The Relationship Between Engelmann Spruce Radial Growth and Spruce Beetle Infestation in Northwestern Colorado

Alexandra Todorovic-Jones

University of Colorado Boulder

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The Relationship Between Engelmann Spruce Radial Growth and Spruce Beetle Infestation in Northwestern Colorado

By:
Alexandra Todorovic-Jones
University of Colorado Boulder

A thesis submitted to the
University of Colorado at Boulder
in partial fulfillment
of the requirements to receive
Honors designation in
Environmental Studies
April 2013

Thesis Advisors:

Dale Miller, Environmental Studies
Mark Williams, Ph. D, Geography
Thomas Veblen, Ph. D, Geography, Committee Chair

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I dedicate this thesis to Sarah Hart who supervised my entire research process and without whom this thesis could not be possible.
Preface

Most undergraduates take a lab course, either by force or by choice. During my first semester in Boulder, Colorado, I was forced to take a lab and choose an environmental systems course about climate and vegetation. While I had a strong background in environmental advocacy, I did not have any experience with environmental science. Throughout that course, my teacher, Teresa Chapman, bore my interest in both environmental science and geography. Teresa, the most energizing teacher I have had in my college career, encouraged students to learn in and outside the classroom. Once a week, she encouraged us to implement our geographic knowledge on our local environment, to learn about the systems around us. Teresa also emailed the class research opportunities, urging us to apply our soft skills and become research assistants. I can never thank Teresa enough for her continued encouragement and motivation.

Teresa’s email incited me to apply for a research position with Sarah Hart, a PhD candidate in the Geography department. I had no idea what I was getting myself into and arrived to the interview suited up. When I met Sarah, I felt foolish; I was wearing heels and an A-line skirt to an interview for a field position. My lack of knowledge about what the position required was obvious. Even though, Sarah could tell within one glance that I had no in field or backcountry experience, she took a chance and gave me the research position.
During that summer I worked in Western Colorado with Sarah. I learned how to complete the physical labor, coring trees and recording data, but I also learned something more abstract. The long hikes gave me time and space to relax, but more importantly gave me a chance to fully appreciate our forests. As a New Englander, sometimes the ocean is all I had to experience the environment in its bare form. However, in Grand Mesa I learned how to welcome the smell of forests, the taste of sun-soaked sweat, and the sound of my boots on the trail. Being in the forest also gave me space to think about who I was and what that really meant. Without that time spent in Grand Mesa, I may have never fully grasped what was most important to me. Through that experience, I learned that I need nature. I need it as a concept, as an escape, as a clarification of who I am.

Sarah did more than give me a chance to learn about myself, she also gave me advice on what to do next. As an undergraduate, you are always seeking to find your own path, but sometimes you need affirmation that what you are doing is right. Sarah gave me that affirmation, not by telling me I was right, but by describing her own career path. Sarah has complete confidence about who she is and what she does, and that assurance gave me the confidence to embark on my own path and to trust that it will work.

I want to also thank Dr. Thomas Veblen, Sarah’s mentor, for giving me the opportunity to work under his wing and for sponsoring my thesis. In Dr. Veblen, I found a personable mentor who offered advise on both my current work and my future career path. Even when he was busy traveling on another continent, he gave me the time and advice I needed. In addition, I want to thank Dr. Mark Williams for his oversight on my
thesis. Even though we never met in person to talk about my thesis, he was always available to send some advice my way. Lastly, I want to thank, my professor and advisor, Dale Miller for his weekly oversight in and out of class. Professor Miller’s supervision and encouragement gave me motivation to complete drafts on time and the confidence to finish my project. This piece of literature is a summation of my academic experiences and my brilliant advisors and teachers, without whom I would not be where I am today.
Abstract

This research examines relationships between annual radial growth and the status of spruce beetle (*Dendroctonus rufipennis*) outbreak in Engelmann spruce (*Picea engelmannii*). Spruce beetle has affected over 392,000 hectares from 1998-2011 in Colorado and Wyoming’s subalpine forests, as well as extensive areas in other western states. This research aims to help forest managers, academic researchers, and policy makers determine better management techniques for our national forests. I examined ecological data from tree samples in 18 forest stands in Western Colorado. After analyzing data from tree samples, the radial growth rates between unaffected and affected trees were compared. Results of this study show that affected trees are more likely to have faster overall radial growth rates than unaffected trees. However, radial growth rates from the 5 or 10 years of outermost rings representing growth rates immediately prior to death or attack by spruce beetle did not significantly differ. More research is needed to evaluate whether faster growing spruce invest less in tree defense mechanisms and are therefore more likely to get attacked.
Introduction

Currently, an outbreak of spruce beetle, which attacks primarily Engelmann spruce, has affected over 392,000 hectares from 1998-2011 in Colorado and Wyoming’s subalpine forests, as well as extensive areas in other western states (Ciesla, 2012). Indeed, spruce beetle infestation of spruce-fir forests is believed by many land managers to be the next catastrophic event to affect Colorado’s forests (Chase, 2008).

While the spruce beetle is the most destructive bark beetle in spruce forests throughout North America, few in the general public witness the widespread mortality because Engelmann Spruce is mostly found on remote high elevation slopes (Ciesla, 2012). Due to Engelmann Spruce’s importance and prominence in subalpine forests’ ecological systems, a greater understanding of spruce beetle disturbance is necessary for managers to conserve and maintain forest health. My project aims to understand the relationship between annual radial growth and the spruce beetle (*Dendroctonus rufipennis*) infestation in Engelmann spruce (*Picea engelmannii*). Specifically, I seek to understand if radial growth, an indicator of tree vigor, is related to the likelihood of infestation by spruce beetle. My hypothesis is that trees with slower growth rates are more likely to be infested by the beetle.

This research also supplements the ongoing work of my faculty advisor, Dr. Thomas Veblen, in studying Colorado’s forest ecology and its natural and anthropological disturbances. Dr. Veblen is now working on a project, funded by the National Science Foundation on spruce beetle outbreak in Colorado. My research provides a valuable foundation for this research program.
During the summer of 2012, I assisted his Ph.D. student, Sarah Hart, with fieldwork and collected the spruce tree core samples that were the basis of my thesis research. Under Dr. Veblen’s consultation and Hart’s continued supervision, I worked in Dr. Veblen’s Biogeography lab, organizing and analyzing tree core ring data.

Ultimately, the larger goal of this research was to provide useful information to forest scientists and managers. In addition to that overarching goal, I had a personal goal of developing my skills as a research scientist. Aiding Dr. Veblen in his research project, will help prepare myself for a future career in environmental policy and management.
Background

Engelmann spruce grows in high elevation forests, typically co-dominant with subalpine fir (*Abies lasiocarpa*). In Colorado, spruce-fir is the most extensive forest cover type (Schrupp et al. 2000). Within these forests, spruce beetle outbreaks and wildfire are the two most important disturbances (Baker and Veblen 1990).

During endemic conditions, spruce beetles attack the underside of dead or fallen trees first, which are generally the result of logging or windblown trees. Outbreak conditions occur as spruce beetles begin to attack apparently healthy trees. The spruce beetle bores into the bark of a tree and creates a larval gallery for its eggs (Figure 1).

![Figure 1: A spruce beetle larval gallery found in an Engelmann Spruce tree (Ciesela & Holston 2012)](image_url)

Extensive beetle colonization typically results in the mortality of the tree. While insect outbreak is a part of natural forest processes, current levels of spruce beetle outbreak are reaching wide-spread and epidemic levels (Strebig, 2013). Warmer temperatures, such as we are experiencing now, are known to favor bark beetle population dynamics (Bentz, 2010). However, far less is known about how warming temperatures may affect the susceptibility of trees to beetle infestation. In some bark beetle outbreaks, the radial growth, an indicator of tree vigor, has been related to susceptibility of trees to spruce
beetle. Since the annual growth of a tree varies with disturbances and climatic changes, my research helps determine if there is a specific relationship between spruce beetle outbreak and radial growth in Engelmann spruce (Fritts, 1976).

Previous research has examined the effects of climate variability and disturbance on radial growth of Engelmann spruce. Research shows that in some locations temperature variability and instances of drought negatively correlate with Engelmann spruce’s radial growth (Villalba et al 1994; Zhang et al, 1999; Woodhouse et al, 2011). At relative dry sites, during July and August, Engelmann spruce’s average radial growth decreases due to the stress of high temperatures (Villalba et al, 1994). Disturbances may cause either increases or decreases in radial growth. Decreases occur when trees are damaged by the disturbance (Ryerson et al, 2003). Increases occur when a proportion of the trees are not affected by the disturbance, while others are killed. The death of part of the stand causes an increase in nutrients, light, and water, which can result in dramatic and sustained increases in tree radial growth referred to as “growth releases” (Veblen et al, 1991).

The radial growth of trees may also be an important predictor of susceptibility to disease and insect infestation. A study in 1928 noted a spruce beetle outbreak on slow growing trees in Alaska (Watson, 1928). Later, in 1985, scientists followed up with a similar study in Alaska researching radial growth in relation to spruce beetle outbreak (Hard, 1985). These preexisting studies have only been conducted in Alaska and have employed very different research methods. My research focuses on the spruce beetle outbreak happening in Colorado and aims to use modern dendroecological research methods.
Biological and Societal Importance

The spruce beetle is reaching epidemic levels, with 183,000 new affected hectares detected within in 2012 (Strebig, 2012). This puts the total affected acreage since 1996 to nearly 1 million hectares (Strebig, 2012). Forest scientists and managers believe that spruce beetle progression (shown in Figure 2) is symptomatic of Colorado’s wide spread old growth and increasingly vulnerable forests (Chase, 2007).

