobilus receptivity or by inhibiting germination (Zobel 1969).

As seeds age, viability can be maintained for some time. However, they eventually enter a period of rapid decline during which some seeds completely fail to germinate and grow normally. The differences in viability among seeds of the same age can be related to heterogeneity of individual seeds within a seed lot (Kozlowski 1972). Frequent fire is an important technique to perpetuate the existence of genetic diversity within stands and would allow for regular population turnover (Gibson et al. 1990).

Cones Per Tree

The number of cones per tree increased with tree age class based on ocular estimates This is expected since tree crown surface area increases with tree size and age. More cones with increasing tree age suggests burning in stands with higher components of older trees since the number of cones per tree increases faster with age than the number of viable seed per cone decreases.

VI. CONCLUSION AND RECOMMENDATIONS

To enhance forest health and reduce fuel concentrations, the United States Department of Agriculture and the United States Department of the Interior have established a national program to increase the use of prescribed fire as a management tool. Without periodic fire, it is unlikely that fire dependent species such as the Table Mountain pine will achieve optimal regeneration.

To achieve success, several factors are needed including adequate seedbed with available moisture and light, fire intervals that do not negatively affect the microbial activity in the soil, and an adequate and viable seed crop. Tree age is not a factor since stands older than 10 years of age provided an adequate and viable seed source. Although cones did show some difference in their ability to provide adequate viable seed numbers, there would be no way to discriminate among cones of different ages when burning. Further, although the seeds of Table Mountain pine mature in the fall of the second season, winter provided the highest percentage of viable and number of viable seed.

If management of declining populations is to be effective, the development of a prescribed burning plan should consider tree age and season in which burning is implemented to ensure that an adequate and viable seed source is present.

Further investigation into seed biology should be considered. This study was limited to one year and forced to eliminate trees originally selected due to insect damage and drought conditions. Conducting this research over a longer period of time and over a wider area, would better qualify results.

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APPENDIX

Table A-1: Fall collection data for a study conducted on Table Mountain pine stands in the Cherokee, Sumter, and Chattahoochee National Forests.

		2 yr. Cone Seeds			3 yr. Cone Seeds			4 yr. Cone Seeds			5 yr. Cone Seeds		
Tree#	Tree Ag yrs.@bh	Ext.	#Seeds Germ.	#Seeds Viable	Ext.	#Seeds Germ.	#Seeds Viable	Ext.	#Seeds Germ.	#Seeds Viable	Ext.	#Seeds Germ.	#Seeds Viable
1	45	5	3	2	0	0	0	17	12	1	0	0	0
2	34	84	56	39									
3	40				128	85	0	47	31	9	58	39	2
4	66	113	75	0	105	70	46	85	57	33	18	12	5
5	17	56	37	1	40	27	0	12	8	0	103	69	1
6	50	0	0	0	0	0	0	48	32	0	0	0	0
7	26	0	0	0	69	46	0	10	7	0	2	1	1
8	64	35	23	1	0	0	0	18	12	0	55	37	0
9	98	51	34	0	104	69	0	0	0	0	29	20	0
10	17	77	51	0	89	60	1	80	53	0			
11	53				0	0	0				79	53	39
12	56	7	4	0	0	0	0	31	21	0	0	0	0
13	66	0	0	0	23	16	4	1	1	0	2	1	0
14	94	93	62	26	30	20	6						
15	95				0	0	0	0	0	0			
16	92	37	25	2	1	1	1						
17	85	64	43	13	3	2	1	0	0	0			
18	17	104	69	7	106	71	18	40	27	3			
19	15	0	0	0	0	0	0	115	77	50			
20	17	0	0	0	0	0	0	59	39	32			
21	51	0	0	0	0	0	0	92	61	42	61	41	28

Table A-1: Fall collection data for a study conducted on Table Mountain pine stands in the Cherokee, Sumter, and Chattahoochee National Forests (cont.).

