POST-FIRE RECOVERY AND SUCCESSIONAL DYNAMICS OF AN OLD-GROWTH RED SPRUCE FOREST IN THE SOUTHERN APPALACHIAN MOUNTAINS

A Thesis

by

ADAM R. KRUSTCHINSKY

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2007

Major Subject: Geography

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Chair of Committee,	Charles W. Lafon
Committee Members,	David M. Cairns
	Fred E. Smeins
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ABSTRACT

Post-fire Recovery and Successional Dynamics of an Old-Growth
Red Spruce Forest in the Southern Appalachian Mountains. (May 2007)
Adam R. Krustchinsky, B.S. Texas A&M University
Chair of Advisory Committee: Dr. Charles Lafon

Red spruce is a shade-tolerant conifer whose distribution and abundance reflect Quaternary climate history as well as natural and anthropogenic disturbances. This species once extended further south than its present localities, because of natural and anthropogenic disturbances such as logging, windthrow, and fire. Little is known about the disturbance regime of this species, because long term stand dynamics are difficult to obtain. This-long lived species is hypothesized to be suffering a decline in radial growth, density and abundance at the present time. Recent research suggests pollution, biotic stresses, climate change and natural stand dynamics are the driving forces behind these decreases.

The purpose of this study is to investigate the influence of fire in a mesic ecosystem, specifically a high-elevation red spruce (*Picea rubens* Sarg.) forest on Whitetop Mountain in the southern Appalachian Mountains. Six plots were established in a high elevation red spruce stand to characterize the stand composition. Tree ring data were collected to investigate radial growth relations to inter-annual climatic variability and cross-sections were used to investigate fire history. Red spruce continued to establish throughout the 19th century until a severe fire occurred in 1919 and caused a new cohort of yellow birch (*Betula alleghaniensis* Britt.) to establish within the stand. Logging and fire caused high mortality in the stand, yet many spruce remain that outdate the past disturbances. Red spruce saplings continue to persist in the stand, showing regeneration despite the abundant hardwoods. Moisture was the main contributing factor to red spruce growth in the dendroclimatic analysis. Red spruce radial growth was significantly correlated to high precipitation and low temperatures of the previous growing season, which is similar to recent research results. This study collaborates the current literature on red spruce growth along with the results found here in creating a model to represent the growth characteristics of red spruce when inter-mixed with hardwoods after a severe disturbance.

ACKNOWLEDGEMENTS

I thank Dr. Charles W. Lafon of the Department of Geography, Texas A&M University for serving as my graduate and undergraduate advisor. His generosity and professional comments have taught me many lessons in my research and life. I thank Dr. David M. Cairns for his support throughout my academic career and the investments he has made in me. My involvement in his field work and data analysis is something that most students do not get to take part in and I feel honored to have been part of it. I thank Dr. Fred Smeins for serving on my committee and for his constructive criticism throughout my graduate career. I thank my wife Lori, for her support in the strenuous times in preparing my work, long hours of studying and her assistance in data collection. I also want to thank Daehyun Kim for showing his extensive knowledge in biogeographical processes and his never ending interests in the American way of life. Thanks are also due to the United States Forest Service personnel, in particular Steve Croy and the rangers of the Mount Rogers office within the Jefferson National Forest. Many thanks are given to my colleagues at Texas A&M University for their criticisms and interests in my work throughout the years.

TABLE OF CONTENTS

Page

CHAPTER

CHAPTER Page

LIST OF TABLES

LIST OF FIGURES

FIGURE Page

CHAPTER I

INTRODUCTION

Disturbances that kill or damage plants alter species composition and stimulate ecosystem processes such as succession and invasion (Sousa, 1984; Foster and Boose, 1995; Fraver and White, 2005). They often delay competitive exclusion and thereby help maintain species diversity (Connell, 1978; Huston, 1979). Disturbances act in concert with physical and biotic factors to drive vegetation structure and function (Thonicke et. al., 2001). Disturbance has been an important theme of recent literature in vegetation science (Hobbs and Huenneke, 1992; Chappell and Agee, 1996; Soule', Knapp and Grissino-Mayer, 2004; Lafon, Hoss and Grissino-Mayer, 2005).

Fire events have been recognized as an important primary disturbance affecting the vegetation dynamics of many ecosystems (Sousa, 1984) at global, regional and local scales (Thonicke, Venevsky, Sitch and Cramer, 2001). Research into mechanisms of plant succession following fire has emphasized the significance of life history characteristics of species in determining vegetation dynamics (Dix and Swan, 1971; Hobbs and Huenneke, 1992; Cheney, Gould and Catapole, 1993). Recent research has addressed the importance of fire in dry forests (Brose and Waldrop, 2006), grasslands (Daubenmire, 1968; Cheney, Gould and Catapole, 1993; Morgan, 1999), and shrublands (Keeley and Fotheringham, 2001) and has shown that species respond differently to the

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This thesis follows the formatting of Ecology.

severity and frequency of fire (Turner, Romme, Gardner, and Hargrove, 1997). This research will investigate the influence of fire in a wet high-elevation red spruce (*Picea rubens* Sarg.) forest in the southern Appalachian Mountains.   Little is known about the role of fire and other disturbances in Southern Appalachian spruce stands.

Red spruce is a conifer species of the southern boreal forests throughout eastern North America. In the southern Appalachian Mountains, the species is restricted to the highest peaks (Adams and Stephenson, 1989). Because of past logging and fires, spruce forests of the Appalachian Mountains are less extensive than in the past, often limited to small mountaintop stands (Shields, 1962; Stephenson and Adams, 1984). It is an important species, ecologically and economically, because of its aesthetic appeal to tourists and high value in timber/paper sales. Red spruce forests are home to many endemic animals, including several federally-listed endangered species such as the Carolina flying squirrel (*Glaucomys sabrinus coloratus*) and Weller’s salamander (*Plethodon welleri*) (Sullivan, Lautenschlager and Wagner, 1999; Loeb, Tainter and Cazares, 2000).

Whitetop Mountain in southwestern Virginia presents a rare opportunity to study the role of disturbances in a red spruce forest, and most importantly the response of a red spruce forest to fire. In the summer of 2004, a southern pine beetle (*Dendroctonus frontalis* Zimmermann) infestation of the red spruce was treated by the US Forest Service on Whitetop Mountain, resulting in the clearing of dozens of red spruce trees in an old-growth forest. This extensive clearing normally would not have been conducted because of the rarity of red spruce forests in the southern Appalachian Mountains. As a result, I was able to obtain spruce cross-sections that contain fire scars formed decades ago. These enabled me to date the occurrence of fire and to examine subsequent vegetation recovery. Additionally, I will investigate forest response to timbering because the stand appears to have been selectively logged in the past, despite its characterization as “old-growth” by the U.S. Forest Service.

Few studies have described the disturbance regimes in the central and southern Appalachian red spruce forests (Adams and Stephenson, 1991). Studies of disturbance in this forest type have emphasized gap dynamics (White, MacKenzie and Busing, 1985; Macguire, Brissette, and Gu, 1998; Battles and Fahey, 2000) and seedling recruitment (Nicholas, Zedaker and Eager, 1992; Wu, McCormick and Busing, 1999). Previous studies have not investigated the impacts of fire on red spruce forests because of the infrequency of fire in these cool, moist sites. My purpose is to provide insights about the post-disturbance successional patterns and forest dynamics that are a result of fire in red spruce forests in the southern Appalachian Mountains. My research will also elucidate the influence of climatic variability on the growth of red spruce. Red spruce forests may be threatened by ongoing climatic changes, which could favor the upslope encroachment of competing hardwood trees.

CHAPTER II

OBJECTIVES

The objective of this study is to investigate red spruce forest dynamics and response to disturbance and climate in a high-elevation stand in the southern Appalachian Mountains. This research is important as old growth spruce stands are rare within the southeast boreal forest, yet provide a number of unique ecological functions. Coupled with this, past methods used to collect stand history data oftentimes caused tree mortality and were therefore avoided when possible (Lorimer, 1980). This combination has led to a sparse data set for southeastern spruce stands.

The following questions serve as a framework for conducting this research:

1. Fire characteristics: When did fires occur in the stand, according to the fire-scar record preserved in the spruce cross sections? Did the surviving trees exhibit increased radial growth, which would imply that the fires were severe enough to cause substantial tree mortality?
2. Stand response to disturbance: Were fires followed by the establishment of a new cohort of trees (e.g. yellow birch, *Betula alleghaniensis*) that are considered to be disturbance-dependent? Did red spruce recruitment occur after fires? Did the response of the red spruce forest to logging differ from its response to fire?
3. Climate response: How does the radial growth of red spruce respond to inter-annual climatic variability?

CHAPTER III

LITERATURE REVIEW

Fundamentals of Disturbance

Disturbances provide spatial and temporal heterogeneity in a landscape structure (Sousa, 1984). In recent years, disturbances have been the focus of much research to determine their importance on various landscapes and to interpret the influence of invasive species encroaching on natural habitats.

Pickett and White (1985) define a disturbance as “any relatively discrete event in time that disrupts ecosystem, community or population structure and changes resources, substrate or availability, or the physical environment.” Additional definitions have been proposed, for example, processes that can remove or damage biomass (Grime, 1985), or changes in the community structure caused by events outside the ecosystem’s hierarchal level (Pickett, 1991). For this thesis, I will follow the definition proposed by Grime (1985).

Disturbances are characterized by their frequency, intensity and severity. Frequency is best described as how often a disturbance occurs (Frelich, 2002). The amount of energy imparted by a disturbance is intensity. For example, the amount of heat released by fire in a given unit of time would be an example of intensity. Severity can be described as the amount of plant mortality that results from the disturbance.

Connell’s (1978) intermediate disturbance hypothesis proposes that species diversity is highest when disturbance is neither too high nor too low in frequency and severity. Highest levels of diversity are maintained when disturbances occur at an intermediate frequency or severity. Low disturbance frequencies result in competitive exclusion, favoring the dominant species. Higher frequencies permit only the species that are tolerant of disturbances to persist in the community.

Disturbance can have a variety of influences on the successional development of vegetation. Disturbances may “set back” succession to an earlier stage of development (Abrams and Scott, 1989). In many cases, however, they accelerate the replacement of pioneer tree species by later-successional species. Disturbances also may shift vegetation development toward a novel trajectory (Sprugel, 1976) especially if the disturbance regime is altered beyond historical conditions. Disturbance regimes and stand dynamics of red spruce forests have stimulates considerable interest. In the following sections I review red spruce biogeography- its distribution, disturbance regimes, and climatic relations.

Quaternary Changes in the Distribution of Red Spruce

During the last glacial maximum, glaciers reached as far south as 41°N and covered much of North America. Ocean levels were reduced and temperatures were 12° C lower than at present (Watts, 1979), resulting in a cold, dry climate. Before the glacial maximum, red spruce is thought to have occurred between 34° and 37°N and it was intermixed with fir (*Abies*), larch (*Larix*), jack pine (*Pinus banksiana*), and hardwoods in low elevations (Delcourt and Delcourt, 1988). Spruce-pine forests only occurred at low elevations, and persisted until approximately 12,500 years ago, when an abrupt shift in climate and vegetation occurred.

The Laurentide glacier shrank approximately 15,000 years ago (Prentice, Bartlein and Webb, III, 1991). *Picea* nearly disappeared from the pollen record in the southeastern North America (approximately 9,000 years ago), suggesting that the warmer climates forced it into the highest bogs and mountaintops. After the Holocene maximum, the extent of spruce was similar to present day (Jacobsen et al. 1987) extending as far south as Tennessee and as far north as Maine and Canada accompanied by *Betula* and *Acer* species (Watts, 1979). Approximately 2,000 years ago, red spruce expanded as the global temperatures cooled (Lindbladh, Jacobson and Schauffler, 2003). In summary, *Picea* was abundant during the late glacial in southeast North America, became uncommon in the mid Holocene, and expanding and to some extent in the late Holocene.