Spruce Beetle Progression in Southwestern Colorado, 2001 – 2011


Land managers and policy makers are concerned about societal vulnerability to the consequences of bark beetle outbreaks for a number of reasons including potential
impacts on wildfire potential, tree-fall hazard for people and infrastructure, watershed function and water resources. As a result, the current mountain pine beetle and spruce beetle outbreaks in the Rocky Mountain region have triggered large expenditures on vegetation treatments and other measures to mitigate potential impacts from massive tree mortality caused by bark beetles. Nevertheless, the actual impacts of insect-caused tree mortality on these hazards and resources are much debated and in need of further research (Romme et al. 2006; Hicke et al. 2012).

Another concern of forest managers is that as climatic warming continues spruce beetle outbreak will become more widespread and severe (Berg et al, 2006). Drought stresses forest stands, leaving the forests more vulnerable to outbreak (Berg et al, 2006) (DeRose & Long, 2012). Engelmann spruce trees are vital for the resilience of subalpine ecosystems and are useful for a variety of societal purposes. Spruce trees are often used for constructional material for homes and musical instruments. The trees are also used for Christmas trees, pulp, and for other lumber purposes. Secondly, spruce trees help maintain the stability of ecosystems in the Rocky Mountains and in other North American forests (USDA, 2013). My project aims to help forest managers and policy makers better understand the relationship between spruce beetle and growth rates of Engelmann spruce. If a slower growth rate leaves a tree more susceptible to insect outbreaks and mortality, then managers and scientists should target older forests and study what causes slower tree growth.

Retrospective studies in Colorado have shown that past spruce beetle outbreaks such as the extensive 1940s outbreak that killed most of the spruce timber volume in White River National Forest have not resulted in increased rates of wildfire (Bebi et al.
Likewise, the spruce beetle outbreak that began in the late 1990s in White River and Routt National Forests did not result in exceptionally high fire severities or extents of fire spread in 2002 (Bigler et al. 2005; Kulakowski and Veblen 2007). Similarly, in Utah and other areas of the U.S. West both observational and modeling studies have concluded that catastrophic fires are not an inevitable consequence of bark beetle outbreaks (DeRose and Long 2009; Hicke et al. 2012). Despite the conclusions of these peer-reviewed studies that beetle-caused tree mortality is not a dominant influence on wildfire activity in comparison with the more obvious influence of exceptionally warm-dry weather, the public and land managers remain concerned that bark beetle outbreaks have elevated wildfire potential. A common view among some forest managers is that spruce-fir stands are unnaturally dense due to fire suppression (USDA 2006) but the effectiveness of 20th century fire suppression on the natural fire regimes of spruce-fir forests where fire return intervals were long, usually at least 100 to over 300 years has been questioned (Romme et al. 2006). High tree density is a natural characteristic of spruce-fir forests and should not be interpreted as being either unprecedented or attributable to fire suppression policy. Nevertheless, high stand densities as well as other factors such as climate change do affect radial growth rates of Engelmann spruce that are hypothesized to affect susceptibility to spruce beetle attack. Thus, this study aims to provide land managers with a better understanding of the relationship of tree growth rate to susceptibility of Engelmann spruce to spruce beetle-caused mortality which in turn may improve our ability to plan for and mitigate the effects of spruce beetle outbreaks.
Methods

During the summer of 2012, I helped Ph. D. student, Sarah Hart collect the tree core samples and plot data that I used for my research. That experience familiarized me with the species’ characteristics and allowed me to get a general background on forest ecology in Colorado. At the end of the summer, I worked in the Biogeography lab, mounting, sanding, and analyzing tree cores. Since my research built upon the same methods and samples I had used during the summer field season, I was prepared to complete this research project.

Study Area

The study area is located in Western Colorado. All of the sample stands were spruce-fir located in Grand Mesa National Forest, which is managed by the United States Forest Service. These forests total 346,555 hectares of land and are located near Grand Junction, Colorado. Engelmann spruce-subalpine fir cover usually occurs at elevations from 10,000 to 12,000 feet and is in the subalpine climatic zone (30-40 inches precipitation annuals, 50-70 frost free days, 30-40°F mean annual air temperature) (US Forest Service, 2006). Unlike other parts of Colorado, Grand Mesa National Forest experiences its highest precipitation rates from July-August (Kulakowski & Veblen, 2006). The two major tree species in Grand Mesa National Forest’s subalpine forest are
Engelmann spruce and Subalpine fir. Engelmann spruce-Subalpine fir cover composes 26% (93,300 acres) of the forest and Aspen cover composes an equal 26% (shown in figure 3) (US Forest Service, 2006).

![Figure 3: Map of Current Vegetation in Grand Mesa Geographic Area. Red line is Grand Mesa Geographic Area. Green Line is National Forest Forest Boundary. (US Forest Service. 2006. Chapter 2. Existing Vegetation—Forest Scale. Existing Vegetation 2: 1-21.)](image)

The greater amount of spruce-fir cover is not species-mixed with aspen cover, since aspen usually occurs at a lower elevation. Most of the spruce-fir cover is between 100-160 years old (US Forest Service, 2006).
The samples sites were previously studied by Kulakowski and Veblen and are known to have established after an 1879 fire. Among the sample sites, the last known spruce beetle outbreak before the fire was in 1849. The extent of fire in comparison to areas of spruce–fir stands, and the 1849 spruce beetle outbreak is shown in Figure 4 below.

Figure 4: A map that shows the extent of the fire in comparison to the extent of spruce-fir zones. Locations of study sites for sampling susceptibility to SB across Grand Mesa National Forest. Spruce beetle activity identified in USFS aerial detection surveys over the time period from 1998-2011 is shown in dark gray. A 30 m resolution grid of spruce-fir cover obtained from the Landfire Existing Vegetation Type dataset is shown in light gray. Stippled areas indicate burns dating from ca. 1879 mapped by Sudworth in 1898 and later digitized by Bebi et al. (2003). The rectangle in the inset box indicates the location of the study area. Shaded areas within the inset indicate National Forests.
Sample Sites and Field Methods

In the summer of 2012, tree-ring samples of Engelmann spruce were collected at 18 sites across Grand Mesa National Forest. All the sample sites, ranging from 39.144 to 39.031 latitude to -107.64879 to -108.17138 longitude, are located in Grand Mesa National Forest (latitude and longitude of specific sites shown in Table 1). Each site, according to GIS data, we believe to have regenerated after an 1879 fire, which was mapped by the Sudworth (1900) and later digitized by Bebi et al. (2003). We assume that following the fire (within 5 years) there was a pulse of tree regeneration. Since, Engelmann spruce trees have thin bark, shallow roots, and low branches, the trees are very susceptible to fire; there are likely few trees from my sample set that survived the 1879 fire. Engelmann spruce forests also tend to experience high intensity crown fires, which burn most of the trees within the stands. All the sample sites, ranging from 39.144 to 39.031 latitude to -107.64879 to -108.17138 longitude, are located in Grand Mesa National Forest (latitude and longitude of specific sites shown in Table 1).

Table 1: Names of sample sites and descriptive information. “Affected” means affected by the current (i.e. early 2000s) spruce beetle outbreak. “Control” means unaffected by the current (i.e. early 2000s) spruce beetle outbreak.

<table>
<thead>
<tr>
<th>Name of Site and Control/Affected Designation</th>
<th>Latitude</th>
<th>Longitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bull Basin Affected</td>
<td>39.0879961</td>
<td>-108.0000746</td>
</tr>
<tr>
<td>Location</td>
<td>Latitude</td>
<td>Longitude</td>
</tr>
<tr>
<td>----------------------------------</td>
<td>-------------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>Bull Basin Affected 2</td>
<td>39.08550694</td>
<td>-107.9930786</td>
</tr>
<tr>
<td>Bull Basin Control</td>
<td>39.08926194</td>
<td>-108.0033008</td>
</tr>
<tr>
<td>Bull Basic Control 2</td>
<td>39.08590917</td>
<td>-107.9922725</td>
</tr>
<tr>
<td>Buzzard Park Affected</td>
<td>39.14280833</td>
<td>-107.6508778</td>
</tr>
<tr>
<td>Buzzard Park Affected 2</td>
<td>39.14129444</td>
<td>-107.6526139</td>
</tr>
<tr>
<td>Buzzard Park Control</td>
<td>39.14426111</td>
<td>-107.6487861</td>
</tr>
<tr>
<td>Buzzard Park Control 2</td>
<td>39.14089167</td>
<td>-107.6555444</td>
</tr>
<tr>
<td>East West Bench Trail Affected</td>
<td>39.05441643</td>
<td>-108.129252</td>
</tr>
<tr>
<td>East West Bench Trail Affected 2</td>
<td>39.04468361</td>
<td>-108.1197158</td>
</tr>
<tr>
<td>East West Bench Trail Control</td>
<td>39.0524748</td>
<td>-108.1312487</td>
</tr>
<tr>
<td>East West Bench Trail Control 2</td>
<td>39.04494444</td>
<td>-108.1207475</td>
</tr>
<tr>
<td>Last Chance Affected</td>
<td>39.14426111</td>
<td>-107.6487861</td>
</tr>
<tr>
<td>Last Chance Affected 2</td>
<td>39.0585148</td>
<td>-107.7829191</td>
</tr>
<tr>
<td>Last Chance Control</td>
<td>39.04596389</td>
<td>-107.78855944</td>
</tr>
<tr>
<td>Last Chance Control 2</td>
<td>39.04714072</td>
<td>-107.7896384</td>
</tr>
<tr>
<td>West West Bench Trail Affected</td>
<td>39.03808995</td>
<td>-108.171384</td>
</tr>
<tr>
<td>West West Bench Trail Control</td>
<td>39.03813382</td>
<td>-108.171336</td>
</tr>
</tbody>
</table>

The sample plots are located in 4 different locations within Grand Mesa National Forest: Bull Basin, Buzzard Park, East West Bench Last Chance, and West Bench Trails. The elevations of the sample sites ranged from 2027-3188 meters. Since, the forest type in Grand Mesa National Forest is generally homogenous, we did not have to control for mixed species composition. At each site, data was collected in two plots of ongoing (from
2000-2012) spruce beetle outbreak and two plots of zero to low spruce beetle attack (some of the sites were collected by my mentor and Ph. D candidate, Sarah Hart, before I started research).

