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Fuel Dynamics Across Southern Appalachian Landscapes

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FUEL DYNAMICS ACROSS SOUTHERN APPALACHIAN LANDSCAPES

A Thesis
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Clemson University

In Partial Fulfillment
of the Requirements for the Degree
Masters of Science
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by
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Accepted by:
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ABSTRACT

Although there have been several individual studies measuring hardwood fuels, across the central Hardwood Region and southern Appalachian Mountains, little is known of how hardwood fuels are distributed across the landscape. Understanding this distribution is essential for fire management planning. Previous studies suggest that the decay rate of litter and fine woody fuel is greater on mesic sites as compared to dryer sites. In the southern Appalachian Mountains, northeast facing slopes and protected bottoms are generally the more mesic sites, while southwest facing slopes and exposed ridge tops receive sunlight for longer periods and should be more xeric.

The objectives of this study were to measure the annual accumulations and decomposition of leaf litter, fine woody fuel and total fuel loadings on undisturbed sites across different topographical positions in the southern Appalachian Mountains. The study site was located in Rabun County Georgia on the Warwoman Wildlife Management Area (WWMA). There were five "treatments" used in this study, representing five topographic positions: ridge tops and middle slopes, and lower slopes on northeast (325^{0}- 125^{0}) and southwest (145^{0} - 305^{0}) aspects. Sites with lower slope positions and northeast aspects were considered more productive than those with middle slope and southwest aspects, because they are more protected (shaded) and should have had greater soil moisture. Ten plots (replicates) were established at each topographic position for a total of 50 plots.

The results suggest that there are few differences in accumulation and decomposition of leaf litter, 1-, 10-, and 100-hour fuels among different topographical positions. The only exception was coarse woody debris (CWD), which was significantly more on northeast facing slopes (26.6 t/ha) compared to all other slope positions (10.8 t/ha). Ericaceous shrubs were present on 74% of plots and could have influenced the results. Further study is needed to determine if ericaceous shrubs impact both the accumulation and decomposition of hardwood fuels across the southern Appalachian Mountains.

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CHAPTER I

INTRODUCTION

Fire has been a dominant disturbance type shaping the landscape of the southern Appalachian Mountains for millennia (Graham and McCarthy 2006, Stanturf et al. 2002, Van Lear and Waldrop 1989, Lorimer 1992). Before the advent of man, 12,000 to 14,000 years before present, fires were ignited by lightning, occurring mainly during the thunderstorm season in spring and summer (Stanturf et al. 2002). After the emergence of man, the fire season was extended beyond spring and summer, and in addition fire frequency and the extent of area burned also increased. Before European settlement, fire return intervals ranged between 2.8 and 14 years. After European settlement, fire frequency increased to intervals of two to 10 years (Cutter and Guyette 1994, Sutherland 1997, Stanturf et al. 2002).

For approximately 70 years, fire has been suppressed in southern Appalachian ecosystems, and the result of fire suppression has been a build up of fuels and an expansion of ericaceous shrubs such as mountain laurel (*Kalmia latifolia*) and rhododendron (*Rhododendron maximum*) (Vose and Swank 1993, Vose 2000, Kolaks 2004, Van Lear and Watt 1992). Increased fuel loadings and the expansion of ericaceous shrubs, coupled with an increasing human population in the southern Appalachian Mountains, have primed these ecosystems for intense, severe fires. Mountain laurel and rhododendron, though hard to ignite, once ignited can burn with erratic fire behavior resulting in mixed severity or even stand replacement fires (Stanturf et al. 2002, Waldrop and Brose 1999, Waldrop et al. 2007). Harrod et al. (2000) suggest that reductions in fire frequency through active fire suppression and changing patterns in land uses have resulted in a decrease in fire frequency, and thus increasing stand densities. The result has been a less diverse and productive understory. In addition, an increase in canopy density and decreasing grass cover have combined to shift the disturbance regime from frequent low intensity surface fires to infrequent but catastrophic crown fires (Harrod et al. 2000).

The southern Appalachian Mountains have diverse topography (Graham and McCarthy 2006), which produce a complex mosaic of site types. Each site type is affected by soil and topography (slope, slope position, elevation and aspect), which influence temperature, light, and moisture (Coopenheaver et al. 2006, Graham and McCarthy 2006, and Waldrop et al. 2007). These variables produce drastically different fuel conditions that change both temporally and spatially. The fuel dynamics of this area can be as complex as the mountains themselves. Rubino and McCarthy (2003) stated that stand composition varies drastically with topographic gradient resulting in different edaphic climaxes that can be found within close proximity of one another. This mosaic of vegetative communities can change fuel characteristics over very short distances (< 100 meters) with changing microclimate (Graham and McCarthy 2006).

There exists a need to understand how hardwood fuels are distributed across southern Appalachian landscapes. An understanding of how fuels accumulate and decay would give fire planners the knowledge to apply appropriate silvicultural treatments to obtain desired management objectives. There have been several studies examining fuel loads in the southern Appalachian Mountains and central Hardwood Region including, dynamics of coarse woody debris (Waldrop 1996), fuel loading in the central Hardwoods Region (Kolaks et al. 2003), evaluation of coarse woody debris and forest vegetation

(Rubino and McCarty 2003), coarse woody debris dynamics in the southern Appalachians (Webster and Jenkins 2005), and forest floor fuel dynamics in mixed-oak forest (Graham and McCarthy 2006). These studies yielded useful information about fuel loadings in these ecosystems enabling fire planners to use the data directly for fire planning or in fire behavior modeling (Waldrop et al. 2007), but none of these studies analyzed how accumulations and decomposition of fuels differed across differing topographical gradients. Graham and McCarthy (2006) stated that varying microclimates resulting from highly dissected landscapes produce very different fuel conditions dependent on slope position, percent slope, and slope aspect, all of which effect moisture. Moisture in turn influences both the productivity (inputs) and decay (loss) rates of fuel on these sites.

In a recent study, fuels on disturbed and undisturbed sites in the southern Appalachian Mountains, Waldrop et al. (2007) measured fuel loadings on 1008 plots. Among these plots, 705 were undisturbed sites. Total basal area for undisturbed sites averaged 29.1 m^2/ha and was higher on lower slope positions and decreased towards the ridge tops. Litter on these plots was heavier on ridge tops and decreased downhill in both the northeast and southwest slopes, suggesting that decomposition exceeded leaf litter inputs on the more mesic sites. This study found that there was 12% less litter on northeast lower slopes (3.8 t/ha) than on ridge tops (4.2 t/ha). There were significantly less 1-hour fuels on ridge top positions (0.6 t/ha) as compared to the other slope positions (0.7 t/ha). There were also no significant differences in 1000-hour fuel loadings on undisturbed sites, though there was on average more 1000-hour fuels on northeast lower slopes (44 t/ha) as compared to other slope positions (35 t/ha). There was more mountain laurel on southwest slopes and rhododendron was most common on northeast lower slopes.

Previous studies suggest that differing decomposition rates balance the loading of downed woody fuels across topographic gradients (Lang and Forman 1978, Abbott and Crossley 1982, Waldrop 1996, Kolaks et al. 2003, Waldrop et al. 2005, Webster and Jenkins 2005, Graham and McCarty 2006, Waldrop et al. 2007). However, inputs and decay rates of leaf litter and fine and coarse woody fuels have never been measured across differing topographic gradients. The overall objective of this study was to measure inputs and decomposition rates of leaf litter and fine and coarse woody fuels across a topographic gradient in the southern Appalachian Mountains. Specific objectives include:

1. to determine the annual input of leaf litter and woody fuels at different topographic positions in the southern Appalachian Mountains,
2. to determine the decomposition rate of leaf litter and woody fuels at different topographic positions in the southern Appalachian Mountains, and
3. to compare total fuel loading on undisturbed sites at different topographic positions in the southern Appalachian Mountains.

CHAPTER II

LITERATURE REVIEW

Fire History

The southern Appalachian Mountains have been revered for their vast diversity of vegetation; this diversity was the result of many different variables including a mosaic of soils, and topography (slope, slope position, elevation, and aspect), that influenced temperature, light, and moisture. Other influences include weather patterns and various disturbances (Copenheaver et al. 2006, Waldrop et al. 2007). Until approximately 70 years ago, fire had been the most prevalent disturbance type affecting many plant communities in the southern Appalachian Mountains for millennia (Graham and McCarty 2006, Waldrop et al. 2007). Today fire has been replaced by land clearing for urban development as the most common disturbance type in southern forest (Stanturf et al. 2002). Before the emergence of man into the southern Appalachian Mountains, spring and summer were the primary burning seasons with fires ignited by lighting from thunderstorms. Fire regulated the evolution of fire tolerant species with traits such as high crowns, thick bark, serotinous cones, and the ability to re-sprout after a fire, all of which are necessary in ecosystems dominated by frequent low-intensity fires (Van Lear 1996). There are several species in the southern Appalachians that are dependent on fire for their reproduction, including most oak species as well as some pines, most notably Table Mountain pine (*Pinus pungens)* and pitch pine (*Pinus rigda*). The adaptation of serotinous cones in Table Mountain pine allows the seeds to be dispersed when the seeds of other pines have been destroyed (Stanturf et al. 2002). After the canopy is opened by fire, many but not all, natural pine stands develop in the southern Appalachians and, without frequent low intensity fires, hardwoods would dominate (Van Lear 1996).

Approximately 12,000 years ago the frequency of fires drastically increased with the emergence of man (Native Americans) into the Appalachian Mountains (Van Lear and Waldrop 1989). DeVivo (1991) reported that fire was the principle instrument used by Native Americans to clear vegetation, open the forest to improve visibility, improve forage, and control weeds. Native Americans also burned to lessen the danger of wildfire near or around their villages. Fires were set at frequent intervals to promote the growth of desirable species such as blueberries (*Vaccinium vacillans*), which are beneficial to both man and wildlife. The most widespread use of fire was most likely in the clearing of land for agriculture, and by approximately 1000 to 800 A.D., Native Americans were planting corn, beans, and squash (DeVivo 1991, Stanturf et al. 2002). European settlement into the region in the late 1800's and early 1900's had an even more influential effect, than that of the Native Americans, on the vegetation with widespread logging, land clearing, mining, and large scale high-intensity fires from logging slash.

