EFFECTS OF FUEL TREATMENTS ON BASAL AREA LOSS AND SOIL BURN SEVERITY IN THE CEDAR CREEK AND CUB CREEK 2 FIRES

by

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A professional paper submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Land Resources and Environmental Sciences

MONTANA STATE UNIVERSITY
Bozeman, Montana

May 2022

DEDICATION

This paper if dedicated to all the wildland firefighters who fought the Cedar Creek and Cub Creek 2 fires in the summer of 2021. Thank you for your hard work, dedication, and sacrifice to protecting public lands and private property during this natural disaster.

ACKNOWLEDGEMENTS

I would like to thank Dr. Scott Powel for his mentorship in assisting me with completing this project, as well as his guidance throughout this program as my academic advisor. I would also like to thank the U.S. Forest Service Methow Valley Ranger District for providing me with not only my personal employment as a wildland firefighter which allowed to be study these fires personally but also Wesley Page for his guidance for the project. Thank you to my parents for their support and encouragement through this program and August Griswold for his firefighting knowledge, editing skills, and patience while I completed this program.

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ABSTRACT

Fire regimes in the western United States have been significantly altered by the wildland fire suppression activities standard within 20th century land management practices. Well-intentioned fire suppression activities have increased tree stand density, fuel connectivity and loading, and the competitive stress placed on the forests. These changes, coupled with the forces of climate change have led to an increase in fire severity, the length of the fire-season, and the amount of area burned by fire. Modern hazardous fuel-reduction treatments such as thinning and prescribed burning can be used by land managers to reduce the frequency and extent of stand-replacement fires, with the goal of returning the fire regimes to their historical characteristics. Therefore, the aim of my study was to evaluate forested areas that have been damaged from large high severity fires to determine the impact, if any, that recent hazardous fuel reduction treatments had on post fire soil burn severity and basal area loss. In July 2021, the Cedar Creek fire and the Cub Creek 2 fire ignited in the dry-ponderosa pine forests surrounding the Methow Valley of Washington. Both fires were very large and burned through areas that had undergone fuel reduction treatments in the previous five years as well as areas that had not received fuel reduction treatments in that time period. The fire damage generated by these events provided the data for my study. I analyzed post fire soil burn severity and basal area loss using QGIS to create maps and calculate percentage area of fire effects for these variables. Treated areas were compared to similar untreated damaged areas, each classified by slope, aspect (north or south), and fuel type to aid in the analysis. Areas subject to fuel reduction treatments in both fires exhibited reduced proportions of high fire severity effects and greater proportions of low fire severity effects than did their comparison untreated areas. Consequently, with increases in fire severity and size, and the rising costs of fighting these fires, fuel reduction treatments can be used to reintroduce fire into the landscape at lower severity to improve forest resiliency.

INTRODUCTION

Central Washington Forest Fire Regimes

Fire regimes are defined by fire frequency, the mean number of fires per defined period of time, extent, area burned, intensity, and seasonal timing (Loehman, 2014). Central Washington has a mixed-severity fire regime, defined by 20-70% of the overstory or basal area being killed by the sum of all fire effects (Perry, 2011). Mixed-severity fires create heterogeneity and patchiness of forest structure and composition, patch sizes can have a broad range determined by local forest conditions and climate drivers (Perry, 2011). Low and mixed severity fires provide important feedbacks and effects to ponderosa pine (*Pinus ponderosa*) dominated stands such as the regeneration of fire-tolerant trees with the exposure of mineral soil by fires, elevating crown bases by consuming seedlings, saplings, and pole sized trees, as well as cycling nutrients and reducing the long-term threat of crown fires (Hessburg, 2005).

The fire exclusion and suppression practices of the 20th century have caused changes in fire regimes, interannual variability in temperature, drought conditions, and snowpack (Raymond, 2012). These changes have been found to be correlated with increased annual area burned and the length of the fire season (Raymond, 2012). The consequences can be seen in the now unhealthy dry ponderosa pine forests commonly found in Central Washington, which are categorized by high stand density, increased fuel continuity, and favored fire and drought susceptible tree species (Merschel, 2021, Fulé, 2012). These forests vulnerability to insect outbreaks, forests diseases, competitive stress, and uncharacteristically large or intense forest fires has increased over time (Hessburg, 2005).

In the ponderosa pine forests of the Pacific Northwest, there has been a six-fold increase in the proportion of forests burned at high-severity compared to historical fire regimes, with over half being burned in uncharacteristically large patches (Merschel, 2021). In these forests, understory fuel development has propagated crown fires which have killed old-growth stands not normally subject to fires of high intensity (Mitchell, 2009). Ecosystem resiliency is the ability of a system to absorb a perturbation disturbance and return to a similar set of previous functions and processes (Waltz, 2014). Ponderosa pine forest resiliency is affected by landscape-scale disturbances such as wildfires.

Hazardous Fuel Reduction Treatments

A hazardous fuel reduction treatment is a management action which aims to improve forest structure and fuel loads in forests altered by fire exclusion (Johnson, 2019). Techniques to reduce hazardous fuels can include thinning, prescribed burning and directed naturally occurring wildland fires (Odland, 2021). Fuels that are removed by thinning should then be treated with piling and burning, mastication, mulching, chipping, or broadcast burning to remove them from the landscape (Clyatt, 2017).

The most effective method for reducing extreme fire behavior is thinning followed by prescribed burning (Banerjee, 2020). Prescribed burning reduces litter depth and surface fuels which can cause mortality to larger trees during a fire, this process promotes understory soil health and diversity (Stevens, 2014). Fuel reduction treatments not only create a more open forest structure, but they also improve overall ecosystem function by increasing rates of decomposition and nutrient cycling, water availability, carbon storage, plant diversity, and potential wildlife habitat (Kalies, 2016).

Fuel management is a key component to restore fire-resilient forest structure and mitigate the negative results of wildfires in the dry forests of the Pacific Northwest (Wimberly, 2014). Compared to historical conditions, contemporary dry coniferous forests across western North America have higher stem densities, higher canopy bulk densities, higher fine and coarse woody fuel loadings, and lower canopy base heights (Johnson, 2019). By implementing fuel reduction management actions forests become closer to their historical conditions, which reduces their susceptibility to high-severity fires (Johnson, 2019).

The primary objective of fuel treatments for fire hazard reduction is to reduce extreme fire behavior and to increase forest resiliency for future wildfires (Johnson, 2019). In fuel loaded landscapes, thinning is an important management tool to prevent high intensity crown fires (Banerjee, 2020). Fuel reduction treatments also increase ecosystem resiliency by retaining large trees, which facilitate forest regeneration after a fire and maintain structural components (Waltz, 2014, Stevens, 2014). By thinning small diameter trees (ladder fuels), basal area loss is significantly lower in treated sites compared to untreated after a wildfire (Waltz, 2014).

The effectiveness of thinning treatments reduces with the passage of time, and timing is very important for a successful thinning operation to give the desired results (Banerjee, 2020). The duration of treatment effectiveness depends on site productivity and the rate of accumulation of flammable live and dead surface fuels (Prichard, 2020). Therefore, fuel reduction treatments must be periodically repeated to effectively reduce extreme fire behavior and attain other secondary objectives such as forest resiliency, wildlife habitat, etc.

A forestry study involving three different forest types in Washington state (east cascades ponderosa pine forest, west cascades western hemlock (*Tsuga heterophylla*) Douglas-fir (*Pseudotsuga menziesii*) forest, and coast range western hemlock and Sitka spruce (*Picea sitchensis*) forests) all benefited from fuel reduction treatments to reduce fire severity (Mitchell, 2009). While these treatments resulted in a temporary reduction in mean stand carbon storage, particularly in the west cascades and coast range, fuel reduction was still advised for stands in the eastern cascades due to uncharacteristically high understory fuel accumulation (Mitchell, 2009).

With the escalating frequency of high severity wildfires in the west, the demand for active management solutions is becoming critical. Therefore, the goal of my study was to examine how fuel reduction treatments effect basal area loss and soil burn severity compared to similar untreated areas after the occurrence of uncharacteristically large and severe wildfires in the dry and fuel loaded forests of Central Washington. The 2021 Cedar Creek and Cub Creek 2 fires burned over areas that had recently undergone fuel reduction treatments as well as adjoining areas that were untreated. As such, these areas were ideal for comparison using GIS data sets. In addition, my experience serving the public as a wildland firefighter influenced me to pursue this topic of research as I personally fought both fires. Combining this research with my employment gave me a thorough comprehensive understanding of the unhealthy nature of dry ponderosa pine forests, how large and severe wildfires can ravage the landscape, as well as the challenges associated with full suppression wildland firefighting. These experiences have fueled my interest in understanding the effectiveness of fuel reduction treatments, as well as understanding the consequences of fuel loading and climate change on how we manage wildfires and our forests.

METHODS

Study Area

The Cedar Creek fire started on July 8, 2021, 4 miles west, southwest of Mazama, Washington (Methow Valley Ranger District, 2021) (Figure 1). The Cub Creek 2 fire started on July 16, 2021, 5 miles north of Winthrop, WA. (Methow Valley Ranger District, 2021) (Figure 1). The Cedar Creek fire totaled an area of 55,572 acres (22,489,104.11 m^2) (Methow Valley Ranger District, 2021). The Cub Creek 2 fire totaled an area of 70,186 acres (284,032,664.89 m^2) (Methow Valley Ranger District, 2021). Due to fuel reduction treatments having been performed before the occurrence of these fires this was a unique opportunity to study how fuel reduction treatments affect basal area loss (BAL) and post fire burn severity outside of a modeling or lab setting. Twelve sites within the Cedar Creek and Cub Creek 2 fires were identified which had received previous hazardous fuel reductions treatments ranging from under-burning (prescribed burning), burning piles, and pre-commercial thinning (Figure 2, Table 2). The fuels involved in these fires were characterized as brush (2 feet), closed timber litter, and timber (litter and understory) (Methow Valley Ranger District, 2021). The primary carrier of these fires was timber litter with large wood and moisture stressed brush (Methow Valley Ranger District, 2021).