Engelmann Spruce trees were easily identifiable from other trees in the sites because they have distinctive gray-brown scales and evergreen needles (Colorado State University, 2013). Most other trees in the site were Subalpine Fir, which has rounder needles and bark that forms horizontal lines (Colorado State University, 2013). At each site, we set a 20 by 20 meter transect and recorded whether the site was an affected site (a plot of trees under attack by spruce beetles, including trees that have already died from spruce beetle) or a control site (a plot of zero to low spruce beetle outbreak). At each plot, we used an increment borer to drill into the trees (ca. 0.40 m above the ground) and collected tree cores from 20 spruce trees within that plot. Each site had at one pair plot (meaning each pair had one unaffected plot and one affected plot), which was close in proximity. Some of the trees were too rotten to be collected from the data point and therefore were omitted from data collection. The trees that were too rotten most likely had died much earlier than c. 2010 because the tree ring was no longer in tact. However, some of the standing dead trees, rotten or not, did not show signs of having been killed by spruce beetle, i.e. lack of spruce beetle galleries. For the paired plots within the site, one of the plots was affected and the other plot was unaffected. While coring the trees in the plot, we collected data about the plot (elevation, latitude, longitude, slope, and position) as well as data about each tree in the plot (tree ID, species, status as live or dead (Table 2), diameter at breast height, decay class (Table 3), crown height, and distance away from spruce beetle outbreak (Tables 4). All of the tree cores were placed in straws, sealed with
tape or staples, and given a unique tree ID. Following the collection of the field data, tree cores were brought back to the University of Colorado Biogeography Lab.

Table 2: Living and Affected Level Status Assigned

<table>
<thead>
<tr>
<th>Status</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>0</td>
<td>Dead and Unaffected Tree</td>
</tr>
<tr>
<td>1</td>
<td>Live and unaffected Tree</td>
</tr>
<tr>
<td>2</td>
<td>Dead and Spruce Beetle Affected Tree</td>
</tr>
<tr>
<td>3</td>
<td>Live and Spruce Beetle Affected Tree</td>
</tr>
</tbody>
</table>

Table 3: Decay Classes Assigned (following Mast & Veblen, 1994)

<table>
<thead>
<tr>
<th>Decay Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Needles, twigs, and branches present.</td>
</tr>
<tr>
<td>B</td>
<td>Twigs and branches present. No needles.</td>
</tr>
<tr>
<td>C</td>
<td>Branches present. No needles or twigs.</td>
</tr>
<tr>
<td>D</td>
<td>No needles, twigs, or branches remain.</td>
</tr>
</tbody>
</table>

Table 4: Crown Height Assigned

<table>
<thead>
<tr>
<th>Crown Height</th>
<th>Description</th>
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<tr>
<td>1</td>
<td>Dominant</td>
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<tr>
<td>2</td>
<td>Intermediate</td>
</tr>
<tr>
<td>3</td>
<td>Suppressed</td>
</tr>
</tbody>
</table>
Dendrochronological Analyses

After the collecting all the tree cores within the field, we started organizing and mounting the collected tree core samples in the lab. I first started gluing samples onto wooden mounts. I also labeled the corresponding unique tree ID onto the wooden mount. Then, I put clips on the cores to hold the tree cores in place and prevent the cores from bending on the wooden mount, while the tree cores dried. This is important because the fresh samples of the tree cores are moist when bored and inserted in plastic straws during the fieldwork season. After 36 hours of drying, the tree cores samples were sanded through progressively higher grits, up to 600 grit. This degree of fine sanding allowed for effective analysis in the lab and allowed me to measure growth patterns (Stokes and Smiley 1968) (Figure 5).

Figure 5: Tree Cores Mounted

Once I got all the tree cores mounted, dried and sanded, I transported them to the lab to measure the annual radial growth patterns. The ring widths of each individual
mounted tree core were measured using a Velmex stage equipped with a light microscope in conjunction with the dendrochronological program, Medir, which records the width of each annual tree ring. I calibrated the program with the microscope points at the pith of the tree core sample. From there, I slowly moved the sample until a ring was reached and then I noted the width distance in the computer (pictured in figure 5). After multiple repetitions, I reached the bark and completed the entry for the sample on the computer system (Speer, 2010) (Figure 6).

Figure 6: A picture of the tree measurement process through a light microscope. A tree ring is easily identifiable by looking at the middle of the cross.

Statistical Analyses

After I finished cataloging the radial growth for all the trees, I organized the spruce beetle outbreak data that correlated to each tree, separating spruce beetle affected trees from spruce beetle unaffected trees. To evaluate data, I used the open source,
statistical software, R. The package dplR, was used to evaluate my tree cores, because it converts Medir files to easily read statistical files. In the dplR package, I compared radial growth patterns of trees, affected versus unaffected by spruce beetle, in order to determine if radial growth is related to susceptibility to outbreak. After getting the raw results in R, I then limited the comparison of unaffected and affected trees by separating all the tree cores into two categories, young and old. Tree cores were categorized as young trees if they were less than 100 years old. Tree cores were categorized as old trees if were a 100 years old or greater. I separated trees in age groups, because I believe that the trees that are younger than 100 years did not regenerate in the initial pulse following the fire. Thus, they would have established beneath a forest canopy and probably grown at slower rates than the initial colonists of the open site created by the fire. Some of the trees were older than expected. Since we assumed the trees regenerated within 5 years after the 1879 fire and that all trees died during that fire, the oldest tree core should have been c. 122 years old at coring height (assuming c. 5 years to reach coring height). Whenever a tree was older than the age expected for the post-fire cohort that established after the 1879 fire, I took it out of my data set. After separating for age, I also separated samples into living and dead trees.

In dplR, I used a one-way t-test and a two-tailed t-test to determine the statistical significance between unaffected and affected tree group’s means. My null hypothesis is that radial growth is not greater in unaffected Engelmann spruce trees than in affected Engelmann spruce trees. This allowed me to see if the means were the same or different, in order to see if there was a significant relationship. Lastly, I constructed boxplots in R, so I could visually evaluate my data.
Results

A Relationship Between Fast Radial Growth and Spruce Beetle Affected Trees

At the 18 sample sites, I compared the radial growth rates of trees affected by and unaffected by spruce beetle attack. All of the sample trees were assumed to have started growing within 5 years after the 1879-year fire in Grand Mesa National Forest. Growth rates were recorded from every year since the tree started growth, at the pith, to the outermost ring of the tree at the bark. Considering all sampled trees regardless of age or status as live or dead (all class of trees in Table 2 included), the mean growth rate over the full life span for the affected trees is 0.136 mm per year. The mean growth rate for the unaffected trees is 0.091 mm per year. The mean growth rate of affected and unaffected trees is significantly different (p=0.05). Across the 18 plots in Grand Mesa, affected trees grew faster than unaffected trees (Figure 7).
Figure 7: The relationship rates between radial growth and spruce beetle infestation. Mean of affected trees = 0.136 mm and mean of unaffected trees = 0.091 mm. I included all sample spruce, unless they were older than the 1879 fire. This graph includes all 4 categories of trees listed in Table 2, i.e. dead affected trees, dead unaffected trees, live affected trees, and live unaffected trees. Sample size for affected is 48 trees and for unaffected trees is 147.

However when I examined the growth rates from the outermost 5 and 10 rings including both living and dead trees and including both young and old trees. For 5 and 10 years of growth prior to the outermost ring of the tree there was no significant
difference between unaffected and affected tree’s radial growth rates. For the 10 years of
growth prior to the outermost ring of the tree, the mean growth rate for the affected trees
is 0.086 mm per year. The mean growth rate for the unaffected trees is 0.055 mm per
year. The mean growth rate of affected and unaffected trees was not significantly
different (p>0.05) when limited the comparison to living affected and unaffected trees for
death and affected sites. For the outermost 5 years of growth, the mean growth rate for
the affected trees is 0.091 mm per year. The mean growth rate for the unaffected trees is
0.058 mm per year. The mean growth rate of affected and unaffected trees was not
significantly different (p>0.05) when limited the comparison for unaffected and affected
sites by separating trees for dead or live, young or old, and or just affected sites. Across
the 18 plots in Grand Mesa, affected trees did not grow faster than unaffected trees 10
years of growth prior to the outermost ring of the tree.