Modern Distribution of Red Spruce

The northern extent of red spruce today is in southern Canada. Pure red spruce stands cap mountaintops in the northern part of the species range. Spruce is often intermixed with hardwoods and other conifers on much of the landscape. In the southern parts of its range, red spruce is limited to the highest peaks of the southern Appalachian Mountains (Adams and Stephenson, 1989).

Red spruce in central and southwestern Virginia ranges in elevation between 975 and 1700 m, although mature stands are not present below 1200 m (Stephenson and

Adams, 1984). In Virginia, red spruce only exists in a few communities at no more than about a few dozen localities (Hoffman, 1950, Mazeo 1966, Adams and Stephenson 1989). Adams and Stephenson (1991) estimate that no more than 24 pure red spruce stands remain in Virginia.

Disturbance Regimes of Red Spruce Forests

Disturbance regimes of red spruce communities, though stimulating much interest in recent years, are not clearly understood. Red spruce has thin bark, shallow root systems and flammable needles, making the species susceptible to mortality from fires. A single low intensity surface fire can destroy an entire stand of spruce (Murphy, 1917). However, moist microsite conditions in red spruce forests prevent frequent fires from naturally occurring, thus ice storms, wind, logging and climatic variability are the most common disturbances in these forest types.

Windthrow is the dominant natural disturbance agent in red spruce forests in the southern Appalachian Mountains (Sprugel, 1976; Reiners and Lang, 1979; Foster and Reiners, 1983; White et. al. 1985; Clebsch and Busing, 1989). Windthrow of older trees, along with individual tree mortality is the main disturbance type creating small tree gaps. Red spruce is an extremely shade-tolerant species and windthrow can favor regeneration within the small gaps (Runkle, 1985); however larger openings often favor the shade-intolerant species. Wu et al. (1999) estimated that the recovery time for canopy closure with small gaps is less than 60 years, with an average of 29 years. White et al. (1985)

proposed that small gaps (<200 m²) took an average of 50 years to recover, with a return interval of 100 years.

Individual tree mortality has highly localized effects on forest composition and structure (Clebsch and Busing, 1989). It is within these gaps that permit seedlings establish and later gaps permit these seedlings to grow up into the canopy. Succession in these forests is generally directional and moves from shade-intolerant species in early successional stages to shade-tolerant species in the late successional period (Bergeron and Dubuc, 1989). The rate at which red spruce radial growth responds to canopy gaps varies, but mature trees can take as long as 5 years (Brix and van den Driessche, 1977)

Climate warming has been proposed (Cook and Jacoby, 1977; Johnson, Friedland and Dushoff, 1986) as a catalyst in reducing the abundance of red spruce forests in the Appalachian Mountains. Dendroecological investigations of tree ring growth have been shown to be an effective tool in determining the response of red spruce to climate change. One example of these climatic variations is the warming of temperatures and lower precipitation amounts between the mid 1950s and late 1960s. A decrease in red spruce density and basal area over 15 years in northern New England as a result of climatic variations since the mid-1950s has been shown in many reports (Cook and Jacoby, 1977; Siccama, Bliss and Vogelmann, 1982; Scott, Sicamma, Johnson and Breisch, 1984). During this time, a drought occurred in the high elevation red spruce stands, altering growth rates and densities across its extent.

Logging has been an important disturbance in forests of eastern North America. Colonial expansion, as well as the establishment of commercial timber companies that began in the mid-1850s, resulted in many forests being leveled and the loss of many species that are becoming less extensive today. The southern Appalachian Mountains were heavily logged between 1880 and 1925 (Stephenson and Adams, 1984; Pyle and Schafale, 1988) reducing red spruce populations by half; some accounts suggest up to 90 percent loss. Murphy (1917) reported a decrease in red spruce acreage from 445,000 to 60,000 acres as a result of logging in the beginning of the century. Further, red spruce forests in West Virginia declined from approximately 200,000 to 600,000 hectares of red spruce and have now been reduced to 17,500 to 44,500 hectares (Mayfield, 1997). Subsequent fires persisted in this region after the logging, causing forests to have a shift in their composition to hardwoods (Pyle and Schafale, 1988).

Beginning in 1902, logging shifted from the northeast United States and Canada to the more southern forested areas of Virginia and West Virginia. In 1909, the spruce of Virginia produced an estimated 79,672,000 board feet of saw-timber (4.9% of the U.S. spruce production). To compare these figures, Maine, the leading spruce producer, cut an estimated 421,297,000 board feet of spruce saw-timber (24% of U.S. spruce) (Murphy, 1917). Once the spruce was cut in these areas, slash was left by the loggers, often resulting in fires to spread causing higher mortality.

Red Spruce Forest Succession Models

Different types of models have been proposed to describe and predict the dynamics of forest ecosystems (Bugmann, 2001). Gap models have been widely used in exploring the successional sequence of red spruce forests (Urban, Bonan, Smith, and

Shugart, 1991; Bugmann, 1997; Larocque, Archambault and Delisle, 2006). What has been learned from these models is that red spruce consistently increases in abundance and biomass throughout time. However, the interacting species, such as yellow birch, fluctuate in their basal area and abundance throughout time. Red spruce typically peaks at 140 years in abundance; however, at lower elevations the peak could be much sooner (Leak, 1991). Once red spruce has become established in the forest, it continues to increase in biomass, until the carrying capacity of the community is reached. Once the carrying capacity is reached, red spruce biomass remains relatively constant.

Climate Relations of Red Spruce

Red spruce forests located in the southern Appalachian Mountains have a longer growing season than forests in the northern extent. Longer growing seasons, in combination with high humidity and rainfall, explain the higher growth rates than in north (Oosting and Billings, 1951). Tree ring studies have proven to be effective in investigating the climate-growth relationships of red spruce. Inter-annual variations in tree ring radial growth are associated with temperature rather than rainfall (Conkey, 1979; Cook, 1987) and have shown positive results in locating climate signals in the past that may have altered forest composition and distribution. In conducting such research, ring width variability is examined and is tested via statistical methods to find correlations between climate factors such as temperature, precipitation and PDSI (Palmer Drought Severity Index). PDSI is a measure of detecting abnormal wet or dry conditions.

Comparative research suggests that red spruce radial growth is highly correlated to previous year's climate. In the southern Appalachian Mountains, radial growth is negatively correlated to previous year's late summer temperatures, suggesting that extreme temperatures do not favor red spruce growth (Sicamma, 1974; Conkey, 1979; Johnson et al., 1986; Cook, Johnson and Blasing, 1987). The general consensus among current research is that red spruce favors cool summers, early winters and high precipitation to have above normal growth.

Red spruce response to PDSI is not clearly understood. Attempts in finding correlations between ring widths and PDSI have been made (Cook and Jacoby, 1977; Adams, Stephenson, Blasing and Duvick, 1985), yet are not conclusive. Two significant droughts have been documented in the northern and southern Appalachian Mountains, taking place in the 1930s and 1960s (Cook and Jacoby, 1977; Adams et al. 1985; Johnson et al., 1986; Johnson, Cook and Sicamma, 1988). Ring width variability has been shown to be correlated to the onset of drought since the 1960s and has shown poor recovery since in sampled stands (Adams et al., 1985). The correlations found were derived from annual July PDSI values and December PDSI values. Narrower ring widths and higher PDSI values are the signature marks of these drought onsets, resulting in dieback and foliage loss to the red spruce, along with other species as well such as fir. As a result, red spruce is limited in making a recovery from drought due to the loss of resources.

CHAPTER IV

STUDY SITE

General Description

Whitetop Mountain is located in the Jefferson National Forest in southwestern Virginia at 36°38`19``N, 81°36`37``W (Fig. 1 (USGS, 1989)). It is the second highest peak in Virginia (1682m), and the adjacent peak Mount Rogers (1746 m) together form the Balsam Mountains (Stephenson and Adams, 1984). Whitetop Mountain serves as a tri-border between Grayson, Smythe and Washington counties, along with residing near the border of Tennessee, Virginia and North Carolina.

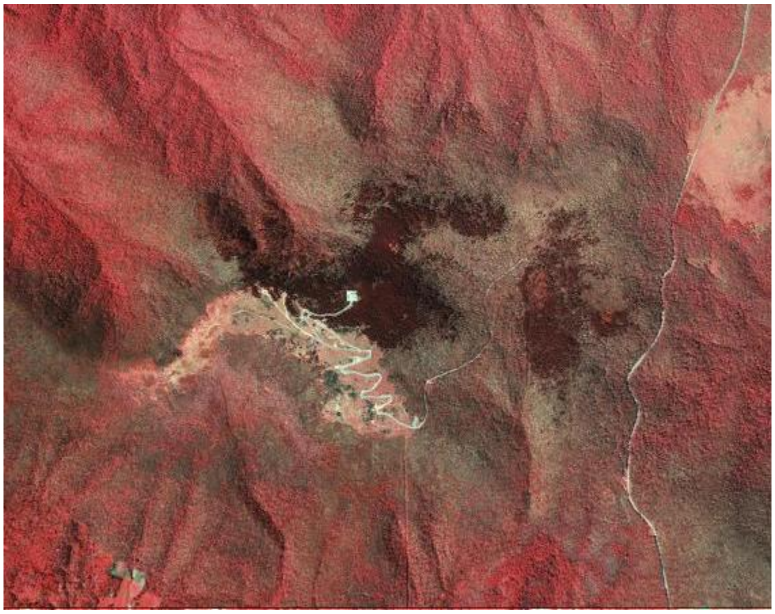


Fig. 1 – DOQQ (USGS, 1989) image of Whitetop Mountain, VA. The winding road in the center of the image is Forest Service Rd. 89. The dark shaded areas are red spruce stands. The road on the right is Virginia Route 600 which passes through the gap between Mount Rogers and Whitetop Mountain.

The soils of Whitetop Mountain are derived from igneous rocks (rhyolite) and are poorly sorted (Coile, 1938). The soils are considerably acidic, ranging from 3.5pH to 5.5pH. The two soil types upon the crest and slopes are Burton stony loam and Ashe stony loam (Coile, 1938). Ashe stony loam is the most common soil layer within Grayson County, ranging in depth from 6 to 10 inches. It is a light brown or brownish yellow loam. In moist sites, the surface layer can extend as deep as 18 inches where biomass has accumulated or in drainage areas. The sub-soil extends approximately 28 to 30 inches deeper and is light brownish-yellow or deep-yellow clay or clay loam (Devereux, 1930). A dark, thin layer on the summit is composed of organic content (Shields, 1962) which is often eroded in heavy rains, exposing the underlying igneous rocks.

Mean January and July temperatures in Marion, Virginia (approximately 19.3 km from Whitetop at 661 m) are 1.4° C and 22.4° C (Stephenson and Adams, 1984), respectively. The annual average precipitation in Marion is 133 cm; however, Adams and Stephenson (1989) propose that the summit may receive as much as 150 cm annually due to orographic enhancement.

Little is known of the land use history of Whitetop Mountain before 1900. A early role of Whitetop Mountain was its establishment in 1772 as part of a boundary line between the Cherokee Nation and the colony of Virginia (Shields, 1962). Coale (1874) conducted a biography on Wilburn Waters, a notorious miner and hunter, and described Whitetop as remote and poorly accessible (Coale, 1874). Pyle and Schafale (1988) located a map of Grayson County from 1897 with a hotel near the summit of Whitetop.