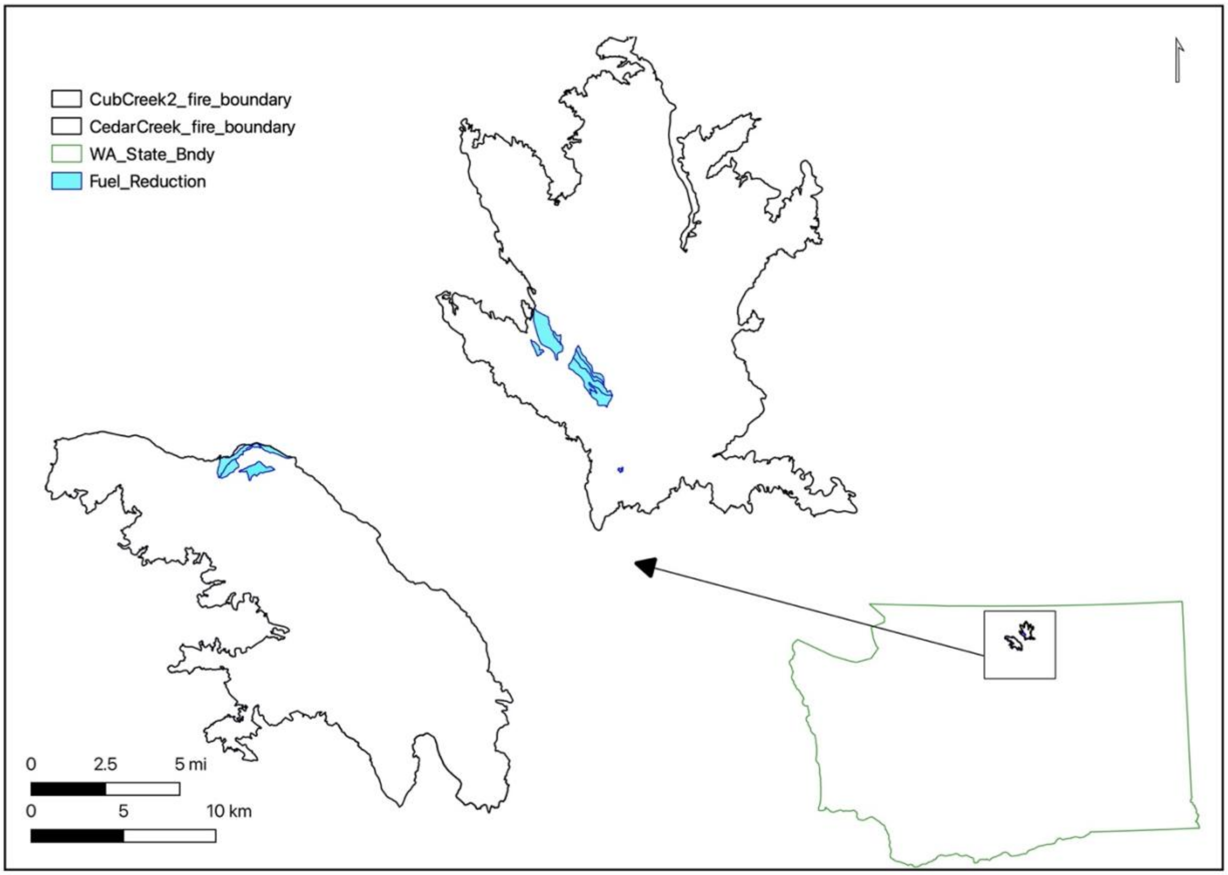

Figure 1. Study area within Washington State.

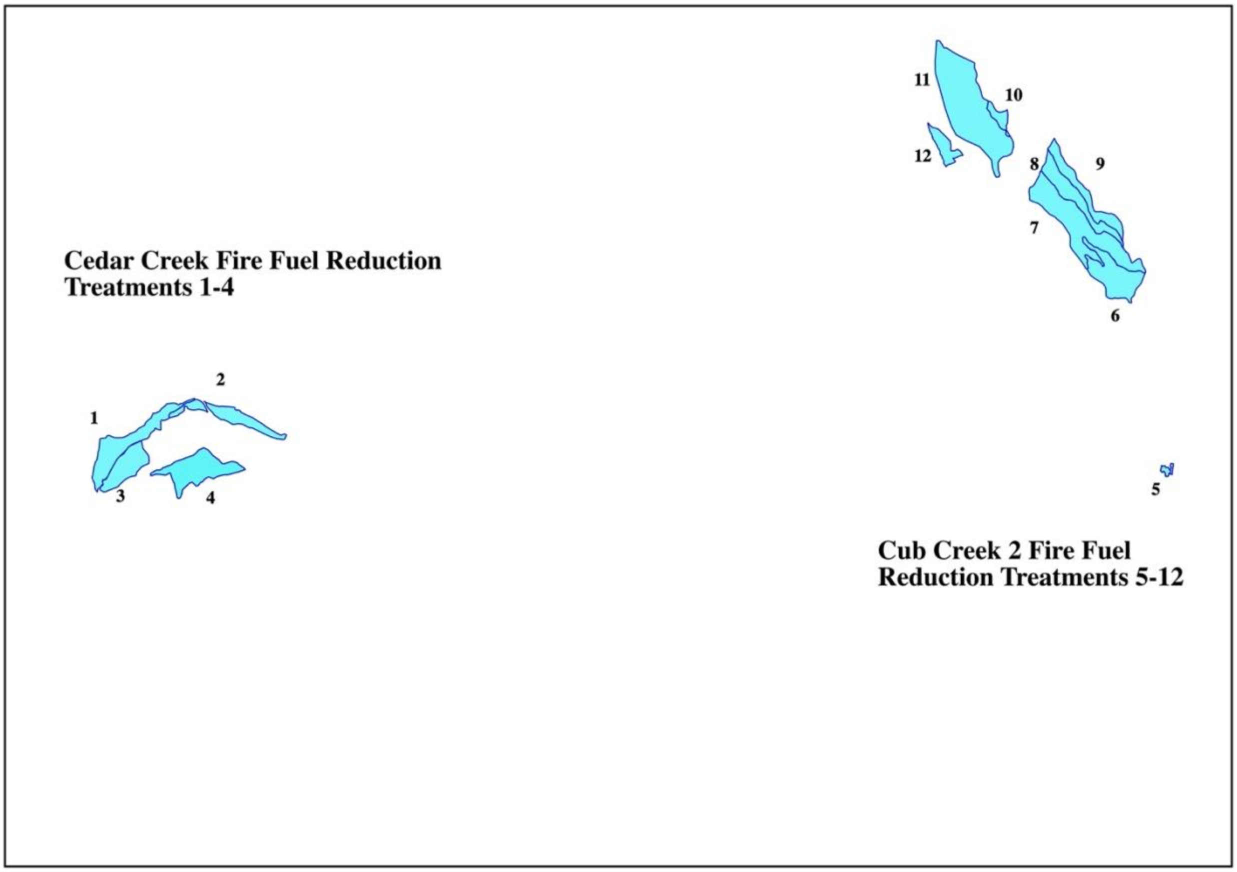

Figure 2. Fuel reduction treatment Patches 1-4 within the Cedar Creek fire and Patches 5-12 within the Cub Creek 2 fire.

The eastern cascades of central Washington are home to a wide variety of ecosystem types, but the two most prominent in this region are sagebrush-steppe ecosystems, ponderosa pine and Douglas fir forests at low elevation, and lodgepole, white pine and larches at higher elevations (Perry, 2011). The areas containing the Cedar Creek and Cub Creek 2 fires were primarily within the ponderosa pine and Douglas fir forest types, with small areas in the sagebrush steppe ecosystem of the low country and the lodgepole, white pine and western larch forests of high elevation. Ponderosa pines and Douglas firs, the two species which dominate the forests of Central Washington, have high crowns and thick bark which enable a greater resistance to fire caused mortality as well as the ability to regenerate well postfire, preferring exposed mineral soil for seedlings (Raymond, 2012). These forests are dry conifer forests. This region is categorized by hot dry summers with most of their precipitation being in the form of a winter snowpack (Littell, 2010).

Data sources and descriptions

The United Stated Department of Agriculture (USDA) collected the initial basal area loss and soil burn severity data found at United States Geological Survey (USGS) Burn Severity Portal via the Burned Area Emergency Response (BAER) (USGS, 2021) and the Rapid Assessment of Vegetation Condition after Wildfire (RAVG) (USGS, 2021).

Fuel reduction treatments were stored in the USDA Forest Service National Datasets (FACTS) (United Stated Department of Agriculture Forest Service, 2021). I used these data base to find fuel treatments performed from 2016 to 2021 within each fire area.

Anderson's 13 fuel model, aspect, and slope were all determined using available data collected from Landfire (Landfire, 2022). Metadata, data description, and the data dictionaries for all topographical and fuel modeling raster layers were found using the Landfire database (Landfire, 2022)

Fire behavior data for the Cub Creek 2 and Cedar Creek fires were collected from Wildifre.org (Wildfire, 2021). Climate data were collected from the RAWS USA Climate Archive using the NCSB station (RAWS, 2021).

Finally, my recollection of the fire behavior was based on my personal observation for the duration of both fires. I was present for both fires as a wildland firefighter through my employment with the USFS Methow Valley Ranger District, observing fire behavior, protecting homes, collecting weather data, and preforming a variety of tasks associated with preventing the spread of wildfires. I witnessed fire behavior and intensity in areas of the fires closed off to the public, had access to non-public maps and information, and spoke to several supervisory wildland firefighters during my time fighting the fires.

Approach

All GIS visualization and basic image processing and analysis were performed in QGIS 3.18.1-Zurich. I used the Assigned Coordinate Reference System ESPG:32148 and all raster and vectors layers were re-projected to this. The files for soil burn severity and basal area loss were pre-processed from their sources for QGIS and displayed the entirety of the Cedar Creek and Cub Creek 2 fires. Boundary layers of the two fires were pre-created as well and used as base maps for other layers. I classified soil burn severity by using the attribute table to identify areas of unburned, low, moderate, and high which were described within the metadata and by BAER. New layers were created for each new subset to create maps showing each of these layers within the fires to accurately display the different categories for soil burn severity.

According to the USDA RAVG metadata, I classified basal area loss in symbology into 4 classes: 0-25%, 25-50%, 50-75%, and 75-100%. I used the terminology of “unburned”, “low”, “moderate”, and “high” for BAL to make figures easier to interpret (Table 1). Post fire soil burn severity and basal are loss are the two parameters I used to measure the fire severity effects in the treated vs untreated sites within the study area. I determined effectiveness of fuel treatments by calculating proportion of each class by area; “unburned”, “low”, “moderate”, or “high” for soil burn severity and basal area loss. Fuel treatments were expected to have a decreased proportion of high post fire soil burn severity and basal area loss compared to sites which did not receive fuel reduction treatments with similar ecosystem characteristics, including slope, aspect (north or south), and fuel modeling category as determined by Landfire using the 13 Anderson Fire Behavior Fuel model (Table S1).

Table 1. Basal area loss original vs modified categories.

Basal Area Loss	1	2	3	4
Original Categories	0-25%	25-50%	50-75%	75-100%
Modified Categories	Unburned	Low	Moderate	High

Hazardous fuel treatments were imported as vector layers which I filtered using the attribute table function to only include fuel treatments which occurred within the Okanogan Wenatchee National Forest, occurring from 2016 to 2021. These treatments were then clipped to the area within the Cub Creek 2 and Cedar Creek fires to show which treatments occurred within the areas of the fires. Prescribed fires are considered effective in reducing fire severity, particularly less than 5 years post-treatment, hence I used this cutoff for fuel reduction treatments (Kalies, 2016). Setting this limit on the timeline of fuel treatments helps to account for the longevity of recent fuel treatments. Fuel treatments performed earlier than 2016 would have significant understory re-growth and therefore would not be an accurate assessment of the effects of recent fuel treatments on wildfires. I identified hazard fuel treatment types using the attribute table. Patches 1, 2, and 3 received pile burning, patch 4 received pre-commercial thinning followed by pile burning, patch 5 received pre commercial thinning and patches 5-12 received under-burning (Table 2).

Table 2. Fuel treatment patch number, fuel model, aspect, slope, and fuel reduction treatment.

