Spatial Distribution of Charcoal after a Prescribed Fire on Middle Mountain, VA

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ABSTRACT

This study examines the spatial distribution of surface charcoal after a managed fire and its relationship to fire intensity and site characteristics. Such studies are lacking for the southern Appalachian Mountains. In April 2010, The Nature Conservancy conducted a ~150ha prescribed burn in pine- and oak-dominated forests on the eastern slope of Middle Mountain in western Virginia. Data were from three randomly located transects totaling 2751m from the base of the slope extending to the highest elevations. At 50m intervals I collected 400cm^2 surface samples (n=56) down to mineral soil, and recorded the nearest four trees, their diameters and bole char height, and other site and understory characteristics. Charcoal fragments >2mm were wet-sieved from 200mL subsamples of the surface material, dried, and weighed. Charcoal deposition and char heights on trees examined in this study showed high spatial variability in fire intensity. Average charcoal deposition across all samples was 103 kg/ha, with individual samples ranging from 0–884kg/ha, which was in the range of findings from other studies. Char height was weakly correlated with charcoal abundance suggesting a relationship between fire intensity and charcoal production. Slope was moderately correlated with charcoal deposition, with higher deposition on steeper slopes. Average char height for all trees and species was in the range of 1–3m, but char height on pines averaged 7.3m, where fires intensity appeared to increase. This work can inform land managers on fire behavior and carbon flux and has implications for reconstructions of long-term fire history from soil charcoal.

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Chapter 1: Introduction and Research Objectives

1.1 Introduction

Wildland fires can have a profound impact on vegetation and the general health of an ecosystem (Brose et al., 2001, Van Lear and Waldrop, 1989). Although fire behavior and landscape interaction studies in the southern Appalachian Mountains are scarce, detailed information about fire effects on the landscape can help land managers better understand the processes involved in prescribing fire as an ecosystem management tool. This study examines how charcoal is produced and distributed following a prescribed fire. This information can be applied to paleoecological studies aimed at reconstructing long-term fire history in from soil charcoal in forest stands, where lakes and wetlands (good sites for preserving sedimentary charcoal) do not exist (Fesenmeyer and Christensen, 2010; Hart et al. 2008; Welch, 1999).

Currently, fires are managed at our study site to control vegetation type and succession. This study has generated data and information that may assist land managers at the Warm Springs Mountain (WSM) Preserve and U.S. Forest Service (USFS) by providing information on the dynamic interaction of fire with the landscape. Data gathered in this study combined with a Nature Conservancy – USFS high resolution vegetation map (Figure 1.2, Figure 1.3) gives land managers more information about charcoal production and fire behavior within each plant community. This also aids in maintaining vegetation and help promote a healthy ecosystem.

In 2002, The Nature Conservancy (TNC) purchased more than 3,500 ha of land from private ownership along the crest of Warm Springs Mountain (Babylon, 2003). The WSM Nature Preserve, located in the southwestern portion of Bath County, Virginia, is part of the Ridge and Valley physiographic province (Figure 1.1). The area is characterized by continuously forested ridges with farms in interspersed valleys. Vegetation grows in stunted form on the highest ridges and at Bald Knob, the highest elevation and forms Virginia's only substantial Montane Pine Barren (Ludwig et al. 1999). The remainder of the preserve encompasses a variety of overstory and understory vegetation, along with several endangered species (Powers, 2010). Most of the midslope areas, where this research was conducted, are characterized by mesic oak, hickory, and pine forests. The rarity of this site and surrounding areas on Middle Mountain provide a location to study fire effects on vegetation and impacts of prescribed fire on the landscape.

1.2 Research Objectives

This project examines questions regarding the interactions between fire, vegetation, and the landscape in recently burned forest on the upper slopes of Middle Mountain, a part of the WSM Preserve in west central Virginia. Few studies have gathered information regarding the deposition and accumulation of charcoal after a fire event, and a literature review revealed no published work in the eastern United States or southern Appalachian Mountains; this study addresses gaps within the literature regarding how charcoal is distributed across multiple slopes and vegetation types following a prescribed fire.

My research objective were to: 1) examine relationship between bole char heights with charcoal deposited into the soil, 2) examine relationships between overstory species, slope, and char height to fire intensity, and 3) document spatial variations in charcoal deposition from a single fire event. This research provides quantitative data on the quantity of charcoal left on the ground surface immediately following a fire; information that has never been gathered in the Appalachian Mountains. These data provide a basis for inferences on soil conditions following a fire, and have implications for carbon sequestration and studies examining ancient charcoal. In addition, they contribute to a better understanding of the spatial distribution of charcoal on forested slopes which support n other fire history studies based upon charcoal in soils in the Appalachians and possibly in other mountain ranges.

There are two additional chapters in this thesis. Chapter 2 is a literature review of the history of fire and forests in the Appalachians, site characteristics, and methods used in fire effects studies similar to this one. Chapter 3 is a manuscript draft written for submission to the Natural Areas Journal.

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Chapter 1 Figures

Figure 1.1. Top: Bath County, VA (shaded in white), (Google Earth, 2011); Lower: Middle Mountain study site circled in red (Google Earth, 2010).

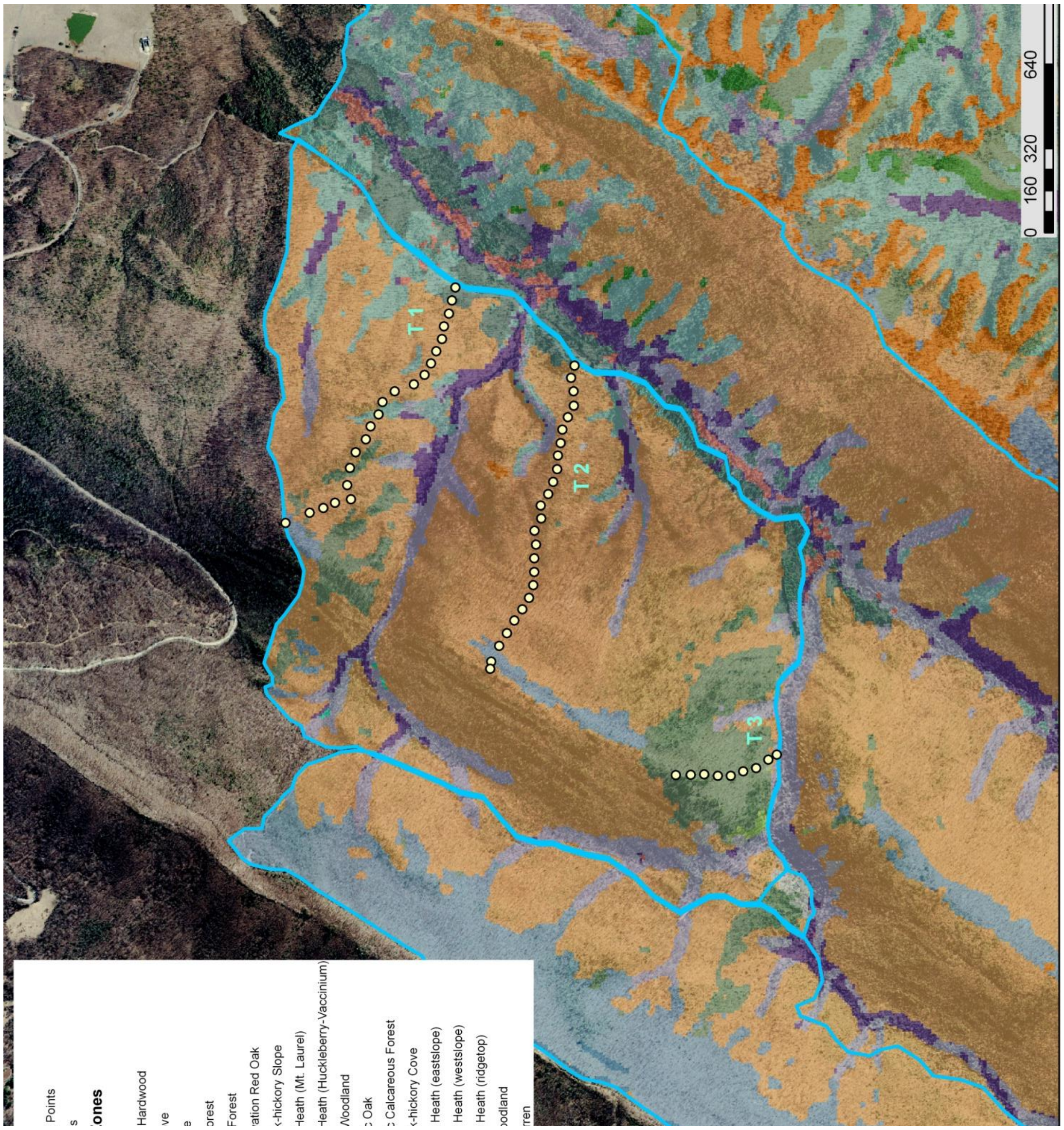

Figure 1.2. Vegetation map produced by The Nature Conservancy and the US Forest Service with the study area outlined in blue. Vegetation/ecological zone key on upper left of image and individual sampling points are yellow dots.

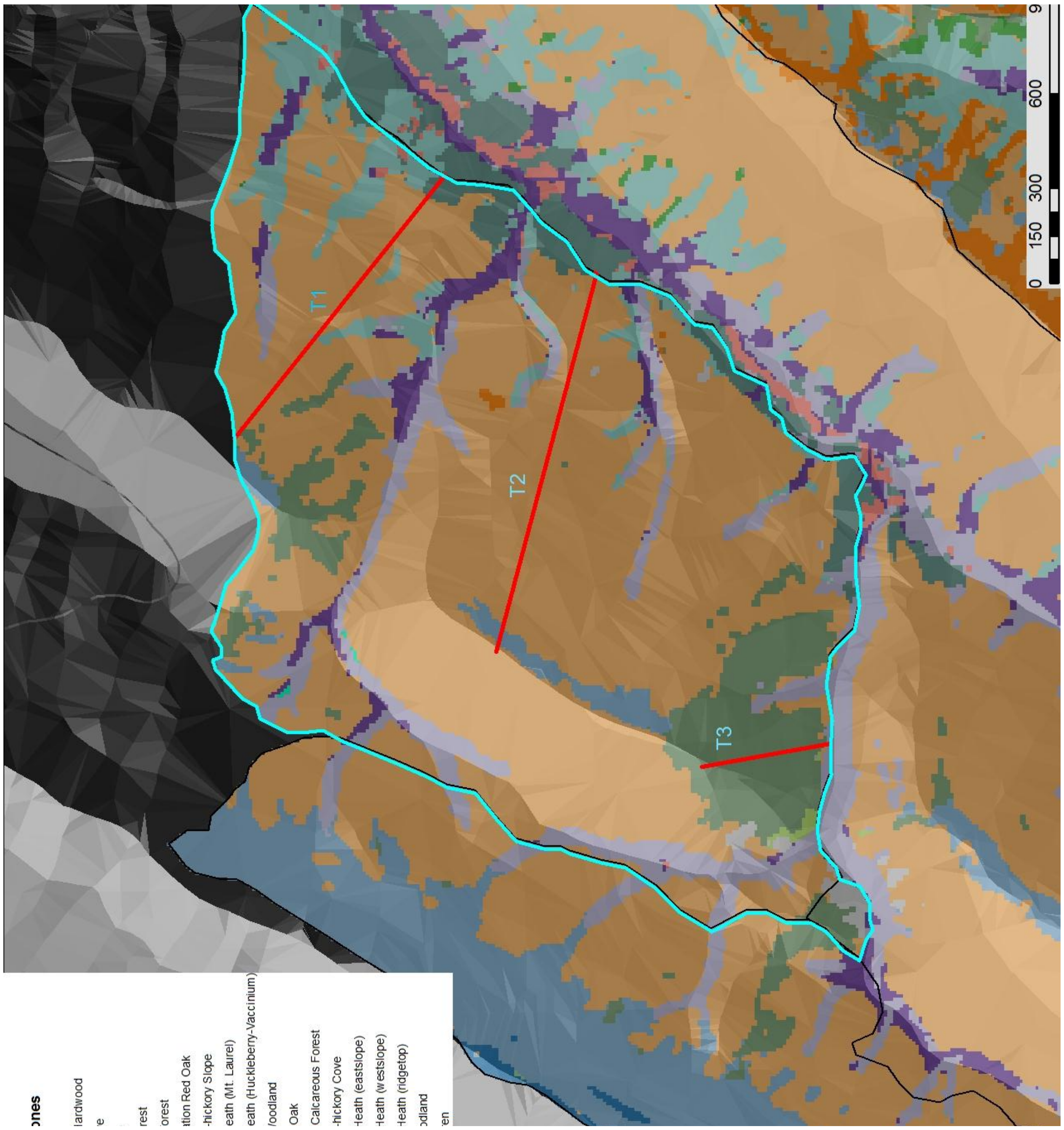

Figure 1.3. Vegetation with Virginia TIN elevation background. Vegetation/ecological zone key on upper left of image.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Minimal research has been conducted in the eastern United States regarding preservation of soil charcoal over time and accumulation rates following forest fires. Research on fire behavior and management is abundant, but its role as an ecosystem process on larger scales is understudied (Hart et al., 2008). The history of forest succession and evolution through the Holocene in the southern Appalachian Mountains is also understudied (Fesenmeyer and Christensen, 2010). In my research area, interaction between fire and the forests of central and southern Appalachia are not well understood, as compared to regions to the west, such as the Cumberland Plateau which has had considerable study in the recent past (Green et al., 2010; Hart et al., 2008; Blankenship, 2006). The paucity of study in Appalachia may be due in part to rugged terrain, difficult access, and extensive private landholdings of forest resources.