By the 1920's the U.S. Forest Service was opposed to the use of fire in the forest, including low intensity prescribed fire. There was no thought of the ecological benefits of fire when the movement for fire suppression started (Van Lear and Waldrop 1989). Some species such as Table Mountain pine and pitch pine are less plentiful now than in the past due to fire suppression over the past 70 years, and fears are these species could become endangered (Van Lear 1996). Today, our public lands are maintained under wildfire suppression and are overstocked and crowded due to harvesting restrictions, which leads to increased fuel loadings and an increased probability of uncontrollable wildfire. Under wildfire suppression, there has also been a species composition change from oaks to more shade tolerant and fire intolerant species such as red maple, white pine, and blackgum. Although these shade tolerant species are susceptible to fire as seedlings, they become more resistant as they grow older (Van Lear and Watt 1992, Kolaks 2004). Yellow-poplar (*Liriodendron tulipifera*) at >5cm (2 in.) diameter at breast height (d.b.h.) becomes as fire resistant as oaks (Waldrop and Van Lear 1989, Van Lear and Watt 1992). In addition to the succession of shade tolerant hardwoods, there has also been an expansion of volatile understory species such as mountain laurel and rhododendron (Vose and Swank 1993, Vose 2000, Kolaks 2004, Van Lear and Watt 1992). These understory species, though hard to ignite, can burn with extreme fire behavior once ignited, resulting in mixed severity or stand replacement fires. Ericaceous shrubs can act as vertical fuels allowing fire to climb into the canopy (Waldrop and Van Lear 1989). In addition, these ericaceous shrub species form impenetrable thickets, often preventing desirable oak and pine species from becoming established (Waldrop and Brose 1999, Waldrop et al. 2007). Of particular concern are the number of retirement communities and single family homes being built in the area. There is an increased danger of wildfire, because the major causes of wildfire in the region are debris burning and incendiary fires. Escapes of these fires become more common with increased human population growth (Waldrop et al. 2007).

Decomposition Dynamics

The decomposition of litter is vital to the cycling of forest nutrients. On sites with slow rates of litter decomposition, there can be an accumulation of large nutrient stocks in the soil's surface horizons, and nutrient limitations for primary producers (Melillo et al. 1982). The actual process of litter decomposition is very complex, more complex than can be covered by the scope of this study. Rates of decomposition show great variation as a function of structure, chemical composition of the material being decomposed (substrate quality), the abiotic environment in which decomposition is occurring (temperature, moisture, and aeration status), and the extent that the substrate is exposed to heterotrophs, including both microbial and faunal (Robertson and Paul 2000). Plant tissues vary widely in their litter chemistry and this causes great variation between their decomposition rates, with the largest differences in decomposition found between woody and non-woody tissues (Arets 1997). Howard and Howard (1979) stated "comparisons made between species in the same year, or between years for the same species, have the problem that different species decompose at different rates, and the same species may decompose at different rates in different years because of environmental differences." All these factors combine to cause decomposition rates to vary greatly both between and within ecosystems (Robertson and Paul 2000).

Edmonds (1990) suggests that there are three phases in the decomposition process of fine litter, such as needles and leaves. Phase one, the first few months, is the loss of the labile or fast fraction (sugars and starches) to microbial assimilation or leaching. In phase two, the structural material, such as primary cell wall polymers (cellulose) is broken down. Then finally phase three, where there are very slow decreases in mass because this phase is dominated by the decomposition of lignin. Woody litter goes through a similar process but has one additional stage. There is a time lag before any weight loss or change in specific gravity occurs. This time lag is dependent on the size of the substrate (the smaller the surface to area ratio the longer the time lag). Previous studies have shown that woody litter on average decays at rates approximately 2.5 times slower than does leaf litter material (Abbott and Crossley 1982).

In the early stages of decomposition, chemical properties of the litter regulate the rate of decay (BilGili 1998). Pausas (1997) found that the decomposition rate was not constant, but rather lower in the winter and higher in the spring and autumn. Mackensen and Bauhus (1999) stated that when the fiber saturation point drops below approximately 30% (moisture content of dry mass) there is no water available to fungi and other decomposing organisms, and that very high moisture contents impose physiological barriers to fungal growth, but a moisture content of 30-160% was optimal for most wood decaying organisms. Howard and Howard (1979) reported that low litter moisture content, predominantly oak, from material collected in July and September and again in May had moisture contents of 14%, 24%, and 20%, respectively. These low moisture contents were associated with the virtual cessation of respiration, whereas moisture contents of 27% or greater had no effect on respiration rates. The daily and seasonal fluctuations in moisture depend on the size, position, microclimate, overstory vegetation and the materials stage of decay. Dawyer and Merriam (1979) found that the moisture content on lower sites was both higher and less variable temporally when compared other site positions. Moisture content is negatively correlated with wood density. Materials in earlier stages of decay have lower moisture content than do materials in later stages of decay (Zhou et al. 2007).

Just as moisture content, temperature acts to impede fungal growth in the same manner. At temperatures above 40 ^{0}C most wood decaying organisms can not reproduce. The most favorable temperatures for fungal reproduction in wood is between 25-30 ^{0}C, with the temperature between 13 ^{0}C and 30 ^{0}C the Q_{10} for fungal respiration to be between 2 and 3, so the respiration increases by a factor of 2-3 for every 10 ^{0}C increase in temperature (Mackensen and Bauhus 1999).

Forest Floor Dynamics

Litterfall is a vector for both energy flow and nutrient cycling, making it one of the most important processes in forested ecosystems. In temperate deciduous forest approximately 50% of the annual aboveground biomass produced is leaf material, making it a major component of total litterfall, with the remainder of the litterfall material being comprised of woody limbs, bark, fruit, and reproductive parts, and in these same forests, litterfall accounts for 55 to 90% of the total nutrient transfer back into the ecosystem through the decay process (Grigal and Grizzard 1975, Muller and Martin 1983). Numerous studies have indicated that approximately 70% of the annual uptake of macronutrients (N, P, K, Ca, and Mg) is returned thru litter fall (Lang 1974, Grigal and Grizzard 1975, Muller and Martin 1983).

There have been many studies over the past thirty years monitoring fuel accumulations/inputs over a variety of slope positions, aspects, cover types, and elevation gradients. There were no standardized methods of separating the different components of litterfall (leaves, woody fuels (limbs and twigs), bark, flowers, and reproductive parts); therefore there are variations in the results of these studies. In addition, the lack of uniformity between different studies makes it difficult to compare the results from one forest to another.

Lang (1974) conducted a study on the William L. Hutcheson Memorial Forest (WLHMF), a mixed oak forest the New Jersey Piedmont. The mean annual precipitation for WLHMF is 112 centimeters and no mean annual temperature was reported. The study areas has not been unnaturally disturbed for at least two centuries, and was described as approximating climax, near virgin, and mature. Litter was collected in sixteen 0.67 meter square litter traps with 15 centimeter high sides and fiberglass mesh bottoms. After collection, the litter material was separated into three separate components: leaf material, flower and fruit material, and woody branches. The two year average litter deposition was 648.1 grams (oven dried weight) per meter square with 466.3 grams of leaf material, 71.2 grams of flower and fruit material, and 110.7 grams of woody branch material. In order to calculate the decay rate of leaf and woody branch material, white oak (*Quercus alba*) leaves, and small red maple and black oak (*Quercus velutina*) branches 1.0-2.5 centimeter in diameter, were tethered together and laid flat on the forest floor. The white oak leaves were on separate tethers from the woody branch material. White oak leaves lost 69 percent of their initial mass in one year, yielding a 100 percent turnover time (t_{100}) for the white oak leaves of 1.5 years. In contrast the red maple branches lost between 16-24 percent of their initial mass while black oak branches lost between 10-15 percent of their initial mass, yielding a 100 percent turnover time (t_{100}) for the woody branches of 4 years.

In a similar study, Rochow (1974) collected litterfall in the Ashland Wildlife Area (AWA), a mixed oak forest, in the southeast corner of Boone County, Missouri for three years: 1968, 1969, and 1970. White oak is the most dominant species followed by red oak groups on the AWA. The AWA is characterized by elevations ranging from 175 to 245 meters above sea level, with a mean annual temperature of 12.8 ^{0}C, and mean annual precipitation of 94 centimeters a year. This study used a much different technique for litter collection. In a prior study, seventy-five 0.08 ha plots had been sampled. For this study 18 of the 75 original plots were chosen for detailed analysis. Two eight meter square sub-plots were staked within the 18 sub-plots and the residual litter material was sprayed with aerosol paint during August and September of 1968, just prior to litterfall. The painted material served as a way to identify new from old material. The study plots were separated by cover type and the leaf litter grand mean was 349.1 grams (dry weight) per meter square, and woody material at 107.6 grams (dry weight) per meter square. Rochow defined leaf litter as (leaves, flowers and fruit), and woody litter as (twigs, branches, and bark). It was suggested that decay rates were generally greater on mesic and bottomland plots compared to upland plots. One reason for the higher decay rates was species composition; the more mesic sites were dominated by *Ulmus* spp., *Acer* spp., *Fraxinus* spp., and mesic *Carya* spp. and all exhibit greater decay rates than upland *Quercus* species. The 100 percent turnover time (t_{100}) for leaf litter was 2.9 years and for woody fuels 4.3 years. This is a longer turnover time for leaf material than those reported by Lang, but the same turnover time for woody material.

Orndorff and Lang (1981) conducted a study in the Allegheny Mountains of West Virginia in the Coopers Rock State Forest (CRSF). The CRSF is a second growth forest of mixed hardwood, is characterized by elevations ranging from 262 to 792 meters above sea level. The mean January and July temperatures are -1 and 20 ^{0}C respectively with a mean annual precipitation of 140 centimeters per year. Two stands were chosen on southwest facing slopes because they were representative of local topography and forest cover. The slope percent ranged from 5 to 40 percent with a median slope percent for stand one at 27 percent and 35 percent for stand two. The accumulation of leaf litter averaged 336.0 grams per meter square dry weight for both stands. The mean annual mass loss for leaves confined in litter bags was determined to be 38.3 percent of their initial mass. It was suggested by Orndorff and Lang (1981) that the down slope movement of leaves can alter both the accumulation and decay of litterfall material on sites with significant slopes. The down slope movement of leaves was measured in the CRSF by the use of three large enclosures ten meters by ten meters square with one meter high sides. Two of the enclosures were fenced on four sides with 2.5 centimeter wire mesh and the third enclosure only had mesh on three sides. The enclosure with three sides had the open side orientated upslope to catch leaves moving down slope. Prior to litterfall, there were no significant differences between litter accumulations in the enclosures. After litterfall the three sided enclosure had accumulated twice the amount of leaf litter than the two four sided enclosures. Results showed more litter was lost from steep mid-slope positions than is gained, and that valleys on less steep slopes are net accumulators of leaf litter. The shape of ridge tops shows wide variations in regards to leaf litter redistribution. On narrow ridge tops exposed to winds, leaf litter is readily lost to lower slope positions, where as gently sloping broad ridges act like valleys and collect large quantities of leaf litter. It was also suggested that on drier southwest facing slopes leaf litter is more easily blown about and moves down slope faster than leaf litter on more mesic northeast facing. The results of the down slope movement of leaves can be far reaching. The loss of leaf material from upper southwest facing slope positions can lead to a reduction in soil organic matter as compared to the base of the slope and northeast facing slope positions. In addition, soil nutrients may also be transported down slope, with elements such as calcium, phosphorus and nitrogen being found in higher concentrations in the soil at lower slope positions.