Tree#	Tree Ag yrs.@bh	2 yr. Cone Seeds Ext.	2 yr. #Seeds Germ.	2 yr. #Seeds Viable	3 yr. Cone Seeds Ext.	3 yr. #Seeds Germ.	3 yr. #Seeds Viable	4 yr. Cone Seeds Ext.	4 yr. #Seeds Germ.	4 yr. #Seeds Viable	5 yr. Cone Seeds Ext.	5 yr. #Seeds Germ.	5 yr. #Seeds Viable
22	52	0	0	0				0	0	0			
23	50	60	40	1	0	0	0	18	12	0	7	5	0
24	55	0	0	0	69	46	20	35	23	10	0	0	0
25	59	0	0	0	53	35	3	52	35	0	32	21	0
26	52	0	0	0	96	64	0				0	0	0
27	57	101	67	0	102	68	0	77	51	0	94	63	14
28	68												
29	70	23	15	11	41	27	13	0	0	0	28	19	9
30	67	0	0	0	0	0	0						
31	135	113	75	18	3	2	2	1	1	0	93	62	36
32	70	0	0	0	0	0	0	0	0	0	34	23	18
33	46	37	25	7	14	9	3	109	73	53			
34	64	48	32	19	4	3	0	53	35	15	79	53	32
35	69	28	18	14	55	37	31	96	64	53	54	36	25
36	76	30	20	3	89	59	2	1	1	0	0	0	0
37	32	98	65	12	46	31	12	92	61	26	91	60	42
38	18	94	62	32	55	37	19	78	52	34			
39	22	66	44	2	8	5	3	1	1	0			
40	43	14	9	4	46	31	20	7	5	5	154	103	92
41	22	52	35	11	97	65	1	2	1	0	24	16	3
42	23				108	72	19	109	73	23	103	69	0

Table A-1: Fall collection data for a study conducted on Table Mountain pine stands in the Cherokee, Sumter, and Chattahoochee National Forests (cont.).

Tree#	Tree Ag yrs.@bh	2 yr. Cone Seeds Ext.	2 yr. #Seeds Germ.	2 yr. #Seeds Viable	3 yr. Cone Seeds Ext.	3 yr. #Seeds Germ.	3 yr. #Seeds Viable	4 yr. Cone Seeds Ext.	4 yr. #Seeds Germ.	4 yr. #Seeds Viable	5 yr. Cone Seeds Ext.	5 yr. #Seeds Germ.	5 yr. #Seeds Viable
43	20	7	5	0	127	85	22	73	49	27	121	81	0
44	80	0	0	0	27	18	10	102	68	58	112	75	42
45	74	17	12	10	47	31	8	22	15	8	72	48	14
46	65	7	5	0	60	40	0	71	47	7	66	44	1
47	80	2	1	1	0	0	0	52	35	1	72	48	0
48	73	19	13	2	70	47	0	79	53	11	89	59	0
49	75	8	6	0	84	56	0	58	39	0	62	41	0
50	60	61	41	38	92	61	19	80	53	41	49	33	19
51	62	7	5	1	0	0	0	65	43	23	85	57	32
52	45	24	16	9	17	11	5	9	6	2	0	0	0
53	26	28	19	5	93	62	0	129	86	0			
54	81	35	23	17	0	0	0	0	0	0	89	59	10
55	16	36	24	18	88	59	17	118	79	36			
56	17	61	41	19	0	0	0	130	87	38	59	39	27
57	30	26	17	9	95	63	3	102	68	7	14	9	0
58	31	26	17	0	76	51	0	78	52	2	35	23	0
59	34	103	69	1	101	67	0	56	37	0	15	10	3
60	21	33	22	1	107	71	60	12	8	0	28	19	14
61	20	52	35	1	74	50	40	97	65	25	86	57	42
62	44	38	25	9	20	13	11	29	19	12	0	0	0
63	148	25	17	8	31	21	3	29	19	8	70	47	33

Table A-1: Fall collection data for a study conducted on Table Mountain pine stands in the Cherokee, Sumter, and Chattahoochee National Forests (cont.).

Tree#	Tree Ag yrs.@bh	2 yr. Cone Seeds			3 yr. Cone Seeds			4 yr. Cone Seeds			5 yr. Cone Seeds		
		Ext.	#Seeds Germ.	#Seeds Viable	Ext.	#Seeds Germ.	#Seeds Viable	Ext.	#Seeds Germ.	#Seeds Viable	Ext.	#Seeds Germ.	#Seeds Viable
64	27	65	43	35	3	2	0	1	1	0	0	0	0
65	67	18	12	0	78	52	0	133	89	1	0	0	0
66	58	54	36	9	114	76	0	0	0	0	63	42	7
101	8	0	0	0	67	45	0						
102	6	154	103	5	183	122	50						
103	5	29	20	0									
104	5	32	21	0									
105	8				31	20	3						
106	7	4	3	0	51	34	0	4	3	0	30	20	2
107	9	17	11	0	24	16	2	17	11	1			
108	6	64	43	1									
109	12	42	28	0	26	17	0	53	35	0	42	28	1
110	6	63	42	1									
111	6	53	35	14	95	63	14	94	63	0			
Totals		2700	1799	439	3465	2311	492	3079	2056	697	2459	1642	594

