WILDFIRE EFFECTS ON SMALL MAMMALS IN WESTERN NORTH CAROLINA

A thesis presented to the faculty of the Graduate School of Western Carolina University in partial fulfillment of the requirements for the degree of Master of Science in Biology

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ABSTRACT

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Fire can impact an ecosystem by changing environmental factors and small mammal abundances. Historically, wildfires have been uncommon in high elevation northern hardwood forests of the Southern Appalachian Mountains. In addition, little is known about wildfire effects on small mammals. In 2016, after the second hottest summer and fourth driest year on record, wildfires burned parts of Western North Carolina. Three questions were addressed in this study: Does the number of small mammals significantly differ between burned and unburned areas after two years of recovery? Are small mammals more abundant further from or closer to the fire boundary? If the number of small mammal captures differs with proximity to the fire boundary or between burned and unburned areas, do these differences correlate with environmental factors such as temperature, duff depth, and leaf litter depth?

To answer these questions, Sherman live traps were placed in an area within the Nantahala National Forest near Wine Springs Bald (WS). Sixty traps were placed along transects located 5 and 15 meters on either side of the fire boundary at WS in the summer of 2018. Traps were opened for 3-4 days and checked every morning and night. Temperature, duff depth, and leaf litter depth were measured at four traps on each transect. The most individuals captured were *Peromyscus sp. (194)* and the second most captured species was *Blarina brevicauda (11)*. Overall, there was no statistically significant difference in small mammal abundance between the burned and unburned transects. However, more *Napaeozapus insignis* were caught in the burned area and more *Blarina brevicauda* in the unburned area. In addition, there was no statistically significant difference in small mammal abundance between transects located five meters away and those fifteen meters away from the fire boundary. *Sorex sp.* had more individuals captured in 5 m transects and *Napaeozapus insignis* had more individuals captured in 15 m transects. Duff depth, leaf litter depth, and temperature were also similar between burned and unburned transects and between five meter and fifteen meter transects.

CHAPTER 1: INTRODUCTION AND LITERATURE REVIEW

Historically, humans have set fires to manage the land for agriculture or other purposes (Van Lear and Waldrop 1989; Lafon et al. 2017). In the mid-20th century, the number of fires decreased due to wildfire prevention (Van Lear and Waldrop 1989; Lafon et al. 2017). However, in fall 2016, when soil moisture (0-200 cm) was the second lowest on record (Park Williams et al. 2017), and at the end of a growing season that was 2°C warmer than average (at 685m; USDAa 2018), human caused and natural wildfires (Balch et al. 2017; United States Geological Survey 2017) burned throughout western North Carolina, including parts of the Nantahala National Forest outside of Franklin, NC (United States Geological Survey 2017). This area has northern hardwood forests that occur at elevations above 1200m-1300m in the southern Blue Ridge mountains (Trani et al. 2007). Northern hardwood forests are mesic with a thick organic soil layer (LANDFIRE 2007) where fire is a rare disturbance (LANDFIRE 2005, 2007). However, severe drought can result in fires in northern hardwood forests (LANDFIRE 2005, 2007). High temperatures and low precipitation resulted in a severe drought that lead to the numerous wildfires that occurred throughout the region (Konrad and Knox 2017; Park Williams et al. 2017). Coweeta Hydrological laboratory recorded the second hottest summer on record, 23.33 □ (June-August 2016 at 685m elevation), since the late 1930s (USDAa 2018). The hydrological laboratory also measured the fourth driest year on record, totaling 67.43 inches of precipitation (at 1364 m in elevation; (USDAb 2018). The severe drought led to the fuel load drying, i.e. leaf litter (Konrad and Knox 2017), that set the stage for numerous human caused wildfires throughout western North Carolina (Balch et al. 2017; USGS 2017).

Fire can change environmental features such as leaf litter (Greenberg et al. 2006, 2007; Loucks et al. 2008; Raybuck 2011), duff depth (Loucks et al. 2008), and canopy cover (Greenberg et al. 2007). For example, Loucks et al. (2008) reported leaf litter reduction of 60% and duff depth reduction of 36% in their study area in hardwood forests in Kentucky. Leaf litter ground cover (Raybuck 2011) and leaf litter depth (Greenberg et al. 2006, 2007) have been observed to be less after a fire. Higher intensity fires can cause a change in canopy cover (Greenberg et al. 2007). However, duff depth (Greenberg et al. 2007) and coarse woody debris cover (Greenberg et al. 2007; Raybuck 2011) also have been observed to not have changed after a prescribed fire. Further, over time, environmental features will change, such as leaf litter depth that increases after post-leaf fall (Loucks et al. 2008).

The habitat requirements of small mammals can lead to different responses to fire disturbance and influence trapping results among small mammal species. Leaf litter is an important habitat feature for small mammals such as shrews (Webster et al. 1985); a decrease in leaf litter depth can result in fewer shrew captures in burned areas (Greenberg et al. 2007). Edge habitat created from disturbances can also affect small mammal distribution and abundance. Masked shrews (*Sorex cinereus*) and smoky shrews (*Sorex fumeus*) may be more abundant along edges (Menzel et al. 1999). Soil temperatures can increase due to canopy cover openings (McCarthy and Brown 2006), which is important for the survival of small fossorial mammals with high metabolic rates that result in high evaporative heat loss (Deavers and Hudson 1981). For example, northern short-tailed shrews (*Blarina brevicauda*) have higher metabolic rates at 31□ (Deavers and Hudson 1981). Small mammals are also regulated by water availability, such as northern short-tailed shrews; a species that has high water demands (Whitaker and Hamilton 1998). Woodland jumping mice (*Napaeozapus insignis*) can be found near streams (Whitaker and Hamilton 1998), whereas many *Sorex spp.* and *Peromyscus spp.* are found near damp areas (Webster et al. 1985). *Peromyscus spp.* have a variety of responses to fire; they can become more abundant in burned sites (Greenberg et al. 2006, Converse et al. 2006; Borchert et al. 2014) or be unaffected by fire (Ford et al. 1999; Raybuck 2011). A possible reason for the variable responses could be habitat variation, as suggested by Greenberg et al. (2006). Other small mammal species such as golden mice (*Orchrotomys nuttalli*), northern short-tailed shrews (*Blarina brevicauda*), woodland jumping mice (*Napaeozapus insignis*), and southern-red backed voles (*Myodes gapperi*) may not be affected by high intensity burns (Ford et al. 1999).

As mentioned previously, northern hardwood forests have long fire intervals (LANDFIRE 2005, 2007). Due to how uncommon fire disturbance is in northern hardwood forests, the main goal of this study was to add to overall literature regarding wildfire effects on small mammals within this forest type. To analyze these effects, I established a small mammal trapping project at a northern hardwood forest site (WS) burned by the 2016 wildfires near Wine Springs bald in the Nantahala National Forest. The first objective of this study was to determine what small mammals are utilizing the study area almost 18 months after the wildfires. The second objective was to determine if there is a difference in small mammal abundance near versus further away from the fire boundary. The third objective was to investigate different environmental factors, specifically temperature, leaf litter, and duff depth, that could affect small mammals inhabiting either the burned or unburned site. Specifically, I am investigating the difference between these environmental factors between burned and unburned areas and transects located either 5m or 15m away from the fire boundary. I hypothesize that the number of small mammals captured will be higher in the unburned areas compared to the burned areas. This is based on the changes to the habitat after a fire and therefore the changes in the small mammal community. For example, the need of leaf litter for some small mammals, such as shrews (Webster et al. 1985). In addition, I hypothesize that there would be more small mammal captures in traps located five meters away then fifteen meters away from the fire boundary; that the small mammals will utilize edge habitat over the interior of the forest. This study provides some insight into the effects fire has on northern hardwood forests and the small mammals inhabiting the area.

