Fuels of the Southern Appalachian Fire and Fire Surrogate Study following Hurricane Helene and the Black Cove Wildfire Complex

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Thesis submitted to the faculty of the Virginia Polytechnic Institute and State University in

partial fulfillment of the requirements for the degree of

Master of Science

in

Forestry

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May 1, 2026

Blacksburg, VA

Keywords: Fuels, Green River Game Land, Prescribed Fire, Silviculture, Storms, Wildfire

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ABSTRACT

Wildland fuel loading estimates are used to approximate potential fire behavior when planning and implementing wildland fire management. Managers consider the relationships of fuel volume and structure to wildland fire behavior and resulting ecological responses. As active fire and fuels management becomes more widespread after decades of active fire suppression and limited or infrequent forest management, managers increasingly seek to incorporate prescribed fire for a range of stewardship goals and outcomes. As development in rural areas expands the wildland urban interface, managers may consider alternative fuel treatments in areas where prescribed fire may not be feasible or practical. Initiated in the early 2000s, the National Fire and Fire Surrogate Study (FFSS) compared the effects of prescribed fire to those of fire surrogate treatments on a variety of ecological responses, including fuels and potential fire behavior, at multiple locations across the country. For the southern Appalachian Mountains, the treatments implemented in the study included prescribed fire, mechanical felling (shrubs and midstory), a combination of prescribed fire and mechanical felling, and untreated controls. Over a period of 24 years, sites were repeatedly treated and monitored to determine the efficacy of each treatment in producing desired outcomes. Following 24 years of management and study, the FFSS site at the Green River Game Land, in Henderson and Polk counties, North Carolina, was impacted by two major disturbances over a six-month period – Hurricane Helene in September 2024 followed by a large wildfire in March 2025. From June to July 2025, fuel loading and structure at the site were measured and assessed to determine how changes in fuels may have differed between the treated areas. Our results suggest that, for the period between 2014 and 2025, decreases in ground fuel (O Horizon) mass differed between the treatments. The decrease was greatest in the control treatment, which did not differ from the mechanical-only treatment, but did differ from the burn-only and mechanical+burn treatment. Fine woody fuel mass decreased in all treatments and did not differ between the treatments. Coarse woody debris only decreased in the burn-only and mechanical+burn treatments, but differences between the treatments were not statistically significant. Currently, the mean total fuel mass range for the control, mechanical-only, and mechanical+burn treatments is 45.32-50.60 Mg ha^{-1}. The burn-only mean total fuel mass is 26.93 Mg ha^{-1}, nearly half of what is present in the other treated or control areas. Understanding the long-term fuel dynamics at this location will provide critical information for the southern Appalachian Mountain region as scientists and managers consider fuel reduction treatments to alter fuel complexes, with and without storm impacts from Hurricane Helene.

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GENERAL AUDIENCE ABSTRACT

In wildland fire ecology and management, the logs, twigs, leaves, and other combustible materials in a landscape are referred to as *fuel*. The amount of fuel, its dryness, and the way that it lays or stands, affects the way that wildfires burn. An area with abundant fuel, or fuel that is densely packed together, is likely to burn more severely than an area with less fuel, or fuel that is more scattered on the forest floor. Managing fuel is crucial to managing fire in a way that makes it less dangerous for people and more beneficial to nature. Fuels treatments are methods of managing fuel. These treatments may include prescribed burning or other methods of altering fuel volume or structure. Prescribed fire is often the preferred method of managing fuels in the eastern US. Relative to other potential treatment options, it is less expensive and may assist in meeting a variety of land management objectives. However, different treatments impact different ecosystems in different ways, therefore treatment effectiveness is often very site-specific. The National Fire and Fire Surrogate Study, initiated in the early 2000s, sought to determine whether alternative treatments could have the same ecological benefits as prescribed fire. The Green River Game Land in western North Carolina was chosen as the sole research site in the southern Appalachian Mountains. It has been repeatedly treated and monitored since 2001. In 2024, the area was impacted by Hurricane Helene, causing significant impacts to parts of the Game Land, including areas within the study site. In March 2025, a large wildfire burned through Green River, impacting the study site to varying degrees. During June-July 2025, fuel loading and structure were remeasured to determine how the treated areas responded to both Hurricane Helene and the Black Cove Wildfire Complex. The results showed that the amount of fresh and decomposed leaves decreased most in the control treatments, where no management activities had taken place since 2001. However, the decrease in the control was not greater than areas where shrubs and smaller trees were felled, but it was greater than sites that included only prescribed fire or sites that were managed with prescribed fire and felling of the shrubs and small trees. Overall, the amount of fuel currently present in all of the treatments is lowest in the places where prescribed fires were used without the combination of felling. This information is important to consider as individuals respond to Hurricane Helene and plan for what may be done to reduce wildfire hazard long-term in the southern Appalachian Mountains as managers proceed with future forest restoration efforts or seek to decrease fire hazard in the wildland-urban interface.