Oak-dominated forests in the Appalachians are a unique phenomenon, as oaks are normally characterized as an early to mid-successional species and their dominance is likely attributed to a correlation between multiple climatic and fire conditions (Abrams, 1992). Many of the forests in Appalachia have been extensively logged since settlement, as the previously dominant chestnut trees were very large and valuable for the expanding timber industry (Gravatt and Gill, 1930). Forests in Appalachia today are continually modified by farming, logging, and construction. The Warm Springs Mountain Preserve presents a unique study area of rare woodland and forest communities that have remained relatively undisturbed for the last 70 years (Babylon, 2003). Although few field studies have focused on the Warm Springs Preserve, Powers (2010) extensively studied vegetation dynamics within different forest communities on the far southwestern edge of the Warm Springs Preserve. He incorporated charcoal data into his work by quantifying macroscopic charcoal present in soil profiles of 16 separate cores taken in and around the pine barren, although he did not record any charcoal found on the surface above mineral soil, or within the surrounding oak forest downslope of the pine barrens (Powers, 2010).

Babylon (2003) conducted a management study on the Nature Conservancy and the Warm Springs Preserve, also describing the history and available natural resources of the preserve. Ludwig et al. (1999) published an inventory of biology and zoology, including endangered species, made recommendations for conservation strategies to be carried out within the preserve, and suggested conservation boundaries prior to purchase by the Nature Conservancy. Since the establishment of the WSM preserve, active prescribed burning has been conducted on a yearly basis across multiple tracts of land to manage vegetation and maintain a healthy ecosystem.

2.2 Fire in the Landscape

The role and frequency of wildland fire make a significant contribution to the determination of forest composition, diversity, and succession (McEwan et al. 2004; Delcourt and Delcourt, 1997; Abrams 1992). Modern prescribed fire is often used to mimic burning regimes thought to be conducted by Native Americans in the tallgrass prairies of the Midwest (Howe, 1994), as well as in the Appalachians. In the eastern United States, mixed forests thrive upon periodic fires which manage understory species and promote healthy ecosystems. Some oak species have even adapted to utilize periodic understory-clearing fires set by prehistoric humans (Brose, et al 2001). Native Americans frequently used fire as a tool to maintain land for hunting, increase mast and berry production, and to manage vegetation (Abrams and Nowacki, 2008; Delcourt and Delcourt, 1997). Fires set by natives occasionally resulted in unintentionally managed ecosystems that are still in existence today, as seen in the eastern prairies of North America and the mixed pine/oak and oak forests of Appalachia (Abrams and Nowacki, 2008).

After North America was colonized, settlers in Appalachia continued to follow the firing practices established by Native Americans (Pyne et al. 1996). The first settlers in the Appalachians realized the high value of old growth forests for the timber industry. Once logging became an established trade in the southern Appalachians, ecosystem dynamics within logged areas changed and fire susceptibility greatly increased with the presence of large tracts of slash (Brose et al. 2001).

2.3 Topography and Fire

The mountainous topography of the southern Appalachians is a major contributing factor to the distribution and development of forest communities (Copenheaver et. al., 2006). Topographic and vegetation variations, even over a small area, can have significant impacts on fire behavior (Wimberly and Reilly, 2007). Under normal circumstances, an increase in elevation usually results in more damp conditions as a consequence of lower temperatures at high altitudes and increased precipitation (Lafon and Grissino-Mayer, 2007). Lafon and Grissino-Mayer (2007) also found a lessened ignition potential at higher elevations in the Ridge and Valley Province, possibly stemming from the typically moist conditions.

Native Americans were not the only source of prehistoric fires; several publications indicate large tracts of mixed-oak forest across the Allegheny and Cumberland plateaus were burned during the 1870-1940 period, likely by widespread natural ignitions (McEwan et al. 2007; Van Lear and Waldrop, 1989), and areas of the central Appalachians were heavily influenced by thunderstorm ignitions as far back as the 1600's and 1700's (Aldrich et al. 2010). Other research conducted by Delcourt and Delcourt (1997) indicated that lightning-set fires were uncommon in the Cumberland Plateau of Tennessee and Kentucky and rarely would a lightning strike in a mesic, deciduous forest result in a wildfire.

Prior to colonization and settlement, it is thought that lightning induced fires in the Appalachians were usually limited to xeric ridgetops that could, however, creep downslope away from the drier peaks (Williams, 1998). Recent studies suggest that some fires in the central and southern Appalachians were not limited to ridgetops, but burned across multiple ridgelines, vegetation types, and even across water features and natural firebreaks if environmental conditions were favorable (Lafon, 2010). Comparatively in Virginia, the Ridge and Valley province (where the Warm Springs preserve is located) is second behind the Blue Ridge province for lightning-set fire occurrence (Lafon and Grissno-Mayer, 2007).

Lightning is a potential ignition source for fires in this study area due to topography. High, exposed ridges, such as Warm Springs Mountain and Middle Mountain, could potentially attract lightning strikes that would support ignition if fuels are sufficiently dry. Ignition would be unlikely within the montane pine barren due to continually damp conditions, but a strike within upland oak and pine stands could potentially ignite a wildfire that could spread downslope and across ridges (Lafon, 2010). Additional information suggests that an increase in fire severity can result in increased charcoal production, suggesting that a low ground fire will not produce as much charcoal as a large crown fire (Long et al., 1998).

Wimberly and Reilly (2007) also found, through analysis of satellite imagery of Linville Gorge in North Carolina, that features such as topographic barriers and changes in forest communities constrains fire severity. Most previous studies within Canada and the western United States have shown that variations in topography or forest type have little overall effect on fire severity (Wimberly and Reilly, 2007).

2.4 Fire Suppression History

Historically, the Appalachian landscape frequently burned (Lafon, 2010; Aldrich et al., 2009; Brose et al., 2001; Delcourt and Delcourt, 1997), and some burning practices established by Native Americans were adopted by settlers (Pyne et al. 1996). Over time, these practices declined, and with establishment of the Weeks Act in 1911, fire suppression became a high priority (Brose et al, 2001). By the 1930s a network of fire observation systems and communication had been established for a quick response to any threat of wildfire (Brose et al., 2001). Several recent soil charcoal and dendrochronological studies across the Appalachians and Cumberland Plateau regions note a dramatic decrease in, and sometimes complete absence of fire since that time period (Lafon, 2010; Aldrich et al., 2009; McEwan et al., 2007).

The reduction or absence of fire in the landscape has resulted in the degradation of many pine and oak communities (Harmon, 1982), and an increase in fire susceptible species and fuel abundance (Lafon et al., 2005). It is now understood that a correct application of fire can be used as a tool to increase diversity and simultaneously maintain a healthy ecosystem (Wimberly and Reilly, 2007).

2.5 TNC Land Management

Changes in land use during the last 300 years at similar study sites within 20 km of Middle Mountain were found to have little to no effect on fire frequency (Lafon, 2010; Aldrich et al., 2009). Currently, land managers at the WSM preserve utilize a community-based system of conservation to "involve local citizens and promote a proper balance between economics and the environment" (Babylon, 2003 p.2). This management practice informs local residents of the Nature Conservancy's mission and allows the exchange of information and ideas from managers to those that utilize the land. This process also allows community feedback about applications of prescribed burning and other land management practices at the WSM preserve (Babylon, 2003).

Purchasing the land on Warm Springs Mountain did ensure full protection (Babylon, 2003), as the Pine Barrens are a dynamic and fragile ecosystem, as well as many surrounding species that are endangered or threatened. Without the use of prescribed fire, the barren may eventually succumb to oak encroachment, and the surrounding oak forest may intermix with maples, two occurrences that land managers are trying to prevent (Smith, 2010).

Managing land with fire is a difficult task and results can vary with each prescribed burn. Elliott et al. (1999) described results from a prescribed fire in western North Carolina and suggested that successful pine regeneration requires a large cone crop to successfully produce enough surviving seeds after the fire. Immediately following the studied burn, pine germination was extremely high but, one year later most seedlings had died and seedling numbers had decreased below levels observed before the fire (Elliott et al., 1999). This research will reveal information about ecosystem processes at the preserve on a broad scale, across multiple vegetation types and slopes.

2.6 Charcoal Distribution

Macroscopic charcoal has long been used as a proxy for interpreting the presence of fire in the landscape (e.g. Heyward, 1937). Measurements of macroscopic charcoal production from wildland fire have only been conducted in a few studies (Clark et al., 1998; Ohlson and Tryterud, 1999), while several others studying charcoal production and accumulation have been carried out in far northern latitudes (e.g. Lynch et al. 2004; Tinner et al, 2006) and in the western United States (Gardner, 2001). Few studies have been able to correlate charcoal distribution to an accumulation rate, though Higuera et al. (2005) examined charcoal records in small hollows and calibrated them locally to dendrochronological data. With this combination, an accumulation and sedimentation rate was determined for the study site. Most fires detected were of moderate to high intensity, and detecting low intensity fires was found to be difficult (Higuera et al., 2005). Currently, no literature regarding studies conducted in the Appalachian Mountains examining charcoal production and accumulation during and after a fire event has been found.

There are conflicting results regarding charcoal distribution across the landscape after wildland fire. Clark et al. (1998) studied the distribution of charcoal within a live burn area using charcoal traps and determined that an insignificant amount of charcoal was transported outside of the burn perimeter. Ohlson and Tryterud (1999) had similar results from a charcoal trap study conducted on three prescribed fires in Scandinavia. They found that most charcoal particles transported by the fire were captured in traps within the boundary of the fire itself and 45 percent of all charcoal was contained in traps less than 1 m from the fire edge. Lynch et al. (2004) also found similar results in their study, supporting that macroscopic charcoal did not travel far from the burned area. Blackford (2000) recorded a drastic drop in the presence of charcoal past the terminal edge of their studied burn area in England, indicating that almost no charcoal was transported past the upwind area of the fire front. Conversely, Tinner et al. (2006) indicated that a significant amount of airborne macroscopic charcoal was not limited to the fire boundary. Their study trapped charcoal at distances several tens of meters from the terminal edge of the fire. Similar to that study, Anderson (1968), and Pisaric (2000) found transported macroscopic material several tens of kilometers downwind of the fire front. These were very large fires associated with locally strong winds, implying a relationship between long material transport distances and high wind speed.

Determining the behavior and deposition rates of charcoal from prescribed and natural fires at the Warm Springs Mountain nature preserve will add valuable data to an unstudied subject and location. This will further our understanding of charcoal deposition in pine and oak communities, as well as in the Appalachian Mountains.

2.7 Bole Char Heights

A survey of vegetation scorch heights and bole char can be a valuable tool to assess fire information at a local level. These measurements are made by surveying heights of char marks on the main tree bole following a fire (e.g. Ritchie et al, 2007; McHugh and Kolb, 2003; and Waldrop and Brose, 1999). While several studies focus on fires and species found in the western United States (e.g. Ritchie et al, 2007; McHugh and Kolb, 2003), Waldrop and Brose (1999) studied fire effects on a southern Appalachian table mountain pine stand and provide the most applicable information to this study regarding fire effects in the Appalachians. Vegetation characteristics from their study sites are similar to conditions found in the Warm Springs area, and specifically mention the role of rhododendron and mountain laurel affecting fire behavior. Several studies also reference the use of bole char measurements to represent fire conditions. Strom and Fulé (2007) inferred that bole char height increases with fire intensity in a Ponderosa pine community while Ritchie et al (2007) made a similar statement with the exception that trees over 10cm were best suited to represent fire conditions when measuring bole char heights. Welch et al (2000) used mean bark char height to indicate mean flame height following a prescribed fire in Appalachian pine stands, and Waldrop and Brose (1999) determined that an increase in fire intensity lead to an increase in bark char heights.

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CHAPTER 3: MANUSCRIPT

Spatial distribution of charcoal after a prescribed fire on Middle Mountain, VA

3.1 Abstract

This study examines the spatial distribution of surface charcoal after a managed fire and its relationship to fire intensity and site characteristics. Such studies are lacking for the southern Appalachian Mountains. In April 2010, The Nature Conservancy conducted a ~150ha prescribed burn in pine- and oak-dominated forests on the eastern slope of Middle Mountain in western Virginia. Data were from three randomly located transects totaling 2751m from the base of the slope extending to the highest elevations. At 50m intervals I collected 400cm^2 surface samples (n=56) down to mineral soil, and recorded the nearest four trees, their diameters and bole char height, and other site and understory characteristics. Charcoal fragments >2mm were wet-sieved from 200mL subsamples of the surface material, dried, and weighed. Charcoal deposition and char heights on trees examined in this study showed high spatial variability in fire intensity. Average charcoal deposition across all samples was 103 kg/ha, with individual samples ranging from 0–884kg/ha, which was in the range of findings from other studies. Char height was weakly correlated with charcoal abundance suggesting a relationship between fire intensity and charcoal production. Slope was moderately correlated with charcoal deposition, with higher deposition on steeper slopes. Average char height for all trees and species was in the range of 1–3m, but char height on pines averaged 7.3m, where fires intensity appeared to increase. This work can inform land managers on fire behavior and carbon flux and has implications for reconstructions of long-term fire history from soil charcoal.