CHAPTER 2: METHODS

Area of study

The study area (hereafter WS) was between Sawmill Gap, Wine Springs Horse Camp, and the Dirty John Shooting Range in the Nantahala National Forest near Franklin, NC (35.16740 latitude, -83.608935 longitude). The fires at WS were reported to have started November 3, 2016 and resulted in approximately 376,358 m^2 of land burned at WS (USDAc 2016). The WS area elevation ranges from approximately 1286-1428 meters (Monar 2018) and is a northern hardwood forest (Schafale 2012). Small mammals predicted to inhabit the forest community type are white-footed mice, deer mice, golden mice, southern red-backed voles, woodland voles (*Microtus pinetorum*), northern short-tailed shrews, eastern woodrats (*Neotoma floridana*), smoky shrews, masked shrews, eastern chipmunks (*Tamias striatus*), and pygmy shrews (*Sorex hoyi*) (Webster et al. 1985; Ford et al. 1999; Greenberg et al. 2006; Raybuck 2011).

Survey methods

To determine if captures of small mammals differ between burned and unburned areas, Survey Units were located on each side of the fire line between burned and unburned area. Survey Units were first established in ArcGIS (ESRI, Redlands, CA) before initial trapping and spaced at least 60 m apart (Figure 1). Each Survey Unit consisted of four transects that were each 140 m long. In each transect, traps were placed 10 meters apart for a total of 15 traps per transect. On each side of the fire boundary, the first transect was spaced 5 meters away from the fire boundary (5m). The second transect was spaced 10 meters away from the first transect and 15 m away from the fire boundary (15m). The 5m and 15m transects were established to determine if small mammals were using areas closer to the fire boundary or were inhabiting further into the specific areas.

Trapping occurred at WS from May 15th, 2018 to August 27th, 2018. Each trapping session lasted for three to four nights at each Survey Unit. Sherman traps were baited with a bacon grease, oats, and peanut butter baked mixture until mid-June. Traps were then baited with a mixture of oats, dried mealworms, and black oil sunflower seeds to reduce the number of traps damaged by American black bears (*Ursus americanus*). In addition, a piece of Poly-Fil was placed in each trap for insulation until mid-June. Traps were checked every morning and evening; each captured animal was marked with a sharpie on its belly. Everyday a different colored sharpie was used to help identify recaptures.

At the end of the trapping season, leaf litter depth, duff depth, and the highest burn mark were measured. Each variable was measured at the first, fifth, tenth, and fifteenth trap of each trapping line. Leaf litter depth and duff depth were measured three times at random locations within one meter of each selected trap. Leaf litter and duff depth data from each specific trap was averaged for all six transects were collected. This collected data then was averaged for each specific transect for analysis between burned and unburned areas. The other environmental factor measured was temperature. Temperature was measured during each trapping session with 3-4 iButtons placed 3.5-5 cm above the ground on each of the four transects (for a total of 12-16 iButtons being placed at a time). Each iButton was set to record temperatures every 30 minutes.

Statistical Methods

To analyze the distribution of small mammals, a chi-square test was used for analysis to compare capture results in burned (B) versus unburned (UB) areas, the 15m vs 5m transects, and to compare transects within either the burned or unburned area (R Core Team 2013). Species with fewer than 10 individuals were placed in a miscellaneous group to fit the requirements for the chi-square test. In addition, recaptured individuals were removed from all analyses. Species richness was calculated for the burned area, unburned area, 5m transects, and 15m transects with any unknown species removed from calculations. Catch effort per unit was calculated and used in a Welch's t-test for each of the most caught species, *Peromyscus sp*, *Blarina brevicauda*, *Sorex sp.*, and *Napaeozapus insignis*, separately between burned and unburned (B vs UB) or transect locations (15m vs 5m) for further analysis. Using the same trapping data in the previous statistical analyses, occupancy presence models were applied in the program PRESENCE (MacKenzie and Hines 2018). These models were used to compare capture data of each trap between burned and unburned areas, between transects, and between both transects and area. Covariates for this model included burned, unburned, 5m transects, and 15m transects. The data were analyzed comparing either the area covariates to each other, the transect covariates to each other, or comparing all the covariates to each other. The model that resulted with the lowest AIC and highest best fit was used for analysis.

Temperatures were compiled and the average for each trapping session per iButton was calculated. The iButton averages per trapping session was used to run an ANOVA to compare between burned and unburned areas and between the 5m and 15m transects (R Core Team 2013). Using the survey units as a blocking variable, a randomized complete block design was utilized for the ANOVA and a log-likelihood ratio test was performed to test the effects of the random blocks. In addition, the averages were used to calculate summary statistics, which were used to create a boxplot to compare results between B vs UB, 15m vs 5m transects, and 15m vs 5m transects in each respective area (R Core Team 2013).

Duff depth and leaf litter depth were averaged for each transect then was used to run a Welch's t-test to compare between burned and unburned areas and between the 5m and 15m transects. The duff depth and leaf litter averages were also graphed as a boxplot to compare the data between B vs UB, 15m vs 5m transects, and 15m vs 5m transects. In addition, the minimum, average, and maximum were calculated for each environmental factor for comparison between B vs UB, 15m vs 5m, and 15m vs 5m in each respective area (R Core Team 2013).

CHAPTER 3: RESULTS

Small Mammal Trapping

A total of 6 Survey Units, 24 transects were trapped from May 15th, 2018 to August 27th, 2018 (Survey Units 2, 6, 7, 10, 11, and 13; Figure 1). The main four species captured were *Peromyscus sp.*, *Sorex sp.*, *Blarina brevicauda*, and *Napaeozapus insignis* (Tables 1, 2, 3, and 4). Miscellaneous species captured were an unidentifiable Mustelidae species (1), *Glaucomys volans (1)*, *Ochrotomys nuttalli (1)*, *Tamias striatus (8)*, and unknown mice species (6). The most captured species was *Peromyscus sp.,* and the second most captured species was northern short-tailed shrew (Tables 1 and 2). Without including recaptures, captures between burned and unburned areas did not differ significantly (p=0.7734 (Table 5)). There was no significant difference in *Peromyscus sp.* (p=0.361, *Blarina brevicauda* (p=0.0575), *Sorex sp.* (p=0.327), or *Napaeozapus insignis* (p=0.863) captures between burned and unburned area (Table 6). *Peromyscus sp.* and *Sorex sp*. did not differ in captures between burned and unburned, but more *Napaeozapus insignis* were caught in the burned area and more *Blarina brevicauda* in the unburned area (Table 1). Species richness in the burned area was six and in the unburned was seven.

Between the 5m transects and the 15m transects, there was no significant difference between small mammal captures (p=0.78, Table 4). The most captured species in the 5m and 15m transects was *Peromyscus sp.* The second most captured species within the 5m transects was *Sorex* sp.; within the 15m transects, *Napaeozapus insignis* was the second most captured species (Table 2). There was no significant difference in *Peromyscus sp.* (p=0.791), *Blarina brevicauda* (p=0.333), *Sorex sp.* (p=0.0517), or *Napaeozapus insignis* (p=0.868) captures between the 5m and 15m transects (Table 7). *Sorex sp.* had more individuals captured in 5m transects and *Napaeozapus insignis* had more individuals captured in 15m transects (Table 2). The species richness for 5m transects was eight and for the 15m transects was five.