Treatment Patch #	1	2	3	4	5	6	7	8	9	10	11	12
Fuel Model	10	10	10	8	8	8	8	8	2	8	8	8
Aspect	north	north	north	north	south	south	south	south	south	south	south	north
Slope Range	1-34	12-34	12-23	1-34	10-20	1-34	1-34	1-23	1-12	1-23	1-45	1-20
Fuel Treatment	pile burn	pile burn	pile burn	precommercial thinning & pile burn	under burn	under burn	under burn	under burn	under burn	under burn	under burn	under burn

I used Anderson's 13 fire behavior fuel model which represents distinct distribution of fuels loading found among surface fuel compounds (live and dead), size classes and fuel types (Landfire, 2022). This system categorizes fuels, and therefore vegetation, into unique and distinctive categories which I used to identify comparison control groups within the fires and fuel reduction treatment patches for comparison. The fuel model described by the most common fire-carrying fuel types (grass, brush, timber litter, or slash), loading and surface area-to volume ratio by size class and component, fuel bed depth, and moisture of extinction (Table S1). I categorized treated patches by using the dominant fuel model type, slope (in percentage), and aspect (in degrees). Aspect was grouped as northerly or southerly for this analysis, with northerly being defined as greater than 270° but less than 45° and southerly defined as less than 270° but greater than 45°. All raster layers from Landfire were checked against the available metadata and symbology was used to display accurate values for the data represented.

Using these variables for each fuel treatment patch I matched areas within each of the prescriptive fires to untreated patches within the fire to compare basal area loss and post fire soil burn severity. I used a raster calculator to select each of the variables and create new raster layers for each untreated area which corresponded to the 12 fuel reduction treatment patches in this study. This allowed for a direct comparison of the fuel reduction treatments and untreated areas on post fire soil burn severity and basal area loss within the Cedar Creek and Cub Creek 2 fires.

For the analysis of post fire soil burn severity, I took the comparison untreated raster layers and created vectors out of the raster layers as my post fire soil burn severity layers for each fire were vector layers. I then used the intersect tool for each of my soil burn severity category layers (unburned, low, moderate, and high soil burn severity) which I created using the select features option via the attribute table. I intersected each of the categorized for post fire soil burn severity and the control patch vector layers to see which section of my control areas had unburned, low, moderate, or high post fir soil burn severity. I repeated these steps for each soil burn severity category for each of my control areas for each patch (Figures 3, 5).

For basal area loss, I used the raster calculator to isolate each class (Table 1) within the raster layers, creating new layers for each class. I then used my previously created separate raster layers for the characteristics of all treated and untreated areas (Table 2). I used the intersect tool to create individual layers for the untreated and treated areas where the intersected with each class for basal area loss, created “unburned”, “low”, “moderate”, and “high” layers for each area (Table 1, Figures 4, 6).

Judgement sampling was used to determine untreated vs treated sites, due to limited availability of fuel treated sites. I used the treated vs. untreated areas to directly compare basal area loss and post fire soil burn severity. Area of post fire soil burn severity was calculated using the attribute table to calculate area for unburned, low, moderate, and high post fire soil burn severity. For basal area loss the raster calculator was used to separate by the 4 separate classes: 0-25%, 25-50%, 50-75%, and 75-100% for each of the untreated layers and the raster layer unique values report was used to show area of each raster layer (Table 1).

When determining the control areas, the experimental treatment areas would inherently also be selected in QGIS for basal area loss and post fire soil burn severity. This overlap was subtracted from my proportional calculations and is not reflected in my results, only in my final maps. To calculate the percentages of each category for post fire soil burn severity and basal area loss the individual area for each category (the part) was divided by the total area for all categories (the whole) and multiplied by 100 to get a percentage. Percentages were used as the area of the fire which received fuel reduction treatments were much smaller than the comparison untreated areas within the fire. Using percentages allowed for a comparison of proportion of fire effects for treated vs. untreated areas which were proportional to total area for each. Accuracy is dependent on human error, as well as the transfer of coordinate systems, the crashing of QGIS, and fixing of geometry which was constantly occurring during my study of this subject.

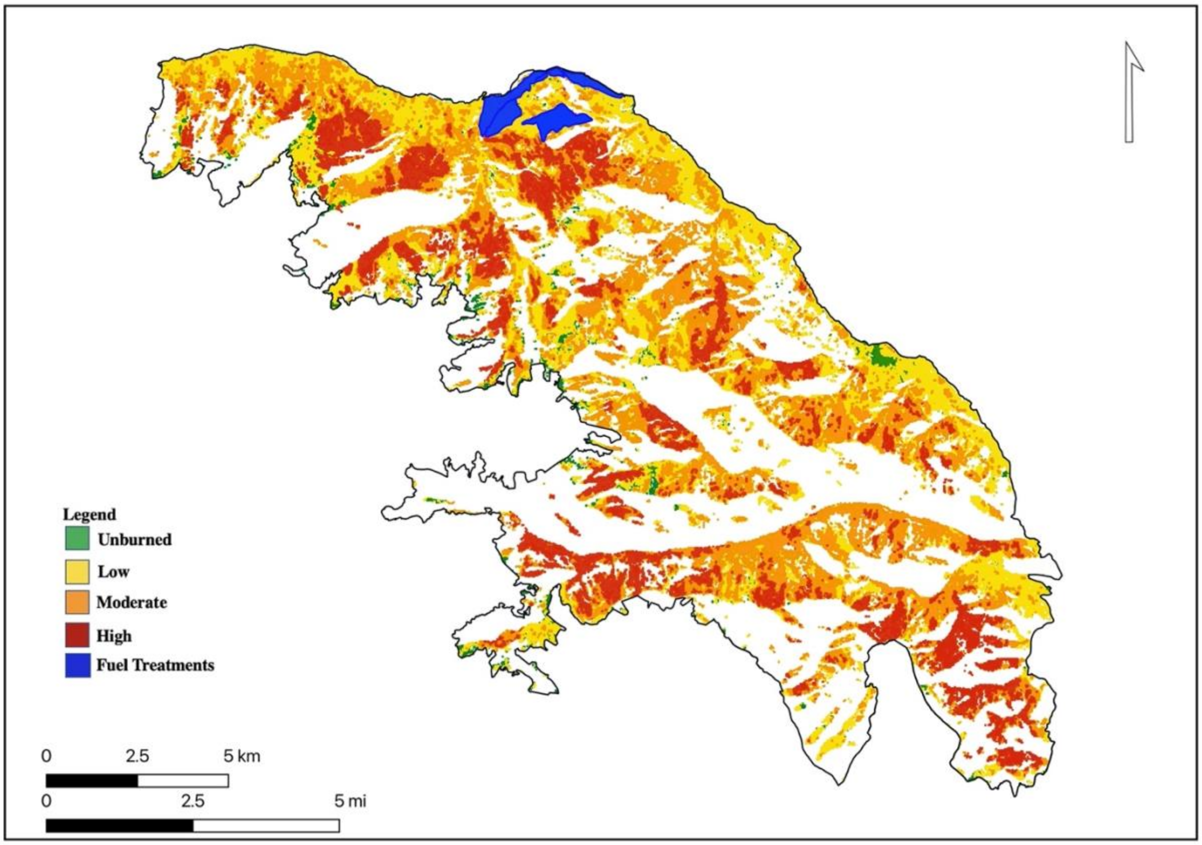

Figure 3. Soil burn severity of untreated areas within the Cedar Creek fire. See Table S2 for defined classes.

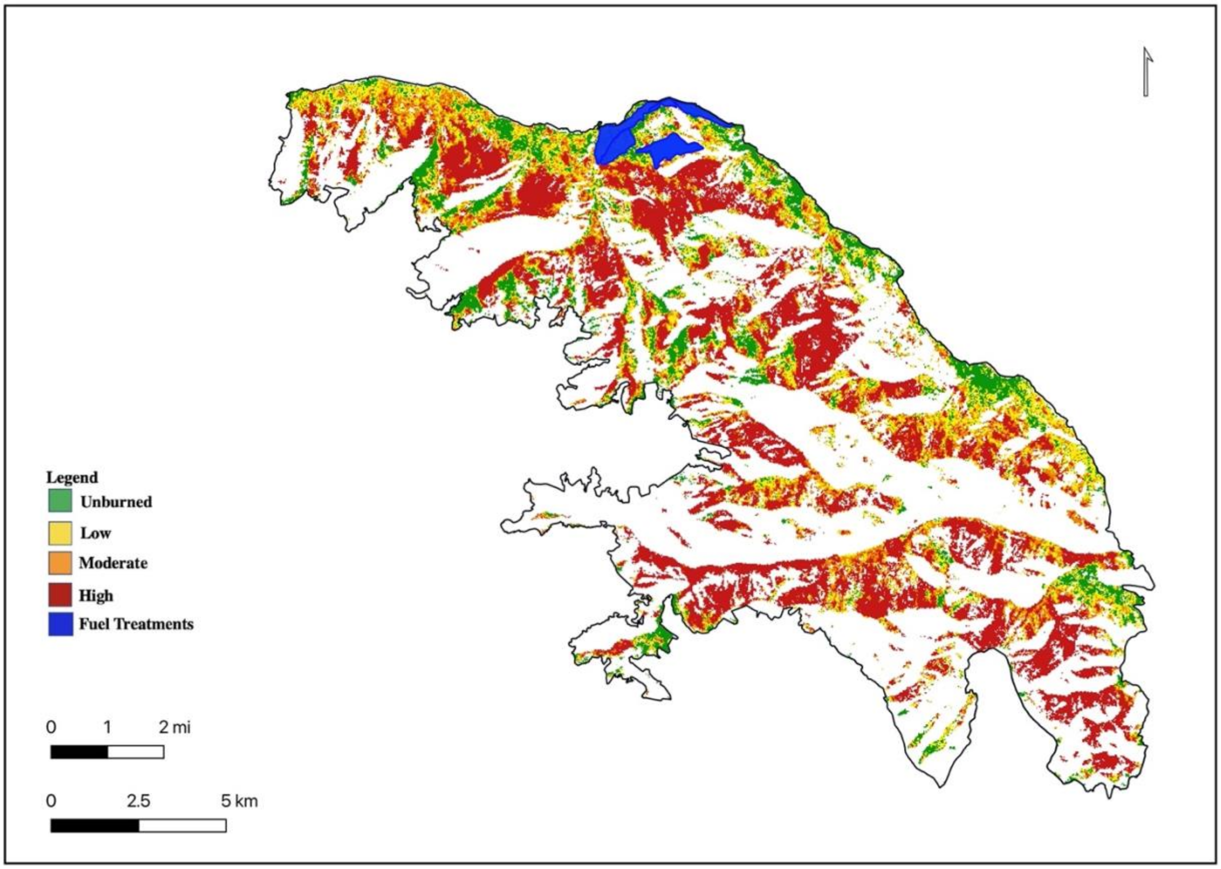

Figure 4. Basal area loss for untreated areas within the Cedar Creek fire. BAL categories are defined in Table 1.