Table A-2: **Winter collection data for a study conducted on Table Mountain pine stands in the Cherokee, Sumter, and Chattahoochee National Forests.**

Tree#	Tree Ag yrs.@bh	2 yr. Cone Seeds			3 yr. Cone Seeds			4 yr. Cone Seeds			5 yr. Cone Seeds		
		Ext.	#Seeds Germ.	#Seeds Viable	Ext.	#Seeds Germ.	#Seeds Viable	Ext.	#Seeds Germ.	#Seeds Viable	Ext.	#Seeds Germ.	#Seeds Viable
1	45	0	0	0				55	36	34			
2	34	14	10	2									
3	40	84	56	30	46	31	0	22	15	1	52	35	7
4	66	51	34	16	72	48	8	83	55	9	50	33	16
5	17	66	44	8	38	25	3	33	22	10	64	43	24
6	50	20	13	0	0	0	0	0	0	0	13	9	7
7	26	46	31	2	25	17	1	62	41	36	12	8	7
8	64	63	42	2	10	7	0	82	55	26	35	23	15
9	98	62	41	14	46	32	19	103	69	43			
10	17	63	42	21	75	50	0	24	16	15	27	18	16
11	53	116	77	72	0	0	20	103	69	51	0	0	0
12	56	42	28	7	38	25	6	1	1	0			
13	66	0	0	0	29	19	3	46	31	1			
14	94	4	3	1	9	6	3	12	8	6	34	23	12
15	95	0	0	0				15	10	9	14	9	6
16	92	15	10	4	18	12	1						
17	85	5	3	1	88	59	41	32	21	8			
18	17	74	49	10	0	0	0	1	1	0			
19	15	0	0	0									
20	17	0	0	0									
21	51	65	43	36	0	0	0	39	26	21			

Table A-2: Winter collection data for a study conducted on Table Mountain pine stands in the Cherokee, Sumter, and Chattahoochee National Forests (cont.).

Tree#	Tree Ag yrs.@bh	2 yr. Cone Seeds			3 yr. Cone Seeds			4 yr. Cone Seeds			5 yr. Cone Seeds		
		Ext.	#Seeds Germ.	#Seeds Viable	Ext.	#Seeds Germ.	#Seeds Viable	Ext.	#Seeds Germ.	#Seeds Viable	Ext.	#Seeds Germ.	#Seeds Viable
22	52	27	18	9	40	27	24				63	42	37
23	50										56	37	29
24	55	23	15	3	17	11	11	39	26	21			
25	59	98	65	19	30	20	18	74	49	32	0	0	0
26	52	1	1	0	23	15	15						
27	57	105	70	13	107	71	58	53	35	14	48	32	2
28	68	68	45	17	97	64	27						
29	70												
30	67												
31	135	49	33	24	37	25	21						
32	70	49	33	3	33	22	15	27	18	13	9	6	1
33	46	65	43	15	31	21	8						
34	64	93	62	12	6	4	0	91	61	25	95	63	25
35	69	40	27	5	139	93	21	35	23	19	47	31	6
36	76	38	25	1				67	45	8	38	25	6
37	32	86	57	17									
38	18	42	28	10	43	29	16	37	25	2			
39	22	34	23	5	56	37	5	61	41	28			
40	43	53	35	16	65	43	12	31	21	12	95	63	26
41	22	38	25	6	23	15	2	44	29	9	29	19	6
42	23	2	1	0	11	7	0	98	65	18	16	11	4

Table A-2: Winter collection data for a study conducted on Table Mountain pine stands in the Cherokee, Sumter, and Chattahoochee National Forests (cont.).

		2 yr. Cone Seeds			3 yr. Cone Seeds			4 yr. Cone Seeds			5 yr. Cone Seeds		
Tree#	Tree Ag yrs.@bh	Ext.	#Seeds Germ.	#Seeds Viable	Ext.	#Seeds Germ.	#Seeds Viable	Ext.	#Seeds Germ.	#Seeds Viable	Ext.	#Seeds Germ.	#Seeds Viable
43	20	103	69	63	64	43	39	31	21	13	77	51	45
44	80	59	39	17	92	61	26	110	73	54	90	60	41
45	74	15	10	1	52	35	13	83	55	51	67	45	20
46	65	39	26	9	31	21	19	74	49	42	71	47	33
47	80	8	5	2	55	37	19	14	9	8	84	56	21
48	73	42	28	0	88	58	8	93	62	45	78	52	43
49	75	37	25	1	95	63	14	91	61	3			
50	60	34	23	17	36	24	11	67	45	39			
51	62	11	7	1	70	47	36	78	52	36			
52	45	28	17	5	61	41	34	102	68	61	3	2	1
53	26	126	84	1	37	25	1	118	79	17			
54	81	22	15	2	6	4	0	107	71	53	131	87	53
55	16	69	46	20	52	35	6	99	66	57			
56	17				76	51	33	81	54	43			
57	30	29	19	11	68	45	8	86	57	54	86	57	46
58	31	62	41	9	72	48	2	121	81	12	101	67	32
59	34	105	70	18	104	69	53	105	70	62			
60	21	44	29	2	94	63	17	14	9	0			
61	20	65	43	7	50	33	8	55	37	20	58	39	18
62	44	19	13	7	35	23	17	30	20	3	64	43	26
63	148	37	25	1	24	16	2	42	28	21	70	47	26