3.2 Introduction

This project addresses questions regarding the interactions between fire, vegetation, and the landscape in recently burned mixed pine and deciduous forest on the upper slopes of Middle Mountain, a part of the Warm Springs Mountain (WSM) Preserve in west central Virginia. Few studies have gathered information regarding deposition and accumulation of charcoal after a fire event, and a literature review found no published work pertaining to the eastern United States or southern Appalachian Mountains. This study addresses gaps within the literature regarding how charcoal is distributed across multiple slopes and vegetation types following a prescribed fire. Our objectives were to: 1) examine relationship between bole char heights with charcoal deposited into the soil, 2) examine relationships between overstory species, slope, and char height to fire intensity, and 3) document spatial variations in charcoal deposition from a single fire event. This research provides quantitative data on charcoal left in the soil profile immediately following a fire; this information has never been gathered in the Appalachian Mountains. These data provide a basis for drawing inferences on soil conditions following a fire, as well as implications for carbon sequestration in southern Appalachian forests. In addition, a better understanding of the spatial distribution of charcoal on forested slopes may be used to provide insights to long-term fire history studies based upon soil charcoal in the Appalachians and possibly in other mountain ranges.

Many factors can affect vegetation patterns and fire characteristics. The rugged topography and complex local geology of Appalachia weigh heavily in determining the dominant tree species (Copenheaver et.al., 2006, Ludwig et al., 1999). Small variations in local and regional topography affect fire behavior (Wimberly and Reilly, 2007), though topography alone does not determine fire behavior; many other conditions and environmental factors can influence fire behavior during a prescribed burn (Whitlock and Larsen, 2001). Charcoal accumulations following a fire can vary greatly, even over short distances (Bradshaw et al., 2007). Although charcoal accumulation and trapping studies have been conducted in far northern regions (Tinner et al, 2006; Lynch et al. 2004; Ohlson and Tryterud, 1999) and the western United States (Gardner, 2001), studies of surface charcoal in the Appalachian Mountains are curiously absent, though fire is a relatively frequent disturbance (Aldrich et al., 2010). Others have discussed prehistoric fire and forest succession utilizing fossil charcoal data from soil cores (Fesenmeyer and Christensen, 2010). Conclusions present conflicting results exist regarding the distribution of charcoal across the landscape; several studies indicate that charcoal particles do not travel far beyond fire perimeters (Lynch, 2004; Blackford, 2000; Clark et al, 1998), while others suggest transport distances of several kilometers with dispersal (Tinner et al., 2006) similarly seen in larger fires with strong convection columns (Pisaric, 2000; Anderson, 1968).

In pre- and early settlement periods, the Appalachian Mountains frequently burned (Lafon, 2010; Aldrich et al., 2009; Brose et al., 2001; Delcourt and Delcourt, 1997). This burning continued through the industrial era via natural ignitions (McEwan et al. 2007; Van Lear and Waldrop, 1989), but ceased by the 1930s (Brose et al., 2001). Until recently, large fires in the Appalachian landscape were infrequent (Lafon, 2010; Aldrich et al., 2009; McEwan et al., 2007), resulting in the degradation of several ecological communities (Harmon, 1982) and an increase in fire susceptible species and fuel abundance (Lafon et al., 2005). This was mainly due to the instatement of fire suppression policies (Brose et al., 2001). Now it is understood that correctly applying fire to the landscape can result in increased biodiversity and the maintenance of healthy ecosystems (Wimberly and Reilly, 2007).

Here, we examine the abundance and spatial patterns of charcoal contained within the boundaries of a managed fire, as well as postfire vegetation conditions and bole char as an indicator of fire intensity (Welch et al., 2000; Waldrop and Brose, 1999). We found relationships between fire intensity and charcoal production, as higher intensity fires tend to produce more macroscopic charcoal particles (Whitlock and Larsen, 2001; Ward and Hardy, 1991). We also describe correlations between bole charring and fire intensity to quantities of charcoal deposited into the soil. Finally, we compare relationships between overstory species characteristics (such as DBH, basal area, and char height) to topographic variations, inferred fire intensity from this prescribed fire to determine which factors affect charcoal production more strongly.

3.3 Methods

Study Site

The Warm Springs Preserve was established in 2002 and contains 3751 ha of diverse and rugged Appalachian forest (Babylon, 2003). The preserve ranges in elevation from approximately 580 m above sea level near Mare Run in the northeastern part of the preserve to 1287 m at Bald Knob, the highest elevation in the area. Land managers with the USFS and WSM preserve focus on restoring the habitat by using prescribed fire as a vegetation management tool. Their intent is to restore the historical fire regime of pine and pine-oak communities located within the preserve.

Vegetation varies depending on slope, elevation, and aspect but mainly comprises mesic oak-hickory forest interspersed with pine. Powers (2010) found (through maximum depth of sample cores) that soils at the ridgeline of the WSM preserve were at most 50 cm thick, though normally no deeper than 30 cm due to the ridgetop setting. Bedrock in the in the WSM preserve is Tuscarora sandstone, a resistant and thick white quartzite sandstone that terminates in the southwestern end of our study site. Areas at the northeastern end of the study site are underlain by calcareous mudstones, sandstones, and shales (Ludwig, et al. 1999). Most of the study area is xeric forest with excellent downslope drainage.

The WSM preserve is situated in the Ridge and Valley province, where winters are cold and summers typically mild. Temperature averages 10.5°C annually, with a maximum average of 21.6°C in July and a minimum of -1.1°C in January (NWS, 2010). Precipitation averages 1085 mm per year, with May the wettest month and December the driest. The site receives approximately 660 mm of snow annually (NWS, 2010). Ridgetops in the area can experience high winds associated with changes in pressure and individual storm systems. The nearest National Weather Service (NWS) site is located at the Ingalls Field Airport on the crest of Warm Springs Mountain, approximately 10 km southwest and 700 m higher than the study site. Records at this site date to 1971.

Site and Sample Locations

The prescribed fire was conducted in April, 2010 during pre-leaf emergence using an area ignition method via helicopter and hand ignition along some of the fire perimeters. This fire was intended to remain at low intensity to mimic the historic fire regime and manage a large understory vegetation growth of rhododendron, and mountain laurel, and leaf litter. When Nature Conservancy managers conducted the prescribed fire, a unique opportunity to study fire effects arose that permitted examination of multiple variables such as vegetation, elevation, slope, and fire intensity. Land managers from the Nature Conservancy supplied base layers from their geographic information system (GIS) for this research project. These layers included a burn boundary file and vegetation coverage information illustrating differing "ecological zones." These zones were created by the USFS GIS models to simulating dominant vegetation coverage across the entire George Washington and Jefferson National Forests. The ecological zones indicated differences in dominant vegetation coverage and were used as a reference in the field during sample collection. Additional aerial photographs from the 2010 National Agricultural Imaging Program (NAIP) were incorporated as a mosaic into the GIS, along with TIN elevation data downloaded from gisdata.virginia.gov and topographic quadrangles downloaded from Virginia Tech's online library.

We established two baselines (for three transects) along the southern and western boundaries of the burn, and along the contour of slope. The first baseline (for Transects 1 and 2) was located parallel to Mare Run Trail, a U.S. Forest Service access road to private land, and the other (for Transect 3) along a straight line extending from the original baseline's termination to the northwestern boundary of the fire. Using ArcGIS 9.3 and Microsoft Excel, we established three randomly located transects extending perpendicular to the baseline up the burned eastern and southern slopes of Middle Mountain (Figure 3.1). We collected a surface sample every 50 m from the baseline of the transect to the termination near the ridgeline.

Transects 1 and 2 extend from Mare Run Trail to the ridge top on the eastern slope of Middle Mountain. Both transects were located in similar vegetation cover, mainly oak-pine forest, with a thin band of mesic oak and hickory approximately 70 m wide and 700 m long on the eastern side of the ridge crest (Figure 3.1). Transect 3 was located in the vicinity of Mare Run, a small creek that flows across a gap in Middle Mountain and that served as the southwestern boundary of the fire. Transect 3 traverses a more pine-dominated forest community and is located on a more southerly-facing slope than the other two transects.

Field Methods

Surface sampling was conducted over a 4 month period from May-August 2010. For navigation and to record sample locations in the field, we used a Trimble Pro XRT and Nomad. Coordinates for each transect were pre-programmed into the Nomad and the navigation function allowed the field team to stay as close to the "lab-generated" transect as possible (Table 3.1). A surface soil sample was collected every 50 m as indicated by the "distance traveled" and "distance to destination" display on the GPS unit. We also cross-referenced printed topographic maps showing local features and topography. Occasionally the GPS would encounter difficulty communicating with satellites due to locally steep topography and a dense tree canopy, which resulted in some signal scattering (multipathing). When effect this occurred, we waited for a more accurate signal to continue sampling as close to the transect line as possible.

We collected each sample from a surface area of 20 x 20 cm (400 cm^2). An outline was cut vertically with a small trowel and all material was removed down to mineral soil (Figure 3.2). Since fires are often slowed or stopped by mineral soil, most charcoal would not have been transported deeper into the soil profile this soon after the prescribed fire. Surface samples were removed to labeled Zip-Lock bags and returned to our laboratory at Virginia Tech. The field team also recorded field observations, such as the presence of visible charcoal pieces on the ground surface, characteristics of the vegetation, and slope angle to consider links with charcoal production.

We revisited the transects during late spring, 2011 to collect more detailed information about the forest composition and structure immediately adjacent to each sample site. Using our previously recorded coordinates and a GPS, we navigated to each sample location and logged the closest four living trees using the point-centered quarter method (Mitchell 2007). This method divides the land into four quadrants centered on the surface charcoal sample. The nearest living tree and all living rhododendron and mountain laurel in each quadrant were recorded, along with the distance to each tree from the center. We recorded the species identification, diameter at breast height (DBH), the distance from the tree to the charcoal sample location, and bole char height. The field team also noted understory observations in each quadrant including the number of shrubs burned by the prescribed fire and an approximate burning height on the understory, if any partially charred leaves were left behind. Vegetation density measurements were not recorded.

Bark char heights, defined by highest area on the bole blackened (charred) by fire, were measured following Waldrop and Brose (1999) (Figure 3.3). Bole chars created during the prescribed fire can indicate flame height on the tree bole and serve as proxy of fire conditions during the burn (Strom and Fulé, 2007; Ritchie et al, 2007). Bark char is usually a triangular form pointing up the tree bole and can range in severity depending on the characteristics of the fire when it was interacting with the tree. Some bole chars directly lead to a fire scar while other instances only damage the outermost layers of the bark. The height and severity of the burning of the bole directly relates to the fire severity and local conditions such as wind, slope, and fuel availability. Char heights below 2 m were measured with a measuring tape, while heights above 2 m on the bole were measured using a Nikon Forestry 550 range finder with a built-in hypsometer and inclinometer. This device uses laser sight and allows the user to sight a target reticule at the apex of the fire scar and lock this height into the device. Calculations from the differences in angle measurement automatically display the height of the fire scar. Accuracy of the device was assessed prior to field use by measuring distances up the bole by hand and validating them with the range finder.

Laboratory Methods

Surface samples were stored at Virginia Tech's Paleoenvironments laboratory in a refrigerator at approximately 7° C to minimize decomposition. The technique of collecting all material to mineral soil resulted in variability in total sample volumes (soil plus litter), as some areas were very rocky with thin soil, while others had thick organic layers under the most recent leaf fall. This effect was normalized by subsampling a known volume (200 mL) from each entire sample in the laboratory. We mixed the samples thoroughly to randomize the subsample as much as possible.

USA Standard 2 mm and 500 µm round sieves were used to screen and sort material by size class. We flushed the entire sample through nested sieves with hot water. If large pieces such as leaves or twigs were blocking the flow of material, they were washed by hand over the sieve and then removed to process the sample more efficiently. After all materials had passed through the sieves, we examined the contents of the 2 mm sieve under a Leica binocular stereozoom microscope to identify and remove charcoal fragments. The contents of the 500 µm sieve were stored wet in plastic bags and returned to the laboratory refrigerator for future analysis.

The washed charcoal > 2 mm in size was removed from the sieve with forceps and dissecting probe and stored wet in glass vials. The vials were pre-weighed to the nearest 0.0000 gram with a Mettler Toledo AB104-F balance. The cleaned, wet charcoal was dried in the glass vials in an oven at 100° C for 24 hours to evaporate the water. The vials were then reweighed to determine the total mass of the dry charcoal.

After all data had been compiled from forest and charcoal sampling, we ran a basic correlation analysis on the information and a t-test on the averages to examine results for statistical significance.

3.4 Results

Forest metrics

We recorded 13 species in our survey of 223 trees along three transects at Middle Mountain (Table 3.2). Chestnut oak (*Quercus prinus*) was most common (42%), followed by red oak (*Quercus rubra*, 17%), and red maple (*Acer rubrum*, 11%). Most canopy species (oaks and pines) had similar average DBH (Figure 3.4, Table 3.3). Species represented by only one individual were not included in the calculated standard deviations and confidence intervals. Deciduous species represented 75% of all species surveyed, while the other 25% were pine.