ACKNOWLEDGEMENTS

I would like to acknowledge the contributions of Jonathan McCall of the North Carolina Wildlife Resources Commission. His assistance was instrumental to the progress we were able to make at Green River. Colleague Armin Wiese has been an invaluable source of insight and information, and his own hard work has contributed vital data to this project. Bryn Buff's assistance with data collection in the field was crucial to this work and is greatly appreciated. I would also like to thank the countless number of individuals that have worked at Green River since 2001. This thesis would not be possible without their prior efforts. Funding for my project was provided by the Department of Forest Resources and Environmental Conservation at Virginia Tech. Additional thanks to the efforts of Dr. Adam Coates and my committee members, Drs. Mark Ford and Don Hagan.

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Chapter 1. Introduction

Wildfire ecology of the eastern US remains relatively understudied as compared to the western US, where larger and more intense wildfires draw more national attention (Hiers et al. 2020). While wildfires in the East are generally smaller, less intense, and typically less threatening to humans and other natural resources, they can occur at equal or greater frequency than those in the West and may be no less impactful ecologically (Donovan et al. 2023). Fire return intervals are generally shorter in the southeastern US than in most other regions of the country (Gabbert 2015). In the southern Appalachian Mountains, humans' relationship with wildland fire is long and storied. It pre-dated European settlement and profoundly shaped the region's ecology (Lafon et al. 2017).

North Carolina's Green River Game Land (GRGL) hosts southern Appalachia's sole Fire and Fire Surrogate Study (FFSS) research site. One of only four FFSS sites that have remained active since the study's inception in 2001, and the only active site east of the Mississippi River, GRGL is a crucial source of information for scientists and other professionals seeking to inform research or strategy in wildland fire and fuels management.

Since 2002, GRGL has been actively managed in accordance with the FFSS suite of treatments. Mechanical (chainsaw) felling of the shrubs and midstory has occurred twice in the mechanical-only treatment (2002 and 2012) and once in the mechanical+burn treatments (2002). Prescribed burning has occurred five times (2003, 2006, 2012, 2015, and Spring 2024) in the burn-only and mechanical+burn treatments. Numerous research papers have been published to describe the effects of these treatments on ecological properties and processes, with Bernal et al. (2025) and Taylor et al. (2025) serving as the latest assessments prior to the inception of this thesis project.

In late September 2024, GRGL was impacted by Hurricane Helene. Its high winds and excessive rain caused extensive impacts to the region (Dale et al. 2025). Within GRGL, the storm caused significant but patchy blowdowns, adding substantial fuel loads in some areas, whereby having little or no discernable impact to others. In impacted areas, downbursts felled patches of mature overstory trees, creating canopy gaps of various sizes and depositing fuels of various timelag classes. Moreover, Helene's arrival coincided with the start of North Carolina's fall wildfire season, adding complexity to incident response by increasing fuel loading and limiting access to vital infrastructure.

In late March 2025, the Black Cove Wildfire Complex burned through GRGL, impacting approximately 60% of the FFSS treatments. Storm-related increases in fuel load, in addition to challenges to access posed by damage and blockage of key infrastructure, may have strongly influenced fire effects. Wildfire managers working the fire noted elevated fire behavior in areas that contained what was deemed to be storm-related fuel loading, and many suppression resources were delayed in their response as fire crews spent hours clearing roads and trails of storm debris to gain access for suppression activities.

These compounded disturbances presented a unique opportunity to examine the efficacy of the FFSS fuel reduction treatments following two major natural disturbances. In this thesis, Chapter 2 presents a summary of scientific literature related to disturbance ecology and the responses of wildland fuel loads to disturbances in the eastern United States. Chapter 3 presents research from fuels data that was collected at GRGL in Summer 2025 following both Hurricane Helene and the Black Cove Wildfire Complex near Hendersonville, NC. In Chapter 4, I provide next steps and some additional preliminary analyses that should be considered as land managers and scientists move forward in post-Helene forests, particularly if lands they are managing include multiple prescribed fires or fuel reduction treatments.

Chapter 2. Literature Review

2.1 History of fire in the southern Appalachian Mountains

Fire history records constructed from fire scar and soil charcoal data indicate that southern Appalachian forests experienced frequent low- and mixed-intensity fires for millennia (Lafon et. al 2017). This fire frequency has been drastically altered by human activity in recent years (Alexander et al. 2021, Nowacki and Abrams 2008). In the summer of 1910, the newly-created US Forest Service reeling from the impacts of the largest and most devastating wildfires in the nation's history began to formulate its approach to fire protection (Pyne 1981). The long legacy of what would come to be known as prescribed fire, used for centuries by indigenous peoples and frontiersman alike (Stambaugh et al. 2018), was strongly curtailed by the US Forest Service in an effort to appease industrial foresters and a general public that had come to fear any and all wildland fire. Following the logging boom of the early 20th century, higher incidence of high intensity fires, many burning through areas heavily loaded with logging slash, prompted authorities to adopt more heavy-handed policies of fire suppression without complimentary programs to manage the accumulation of fuels (Busenburg 2004). In 1935, the US Forest Service established its "10 AM Policy," mandating that all fires be extinguished by 10 AM the following day. The policy embodied federal and state governments' inclination to attempt to entirely exclude fire from the landscape. While this policy and others like it failed to completely exclude fire, it succeeded in drastically reducing the frequency and spatial extent of large fires (Lafon et al. 2017).