In the burned area, there was no significant difference between overall small mammal abundance in the 5m and 15m transects (p=0.1235; Table 5). There was a difference in where *Sorex sp.* individuals were captured within the burned area; two individuals were captured in the 15m transect and eighteen individuals captured in the 5m transect (Table 3). There was also a difference in what transects *Napaeozapus insignis* were captured; seven individuals captured in the 15m transects and two in the 5m transects (Table 3). The unburned area also had no significant difference in overall small mammal abundance between the 5m and 15m transects (p=0.944; Table 5). There was a difference where *Blarina brevicauda* individuals were captured; 5 individuals captured in the 5m transects and 3 in the 15m transects (Table 4).

The majority of captures for this study were at three trapping sessions that were located near a road or a stream. Out of the total eleven northern short-tailed shrews captured, five were captured on "Survey Unit 13," three on "Survey Unit 11," and two on "Survey Unit 10." In addition, all northern short-tailed shrew captures on "Survey Unit 11" and "Survey Unit 10" were within the unburned area. "Survey 10" and "Survey Unit 11" were located near a creek that was in the unburned area. The creek was located approximately 92 meters to 153 meters away from the fire boundary at "Survey Unit 11" (ESRI 2011; Figure 1). The creek was located 136.6 to 159 meters away from the fire boundary at "Survey Unit 10" (ESRI 2011; Figure 1). "Survey Unit 13" had a small creek that ran near the unburned 15m transects and intersected to run near the s0ixth trap location of both unburned transects.

The model with the highest AIC, a single season: heterogeneity (Royle/Nichols) Poisson model that compared burned and unburned trapping data, was utilized for analysis. This model is utilized when there is a variation in abundance of the captured organisms that results in the heterogeneity in the probability of detection (Royles and Nichols 2003). The probability of occupancy, the probability a small mammal is present at a trap (MacKenzie 2012), for the burned transects resulted in Ψ (psi) = 0.61 (sd=0.273, 95% confidence interval=0.0739-1; Table 8). The probability of occupancy for the unburned transects Ψ =0.526 (sd=0.216, 95% confidence interval=0.104-0.949; Table 8).

Environmental data

Minimum to maximum temperatures ranged from 11□ to 34.5□ in the burned transects and the daily average was 17.19□ (Figures 2 and 3). In the burned transects located at 5m, minimum to maximum temperatures ranged from 11□ to 33□ and the daily average was 17.05□ (Figure 3). Along the 15 m transect in the burned area, the overall average temperature was 17.36□ and minimum to maximum temperatures ranged from 11.5□ to 34.5□ (Figure 3). Minimum to maximum temperatures in the unburned transects ranged from 11□ to 30.5□ and the overall average was 17.04□ (Figure 2 and Figure 4). The overall average temperature from the transects located at 15m in the unburned area was 17.22□ and minimum to maximum temperatures ranged from 11□ to 30.5 □ (Figure 4). Minimum to maximum temperatures along the transects located at 5m ranged from 11□ to 28.5 □ and the daily average was 16.9□ (Figure 4). There was no significant difference in the average iButton temperatures between burned vs unburned (p=0.3245, Table 8), 15m vs 5m transects (p=0.136, Table 9), and between both transects and area (p=0.5745, Table 9). There was significance difference in the average iButton temperatures due to Survey Units (p=3.613x10^{-10}, Table 10), which were trapped on different dates throughout the summer.

The average temperature recorded by the Coweeta Hydrologic Laboratory, NC (elevation: 685m) for the summer was 22.77 □ (USDAa 2018). This average was higher than what was collected at WS (17.04□ in the unburned area and 17.19□ in the burned area), but that could be due to the difference in elevations. Precipitation recorded at an elevation of approximately 1364 meters for 2018 was overall the highest recorded since 1937 (339.83 cm) and the fourth highest record from May 2018- August 2018 at 47.32 inches (USDAb 2018).

The overall average leaf litter depth was 0.19 cm and averages per transect ranged from 0.05-0.41 cm in the burned transects (Figure 5 and Figure 7). Duff depth averages per transect ranged from 0.13-1.05 cm in the burned transects and overall averaged 0.514 cm (Figure 6 and Figure 8). The overall average leaf litter depth in the unburned transects was 0.127 cm and average leaf litter depth per transect ranged from 0.04-0.38 cm (Figures 5 and 9). The leaf litter depth averages were not significantly different between the burned and unburned area (p=0.264 (Table 11)). In addition, there was no significant difference in average leaf litter depth between the 5m and 15m transects (p=0.892 (Table 12)).

Average duff depth in the unburned transects ranged from 0.12-1.54 cm and overall averaged 0.686 cm (Figure 6 and Figure 10). The fifteen meter transects had an overall leaf litter depth average of 0.173 cm and averages ranged from 0.05-0.41 cm. The five meter transects had an overall leaf litter depth average of 0.144 cm and averages ranged from 0.05-0.36 cm. The duff depth for the five meter transects overall averaged 0.652 cm and averages ranged from 0.12-1.54 cm. The duff depth for the fifteen meter transects ranged from 0.13-1.12 cm and averaged 0.548 cm. There was no significant difference between the duff depth between the 5m and 15m transects (*p*=0.0985 (Table 112). There was a significant difference in duff depth between the burned and unburned areas (*p*=0.00973 (Table 11)). The highest scorch mark recorded in the burned area was 80 cm high.

CHAPTER 4: DISCUSSION

The results from the data collected at WS did not support my hypothesis that the number of small mammals captured would be higher in the unburned areas compared to the burned areas. These results are similar to the findings of Ford et al. (1999), who trapped small mammals before and after a series of prescribed fires in the Nantahala National Forest, 1.5 km northeast from Wine Spring Bald, in upper slope pitch pine, midslope oak, and rhododendron areas. They found no significant difference in *Peromyscus sp.*, golden mouse, northern short-tailed shrew, woodland jumping mouse, and southern-red backed vole captures between burned and unburned areas (Ford et al. 1999). The majority of individuals captured were *Peromyscus sp*. and did not have a difference in captures between burned or unburned areas (Ford et al. 1999). However, some studies have reported that *Peromyscus sp.* utilized burned areas over unburned areas (Converse et al. 2006; Greenberg et al. 2006; Borchert et al. 2014). The resulting small mammal abundance in my study could be due to the similarity in the environmental measures of temperature, leaf litter depth, and duff between areas and transects. However as previously mentioned, *Peromyscus sp.* have a variety of responses to fire.

There was no significant difference in small mammal distributions or individual species captures between burned and unburned areas. However, northern short-tailed shrew captures were close to being significant in value at p=0.0575; more than half of northern short-tailed shrews captured were in the unburned area. Ford et al. (1999) reported no significant difference between the average number of northern short-tailed shrews caught. The resulting northern short-tailed shrew captures in my study could be due to the proximity of water to the Survey Units; northern short-tailed shrews have high water requirements (Whitaker and Hamilton 1998).

Temperature, leaf litter depth, and duff depth were similar within the burned and unburned areas. However, the temperatures in the burned area were more variable. The variability could have been an issue for northern short-tailed shrews due to their high evaporative heat loss (Deavers and Hudson 1981). Northern short-tailed shrews have higher metabolic rates at 31□ which was within the range of temperatures in the burned area (Deavers and Hudson 1981).