Chestnut oak (*Quercus prinus*; n=100) had the largest average basal area on Middle Mountain (Figure 3.5, Table 3.4), though the only paper birch (*Betula papyrifera)* we measured had a larger basal area. All other oak species (red oak, post oak and white oak) had average basal area measurements within 100 cm^2. Sourwood (*Oxydendrum arboreum)* and red maples (*Acer rubrum)* had a much smaller average basal area, though the standard deviation between individuals was lowest among all species recorded (Table 3.4).

Overstory vegetation across all transects was very similar. MMT1 and 2 were both located on very similar eastern-facing slopes and were characterized by mesic oak and hickory slopes with localized pine stands in steeper areas with a southerly aspect. MMT3 was both shorter and steeper than the first two transects, and located on a southern-facing slope. MMT3 was much more rocky with a less dense understory and also classified in a different vegetation category than MMT1 and 2 (Pine-Oak Heath, Figure 3.1), though similar overstory vegetation (oak, maple, and localized pine stands) was observed here.

Charcoal deposition

The amount of charcoal deposited into the soil varied widely across the transects as some samples exhibited no evidence of charcoal or fire and others represented deposition loads of more than 800 kg/ha (Figures 3.6 and Table 3.5). By transect, MMT3 averaged the largest amount of charcoal by sample, with 0.09 grams per 200 mL subsample and a total of 0.86 grams of dry charcoal across the transect. MMT1 followed with 0.06 grams per sieved subsample but had a total of 1.4 grams of dry charcoal after laboratory analysis had been completed. MMT2 was last with 0.04 grams of charcoal per subsample and a total of 1.1 grams of dry charcoal for the transect.

Charcoal deposited at the soil surface, with weights standardized to kg/hectare, was correlated with sample weight (as expected that a larger sample will contain more charcoal), (Figure 3.7) and weakly related to bole char height ($p=0.01131$) (Figure 3.8). In terms of slope, charcoal mass was correlated with an increase in slope ($p=0.057$), the most significant value for a relationship in all data (Figure 3.9). Bole char heights and inferred fire intensity were not correlated with and increase in elevation (Figure 3.10). Charcoal >2 mm was absent from four of a total of 56 subsamples.

Spatial patterns of charcoal production vary widely on Middle Mountain appear to relate to local variations in topography, slope, vegetation, and fire intensity. In several instances across all transects, a wave-pattern was visible with changes in slope (Figure 3.6). Several charcoal samples were taken in relatively flat areas, indicating that charcoal deposition is reduced in areas of reduced slope; in other areas, increased charcoal was coincident with steeper slopes. Also along these transects, bole char heights exhibit a similar wave form (Figure 3.6), as shown in the scatterplot displaying a weak relationship between overall elevation and char height (Figure 3.10). Several areas along all three transects with a higher occurrence of pine indicate higher amounts of charcoal and similarly high bole chars.

Bole char heights

Char height varied considerably between species and sample sites (Figure 3.11). Char heights averaged 115 cm for all species (Table 3.5, Figure 3.12) and 33% of all individuals were in the range of 100–300 cm. Char heights on pitch pines *(Pinus rigida*) were well above the interspecies average with an average of 730 cm; most trees in these stands exceed 15 m and were completely charred and dead following the fire. Red oaks and pitch pines had the highest correlation between DBH and char height, with pitch pines positively correlated and red oaks had the highest of all correlation values between char height and DBH (Figure 3.13). The average char height of red maples (42.2 cm) is much lower than the 100–300 cm range where most heights fell. The relationship between char height and DBH for red maples was neutral.

Sourwoods (*Oxydendrum arboreum*) also showed no correlation between char height and DBH, though there were 20 individuals sampled across all of the Middle Mountain transects.

Post oaks (*Quercus stellata*, n=6) and white oaks (*Quercus alba*, n=8) were too rare in our sites to provide adequate samples for statistical comparisons (Figure 3.13). In these graphs, post oaks illustrated a negative correlation between char height and DBH, as did white oaks. Species that had only one individual sampled (beech, black cherry, hickory, paper birch, striped maple and white pine) were not graphed with averages, but are displayed together (Figure 3.9).

Field Observations

Middle Mountain Transect 1 (MMT1) and transect 2 (MMT2) were similar in terms of length, slope, and vegetation type. Both areas, though randomly selected were primarily located in mesic oak slopes (Figure 3.1) along the entire length of the transect. A few anomalous areas with more southern/southwestern facing slopes contained localized areas of pitch pines that had been completely killed by a crown fire in excess of 15 m, the maximum height of the tallest pines. Heavy resprouting was occurring in the understory, mainly in the form of rhododendron, mountain laurel, and root suckers from previously killed or fire damaged trees.

Along MMT1, rhododendron and mountain laurel were common, occurring in 16 of 22 samples. We recorded fire-killed trees in 19 of the 22 sample locations. Our transect ended at the top of the ridge, but a firebreak approximately 2 m wide appeared to have stopped the fire short of the highest elevations in the area. Variations in fire intensity along both MMT1 and MMT2 were observed within close proximity to one another; within 250 m (between samples 11 and 15) the highest variation in fire intensity was observed along the transect with 15-m high pines at site 11 completely burned, and very little visual evidence of fire at site 15.

Heath shrubs (rhododendron and mountain laurel) were common (present in 20/25 samples locations) on MMT2. Two samples in MMT2 exhibited signs of partially-scorched rhododendron. Seven individuals with MMT2 Sample 14 and six individuals with MMT2 sample 15 were still alive following the prescribed fire; both exhibited partial scorching on the lower extremities of the plants. Dead trees were a common occurrence in MMT2, present in 18 of 25 sample locations. MMT2 appeared to be a wetter transect, with several of the sample locations in proximity to small streams and springs with high flow at the time of field sampling. The pitch pines observed along this transect also had high bole chars and were located on a more southerly and southwestern facing slopes, similar to those on MMT1. Our observations of other pitch pines (not measured) in close proximity to those sampled indicated similar characteristics of high charring. The narrow (1-m-wide or less) fireline at the top of Middle Mountain near the termination of transect 2 allowed the fire to crest the ridge and continue toward the north downslope.

The shorter transect, MMT3, was less similar than the other two transects (MMT1 and 2) in terms of dominant vegetation. MMT3 was located on a more southerly slope in an area more suitable for pine (Figure 3.1), rather than mesic oak and hickory slopes of MMT1 and 2. MMT3 was notable more rocky and steep than the other two. Of the nine samples along the 450 m transect, seven indicated the presence of dead rhododendron, and one sample (sample 6) also had partially scorched but surviving rhododendron. Dead trees, similarly to the rhododendron, were recorded in all but two of the nine samples. The highest elevations of MMT3 contained a community not represented in our other transects; a rock exposure running parallel to the ridgeline of Middle Mountain above Mare Run delineates a pine-dominated community to the west and an oak-dominated community to the east. All pines to the west of the ridgeline were either killed or heavily damaged by the fire and the oaks to the eastern side of this rock formation showed very little evidence of bole chars. MMT3 terminated in the middle of the pitch pine stand, where char heights in excess of eight m were recorded on all four trees in the terminal sample. We noted that a few individuals in vicinity had green needles in the treetops, but most pines were completely killed by the fire. We did not observe any resprouting in the pines and surface was littered with visible charcoal.

3.5 Discussion

This research showed that charcoal deposition after a fire in the southern Appalachians was highly variable across the landscape. Our results are in agreement with a study by Ohlson and Tryterud (1999) in Scandinavia's boreal forest. Their study found that charcoal production during an experimental forest fire varied widely even over very small distances. Their study used charcoal collection traps during the fire, while ours involved collection of surface samples several months postfire. At Middle Mountain, charcoal loads between 0 kg/ha and 884 kg/ha were deposited. Given the delay between the fire and our sampling (4 months), some charcoal could have eroded and thus our weights may underestimate the original charcoal deposition after the fire. We did not find a pattern of increased charcoal accumulation on lower slopes, however, that would support that idea. Variations in microtopgraphy may also have an effect on surface accumulation of charcoal at our site, as previously described in the Cumberland Plateau (Hart et al., 2008). This variation may play a greater role in the effects of random sampling and the total amount of charcoal represented by a single sample for a large area.

The maximum charcoal deposition load in the sites of Ohlson and Tryterud (1999) was 6800 kg/ha, and other studies have indicated even higher deposition values into the tens of thousands of kg/ha (Ohlson and Tryterud, 1999; Bradshaw et al., 1997). Lower charcoal production in our site compared with the Scandinavian sites (Ohlson and Tryterud, 1999) likely relates to differences in fire intensity and vegetation type. Their study sites experienced a high intensity ground fire, periodically escalating into a full crown fire, whereas the managed Middle Mountain fire was mostly a low to medium intensity ground fire and only crowned in localized pine stands. Vegetation at the Scandinavian sites was predominantly coniferous while hardwoods dominated our stands at Middle Mountain, and at both sites, fire some in conifer stands appeared to increase to a high intensity crown fire.

We initially hypothesized that some downslope movement may have occurred between the time of the fire and sampling (~4 months) if there had been any extreme weather events, in particular heavy rainfall. Climatological data from the Hot Springs, VA National Weather Service meteorological station, approximately 7.5 km to the southwest, indicated that the highest rainfall rate observed during the time period between the fire and sampling was 7.62 mm/hr (or 0.3 in/hr). This precipitation rate would probably not mobilize downslope movement of macroscopic charcoal, but there was potential for an isolated thunderstorm over the study site that would not be recorded by any weather station. Such an event could transport some burned material downslope or move it deeper into the soil.

The potential for downslope movement in this area is high due to steep slopes and the relatively common high rainfall events that occur at high elevation. We revisited some of the charcoal sampling sites multiple times during the year following sampling and found downslope movement into the bowl-shaped voids left by the 20x20 cm sample removal (to mineral soil). Microtopography is highly variable in our study area and would likely exert strong influence on the erosion or accumulation of charcoal at any given site.

Char heights measured in the interior samples away from fire boundaries have lower heights indicating a less intense fire. We think this pattern is related to ignition practices that may cause a higher intensity fire around the burn edge. Areas that were ignited by hand along the perimeter of the burn boundary may have experienced higher fire intensites due to a more linear fire line rather than the lower intensity spot fires seen with an area ignition. The helicopter ignition dropped small incendiary devices over a wide interior area with the intent to create many small fires rather than one large head fire. These less intense interior fires were indicated by lower char heights, and less charcoal in some samples. An interior location, such as the middle of a transect may provide the best opportunity to record more natural fire effects with less influence from human interaction. Further sampling in an area like this, especially during an active fire, would provide valuable information about the conditions during the burn compared with the fire boundaries, where there is a higher probability of direct human influence.

Along several samples of each transect, we noted a periodic increasing and decreasing wave pattern of charcoal deposition (Figure 3.12). We hypothesize this may be due to localized changed in topography; as slope increases along several consecutive points, charcoal deposition coincidently increases, and as the terrain levels out, a drop in charcoal is observed. This may be due in part to an increased fire intensity moving uphill. Several studies have indicated that a fire front will increase speed with an increase in slope (Linn et al, 2007; Cova et al., 2005; Richards, 1999), which would coincide with higher charcoal deposition, described by Higuera et al. (2005). This phenomenon was observed periodically on all transects, but is most evident on MMT2 where charcoal quantities are higher in steeper areas and much lower on flat terrain.

We observed several examples (16 of 224 trees) of inhibited bole charring due to topographic and surface features, a phenomenon briefly discussed by Behling et al. (2007). In each case, a unique instance of ground cover (e.g., moss, rocks, or deadfall) prevented fire from reaching the base of the tree. Twelve of the 16 trees were protected at the base while four trees were in close proximity to Mare Run, an area with dense and diverse vegetation. These factors, combined with locally rocky conditions, likely prevented the fire from affecting the sampling sites in that area.

Only four of 56 samples did not contain charcoal. Two were in very rocky and open terrain, and two were in moderately steep areas with a heavier understory of rhododendron. Areas with the more open terrain were characterized by less charcoal, and less overall soil depth. In this case, more rocky terrain with less vegetation would not burn as readily, resulting in less charcoal produced. We hypothesize that a very dense understory would harbor more moisture reducing fire intensity and potentially resulting in lower charcoal production. The positive relationship between charcoal mass extracted from sample weight may aid in visualizing this occurrence (Figure 3.7). Rocky areas with presumably thinner soils were characterized by less charcoal abundance. Areas that appeared to have deeper soil, such as flats or gentle slope, have a higher likelihood of harboring more charcoal fragments following a fire.

Most rhododendrons were completely killed by the prescribed fire and we observed high rates of resprouting. In the two years following the prescribed burn, many individuals were newly sprouting from the roots and new shrubs such as blueberry were growing, as Elliott et al., 1999 discussed. Hooper (1969) discussed fire impacts on rhododendron from a prescribed fire in western North Carolina and very similar results (heavy root resprouting, partially scorched individuals) were observed at the WSM preserve. Partially scorched rhododendron (or any partially scorched vegetation) can be a good indicator of flame height since the fire will consume all living material; any boundaries between living and nonliving vegetation serves as a proxy for conditions during the burn. If land managers wish to maintain a more open understory forest, especially in the Appalachians, more frequent prescribed burning may be the key, though fire alone may not be enough for managing rhododendron.