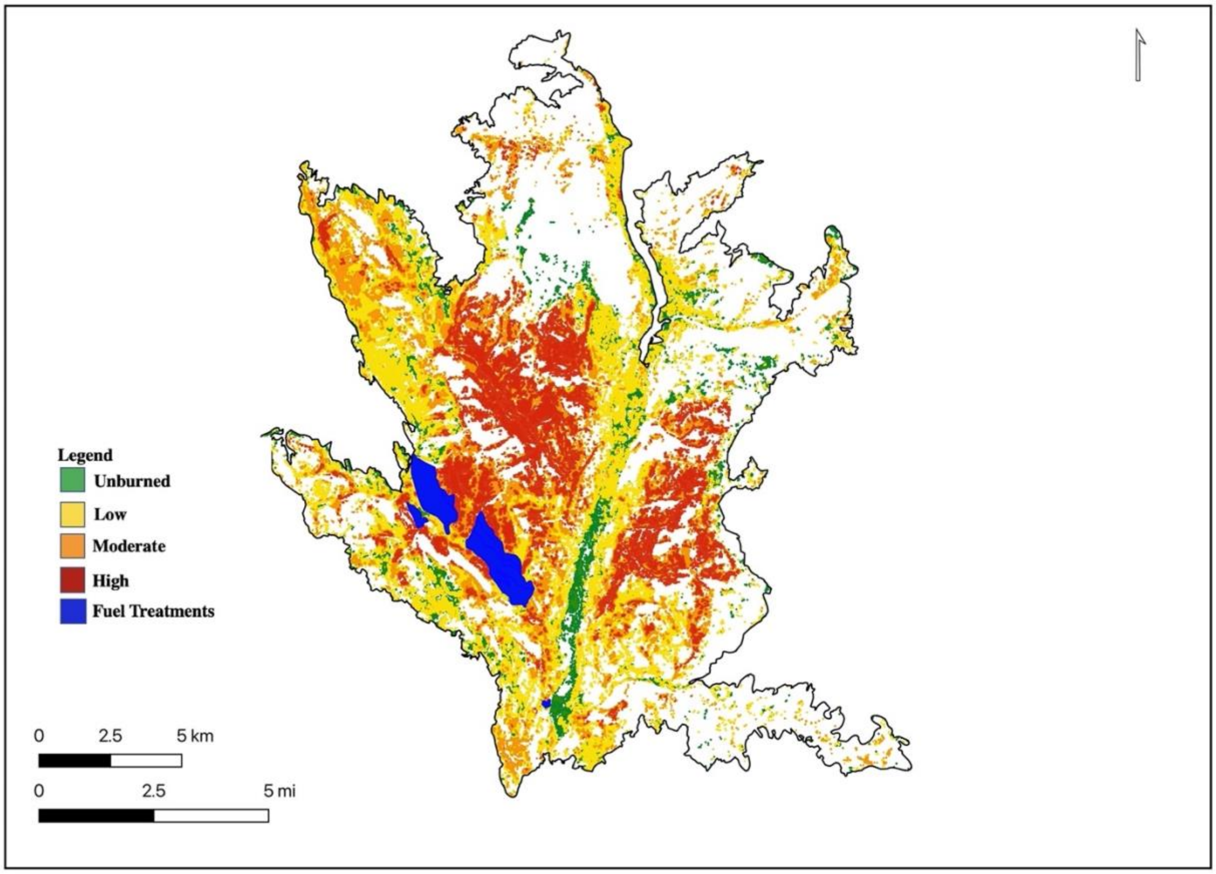

Figure 5. Soil burn severity of untreated areas within the Cub Creek 2 fire. See Table S2 for defined classes.

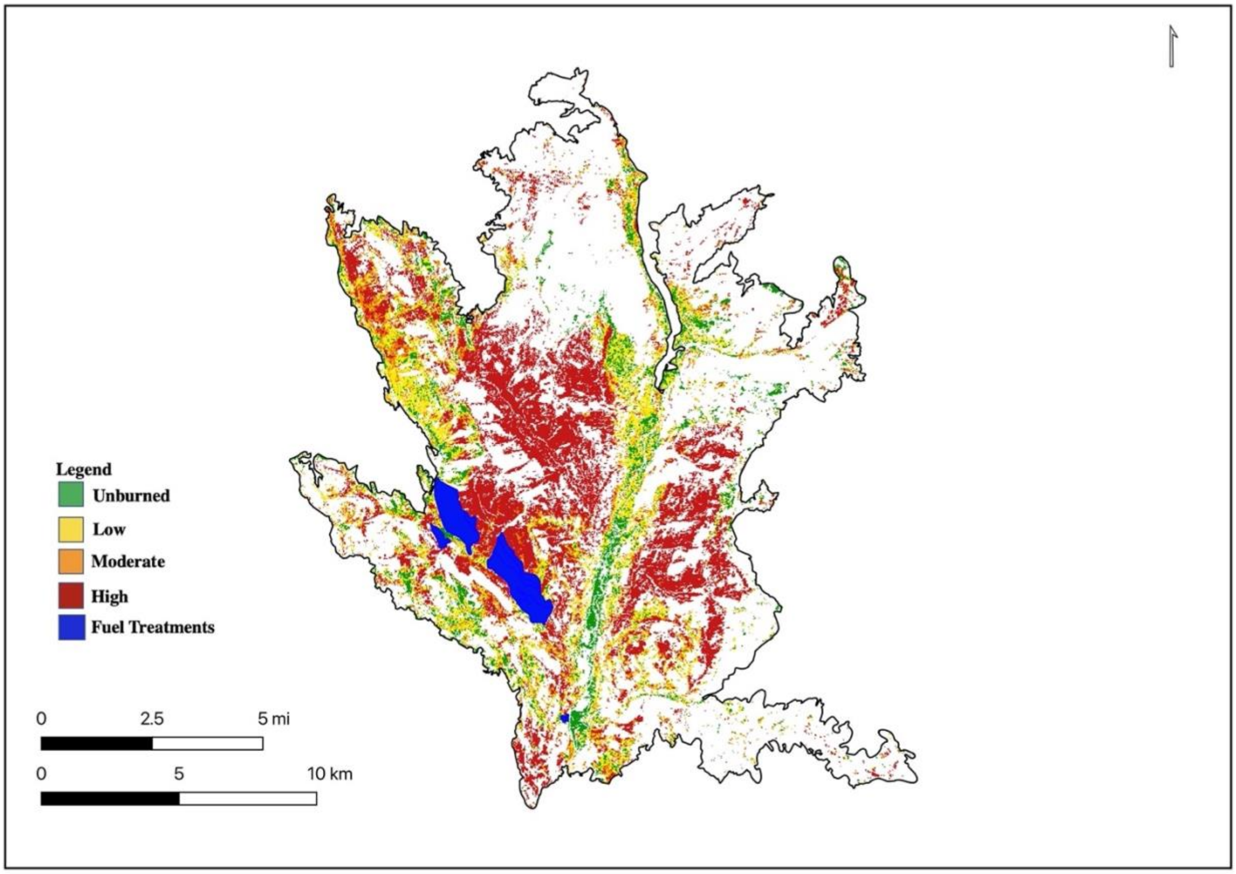

Figure 6. Basal area loss of untreated areas within the Cub Creek 2 fire. BAL categories are also defined in Table 1.

RESULTS

The fuel reduction treatment patches (Nos. 1-4) within the Cedar Creek fire displayed an overall higher percentage of low fire severity effects when compared to the control areas which had higher percentage of high fire effects. The treated areas within the fire had no high soil burn severity effects and dominated in low soil burn severity effects (Table 3, Figure 7). Untreated areas had almost even percentages of low, moderate, and high soil burn severity (table 3, Figure 7). Basal area loss for the untreated areas of the Cedar Creek had an extremely small percentage of high severity BAL, with unburned and low BAL dominating most of the area (Table 4, Figure 8). Untreated areas had the greatest percent area of high BAL effects (Table 4, Figure 8).

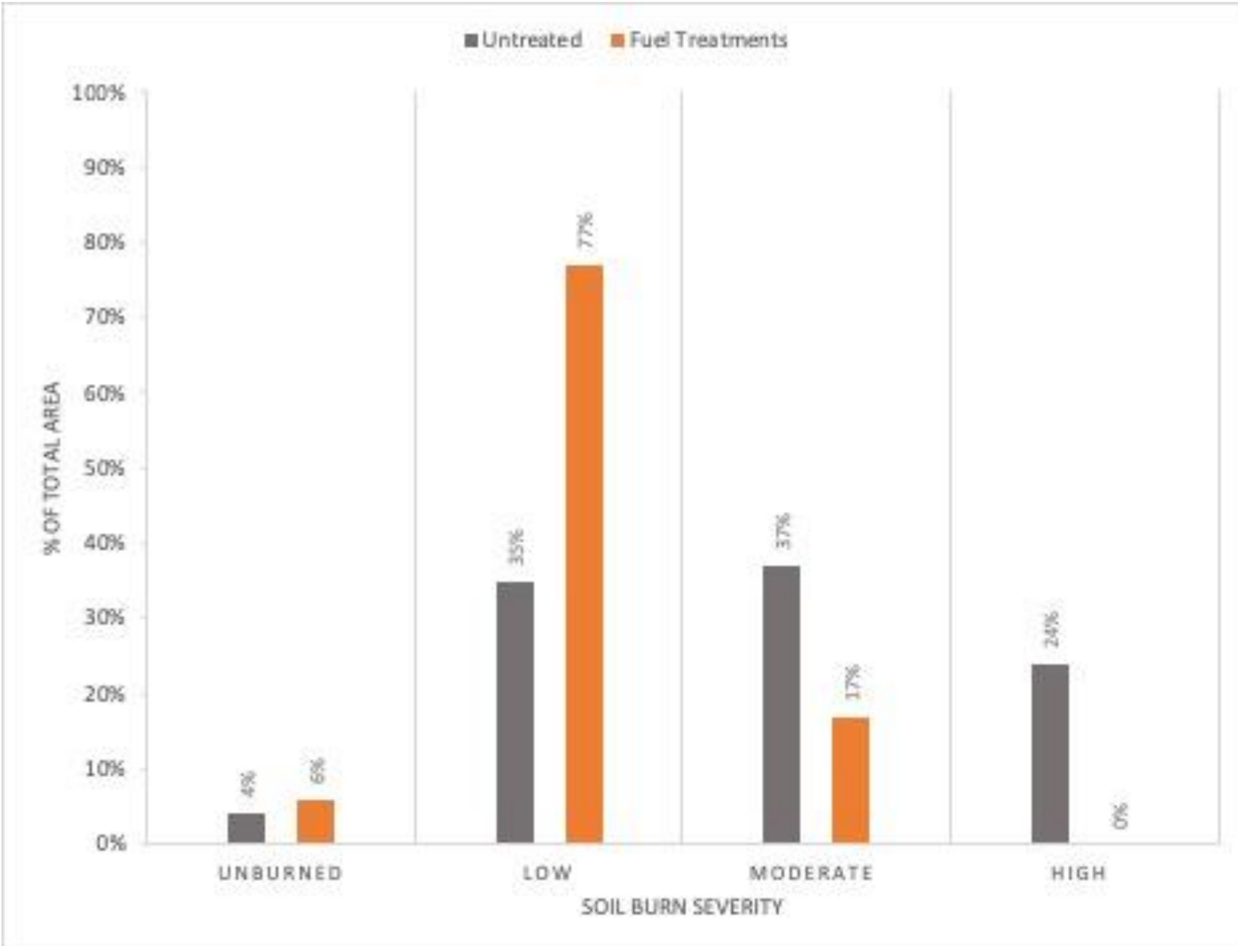

Figure 7. Post fire soil burn severity for proportions of untreated fuel reduction treatment areas within the Cedar Creek Fire.