After analyzing all of the affected and unaffected trees, we limited the comparison
for unaffected and affected sites by separating trees for age of tree by comparing growth
rates of trees within age classes of ≥ 100 years versus < 100 years old. These categories
included both living and dead trees. The mean growth rate for the young affected trees is
0.15 mm per year. The mean growth rate for the young unaffected trees is 0.09 mm per
year. The mean growth rate of young affected and unaffected trees is significantly
different (p=0.05). Young affected trees grew significantly faster than young unaffected
trees at the 18 different sites in Grand Mesa National Forest. The mean growth rate for
the old affected trees is 0.131 mm per year. The mean growth rate for the old unaffected
trees is 0.091 mm per year. The mean growth rate of old affected and unaffected trees is
significantly different (p=0.05). Old affected trees grew significantly faster than old unaffected trees at the 18 different sites in Grand Mesa National Forest (Figure 8).

![The Relationship Between Radial Growth and Spruce Beetle Infestation (Controlling for Age)](image)

Figure 8: The relationship rates between radial growth (over the full life span of each tree) and infestation in Grand Mesa National Forest after limiting the comparison of unaffected and affected trees by separating for young verse old. The mean for young affected trees was 0.15 mm, young unaffected trees was 0.09 mm, old affected trees was 0.131 mm, and old unaffected trees 0.091 mm. Sample size for young affected is 13 trees, for young unaffected is 32 trees, for old affected is 35, and for old unaffected trees is 115.
After I separated my data into 4 classes of young/dead, young/live, old/dead, and old/alive trees, we limited the comparison of unaffected and affected trees by separating dead trees from live trees. The mean growth rate for the dead affected trees is 0.139 mm per year. The mean growth rate for the dead unaffected trees is 0.062 mm per year. The mean growth rate of dead affected and unaffected trees is significantly different (p=0.05). Dead affected trees grew significantly faster than dead unaffected trees at the 18 different sites in Grand Mesa National Forest. The mean growth rate for the live affected trees is 0.137 mm per year. The mean growth rate for the live unaffected trees is 0.04 mm per year. The mean growth rate of live affected and unaffected trees is significantly different (p=0.05). Live affected trees grew significantly faster than live unaffected trees at the 18 different sites in Grand Mesa National Forest (Figure 9).
Figure 9: Growth rates (full life span of the tree) of unaffected and affected tree for live versus dead trees. Trees of all ages are included. The mean growth rate for dead affected was 0.139 mm, dead unaffected was 0.062 mm, live affected was 0.137 mm, and live unaffected was 0.04 mm. Sample size for dead affected is 40 trees, for dead unaffected is 18 trees, for live affected is 8, and for live unaffected trees is 129.

Finally, we compared tree growth rates in plots affected by SB with plots not affected by SB outbreak. The affected sites still have unaffected trees within the plots, but are mostly affected trees. We separated the unaffected from the affected trees and then looked at radial growth rates. The mean growth rate for the affected trees is 0.136 mm per
year. The mean growth rate for the unaffected trees is 0.09 mm per year. The mean growth rate (for only affected sites) of affected and unaffected trees for only is significantly different (p=0.05). From only affected sites, affected trees still grew significantly faster than unaffected trees at the 18 different sites in Grand Mesa National Forest (Figure 10) (all t-test data shown in Table 5 below).

**The Relationship Between Radial Growth and Spruce Beetle Infestation Only Affected Sites**

![Box plot showing radial growth rates for affected and unaffected trees](chart.png)

Figure 10: The relationship rates between unaffected and affected trees' radial growth (full life span of the tree) in only affected sites. The mean growth rate for affected trees was 0.136 mm. The mean growth rate for unaffected trees was 0.09 mm. Sample size for affected is 39 trees and for unaffected trees is 36.
Table 5: T-Test Data from the original data set and controls (*= values are significant, highlighted yellow= not significant)

<table>
<thead>
<tr>
<th>Data Set</th>
<th>Affected Trees’ Mean in mm</th>
<th>Unaffected Trees’ Mean in mm</th>
<th>T value</th>
<th>Degrees of Freedom</th>
<th>P Value</th>
<th>95% Confidence Interval</th>
<th>P Value for Two Tailed T-test</th>
<th>95% Confidence Interval for Two Tailed T-Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Affected (n=48) vs. Unaffected (n=147) Trees *</td>
<td>0.136</td>
<td>0.091</td>
<td>5.883</td>
<td>83.617</td>
<td>8.048e-08</td>
<td>0.03 - 0.06</td>
<td>4.024e-08</td>
<td>0.032-Inf</td>
</tr>
<tr>
<td>Affected (n=48) vs. Unaffected (147) (10 Outermost Rings)*</td>
<td>0.086</td>
<td>0.055</td>
<td>3.154</td>
<td>63.423</td>
<td>0.002</td>
<td>0.011-0.051</td>
<td>0.001</td>
<td>0.015-Inf</td>
</tr>
<tr>
<td>Affected (n=48) vs. Unaffected (n=147) (5 Outermost Rings)</td>
<td>0.091</td>
<td>0.058</td>
<td>2.992</td>
<td>61.044</td>
<td>0.004</td>
<td>0.011-0.055</td>
<td>0.002</td>
<td>0.015-Inf</td>
</tr>
<tr>
<td>Young Trees (n=45) *</td>
<td>0.15</td>
<td>0.09</td>
<td>3.647</td>
<td>21.174</td>
<td>0.002</td>
<td>0.026-0.094</td>
<td>0.001</td>
<td>0.032-Inf</td>
</tr>
<tr>
<td>Young Trees-10 Outermost Rings (n=45)*</td>
<td>0.107</td>
<td>0.05</td>
<td>2.501</td>
<td>14.137</td>
<td>0.025</td>
<td>0.008-0.106</td>
<td>0.013</td>
<td>0.017-Inf</td>
</tr>
<tr>
<td>Young Trees (5 Outermost Rings) (n=45) *</td>
<td>0.116</td>
<td>0.053</td>
<td>2.507</td>
<td>13.79</td>
<td>0.025</td>
<td>0.009-0.117</td>
<td>0.013</td>
<td>0.019-Inf</td>
</tr>
<tr>
<td>Old Trees (n=150) *</td>
<td>0.131</td>
<td>0.091</td>
<td>4.612</td>
<td>62.606</td>
<td>2.023e-05</td>
<td>0.022-0.056</td>
<td>1.012e-05</td>
<td>0.025-Inf</td>
</tr>
<tr>
<td>Old Trees (10 Outermost Rings) (n=150)*</td>
<td>0.078</td>
<td>0.056</td>
<td>2.1</td>
<td>50.755</td>
<td>0.041</td>
<td>0.001-0.042</td>
<td>0.02036</td>
<td>0.004-Inf</td>
</tr>
<tr>
<td>Old Trees (5 Outermost Rings)</td>
<td>0.081</td>
<td>0.06</td>
<td>1.899</td>
<td>48.104</td>
<td>0.064</td>
<td>0.001-0.046</td>
<td>0.032</td>
<td>0.003-Inf</td>
</tr>
<tr>
<td></td>
<td>(n=150)</td>
<td>(n=58)</td>
<td>(n=58)</td>
<td>(n=58)</td>
<td>(n=58)</td>
<td>(n=58)</td>
<td>(n=137)</td>
<td>(n=137)</td>
</tr>
<tr>
<td>--------------------------------------</td>
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<td>--------</td>
<td>--------</td>
<td>--------</td>
<td>---------</td>
<td>---------</td>
</tr>
<tr>
<td>Dead Trees*</td>
<td>0.139</td>
<td>0.062</td>
<td>8.703</td>
<td>54.488</td>
<td>6.834e-12</td>
<td>0.059-0.095</td>
<td>3.417e-12</td>
<td>0.062-Inf</td>
</tr>
<tr>
<td>Dead Trees-(10 Outermost Rings)</td>
<td>0.093</td>
<td>0.025</td>
<td>6.142</td>
<td>47.111</td>
<td>1.628e-07</td>
<td>0.046-0.096</td>
<td>8.141e-08</td>
<td>0.049-Inf</td>
</tr>
<tr>
<td>Dead Trees (5 Outermost Rings)</td>
<td>0.134</td>
<td>0.094</td>
<td>3.413</td>
<td>9.253</td>
<td>0.007</td>
<td>0.014-0.067</td>
<td>0.007</td>
<td>0.014-Inf</td>
</tr>
<tr>
<td>Live Trees (10 Outermost Rings)</td>
<td>0.067</td>
<td>0.058</td>
<td>0.428</td>
<td>7.516</td>
<td>0.681</td>
<td>-0.041-0.059</td>
<td>0.34</td>
<td>-0.031-Inf</td>
</tr>
<tr>
<td>Live Trees (5 Outermost Rings)</td>
<td>0.075</td>
<td>0.061</td>
<td>0.493</td>
<td>7.309</td>
<td>0.637</td>
<td>-0.053-0.081</td>
<td>0.318</td>
<td>-0.04-Inf</td>
</tr>
<tr>
<td>Only Affected Sites</td>
<td>0.136</td>
<td>0.09</td>
<td>4.481</td>
<td>72.846</td>
<td>2.705e-05</td>
<td>0.026-0.067</td>
<td>1.353e-05</td>
<td>0.029-Inf</td>
</tr>
<tr>
<td>Only Affected Sites (10 Outermost Rings)</td>
<td>0.094</td>
<td>0.068</td>
<td>1.925</td>
<td>71.919</td>
<td>0.058</td>
<td>-0.001-0.054</td>
<td>0.029</td>
<td>0.003-Inf</td>
</tr>
<tr>
<td>Only Affected Sites (5 Outermost Rings)</td>
<td>0.101</td>
<td>0.072</td>
<td>1.849</td>
<td>70.654</td>
<td>0.06868</td>
<td>-0.002-0.059</td>
<td>0.034</td>
<td>0.003-Inf</td>
</tr>
</tbody>
</table>

The mean overall growth rates of the original set and each control case are significant, so we can reject the null hypothesis, that affected and unaffected trees have the same rate of radial growth. Affected trees had significantly faster growth rates than unaffected trees. However, the relationship between radial growth and infestation level
was not significant during the last 5 or 10 years of growth for our sample set. Since both affected and unaffected sites were intermixed between unaffected and affected trees, there was no significant relationship between radial growth and infestation level when we compared affected sites to unaffected sites.
Discussion

The results indicate that there is a likelihood that affected trees had faster mean growth rates over their full life spans than unaffected trees in Northwestern Colorado. Therefore, we can reject the null hypothesis that there is no relationship between the level of infestation and radial growth in the sample population. The results show that affected Engelmann spruce trees grow faster than unaffected Engelmann spruce trees in Northwestern Colorado. These results do not support my initial hypothesis that for all years of growth, affected trees would grow slower than unaffected trees.