Table A-2: Winter collection data for a study conducted on Table Mountain pine stands in the Cherokee, Sumter, and Chattahoochee National Forests (cont.).

		2 yr. Cone Seeds			3 yr. Cone Seeds			4 yr. Cone Seeds			5 yr. Cone Seeds		
Tree#	Tree Ag yrs.@bh	Ext.	#Seeds Germ.	#Seeds Viable	Ext.	#Seeds Germ.	#Seeds Viable	Ext.	#Seeds Germ.	#Seeds Viable	Ext.	#Seeds Germ.	#Seeds Viable
64	27	24	16	0	57	38	3	93	62	20			
65	67	9	6	0	72	48	11	47	31	15			
66	58	15	10	0	64	43	0	124	83	0	33	22	3
112	5	26	17	2									
113	6	6	4	0	5	3	0						
114	6	0	0	0									
115	7	33	22	1									
116	7	9	6	1									
117	10							31	21	0			
118	8	54	36	2	60	40	5	37	25	2			
119	7	81	54	0	90	60	9	85	57	15			
120	6	25	17	0	0	0	0						
Totals		2937	1954	601	2862	1909	752	3388	2260	1217	1810	1205	660

Table A-3: Spring collection data for a study conducted on Table Mountain pine stands in the Cherokee, Sumter, and Chattahoochee National Forests.

Tree#	Tree Ag yrs.@bh	2 yr. Cone Seeds			3 yr. Cone Seeds			4 yr. Cone Seeds			5 yr. Cone Seeds		
		Ext.	#Seeds Germ.	#Seeds Viable	Ext.	#Seeds Germ.	#Seeds Viable	Ext.	#Seeds Germ.	#Seeds Viable	Ext.	#Seeds Germ.	#Seeds Viable
1	45	47	31	0	3	2	1	72	48	30			
2	34	86	57	17									
3	40	76	51	1	0	0	0	48	32	5	0	0	0
4	66	30	20	5	32	21	3	56	37	25	13	9	4
5	17	67	45	0	0	0	0	0	0	0	24	16	2
6	50	0	0	0	7	5	0	0	0	0			
7	26	0	0	0	7	5	1	0	0	0	4	3	0
8	64	0	0	0	31	21	2	32	21	2	27	18	1
9	98	0	0	0	0	0	0	55	37	4			
10	17	71	47	8	42	28	24				25	17	3
11	53	26	17	0	38	25	8	52	35	5	75	50	33
12	56	0	0	0									
13	66	13	9	1				0	0	0			
14	94				36	24	14						
15	95	11	7	4									
16	92	0	0	0	1	1	0	3	2	1			
17	85	12	8	1	49	33	15	26	17	6	2	1	1
18	17				103	69	4						
19	15												
20	17	30	20	7	50	33	6						
21	51												

Table A-3: **Spring collection data for a study conducted on Table Mountain pine stands in the Cherokee, Sumter, and Chattahoochee National Forests (cont.).**

Tree#	Tree Ag yrs.@bh	2 yr. Cone Seeds			3 yr. Cone Seeds			4 yr. Cone Seeds			5 yr. Cone Seeds		
		Ext.	#Seeds Germ.	#Seeds Viable	Ext.	#Seeds Germ.	#Seeds Viable	Ext.	#Seeds Germ.	#Seeds Viable	Ext.	#Seeds Germ.	#Seeds Viable
22	52	0	0	0	16	11	10				56	37	30
23	50							15	10	0			
24	55				40	27	20	17	11	6			
25	59	23	15	8	20	13	2						
26	52	0	0	0									
27	57	49	33	3	12	8	2				53	35	0
28	68	32	21	5									
29	70												
30	67	0	0	0	15	10	3						
31	135	40	27	4	24	16	9						
32	70	0	0	0	19	13	2	27	18	1	30	20	7
33	46				58	39	27				49	33	3
34	64	25	17	3	40	27	8				50	33	24
35	69	2	1	0	4	3	32	97	65	3	76	51	15
36	76	28	19	2	56	37	4	61	41	3	56	37	13
37	32	70	47	12									
38	18	72	48	8							41	27	2
39	22	5	3	0	35	23	2	62	41	25	26	17	10
40	43	61	41	25	42	28	12	39	26	17	0	0	0
41	22	21	14	5									
42	23	0	0	0				83	55	13	27	18	5