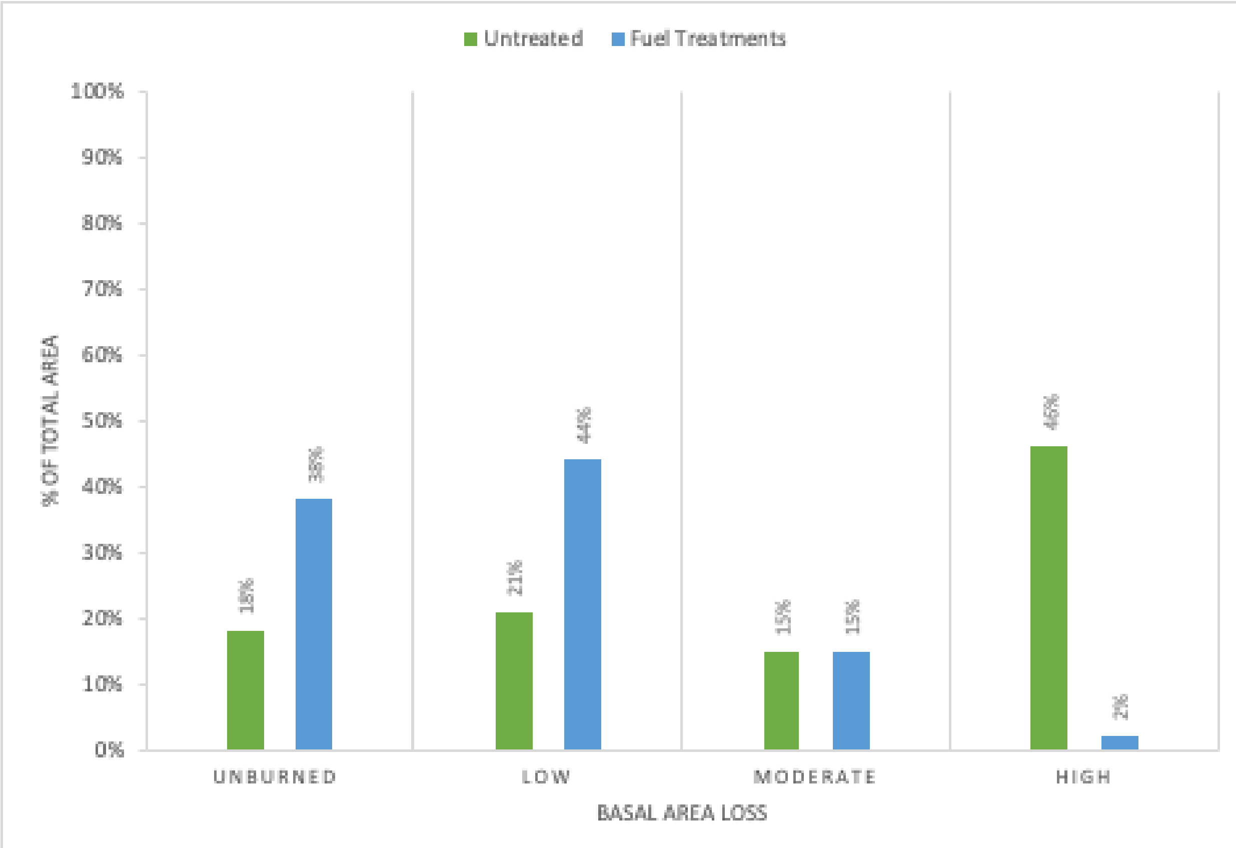

Figure 8. Basal area loss of untreated and fuel reduction treatment areas within the Cedar Creek fire. See Table 3 for categories.

Patches subject to fuel reduction treatments within the Cub Creek 2 fire (Nos. 5-12) displayed a higher percentage of unburned and low fire effects when compared to the control areas which had greater percentage of high fire severity effects. Soil burn severity of the untreated areas had a higher percentage of unburned and low, as well has a lower percentage of moderate and high effects compared to untreated areas (Table 3, Figure 9). For basal area loss treated areas have higher percentages of unburned and low BAL (Table 4, Figure 9). For treated areas we still see high severity BAL present, but these had a reduced area percentage compared to untreated areas (Table 4, Figure 9).

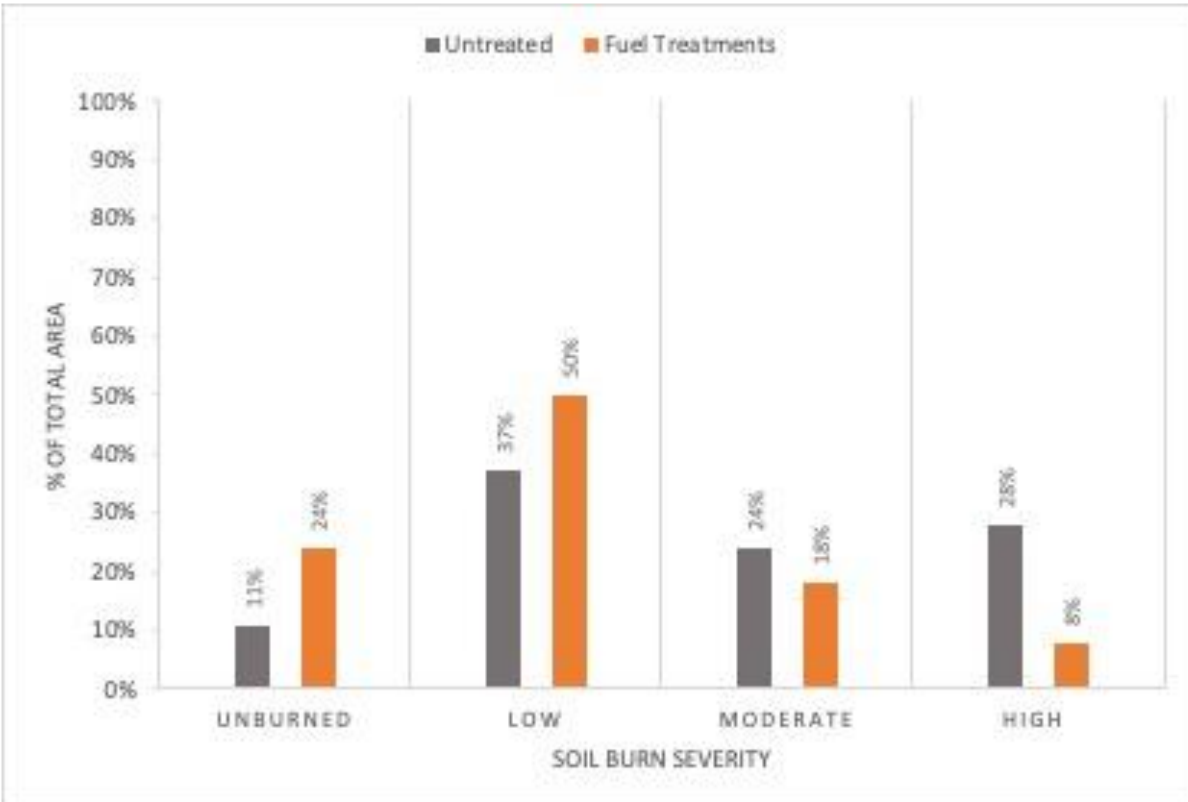

Figure 9. Post fire soil burn severity for proportions of untreated vs fuel reduction treatment areas within the Cub Creek 2 fire.

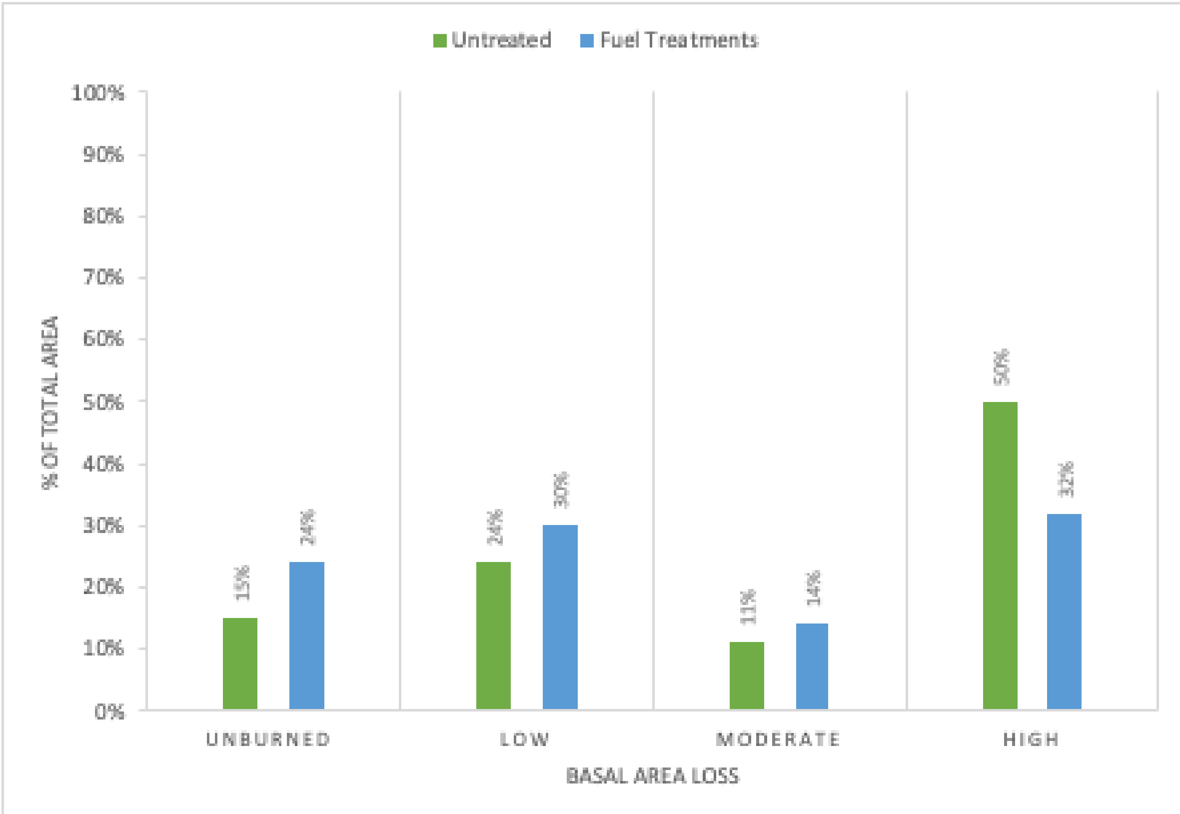

Figure 10. Basal area loss of untreated vs fuel reduction treatment areas within the Cub Creek 2 fires. See Table 3 for categories.

Table 3. Soil burn severity of untreated and fuel reduction treatment areas within Cedar Creek and Cub Creek 2 fires.

Fire	Soil Burn Severity	Unburned	Low	Moderate	High
Cedar Creek Fire	Untreated	4%	35%	37%	24%
	Fuel Treatments	6%	77%	17%	0%
Cub Creek 2 Fire	Untreated	11%	37%	24%	28%
	Fuel Treatments	24%	50%	18%	8%

Table 4. Basal area loss of untreated and fuel reduction treatment areas within Cedar Creek and Cub Creek 2 fires.