The hypothesis that there would be smaller mammal captures at traps located five meters away than fifteen meters away from the fire boundary was also not supported. However, more *Sorex sp.* individuals were captured in the 5m transects. Leaf litter and duff depth are important for shrew habitats (Webster et al. 1985), but there was not a significant statistical difference of leaf litter or duff depth between burned and unburned areas at WS. Masked shrews (*Sorex cinereus*) have been reported to be less abundant in wildlife openings and more abundant along edges (Menzel et al. 1999). Although the difference was not significant, Menzel et al. (1999) also reported smoky shrews (*Sorex fumeus*) were more abundant along edges than within wildlife openings (Menzel et al. 1999). The *Sorex sp.* that were captured in my study were on the edge alongside the fire boundaries; at the transects 5m from the fire boundary. The fire boundaries were either old forest service roads, created fire lines, or a paved road.

During my study, the majority of captures were at three Survey Units that were located near a road or a stream. As mentioned previously, “Survey Unit 10” and “Survey Unit 11” were located near a stream. In addition, the fire boundary at “Survey Unit 10” and “Survey Unit 11” was a paved road, so the location of the 5m transects were based off the edge of the paved road. “Survey Unit 13” had a stream that intersected on through the unburned transects. Woodland jumping mice can be found near streams and, as mentioned previously, northern short-tailed shrews have high water demands (Whitaker and Hamilton 1998). In addition, many *Sorex sp.*

and *Peromyscus sp.* are found near damp areas (Webster et al. 1985). Therefore, the location of these transects might have played a factor in the captures of individuals. Another possible reason for the majority of captures at Survey Units 10, 11, and 13 could be due to switching bait from a peanut butter, oat, and bacon grease mixture to a mealworm and oats mixture halfway through my project. The bait was switched while trapping Survey Unit 11 in June. Survey Units 2, 6, and 7 were all completed with the peanut butter mixture whereas Survey Units 10 and 13 were completed with oats and mealworms. The small mammals could have preferred the new bait and could have resulted in more individuals being trapped at these transects. Finally, depending on weather, time, or black bears interferring with traps not every trap was set during a trapping session which could have led to a difference in the overall captures of my study. The probability of occupancy, as calculated by the occupancy model for both the burned and unburned areas, were very similar in ranges. Therefore, the differences between burned and unburned areas should not have affected the chances of a small mammal occupying the traps.

Average leaf litter depth and average duff depth were similar and their ranges overlapped between unburned and burned sites, 5m and 15m transects in the unburned area, and 5m and 15m transects in the burned area. Of the environmental factors measured (temperature, duff depth, and leaf litter depth), only duff depth differed between burned and unburned areas. While there was an approximately 0.2 cm difference of means across duff depth samples between burned and unburned areas, this difference in the duff layer was likely too small to be ecologically significant to any small mammals. Therefore, the results of my research suggest that two years after fire, the burned area has recovered since the initial disturbance; the burn area's average leaf litter depth, duff depth, and daily temperature are similar to those in the unburn area. The similarity between leaf litter depth and duff depth could be due to leaf fall from the previous year

(Loucks et al. 2008). Average temperatures did not differ between areas or transect location; large variation in average temperatures, likely due to the differences in the timing of surveys over the year, could have obscured differences among locations.

Eighteen months after the 2016 wildfires, there was no evidence that the small mammal community was affected by fire disturbance. The close similarity of measured environmental features between areas and the transects could be a reason for this observed result due to their importance as habitat requirements for many small mammal species. Continued research into wildfires within the Southern Appalachian Mountains is important to further understand and expand upon previous knowledge of the effects that fires have upon small mammal species. With the variation in temperatures and precipitation due to climate change resulting in drought that increases the chances of wildfires, research into the effects of wildfires on small mammals is increasingly more important. Additional research in areas similar to my field site at Wine Springs (WS) that contain mesic forests where fire disturbance is rare is also needed. Due to the long intervals between fire disturbance within these forest types, the responses of small mammals within these habitat types is not well known. Future research could expand upon my study to include other environmental factors, such as slope or the close proximity of paved roads, that could help provide more insight into wildfire effects on small mammals.

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APPENDICES

Appendix A: Tables

Table 1: Summary of captures of each species caught in Burned or Unburned areas at the Wine Springs fire in the Nantahala National Forest from May 2018-August 2018

Area	*Peromyscus sp.*	*Sorex sp.*	*Napaeozapus insignis*	*Blarina brevicauda*	Miscellaneous[1]	Total
Burned	92	11	9	3	5	120
Unburned	100	12	4	8	12	136
Total	192	23	13	11	17	256

[1]Miscellaneous species include: an unidentifiable Mustelidae species (1), *Glaucomys volans (1)*, *Ochrotomys nuttalli (1)*, *Tamias striatus (8)*, and unknown mice species (6)

Table 2: Summary of each species caught at transects located five meters away (15m) or fifteen meters away (5m) from the fire boundary at the Wine Springs fire in the Nantahala National Forest from May 2018-August 2018

Location	*Peromyscus sp.*	*Sorex sp.*	*Napaeozapus insignis*	*Blarina brevicauda*	Miscellaneous[1]	Total
5m	90	16	4	6	9	125
15m	102	7	9	5	8	131
Total	193	23	13	11	17	256

[1]Miscellaneous species include: an unidentifiable Mustelidae species (1), *Glaucomys volans (1)*, *Ochrotomys nuttalli (1)*, *Tamias striatus (8)*, and unknown mice species (6)

Table 3: Summary of each species caught in five meters away (5m) or fifteen meters away (15m) from the transect in the burned area at the Wine Springs fire in the Nantahala National Forest from May 2018-August 2018

Area	*Peromyscus sp.*	*Sorex sp.*	*Napaeozapus insignis*	*Blarina brevicauda*	Miscellaneous[1]	Total
5m	48	9	2	1	4	64
15m	44	2	7	2	1	56
Total	92	11	9	3	5	120

[1]Miscellaneous species include: an unidentifiable Mustelidae species (1), *Glaucomys volans (1)*, *Ochrotomys nuttalli (1)*, *Tamias striatus (8)*, and unknown mice species (6)

Table 4: Summary of number of each species caught per area in transects located five meters away (5m) or fifteen meters away from the fire boundary (15m) in the unburned area at the Wine Springs fire in the Nantahala National Forest from May 2018-August 2018

Location on	*Peromyscus sp.*	*Sorex sp.*	*Napaeozapus insignis*	*Blarina brevicauda*	Miscellaneous[1]	Total
5m	41	7	2	5	5	60
15m	59	5	2	3	7	76
Total	100	12	4	8	12	136

[1]Miscellaneous species include: an unidentifiable Mustelidae species (1), *Glaucomys volans (1)*, *Ochrotomys nuttalli (1)*, *Tamias striatus (8)*, and unknown mice species (6)

Table 5: Chi-square results for captures in burned vs unburned (B vs UB), transects located 5 meters away vs 15 meters away from the fire boundary (5m vs 15m), 5 meters vs 15 meters in burned area (B 5m vs 15m), and 5 meters vs 15 meters in unburned area (UB 5m vs 15m)

Comparisons	χ^2	*d.f.*	*p*-value
B vs UB	6.4803	10	0.7734
5m vs 15m	6.3629	10	0.7839
B 5m vs 15m	10.027	6	0.1235
UB 5m vs 15m	1.7147	6	0.944