Table A-3: **Spring collection data for a study conducted on Table Mountain pine stands in the Cherokee, Sumter, and Chattahoochee National Forests (cont.).**

Tree#	Tree Ag yrs.@bh	2 yr. Cone Seeds			3 yr. Cone Seeds			4 yr. Cone Seeds			5 yr. Cone Seeds		
		Ext.	#Seeds Germ.	#Seeds Viable	Ext.	#Seeds Germ.	#Seeds Viable	Ext.	#Seeds Germ.	#Seeds Viable	Ext.	#Seeds Germ.	#Seeds Viable
43	20	113	75	46	68	45	42	10	7	0			
44	80	42	28	9	85	57	18	78	52	37	80	53	24
45	74	20	13	6	33	22	1	38	25	6	39	26	0
46	65	34	23	9	41	27	20	35	23	4	38	25	8
47	80	0	0	0	49	33	32	40	27	15	32	21	8
48	73	16	11	7	1	1	0	28	19	16	19	13	13
49	75	39	26	3	77	51	7	29	19	7	92	61	3
50	60	3	2	2	41	27	12	30	20	20	66	44	17
51	62	12	8	3	98	65	30	48	32	10	7	5	4
52	45	18	12	0	43	29	5	74	49	14	100	67	4
53	26	51	34	0	54	36	1	98	65	0	59	39	15
54	81	18	12	2	81	54	42	5	3	3			
55	16	37	25	24	59	39	20						
56	17							50	33	31			
57	30	56	37	22	68	45	40	70	47	19	17	11	6
58	31	47	31	21	90	60	2	47	31	25	75	50	30
59	34	14	9	7	24	16	4	29	20	5	61	41	35
60	21	45	30	10	77	51	44				16	11	5
61	20	56	37	27	73	49	12	77	51	45	18	12	4
62	44	19	13	5	14	9	6	12	8	7			
63	148	21	14	1	29	19	18	38	25	20	27	18	5

Table A-3: **Spring collection data for a study conducted on Table Mountain pine stands in the Cherokee, Sumter, and Chattahoochee National Forests (cont.).**

Tree#	Tree Ag yrs.@bh	2 yr. Cone Seeds			3 yr. Cone Seeds			4 yr. Cone Seeds			5 yr. Cone Seeds		
		Ext.	#Seeds Germ.	#Seeds Viable	Ext.	#Seeds Germ.	#Seeds Viable	Ext.	#Seeds Germ.	#Seeds Viable	Ext.	#Seeds Germ.	#Seeds Viable
64	27	45	30	0				48	32	16			
65	67	56	37	5	24	16	1	60	40	6			
66	58	49	33	0	79	53	0	53	35	1	134	89	5
121	5	108	72	45									
122	5	31	21	4									
123	6	75	50	6									
124	6	49	33	2	17	11	0						
125	8												
126	9				31	21	4						
127	9	41	27	0									
128	9	122	81	1									
129	10	28	19	0									
130	10	122	81	1	105	70	5						
Totals		2284	1522	387	2141	1428	577	1742	1159	453	1514	1008	339

Table A-4: Summer collection data for a study conducted on Table Mountain pine stands in the Cherokee, Sumter, and Chattahoochee National Forests.