Before 1900, various parts of Whitetop were used for livestock grazing, but exact locations are not documented.

In 1902, much of Mount Rogers, adjacent to Whitetop, was logged. Railroads and access roads were constructed to remove the timber. Between 50,000 to 100,000 board feet per acre were removed from the Mount Rogers area when logging began (Pyle and Schafale, 1988). However, this is only an estimate since detailed logging records were not kept until approximately 1924 (Pielke, 1981). From 1902 to 1909, Whitetop Mountain timber was not cut because the trees were not mature (Pyle and Schafale, 1988). A longtime resident of Konnarock, Virginia, which is located at the base of Whitetop Mountain, informed Pyle and Schafale (1988) that the mature red spruce was selectively harvested from Whitetop Mountain between the end of World War I and the U.S. Forest Service acquisition in 1922. Beginning in 1930, in addition to the hotel tourist traffic on the summit, Whitetop Mountain became a tourist attraction because of the scenery and a fiddler’s convention (Pyle and Schafale, 1988).

Forest Condition in 1922

I located an Examination Report in the George Washington and Jefferson National Forest Supervisor’s Office in Roanoke, Virginia. This report contained information such as logging patterns, brief land use history and tree inventories. It was written in 1922 by H.L. Russell, a forest examiner involved in the purchase of the land by the Forest Service.

Two tracts of land on and around Whitetop Mountain were purchased from the Douglas Land Company in 1922 at $4.00 per acre. The purchase included two separate tracts, 2b (Fig. 2) containing 528 ha. and 2c (Fig. 3) with 542 ha. Upon purchase of the tracts, forest examinations were conducted by Russell to inventory trees and assess the quality of the land. Tract 2b is of most importance to this study because it is the location of the stand I sampled.

Maps associated with the examination report (Fig. 2 – 4) provide information about stand location and logging activities. The red outlined area in Fig. 2 depicts the red spruce stand present on Whitetop today and is classified as "Cut-Over" (refer to Fig. 2). The areas marked with "S" refer to areas that are spruce dominated.

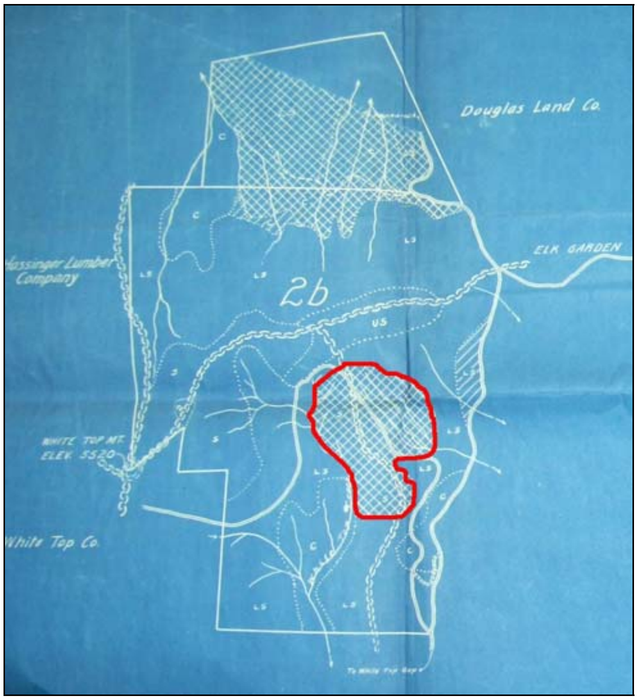


Fig. 2 – Map from Examination Report of 1922 (Russell, 1922) showing the survey boundaries of tract 2b along with species and logging information. The red outlined area is the red spruce stand that is the furthest right in Fig. 1 along the service road.

Fig. 3 – A snapshot of tract 2c, west of tract 2b, from the Douglas Land Company sale of Whitetop Mountain (Russell, 1922).

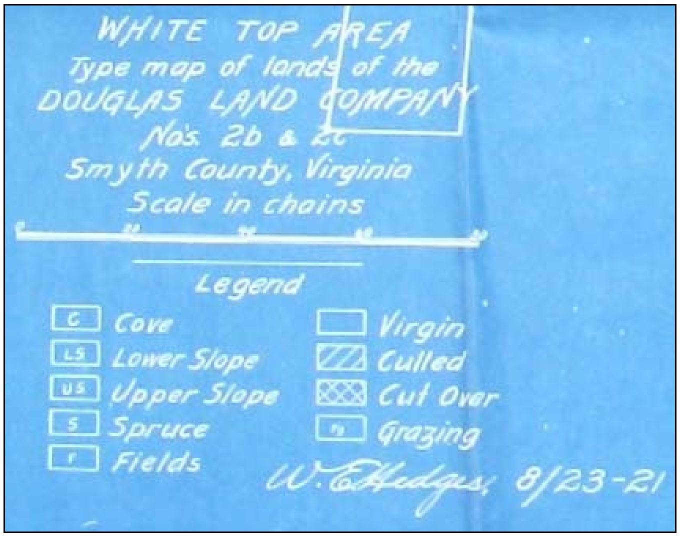


Fig. 4 – The map legend for Figs. 2 and 3 (Russell, 1922).

The report describes tract 2b as being left alone for the most part, with only select trees being cut that were of profitable size. The remaining trees in the stand were left alone for future cutting if necessary. The report indicates logged areas in these two tracts were “heavily” timbered for red spruce (only on Mount Rogers), sugar maple, red oak, ash, beech and birch. Spruce was overlooked in tract 2b because of many small, unprofitable trees, but noted as “timber of good quality” that would be profitable to cut at a later time.

Current Status of Study Area

Two clear cuts were created during 2004 in spots infested by southern pine beetle (Fig. 5). These clear cuts were approximately 0.8 hectares each, located on both sides of the Forest Service road on Whitetop Mountain approximately 100m apart. The two cleared areas are within the same red spruce stand, but will be described as two different areas of the site. The northern clearing will be referred to as the east side of the stand and the other clear cut will be described as the west side of the stand. This terminology will be used consistently throughout this study. The clear cuts that were cut in 2004 are within the red outlined area in Fig. 2 (USGS, 2000), and also the most eastward red spruce stand in Fig. 1.

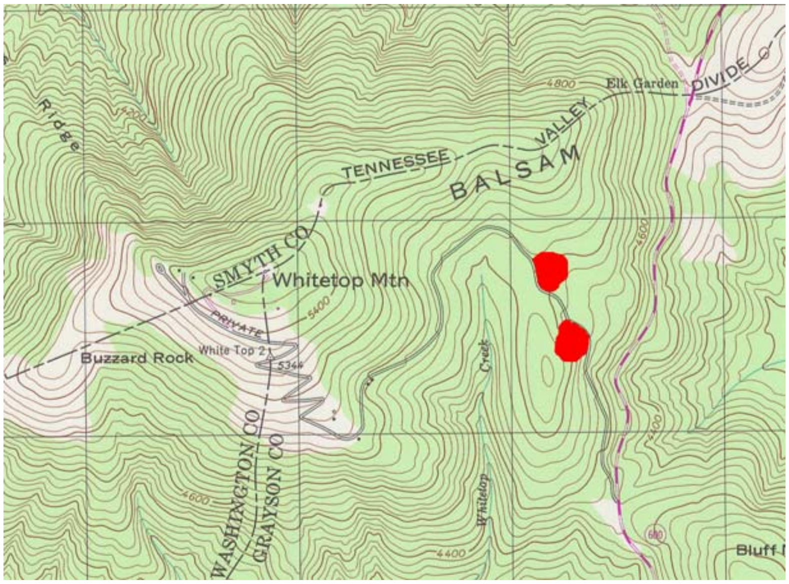


Fig. 5 – USGS (2000) topographic map of Whitetop Mountain. The private road labeled on the map is Forest Service Road 89. The red shaded areas are the GPS point boundaries in which I collected of the clearings made by the US Forest service in 2004. These clearings are within the same red spruce stand indicated in Fig. 2.

The west side of the stand (Fig. 6) was cleared much more than the east (Fig. 7), leaving few living trees standing regardless of species. All spruce trees, mature and juvenile, were removed from both clear cuts. The only living trees to remain were juvenile birch and sugar maple trees. Both clearings have many dead trees, mostly hardwoods, lying on the forest floor; however some living hardwoods remain today. The infected spruce trees were cut at the base. Because of heavy visitor traffic along this road today, a placard was placed near the clearings to explain to tourists the reason for the timber cuts.

Fig. 6 – West side of the stand that was cleared in 2004.

Fig. 7 - East side of the stand that was cleared in 2004

The west side of the stand is dominated by red spruce (Fig. 8) with striped maple (*Acer pensylvanicum* L.), sugar maple (*Acer saccharum*), red maple (*Acer rubrum*), black cherry (*Prunus serotina* Ehrh.), service berry (*Amelanchier arborea*), yellow birch (*Betulla alleghaniesis* Britton) and mountain ash (*Sorbus amaericana*).

Fig. 8 – Spruce-dominated community on the west side of the stand with easy navigation along forest floor.

The understory of the west side of the stand has a clear understory and is easy to navigate through, but patches of great rhododendron (*Rhododendron maximum)* are present along stream channels and damp sites. Another obstacle to note in the stand was downed snags. These snags were mostly mature spruce that caused great piles of debris in their paths.

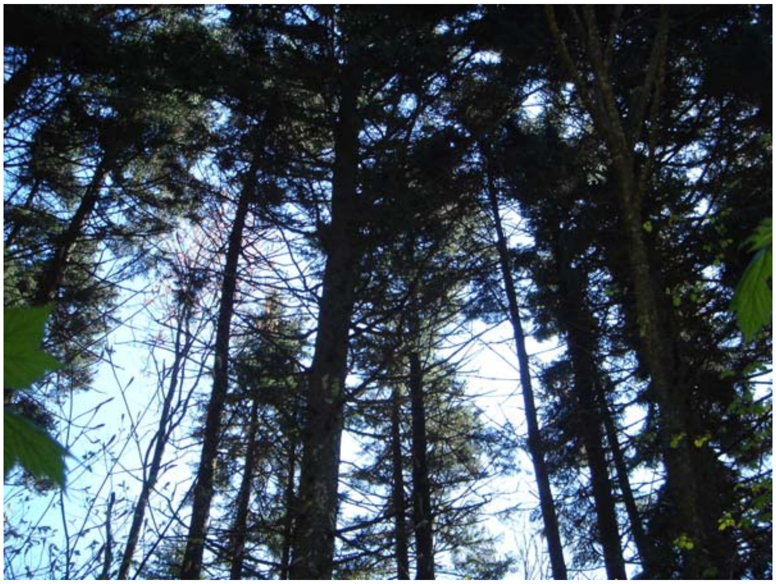


Fig. 9 - Canopy cover of the west side of the stand consisting of mostly red spruce.

The canopy on the west side of the stand was dense with red spruce cover, along with occasional treefall gaps (Fig. 9). Saplings of various sizes were present in patches along with numerous seedling patches. Seedling and sapling patch locations were consistent with canopy gap openings.

The east side of the stand (Fig. 10) is quite different than the western side. It is mainly composed of hardwoods, most importantly yellow birch, sugar maple and striped maple. Spruce is present along the road, but becomes less abundant down-slope the east; however some seedlings and saplings still persist. Moving approximately 200 m from the road, yellow birch becomes the dominant species, with few spruce saplings measuring approximately 10 to 15 cm DBH. When moving away from the road to the east, the canopy on the east side of the stand is more open than the west. This was partially due to the hardwoods not in leaf at the time of sampling, but also there were fewer trees. The forest floor was covered with leaf litter and downed logs, but for the most part, was relatively open and easy to navigate through.