Table 6: Welch's t-test results for *Peromyscus sp.*, *Blarina brevicauda*, *Sorex sp.*, and *Napeaozapus insignis* catch per unit effort between burned and unburned areas

Species	Mean (μ) of the Differences	*t*-value	*p*-value
Peromyscus sp.	-0.0066	-0.364	0.361
Blarina brevicauda	-0.0045	-1.711	0.058
Sorex sp.	-0.0017	-0.461	0.327
Napeaozapus insignis	0.0047	1.149	0.863

Table 7: Welch's *t*-test results for *Peromyscus sp.*, *Blarina brevicauda*, *Sorex sp.*, and *Napeaozapus insignis* capture per unit effort between transects that were 15m and 5m away from the fire boundary

Species	Mean (μ) of the Differences	*t*-value	*p*-value
Peromyscus	0.0137	0.842	0.791
Blarina brevicauda	-0.0008	-0.445	0.333
Sorex sp.	-0.0087	-1.776	0.052
Napeaozapus insignis	0.0043	1.176	0.868

Table 8: Probability of detection from a single-season heterogeneity Royles/Nichols poisson model of best fit comparing burned and unburned covariates

Covariate	psi	Standard Deviation	95% confidence interval
Burned	0.61	0.273	0.0739 - 1
Unburned	0.526	0.216	0.104 - 0.949

Table 9: ANOVA summary of average temperatures taken within the Wine Springs area from May 2018- August 2018

Units	Sum Square	Mean Square	*f*-value	*p*-value
Area (Burned and Unburned)	0.3465	0.347	0.9965	0.3245
Location (5m and 15m transects)	0.8054	0.8054	2.317	0.136
Area: Location	0.112	0.112	0.3207	0.5745

Table 10: Log-likelihood ratio test for the effects of random blocks (Survey Units) on measured average temperatures

Units	Log likelihood	AIC	*p*-value
Survey Unit	-66.29	142.6	3.613×10^{-10}

Table 11: Welch's *t*-test results for environmental factor averages between burned and unburned areas

Environmental Factor	Mean (μ) of the Differences	t-value	p-value
Leaf Litter	0.0629	1.353	0.9085
Duff Depth	-0.194	-2.426	0.00973

Table 12: Welch's *t*-test results for environmental factor averages between transects that were 15m and 5m from the fire boundary

Environmental Factor	Mean (μ) of the Differences	t-value	p-value
Leaf Litter	0.0374	1.257	0.8924
Duff Depth	-0.0987	-1.31	0.0985

Appendix B: Figures

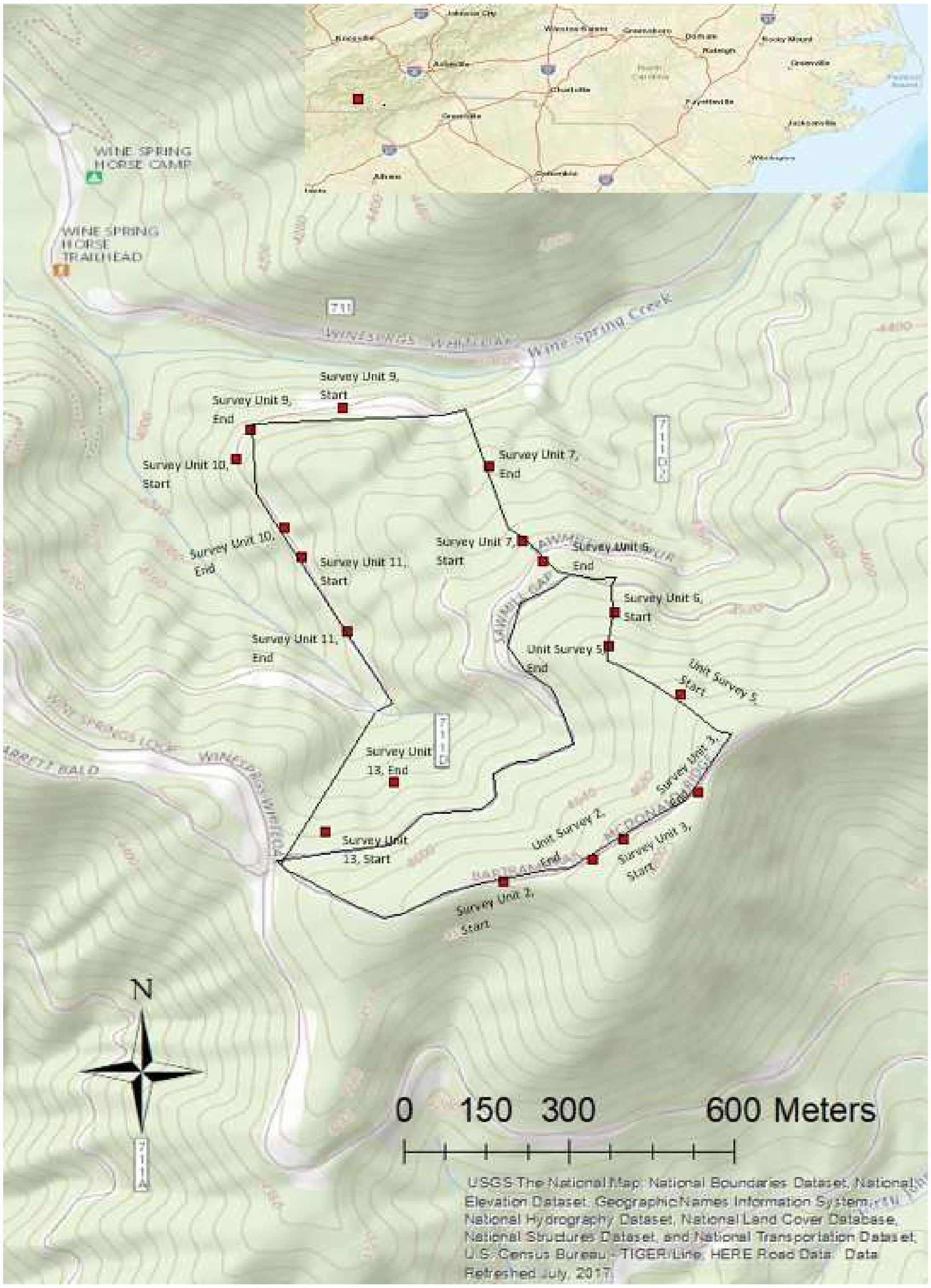

Figure 1: Map of estimated fire boundary at Wine Springs fire in the Nantahala National Forest from May 2018-August 2018 by USFS and with estimated Survey Units (SU). Each SU designates the beginning and ending estimated starting points (Trap 1=beginning, Trap 15=ending) of the set of transects within each SU.