Tree#	Tree Ag yrs.@bh	2 yr. Cone Seeds			3 yr. Cone Seeds			4 yr. Cone Seeds			5 yr. Cone Seeds		
		Ext.	#Seeds Germ.	#Seeds Viable	Ext.	#Seeds Germ.	#Seeds Viable	Ext.	#Seeds Germ.	#Seeds Viable	Ext.	#Seeds Germ.	#Seeds Viable
1	45	0	0	0	0	0	0	0	0	0			
2	34												
3	40	0	0	0	0	0	0	24	16	0	56	37	0
4	66	5	3	1	17	11	0	0	0	0			
5	17	27	18	0				7	5	2	93	62	11
6	50	23	15	0				0	0	0	0	0	0
7	26	1	1	0	0	0	0	51	34	0	0	0	0
8	64	0	0	0	65	43	0	0	0	0	47	31	1
9	98	20	13	0	81	54	0	0	0	0			
10	17	55	37	1	42	28	5	56	37	20			
11	53	0	0	0	13	9	2	0	0	0	67	45	3
12	56	0	0	0	68	45	3	0	0	0			
13	66	0	0	0	32	21	9	33	22	0			
14	94												
15	95												
16	92	6	4	1							7	5	1
17	85	0	0	0	45	30	13	19	13	0			
18	17				74	49	1						
19	15	79	53	40									
20	17							57	38	33			
21	51	69	46	4	0	0	0				53	35	7

Table A-4: Summer collection data for a study conducted on Table Mountain pine stands in the Cherokee, Sumter, and Chattahoochee National Forests (cont.).

Tree#	Tree Ag yrs.@bh	2 yr. Cone Seeds Ext.	2 yr. #Seeds Germ.	2 yr. #Seeds Viable	3 yr. Cone Seeds Ext.	3 yr. #Seeds Germ.	3 yr. #Seeds Viable	4 yr. Cone Seeds Ext.	4 yr. #Seeds Germ.	4 yr. #Seeds Viable	5 yr. Cone Seeds Ext.	5 yr. #Seeds Germ.	5 yr. #Seeds Viable
22	52												
23	50												
24	55	0	0	0							19	13	3
25	59	0	0	0	70	47	20	0	0	0			
26	52				0	0	0	0	0	0			
27	57	0	0	0	118	79	13						
28	68												
29	70												
30	67												
31	135	59	39	5	14	9	0	0	0	0	0	0	0
32	70												
33	46												
34	64	37	25	9	13	9	0	0	0	0	112	75	22
35	69	33	22	12	46	31	8	30	20	0	25	17	1
36	76	37	25	0	93	62	1	81	54	1			
37	32												
38	18												
39	22												
40	43	21	14	2	78	52	7	59	39	10	118	79	5
41	22												
42	23	0	0	0	99	66	20	0	0	0	32	21	3

Table A-4: Summer collection data for a study conducted on Table Mountain pine stands in the Cherokee, Sumter, and Chattahoochee National Forests (cont.).

Tree#	Tree Ag yrs.@bh	2 yr. Cone Seeds			3 yr. Cone Seeds			4 yr. Cone Seeds			5 yr. Cone Seeds		
		Ext.	#Seeds Germ.	#Seeds Viable	Ext.	#Seeds Germ.	#Seeds Viable	Ext.	#Seeds Germ.	#Seeds Viable	Ext.	#Seeds Germ.	#Seeds Viable
43	20				108	72	10	10	7	0			
44	80	42	28	9	12	8	1	23	15	10	72	48	4
45	74	3	2	1	58	39	20	39	26	19	62	41	16
46	65	56	37	25				9	6	2	25	17	12
47	80	0	0	0	8	5	1	19	13	11	20	13	0
48	73	1	1	0	43	29	5	96	64	60	2	1	0
49	75	33	22	2	108	72	40	99	66	7	71	47	1
50	60	0	0	0	50	33	1	0	0	0	45	30	3
51	62	15	10	4	89	59	20	69	46	22	111	74	40
52	45	33	22	0	74	49	4	73	49	3	14	9	0
53	26	64	43	1	57	38	0	77	51	4			
54	81	18	12	5	53	35	19	103	69		83	55	0
55	16												
56	17							101	67	26			
57	30				77	51	24	92	61	5	0	0	0
58	31	45	30	15	8	5	1	84	56	50	67	45	40
59	34	52	35	15	9	6	0	76	51	50	21	14	7
60	21				93	62	42	0	0	0			
61	20	64	43	9	52	35	12	59	39	12			
62	44												
63	148	28	19	2	36	24	0	41	27	23	58	39	9

Table A-4: Summer collection data for a study conducted on Table Mountain pine stands in the Cherokee, Sumter, and Chattahoochee National Forests (cont.).