One hypothesis to explain the association of greater spruce beetle infestation with more rapid radial tree growth is based on the greater susceptibility of larger Engelmann spruce trees to attack. In the same study area, larger diameter trees have been shown to be more likely to be attacked by spruce beetle (Hart et al. submitted m.s.). The association of increased spruce beetle attack with trees of larger size previously has been attributed mainly to the greater amount of bark for insulating beetle larvae against cold winter temperatures and the abundance of phloem to support large populations of the beetle (Schmid and Frye, 1977). For trees of the same age, higher mean radial rates result in larger tree size. However, in the current study even trees of different ages showed an association of spruce beetle attack with greater growth rate implying that the explanation is more complex than the traditional one emphasizing winter insulating effect of the bark and amount of food for larvae.
Another hypothesis is that unaffected trees grow slower than affected trees because they invest more resources into defense mechanisms. For example, conifers that have slow initial growth (i.e. the first 50 years) are likely to reach greater maximum ages (Bigler and Veblen 2009). In the case of mortality caused by spruce beetle, slowly growing trees may invest more resources into production of resin and resin canals than faster growing trees. Resin canals, the main method of defense for trees, are apparent in Pines, Spruces, Larches, and Douglas Firs (McBroom, 2013) (Figure 11).

![Resin Canals](http://www.faculty.sfasu.edu/mcbroommatth/Lectures/Wood_Science/Lab_2_Resin_Canal_Species.PDF)


Spruce beetles use pheromones attract other spruce beetles to attack host trees, and trees uses defense mechanisms such as resin and bark type to resist attack (Christiansen et al, 1987). Conifer defense against bark beetles is mediated primarily through resin flow, which can create a physical barrier to beetles and contains toxic terpenes and phenolic compounds (Raffa et al. 2008).
The amount and type of resin ducts or canals vary among different trees (Christiansen et al, 1987). The amount and type also vary due to the tree’s historical frequency of attack (Christiansen et al, 1987). Trees that are less exposed to beetles are less likely to have effective tree resin (Christiansen et al, 1987). In addition, tree resin requires large amounts of energy from trees in order to make the chemicals within the resin (Christiansen et al, 1987). Engelmann spruce trees use longitudinal and transverse resin canals to protect themselves from insect attacks (McBroom, 2013). In trees other than Engelmann spruce, such as ponderosa pines, the amount and type of resin defense, instead of radial growth, have shown to be the best model for the predictors of bark beetle-caused tree mortality (Kane & Kolb, 2010).

Previous research also shows that the amount of carbon in resin and likelihood of survival from a bark beetle attack are positively correlated (Kane & Kolb, 2010). Research has also shown that lodgepole pines with higher levels of monoterpenes in their resin tend to survive beetle attacks (Boone et al, 2011). Therefore the measurement of the level and chemical nature of monoterpenes in trees is important to research in relationship to the level of infestation.

There is also a relationship between levels of oleoresin pressure and flow rate of resin between trees that were attacked and trees that were not attacked by beetles (Mitton & Sturgeon, 1982). Mitton and Sturgeon show that beetles attack trees that are low in oleoresin pressure and flow (Mitton & Sturgeon, 1982). Since the trees with low oleoresin pressure are using less energy, those trees that were attacked most likely had a higher growth rate.
However there are several opposing studies which show relationships between slow radial growth and tree mortality, related to beetle attack and drought. As mentioned previously, a study in Alaska noted a spruce beetle outbreak on slow growing trees (Watson, 1928). In 1985, a similar study was conducted, which showed that spruce beetle attacked slowly growing (in rates recent to death) spruce trees (Hard, 1985). In addition, other research shows that western Balsam bark beetles were more likely to attack slow growing than fast growing subalpine fir (Bleiker et al, 2005). In drought-linked mortality studies, both spruce and fir were also more likely to die if they had lower growth rates during the 5 to 10 years immediately prior to the drought-inducing mortality event (Bigler et al 2007). Results may vary among studies because tree type, location, length of radial growth (i.e. growth early in the life history of the tree or growth immediately preceding death) measured and exposure to beetles are all factors which influence the relational aspects of an individual trees radial growth, level of infestation, and resin type.
Conclusion

In this study, there was a significant relationship between Engelmann spruce trees affected by spruce beetle and faster mean rates of radial growth measured over the full life span of the tree. This research finding may be due to an intervening variable, such as type or amount of resin production and other chemical defenses. While other studies have discerned somewhat different results, different tree species have different levels and toxicity of resin, which could possibly affect the relationship between radial growth and level of infestation.

Recommendations for Future Research

Future analyses of the dataset used in this study can resolve some of the uncertainties of the interpretation of the current results. For example, tree core samples can be stratified into 2 or 3 size classes to determine if the greater susceptibility to spruce beetle attack associated with growth rate is valid for small, medium and large diameter trees. In order to better understand Engelmann spruce forest management implications, more research must be done to evaluate the relationship between radial growth, resin amount and type, other Engelmann spruce defense mechanisms and level of infestation. Future research should evaluate the type of resin found in Engelmann spruce. If research finds that resin efficacy can be easily measured, then future studies should look at the amount and/or density of resin canals to evaluate their relationship to radial growth and level of infestation. In future studies, researchers should also examine the level of carbon and monoterpenes in resin canals of Engelmann spruce trees in order to accurately evaluate whether resin canals affect level of infestation. In conclusion, forest scientists
and managers must evaluate how tree defense mechanisms affect radial growth and level of infestation in order to better manage and conserve our subalpine forest systems.

Acknowledgements

I would like to acknowledge Sarah Hart and Jason Sauer for help in the field and lab. This research was supported by the National Science Foundation, the Undergraduate Research Opportunities Program, and the Howard Hughes Medical Institute.
Literature Review


APPENDIX A:

R Code for Affected vs. Unaffected Data

#LOAD DATA
library(dplR)

# READ in Control Data
ControlDataSet <- read.rwl("/Users/alexandratodorovic-jones/Documents/Tree Core Research/ControlDataIndividual.rwl", header=F);

#CHANGE END YEAR
end.year <- 2012 # can change this to match year of sampling
ControlDataSet.ts <- NULL

# create empty object to hold new data
for(i in 1:ncol(ControlDataSet)){
  ControlDataSet.ts <- cbind(ControlDataSet.ts, ts(na.omit(ControlDataSet[,i]), end=end.year))
}

# reset column names to that of original data set
colnames(ControlDataSet.ts) <- colnames(ControlDataSet)

# set row names to the years
rownames(ControlDataSet.ts) <- as.character(time(ControlDataSet.ts))

# plot segments
#seg.plot(ControlDataSet,main='Tree Core Ring Growth of Control Trees since 1850')

#stats
ControlDataSet.stats <- rw1.stats(ControlDataSet)

# Store the averages (col 5) from the stats variable
ControlAverage <- t(ControlDataSet.stats[5])

#setting up box plot
Cbox <- as.numeric(ControlAverage)

# READ in Affected Data
AffectedDataSet <- read.rwl("/Users/alexandratodorovic-jones/Documents/Tree Core Research/AffectedDataIndividual.rwl", header=F);

#CHANGE END YEAR
end.year <- 2012 # can change this to match year of sampling
AffectedDataSet.ts <- NULL

# create empty object to hold new data
for(i in 1:ncol(AffectedDataSet)) {
  AffectedDataSet.ts <- cbind(AffectedDataSet.ts, ts(na.omit(AffectedDataSet[,i]), end=end.year))
}

# cycle through dataset remove missing values and change the last year to the specified end year

colnames(AffectedDataSet.ts) <- colnames(AffectedDataSet)

# reset column names to that of orginal data set
rownames(AffectedDataSet.ts) <- as.character(time(AffectedDataSet.ts))  # set row names to the years

# stats
AffectedDataSet.stats <- rwl.stats(AffectedDataSet)
AffectedAverage <- t(AffectedDataSet.stats[5])

# setting up box plot
Abox <- as.numeric(AffectedAverage)

# boxplot data
png(filename="/Users/alexandratodorovic-jones/Documents/Tree Core Research/Individual.png", width=800, height = 800)
boxplot(Abox, Cbox, col=c("red", "blue"), names=c("Affected", "Unaffected"), main="The Relationship Between Radial Growth and Spruce Beetle Infestation", xlab="Status of Infestation", ylab="Radial Growth (in mm)", cex.axis=1.5, cex.main=1.5, cex.lab=1.5, cex.sub=1.5)
dev.off()

t.test(Abox, Cbox)
t.test(Abox, Cbox, alternative="greater")

###########################################################
############ READ in last 10 years #########################
###########################################################

ControlDataSetLength <- length(ControlDataSet.ts[,1])