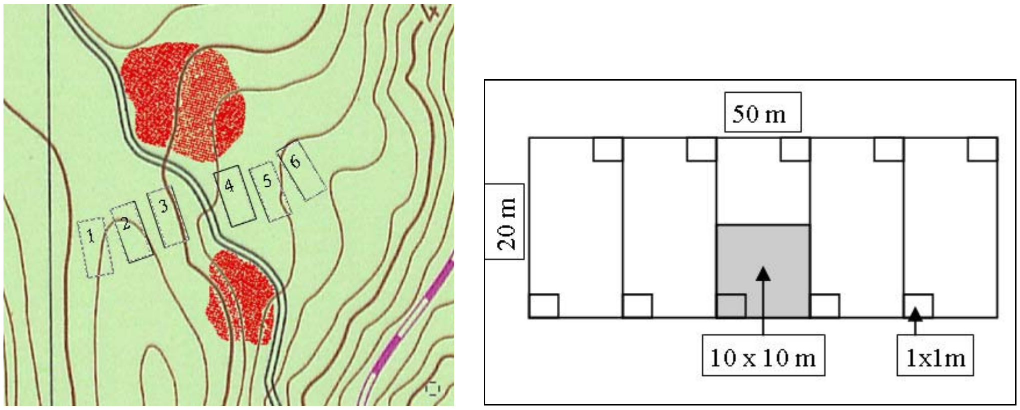
Fig. 10 – An example of the eastern side of the stand consisting of mainly yellow birch and few red spruce seedlings and saplings.

CHAPTER V

METHODS

Field Methods

In the summer of 2004, Forest Service personnel cut cross sections from the spruce stumps that remained after the southern pine beetle infected trees were harvested. To characterize stand structure and composition, I established six plots adjacent to the clear cuts during May 2006, as shown in Fig. 11a. All plots were laid out along a central transect line. Each plot measured 20 x 50 m and was 10 m from adjacent plots. Each plot was divided into five subplots measuring 10 x 20 m and labeled as sub-plots A-E as shown in Fig. 11b. A GPS unit was used to record each of the plot corners.



(a) (b)

Fig. 11 – Plot design for stand composition. a. Plot layout within cleared areas. b. A sketch of a single plot design. Saplings were collected is the dark grey area and the seedling nests the small 1x1m areas.

“Trees” were defined as being >50 cm height and >5 cm in DBH (Fig. 12). The species and DBH of each living tree was recorded and the tree was assigned an identification number. Dead trees, standing or uprooted, were recorded, but not cored or given an identification number. An increment borer was used to extract a core from the base of each tree. Red spruce trees were cored twice from opposite sides in order to collect as close to the pith as possible.

Fig. 12 – An example of a red spruce tree.

“Saplings” were defined as being greater than 50 cm in height, but less than 5 cm in DBH (Fig. 13). Saplings were sampled within a 10 x 10 m subplot nested inside each plot (Fig. 11b). One cross section was obtained from each sapling present.

Fig. 13 – An example of a sapling.

“Seedlings” (Fig. 14) were defined as woody stems less than 50 cm in height. Seedlings were recorded in nested plots as well, measuring 1 by 1 m, with a total of 10 seedling subplots per plot (identified as numbers 1 through 10 in Fig. 11b). Each seedling was recorded by counting each individual, and noting the number and species type.

Fig. 14 – An example of a red spruce seedling.

I noticed a compositional shift in the tree stratum while conducting field work and I realized that the two sides of the stand needed to be analyzed separately because of a distinct composition difference. The reason for this shift from spruce to birch (moving west to east) is unknown at this time, but may be due to the road, between the two parts of the stand, acting as a fire block in the past decades with fire activity. In the remaining parts of the analysis, I will be examining more closely the differences in the two sides of the stand and also examine the compositional gradient that may be present.

Laboratory Methods

All increment cores were prepared at the Plant Geography Laboratory in the Department of Geography at Texas A&M University. Each sample collected in the field was air dried for at least 48 hours and then glued to a wooden core mount and labeled. A belt sander was used with extra coarse (80 grit) sandpaper to plane the surface of the cores, and then with progressively finer sandpaper (220, 320, 400 grit) to prepare a smooth surface with easily visible rings.

A master chronology (Stokes and Smiley, 1968) was constructed based on the cores from 18 trees and was used for crossdating. Crossdating (Fritts, 1976) allows each ring to be assigned correctly to the year of formation. The purpose of the master chronology is to ensure the correct dating of all the cores with irregular growth patterns that are not easily identifiable. The increment cores that were chosen for the master chronology were those with a consistent growth pattern to each other with a life span that dated as far back as possible. A total of 16 red spruce increment cores were used in the master chronology while attempting to use an equal number of cores from each plot.

The master chronology was measured using Measure J2X software and a Velmex measuring system with 0.001mm precision. The dendrochronology package COFECHA (Grissino-Mayer, 2001b) was used to crossdate the measured ring-width series statistically. Crossdating is the matching of year to year variations in ring width among different trees (Grissino-Mayer, 2001a). The master chronology extended from 1895-2005.

A total of 227 cores (from 147 trees) (Table 1) were measured and then crossdated against the master chronology. Although two cores were taken from each tree in the field, some cores were of no use upon measurement because of rot or damage in transit. For the 49 spruce cores (from 41 trees) that did not crossdate, simple ring counts were used to estimate tree age. For cores that did not intersect the pith, standard pith estimators (Applequist, 1958) were used to estimate the pith date based on the curvature and width of the inner rings.

Table 1 - Descriptive statistics and results of COFECHA analyses.

Species	No. series	Master series interval	Series inter-correlation	Average mean sensitivity	Mean length of series (years)
Picea rubens	227	1835–2005	.453	0.244	125.8

Seven spruce cross sections contained fire scars. Each cross-section was sanded, measured and crossdated against the master chronology, then each fire scar was dated and recorded. Saplings were aged solely by ring counts (i.e. were not crossdated) because they did not contain enough rings for crossdating.

Yellow birch cores were sanded to a fine surface for clear ring visibility. However, when measured, the yellow birch cores could not be crossdated against the spruce chronology or each other. Therefore, ring counts along with pith estimations were conducted to estimate the dates of establishment. Age class histograms were constructed to identify pulses of recruitment.

Dendroclimatological Methods

Climate data for the summit of Whitetop Mountain are not available for the length of the chronology in this study; therefore I used state division climate data to estimate the climate patterns in the region of the site. Whitetop Mountain rests near the borders of three states, therefore the state divisions adjacent to its location were used in averaging the climate data. Climate data were obtained from the National Climatic Data Center (NCDC, 2006). State division data (Fig. 15) were obtained for divisions 2, 1 and 6 for North Carolina, Tennessee and Virginia, respectively.

Variables of interest within this data set were Palmer Drought Severity Index (PDSI), mean monthly temperature and precipitation for a total of 111 year span (1895-2005). PDSI characterizes moisture conditions based on both precipitation and temperature. PDSI values often are correlated with ring widths of eastern trees (Adams et al., 1985). Within each variable's data set, each monthly value was averaged to each division data set to have a single value for each year of data.

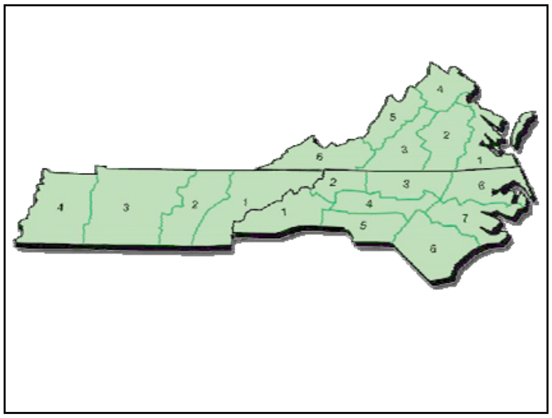


Fig. 15 – Map of state climate divisions used in climate analyses. (Map created from NCDC maps, 2006)

Cores from eight trees were added to the original master dating series to create a dendroclimatology series (i.e. 46 cores from 26 individual trees). The criterion in choosing these extra cores was simple: at least one core of a tree must have a consistent and clear ring-width pattern that could be easy crossdated back to 1900. These cores were similar to the master chronology cores in that they were clear, but were not originally chosen because they did not date as far back as the others. Both cores of each tree were included in the new dendroclimatic series.

The ARSTAN program (Cook and Holmes, 1986) was used to standardize the ring widths for the 26 series. Standardizing the ring widths removes the variance at low frequencies and also removes the overall long-term growth trend (Grissino Mayer et al., 1992). The double-detrending option in ARSTAN (option 2) was used to (1) fit a linear regression or negative exponential model and (2) fit a cubic smoothing spline that retained 50 percent of the ring width variance over a 20 year interval (Cook and Holmes, 1986). The resulting detrended series was therefore appropriate for investigating radial growth response to year-to-year climate variability, but not to longer-term climate trends. Residuals were calculated by dividing the ring width for each year by the modeled value (Johnson et al., 1988).

After standardizing the series, ARSTAN generates a single ring-width index chronology with autocorrelation removed. I correlated this residual chronology with the monthly climate data for January to September of the year of ring formation, and for the previous year by offsetting the data by one year. SPSS v.14 was used to calculate the Pearson correlation coefficient for each month.

Radial Growth Release Methods

To examine the release patterns of the spruce cores I used the program JOLTS, following Holmes (1999). This method is ideal for red spruce trees in that they are shade tolerant and their rings will clearly show the growth following a disturbance. Radial growth patterns have been recently studied (Lorimer and Frelich, 1989; Wu et al., 1999) to not only examine characteristics of disturbances (i.e. frequency and severity) but also detect any sudden changes in the regime. In this study, changes in recent and past growth patterns in red spruce may begin to give insight as to the environmental changes that occurred in the past.

Trees that exhibited a release at a given year when ring width was at least 50 percent greater than the mean ring width of the previous 10 years (program default: jolt release factor of 1.5 (50% growth increase) and 10 year moving average (Holmes, 1999). The increase in ring width was to be maintained for 10 years (Brose and Waldrop, 2006). A major release was identified with a 100 and 50 percent increase in average growth lasting at least 10 years. A 10 year growth period was chosen for this study because of red spruce's shade tolerance characteristics. For example, with a disturbance intense enough to open the canopy, it can be expected that the underlying juvenile spruce saplings will exert an increase in growth with a less dense canopy following a disturbance.

CHAPTER VI

RESULTS

Stand Composition

Red spruce and yellow birch were the dominant species (Tables 3-8) at the time of sampling (Table 2). Sugar maple and striped maple were the next most abundant species, but were much less abundant than red spruce and yellow birch. The remaining 5 species were only found rarely and were not of major importance. The average age of the sampled trees was 126 years (±44 years), with the oldest dating to 1732.

Table 2 –Total inventory of sampled trees, saplings and seedlings.