Muller and Martin (1983) collected litter fall in southeastern Kentucky on Lilley Cornett Woods (LCW) an old-growth and second-growth (35 year old stand) forest stratified by three slope positions (lower, mid, and upper slope positions). The LCW are characterized by elevations ranging from 335 to 600 meters above sea level with three distinct vegetative communities on old growth stands: 1) beech (*Fagus*) and beech-hemlock (*Tsuga)* dominated stands on lower slopes, 2) sugar maple (*Acer saccharum*) basswood (*Tilia*) dominated stands on mid-slope positions, and 3) chestnut oak (*Quecus prinus*)-red maple dominating upper slope and ridge top positions. The vegetative communities on the second growth stands were very similar with more yellow-poplar and eastern redbud (*Cercis canadensis*) both of which are found in early successional stands.

This study used 40 metal hoops 0.22 meter square held one meter above the forest floor by three wooden stakes. Inside the metal hoops were affixed plastic bags with small holes poked in them to allow for water drainage. These litter traps were placed into the field in September of 1979 and the material was collected in November of 1979. “Visual observations at the beginning and end of the collection period indicated that the main body of leaf fall was collected and a detailed analysis of the temporal pattern of leaf fall in deciduous forest suggests that no more than 10% of the actual total leaf fall may have been missing" (Muller and Martin 1983). Samples consisted of nothing but leaf litter. The average leaf fall for the old-growth forest was a dry mass of 290.5 grams per meter square, and the second growth forest was 291.8 grams per meter square. Looking at each forest type by slope position reveals that there were greater accumulations at lower slope positions. The old-growth had greater accumulations on mid-slope positions at 320.9 grams per meter square as compared to the upper slope positions at 259.6 grams per meter square and lower slope positions at 279.1 gram per meter square dry weight. In the second-growth forest lower slope positions averaged 314.0 grams per meter square while upper slope positions averaged 289.9 grams per meter square and lower slope positions averaged 255.0 grams per meter square dry weight. It was suggested that down slope movement of litter accounted for the greater accumulations on lower slope positions. Though there was down slope movement of leaf litter it was found that the micro-site diversity such as windthrow pits, logs, rocks, and understory vegetation can act as reservoirs stopping the down slope movement of leaf litter in the general vicinity of deposition.

Dwyer and Merriam (1981) reported similar results from a study conducted in Ottawa Ontario. The study area was a 13 hectare woodlot dominated by beech and sugar maple. There was no data reported on elevation or mean annual temperature or precipitation. This study used 22 high, level and low sites with each receiving a one meter diameter enclosure with 0.5 meter high sides. Sampling took place from April 1974 to October 1976. There was more litter collected on the low sites as compared to the level and high sites. The mean average dry weight for the low sites was 2438.3 grams per meter square, level sites 1209.9 grams per meter square, and high sites had 416.2

grams per meter square. Accumulations of leaf litter on the lower slope positions were six times that of the upper slopes. It was reported that during litterfall but before snowfall, wind and gravity redistributed leaf litter from exposed high sites to lower sites causing net accumulations on the more protected sites. These findings support the work conducted by Orndorff and Lang (1981) and Muller and Martin (1983).

Blair et al. (1990) conducted a study on the Coweeta Hydrologic Laboratory, near Franklin NC., and suggest the by mixing litter of different species, and resource quality, decay rates could be affected. It was hypothesized that translocation of nutrients among different litters could result in a more rapid and efficient utilization of litter substrates by decomposers. Three species were chosen to represent a range of initial resource qualities and decay rates; flowering dogwood (*Cornus florida*), red maple, and chestnut oak. Litter bags were filled with 3 grams of litter from a single species or a mixture of equal amounts of flowering dogwood and red maple, red maple and chestnut oak, or red maple, flowering dogwood, and chestnut oak. Results reviled that of single litter species, flowering dogwood had the fastest decomposition rate followed by red maple and lastly chestnut oak. It was found that there were no significant interaction effects on first year decomposition rates with mixed litters. There were significant interaction effects on the abundance of decomposer organisms, amounts of net nitrogen released and accumulated during decomposition when the three species were in the presence of one another. It was suggested that although decay rates in the first year of the study were non-significant, interaction effects could become important in the latter stages of decomposition and longer term studies need to be conducted.

Importance of Mountain Laurel and Rhododendron

Van Lear et al. (2002) stated that a major disturbance shaping the current composition and structure of the southern Appalachian Mountains is the exclusion of frequent fire as an ecological process. Exclusion of fire can be regarded as a disturbance because it is a deviation from the normal burning regime that had existed in the region for thousands of years. The exclusion of fire allowed rhododendron to extend upslope far beyond the streamside bottoms where it was confined at the turn of the century. Today rhododendron tends to direct forest succession and development by affecting establishment and growth of advanced regeneration and seedlings. The mechanisms by which advanced regeneration and seedlings are affected are complicated. In the presence of rhododendron light availability is reduced by 80 percent, the frequency and duration of sunflecks is reduced by 96 percent, the availability of water is reduced by 20 percent, and the availability of several soil nutrients (particularly cations) are reduced by variable amounts (Nilsen et al. 2000). With reduced sunlight, the temperature will be lower under a rhododendron canopy than that on a site without rhododendron, and with a 20 percent decrease of water availability there will be greater competition for the water that is available (Van Lear and watt 1992, Nilsen et al. 2000).

It has been estimated that 2.5 million hectares are covered by dense thickets of mountain laurel and rhododendron and they contribute significantly to community structure (Monk and others 1985). The abundance of mountain laurel and rhododendron varies with slope position, soil fertility, and soil moisture. Mountain laurel is more abundant on higher elevation xeric sites, while rhododendron is commonly found on lower elevation mesic and sub-mesic sites. Monk et al. (1985), conducted a study at the

Coweeta Hydrologic Laboratory located near Franklin, North Carolina, reported that in one hardwood forest of more than 40 species with diameters grater than 2.5 centimeters, mountain laurel ranked first in stem density, eighth in basal area, 11th in total standing crop biomass and eighth in net primary production. Similarly, rhododendron ranked second in stem density, fourth in basal area, sixth in total standing crop biomass, and third in net primary production. Van Lear et al. (2002) found at the Coweeta Hydrologic Laboratory that rhododendron stem densities exceeded 17,000 stems per hectare in high coverage plots, and basal area averaged 11 to 22 square meters per hectare where thicket densities were high. Though both species are present in similar densities, rhododendron produces a larger quantity (five times more) of leaves and approximately five times more biomass than mountain laurel (Monk et al. 1985).

Monk et al. (1985) reported both rhododendron and mountain laurel show similar growth characteristics. On mesic sites rhododendron produces 50 to 100 percent more leaves than on xeric sites and the mean weight of the mesic site leaves were 25 to 100 percent heavier than xeric site leaves. Sun leaves of rhododendron from optimal sites have an average surface area of 72.9 cm^2 and average biomass 45.7 $cm^2 g^{-1}$, while shade leaves have an average surface area of 53.8 cm^2 and average biomass 29.8 $cm^2 g^{-1}$. Mountain laurel exhibits the similar characteristics as rhododendron, with more leaves produced on upper portions of the branches and less on shaded lower branches, and the upper non-shaded leaves are heavier. It was also found that rhododendron and mountain laurel leaves have differing life spans. Mountain laurel begins to lose its leaves in late spring of the second year, though a few may persist into the third season, so about half of the leaves on the plant are from the current year's production. In contrast rhododendron leaves can persist for as long as 8 years, though most will be lost after 6 years. In both mountain laurel and rhododendron leaf biomass increases throughout the leaf's life span, though after year five there is a decline in leaf weight for rhododendron. There are also two distinctly different patterns of leaf fall for the two species. Rhododendron drops the majority of its leaves in the fall while mountain laurel sheds leaves all year with two peak litter production periods, one in the fall and another in the spring growing season. On the Coweeta Hydrologic Laboratory, autumn leaf litter production for mountain laurel was 127 kilograms per hectare (12.7 grams per meter square) and 125 kilograms per hectare (12.5 grams per meter square) for rhododendron. Mountain laurel and rhododendron represent 8.8 percent of the total standing crop biomass and more significantly 32 percent of the total leaf standing crop.

Carbon and Nitrogen Dynamics

Cotrufo et al. (1995) state that the quality of the material being decomposed is a major regulatory factor in litter decomposition, with carbon to nitrogen and lignin to nitrogen ratios identified as the qualities most correlated with mass loss. The higher the nitrogen content in the litter being decomposed, the faster the decomposition process proceeds. Litter with higher carbon to nitrogen (C:N) ratio is generally considered to be of lower quality, and is more difficult to be metabolized by decomposer organisms (Callaham et al. 2004). It is well recognized that nitrogen is often the most limiting element for plant growth and biomass production in environments where there is suitable climate and available water for growth. At any one time the vast majority of total fixed (available) nitrogen will be unavailable because it is locked up in standing live biomass or in their dead remains being decomposed (Deacon 2006). Melillo et al. (1982) state the vast majority of nitrogen required by net primary producers is supplied through decomposition and it has been suggested that the nitrogen content of plant material being decomposed has a strong influence over the decay process. Since most of the decomposing organisms have higher concentrations of nutrients in their tissues than in the material they consume, there will be a net immobilization of nutrients until the nutrients occur at higher levels in the decomposing materials than in the decomposing organisms (Gallardo and Merino 1992).

Nitrogen immobilization occurs when carbon to nitrogen ratios are greater than 20:1, and when the carbon to nitrogen ratio is less than 20:1, there is a release of mineralized nitrogen (Havlin et al. 2005). Colman and Crossley (1996) state that in initial stages of decomposition, the nitrogen content of decomposing litter increases and then declines. In decomposing material with high carbon to nitrogen ratios, as quickly as nitrogen is mineralized, it is taken up and immobilized by microbes. Because only about one third of the carbon metabolized by microbes is incorporated into their cells, the remainder is respired and lost as carbon dioxide while nitrogen is held tightly and recycled as they die and are replaced (Brady and Weil 1999). Explanations for increases of nitrogen during the initial stages of the decomposition process have been purposed by fixation, absorption of atmospheric ammonia, throughfall, dust, insect frass, green litter, fungal translocation and/or immobilization (Melillo et al. 1982).