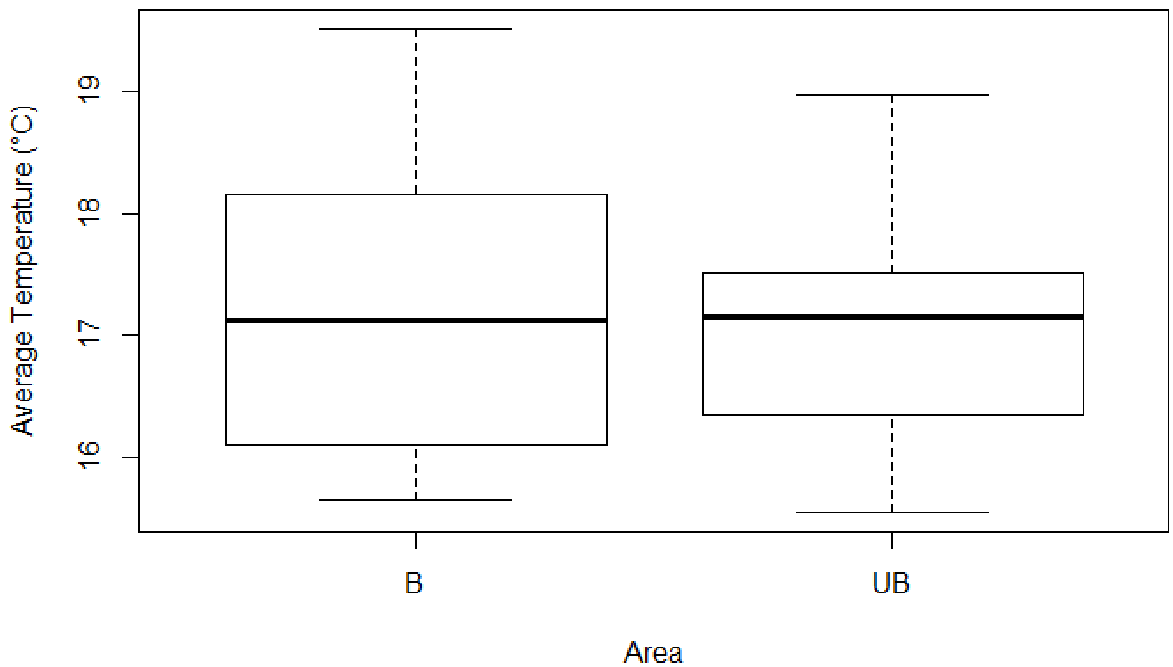

Figure 2: Average temperatures (□) of iButtons within burned (B) and unburned (UB) areas

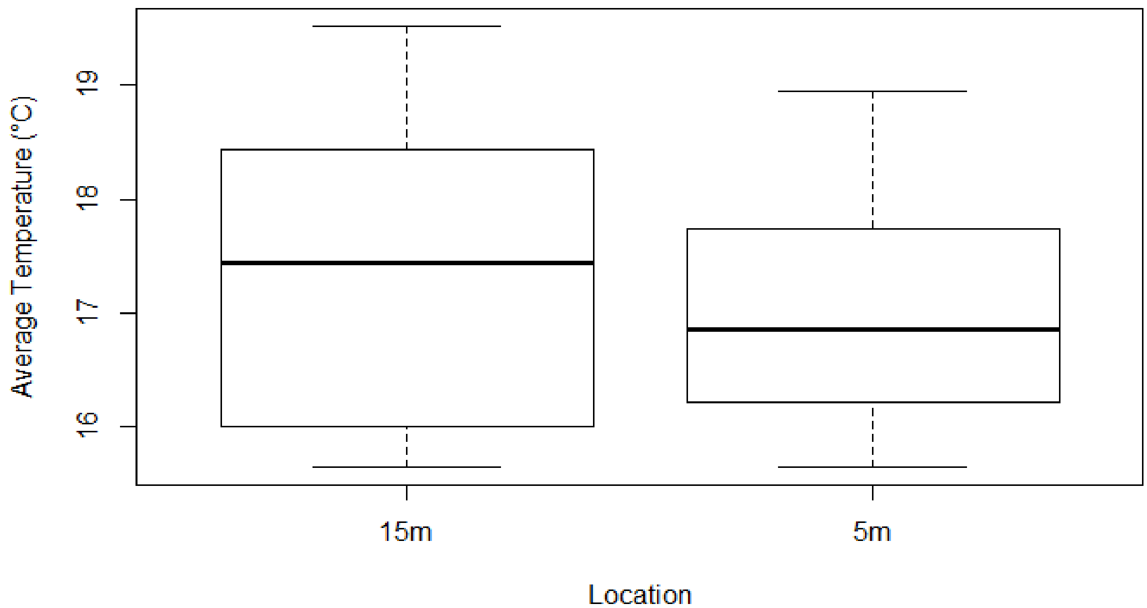

Figure 3: Average temperatures (□) of iButtons in transects located fifteen meters (15m) away from the fire boundary and located five meters (5m) away from the fire boundary in the burned area

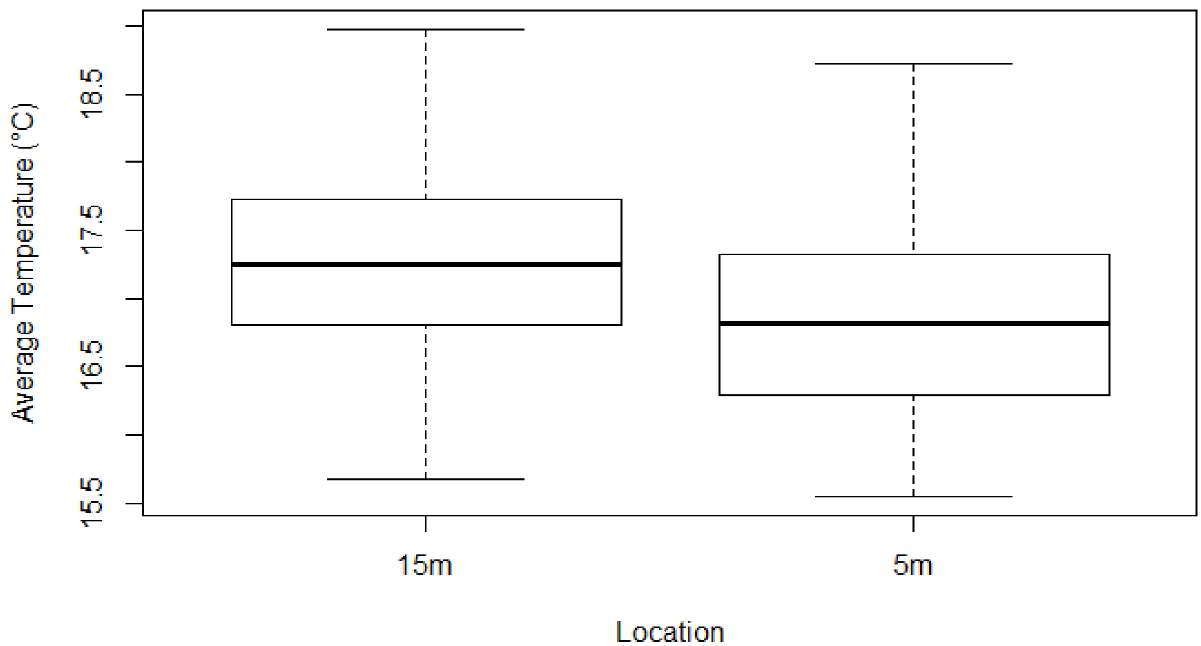

Figure 4: Average temperatures (□) of iButtons in transects located fifteen meters (15m) away from the fire boundary and located five meters (5m) away from the fire boundary in the unburned area