# setting up boxplot control last 10 years

numYears <- 10
CSubsetData <- ControlDataSet.ts[(ControlDataSetLength-numYears):(ControlDataSetLength),]

Control10YRSAverage <- colMeans(CSubsetData)
C10box <- as.numeric(Control10YRSAverage)

# repeat affected last 10 years

AffectedSetLength <- length(AffectedDataSet.ts[,1])

ASubsetData <- AffectedDataSet.ts[(AffectedSetLength-numYears):(AffectedSetLength),]

Affected10YRSAverage <- colMeans(ASubsetData)
A10box <- as.numeric(Affected10YRSAverage)

png(filename="/Users/alexandratodorovic-jones/Documents/Tree Core Research/Past10Years.png", width=800, height = 800)
Past10Box <- boxplot(A10box, C10box, col=c("red", "blue"), names=c("Affected", "Control"),
main="The Relationship Between Radial Growth and Spruce Beetle Infestation for the Past 10 Years", xlab="Status of Infestation", ylab="Radial Growth (in mm)", cex.axis=1.5, cex.main=1.5, cex.lab=1.5, cex.sub=1.5)
dev.off()

t.test(A10box, C10box)
t.test(A10box, C10box, alternative="greater")

###########################################################
############ READ in last 5 years ########################
###########################################################

ControlSetLength <- length(ControlDataSet.ts[,1])
#setting up boxplot control last 5 years
numYears <- 5
CSubsetData <- ControlDataSet.ts[(ControlSetLength-numYears):(ControlSetLength),]
Control5YRSAverage<- colMeans(CSubsetData)
C5box <- as.numeric(Control5YRSAverage)

AffectedSetLength <- length(AffectedDataSet.ts[,1])
ASubsetData <- AffectedDataSet.ts[(AffectedSetLength-numYears):(AffectedSetLength),]
Affected5YRSAverage<- colMeans(ASubsetData)
A5box <- as.numeric(Affected5YRSAverage)

png(filename="/Users/alexandratodorovic-jones/Documents/Tree Core Research/Past5Years.png",width=800, height = 800)
Past5Box <- boxplot(A5box, C5box, col=c("red","blue"),names=c("Affected", "Control"), main="The Relationship Between Radial Growth and Spruce Beetle Infestation for the Past 5 Years", xlab="Status of Infestation", ylab="Radial Growth (in mm)", cex.axis=1.5, cex.main=1.5, cex.lab=1.5, cex.sub=1.5)
dev.off()

t.test(A5box, C5box)
t.test(A5box, C5box, alternative="greater")
APPENDIX B:

R Code for Affected vs. Unaffected Data, Control for Age

#LOAD DATA
library(dplyR)

############### READ in Young Control Data ###############
YControlDataSet <- read.rwl("/Users/alexandratodorovic-jones/Documents/Tree Core Research/ControlDataIndividualYoung.rwl", header=F);

#CHANGE END YEAR
end.year <- 2012 # can change this to match year of sampling
YControlDataSet.ts <- NULL

for(i in 1:ncol(YControlDataSet))
{
  YControlDataSet.ts <- cbind(YControlDataSet.ts, ts(na.omit(YControlDataSet[,i]), end=end.year))
}

#reset column names to that of orginal data set
rownames(YControlDataSet.ts) <- as.character(time(YControlDataSet.ts)) # set row names to the years

#plot segments
#seg.plot(YControlDataSet/main='Tree Core Ring Growth of Control Trees since 1850')

#stats
YControlData.stats <- rwl.stats(YControlDataSet)

# Store the averages (col 5) from the stats variable
YControlAverage <- t(YControlData.stats[5])

#setting up box plot
YCbox <- as.numeric(YControlAverage)

############### READ in Young Affected Data ###############

#READ in Affected Data
YAffectedDataSet <- read.rwl("/Users/alexandratodorovic-jones/Documents/Tree Core Research/AffectedDataIndividualYoung.rwl", header=F);

end.year <- 2012 # can change this to match year of sampling
YAffectedDataSet.ts <- NULL # create empty object to hold new data

for(i in 1:ncol(YAffectedDataSet))
{
  YAffectedDataSet.ts <- cbind(YAffectedDataSet.ts, ts(na.omit(YAffectedDataSet[,i]),
                              end=end.year))
}

#cycle through dataset remove missing values and change the last year to the specified end year
colnames(YAffectedDataSet.ts) <- colnames(YAffectedDataSet)

# reset column names to that of original data set
rownames(YAffectedDataSet.ts) <- as.character(time(YAffectedDataSet.ts)) # set row names to the years

#setting up box plot data
YAffectedDataSet.stats <- rwl.stats(YAffectedDataSet)
YAffectedAverage <- t(YAffectedDataSet.stats[5])
YAbox <- as.numeric(YAffectedAverage)

###########################################################
############   READ in Old Control Data          ##########
###########################################################

#READ DATA
OControlDataSet <- read.rwl("/Users/alexandratodorovic-jones/Documents/Tree Core Research/ControlDataIndividualOld.rwl", header=F);

#CHANGE END YEAR
end.year <- 2012 # can change this to match year of sampling
OControlDataSet.ts <- NULL

#create empty object to hold new data
for(i in 1:ncol(OControlDataSet)){
  OControlDataSet.ts <- cbind(OControlDataSet.ts, ts(na.omit(OControlDataSet[,i]), end=end.year))
}

#cycle through dataset remove missing values and change the last year to the specified end year

colnames(OControlDataSet.ts) <- colnames(OControlDataSet)

# reset column names to that of original data set
rownames(OControlDataSet.ts) <- as.character(time(OControlDataSet.ts)) # set row names to the years

#plot segments
#seg.plot(OControlDataSet,main='Tree Core Ring Growth of Control Trees since 1850')

#stats
OControlData.stats <- rwl.stats(OControlDataSet)
OControlAverage <- t(OControlData.stats[5])

#setting up box plot
OCbox <- as.numeric(OControlAverage)

###########################################################
############   READ in Old Affected Data         ##########
###########################################################

#READ in Affected Data
OAffectedDataSet <- read.rwl("/Users/alexandratodorovic-jones/Documents/Tree Core Research/AffectedDataIndividualOld.rwl", header=F);

day.year <- 2012 # can change this to match year of sampling
OAffectedDataSet.ts <- NULL # create empty object to hold new data
for(i in 1:ncol(OAffectedDataSet)){
  OAffectedDataSet.ts <- cbind(OAffectedDataSet.ts, ts(na.omit(OAffectedDataSet[,i]),
  end=day.year))
}

#cycle through dataset remove missing values and change the last year to the specified end year
colnames(OAffectedDataSet.ts) <- colnames(OAffectedDataSet)

rownames(OAffectedDataSet.ts) <- as.character(time(OAffectedDataSet.ts)) # set row names to the years

#setting up box plot data
OAffectedDataSet.stats <- rwl.stats(OAffectedDataSet)
OAffectedAverage <- t(OAffectedDataSet.stats[5])
OABox <- as.numeric(OAffectedAverage)

#boxplot data
png(filename="/Users/alexandratodorovic-jones/Documents/Tree Core Research/ControlForAgeIndividual.png",width=800, height = 800)
boxplot(YAbox,YCbox,OAbox,OCbox,col=c("red","blue","green","yellow"),names=c("Young Affected", "Young Unaffected", "Old Affected", "Old Unaffected"), main="The Relationship Between Radial Growth and Spruce Beetle Infestation (Controlling for Age)", xlab="Status of Infestation (Young and Old Trees Separated)", ylab="Radial Growth (in mm)", cex.axis=1.5, cex.main=1.5, cex.lab=1.5, cex.sub=1.5)
dev.off()

t.test(YAbox, YCbox)
t.test(YAbox, YCbox, alternative="greater")
t.test(OAbox, OCbox)
t.test(OAbox, OCbox, alternative="greater")

###########################################
######### READ in last 10 years #############
###########################################

#setting up boxplot control last 10 years
YControlSetLength <- length(YControlDataSet.ts[,1])
numYears <- 10
YSubsetData <- YControlDataSet.ts[(YControlSetLength-numYears):(YControlSetLength),]

YControl10YRSAverage<- colMeans(YSubsetData)
YC10box <- as.numeric(YControl10YRSAverage)

#repeat affected last 10 years
YAffectedSetLength <- length(YAffectedDataSet.ts[,1])
YSubsetData <- YAffectedDataSet.ts[(YAffectedSetLength-numYears):(YAffectedSetLength),]
YA10box <- as.numeric(YAffected10YRSAverage)

#setting up boxplot control last 10 years
OControlSetLength <- length(OControlDataSet.ts[,1])
OCSubsetData <- OControlDataSet.ts[(OControlSetLength-numYears):(OControlSetLength),]
OControl10YRSAverage <- colMeans(OCSubsetData)
OC10box <- as.numeric(OControl10YRSAverage)

#repeat affected last 10 years
OAffectedSetLength <- length(OAffectedDataSet.ts[,1])
OASubsetData <- OAffectedDataSet.ts[(OAffectedSetLength-numYears):(OAffectedSetLength),]

 Past10Box <- boxplot(YA10box, YC10box, OA10box, OC10box,col=c("red","blue","green","yellow"),names=c("Young Affected", "Young Unaffected", "Old Affected", "Old Unaffected"), main="The Relationship Between Radial Growth and Spruce Beetle Infestation for the Last 10 Years (Controlling for Age)", xlab="Status of Infestation (Young and Old Trees Separated)", ylab="Radial Growth (in mm)", cex.axis=1.5, cex.main=1.5, cex.lab=1.5, cex.sub=1.5)
dev.off()

t.test(YA10box, YC10box)
t.test(YA10box, YC10box, alternative="greater")
t.test(OA10box, OC10box)
t.test(OA10box, OC10box, alternative="greater")