Dynamics of Coarse Woody Debris

CWD is any woody material that has a large end diameter greater than 7.62 centimeters. CWD influences the ecology of a site for decades or even centuries. It is generally accepted that the larger the diameter of the CWD, the slower the decay. This is because there is a smaller surface area to volume ratio exposing minimal portions of the exterior to mechanical and biological colonization (Zhou et al. 2007). CWD acts as seed germination sites, reservoirs of moisture during droughts (with increasing decomposition maximum moisture content also increases), sites of nutrient exchange for plant uptake, and critical habitat for forest organisms (Zhou et al. 2007). In its later stages of decomposition, CWD can also promote desirable soil structure and act as a controlled release chemical fertilizer (releasing plentiful amounts of carbon, nitrogen, phosphorus, and other nutrients gradually over time) (Van Lear 1996, Zhou et al. 2007). Inputs of CWD are caused by various factors including fire, wind, lightning, insects, disease, ice storms (breaking tree tops and large limbs), competition, and humans. These factors may affect a single tree or an entire landscape such as the disturbance caused by Hurricane Hugo in 1989 (Van Lear 1996). During extended periods without major disturbance, natural succession in forests is dominated by gap-phase dynamics, which occur when a single tree dies. This type of disturbance adds CWD to the system very slowly. In the time following a major disturbance, much of the pre-disturbance and disturbance contributed CWD decays. Therefore, it would be expected that during the early development and mid-successional periods loadings of CWD would decrease because young trees that are dying from competition are too small to contribute to the CWD pool and mortality rates during the mid-successional stage is low. As succession progresses, mortality of older trees occur and CWD loadings increase, reaching their maximum during the old growth stage when large, long lived overstory trees begin to die (Van Lear 1996).

A similar patter was observed in a different ecosystem by Spies et al. (1988) and Spies and Cline (1988) when they used a 900-year chronosequence to describe five successional stages for 196 Douglas-fir (Pseudotsuga menziesii) stands ranging from 40 to 900 years since disturbance. The five stages were: stand initiation, stem exclusion, understory reinitiation, old growth, and climax. The stand initiation stage (lasting 20 to 30 years) showed very little accumulations of CWD despite a high mortality rate, because the stems were too small to contribute to the CWD pool. There was an increase in CWD during the stem exclusion stage (lasting from 10 to 30 years) as the canopy closed and mortality of larger trees began, but input rates were still slow due to the small size of the trees. Canopy dominance declined during the understory reinitiation stage (lasting 100 to 150 years), and this permitted understory herbs, shrubs, and trees to become established. This is the stage that CWD inputs increased significantly. CWD accumulated rapidly in the old growth stage (lasting 500 to 800 years) as natural disturbances such as windthrow, disease, and insects increased mortality rates of large trees, which were the dominant shade-intolerant species. These trees were replaced with shade-tolerant species that are long lived and contributed little CWD in the later years of the old growth stage. Decomposition of CWD was greater than inputs in the old growth stage and CWD loads decreased. When all shade-intolerant species had been replaced by shade tolerant species, the climax stage had been reached. Climax had less CWD inputs than the old growth stage because it was lacking the original overstory dominants. Usually by this stage there had been some type disturbance either natural or anthropogenic and had reinitiated succession.

Waldrop (1996) conducted a similar study to simulate stand dynamics and estimate CWD loadings for southeastern ecosystems. FORCAT (FORests of the CAToosa Wildlife Management Area), a gap model (Shugart 1984), was used to predict fuel loads on disturbed sites in the Cumberland Plateau of East Tennessee for two site types, mesic and xeric. The simulation began with mature stands that were clearcut with no artificial regeneration or site preparation allowed. There was a simulation period of 200 years after clearcutting for each of 100 1/12-ha plots, 100 plots were used in the simulation to account for the variability in Southeastern forest types as suggested by Shugart and West (1979). It has always been assumed that decomposition rates were the same across all site types, but as shown by Abbott and Crossley (1982) decomposition rates are greater on mesic sites, and that by assuming an 8 percent decay rate on mesic sites and a 6 percent on xeric sites, the variations in simulated fuel loads between the sites was largely reduced. The fuel loadings in Waldrop's (1996) study showed the CWD loadings immediately after clearcutting on the mesic site to be 69 Mg/ha and on the xeric site to be 49 Mg/ha, the highest levels at any time during the simulation. Despite the fact that fuel loadings were greater on the mesic sites in year one, the fuel had decomposed to a lesser amount than the xeric site by year 32 to a level of 12.3 vs. 16.9 Mg/ha. Fuel loadings were higher on mesic sites again by year 75, and during the last 50 years of the simulation; fuel loadings on the two sites were nearly identical. Results of Waldrop (1996) supports the findings of Abbott and Crossley (1982), that it is not the size of the CWD present that is important but rather the decomposition rate between different sites that is important to CWD loadings. Mesic sites may produce more CWD than xeric sites, but the small difference in decomposition rates of the two site types (8 percent for mesic and 6 percent for xeric) showed very similar CWD loadings throughout the 200-year simulation.

There were several limitations to this simulation; the first was by defining CWD as dead trees because it was impossible to distinguish standing from down CWD. Secondly, it was not possible to account for inputs from larger limbs that die and fall to the ground and therefore the estimations of total CWD inputs were probably low. Third the decomposition rates for all size classes of CWD and across all succession stages were assumed to be the same. Finally no CWD inputs were accounted for from natural or anthropogenic sources other than the initial clearcut.

Prescribed Fire and Fuel Models

There was very limited use of prescribed fire in the southern Appalachian Mountains until the mid-to-late 1980's, because of the perceptions of the potential damage to valuable hardwoods coupled with the fact that high-intensity fires are hard to control on steep slopes, and the likelihood of soil and site damage (Van Lear and Waldrop 1989). This apprehension is justified because prescribed burns in this region are hard to control, and the vast majority of prescribed fires today are for fuel reduction, wildlife habitat improvements, and restoration of endangered species or threatened communities. The basic information that is available to fire managers in other parts of the country is missing from this region. There are no fuel loading models or photo series available to them and this forces fire managers to use limited measures of fuel or their best guess, which leads them to overestimate fuel loads allowing a margin for error. In the southern Appalachian Mountains, predictions of fuel loadings can be complicated, because fuels are closely associated with site and forest cover type (Waldrop et al. 2007). The amount of dead and down fuel is regulated by the quantity of fuels produced by different species and productivity levels associated with slope position and aspect across the landscape and varying decomposition rates at different sites as proposed by Iverson et al. (2003), Kolaks et al. (2004), and Waldrop et al. (2004). The quantity of fuel present at any given time, since disturbance, is a result of input from dying vegetation minus the quantity lost from decay. Gravity or cultural treatments can also affect the way fuels are distributed across the landscape as shown by Waldrop and others (2004).

Rubino and McCarthy (2003) found that on the Waterloo Wildlife Research Station (WWRS), a mixed-oak forest in Athens County, OH. both percent slope and slope position were significantly correlated with CWD densities. It was suggested that woody debris can be lost from steep slopes and transported to lower slope positions. The lower slope positions will have net accumulations of CWD by both the *in situ* and up slope additions. This study also found no significant relationship between slope aspect and CWD volume or densities. Greater CWD loads were expected on northeast slopes since they are considered to be more productive, but this was not the case in this study. In addition, case-hardening was common for CWD on southwest facing slopes. Once the sapwood decayed only a dry exterior remained for fungi. The CWD found on southwest slopes was hypothesized to persist longer due to lack of moisture, and being extremely low in nutrient content that is fairly decay resistant.

Webster and Jenkins (2005) found topographic position to be a strong predictor of CWD on the Great Smoky Mountain National Park in Western North Carolina and Tennessee. These findings support the findings Rubino and McCarthy (2003) who found that CWD increases significantly with increasing elevation (slope steepness) and relative soil moisture (more mesic sites) on formally undisturbed sites. In addition, sites with a history of diffuse disturbance (scattered home sites, free ranging livestock, small-scale logging, and frequent low-intensity anthropogenic burning) or corporate logging had similar amounts of CWD as undisturbed sites.

CHAPTER III

METHODS

Study Area

This study measured leaf litter, fine woody, and coarse woody fuel accumulations and losses across a topographical gradient to quantify if decay rates exceeded accumulations on more mesic slope positions in the southern Appalachian Mountains.

The study site was in the Warwoman Wildlife Management Area (WWMA), occupying approximately 6397 hectares, within the Chattooga River Ranger District of the Chattahoochee National Forest, Rabun County Georgia. The WWMA is characterized by short, steep slopes with elevations ranging from 244 to just over 1036 meters (Waldrop and others 2007). The average temperature and precipitation during the study period for the area was 12.5 degrees Celsius and received on average 172.8 centimeters of precipitation (NOAA 2008) (Table 1). The long term average precipitation (100 year average, 1907-2007) was 127.3 centimeters annually (NOAA 2008).

Table 1: Mean annual temperature and precipitation for Mountain City GA, 2 SW NOAA monitoring station.

Year	Temperature (^{0}C)	Precipitation (cm)
2004	12.0	196.3
2005	11.9	205.6
2006	12.4	161.9
2007	13.5	127.4
Mean (four year)	12.5	172.8
100 Year Mean		127.3

Study plots for this study were the same as used in the previous study by Waldrop et al. (2007). These plots were used because fuels were previously measured, vegetative surveys had been conducted, and they were allocated by slope position and aspect. With this work completed, the establishment of litter traps on the desired topographic position was easily accomplished.

Red oak were the most common species in the overstory on the WWMA followed by yellow pines, and then all other understory species (Table 2). Red oak species account for 25 percent of the total basal area while white oak species, including chestnut oak, occupy only six percent of the total basal area. This was surprising because chestnut oak is considered a dominant species present on the drier upper slope positions in the southern Appalachian Mountains. Waldrop et al. (2007) reported that chestnut oak and scarlet oak (*Quercus coccinea*) were the most commonly found oak species on dry sites.

Table 2: Basal area by major species groups on the Warwoman Wildlife Management Area.

Species or Group	Basal Area (m^2 / ha)	Percent (%) Total Basal Area
Hickories	5.3	4
Hemlock	7.1	5
White oak	7.9	6
Other overstory	9.1	7
Yellow-poplar	9.5	7
White pine	11.3	9
Maples	13.5	10
Understory	15.7	12
Yellow pines	18.3	14
Red oak	31.8	25
Total Basal Area	129.5	100

Unpublished data collected for Waldrop et al. (2007).

Experimental Design

The study used a completely randomized design, with a subset of plots established by Waldrop et al. (2007). There were 50 plots chosen at random, 10 replicates from each “treatment”. This subset of plots was used to measure the input/accumulation and decomposition (loss) of fuels across differing landscape gradients in the current study. There was already a detailed description of the vegetative cover for the study plots and no re-measurements were conducted. Waldrop et al. (2007) defined topographic position as a combination of slope position and aspect, and assumed that tree productivity and, thus, fuel loadings would be greater on more productive sites. The five "treatments" consisted of topographic positions including ridge tops, middle slopes, and lower slopes on northeast (325^{0} - 125^{0}) and southwest (145^{0} - 305^{0}) aspects. Lower slope positions and northeast sites were considered more productive than middle slope and southwest sites, because they are more protected (shaded) and should have had greater soil moisture. Ten plots (replicates) were established at each topographic position for a total of 50 plots. The study plots for this study had a maximum distance of approximately 550 meters from an open road to reduce any logistical problems with establishing litter traps.