Species	**Tree Basal Area (m^2/ha)**	**Tree Density (stem/ha)**	**Sapling Density (stem/ha)**	**Seedling Density (stem/ha)**
Red Spruce *Picea Rubens* Sarg.	35.05 (±12.57)	350 (±126)	1400 (±1108)	10000 (± 29972)
Yellow Birch *Betulla alleghaniesis Britton*	10.35 (±9.85)	198 (±98)	0 (±0)	7666.7 (±32800)
Sugar Maple *Acer saccharum*	2.70 (±3.62)	35 (±36)	0 (±0)	833.33 (±3340)
Striped Maple *Acer pensylvanicum L.*	1.21 (±9.13)	161 (±91)	1133 (±1133)	0 (±0)
Black Birch Betula lenta	0.63 (±1.22)	5 (±12)	0 (±0)	0 (±0)
Black Cherry *Prunus serotina*	0.43 (±0.84)	5 (±8)	0 (±0)	0 (±0)
Service Berry *Amelanchier arborea*	0.14 (±1.22)	6 (±16)	0 (±0)	0 (±0)
American Wahoo *Euonymus atropurpureus* Jacq.	0.11 (±0.81)	3 (±8)	0 (±0)	0 (±0)
American Mountain Ash *Sorbus Americana*	0.08 (±2.04)	8 (±20)	0 (±0)	0 (±0)
Total	50.68 (±11.02)	771 (±45)	281.44 (±437.4)	2056 (±9907)

Table 3 - Plot 1 inventory.

	Basal Area (m²)	Tree Density (stems/ha)	Sapling Density (stems/ha)	Seedling Density (stems/ha)
Black Birch	0.00	0		
Black Cherry	2.15	20		
Mountain Ash	0.49	50		
Red Spruce	45.14	400	3300	160000
Service Berry	0.83	40		
Striped maple	0.00	260	1300	20000
Sugar Maple	5.92	0		
Wahoo	0.63	20		
Yellow Birch	7.33	170		20000

Table 4 - Plot 2 inventory.

	Basal Area (m²)	Tree Density (stems/ha)	Sapling Density (stems/ha)	Seedling Density (stems/ha)
Black Birch	3.75	30		
Black Cherry	0.00	0		
Mountain Ash	0.00	0		
Red Spruce	48.86	510	1500	370000
Service Berry	0.00	0		
Striped maple	2.25	200	1500	
Sugar Maple	1.70	80		
Wahoo	0.00	0		
Yellow Birch	4.09	70		310000

Table 5 - Plot 3 inventory.

	Basal Area (m²)	Tree Density (stems/ha)	Sapling Density (stems/ha)	Seedling Density (stems/ha)
Black Birch	0.00	0		
Black Cherry	0.00	0		
Mountain Ash	0.00	0		
Red Spruce	45.64	450	1700	60000
Service Berry	0.00	0		
Striped maple	0.73	220	900	
Sugar Maple	0.15	10		
Wahoo	0.00	0		
Yellow Birch	5.15	150		

Table 6 - Plot 4 inventory.

	Basal Area (m²)	Tree Density (stems/ha)	Sapling Density (stems/ha)	Seedling Density (stems/ha)
Black Birch	0.00	0		
Black Cherry	0.43	10		
Mountain Ash	0.00	0		
Red Spruce	31.51	290	1300	10000
Service Berry	0.00	0		
Striped maple	3.45	180	600	
Sugar Maple	0.00	10		
Wahoo	0.00	0		
Yellow Birch	13.88	250		10000

Table 7 - Plot 5 inventory.

	Basal Area (m²)	Tree Density (stems/ha)	Sapling Density (stems/ha)	Seedling Density (stems/ha)
Black Birch	0.00	0		
Black Cherry	0.00	0		
Mountain Ash	0.00	0		
Red Spruce	28.61	280	300	
Service Berry	0.00	0		
Striped maple	0.75	100	2500	20000
Sugar Maple	6.82	80		
Wahoo	0.00	0		
Yellow Birch	12.11	190		50000

Table 8 - Plot 6 inventory.

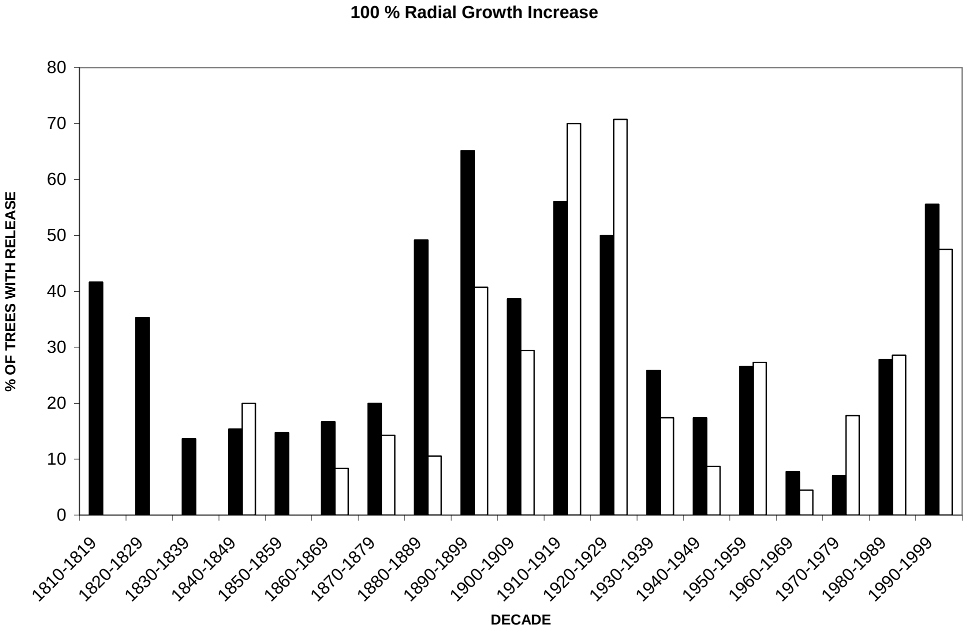
	Basal Area (m²)	Tree Density (stems/ha)	Sapling Density (stems/ha)	Seedling Density (stems/ha)
Black Birch	0.00	0		
Black Cherry	0.00	0		
Mountain Ash	0.00	0		
Red Spruce	10.54	170	300	
Service Berry	0.00	0		
Striped maple	0.06	10	0	10000
Sugar Maple	1.57	30		
Wahoo	0.00	0		
Yellow Birch	19.55	360		20000

Date and Severity of Fires

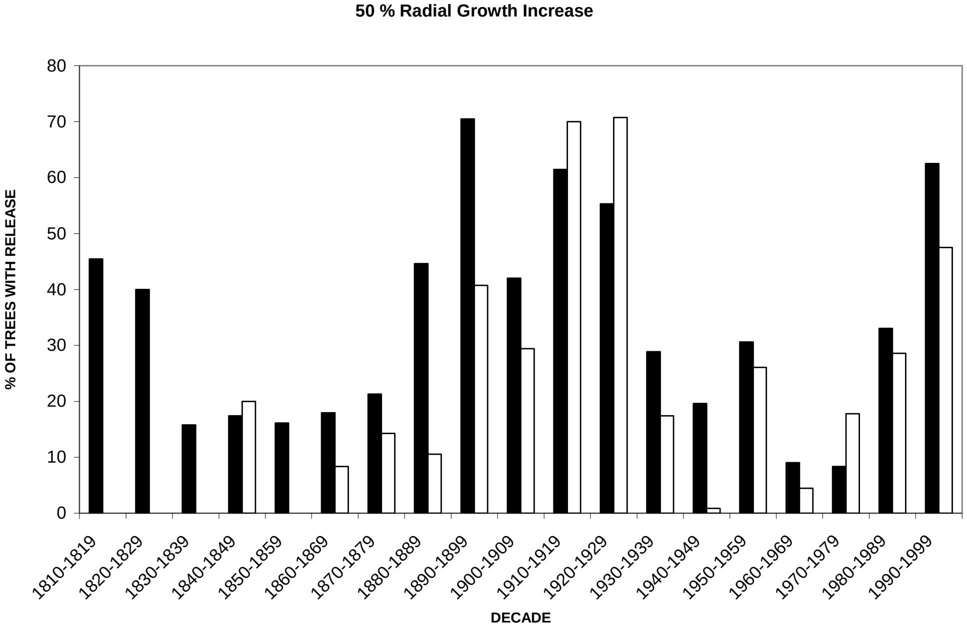
Eight fire scars were found within eight of the cross sections, with fires occurring in 1854, 1902, 1919 and 1939. The 1854 fire was found in only one cross section early in the ring record when the tree was only a sapling. The 1902 fire was found within two cross sections. The 1919 fire was also found within two cross sections and the 1939 fire was found in three cross sections. The scars in the 1900s occurred in the late wood and appear to have resulted from growing season fires. The 1854 fire occurred when the tree was young, 21 years old, and showed no characteristics of being a late season fire. All fire scars were recorded in mature stages of the trees lives, with the exception of the 1854 fire.

Radial Growth Releases

Prior to 1840, the east side of the stand showed no releases that were detected by JOLTS (Fig. 16). The east side of the stand showed the highest number of releases between 1910 and 1929. The period with the most releases for the west side of the stand was between 1880 and 1929. Both sides of the stand showed high number of releases in the 1990s. Few differences were observed between the 100 percent release and the 50 percent release.



(a)



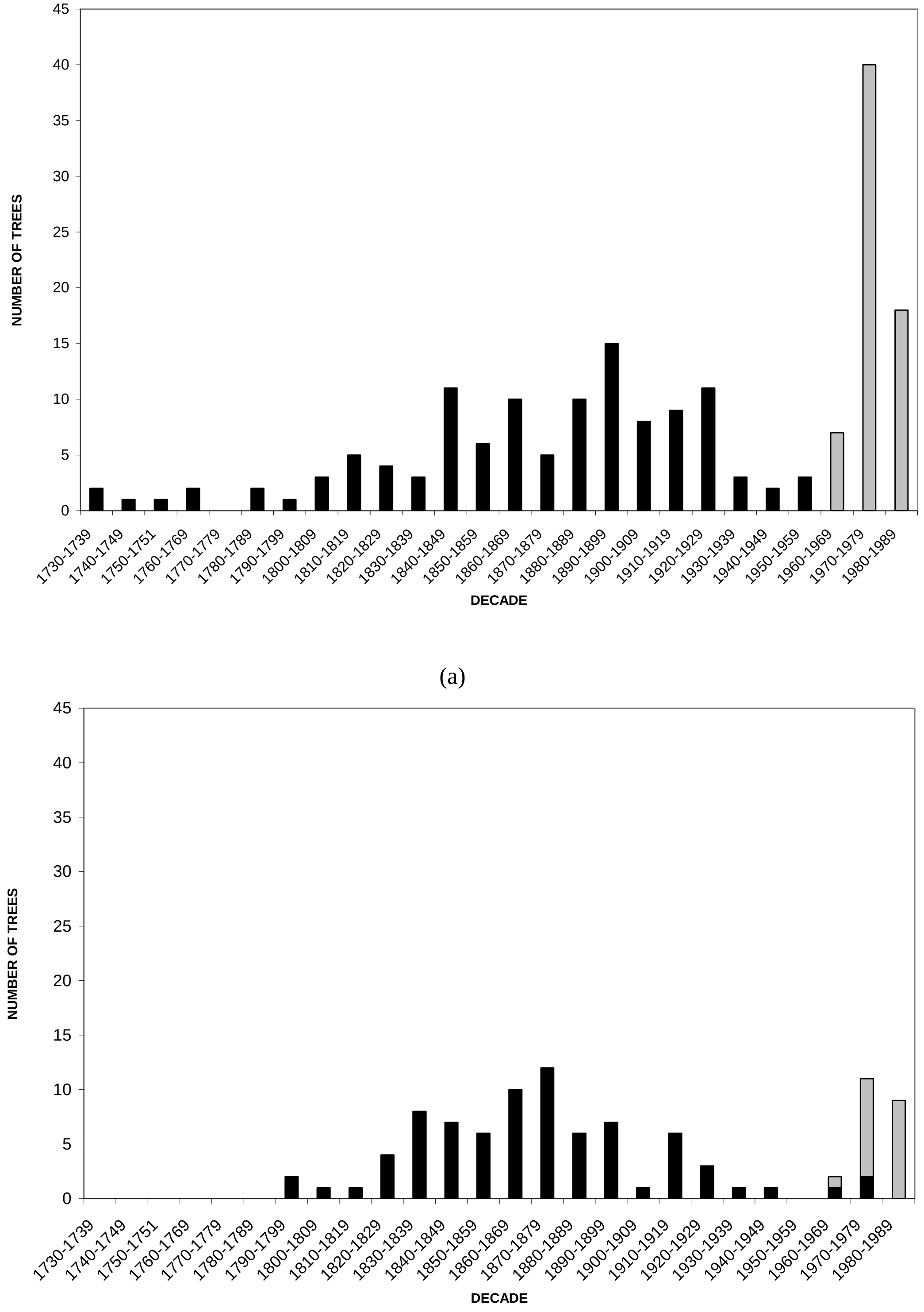
(b)

Fig. 16 – Tables representing the radial growth release outputs. The black bars indicate the western side of the stand and the white bars depict the east side of the stand. Values shown are the decades with >10 trees detected within that year with releases.(a) Percentage of trees with releases in ring record after testing for 100 percent radial width increase. (b) Percentage of trees with releases in ring record after testing for 50 percent radial width increase.