Fire	Basal Area Loss	Unburned	Low	Moderate	High
Cedar Creek fire	Untreated	18%	21%	15%	46%
	Fuel treatments	38%	44%	15%	2%
Cub Creek 2 Fire	Untreated	15%	24%	11%	50%
	Fuel treatments	24%	30%	14%	32%

DISCUSSION

The Cedar Creek and Cub Creek 2 fire were uncharacteristically large and severe fires compared to historical fires in this region. The extreme behavior exhibited in these fires is a result of increased fuel loading and high stand density due to long term fire suppression efforts, forest stand stress brought on by drought and competition, as well as high temperatures combined with decreased moisture availability (Clyatt, 2017). By examining basal area loss and post fire soil burn severity, I measured the effectiveness of fuel reduction treatments in mitigating fire severity in the Cedar Creek and Cub Creek 2 fires.

For the Cedar Creek fire, the results support the claim that fuel reduction treatments reduce high severity fire effects in the form of soil burn severity and basal area loss. The results show higher percent area of low fire severity effects, as well as reduced high fire severity percent area in the treated areas compared to the untreated areas (Figures 7, 8). Fuel reduction treatment patches 1-3 received pile burning which indicates that before 2016 they also most likely received thinning, though this is not confirmed by my study, while patch 4 received thinning and pile burning (Table 2). In the region of the fire where the fuel treatments are located, the fire behavior was flanking or backing. A backing fire is backing into the wind and usually has a low flame length and rate of spread (USDA Forest Service, 2022). A flanking fire parallels the wind direction and the effects of this are between that of a backing and a head fire (USDA Forest Service, 2022).

For the Cub Creek 2 fire, the results also support the claim that fuel reduction treatments reduced high severity fire effects in the form of post fire soil burn severity and basal area loss.

The Cub Creek 2 fire had a decreased percent area of high fire severity effects, as well as an increased percent area of low fire severity effects, in the treated areas compared to the non-treated ones (Figures 9, 10). All fuel reduction treatments in this fire received underburning only. While the high severity effects were still present in this fire, this could be due to the location of fuel treatment within the fire. In the region of the Cub Creek 2 fire where the fuel treatments were located, the fire behavior was flanking and head fires. Head fires are the flaming front of the fire where the fire is moving forward with the wind with tall flame lengths and a high rate of spread, this is the most dangerous type of fire (USDA Forest Service, 2022). Fire types are driven by weather and fuel availability (USDA Forest Service, 2022). This fire behavior led to increased high severity fire effects for the fuel treatment locations within the Cub Creek 2 fire.

The weather during the start and duration of these fires was characterized by high temperatures, low humidity, and high and variable winds (Western Regional Climate Center, 2021). These conditions combined with dry fuel loaded forests resulted in single tree and group tree torching which resulted most frequently in a running crown fire (USDA Forest Service, 2022). Long-term fire suppression efforts contributed heavily to the continuity of fuels in this landscape which in turn influenced the severity of both fires. Both fires exhibited large patches of stand replacement, where basal area loss and post fire burn severity are very high. This was due to running crown fires which burned exceptionally hot, killing large trees that should have been able to withstand a wildfire due to their specific fire adaptions, such as thick bark and high crowns (Raymond, 2012).

The continuation of these types of fires, will be catastrophic for the western United States, with increases severity and intensity these fires will become unmanageable for wildland firefighters. As we saw in these fires, once wildland fires grow to a certain intensity the danger of actively fighting them becomes too high, the only solutions left are evacuations and waiting for the fire to burn itself out. One estimate based on federally owned ponderosa pine forests managed with thinning, prescribed fire, managed wildland fire, and fire suppression where necessary suggests that land areas susceptible to high severity fire could be reduced from 62% to 37% over the next five decades in central Oregon (Charnley, 2017). These practices could potentially be applied to ponderosa pine forests in Washington with similar desired effects.

In the Western United States, more than 10 million hectares of coniferous forest are in moderate or high fire hazard condition classes and pose a significant problem for management (Stephens, 2009). Over 95% of wildland fires in western ecosystems are successfully suppressed in initial attack phase by wildland firefighters, with their size staying under two acres (Banerjee, 2020). Less than 4% of fires cannot be suppressed in initial attack phase due to a variety of reasons including rough terrain, availability of local resources, weather, extreme fire behavior as was experienced in both the Cedar Creek and Cub Creek 2 fires (Banerjee, 2020). This small percentage of extreme fires results in more than 95% of area burned and most of the annual life and property damage (Banerjee, 2020). These limiting factors were reasons the Cedar Creek and Cub Creek 2 fires were suppressed in the initial attack phase, resulting in months on unhealthy air quality, numerous evacuations, and millions of dollars spend on fighting these fires.

NEXT STEPS

The continued study of the effectiveness of fuel reduction treatments is critical to understand how to efficiently manage our forests for health, resiliency, as well as reduce potential fire danger. Tools such as QGIS can be used to measure and validate the effectiveness of fuel reduction treatments on basal area loss and post fire soil burn severity as well as other variables of interest to measure fire burn severity. My study used publicly available data and all analysis was performed remotely, setting the precedent that studies with similar goals could be achieved with these same methods. The use of QGIS reduces the amount of time spent in the field gathering basic data and provides access to anyone with the skills to perform this analysis the opportunity to conduct their own research. Further refinements of this approach would be to include a more complete forest characteristics dataset for more fine-tuned evaluation.

LIMITATIONS

There were limitations in finding ideal untreated areas matching variables of the fuel treatment patches to compare basal areas loss and soil burn severity. Many of these patches were not uniform so the most dominant values (greater than 50% of total patch area) for each variable were selected and used to finding the "matching" untreated area. Values such as slope were measured and filtered as a range as no patches had a uniform slope. Additional variables were originally considered and had to be discarded due to the difficulty in finding appropriate comparable untreated sites, as well as not enough untreated matching area being selected for comparison due to excess variables. The variables that were chosen were selected due to their influence on fire behavior as well as the success in finding "matching" untreated areas. Analyzing a larger number of fire effects, fuel treatment areas, as well as forest characteristics for untreated and treated sites would lead also lead to improved understanding.

CONCLUSION

In both the Cedar Creek and Cub Creek 2 fires, the claim that fuel reduction treatments result in a decrease in the proportion of high basal area loss and soil burn severity, compared to untreated areas is indeed supported by the findings of my study. Although some high fire severity effects were still present in the fuel reduction treatments the percent area was greatly reduced compared to untreated areas. While fuel reduction treatments are not a perfect solution, they allow fire to be reintroduced to the landscape, improve forest resiliency, and reduce the high severity fire effects within their locally applied area (Kalies, 2016). Using QGIS to analyze basal area loss and post fire soil burn severity from wildfires is an efficient and accurate way to better understand the effects of fuel reduction techniques on fire severity.

This study gave me the opportunity to combine my personal experience as a wildland firefighter with a unique research opportunity. Taking my knowledge of wildland firefighting and applying it to a research project that examined the effects of high severity fires was immensely informative and applicable to my life living in a fire-prone area as well as my career. This study has given me a distinctive viewpoint on the issue the western United States is facing with the escalation of high severity fires in extent, area burned, and frequency. As both fuel reduction management practices and wildfires are expected to increase in frequency in the coming years, analyzing the effects of fuel reduction treatments on wildfire behavior and severity can be extremely beneficial for future management practices (Stevens, 2014).

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APPENDICES

APPENDIX A

SUPPLEMEMTAL MATERIALS

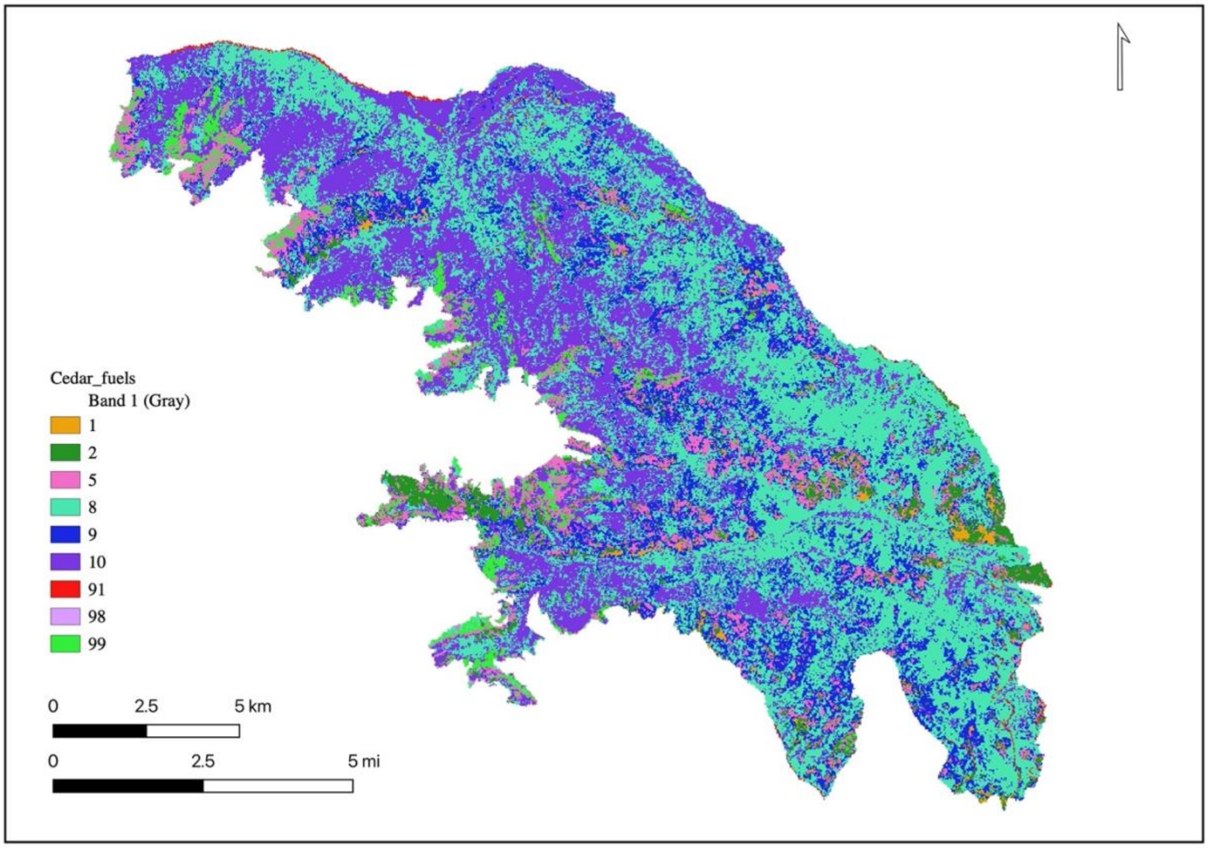

Figure S1. Landfire Fire Behavior Fuels based off Andersons 13 fuel model found within the Cedar Creek fire, refer to Table S2 for full descriptions.