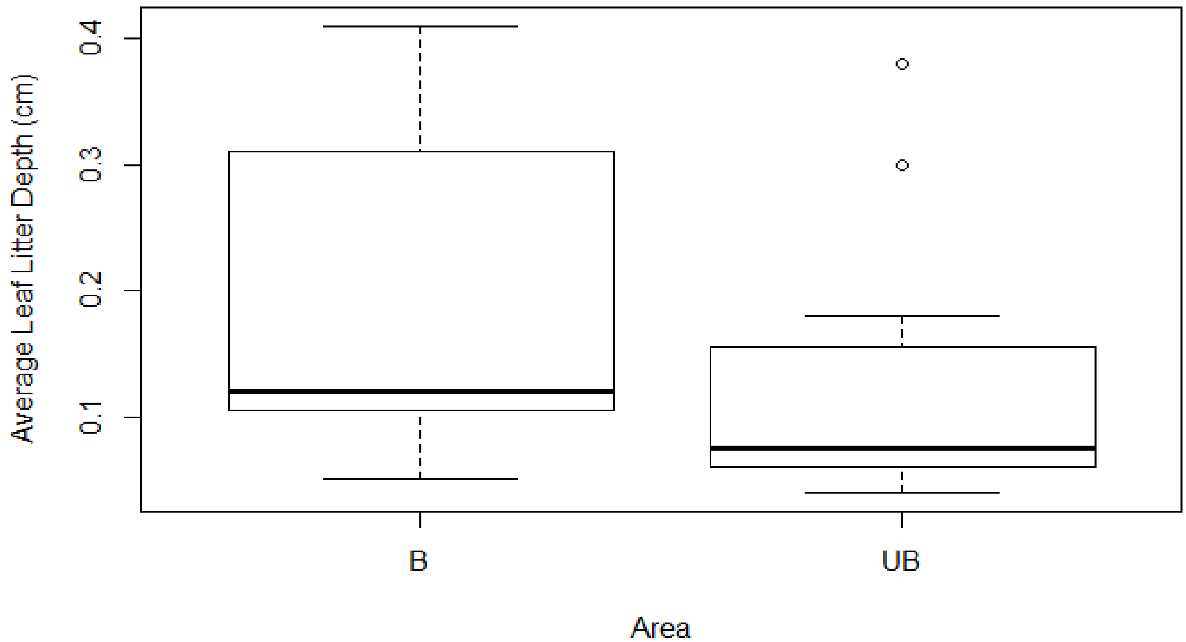

Figure 5: Average leaf litter depth (cm) in the burned and unburned areas

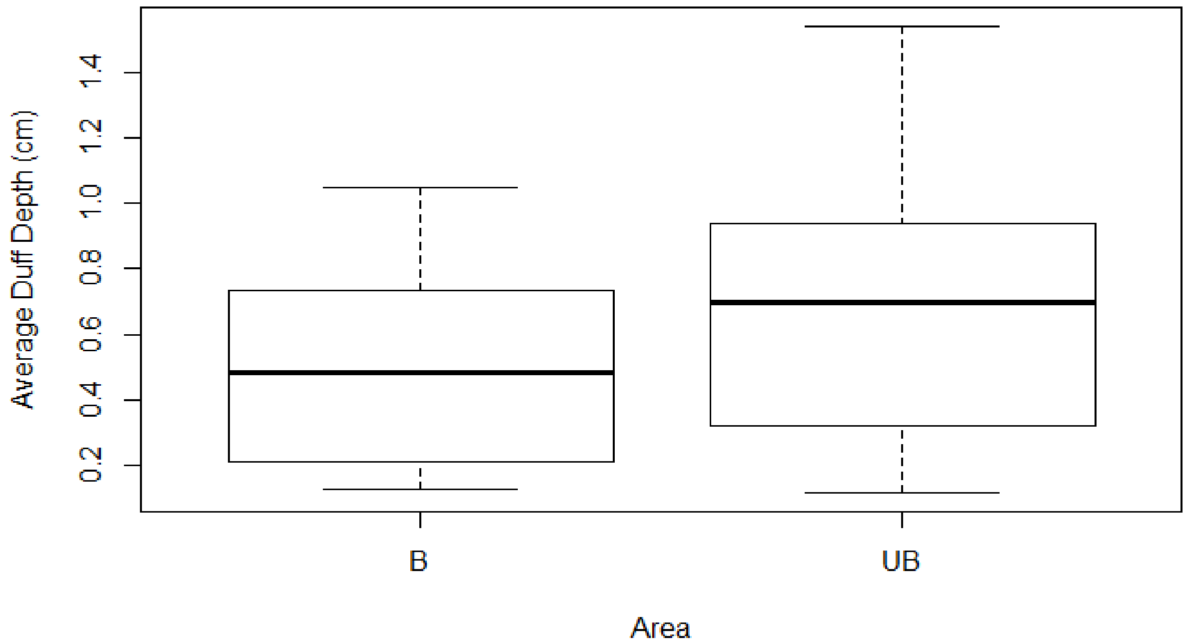

Figure 6: Average duff depth (cm) in burned and unburned areas

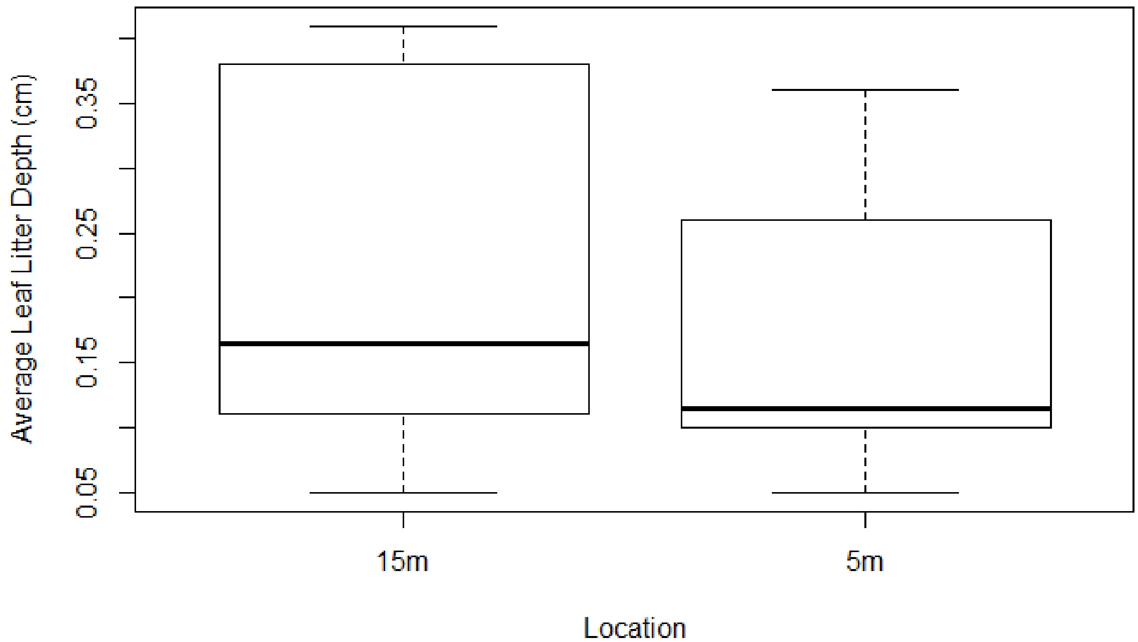

Figure 7: Average leaf litter depth in transects located fifteen meters (15m) away from the fire boundary and located five meters (5m) away from the fire boundary in the burned area