Age Structure of Red Spruce and Yellow Birch

The western side of the stand (Fig. 17a) shows a spruce dominated community with few hardwoods until the 1900s. After the start of the century, red spruce establishment began to slow on both sides of the stand, resulting in an abundance of yellow birch. In recent decades, red spruce saplings established more on the west side of the stand than the east side (Fig. 17b).

Most of the yellow birch in the stand established from 1910 to 1970 (Fig. 18), but a few trees established in the early 1800s as well. The west side of the stand did not have the sharp increase in yellow birch like the east side of the stand did. Beginning in 1910-1919, the east side of the stand began to increase rapidly in yellow birch establishment, reaching its peak between 1930 and 1949. Yellow birch establishment had a peak after 1910 then slightly declined after 1940, then rose again up until 1980.



(a)

(b)

Fig. 17 – Red spruce tree (black bars) and red spruce sapling (grey bars) establishment. (a) Western side of stand; (b) Eastern side of stand.

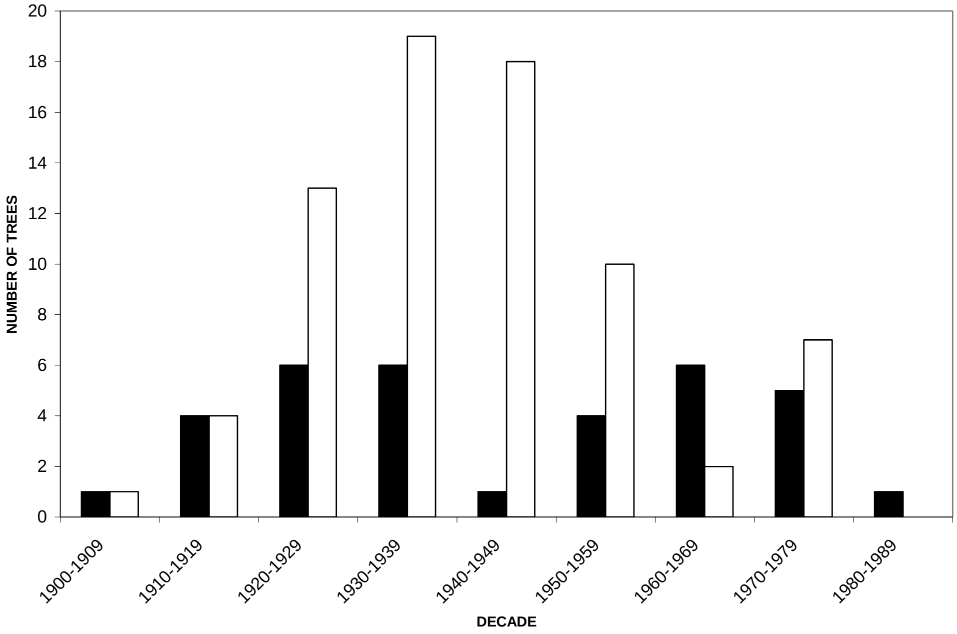


Fig. 18 – Yellow birch tree establishment on the west (black bars) and east (white bars) side of the stand.

Dendroclimatic Relationships

The radial growth of red spruce was correlated with all three climatic variables (Fig. 19). The relationship with PDSI was strongest: a positive correlation with PDSI for the growing season of the previous year. Radial growth was also related positively to precipitation and negatively to temperature of the previous growing season. Further, tree growth exhibited a positive relationship with previous November temperature.

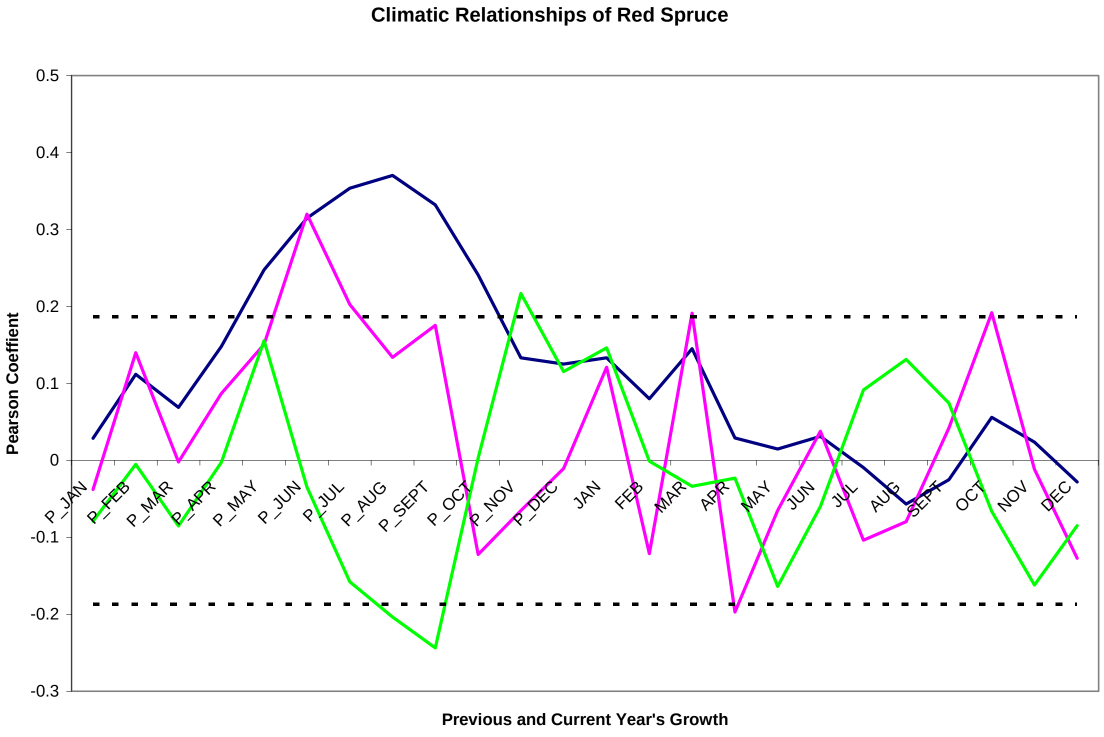


Fig. 19 – Red spruce radial growth correlations with climate. PDSI (Blue), Temperature (Green) and Precipitation (Pink). The dashed lines indicate p=.187.

CHAPTER VII

DISCUSSION

Whitetop Mountain presents a unique response to disturbance with a new cohort of trees being established after a series of fires. The stand in which I sampled has old-growth components, with the majority of the spruce predating the period of logging in the early 20th century. This study presents a general description of not only the disturbance regime of a red spruce forest, but a fire regime and the successional patterns and dynamics associated with fire. Unlike other red spruce studies, this thesis uses valuable fire scarred cross sections to reconstruct the fire regime of Whitetop Mountain, hoping to partially fill the knowledge gap in understanding red spruce response to disturbance, fire in particular. The role of fire in these stands is not clearly understood because it does not occur frequently, but this study provides new insights about fire effects in a red spruce stand.

Chronology of Stand Development

a. The Fire of 1854

The 1854 fire apparently was a low severity fire because even a small sapling survived it with only a scar and did not change much of the stand composition. I am not as confident in this fire because of the lack of data. There was only one scar found in one tree, which makes me less confident that it was indeed a fire and not another type of injury. If any existing yellow birch established after the 1854 fire, they were not present at the time of sampling. Birch establishment patterns may have been higher during this time, but records are lacking and can only be speculated. Red spruce establishment at this time was low as well, and its abundance can also only be speculated because there may have been mature trees present at this time, but had died between then and the time of sampling. Radial growth releases suggest no major shift in growth pattern or structure. Red spruce releases were only detected in 15 percent of the trees in the 1850-1859 decade, giving no strong evidence of a major growth pattern change.

b. The Fire of 1902

The 1902 fire data suggests that it was a low severity fire, causing low mortality and failing to significantly alter the composition of the stand. To support the claim, average monthly PDSI values (Fig. 20) for the year 1902 indicate only a mild to moderate drought (Palmer, 1965) occurring during the summer months. Red spruce typically does not begin to grow until June and normally grows until the middle of August (Hart, 1959). This data, along with the visual confirmation of a late season fire, suggests that the fire must have occurred between June and August. If this claim is true, then the stand was in a mild drought period, and it was not dry enough for a severe burn.

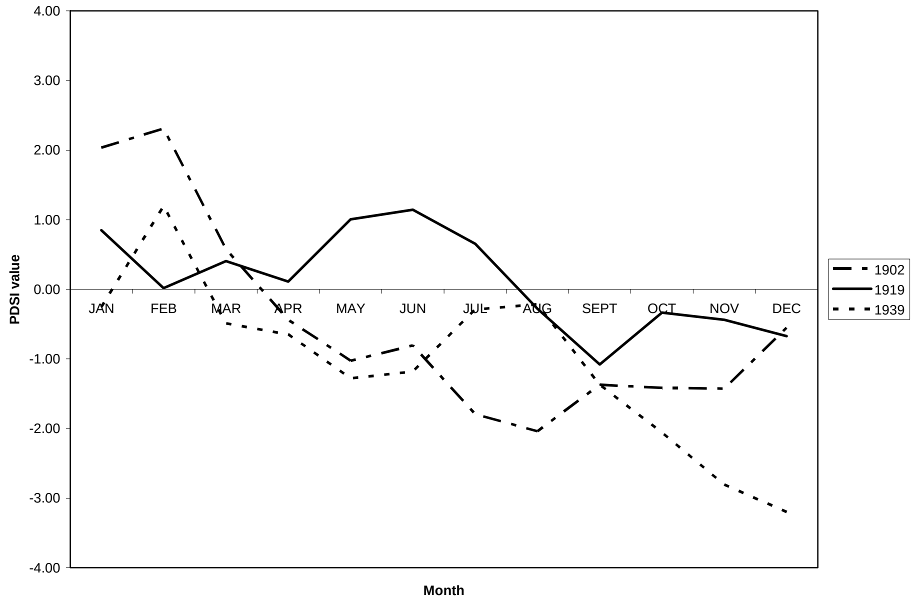


Fig. 20 – PDSI values for the year 1902, 1919 and 1939. Values were collected from the NCDC state-division climate data set for Virginia (Div. 5), Tennessee (Div. 1) and North Carolina (Div. 2).