		2 yr. Cone Seeds			3 yr. Cone Seeds			4 yr. Cone Seeds			5 yr. Cone Seeds		
Tree#	Tree Ag yrs.@bh	Ext.	#Seeds Germ.	#Seeds Viable	Ext.	#Seeds Germ.	#Seeds Viable	Ext.	#Seeds Germ.	#Seeds Viable	Ext.	#Seeds Germ.	#Seeds Viable
64	27	26	17	0	8	5	0	7	5	0	8	5	2
65	67	1	1	0	64	43	0	0	0	0	0	0	0
66	58	38	25	0	107	71	1	47	31	1	135	90	0
131	8	75	50	0	11	7	1						
132	6	19	13	3	32	21	0						
133	5	76	51	1									
134	5	9	6	0	60	40	8	49	33	0			
135	8	9	6	0	17	11	1						
136	7	51	34	1									
137	9	26	17	0	20	13	8						
138	6	59	39	1	42	28	1	3	2	0			
139	12	61	41	11	50	33	1	37	25	1	28	19	0
140	6	23	15	0	34	23	0						
Totals		1399	934	180	2348	1562	323	1630	1087	372	1451	967	191

Table A-5. Data on trees selected from the Cherokee National Forest for a Table Mountain pine study.

Tree#	Tree Age (Yrs.) at bh[1]	dbh (In.)	#Cones	Location[2]
1	45	9.4	50	RKR
2	34	5.3	0	RKR
3	40	8.8	80	RKR
4	66	11.3	50	RKR
5	17	5.3	40	RKR
6	50	6.9	70	RKR
7	26	6.1	70	RKR
8	64	8.5	80	RKR
9	98	12.8	100+	RKR
10	17	4.0	60	RKR
11	53	10.1	100+	RKR
12	56	8.6	100+	RKR
13	66	11.6	100+	RKR
14	94	5.5	50	RKR
15	95	6.5	60	RKR
16	92	7.0	50	RKR
17	85	10.8	80	RKR
18	17	3.8	30	RKR
19	15	2.8	20	RKR
20	17	4.1	20	RKR
21	51	5.4	30	HH/GM
22	52	6.4	60	HH/GM
23	50	10.1	50	HH/GM

Table A-5 (cont.). Data on trees selected from the Cherokee National Forest for a Table Mountain pine study.

Tree#	Tree Age (Yrs.) at bh[1]	dbh (In.)	#Cones	Location[2]
24	55	8.5	75	HH/GM
25	59	8.2	50	HH/GM
26	52	6.8	50	HH/GM
27	57	6.9	25	HH/GM
28	68	10.0	30	HH/GM
29	70	12.0	50	HH/GM
30	67	9.7	50	HH/GM
31	135	11.8	50	HH/GM
32	70	9.5	72	HH/GM
33	46	7.5	15	HH/GM
34	64	11.3	75	HH/GM
35	69	11.4	30	HH/GM
36	76	11.3	50	HH/GM
37	32	5.0	25	HH/GM
38	18	2.8	10	HH/GM
39	22	3.9	10	HH/GM
40	43	7.3	75	HH/GM
41	22	6.6	50	HH/GM
42	23	5.7	20	HH/GM
43	20	3.5	25	HH/GM
44	80	11.3	75	MCR
45	74	8.8	100	MCR
46	65	5.3	75	MCR

Table A-5 (cont.). Data on trees selected from the Cherokee National Forest for a Table Mountain pine study.

Tree#	Tree Age (Yrs.) at bh[1]	dbh (In.)	#Cones	Location[2]
47	80	7.5	50	MCR
48	73	10.1	75	MCR
49	75	11.1	10	MCR
50	60	5.7	75	MCR
51	62	9.9	40	MCR
52	45	12.2	100	MCR
53	26	7.2	20	MCR
54	81	13.2	100	MCR
55	16	2.8	10	MCR
56	17	6.4	25	MCR
57	30	6.7	50	MCR
58	31	5.8	40	MCR
59	34	11.2	40	MCR
60	21	9.0	30	MCR
61	20	6.0	25	MCR
62	44	8.2	50	MCR
63	148	14.4	150+	MCR
64	27	7.8	50	MCR
65	67	14.4	100	MCR
66	58	17.4	100	MCR

[1] bh – breast height (4.5 ft. above high ground at tree base)
[2] RKR: Round Knob Road, HH/GM: Horsehitch Gap/Green Mountain, MCR: Meadow Creek Road

Table A-6. Data on trees selected from the Sumter and Chatahoochee National Forests for a Table Mountain pine study.