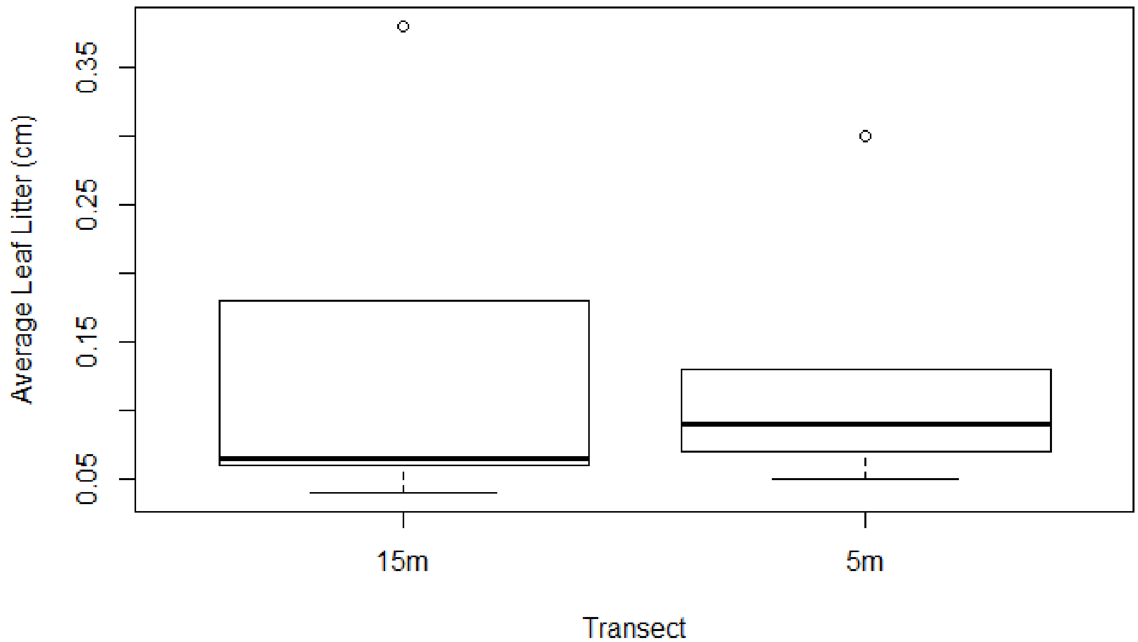

Figure 8: Average leaf litter depth (cm) in transects located fifteen meters (15m) away from the fire boundary and located five meters (5m) away from the fire boundary in the unburned area

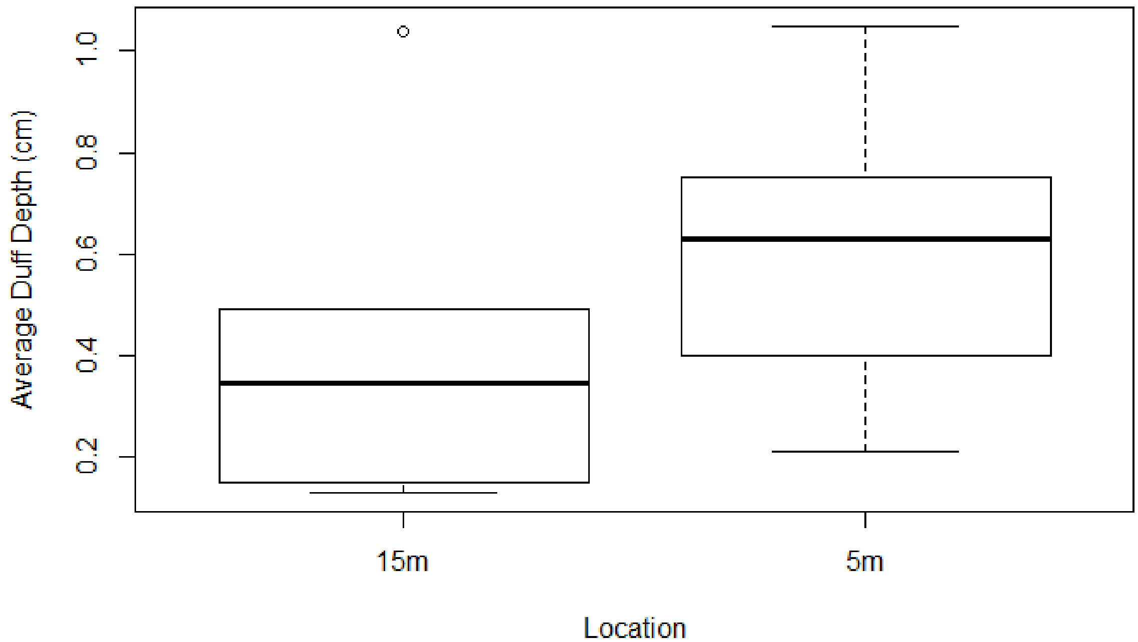

Figure 9: Average duff depth (cm) in transects located fifteen meters (15m) away from the fire boundary and located five meters (5m) away from the fire boundary in the burned area

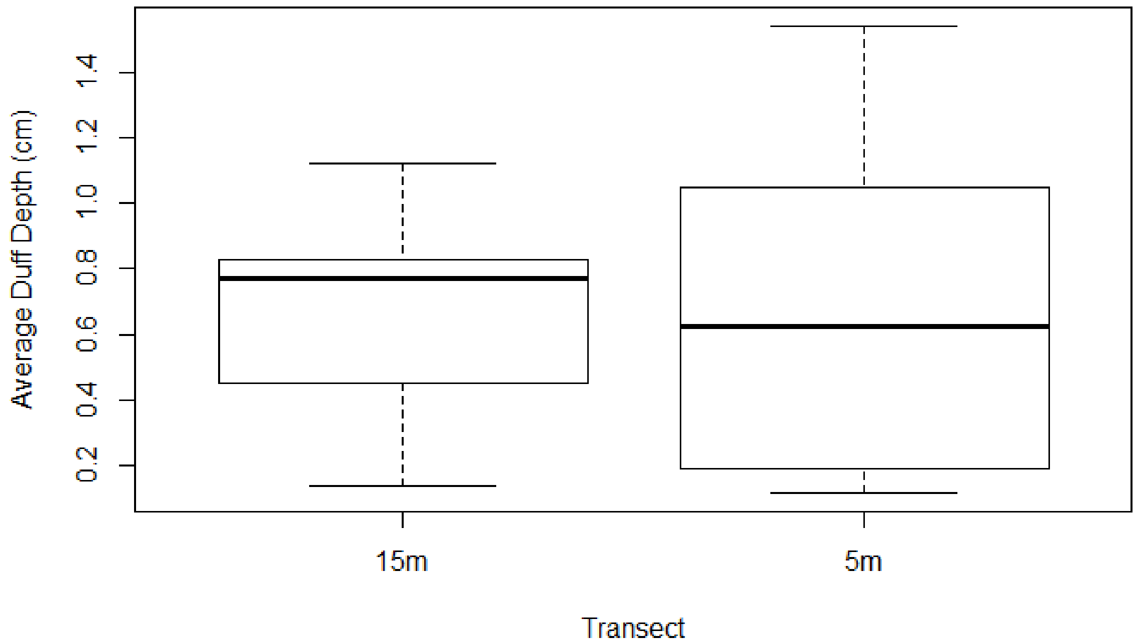

Figure 10: Average duff depth(cm) in transects located fifteen meters (15m) away from the fire boundary and located five meters (5m) away from the fire boundary in the unburned area