Radial growth releases were moderately high during the 1900-1910 decade. As stated before, human activity on Whitetop was increasing at the time off the 1902 fire. The cause and location of this fire is unknown, but it could have possibly been human induced because of the increased activity. No significant red spruce or yellow birch tree establishment occurred as a result of the 1902 fire based on the results presented here. Red spruce establishment declined to one tree being established on the east side of the stand while the west side had eight trees establish; however, future fires may have burned any trees that established at this time. Yellow birch establishment was similar on both sides, establishing one tree per side. This fire apparently caused little mortality in the stand; however, radial growth releases indicate optimal growing conditions that promoted a high number of releases.

c. The Fire of 1919

The 1919 fire caused a major shift in the forest composition due to apparently high mortality within the forest. Because the 1919 fire occurred in the later part of the growing season, the radial growth releases most likely would not have been detected until the 1920's. The high number of releases in the 1900-1919 decade can be attributed to logging within the stand after World War I (~1918) and increased human activity around the summit. Logging in this stand was "selective", resulting in numerous canopy openings being left behind as opposed to large clear-cuts that occurred on Mount Rogers (Pyle and Schafale, 1988). These canopy gaps would have allowed understory trees to release, which were detected in my results between 1910 and 1919. Therefore, if logging began in 1918, releases would not have been detected until the following year, suggesting that the radial growth releases detected in the 1910-1919 decade are the result of logging and the 1920s radial growth releases are the result of the fire, combined with logging.

Radial growth release detections were at their peak following the 1919 fire, with over 50 percent of trees in the sampled stand showing release between 1910 and 1919, most notably the 70 percent of the trees showing releases on the east side. The difference in percent of trees between the two sides of the stand may suggest that the east side of the stand was logged and burned, while the west side was only logged.

Red spruce tree establishment following the 1919 fire showed no significant pulses. The decade following the fire showed a slight increase in red spruce establishment on the west side of the stand and a small decline of spruce establishment on the east side. The low spruce establishment on the east side may be the result of a severe fire killing understory trees. In addition to the mortality of understory trees and mature trees, a severe fire would have set back the establishment of red spruce by killing the seed bank left by prior year's seed fall.

Red spruce seeds require specific conditions to germinate properly, such as adequate moisture and moderate soil temperature, and cool temperatures (Frank and Bjorkbom, 1973). The lack of spruce establishing on the east side of the stand could be supported by this evidence. As a result of the 1919 fire, red spruce never made a strong recovery on the east side of the stand following the 1919 fire, which left it more susceptible to invasion of hardwoods. The west side of the stand showed similar establishment patterns to the east side, with few spruce establishing after the 1920s (less than 10 trees established after 1929).

Yellow birch establishment is the most significant difference within the stand after the 1919 fire. The west side of the stand showed little increase in yellow birch trees establishment (10 trees establishing between 1910 and 1929). This may be a result of more severe fire on the east side of the east side of the stand. Yellow birch establishment rapidly increased after the 1919 fire to 17 trees being established between 1910 and 1929. The increase in yellow birch trees is consistent with an intense fire setting back succession, allowing the faster-growing trees to persist. If the fire was as severe as I believe it to be, then the birch and spruce would have been competing for canopy room, however we see the result of this today.

d. The Fire of 1939

The 1939 fire was the last fire found within the cross sections, and I believe this fire to have been a low severity event. Red spruce release detections show no significant pulses in radial growth in the 1930s or 1940s. Additionally, no major red spruce establishment occurred as a result of the fire, with less than 10 trees establishing between 1930 and 1949. Yellow birch establishment peaked in the 1930s and 1940s, resulting in 37 yellow birch trees to be established on the east of the stand. Less than 10 yellow birch trees established in the 1930s and 1940s continuing to outnumber the red spruce until the present.

From 1920 to 1949, yellow birch out-competed red spruce on Whitetop Mountain, which subsequently resulted in part of the red spruce stand shifting into a mixed spruce-hardwood stand. I believe that the 1919 fire was so severe, that it caused high mortality on the east side of the stand and the 1939 fire was a less severe fire that killed any young spruce that may have germinated after the 1919 fire. As a result, the 1939 fire set back succession, promoting yellow birch to densely establish once again.

e. Saplings

Small gap dynamics best explain the pulse in sapling establishment after the 1960s. Gaps in the canopy are formed by the dieback and windthrow damage done to mature, older tress. As these older trees begin to die, understory growth is promoted (Foster and Reiners, 1986; Battles and Fahey, 2000) because of the excess light available. Once the dead trees fall, little damage is done to the understory, allowing small seedlings and saplings to persist. This study presents a classic example of gap dynamics and canopy recruitment which is the principal process in sub-alpine canopy replacement (Runkle, 1981; Battles and Fahey, 1996; Wu et al. 1999).

Dendroclimatic Relationships

Red spruce was dependent on previous year's moisture availability for the current year's growth pattern. Correlations with PDSI and precipitation suggest that red spruce depends on the previous year's moisture for the following year's growth pattern. The PDSI correlation in this study, extending from May to October of previous year, shows that above average moisture will result in high ring width growth the following year. Additionally, high precipitation will also result in high growth in ring patterns. Previous year's temperature negatively correlated with ring widths, which suggests that high temperatures in the previous year will result in low growth the following year. The results in this study correspond well with what is known about red spruce growth (Conkey, 1979; Adams et al., 1985; Cook, 1987), which is that red spruce requires cool, moist sites that have adequate sunlight and cool soil temperatures. This study coincides well with others indicating that previous year's temperatures are negatively correlated to following year's growth (Conkey, 1979; Cook et al., 1987; McLaughlin, Downing, Blasing, Cook and Adams, 1987). Negative correlations with temperature suggest that high temperatures are not in favor of spruce because of their influence on moisture availability.

The results in this thesis compare to other studies that have examined *Picea* response to inter-annual climatic variability. Abrams, Copenheaver, Black and van de Gevel (2001) examined the old growth bogs of Pennsylvania and found that black spruce (*Picea mariana*) showed few growth releases due to inter-annual climatic variability. *P. mariana* was highly correlated with average monthly temperature (February, April, July and August) and few correlations found with precipitation (November) and PDSI (current October; previous July was negatively correlated). In northern China, Liang, Shao, Hu and Lin (2001) found that Meyers spruce (*Picea meyeri*) correlates to February and March rainfall of the current year and September of the previous year correlated significantly with ring growth. Additionally, previous August and October precipitation positively correlated, but not significantly.

Red Spruce Successional Dynamics

I propose a model (Fig. 22), to represent the successional dynamics of the red spruce stand that is intermixed with hardwoods atop Whitetop Mountain. When mature spruce trees die, they typically fall and leave canopy gaps, resulting in regeneration of spruce saplings (Battles and Fahey, 2000). These saplings are able to withstand many years of suppression and release until they become mature spruce trees. However within larger gaps, from fire for instance, spruce is limited in its growth capability by the higher competitive ability of invasive hardwoods. The faster growing hardwoods, such as yellow birch, limit spruce establishment and result in a more inter-mixed forest.

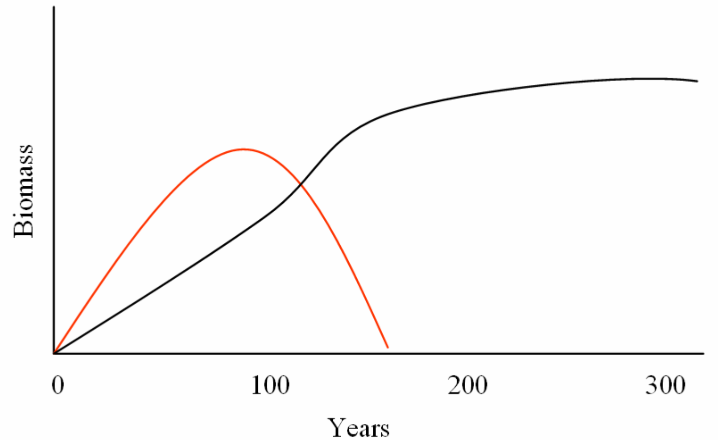


Fig. 21 – Model representing the growth of red spruce (black line) inter-mixed with yellow birch (red line) after a severe disturbance.

In the case of Whitetop Mountain, yellow birch invaded the east side of the stand, limiting the spruce establishment after the 1919 fire. In this model, the x-axis will represent time, starting at time zero with no trees present. The y-axis will represent abundance to show the stand development and replacement over time. As time progresses, yellow birch abundance increases more than red spruce because of its growing capabilities, resulting in a birch dominated forest. Red spruce maintains an increase in its abundance over time, yet it does not exceed the birch abundance until later in its life cycle.

When the 100 year interval approaches, birch abundance begins to decrease because of its short life span. As a result, the understory spruce that have been suppressed for many years begin to release rapidly, taking full advantage of the canopy room left by the dying birch. Between 200 and 300 years, red spruce abundance levels off because of the stand carrying capacity coming to full potential.

This model represents conditions with no major disturbances occurring, such as fire or logging. However, in the case of this thesis, a severe fire did occur in the stand, which resulted in the cycle to start over at time zero. In the case of smaller, more frequent disturbances, such as windthrow, the abundance of red spruce changes very little. If one tree is to fall as a result of wind, then the underlying saplings will soon take its place if it is a smaller gap (Battles and Fahey, 2000), maintaining the abundance level. In the case of larger gaps, abundance will vary, depending on the size of the gap.

The model presented here coincides with previously constructed models of red spruce life histories (Urban et al., 1991; Laroucque, 2006). Red spruce maintains an increase in its abundance throughout time while other species fluctuate in their establishment. Yellow birch is a mid successional species that has poor regeneration characteristics, limiting its establishment capability when other species are competing (Larocque, Archambault and Delisle, 2006).

CHAPTER VIII

CONCLUSIONS

The purpose of this study is to provide insight into post-disturbance successional patterns and forest dynamics of red spruce forests due to fire in the southern Appalachians. Additionally, I investigate the impacts of climate on red spruce radial growth and determine what climatic variables the species depends on for growth. Little information is available on the fire regime within these forests, making management decisions difficult in the event of such disturbances. By filling this knowledge gap, managers will be able to better understand the implications of fire exclusion in these forests. This study has demonstrated that fire is an important component in the stand structure of Whitetop Mountain, in addition to logging and climate. Despite the notion that local conditions, such as cooler temperatures and wetter conditions, would seem to discourage fire events, this study has demonstrated that fire, along with climate patterns and logging activities, is an important component in spruce stand structure.

Whitetop Mountain and surrounding areas sustained logging, tourism and grazing throughout its known land use history. These activities probably contributed to the stand structure we see today (i.e. stand composition, tree age distribution and density). Beginning in the late 19th century, tourism activity increased as a result of a hotel on the summit and the aesthetic appeal of the red spruce forests upon Whitetop's Mountain. Based on my results, the first severe fire was in 1919, causing substantial mortality that resulted in a new cohort of hardwoods to be established. This fire was most likely the result of logging practices within the red spruce stands on Whitetop Mountain, even though logging was selective (Pyle and Schafale, 1988). The service road likely acted as a firebreak, protecting the west side of the stand from more mortality.

This study is similar to other studies (i.e. Cook and Jacoby, 1977; Adams et al. 1985; Cook et al., 1987; Battles and Fahey, 2000) in investigating stand structure of red spruce forests and their climatic responses. This thesis shows that red spruce is moisture dependent and any alteration in its moisture regime can result in excess growth or suppression for many years. PDSI and precipitation had the highest correlation to ring width growth; supporting the claim that normal to above normal reception of moisture stimulates red spruce growth in the following year.