This study represents a “snapshot” of conditions at the time of sampling. Environmental conditions such as seasonal change and weather patterns will undoubtedly change the picture depending on when the site is revisited. More downslope movement due to precipitation and gravity will occur over time, and thus change the spatial distribution of charcoal. Future detailed studies aimed at observing the movement of charcoal particles during the prescribed fire and several years post fire would provide even more insight into these fine scale processes that occur through time on mountain slopes in the southern Appalachians.

3.6 Conclusions

Fire behavior during a prescribed burn can be highly variable and is dependent on many conditions and environmental factors (Whitlock and Larsen, 2001). Several factors such as topography, slope, fuel loading, humidity, and wind conditions can weigh differently in determining fire behavior. Charcoal deposition and char heights on trees examined in this study were highly variable across the landscape and reflected variability in fire intensity across our study area. The study by Higuera et al. (2005) showed that higher fire intensity results in a higher amount of charcoal produced, and represented one of the only studies found describing such patterns and processes. Our results from the study of surface charcoal at Middle Mountain after a prescribed fire are consistent with the findings of Higuera et al. (2005) and Clark et al. (1988), though our statistical relationships were less strong. Both Higuera et al. (2005) and Clark et al.

(1988) described a similar maximum charcoal load of 735 kg/ha from a pine forest fire, this study observed maximum charcoal deposition at 884 kg/ha.

The study of bole char heights and fire effects on different tree species can provide valuable insight into the intensity of a fire, further relating that information to charcoal deposition (Ritchie et al, 2007; Strom and Fulé, 2007; Welch et al, 2000; and Waldrop and Brose, 1999). We found that in most cases for a low to medium-intensity fire in the southern Appalachians, higher char heights can indicate a larger presence of charcoal than surrounding areas with lower bole chars (in relation to fire intensity). Other effects such as topography and dense or wet vegetation (either inhibiting or enhancing fire intensity) can have localized influences not indicative of average fire conditions.

The prescribed fire on Middle Mountain represents a dynamic event in which many factors contributed to the overall results. We observed that: 1) localized topography can influence charcoal deposition during a fire by increasing intensity with an increase in slope, resulting in more charcoal. 2) Pines and chestnut oaks were most susceptible to bole charring and most pines that we surveyed were completely burned during the fire. Bole charring is a good indicator of fire conditions, and 3) can be used as a proxy to estimate the abundance of charcoal in the soil immediately following a prescribed fire. TNC and USFS land managers can use these findings to more accurately plan prescribed fires for vegetation management. Information gathered in this study can also be applied to the central and southern Appalachian region for use in planning vegetation management fires and comparing fire effects on a regional scale. Finally, our results have implications for studies of long-term fire history that use soil charcoal (at depth) as a proxy for past fires. The high spatial variability of surface charcoal indicates that the abundance of charcoal downcore in soils should be interpreted with caution as it may not be related to fire frequency, or even intensity, but could be influenced by microtopograpy and slope processes through time.

Chapter 3 References

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Chapter 3 Figures

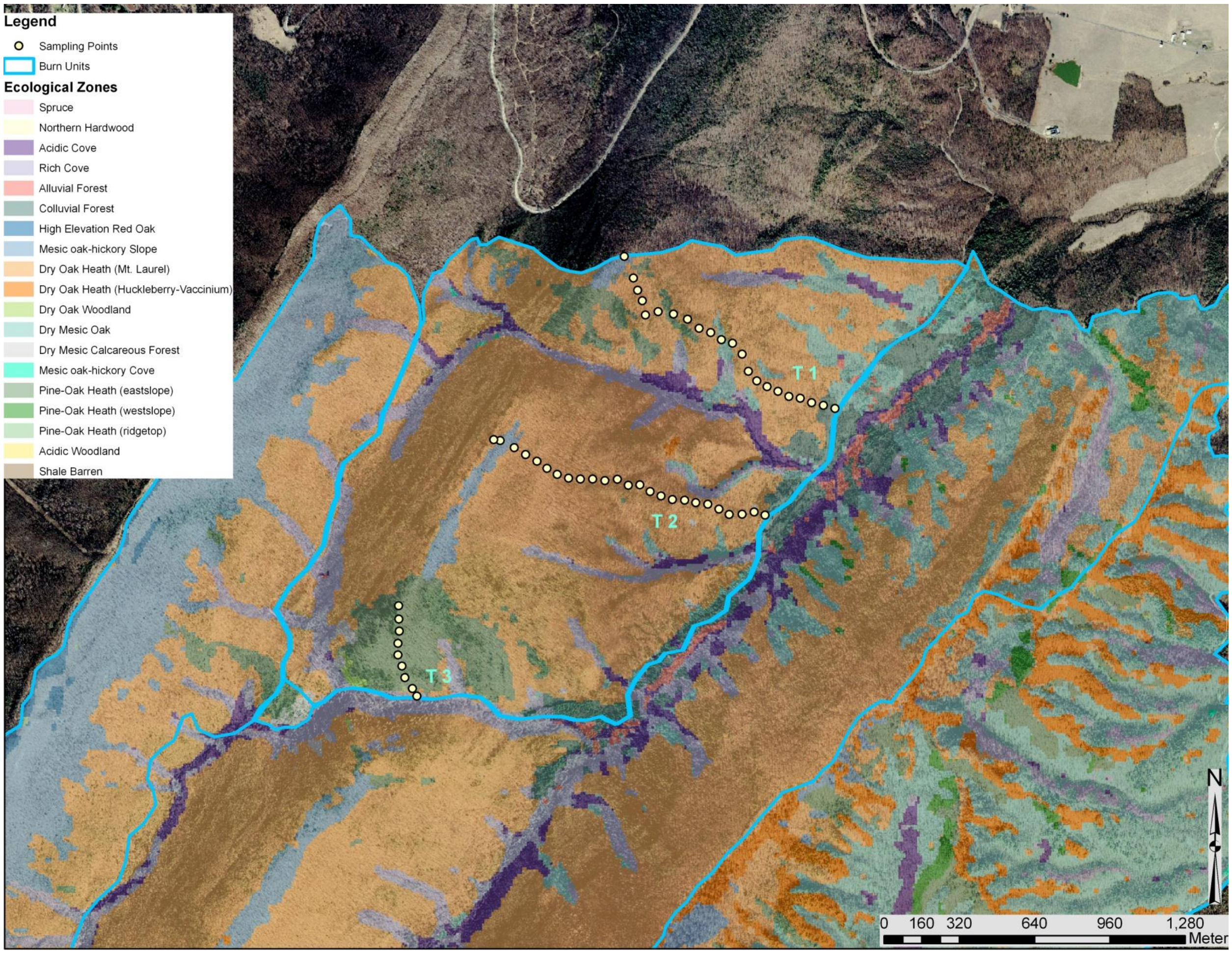


Figure 3.1. Vegetation map produced by The Nature Conservancy and the US Forest Service with the study area outlined in blue. Vegetation/ecological zone key on upper left of image and individual sampling points are yellow dots.

Figure 3.2: Field assistant taking a 20x20cm surface charcoal sample next to a heavily charred stump on MMT2.

Figure 3.3. Field assistant measuring the char height of an oak on MMT1, Middle Mountain, VA.

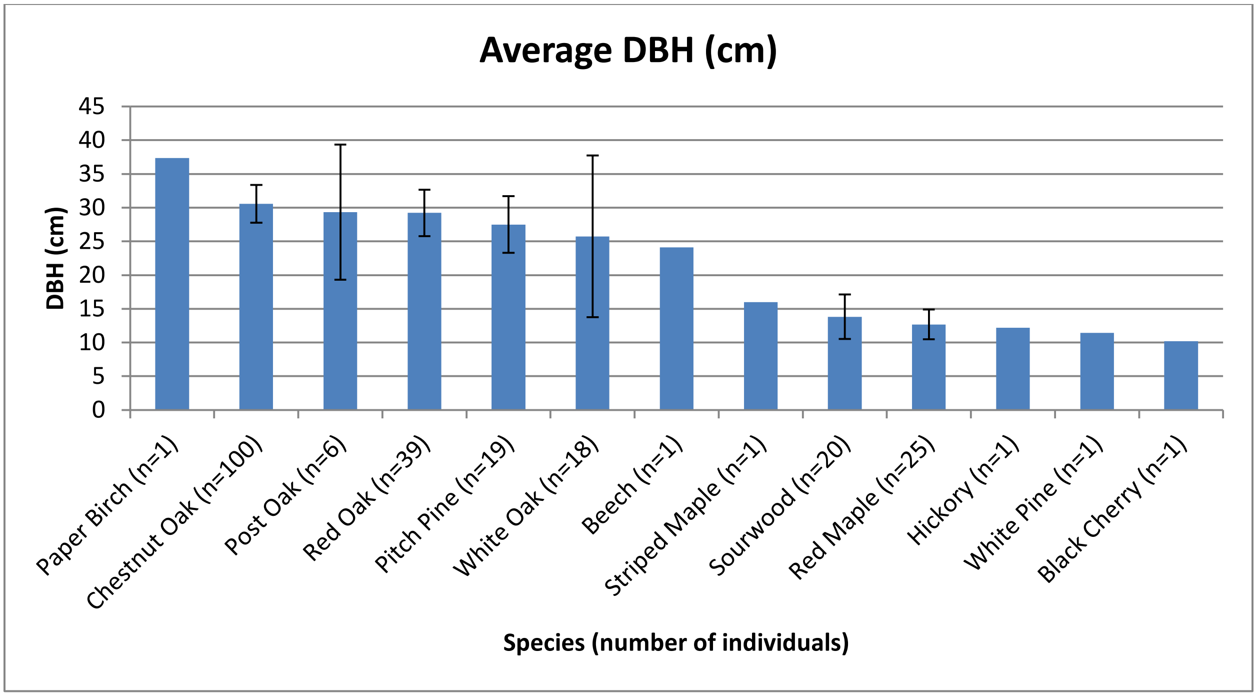


Figure 3.4. Average DBH for each species and number of individuals. Lower and upper 95% confidence intervals are shown by error bars. Species without error bars were represented by only one individual.