Tree#	Tree Age (Yrs.) at bh[1]	dbh (In.)	#Cones	Location[2]
101	8	1.5	5	SCR
102	6	1.8	7	BRA
103	5	1.3	6	BRA
104	5	0.5	3	BRA
105	8	1.5	4	SCR
106	7	2.5	5	DAM
107	9	1.0	9	SCR
108	6	1.0	4	DAM
109	12	4.5	10	SCR
110	6	2.0	5	DAM
111	6	2.0	7	DAM
112	5	1.7	9	DAM
113	6	1.8	3	DAM
114	6	1.5	4	BRA
115	7	1.6	8	DAM
116	7	1.4	5	SCR
117	10	2.2	6	SCR
118	8	1.3	7	SCR
119	7	1.5	3	SCR
120	6	1.4	5	BRA
121	5	1.7	4	BRA
122	5	1.9	6	BRA
123	6	2.1	8	DAM

Table A-6 (cont.). Data on trees selected from the Sumter and Chatahoochee National Forests for a Table Mountain pine study.

Tree#	Tree Age (Yrs.) at bh[1]	dbh (In.)	#Cones	Location[2]
124	6	1.5	4	DAM
125	8	1.4	4	DAM
126	9	2.3	6	SCR
127	9	1.8	7	SCR
128	9	1.6	3	SCR
129	10	2.3	5	SCR
130	10	1.9	8	SCR
131	8	1.8	7	DAM
132	6	1.6	6	DAM
133	5	1.5	3	BRA
134	5	1.6	4	BRA
135	8	2	2	SCR
136	7	1.8	7	DAM
137	9	1.7	3	SCR
138	6	1.4	5	BRA
139	12	2.3	8	SCR
140	6	1.5	6	BRA

[1] bh – breast height (4.5 ft. above high ground at tree base)
[2] SCR: Sarah Creek Road, BRA: Brasstown Road, DAM: Damascus Road

Table A-7. Analysis of variance for number of seeds per cone in Table Mountain pine stands in the Cherokee, Sumter, and Chattahoochee National Forests.

Source	**df**	**F**	**Pr>F**
Tree Age Class	4	2.28	0.0593
Season	3	3.56	0.0140*[1]
Cone Age	3	3.19	0.0233*
Tree Age Class x Season	12	1.20	0.2751
Tree Age Class x Cone Age	12	1.73	0.0561
Season x Cone Age	8	0.73	0.6660
Tree Age Class x Season x Cone Age	28	1.27	0.1633

[1] * - significant at the alpha=0.05 level.

Table A-8. Analysis of variance for percent viability of seed in Table Mountain pine stands in the Cherokee, Sumter, and Chattahoochee National Forests.

Source	df	F	Pr>F
Tree Age Class	4	4.55	0.0012*[1]
Season	3	10.19	0.0001*
Cone Age	3	2.82	0.0383*
Tree Age Class x Season	12	0.37	0.9726
Tree Age Class x Cone Age	12	0.75	0.7044
Season x Cone Age	8	1.58	0.1271
Tree Age Class x Season x Cone Age	28	0.54	0.9763

[1] * - significant at the alpha=0.05 level.

Table A-9. Analysis of variance for number of viable seed per cone in Table Mountain pine stands in the Cherokee, Sumter, and Chattahoochee National Forests.

Source	df	F	Pr>F
Tree Age Class	4	3.20	0.0128*[1]
Season	3	8.13	0.0001*
Cone Age	3	4.04	0.0073*
Tree Age Class x Season	12	0.64	0.8111
Tree Age Class x Cone Age	12	0.90	0.5438
Season x Cone Age	8	1.21	0.2887
Tree Age Class x Season x Cone Age	28	0.69	0.8874

[1] * - significant at the alpha=0.05 level.

Table A-10. Analysis of variance for number of cones per tree in Table Mountain pine stands in the Cherokee, Sumter, and Chattahoochee National Forests.

Source	df	F	Pr>F
Tree Age Class	4	40.80	0.0001*

[1] * - significant at the alpha=0.05 level.

VITA

Ellen Ann Johnson Gray was born in Houma, Louisiana on March 7, 1952. She attended school in the public school system of Terrebonne Parish, Louisiana, including Houma Elementary and Terrebonne Junior High. She graduated from Terrebonne High School in 1970. She attended South Louisiana Beauty School and graduated in August 1970. Ellen entered The University of Tennessee, Knoxville in August 1991 and received a Bachelor of Science Degree in Biology in May 1998. In 1998, Ellen co-wrote an Environmental Assessment and co-revised the Forest Management Plan for the Eastern Band of Cherokee Indian Reservation. She returned to The University of Tennessee in August 1998 and received a Master of Science Degree in Forestry in May 2001. Her Master's Thesis is entitled "Patterns of Seed Production in Table Mountain pine (*Pinus pungens* Lamb.)"

Ellen has two children, two grandchildren and lives in Knoxville, Tennessee and manages the Curriculum Laboratory in the College of Education at the University of Tennessee, Knoxville.