Litter Trap Design and Sampling Procedures

In most litter and woody detritus decay studies, a litter bag of some type is used. However, Binkley (2002) used a method previously described by Wells and Jorgensen (1975) a litter “sandwich.” In the litter sandwich method one piece of screen (with 2 or 3 mm openings) was first fastened to a stable frame (small wooden pieces 5 cm x 5 cm work well), then, after the major litter fall period, another piece of screen was placed on top of the freshly fallen litter. This pattern of fresh litter fall and new screen application can be continued for as long as the study is designed to last. This design mimics the natural dynamics of the forest floor; in addition it alleviates the problem of excluding soil micro and macrofauna. The soil fauna were able to chew small holes into the screen material over the period of the study and access the material inside. Samples can easily be cut from the layers of screen at designated intervals without disturbing other material.

Five one meter square litter trap sandwiches (Wells and Jorgensen 1975, Binkley 2002) were placed at each of the 50 study plots, for a total of 250 litter traps, prior to the major leaf fall in September 2005. The litter trap designated as trap number one was orientated as close to due north as topography and vegetation would allow and approximately one meter from the plot center. The other four traps were equally spaced around the plot center staying as close to one meter as possible within the vegetative cover limitations. The litter traps consisted of 3 millimeter nylon screen (the type used on screen doors), and were 1 meter square. The screen was cut a little larger than 1 meter to allow the material to drape over the sides of the frame for stapling. The meter square of screen was stapled to 4 one meter long 5 by 5 centimeter square boards forming 1 square meter inside the frame. The 5 by 5 centimeter square boards were stapled together in each corner with 10 millimeter staples to help make them more rigid.

January 2006 was designated as the end of leaf fall and sampling began in February 2006. The end of year two sampling started in January of 2007. Sampling took place every three months and consisted of a 10 cm^2 sub-sample cut from within each litter trap, for a total of five samples per plot and 250 samples per sample period. There were four fuel dowels collected, one dowel each from traps 2-5, for a total of four dowels per plot and 200 10-hour fuel dowels per sample period. The order of sub-sampling for samples 1 thru 8 is shown in Figure 1. The ninth, and final, sub-sample consisted of all the material left in trap at the time of sampling.

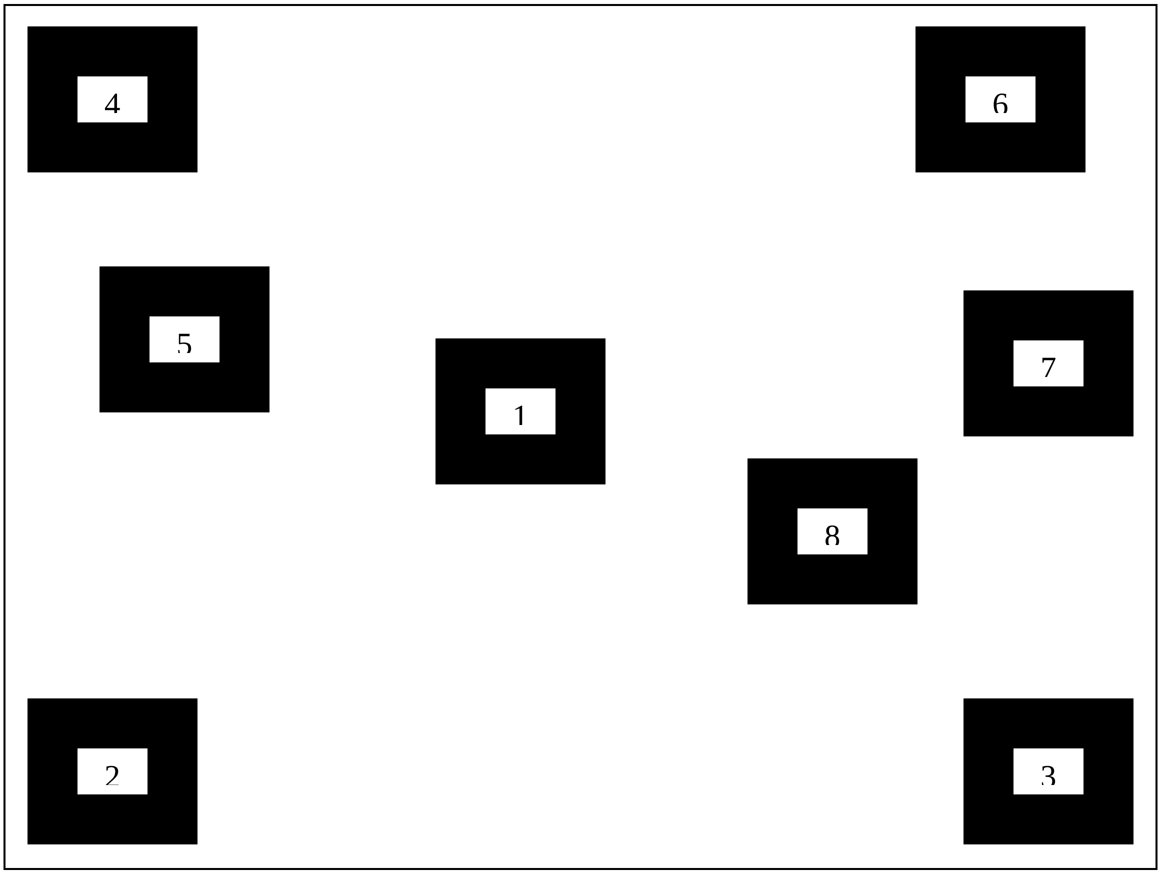

Figure 1: Sampling order for sub-samples 1 thru 8.

Litter traps were emptied and the material was sorted into different fuel categories, litter (including acorns and bark), pine cones, 1- (0-0.64 cm), 10- (0.64-2.5 cm), 100- (2.5-7.6 cm), and 1000-hour fuels (>7.6 cm). All sorting was conducted in the field. The separated materials were then weighed and divided equally among the five traps (the total mass of material was divided by five) at each point. The material was divided into the five litter traps because, in most cases, there was too much litter to place into a single litter trap. Had all the material been placed into a single litter trap, the weight of leaf litter and fuels could have altered decay dynamics, and the traps would not have space for the next years litter fall. In the event that there was not enough litter to divide for all five litter traps a specified amount (an amount equal to the material placed into the previous traps) was collected from an area nearby and placed in the remaining traps. If there were not enough 1-hour fuels to disperse into all five traps the *in-situ* material was divided into the number of litter traps sufficient to obtain a sub-sample in subsequent sampling periods. No additional fine woody fuels were collected.

All 10- and 100-hour fuels were placed into litter trap one, because the quantities were not sufficient to place them into all five litter traps and be able to collect sub-samples in subsequent sampling periods. In most cases the 10- and 100-hour fuels were long single pieces, which made it impractical to divide them into several litter traps. After the material was redistributed, a screen was placed on top of the material and loosely (care was taken not to compress the material) stapled to the wooden frame forming the sandwich.

After screens were stapled on top of the five litter traps, a 10 cm^2 sub-sample was cut from a random location within each trap; the location was the same for all 250 litter traps. All materials that had been removed from the litter traps and sorted into their separate categories were weighed then divided equally among the five litter traps. This 10 cm^2 sub-sample could have been only leaves or a mixture of leaves and woody fuels depending of the quantity of woody material that had been deposited into the litter traps during litterfall. Not all traps received woody fuels, but all traps received leaf litter, either *in-situ* material or material that had been collected from nearby the plot. Those traps that did receive woody fuels, had the woody material mixed with leaf litter to form a homogenous mixture of leaves and woody material (1-, 10-, and 100-hour fuels where present). These samples would later be resorted in the lab. The hole remaining in the screen was stapled with a common office stapler to prevent any fuel material from falling out. The void left where the sub-sample had been removed was filled with litter material from beside the litter trap. This prevented any new material from pooling in the void left by removal of the sample. If the litter trap was located on a significant slope, then two metal surveying pins were fashioned into u shapes (banana clip fashioned) and pushed into the litter trap at offsetting angles to prevent the material inside the litter trap from shifting down slope.

Pine cones were weighed and then strung onto a nylon cord and placed on the ground near litter trap one for re-measurement the following year. Fuel moisture samples were collected from nearby each point consisting of litter, 1- and 10-hour fuels. The fuel moisture samples were placed inside a gallon zip lock bag to preserve the moisture within them and placed inside a cooler to transport to a laboratory. The moisture content analysis was conducted in the lab after a wet and dry weight of each sample had been recorded. Fuel moisture samples were collected from within a gradient from the top of the litter layer to the top of the duff layer. This sampling technique gave a more true representation of the available moisture on each particular study plot. If the material had been collected for one location (either on top of the fuel bed or near the duff layer) there could have been an under or over estimation of the actual fuel moisture for each site.

Four 1000-hour fuel bolts were placed at each point, to simulate inputs of fresh CWD. These bolts were made of, green fresh cut chestnut oak 0.50 meters in length, and between 8.9 and 11.4 centimeters in diameter. Chestnut oak bolts were collected at the end of years one (January 2007) and two (January 2008).

After the first point was sampled it was determined that there were not enough 10-hour fuels to get a sub-sample from each litter trap. To correct this, all 10-hour fuels from the five litter traps at a sample point were placed into litter trap one and strings (10-hour fuel dowels strung together with fishing line through a small hole drilled into one end of the dowel) of 10-hour fuel dowels were placed beside litter traps two thru five. Stringing the 10-hour fuel dowels ensured that they would not become mixed and confused with other dowels. Each dowel had a letter written on one end (the end with the small hole) and the weight of each was recorded before being placed into the field. The 10-hour fuel dowels were cut from within the study area from chestnut oak trees, the same stems provided 1000-hour fuel bolts for each grid point.

A 4 by 20 twenty meter (80m^2) grid was established in a randomly assigned azimuth to sample coarse woody debris (CWD) (>7.62 centimeter in diameter). Orientation of each plot was determined randomly by looking at the second hand of a wristwatch (Brown 1974) and multiplying the seconds by 6; the resulting number was the azimuth (0 to 360 degrees). Once the plot was established, a nylon tape was pulled to the 20-meter mark and a blue plastic pin was placed in the ground to mark the same area be surveyed for new inputs of CWD. CWD was measured within the sampling strip if it was over 1 meter long and had a large end diameter of fifteen centimeters or greater. The small end and large end diameters were measured on all qualifying logs or parts of logs that had fallen within the boundaries of the strip-plot. If a piece extended outside the strip-plot, diameters were measured at the line of intercept of the strip-plot boundary. The length of the entire piece was measured to determine the midpoint. In addition, the piece was identified as hardwood or softwood and the decay class for each stem was recorded, using the following 5 (Thomas 1979):

Class 1: bark is intact; twigs are present; wood texture is sound; log is still round; original wood color.

Class 2: bark is intact; twigs are absent; wood texture is sound or becoming soft; log is still round; original wood color.