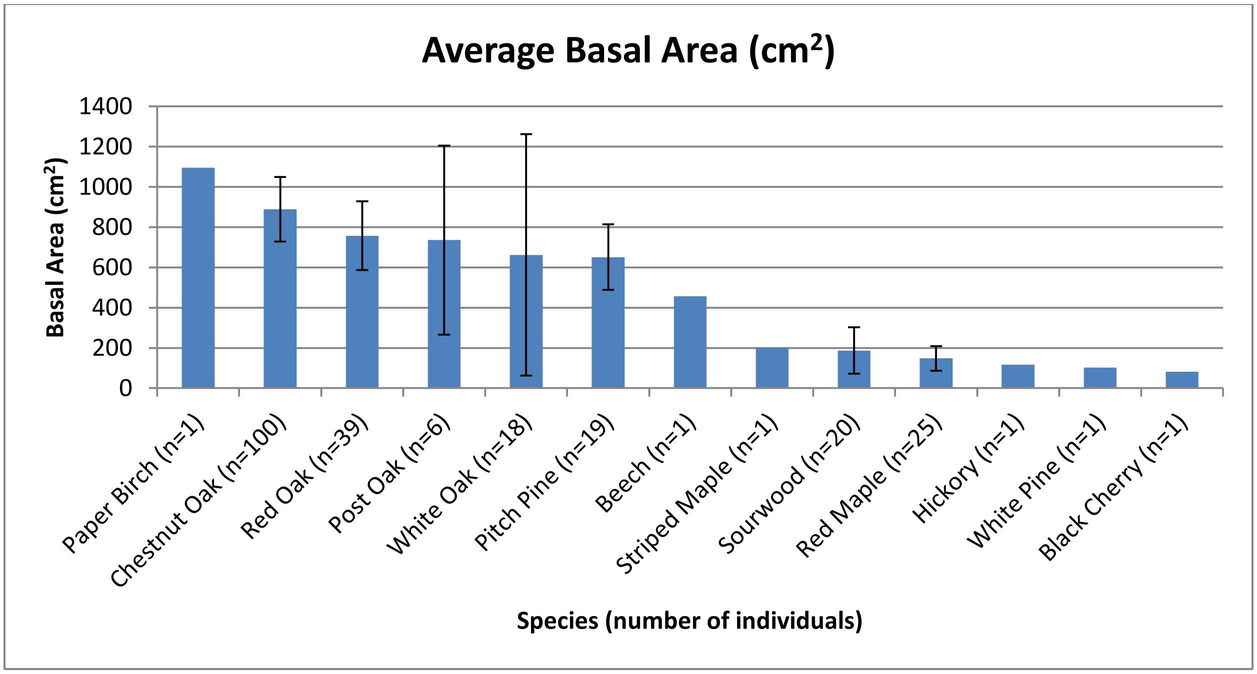
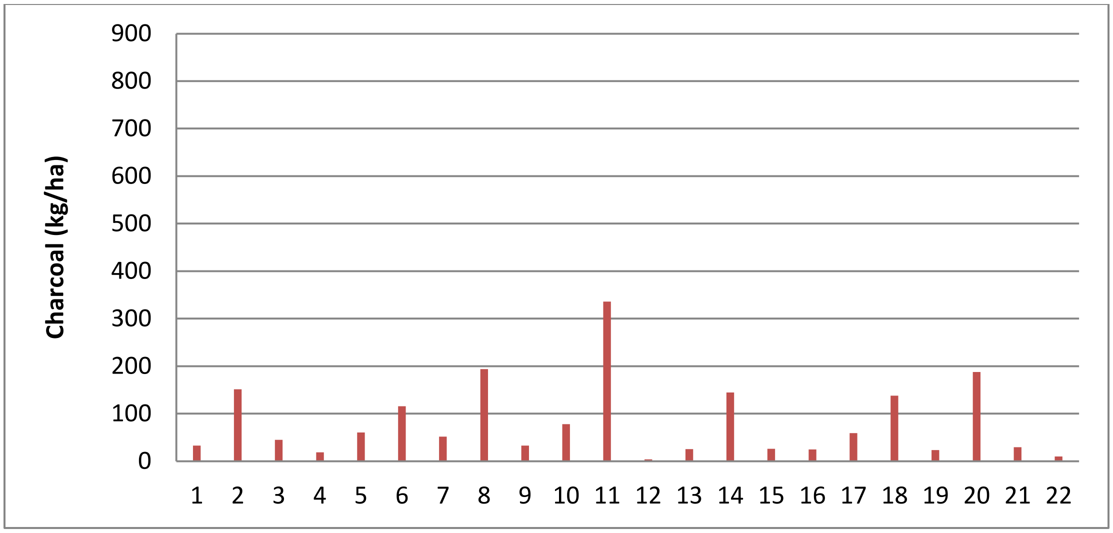
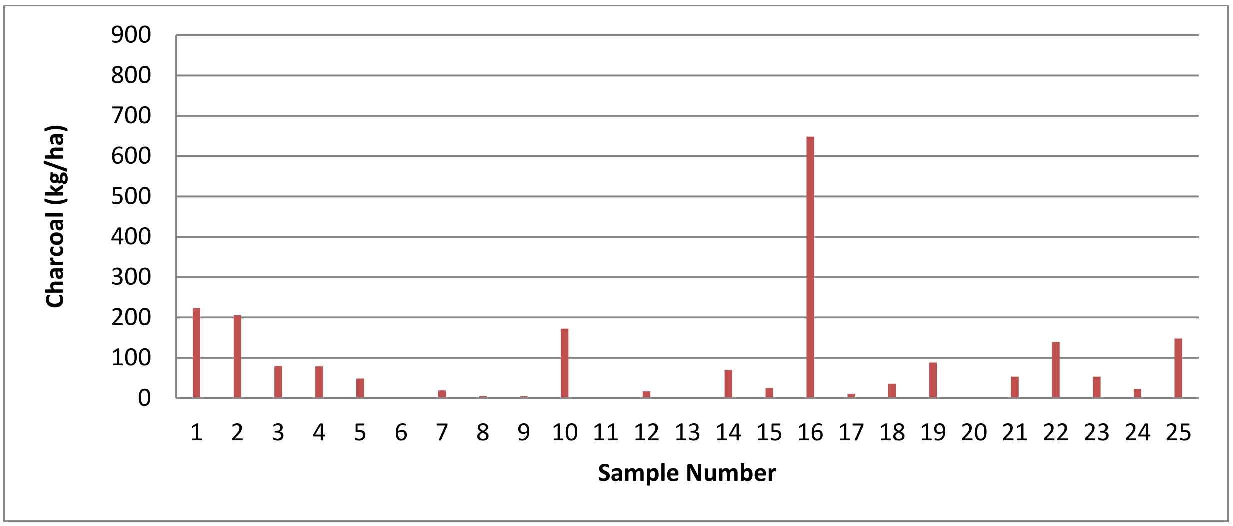


Figure 3.5. Average basal area for each species. Lower and upper 95% confidence intervals are represented by error bars. Only one individual was measured for species without error bars.





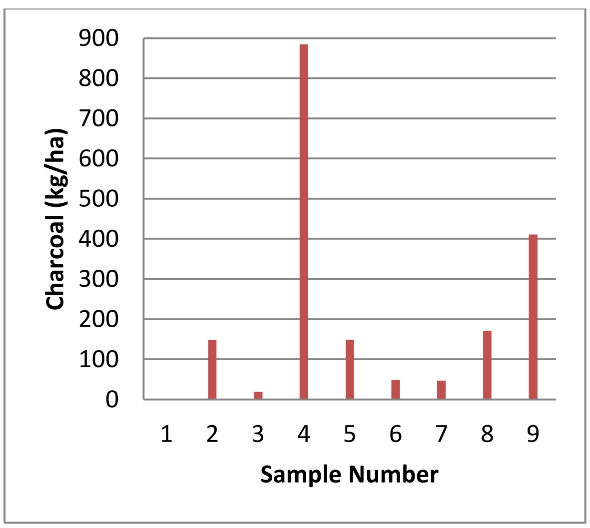


Figure 3.6. Charcoal quantities for each sample in all Middle Mountain transects combined. From top to bottom (MMT1, MMT2, MMT3)

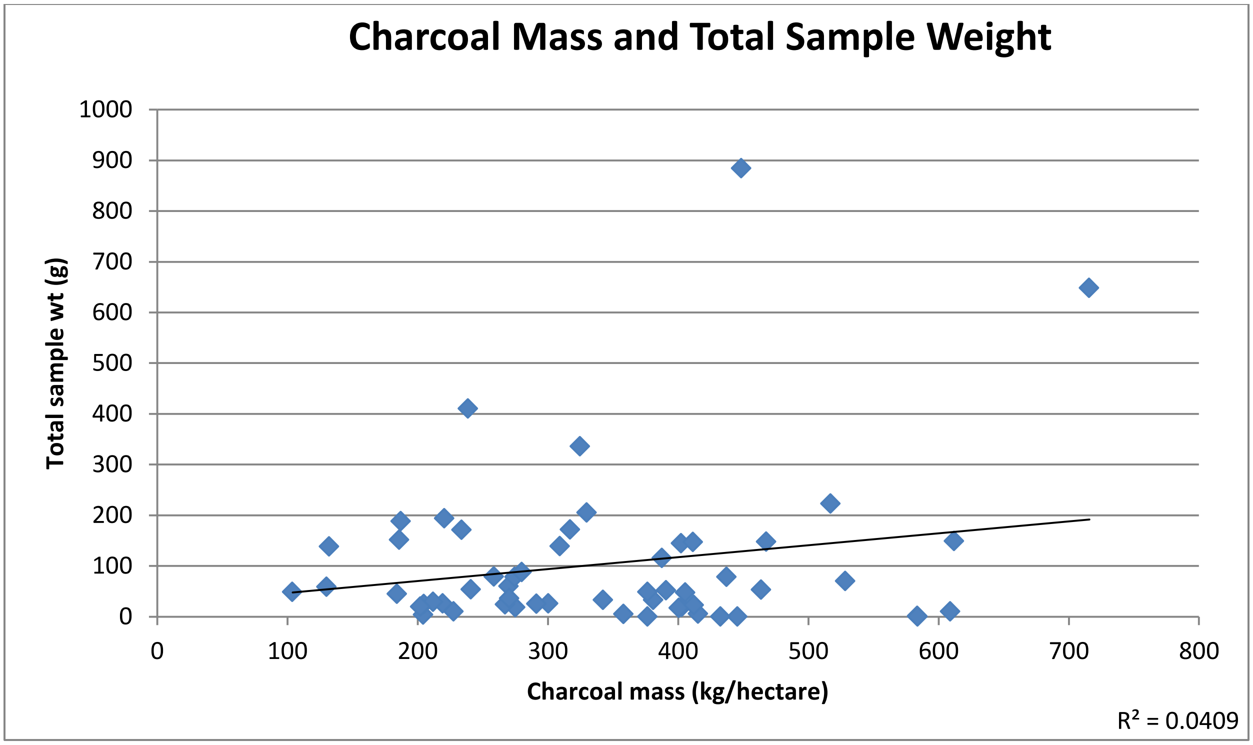


Figure 3.7. Calculated charcoal mass as a factor of total sample weight collected in the field.

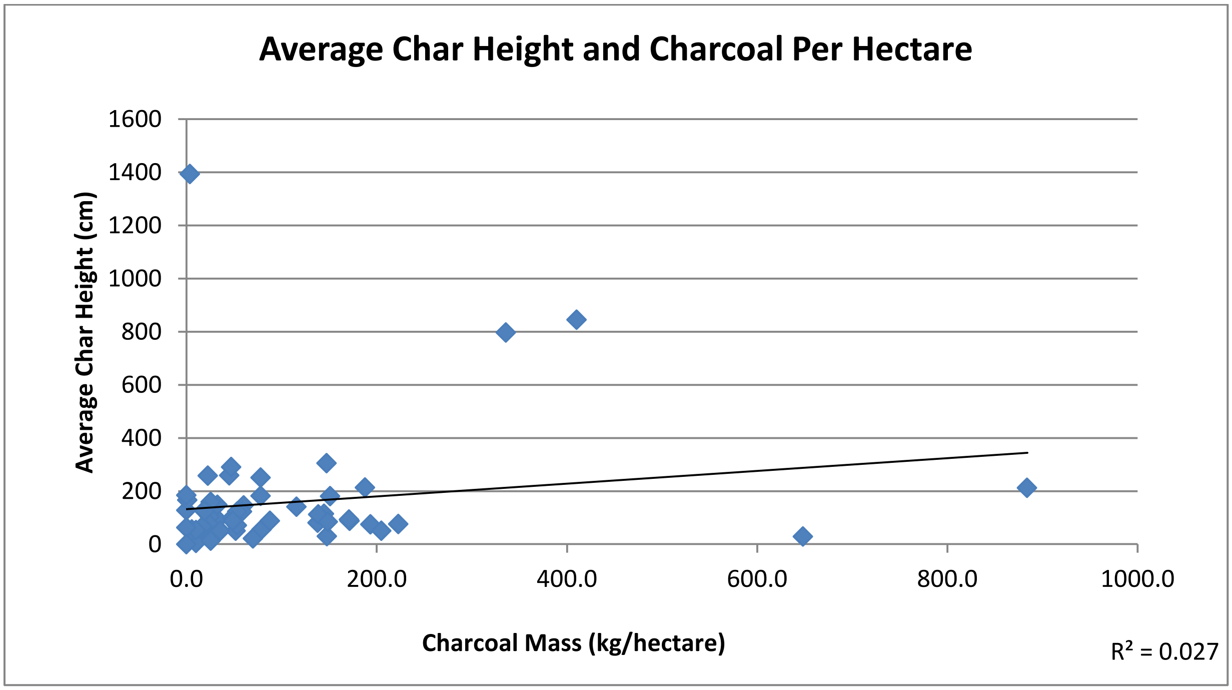


Figure 3.8. Average bole car height and its relationship to charcoal mass deposited following the prescribed fire.

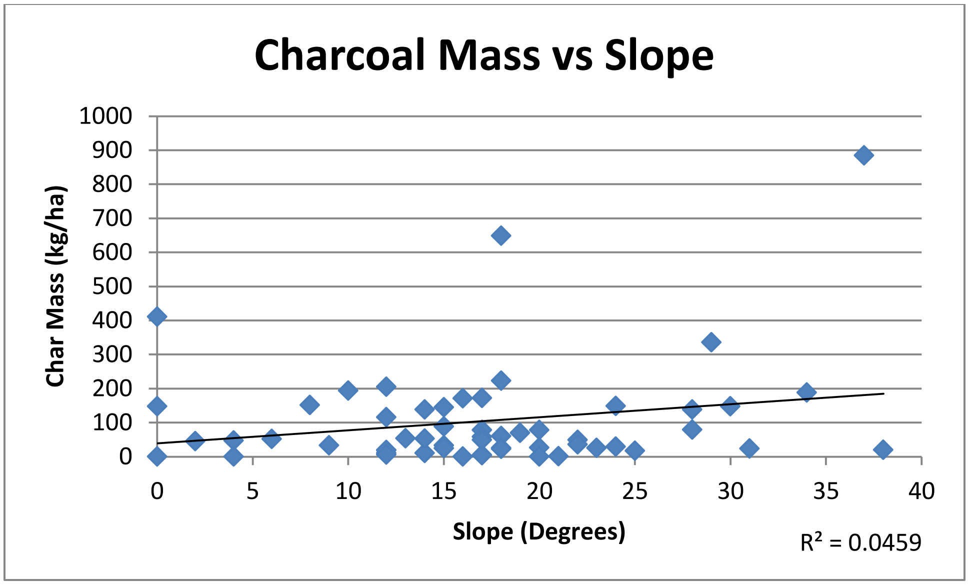


Figure 3.9. Relationship between charcoal mass in kg/ha and the measured slope at a sampling point.