#########################################################
################ READ in last 5 years Young Control ##############
#########################################################

YControlSetLength <- length(YControlDataSet.ts[,1])
#setting up boxplot control last 5 years
numYears <- 5
YCSubsetData <- YControlDataSet.ts[(YControlSetLength-numYears):(YControlSetLength),]
YControl5YRSAverage <- colMeans(YCSubsetData)
YC5box <- as.numeric(YControl5YRSAverage)

YAffectedSetLength <- length(YAffectedDataSet.ts[,1])
YASubsetData <- YAffectedDataSet.ts[(YAffectedSetLength-numYears):(YAffectedSetLength),]
YAffected5YRSAverage <- colMeans(YASubsetData)
YA5box <- as.numeric(YAffected5YRSAverage)

OControlSetLength <- length(OControlDataSet.ts[,1])
OCSubsetData <- OControlDataSet.ts[(OControlSetLength-numYears):(OControlSetLength),]
```r
OControl5YRSAverage <- colMeans(OCSubsetData)
OC5box <- as.numeric(OControl5YRSAverage)

OAffectedSetLength <- length(OAffectedDataSet.ts[,1])
OASubsetData <- OAffectedDataSet.ts[(OAffectedSetLength-numYears):(OAffectedSetLength),]
OAffected5YRSAverage <- colMeans(OASubsetData)
OA5box <- as.numeric(OAffected5YRSAverage)

png(filename="/Users/alexandratodorovic-jones/Documents/Tree Core Research/Past5YearsControlForAgeIndividual.png",width=800, height = 800)
Past5Box <- boxplot(YA5box, YC5box, OA5box, OC5box,col=c("red","blue","green","yellow"),names=c("Young Affected", "Young Unaffected", "Old Affected", "Old Unaffected"), main="The Relationship Between Radial Growth and Spruce Beetle Infestation for the Last 5 Years (Controlling for Age)", xlab="Status of Infestation (Young and Old Trees Separated)", ylab="Radial Growth (in mm)", cex.axis=1.5, cex.main=1.5, cex.lab=1.5, cex.sub=1.5)
dev.off()

t.test(YA5box, YC5box)
t.test(YA5box, YC5box, alternative="greater")
t.test(OA5box, OC5box)
t.test(OA5box, OC5box, alternative="greater")```
APPENDIX C:

R Code for Affected vs. Unaffected Data, Control for Death