Class 3: bark is falling off; twigs are absent; wood texture is hard; log is still round; original wood color is faded.

Class 4: bark is absent; twigs are absent; texture of wood is soft, blocky pieces; shape of log is oval; wood has faded to light yellow or gray.

Class 5: bark is absent; twigs are absent; wood texture is soft and powdery; shape of log is oval; wood has faded to light yellow or gray.

Each piece of CWD was painted so it would not be re-measured in subsequent sampling periods. Each of the CWD grid plots was surveyed during the re-sampling periods; approximately every three months for a total of nine sampling periods. The CWD counts were converted to mean tons per hectare by use of Brown's (1974) equations and specific gravity estimates for southern species by decay class developed by Anderson (1982) and Waldrop et al. (2007), and then a conversion factor was applied to convert to metric tons.

This process of sorting and weighing the fuel material that had been collected in the five litter traps was repeated after the litter fall of 2006. The final sampling period started in December of 2007. At the beginning of the final sampling period in December 2007, there were only 212 still intact and viable to sample. Missing litter traps were destroyed by wildlife, mostly just after mast fall.

At the time of the final sampling period, many of the litter traps located on slopes greater than 15% had material missing from numerous locations within the individual layers of the traps. The area within the litter traps affected most were upslope positions. This material slid down slope either to one of the bent surveying pins or to a location that had already been sampled. Both the surveying pins and stapled holes acted as a barrier impeding the downward movement of the litter material. This created a problem with the sub-sampling data that had been collected over the past two years. In many instances there was no material collected in the sub-samples and during other times there were very large quantities of material collected. Mass of the sub-samples was dependent upon the location the sample was taken from within the litter trap. There was also variation between the five litter traps located at a single plot depending on the slope of the plot. Data from eight separate sub-sampling periods could not be used in mass loss calculations because of the movement of litter. At the time of final sampling and prior to removing the litter material from the traps 66 measurements of litter depths were taken from inside each of the litter traps, 33 for the 2005 litter level and 33 for the 2006 litter level. The top and bottom boards (the two boards perpendicular to the slope) on the litter traps were measured and marked at the 25, 50, and 75 centimeter points, and then a piece of duct tape folded into itself was fashioned into a ruler and marked from zero to 100 centimeters in 10 centimeter intervals. A piece of tape was placed at each of the three marks with pins and then the material within the litter trap was measured from the surface of the screen to the top of the highest litter point at 10 centimeter marks on the duct tape. These data were used to create a mathematical model to account for the litter material shifting down slope inside the traps. None of the models worked because they either over or under corrected for the missing material.

A set of leaves was collected to see if species composition, for specific site types, had an affect on the mean weight of litter collected in the litter traps. The leaves were collected by site type (mesic, intermediate, and xeric), and analyzed for differences in specific leaf weights for a known area. In July of 2008, a collection of 23 different species was collected from the study area; random trees were selected for sampling across different sampling areas. Sampled species were the most common on study plots from each of three slope locations, bottoms (mesic = 8 species), mid-slope (intermediate = 7 species), and ridgetops (xeric = 8 species). Thirty leaves were collected from each species, and placed inside a gallon plastic zip lock bag and inside a cooler to preserve moisture. The species collected from each site type included, mesic (American beech (*Fagus grandifolia*), flowering dogwood, fraser magnolia (*Magnolia fraseri*), northern red oak (*Quercus rubra*), rhododendron, witch hazel (*Hamamelis virginiana*), yellow birch (*Betula alleghaniensis*), and yellow-poplar), intermediate (American chestnut (*Castanea dentata*), black cherry (*Prunus serotina*), blackgum, common persimmon (*Diospyros virginiana*), hickories spp., red maple, and sourwood (*Oxydendrum arboretum*)); and xeric, (black oak, chestnut oak, Allegheny chinkapin (*Castanea pumila*), mountain laurel, sassafras (*sassafras albidum*), scarlet oak, southern red oak (*Quercus falcate*), and white oak). There were no *Pinus* species collected, because there was no easy way to measure the needles precisely for a known area.

Laboratory Analysis

Chestnut oak bolts were taken to the work shop and a 2.54 centimeter wide biscuit was cut (the same week the tree was felled) from each bolt for moisture content analysis. Each bolt and biscuit was numbered to be able to relate each biscuit to a particular bolt. The biscuits were then weighed and placed in an oven for 7 days at 85 ^{0}C or until there were no changes in weight of sub-samples. Green bolts were also weighed and returned to the field. At the end of 7 days the biscuits were removed from the oven and reweighed to obtain a dry weight. Percent moisture content was calculated by as:

((wet weight – oven dried weight) / wet weight) * 100.

This equation was used to calculate moisture content for all leaf litter, fine woody, and coarse woody fuels collected during the study period.

After determining that there would not be enough 10-hour fuels to collect a sample from every litter trap during subsequent re-sampling, 1600 10-hour fuel dowels were cut to a length of 15.25 centimeters. The material used for the 10-hour fuel dowels was the tops of stems that were used as 1000-hour fuel bolts. The tops were cut to the correct diameter class and to a length of 15.25 centimeter in the shop, and drilled for stringing. To prevent the 10-hour fuel dowels from getting out of order (there by losing their known weights) they were strung together. Initial moisture content for the dowels was assumed to be the same as those of the 1000-hour fuel bolts (35%) because they came from the same material at the same time. Each 10-hour fuel dowel was labeled on one end with a permanent marker. The dowels were then placed together into groups of 8, one to be sampled in each of the 8 future sampling periods. The dowels were weighed for wet weight, and strung together with fishing line. During the second sampling period (06/2006) there were four bundles of dowels placed at each point; litter traps two through five received a 10-hour fuel bundle. During each re-sampling one dowel was collected from each litter trap (two through five) and weighed for a wet weight. The dowels were placed inside an oven at 45^{0}C. for a week, allowing adequate time to remove all appreciable moisture from the dowel. The low drying temperature ensured that the nitrogen within the sub-samples would not be volatized. These dowels were sent to a USDA Forest Service Laboratory in Athens GA. for C:N ratio analysis. The carbon to nitrogen ratio was used as a measure of decay, to detect any differences among the different slope and aspect positions.

In the lab, the ten centimeter square sub-samples were sorted into the differing fuel classes (leaf litter, 1-, 10-, and 100-hour fuels) weighed for wet weight and then the sub-sample material was placed inside an oven at 45^{0}C. for 7 days. The same procedure was used on the ten centimeter square sub-samples as the 10-hour fuel dowels after drying. They were then sent to a USDA Forest Service Laboratory in Athens GA. for C:N ratio analysis.

Fuel moisture samples were weighed for a wet weight and placed inside an oven at 85^{0}C. for 7 days. After a week, the samples were reweighed to get an oven dried weight. There was no C:N ratio analysis conducted on the fuel moisture samples and after obtaining a dry weight was discarded.

In the lab, each leaf that had been collected to determine specific leaf weights had a 6.45 cm^{2} sample cut from a random location. Each sub-sample was numbered, with a permanent marker, with a number from one to 30 to keep track of each sub-sample. The sub-samples were weighed to obtain a wet weight, and placed inside an oven at 85 ^{0}C. for 7 days, to obtain a dry weight for moisture content analysis.

Statistical Analysis

Data from this study were analyzed in three major components, 1) accumulation/production (input of leaf litter and fine woody fuels), 2) loss (decay) of leaf litter and fine woody fuels, and 3) total fuel loadings across the topographical gradients. To obtain an accurate assessment of the five slope and aspect positions and differences associated with the material collected, a one-way analysis of variance (ANOVA) was conducted (SAS Institute 2002) with statistical differences are set at $\alpha = 0.05$, and linear contrast was performed to compare the mean of northeast slopes (the slope positions that should have been the more mesic) to the mean of all other slope positions. Mean separation was determined by Fisher's protected least significant differences.

The "treatment" effects model was:

$$y_{ij} = \mu + \tau_i + e_{ij}:$$

Where:
y_{ij} = is the observation for the j th replicate from the i th treatment,
μ = the grand mean,
τ_i = the effect of the i th treatment, and
e_{ij} = the experimental error for the j th replicate from the i th treatment

An appropriate model for the linear contrast is expressed as:

$$C = 3\mu_{NEB} + 3\mu_{NEM} - (2\mu_{RT} + 2\mu_{SWM} + 2\mu_{SWB})$$

Where:
NEB = Northeast Bottoms
NEM = Northeast Mid-slopes
RT = Ridgetops
SWM = Southwest Mid-slopes
SWB = Southwest Bottoms

A matched pair t-test was conducted on the means for leaf litter, 1-, and 10-hour fuels collected in years 2005 and 2006, to determine if there were differences in the quantity of material collected between the two years.

CHAPTER IV

RESULTS AND DISCUSSION

Accumulation/production

Results for 2005 inputs and accumulation will be presented first followed by the 2006 input/accumulation data. All leaf litter and fine fuel information presented are based on dry weight and the mean material present per meter square. Following input/accumulation results are the results for 2005 and 2006 decomposition, 1000-hour fuels, fuel moisture, 10-hour fuels, total fuel loading, specific leaf weight and carbon to nitrogen ratio.

There were no significant differences in accumulations of leaf litter, 1-, 10-, and 100-hour fuels detected among slope position or aspect for either of the two years (2005 or 2006) (Tables 3 and 4). There were significant differences in the quantity of litter, 1-, and 10-hour fuels produced between the two years. There was significantly more litter produced in 2006 than 2005 ($p = 0.0172$) but, there were more 1- and 10-hour fuels produced in 2005 than 2006 ($p = 0.0172$ and 0.0434). In addition, 2005 produced more 100-hour fuels than 2006; no 100-hour fuels were collected in 2006.

One possible reason that the 2006 collection had more leaf litter than 2005 was the litter traps were not placed in the field until August of 2005. The leaves that had fallen earlier in 2005 were not recovered and placed into the litter traps. There were more 1- and 10-hour fuels collected in 2005 than in 2006, this could have been caused by a major wind events or possible damage from a major ice storm in December of 2005. The high variance within each treatment for both years 2005 and 2006 emphasizes the great variability from plot to plot. This variability and lack of significant differences of

Table 3: Accumulations of leaf litter, 1-, 10-, and 100-hour fuel by slope and aspect in 2005.