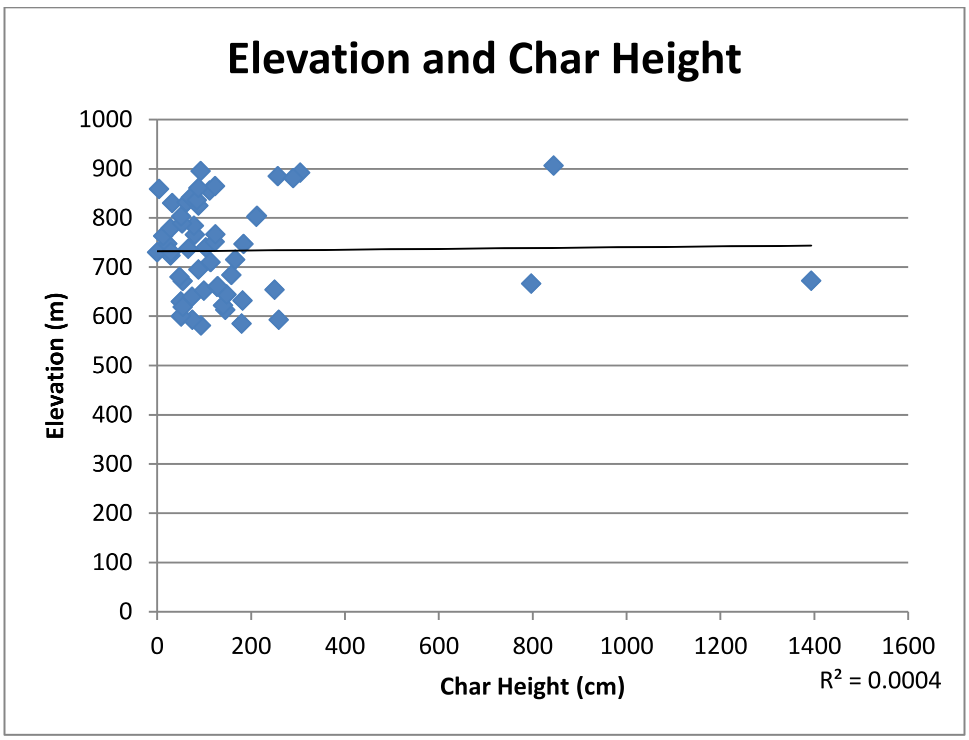
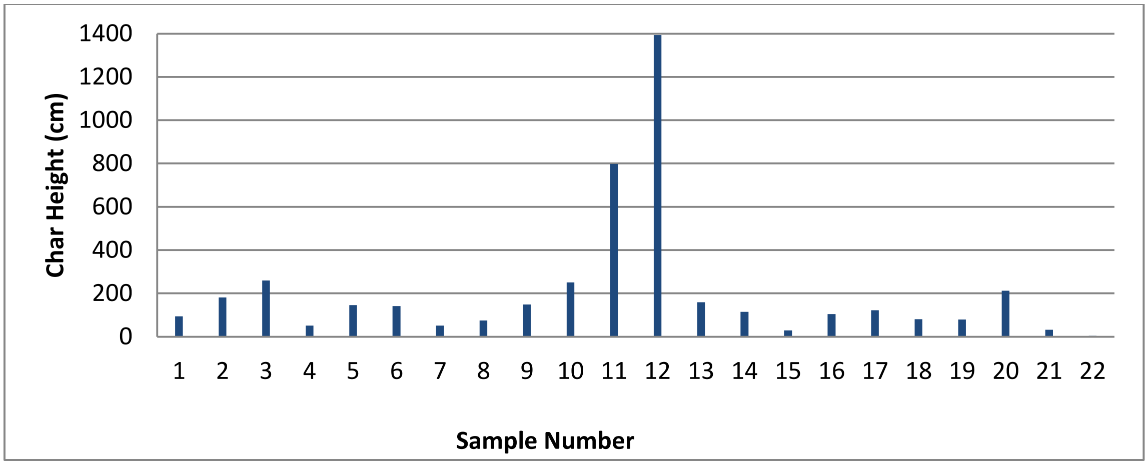
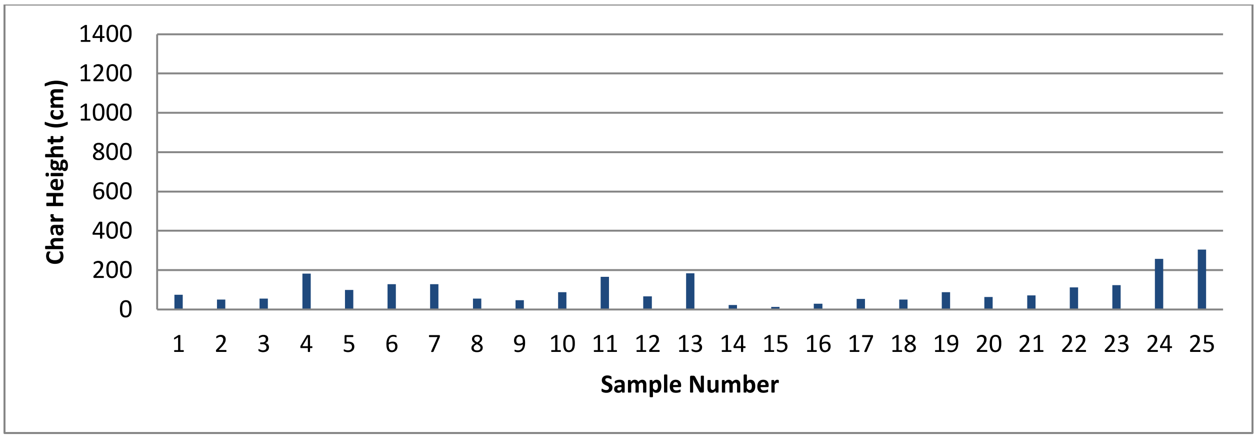


Figure 3.10. A scatterplot displaying the relationship between elevation and char heights observed on tree boles.





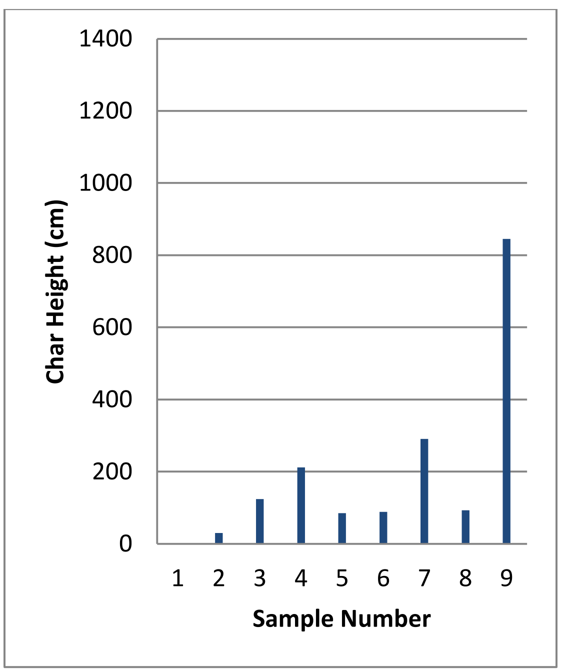


Figure 3.11 Graphic representations of char heights by transect and sample. From top to bottom (MMT1, MMT2, MMT3).

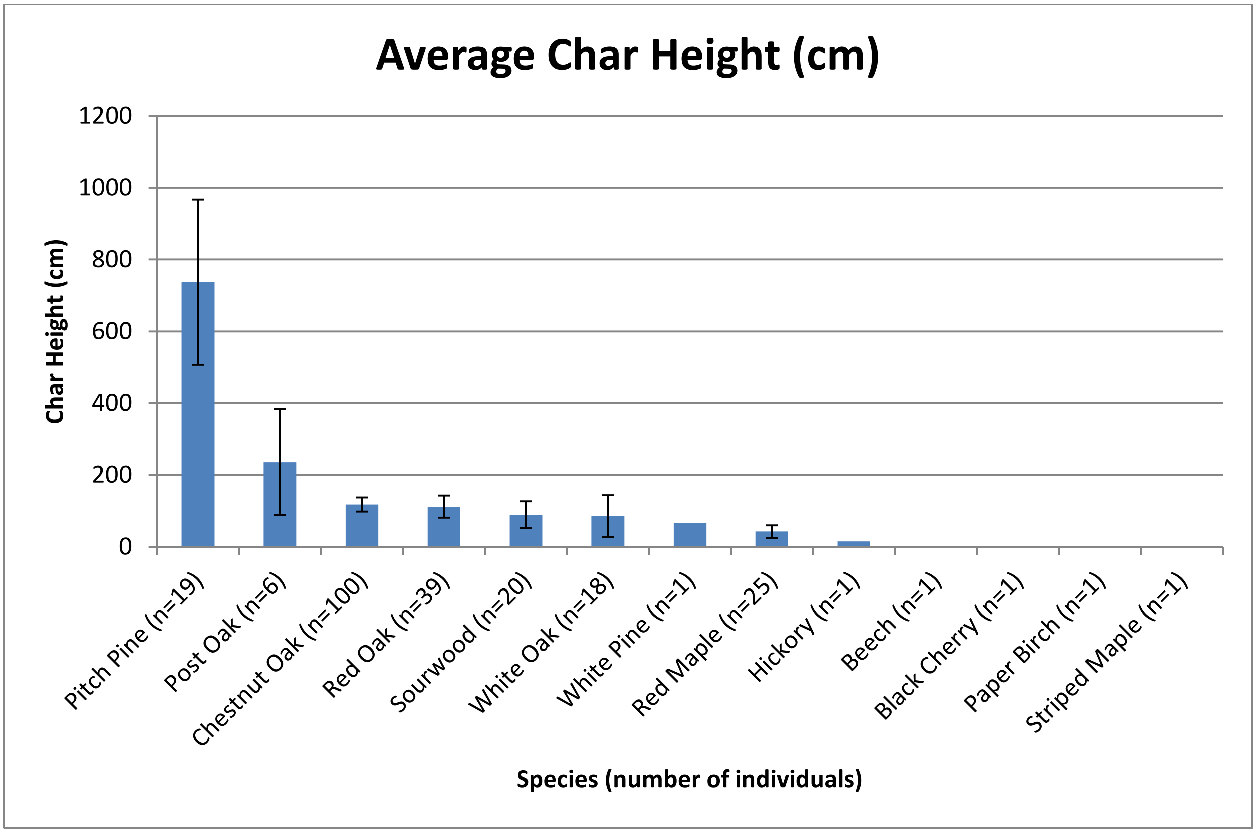
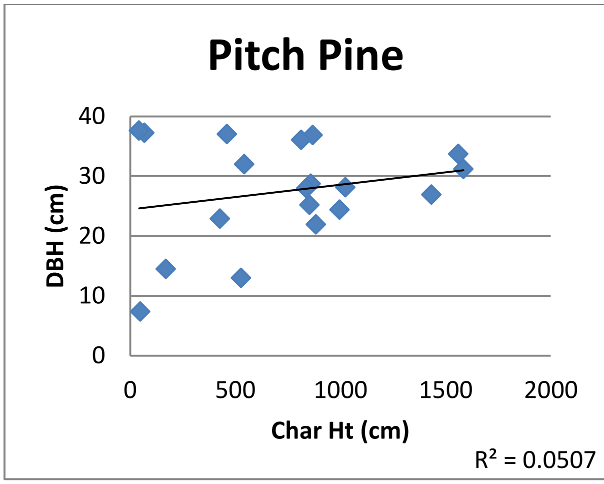
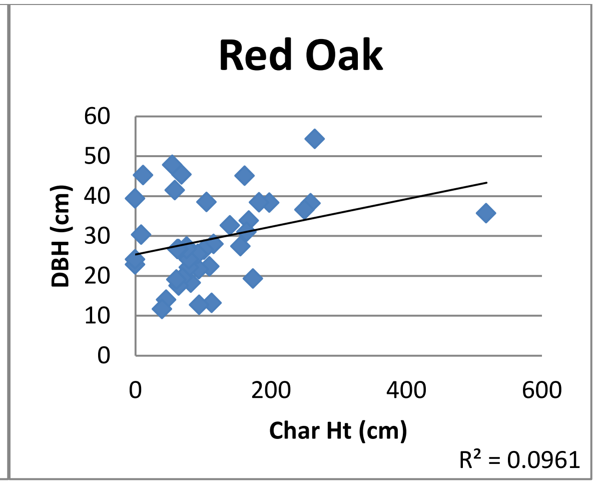
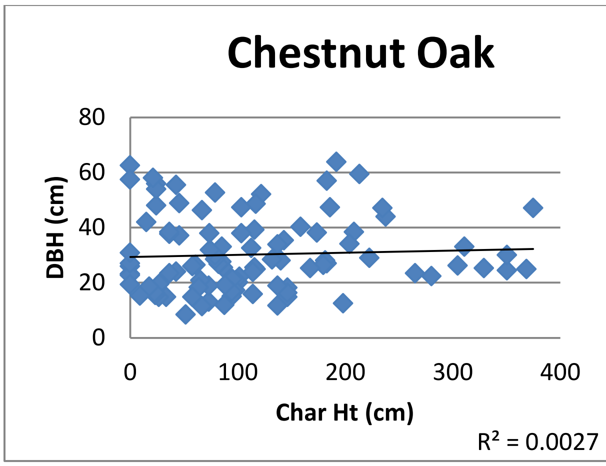
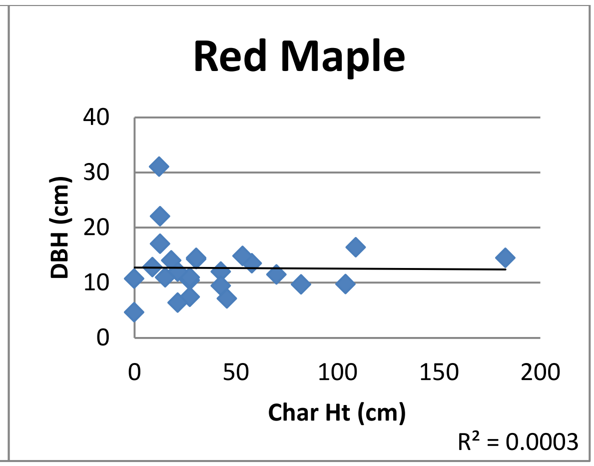


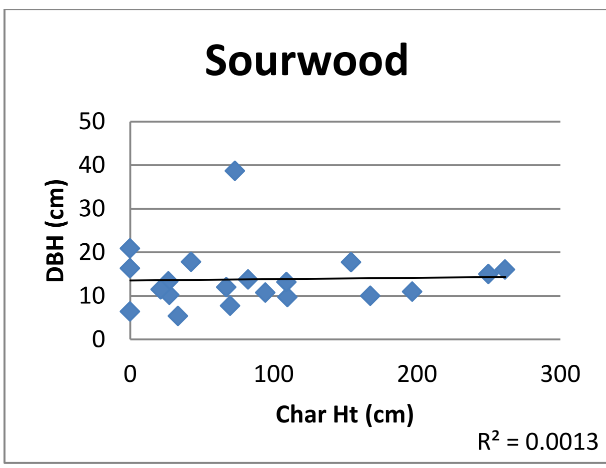
Figure 3.12. Average bole char height by species and number of individuals. Lower and upper 95% confidence intervals are shown by error bars. Species without error bars had only one species and species without an average char height were not charred.