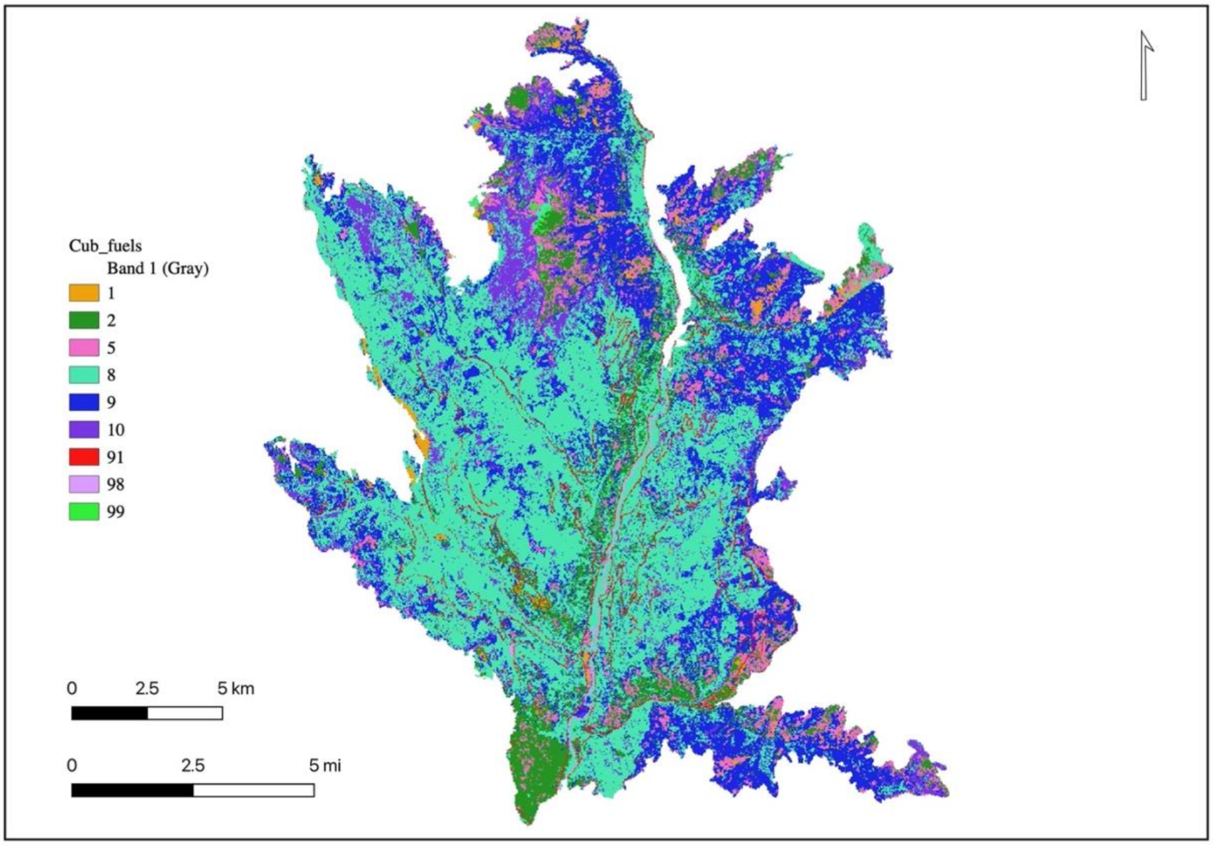

Figure S2. Landfire Fire Behavior Fuels based off Andersons 13 fuel model found within the Cub Creek 2 fire, refer to Table S2 for full descriptions.

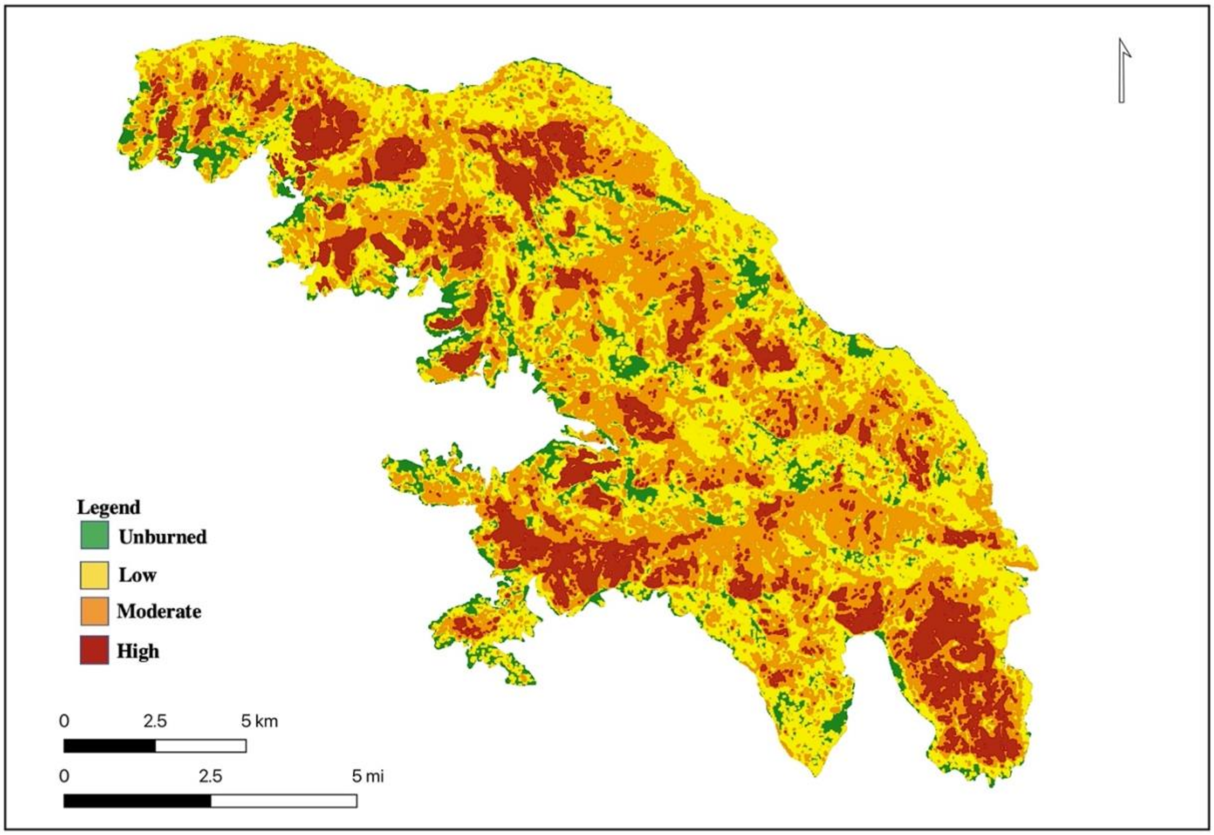

Figure S3. Post fire soil burn severity for the Cedar Creek fire.

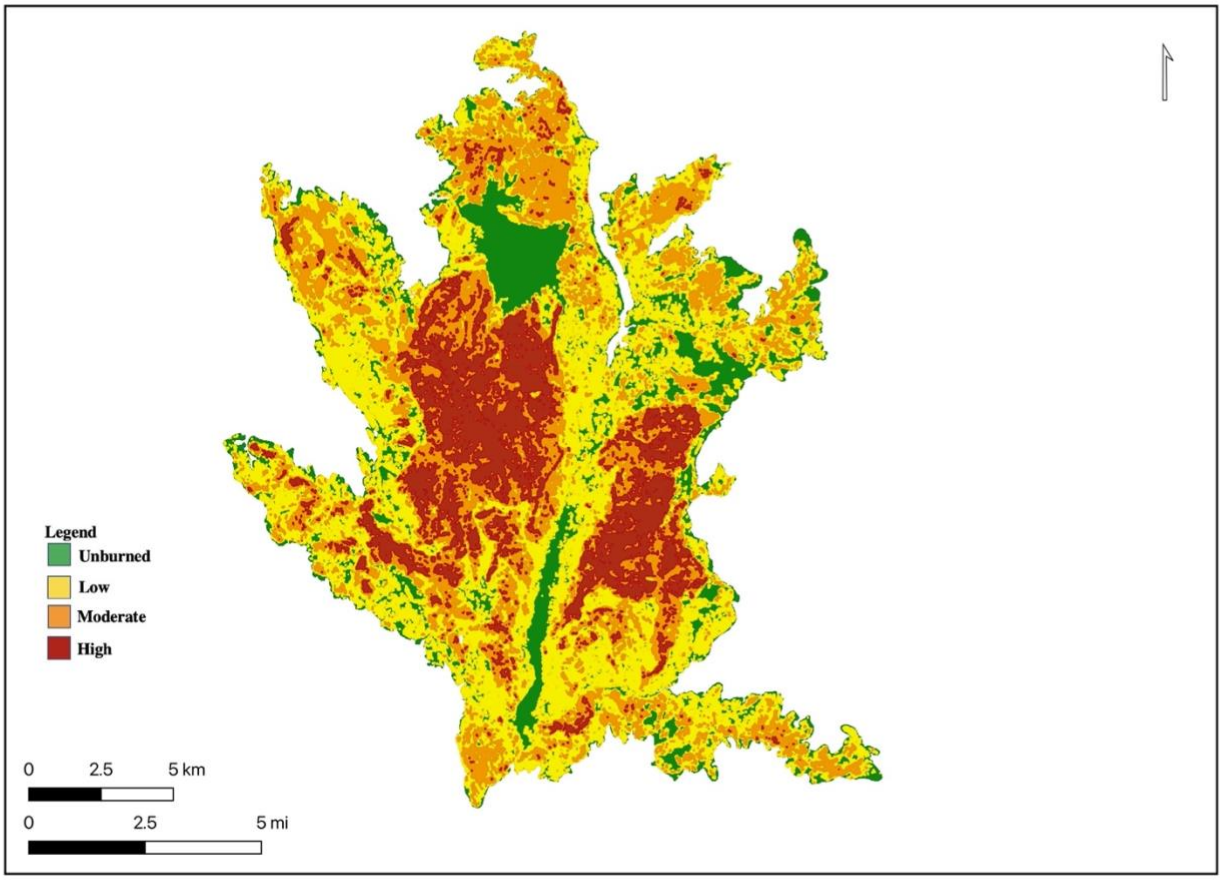

Figure S4. Post fire soil burn severity for the Cub Creek 2 fire.