Component and Slope Position	N	Mean (g/m^2)	Standard Dev.	p-value
<u>Leaf Litter</u>				
Northeast Bottom	10	258.5	144.0	
Northeast Mid-slope	10	261.5	122.2	
Ridge Top	10	232.5	181.7	0.9307
Southwest Mid-slope	10	286.0	119.7	
Southwest Bottom	10	286.2	188.2	
<u>1-Hour Fuel</u>				
Northeast Bottom	10	35.5	18.5	
Northeast Mid-slope	10	35.5	20.2	
Ridge Top	10	28.4	23.8	0.2436
Southwest Mid-slope	10	50.2	29.2	
Southwest Bottom	10	31.6	17.2	
<u>10-Hour Fuel</u>				
Northeast Bottom	10	24.0	18.9	
Northeast Mid-slope	10	23.1	14.6	
Ridge Top	10	27.8	35.0	0.9695
Southwest Mid-slope	10	26.3	17.1	
Southwest Bottom	10	19.3	18.2	
<u>100-Hour Fuel</u>				
Northeast Bottom	10	0.9	2.7	
Northeast Mid-slope	10	0.0	0.0	
Ridge Top	10	0.0	0.0	0.1550
Southwest Mid-slope	10	1.2	2.8	
Southwest Bottom	10	3.1	5.7	

p-values are from an overall F test for differences among treatments.

Table 4: Accumulations of leaf litter, 1- and 10-hour fuel by slope and aspect in 2006.

Component and Slope Position	N	Mean (g/m^2)	Standard Dev.	p-value
<u>Leaf Litter</u>				
Northeast Bottom	10	253.2	171.9	
Northeast Mid-slope	10	299.6	188.4	
Ridge Top	10	300.5	203.4	0.4300
Southwest Mid-slope	7	441.5	324.5	
Southwest Bottom	9	374.0	194.6	
<u>1-Hour Fuel</u>				
Northeast Bottom	10	20.3	14.8	
Northeast Mid-slope	10	28.9	9.4	
Ridge Top	10	27.1	21.1	0.6228
Southwest Mid-slope	8	30.9	15.7	
Southwest Bottom	9	25.7	11.4	
<u>10-Hour Fuel</u>				
Northeast Bottom	10	11.2	32.3	
Northeast Mid-slope	10	13.4	43.6	
Ridge Top	10	13.4	55.3	0.0874
Southwest Mid-slope	8	27.2	63.4	
Southwest Bottom	9	14.4	78.4	

p-values are from an overall F test for differences among treatments.

input material can possibly be attributed to the presence of ericaceous shrubs. Of the 50 total points, 27 (54%) had mountain laurel. This distribution was fairly evenly scattered across all slope and aspect positions with just a few more on the drier slope positions. Rhododendron was present on 20 (40%) of the 50 plots, mostly located on northeast slope positions with a few growing on southwest positions. In combination, mountain laurel and rhododendron were present on 37 of 50 (74%) plots in this study. There could be strong influences on the input of fuel material with either or both of the ericaceous shrub species because both are composed of heavy volatile chemicals that weigh proportionally more than leaves produced by other species (Clinton 2002). In addition there can be 20% reduction in available water to plants and decomposer organisms under rhododendron thickets (Clinton 2002, and Nilsen et al. 2000).

Analysis of CWD data showed significant differences in coarse woody debris loading between the northeast facing slopes and all other slope positions (Table 5). There were no significant differences between slope and aspect positions for CWD, and a linear contrast was conducted to detect minute differences. The subsequent linear contrast showed there was a significant difference between the mean of northeast facing slopes as compared to the mean of all other slope positions (p = 0.0042). The reason for higher 1000-hour fuel loadings on the northeast facing slopes could be gravitational effects, recent wind-throw or possible insect damage. On steeper slope positions larger CWD can travel down slope until it encounters a barrier as demonstrated by Rubino et al. (2003) and Webster and Jenkins (2005). The findings from this study support the findings of Rubino et al (2003), Webster and Jenkins (2005), and Waldrop et al. (2007) who found significantly more CWD on northeast facing lower slope positions.

Table 5: Initial coarse woody debris measured during plot establishment in 2005.

Component and Slope Position	N	Mean (t/ha)	Standard Dev.	p-value
Northeast Bottom	18	22.3 a	55.9	
Northeast Mid-slope	23	30.8 a	87.7	
Ridge Top	22	16.2 b	54.8	0.0717
Southwest Mid-slope	14	8.8 b	26.9	
Southwest Bottom	16	7.3 b	27.7	
Linear contrast comparing northeast slopes vs all others				0.0042

p-values are from an overall F test for differences among treatments. Letters within a treatment group are to determine specific differences among treatments at the 0.05 level.

Pine cones collected during the end of years 1 and 2 litter fall periods were of little use for decay analysis after the final sampling had taken place because many cones were missing, possibly from wildlife consumption. Therefore these data were not analyzed.

Decomposition

The 2005 leaf litter, 1-, 10-, and 100-hour fuels (material that had been in the field for two years) were not significantly different among slope positions or aspect. Similarly, the 2006 leaf litter, 1-, and 10-hour fuels (material that had been in the field for 1 year) had no significant differences among slope positions or aspect (Tables 6 and 7). It was expected that on the more protected sites (northeast slopes and lower southwest slopes) there would be smaller remaining masses, indicating more loss through decay. These sites hold more moisture and therefore should have faster turn-over times as compared to drier site types. However, that pattern was not observed. Ericaceous shrubs could have had an effect on decay. These tightly closed canopies act to keep the micro-site moist and cool, and it is well accepted the both moisture and temperature are two of the main driving forces in the decay process (Clinton 2002, and Nilsen et al. 2000). However Nilsen et al. (2000) reported the though it is moist under a rhododendron canopies, there is 20% less water available to plants and decomposer organisms under a rhododendron canopy due to evapotranspiration by rhododendron. When comparing the percentages of rhododendron and mountain laurel present on all study plots in this study, there was a greater abundance of rhododendron (40%) and mountain laurel (54%) than the findings reported by Waldrop et al. (2007), at 25% and 42% respectively. This could

Table 6: Mean percent original mass remaining for leaf litter, 1-, 10-, and 100-hour fuel by slope and aspect for 2005.

Component and Slope Position	N	Mean	Standard Dev.	p-value
Leaf Litter				
Northeast Bottom	8	54	16	
Northeast Mid-slope	10	62	9	
Ridge Top	10	56	15	0.3719
Southwest Mid-slope	8	67	13	
Southwest Bottom	9	60	19	
1-Hour Fuel				
Northeast Bottom	8	73	11	
Northeast Mid-slope	10	76	8	
Ridge Top	8	78	16	0.1283
Southwest Mid-slope	8	72	12	
Southwest Bottom	9	64	10	
10-Hour Fuel				
Northeast Bottom	6	72	17	
Northeast Mid-slope	8	80	29	
Ridge Top	8	68	18	0.3006
Southwest Mid-slope	8	69	34	
Southwest Bottom	7	51	22	
100-Hour Fuel				
Northeast Bottom	10	0	0	
Northeast Mid-slope	10	0	0	
Ridge Top	10	0	0	0.2301
Southwest Mid-slope	10	12	31	
Southwest Bottom	10	16	30	

p-values are from an overall F test for differences among treatments.

have biased the study findings to lower decay rates than are actually found on the same slope and aspect positions without ericaceous shrubs. The dense closed canopy and higher evapotranspiration rates associated with rhododendron combined with highly acidic and high lignin content found in rhododendron leaves create conditions that are sub-optimal for decomposer organisms, thereby slowing the decomposition process.

Table 7: Mean percent original mass remaining for leaf litter, 1-, and 10-hour fuel by slope and aspect for 2006.

Component and Slope Position	N	Mean	Standard Dev.	p-value
Leaf Litter				
Northeast Bottom	8	61	16	
Northeast Mid-slope	10	58	13	
Ridge Top	10	65	19	0.7975
Southwest Mid-slope	8	61	18	
Southwest Bottom	9	66	11	
1-Hour Fuel				
Northeast Bottom	6	69	20	
Northeast Mid-slope	10	72	10	
Ridge Top	10	81	14	0.3257
Southwest Mid-slope	8	82	16	
Southwest Bottom	8	75	12	
10-Hour Fuel				
Northeast Bottom	7	79	24	
Northeast Mid-slope	8	78	34	
Ridge Top	7	55	44	0.3644
Southwest Mid-slope	8	89	22	
Southwest Bottom	6	75	25	

p-values are from an overall F test for differences among treatments.

Another possible influence on decay in this study was infiltration of fine roots into the layers of litter traps. Mass of fine roots present at the time the material was removed from within the litter traps could not be estimated; however, there were many samples from the more mesic sites that had a substantial quantity of fine roots, based on visual observations.

The small percentages of 100-hour fuels remaining after two years in the field are deceiving. Larger fuels persist longer on the tree's stem where decay processes begin. Once the woody material falls, fragmentation is likely to occur, which was observed for the majority of the 100-hour fuels for the 2005 litterfall period in this study. There was no estimation of the amount of 100-hour fuels that fragmented to the 10-hour fuel class, nor 10-hour fuels to the 1-hour fuel class. Decay was observed but the largest losses of 100-hour fuels were by fragmentation rather than the actual decay process.

1000-hour fuels collected after 1 and 2 years in the field showed no significant differences between slope and aspect (Table 8). These larger fuels take a long time to decay, as shown in previous studies; it can take from 17 to 136 years for CWD to completely decay (Mackensen and Bauhus 1999, and Zhou et al. 2007). The 1000-hour fuel bolts tested in this study were in the field for 1 and 2 years, so significant differences between treatments were not expected. The first year loss data are virtually identical to the second years losses with values ranging from 4 to 8% of the total mass (Table 8). Year 2 had a slightly larger range of 15 to 22%, but if that is divided into an annual basis the loss is very comparable to year one at 7.5 to 11%. It would likely take several years for the decay process to reach a point that significant differences could be detected with these larger fuel bolts.

There were no significant differences in litter moisture detected among slope and aspect positions (Table 9). The mean moisture content for leaf litter collected during the study was virtually identical, with values ranging from 29.3% for ridgetops to 33.1% for northeast bottoms. This adds support to the idea that ericaceous shrubs could have affected the outcome of this study. Mountain laurel found on all slope positions, though primarily on drier slopes, could act to create conditions similar to northeast slopes. This is accomplished by the preservation of moisture and cooler temperatures found under dense closed canopies of mountain laurel.

Table 8: Mean percent mass remaining for 1000-hour fuel bolts after one and two years in the field by aspect and slope.

Component and Slope Position	N	Mean	Standard Dev.	p-value
<u>2007 (After 1 Year in Field)</u>				
Northeast Bottom	20	94	6	
Northeast Mid-slope	20	96	3	
Ridge Top	20	95	5	0.1261
Southwest Mid-slope	18	92	5	
Southwest Bottom	18	94	5	
<u>2008 (After 2 Years in Field)</u>				
Northeast Bottom	9	81	6	
Northeast Mid-slope	10	85	5	
Ridge Top	10	82	10	0.3506
Southwest Mid-slope	9	78	7	
Southwest Bottom	9	80	7	

p-values are from an overall F test for differences among treatments.

Table 9: Average percent fuel moisture content of litter for 24 months.

Component and Slope Position	N	Mean	Standard Dev.	p-value
Northeast Bottom	87	33.1	14.4	
Northeast Mid-slope	90	29.4	10.9	
Ridge Top	90	29.3	12.4	0.3082
Southwest Mid-slope	81	31.2	14.4	
Southwest Bottom	84	30.2	14.8	

p-values are from an overall F test for differences among treatments.