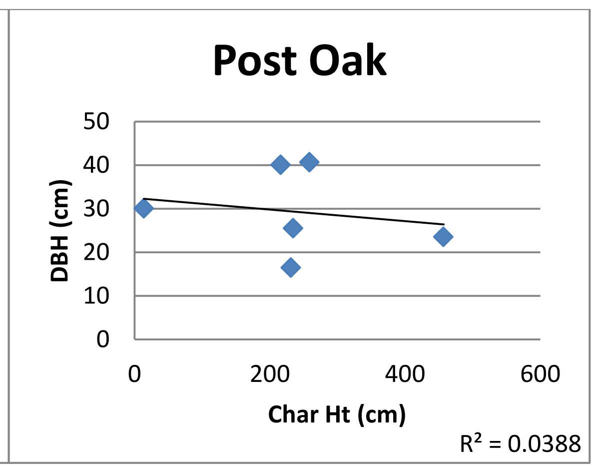

Pitch Pine
DBH (cm)
40
30
20
10
0
0
500
1000
1500
2000
Char Ht (cm)
R² = 0.0507


Red Oak
DBH (cm)
60
50
40
30
20
10
0
0
200
400
600
Char Ht (cm)
R² = 0.0961


Chestnut Oak
DBH (cm)
80
60
40
20
0
0
100
200
300
400
Char Ht (cm)
R² = 0.0027


Red Maple
DBH (cm)
40
30
20
10
0
0
50
100
150
200
Char Ht (cm)
R² = 0.0003


Sourwood
DBH (cm)
50
40
30
20
10
0
0
100
200
300
Char Ht (cm)
R² = 0.0013


Post Oak
DBH (cm)
50
40
30
20
10
0
0
200
400
600
Char Ht (cm)
R² = 0.0388

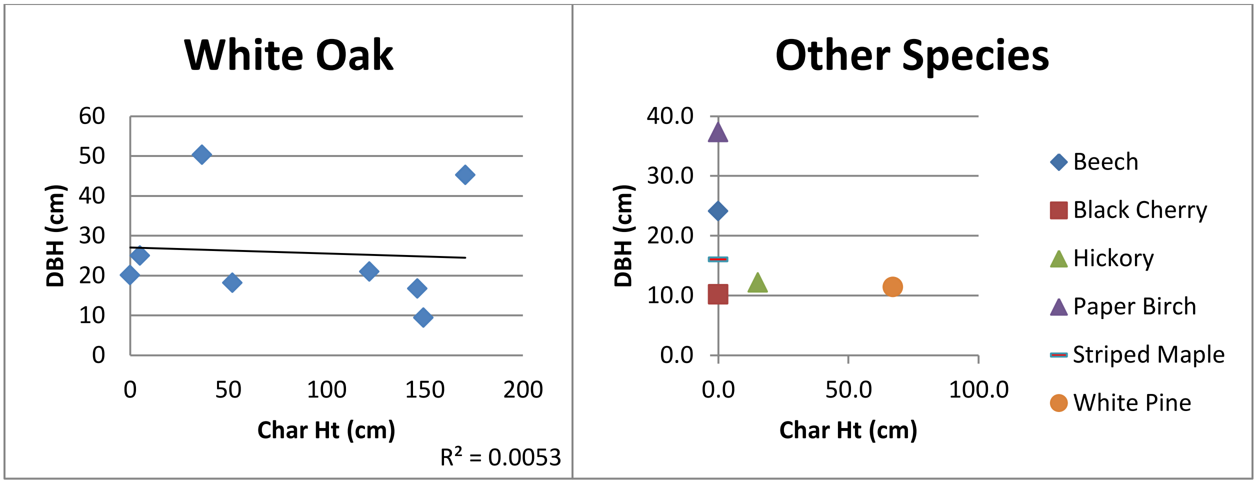


Figure 3.13. Species-level data comparing DBH (y-axis) to char height (x-axis). The "Other Species" graph shows tree species that were measured, but only one individual was present out of all samples.

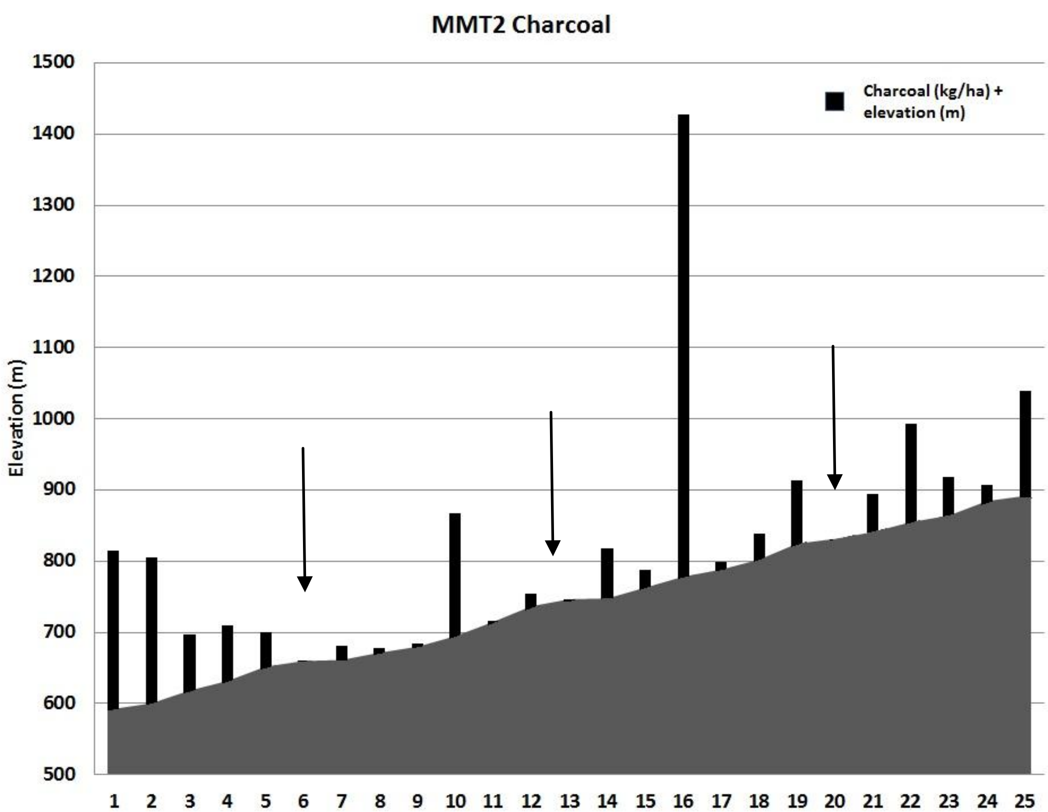


Figure 3.14. Graphic representation of increases and decreases in both slope and charcoal along MMT2 from lowest elevation (1) to highest elevation (25), noted by arrows. Gray area represents changes in slope along the transect from point to point, while black bars represent the amount of charcoal found on the surface (calculated by adding elevation data for each sample to charcoal load in kg/ha).

Chapter 3 Tables

Transect	Coordinates (start) UTM 17N	Coordinates (end) UTM 17N	Total Length (m)	Samples
T1	609682.685, 4210058.62	608861.739, 4210714.382	1052.5	22
T2	609427.269, 4209557.902	608186.9, 4209884.631	1283.4	25
T3	607895.738, 4208825.132	607820.525, 4209232.366	415	9
Totals			**2750.9**	**56**

Table 3.1: Start and end coordinates, total length, and number of samples for each transect used in our study.

Species	Number of Individuals	Average Char Height (cm)	Average DBH (cm)	Average Basal Area (cm^2)
Beech (n=1)	1	0.00	24.13	457.30
Black Cherry (n=1)	1	0.00	10.20	81.71
Chestnut Oak (n=100)	100	117.40	30.58	888.87
Hickory (n=1)	1	15.24	12.19	116.75
Paper Birch (n=1)	1	0.00	37.34	1094.94
Pitch Pine (n=19)	19	737.07	27.50	650.66
Post Oak (n=6)	6	235.50	29.33	735.63
Red Maple (n=25)	25	42.28	12.68	147.68
Red Oak (n=39)	39	111.62	29.23	757.07
Sourwood (n=20)	20	89.38	13.82	187.14
Striped Maple (n=1)	1	0.00	16.00	201.11
White Oak (n=18)	8	85.25	25.74	661.96
White Pine (n=1)	1	67.06	11.43	102.61
Average		**115.45**	**21.55**	**467.96**

Table 3.2: A summary of species sampled with their count, average bole char height, average DBH, and average basal area.

Species	Number of Individuals	Average DBH (cm)	Standard Deviation (cm)	Stderr	Lower 95%	Upper 95%
Beech (n=1)	1	24.13				
Black Cherry (n=1)	1	10.20				
Chestnut Oak (n=100)	100	30.58	14.09	1.41	27.79	33.38
Hickory (n=1)	1	12.19				
Paper Birch (n=1)	1	37.34				
Pitch Pine (n=19)	19	27.50	8.74	2.01	23.28	31.71
Post Oak (n=6)	6	29.33	9.56	3.90	19.30	39.37
Red Maple (n=25)	25	12.68	5.33	1.07	10.48	14.88
Red Oak (n=39)	39	29.23	10.60	1.70	25.79	32.67
Sourwood (n=20)	20	13.82	7.05	1.58	10.52	17.12
Striped Maple (n=1)	1	16.00				
White Oak (n=18)	8	25.74	14.35	5.07	13.74	37.74
White Pine (n=1)	1	11.43				
Average		**21.55**	**9.96**	**2.39**	**18.70**	**29.55**

Table 3.3: Species-level DBH information and statistics.

Species	Number of Individuals	Average Basal Area (cm2)	Standard Deviation (cm)	Stderr	Lower 95%	Upper 95%
Paper Birch (n=1)	1	1094.94				
Chestnut Oak (n=100)	100	888.87	808.54	80.85	728.44	1049.31
Red Oak (n=39)	39	757.07	526.13	84.25	586.52	927.63
Post Oak (n=6)	6	735.63	447.54	182.71	265.97	1205.30
White Oak (n=18)	8	661.96	717.16	253.56	62.39	1261.52
Pitch Pine (n=19)	19	650.66	338.20	77.59	487.65	813.67
Beech (n=1)	1	457.30				
Striped Maple (n=1)	1	201.11				
Sourwood (n=20)	20	187.14	245.36	54.86	72.31	301.97
Red Maple (n=25)	25	147.68	147.51	29.50	86.79	208.56
Hickory (n=1)	1	116.75				
White Pine (n=1)	1	102.61				
Black Cherry (n=1)	1	81.71				
Average		**467.96**	**461.49**	**109.05**	**327.15**	**823.99**

Table 3.4: Species-level basal area information and statistics.

Species	Number of Individuals	Average Char Height (cm)	Standard Deviation (cm)	Stderr	Lower 95%	Upper 95%
Pitch Pine (n=19)	19	737.07	476.82	109.39	507.25	966.87
Post Oak (n=6)	6	235.50	140.83	57.49	87.71	383.29
Chestnut Oak (n=100)	100	117.40	98.81	9.88	97.79	137.01
Red Oak (n=39)	39	111.62	94.80	15.18	80.89	142.35
Sourwood (n=20)	20	89.38	79.81	17.85	52.03	126.73
White Oak (n=18)	8	85.25	69.33	24.51	27.29	143.21
White Pine (n=1)	1	67.06			0.00	0.00
Red Maple (n=25)	25	42.28	41.48	8.30	25.15	59.40
Hickory (n=1)	1	15.24			0.00	0.00
Beech (n=1)	1	0.00			0	0.00
Black Cherry (n=1)	1	0.00			0	0.00
Paper Birch (n=1)	1	0.00			0	0.00
Striped Maple (n=1)	1	0.00			0.00	0.00
Average	**17.15**	**115.45**	**143.12**	**34.66**	**67.55**	**150.68**

Table 3.5. Char height information by species.