```r
#LOAD DATA
library(dplR)
###########################################################
############    READ in Dead Control Data        ##########
###########################################################
DControlDataSet <- read.rwl("/Users/alexandratodorovic-jones/Documents/Tree Core Research/ControlDataIndividualDead.rwl", header=F);
#CHANGE END YEAR
end.year <- 2012 # can change this to match year of sampling
DControlDataSet.ts <- NULL
for(i in 1:ncol(DControlDataSet)){
      DControlDataSet.ts <- cbind(DControlDataSet.ts, ts(na.omit(DControlDataSet[,i]), end=end.year))
}
#reset column names to that of orginal data set
colnames(DControlDataSet.ts) <- colnames(DControlDataSet)
rownames(DControlDataSet.ts) <- as.character(time(DControlDataSet.ts)) # set row names to the years
#plot segments
#seg.plot(DControlDataSet,main='Tree Core Ring Growth of Control Trees since 1850')
#stats
DControlDataSet.stats <- rwl.stats(DControlDataSet)
# Store the averages (col 5) from the stats variable
DControlAverage <- t(DControlDataSet.stats[5])
#setting up box plot
DCbox <- as.numeric(DControlAverage)
###########################################################
############    READ in Dead Affected Data       ##########
###########################################################
#READ in Affected Data
DAffectedDataSet <- read.rwl("/Users/alexandratodorovic-jones/Documents/Tree Core Research/AffectedDataIndividualDead.rwl", header=F);
end.year <- 2012 # can change this to match year of sampling
DAffectedDataSet.ts <- NULL # create empty object to hold new data
for(i in 1:ncol(DAffectedDataSet)){
      DAffectedDataSet.ts <- cbind(DAffectedDataSet.ts, ts(na.omit(DAffectedDataSet[,i]), end=end.year)))
```

# cycle through dataset remove missing values and change the last year to the specified end year
colnames(DAffectedDataSet.ts) <- colnames(DAffectedDataSet)

# reset column names to that of orginal data set
rownames(DAffectedDataSet.ts) <- as.character(time(DAffectedDataSet.ts)) # set row names to the years

#setting up box plot data
DAffectedDataSet.stats <- rwl.stats(DAffectedDataSet)
DAffectedAverage <- t(DAffectedDataSet.stats[5])
DAbbox <- as.numeric(DAffectedAverage)

############################################################
############   READ in Live Control Data         ############
############################################################

#READ DATA
LControlDataSet <- read.rwl("/Users/alexandratodorovic-jones/Documents/Tree Core Research/ControlDataIndividualAlive.rwl", header=F);

#CHANGE END YEAR
end.year <- 2012 # can change this to match year of sampling
LControlDataSet.ts <- NULL

#create empty object to hold new data
for(i in 1:ncol(LControlDataSet)){
    LControlDataSet.ts <- cbind(LControlDataSet.ts, ts(na.omit(LControlDataSet[,i]), end=end.year))
}

# cycle through dataset remove missing values and change the last year to the specified end year
colnames(LControlDataSet.ts) <- colnames(LControlDataSet)

# reset column names to that of orginal data set
rownames(LControlDataSet.ts) <- as.character(time(LControlDataSet.ts)) # set row names to the years

# plot segments
#seg.plot(LControlDataSet,main='Tree Core Ring Growth of Control Trees since 1850')

#stats
LControlDataSet.stats <- rwl.stats(LControlDataSet)
LControlAverage <- t(LControlDataSet.stats[5])

#setting up box plot
LCbox <- as.numeric(LControlAverage)

############################################################
############   READ in Live Affected Data        ############

############################################################


#READ in Affected Data
LAffectedDataSet <- read.rwl("/Users/alexandratodorovic-jones/Documents/Tree Core Research/AffectedDataIndividualAlive.rwl", header=F);

e.end.year <- 2012 # can change this to match year of sampling
LAffectedDataSet.ts <- NULL # create empty object to hold new data
for(i in 1:ncol(LAffectedDataSet)){
    LAffectedDataSet.ts <- cbind(LAffectedDataSet.ts, ts(na.omit(LAffectedDataSet[,i]), end=end.year))
}

# cycle through dataset remove missing values and change the last year to the specified end year

colnames(LAffectedDataSet.ts) <- colnames(LAffectedDataSet)
# reset column names to that of original data set
rownames(LAffectedDataSet.ts) <- as.character(time(LAffectedDataSet.ts)) # set row names to the years

#setting up box plot data
LAffectedDataSet.stats <- rwl.stats(LAffectedDataSet)
LAffectedAverage <- t(LAffectedDataSet.stats[5])
LAbox <- as.numeric(LAffectedAverage)

# boxplot data? YES
png(filename="/Users/alexandratodorovic-jones/Documents/Tree Core Research/ControlForDeadorAlive.png",width=800, height = 800)
boxplot(DAbox,DCbox,LAbox,Lbbox,col=c("red","blue","green","yellow"),names=c("Dead Affected","Dead Unaffected","Live Affected","Live Unaffected"), main="The Relationship Between Radial Growth and Spruce Beetle Infestation (Control for Death)", xlab="Status of Infestation (Dead and Alive Trees Separated)", ylab="Radial Growth (in mm)", cex.axis=1.5, cex.main=1.5, cex.lab=1.5, cex.sub=1.5)
dev.off()

t.test(DAbox, DCbox)
t.test(DAbox, DCbox, alternative="greater")
t.test(LAbox, LCbox)
t.test(LAbox, LCbox, alternative="greater")

###############################################################################
######## READ in last 10 years ################################################
###############################################################################

#setting up boxplot control last 10 years
numYears <- 10

DControlDataSetLength <- length(DControlDataSet.ts[,1])
DSubsetData <- DControlDataSet.ts[DControlDataSetLength-numYears:DControlDataSetLength,]

DControl10YRSAverage <- colMeans(DSubsetData)
DC10box <- as.numeric(DControl10YRSAverage)
# repeat affected last 10 years
DAffectedSetLength <- length(DAffectedDataSet.ts[,1])
DASubsetData <- DAffectedDataSet.ts[[DAffectedSetLength-numYears):(DAffectedSetLength),]

DAffected10YRSAverage<- colMeans(DASubsetData)
DA10box <- as.numeric(DAffected10YRSAverage)

# setting up boxplot control last 10 years
LControlSetLength <- length(LControlDataSet.ts[,1])
LCSubsetData <- LControlDataSet.ts[[LControlSetLength-numYears):(LControlSetLength),]

LControl10YRSAverage<- colMeans(LCSubsetData)
LC10box <- as.numeric(LControl10YRSAverage)

# repeat affected last 10 years
LAffectedSetLength <- length(LAffectedDataSet.ts[,1])
LASubsetData <- LAffectedDataSet.ts[[LAffectedSetLength-numYears):(LAffectedSetLength),]

LAffected10YRSAverage<- colMeans(LASubsetData)
LA10box <- as.numeric(LAffected10YRSAverage)

png(filename="/Users/alexandratodorovic-jones/Documents/Tree Core Research/Past10YearsControlForDeathIndividual.png",width=800, height = 800)
Past10Box <- boxplot(YA10box, YC10box, OA10box, OC10box,col=c("red","blue","green","yellow"),names=c("Young Affected", "Young Unaffected", "Old Affected", "Old Unaffected"), main="The Relationship Between Radial Growth and Spruce Beetle Infestation for the Past 10 Years (Control for Death)", xlab="Status of Infestation (Dead and Alive Trees Separated)", ylab="Radial Growth (in mm)", cex.axis=1.5, cex.main=1.5, cex.lab=1.5, cex.sub=1.5)
dev.off()

t.test(DA10box, DC10box)
t.test(DA10box, DC10box, alternative="greater")
t.test(LA10box, LC10box)
t.test(LA10box, LC10box, alternative="greater")

# repeat affected last 5 years
numYears <- 5

DControlSetLength <- length(DControlDataSet.ts[,1])
DCSubsetData <- DControlDataSet.ts[[DControlSetLength-numYears):(DControlSetLength),]
DControl5YRSAverage<- colMeans(DCSubsetData)
DC5box <- as.numeric(DControl5YRSAverage)

DAffectedSetLength <- length(DAffectedDataSet.ts[,1])
DASubsetData <- DAffectedDataSet.ts[[DAffectedSetLength-numYears):(DAffectedSetLength),]
DAffected5YRSAverage <- colMeans(DASubsetData)
DA5box <- as.numeric(DAffected5YRSAverage)

LControlSetLength <- length(LControlDataSet.ts[,1])
LCSubsetData <- LControlDataSet.ts[LControlSetLength-numYears:(LControlSetLength),]
LControl5YRSAverage <- colMeans(LCSubsetData)
LC5box <- as.numeric(LControl5YRSAverage)

LAffectedSetLength <- length(LAffectedDataSet.ts[,1])
LASubsetData <- LAffectedDataSet.ts[LAffectedSetLength-numYears:(LAffectedSetLength),]
LAffected5YRSAverage <- colMeans(LASubsetData)
LA5box <- as.numeric(LAffected5YRSAverage)

png(filename="/Users/alexandratodorovic-jones/Documents/Tree Core Research/Past5YearsControlForDeathIndividual.png",width=800, height = 800)
Past5Box <- boxplot(DA5box, DC5box, LA5box, LC5box,col=c("red","blue","green","yellow"),names=c("Dead Affected", "Dead Unaffected", "Alive Affected", "Alive Unaffected"), main="The Relationship Between Radial Growth and Spruce Beetle Infestation for the Past 5 Years (Control for Death)", xlab="Status of Infestation (Dead and Alive Trees Separated)", ylab="Radial Growth (in mm)", cex.axis=1.5, cex.main=1.5, cex.lab=1.5, cex.sub=1.5)
dev.off()

t.test(DA5box, DC5box)
t.test(DA5box, DC5box, alternative="greater")
t.test(LA5box, LC5box)
t.test(LA5box, LC5box, alternative="greater")
APPENDIX D:
R Code for Affected vs. Unaffected Data, Only Affected Sites

#LOAD DATA
library(dplR)

#READ in Control Data
#Read Data
ControlDataSet <- read.rwl("/Users/alexandratodorovic-jones/Documents/Tree Core Research/ControlDataIndividualOnlyAffectedSites.rwl", header=F);
#CHANGE END YEAR
end.year <- 2012 # can change this to match year of sampling
ControlDataSet.ts <- NULL
#create empty object to hold new data
for(i in 1:ncol(ControlDataSet)){
  ControlDataSet.ts <- cbind(ControlDataSet.ts, ts(na.omit(ControlDataSet[,i]), end=end.year))
}
#cycle through dataset remove missing values and change the last year to the specified end year
colnames(ControlDataSet.ts) <- colnames(ControlDataSet)
# reset column names to that of original data set
rownames(ControlDataSet.ts) <- as.character(time(ControlDataSet.ts)) # set row names to the years
#plot segments
#seg.plot(ControlDataSet,main='Tree Core Ring Growth of Control Trees since 1850')
#stats
ControlDataSet.stats <- rw1.stats(ControlDataSet)
# Store the averages (col 5) from the stats variable
ControlAverage <- t(ControlDataSet.stats[5])
#setting up box plot
Cbox <- as.numeric(ControlAverage)

#READ DATA
AffectedDataSet <- read.rwl("/Users/alexandratodorovic-jones/Documents/Tree Core Research/AffectedDataIndividualOnlyAffectedSites.rwl", header=F);
#CHANGE END YEAR
end.year <- 2012 # can change this to match year of sampling
# can change this to match year of sampling
AffectedDataSet.ts <- NULL
#create empty object to hold new data
for(i in 1:ncol(AffectedDataSet)){
  AffectedDataSet.ts <- cbind(AffectedDataSet.ts, ts(na.omit(AffectedDataSet[,i]), end=end.year))
}
#cycle through dataset remove missing values and change the last year to the specified end year
colnames(AffectedDataSet.ts) <- colnames(AffectedDataSet)
# reset column names to that of original data set
rownames(AffectedDataSet.ts) <- as.character(time(AffectedDataSet.ts)) # set row names to the years
#plot segments
#seg.plot(AffectedDataSet,main='Tree Core Ring Growth of Affected Trees since 1850')
#stats
AffectedDataSet.stats <- rw1.stats(AffectedDataSet)
# Store the averages (col 5) from the stats variable
AffectedAverage <- t(AffectedDataSet.stats[5])
#setting up box plot
Abox <- as.numeric(AffectedAverage)

# Comparison
library(ggplot2)
library(gridExtra)

# Plotting
p1 <- ggplot() + geom_boxplot(aes(x=ControlAverage), fill='cadetblue')
p2 <- ggplot() + geom_boxplot(aes(x=AffectedAverage), fill='red')

# Combine plots
grid.arrange(p1, p2, ncol=2)
for(i in 1:ncol(AffectedDataSet)){
  AffectedDataSet.ts <- cbind(AffectedDataSet.ts, ts(na.omit(AffectedDataSet[,i]), end=end.year))
}

# cycle through dataset remove missing values and change the last year to the specified end year

colnames(AffectedDataSet.ts) <- colnames(AffectedDataSet)

# reset column names to that of original data set
rownames(AffectedDataSet.ts) <- as.character(time(AffectedDataSet.ts)) # set row names to the years

# stats
AffectedDataSet.stats <- rwl.stats(AffectedDataSet)
AffectedAverage <- t(AffectedDataSet.stats[5])

# setting up box plot
Abox <- as.numeric(AffectedAverage)

# boxplot data? YES
png(filename="/Users/alexandratodorovic-jones/Documents/Tree Core Research/OnlyAffectedSitesControlForIndividual.png",width=800, height = 800)
boxplot(Abox,Cbox,col=c("red","blue"),names=c("Affected", "Unaffected"), main="The Relationship Between Radial Growth and Spruce Beetle Infestation Only Affected Sites", xlab="Status of Infestation", ylab="Radial Growth (in mm)", cex.axis=1.5, cex.main=1.5, cex.lab=1.5, cex.sub=1.5)
dev.off()
t.test(Abox, Cbox)
t.test(Abox, Cbox, alternative="greater")


ControlDataSetLength <- length(ControlDataSet.ts[,1])
# setting up boxplot control last 10 years
numYears <- 10
CSubsetData <- ControlDataSet.ts[(ControlDataSetLength-numYears):(ControlDataSetLength),]

Control10YRSAverage<- colMeans(CSubsetData)
C10box <- as.numeric(Control10YRSAverage)

# repeat affected last 10 years
AffectedSetLength <- length(AffectedDataSet.ts[,1])
ASubsetData <- AffectedDataSet.ts[(AffectedSetLength-numYears):(AffectedSetLength),]

Affected10YRSAverage<- colMeans(ASubsetData)
A10box <- as.numeric(Affected10YRSAverage)

png(filename="/Users/alexandratodorovic-jones/Documents/Tree Core Research/Past10YearsIndividualOnlyAffectedSites.png",width=800, height = 800)
Past10Box <- boxplot(A10box, C10box, col=c("red","blue"),names=c("Affected", "Control"), main="The Relationship Between Radial Growth and Spruce Beetle Infestation Only Affected Sites")
t.test(A10box, C10box)
t.test(A10box, C10box, alternative="greater")

#setting up boxplot control last 5 years
numYears <- 5
CSubsetData <- ControlDataSet.ts[(ControlSetLength-numYears):(ControlSetLength),]
Control5YRSAverage <- colMeans(CSubsetData)
C5box <- as.numeric(Control5YRSAverage)

AffectedSetLength <- length(AffectedDataSet.ts[,1])
ASubsetData <- AffectedDataSet.ts[(AffectedSetLength-numYears):(AffectedSetLength),]
Affected5YRSAverage <- colMeans(ASubsetData)
A5box <- as.numeric(Affected5YRSAverage)

png(filename="/Users/alexandratodorovic-jones/Documents/Tree Core Research/Past5YearsIndividualOnlyAffectedSites.png", width=800, height = 800)
Past5Box <- boxplot(A5box, C5box, col=c("red","blue"),names=c("Affected", "Control"), main="The Relationship Between Radial Growth and Spruce Beetle Infestation Only Affected Sites (Last 5 Years)", xlab="Status of Infestation", ylab="Radial Growth (in mm)", cex.axis=1.5, cex.main=1.5, cex.lab=1.5, cex.sub=1.5)
dev.off()