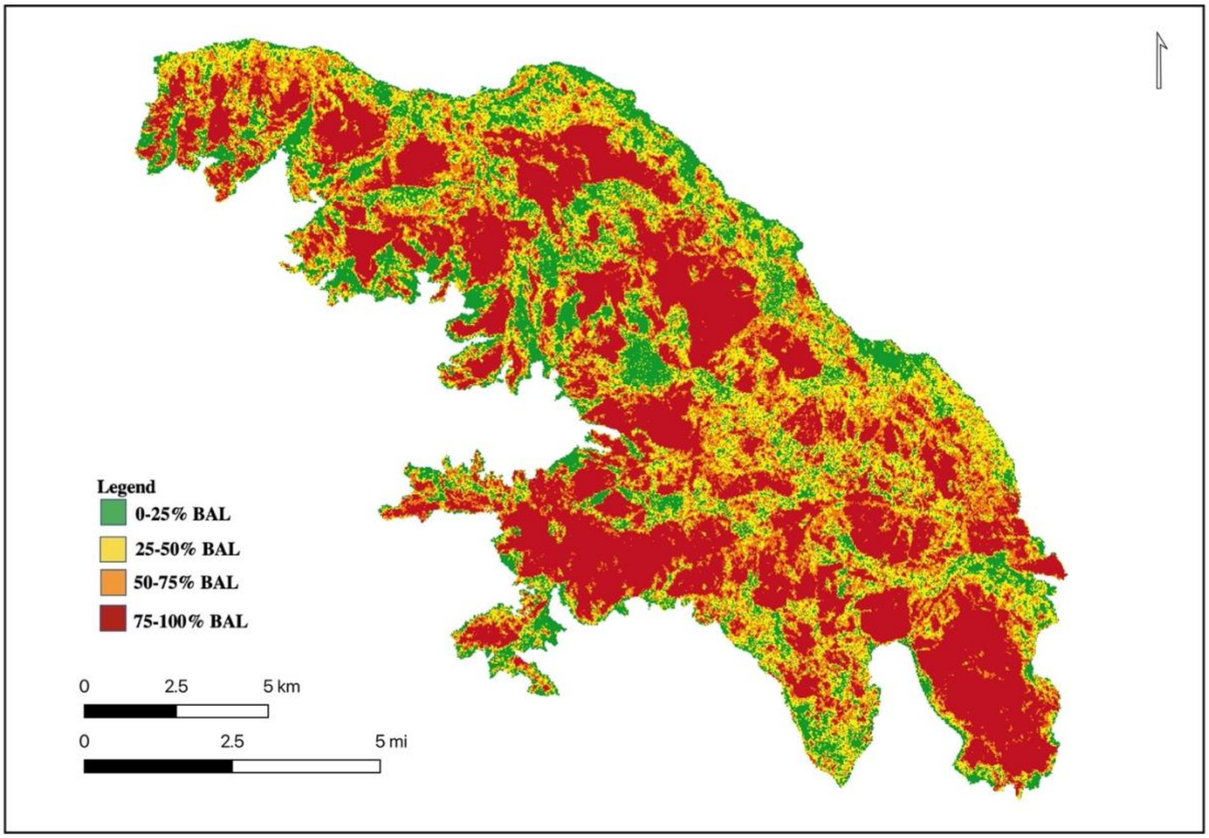

Figure S5. Basal area loss control areas within the Cedar Creek fire.

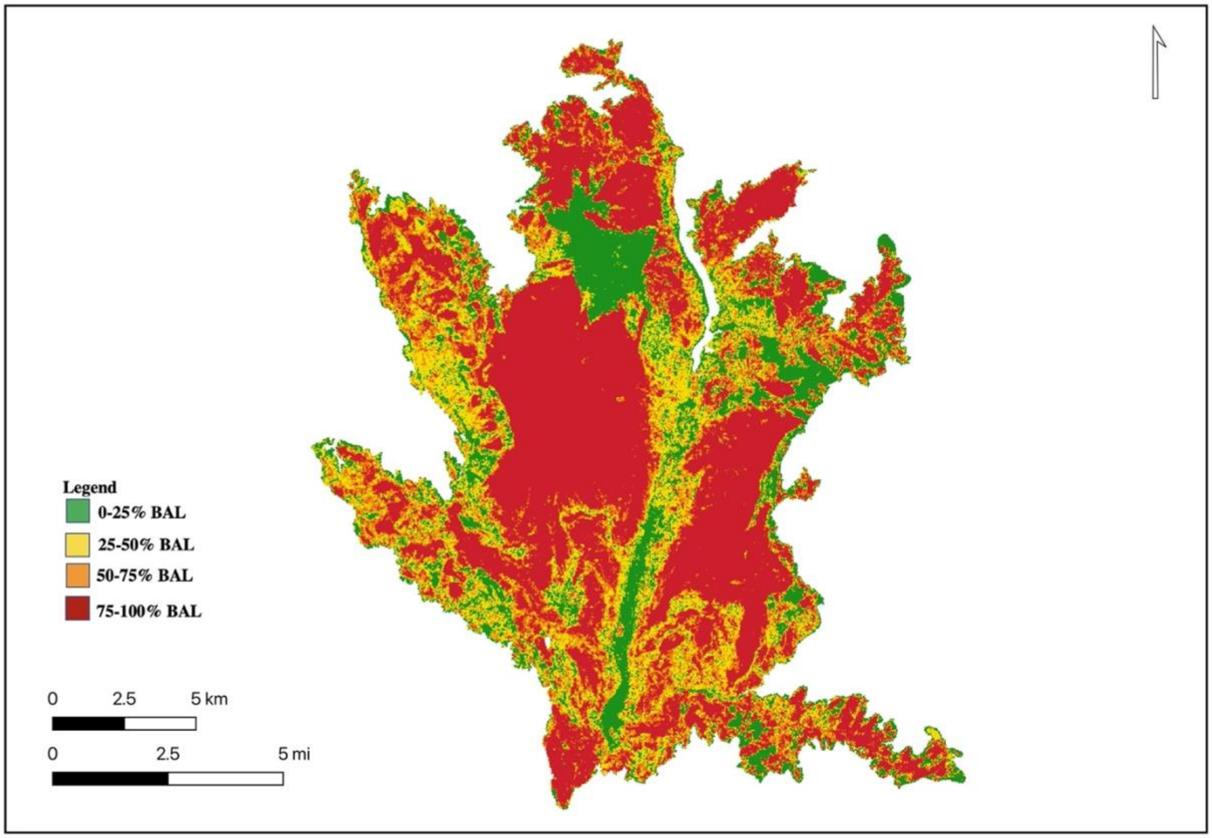

Figure S6. Basal area loss control areas within the Cub Creek 2 fire.

Table S1. Landfire Fire Behavior Fuel Model Attribute Data Dictionary.

LANDFIRE Fire Behavior Fuel Model 13 Attribute Data Dictionary	
Attribute	**Description**
Value	Thirteen typical surface fuel arrangements or "collections of fuel properties" (Anderson 1982) were described to serve as input for Rothermel's mathematical surface fire behavior and spread model (Rothermel 1972). These fire behavior fuel models represent distinct distributions of fuel loadings found among surface fuel components (live and dead), size classes and fuel types. The fuel models are described by the most common fire carrying fuel type (grass, brush, timber litter or slash), loading and surface area-to-volume ratio by size class and component, fuelbed depth and moisture of extinction.
1	FBFM1
2	FBFM2
3	FBFM3
4	FBFM4
5	FBFM5
6	FBFM6
7	FBFM7
8	FBFM8
9	FBFM9
10	FBFM10
11	FBFM11
12	FBFM12
13	FBFM13
91	Urban
92	Snow/Ice
93	Agriculture
98	Water
99	Barren
Count	number of pixels for the corresponding value
FBFM13	Display attribute, fire behavior 13 fuel model
FBFM1	Surface fires that burn fine herbaceous fuels, cured and curing fuels, little shrub or timber present, primarily grasslands and savanna
FBFM2	Burns fine, herbaceous fuels, stand is curing or dead, may produce fire brands on oak or pine stands
FBFM3	Most intense fire of grass group, spreads quickly with wind, one third of stand dead or cured, stands average 3 ft tall
FBFM4	Fast spreading fire, continuous overstory, flammable foliage and dead woody material, deep litter layer can inhibit suppression
FBFM5	Low intensity fires, young, green shrubs with little dead material, fuels consist of litter from understory
FBFM6	Broad range of shrubs, fire requires moderate winds to maintain flame at shrub height, or will drop to the ground with low winds
FBFM7	Foliage highly flammable, allowing fire to reach shrub strata levels, shrubs generally 2 to 6 feet high
FBFM8	Slow, ground burning fires, closed canopy stands with short needle conifers or hardwoods, litter consist mainly of needles and leaves, with little undergrowth, occasional flares with concentrated fuels
FBFM9	Longer flames, quicker surface fires, closed canopy stands of long-needles or hardwoods, rolling leaves in fall can cause spotting, dead-down material can cause occasional crowning
FBFM10	Surface and ground fire more intense, dead-down fuels more abundant, frequent crowning and spotting causing fire control to be more difficult
FBFM11	Fairly active fire, fuels consist of slash and herbaceous materials, slash originates from light partial cuts or thinning projects, fire is limited by spacing of fuel load and shade from overstory
FBFM12	Rapid spreading and high intensity fires, dominated by slash resulting from heavy thinning projects and clearcuts, slash is mostly 3 inches or less
FBFM13	Fire spreads quickly through smaller material and intensity builds slowly as large material ignites, continuous layer of slash larger than 3 inches in diameter predominates, resulting from clearcuts and heavy partial cuts, active flames sustained for long periods of time, fire is susceptible to spotting and weather conditions
Urban	Urban
Snow/Ice	Snow/Ice
Agriculture	Agriculture
Water	Water
Barren	Barren
Red	Red color value range 0 - 1
Green	Green color value range 0 - 1
Blue	Blue color value range 0 - 1
For more information, refer to: http://www.fs.fed.us/rm/pubs_int/int_gtr122.pdf	

Table S2. BAER Soil Burn severity class indicators.

Soil Burn Severity Class	**Substrate - litter/duff**	**Vegetation - understory/shrubs/herbs**	*ANCILLARY FACTORS ONLY! Highly variable and **NOT** key to determining soil burn severity; Very General Guide ONLY:* **Overstory – conifer/hardwoods**
Unburned	not burned	not burned	no fire-caused mortality; overview of canopy appears unchanged
Low	mineral soil unchanged; litter charred or partially consumed; upper duff layer charred; wood/leaf/needle structures charred but recognizable	foliage and smaller twigs (less than ¼ inch) scorched or partially consumed; grasses mostly consumed, black or gray ash; shrub stems intact, canopy scorched.	slight tree mortality possible but generally less than about 10%; overview of canopy may show individuals or small pockets of mortality (brown needles or black sticks)
Moderate	moderate soil heating, moderate ground char; soil structure intact; litter mostly charred but not ashed, however some areas of litter consumption may be found, leaving shallow ash; duff and wood partly consumed; wood/leaf structures may be recognizeable; burned roots and rhizomes usually still present; reduced permeability may be present over some of the area.	foliage, twigs and small stems (¼ to ¾ inch) consumed; shrub stems charred, root crowns intact, shrub canopy consumed.	tree mortality may be mixed and range widely; seedlings are usually consumed, large trees often killed but retain some fine twigs, brown needles or leaves (future mulch) and cones with light to moderate bark char; where tree cover had been dense, the area is usually not dominated by black sticks, but can be in some cases; specific characteristics of this class and percent tree mortality need to be defined for each fire as they can vary by ecosystem
High	High soil heating, deep ground char; litter and duff consumed leaving fine ash, often more than an inch or two deep and often gray or white; surface soil may be visibly altered, often blackened or reddish and usually lacking structure; all or most organic matter is removed; fine roots and rhizomes may be consumed; reduced permeability may be pronounced (strong and/or thick water repellant layer) over much of the area; large fuels completely consumed or nearly so.	all plant parts consumed, including fuels greater than ¾ inch, leaving some or no major stems/trunks of shrubs.	generally 80 to 100% tree mortality; saplings and large trees are dominantly black sticks with moderate to heavy bark char and no needles or leaves remaining. Individuals or small pockets of live trees may remain, but are not dominant in the delineation.