Forest Service personnel face a challenging task in maintaining biodiversity in these stands. In order to properly restore the red spruce to historic levels, severe, large scale fires must be excluded. Fire was shown to have negative impacts on the sampled stand, resulting in a sudden composition shift which will take time to reverse. In addition to protecting red spruce, forest managers must also monitor the endangered species that use these stands as their natural habitats (i.e. Carolina northern flying squirrel and the Weller’s salamander).

Four fires were recorded in the tree ring record, three of which occurred in the early 1900’s. One of these fires, the 1919 fire, was severe enough to cause a long-term shift in stand structure from spruce to disturbance-dependent hardwoods. As a result of these fires, red spruce has been unable to fully recover, establishing less than 20 trees after 1939.

In addition to fire disturbances, red spruce stands were also impacted by logging during this time. Unlike fires, however, logging has been shown to have had a positive effect on spruce stands. Logging was probably the major cause of the radial growth releases between 1910 and 1919. The removal of select red spruce trees would have opened up the canopy, promoting understory trees to grow into the canopy. Together, fire and logging were more damaging than either of these disturbances would have been separately. The combination of intensive logging and deliberately ignited fires allwed the cohort of yellow birch to establish and has prevented the re-establishment of spruce.

The response to the other fires found in this study is thought to be minimal as no major shifts in composition or radial growth releases were detected. The fires appear to be low intensity, causing low mortality. These fires may have been small surface fires, never reaching the canopy, that were quickly extinguished due to moist conditions. Finally, the response of red spruce to inter-annual climatic variability is dependent on moisture and temperatures from the previous year. A combination of higher moisture and low temperatures provides optimal growth conditions for red spruce. Changes in any of these variables results in suppression of red spruce for extended periods of time. The long term climate response of red spruce will be interesting to investigate in future years, because of rising global temperatures and the elevation restrictions of red spruce in the southern Appalachian Mountains.

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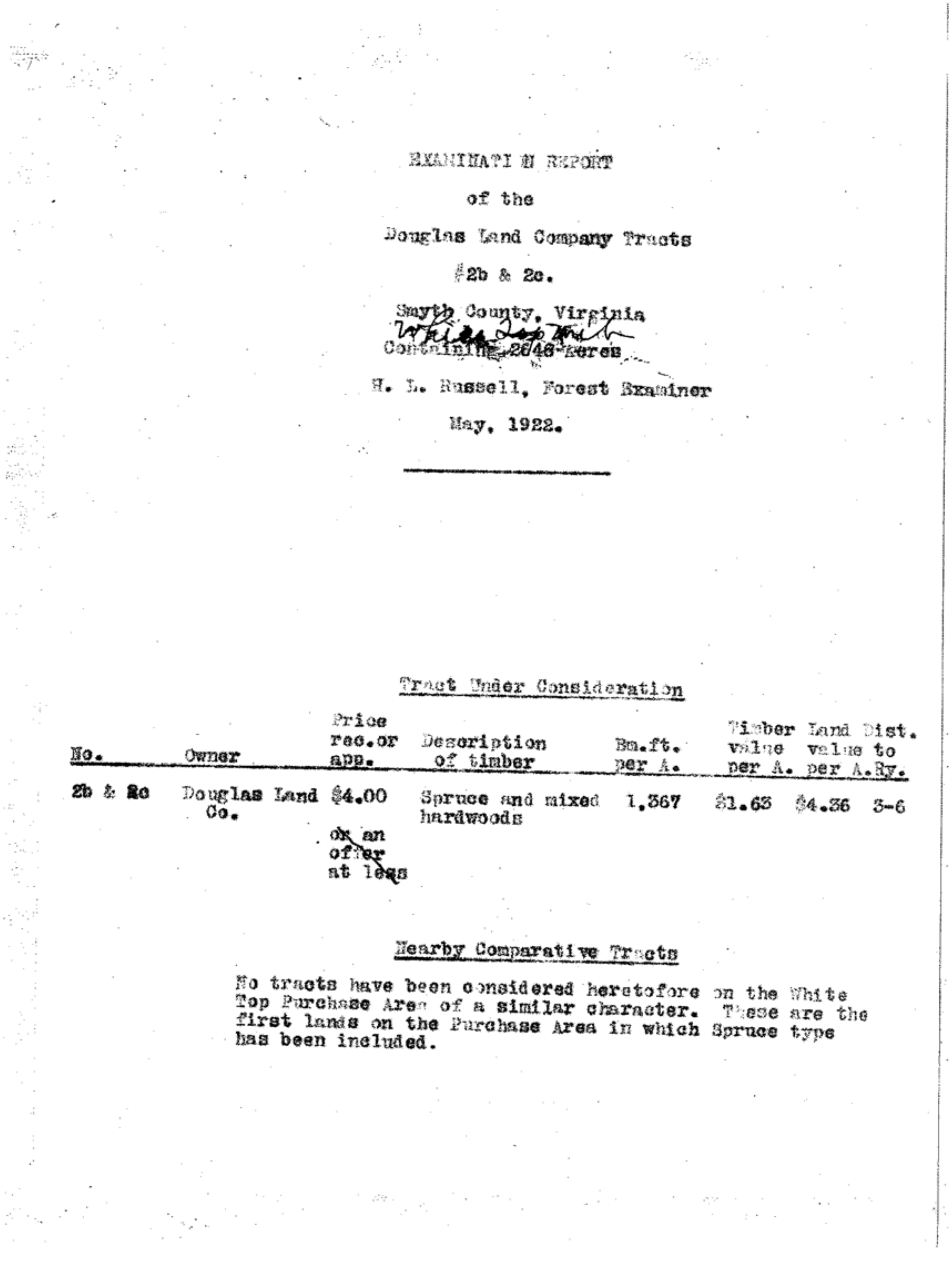
APPENDIX A

FOREST EXAMINER'S REPORT



EXAMINATION REPORT

of the

Douglas Land Company Tracts

#2b & 2c.

Smyth County, Virginia

White Top Unit

~~Containing 2646 Acres~~

H. L. Russell, Forest Examiner

May, 1922.

Tract Under Consideration

No.	Owner	Price rec. or app.	Description of timber	Bm. ft. per A.	Timber value per A.	Land value per A.	Dist. to Ry.
2b & 2c	Douglas Land Co.	$4.00 or an offer at less	Spruce and mixed hardwoods	1,367	$1.63	$4.36	3-6

Nearby Comparative Tracts

No tracts have been considered heretofore on the White Top Purchase Area of a similar character. These are the first lands on the Purchase Area in which Spruce type has been included.

Douglas Land
Lands of ~~WHITE TOP~~ UNIT - #2b,2c.

General Information

The land described in this report is in two tracts of 1306 and 1340 acres respectively. The first crosses the top of White Top Mountain and the second includes all of the top of Balsam or Mt. Rogers which is the highest elevation in the State of Virginia.

Both tracts are in Smyth County, Virginia, on the divide between White Top creek which is a tributary of the Tennessee via the Holston, and Helton Creek, a tributary of New River.

With the exception of the Groseclose, James A. #12 which has been offered and examined and the W. S. Graybeale tract lying east of the Balsam Mt. tract 2c and a tract of the Hassinger Lumber Company, #9a lying to the west of the White Top tract #2b, all of which are forest lands both tracts are completely surrounded by potential grazing land.

It will be possible to add to the White Top tract #2b on the north west and the Balsam Mt. tract #2c can be added to on the ast along Pine Mountain to a considerable extent by buying small tracts when available, one of which (Groseclose, James A. #12-500 A.) has been offered.

While these tracts are isolated from acquired land they do not offer an embarrassing handicap in administration and protection. They will not materially increase the per acre cost of protection, but in them will be protected two of the few remaining stands os spruce in the Southern Appalachians which have held their own against the inroads of forest fires and are in shape to produce a better stand than the original cover, if protected.

Springs from these tracts are depended on for water supply for adjoining grazing areas and considerable fear exists in the section lest these springs should go dry upon the depletion of the forest cover caused by continuous fires on lands already cut over and devastation by fire of existent spruce stands in case such stands are cut.

They are owned by the Douglas Land Company of 14 Wall Street, New York, which has offered them at $4.00 per acre, without reservations.

Description

Slopes face in all directions, but the bulk of both tracts is on the north sides of the mountains. There are a few rock outcrops and cliffs near the tops of the mountains and boulders in some of the hollows, but on the whole the topography is comparatively smooth and logging not difficult.

The soil is a deep rich loam of unusual fertility and in part has a potential capacity for grazing.

Both tracts were originally heavily timbered, sugar maple, beech, birch, ash and red oak predominating on the lower slopes and spruce in solid stands on the upper slopes and mountain tops. So heavy was this spruce stand that the U. S. Spruce Lumber Company built a railroad to the mountain top for its removal, though enough was left to insure a second crop, with protection. Much virgin timber was left, especially on the White Top tract #2b. This timber is of good quality and will be a valuable asset to the citizens of this section in the further development of grazing.

Reproduction is exceptionally well established through out both tracts, there being an average of 14 saplings of merchantable species per acre between 6 and 10" d. b. h. with a proportional amount of smaller stuff coming.

Valuation

Since the southern exposures have a distinct grazing value and the northern exposures a marked potential value for grazing tables are given showing both the grazing and timber growing values.

While the average stand of timber on both tracts is 1,367 feet per acre it should be borne in mind that this timber is not evenly distributed over the entire area but is found principally in pockets and on the virgin subtype as shown on the type map, the heaviest stands being on the most accessible part of the White Top tract #2b all within 4 miles of a railroad station (Konnarock, Va.) by good wagon roads as outlets.

Table #1:- Areas of types and subtypes and value per acre of land and young growth:

Type and subtype	Area subtypes	Area types	Value per Acre	Value per acre for grazing
Cove		482	$6.00	$10.00
Virgin	221			
Culled	65			
Cutover	196			
Lower slope		1378	4.00	6.00
Virgin	761			
Culled	217			
Cut over	400			
Upper slope		49	3.00	4.00
Virgin	49			
Spruce		735	4.00	3.00
Virgin	153			
Cut over	582			
Fields		2	25.00	25.00
Grazing	2			
Total area	2646	2646		
Average value per acre,			4.36	5.87

Lands of Douglas Land C
WHITE TOP UNIT - #2b,2c.

Table 2:- Stand per acre of species and products and value per acre of tract:

Species and products	Stand per acre		Stumpage value per unit	Stumpage value per acre
Chestnut	25	bd.ft.	$2.00	$ 005
mixed oaks	22	"	2.00	.04
beech	198	"	2.00	.40
birch	235	"	2.00	.47
maple	214	"	2.00	.43
poplar & bass wood	14	"	3.00	.04
buckeye	65	"	2.00	.13
Spruce	520	"	0.00	.00
others	74	"	1.00	.07
Total	1,367	"		1.63
Chestnut extract wood	.21		.00	.00

Average value per acre of sawtimber,	$1.63
" " " " " other prod.	.00
" " " " " land,	4.36
" " " " " imp.	.00
Total " " " " " tract,	$5.99*

*To allow the grazing value for the soil will make this total value $7~~.80.~~ .50

Recommendations

It is recommended (a) that this tract be purchase at the price of $ 4.00 peracre, with timber reservations on fifty acres, the acreage to be determined by a horizontal survey, to be made by the United States; (b) that those portions of the tract, the titles to which shall be approved by the Attorney General, be acquired by purchase, and that those portions of the titles to which shall not be approved by the Attorney General, be acquired by a suit of condemnation, the vendors being bound in the purchase contract to testify to the same value for the portions conveyed through condemnation poroceedings as they expect for the portions conveyed through purchase.

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