10-hour fuel dowels were collected from months 2 thru 24. Each sampling period was then analyzed separately and, there were no significant differences detected among slope position or aspect (Figure 2). The 10-hour fuels dowels, just as the 1000-hour bolts, probably would take more than the two years in the field to show significant differences among treatments. These fuels can persist for years on a site because the surface area to volume ratio is small. Regression models, shown in the legend, are almost identical indicating a close linear relationship between all treatments.

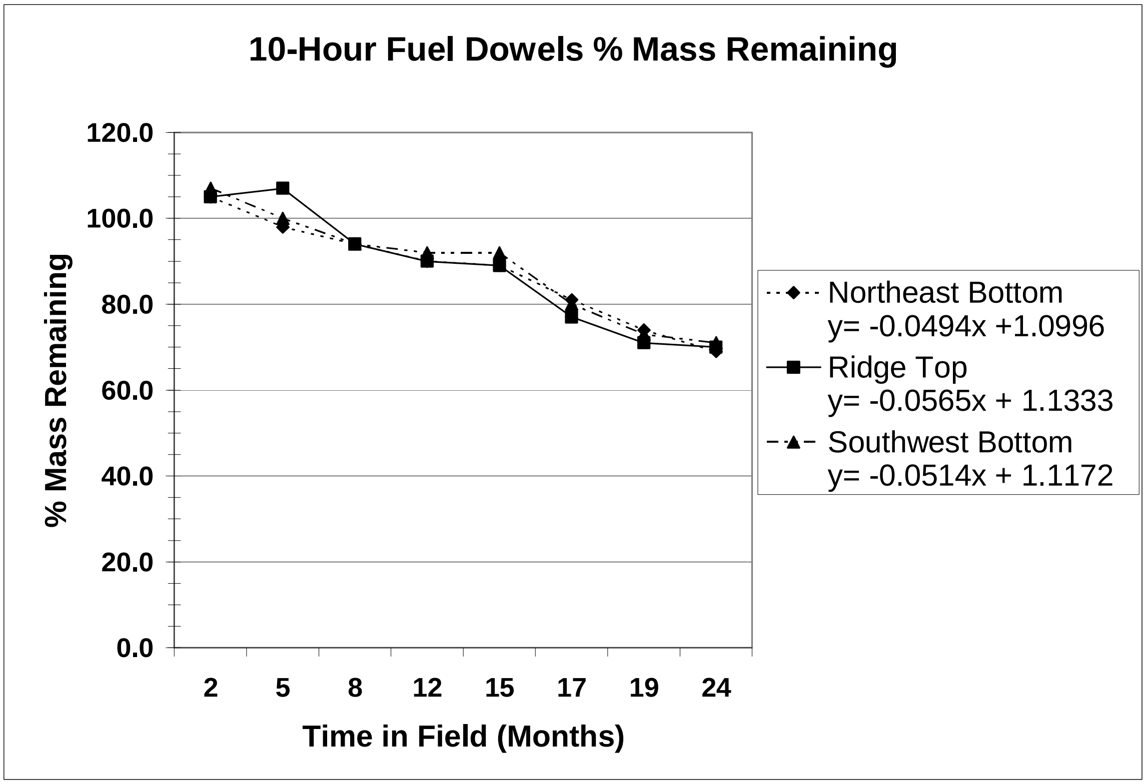

Figure 2: Mean percent mass remaining for 10-hour fuels from months 2 thru 24.

Total Fuel Loadings

It was not expected, after the analysis of litterfall accumulations had been completed, to find significant differences for total fuel loadings across the topographical gradient. There were no differences detected in the quantity of material collected in the litter traps among slope and aspect positions, and therefore, there should not have been detectable differences in total fuel loadings among the same slope and aspect positions. There was, though not significant, more leaf material collected on southwest slope positions as compared to northeast slope positions, and the 1-, 10-, and 100-hour fuels are virtually identical across all treatments (Table 10).

Table 10: Total fuel loadings across all treatments.

Slope and aspect	Litter (t/ha)	1 h (t/ha)	10 h (t/ha)	100 h (t/ha)
Northeast Bottom	1.9	0.3	0.2	0.001
Northeast Mid-slope	2.8	0.4	0.2	0.000
Ridge Top	2.7	0.3	0.2	0.000
Southwest Mid-slope	3.6	0.5	0.3	0.001
Southwest Bottom	3.3	0.3	0.2	0.030

p-values are from an overall F test for differences among treatments.

Individual Leaf Analysis

The initial analysis of individual leaf weight data found there were significant differences among all leaf weights (table 11). The 23 species were divided in groups that were generally specific to a certain site type 1) mesic (bottoms), 2) intermediate (mid-slope), and 3) xeric (ridgetops). A second analysis found significant differences between xeric and all other site types. This second analysis also showed that rhododendron (mean leaf weight of 0.0834 grams per 2.54 centimeters square) was influencing the overall mean for mesic site types because of its large leaf mass. A third analysis was conducted without the rhododendron data, and significant differences existed among all three site types.

Table 11: Means for site specific leaf weights.

Site	N	Mean (g/Area of 2.54 cm^2)	Standard Deviation	p-value
Mesic Bottoms	209	0.0333 c	0.012	
Intermediate Mid-slopes	239	0.0370 b	0.011	<0.0001
Xeric Ridgetops	209	0.0511 a	0.014	

p-values are from an overall F test for differences among treatments and letters within a treatment group are to determine specific differences among treatments.

Carbon Nitrogen Ratios

Carbon to nitrogen ratio analysis for 2005 leaf litter was conducted on three sample periods, the initial samples (04-2006), end of year one (03-2007), and end of year two (03-2008). These data were chosen because, if there were significant differences in the C:N ratios they should have been detectable in the time between sampling. There were no significant differences in C:N ratio among aspect or slope positions detected with p = 0.4223 for the initial sampling, p = 0.8416 for end of year 1 sampling, and p = 0.1102 for end of year 2 sampling (Figure 3).

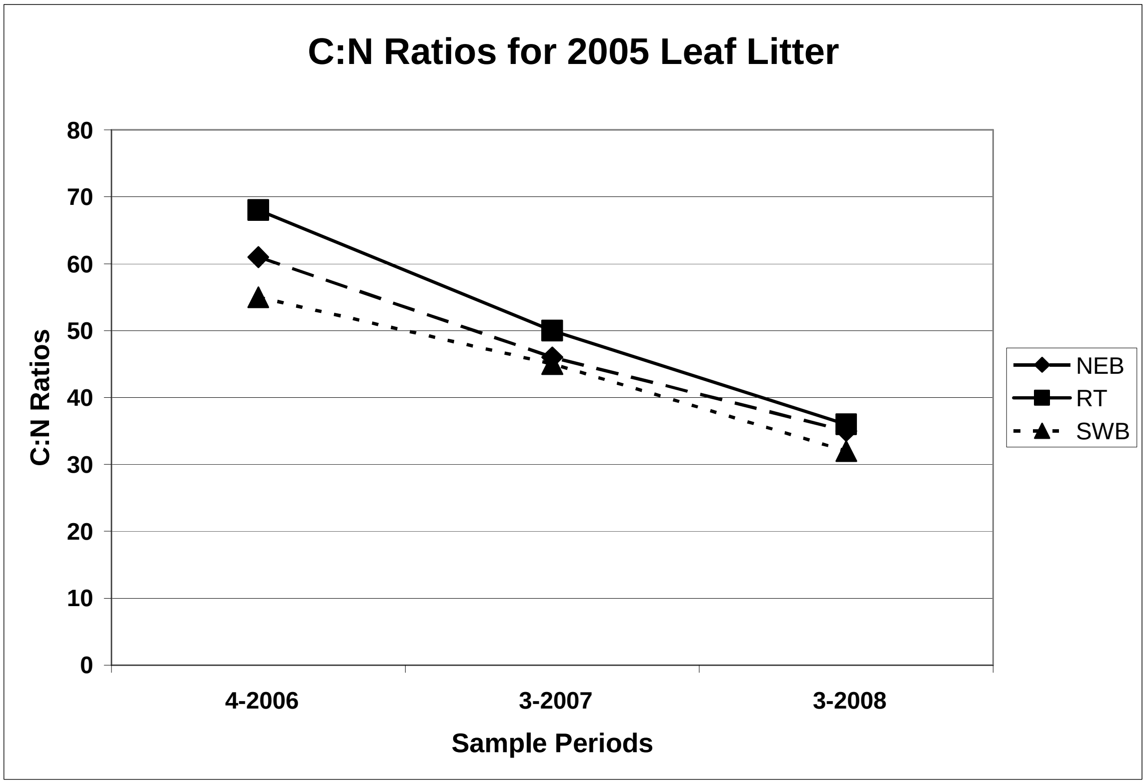

Figure 3: Carbon to nitrogen ratio for leaf litter samples collected over a two year time period (04-2006 to 03-2008).

CHAPTER V

SUMMARY AND CONCLUSION

Significant differences in accumulation and decomposition were not detected for leaf litter, 1-, 10- and 100-hour fuels among the five different slope position and aspect combinations for either year sampled. The results support findings from previous studies. The overall mean for leaf litter accumulations was 299.4 g/m^2 which falls within the range of 291 to 785 g/m^2 reported in other studies. Mean accumulation of woody material was 104.3 g/m^2 just below means of 106.9 and 107.6 g/m^2 reported in previous studies.

Northeast facing lower slopes had significantly greater 1000-hour fuels than other topographic positions (26.6 t/ha and 10.8/ha, respectively). This supports findings of Waldrop et al. (2007), who reported finding 44 t/ha on northeast facing slopes and 35 t/ha for all other slope positions, and Kolaks (2004), who reported 8.4 t/ha on protected slopes and 3.9 t/ha on unprotected slopes.

Decay rates were not significantly different among landscape positions. For 10-hour fuel dowels and 1000-hour fuel bolts, no significant differences were detected across the five topographical positions, and are likely due to the short period of this study. Fuel moisture content did not differ significantly across topographical gradients. Both the decay of 10- and 1000-hour fuels and the moisture content samples could have been influenced by the presence of the ericaceous shrubs.

The hemlock and pine cones that were collected could not be analyzed because there were too many of the original cones missing from the nylon cord that was used to tie the cones. In future studies, cones may be placed into a bag of some type, which should reduce the possibility of losing them.

Further study is needed, with study plots biased against ericaceous shrub species, to validate input and decay differences over different landscape positions in the southern Appalachian Mountains. By biasing against these species, a more diversified species composition could be captured in the litter traps and the influence of ericaceous shrub species could be eliminated or greatly reduced. In addition, a better designed litter trap should be used in order to avoid the problems that were associated with the litter material moving from top to bottom within the litter traps on the steeper slope positions.

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