2.2 Modern fire ecology and fuels management

In the 1970s, fire management policy in the United States began to shift toward a more sustainable, science-based approach (Pyne 1981). The US Forest Service began to recognize the role of fire in regulating ecosystem function and promoting biodiversity and gradually adopted a "let-burn" policy, allowing naturally ignited fires to burn in designated wilderness areas (Center for Public Lands 2023). After decades of heavy public relation campaigns led by the federal government in support of fire exclusion and suppression, let-burn was not always well received by a public exposed to decades of fire suppression directives and approaches. Yet, while the public's perception of fire itself may have remained generally negative, that perception likely reflected a healthy fear of dangerous, intense wildfires, rather than the effects produced by the low-intensity "light burning" encouraged by ecologists. Taylor and Daniel (1984) showed members of the general public images depicting various fire effects ranging from low to high severity. Their results showed that participants favored the effects of low intensity prescribed fire over the severe burns caused by wildfires. The results of the study may better reflect public perception of fire in the western US, where the surveys were conducted, than in the southeast, where cultural burning has persisted to a greater degree despite government restrictions.

Over the ensuing decades, "good fire" has gradually become better understood and accepted by professional fire managers and the public alike (Wu et al. 2022). Today, prescribed fire is widely viewed as good, healthy, and necessary in many regions and forest types, and is being implemented more frequently. As the role that fire plays in all natural processes is better understood, and as professional and private use of this powerful tool becomes more prevalent, practitioners increasingly seek to refine and adapt fire use to the unique conditions, circumstances, and objectives of their respective management areas.

2.3 Fuel loading and fire behavior

The accumulation of fuel continues to pose significant challenges for prescribed fire practitioners, firefighters, and ecologists alike (Keane 2015). Fire behavior prediction is dynamic, combining numerous variables and indices with equal parts perception and intuition (Monadero et al. 2019). Fuel characteristics, and the indices derived therefrom, play critical roles in accurately predicting fire behavior (Linn et al. 2020). Understanding and interpreting fuel models is key to evaluating the fuel characteristics of one's own area of responsibility. No existing fuel models account for storm-related fuel loading in the southern Appalachian Mountains (Coates et al. 2019). When faced with large scale post-disturbance fuel loads, as seen in western North Carolina following Hurricane Helene, managers are left to estimate fuel loading based on estimates calculated under normal conditions in their area. Estimates that can be produced using the data collected for this thesis project may be valuable to those seeking to mitigate fuel-related fire hazards in storm-impacted areas.

2.4 Deadwood

Downed woody material of various sizes, referred to here as deadwood, often constitutes the majority of available fuel mass in a forest (Forrester et al. 2023). The concentration, condition, and structure of these fuels have a significant influence on fire behavior and effects (Keane 2015). The interplay of deadwood characteristics is complex, and thorough assessment and understanding of deadwood dynamics in one’s area of responsibility is crucial to effective fire and ecological management. In the relatively frequent, low intensity fire regimes of the southern Appalachian Mountains, fires are less likely to fully consume large-diameter deadwood as compared to those in drier Western ecosystems which experience less frequent but higher intensity wildfires (Evans 2012). In addition, mixed severity fires in the region may ultimately increase deadwood volume where fire-induced mortality adds more material than is consumed (Bernal et al. 2025).

2.5 The Fire and Fire Surrogate Study

While prescribed fire may often be the most effective, inexpensive, and least destructive tool available to land managers, it may not be feasible in all applications or environmental settings (Waldrop and Goodrick 2012). Acceptance of prescribed fire may vary by region, with regional acceptance or apprehension stemming largely from its perceived threat to various interests. In much of the eastern US, the public may be less amenable to fire use within, or in close proximity to, the wildland-urban interface (WUI). In 2000, the National Fire and Fire Surrogate Study (FFSS) sought to evaluate the impacts of a standardized suite of prescribed fire and fire surrogate treatments on a variety of ecological responses in various ecosystems across the United States (Witherspoon et. al. 2012). The results of this long-term study would, among other things, serve to inform management strategy for areas where fire may be less practical as a tool. In FFSS, a total of 13 research sites were developed at the inception of the study, with continued management and evaluation occurring at four of the sites to date (Bernal et al. 2025). At each site, multiple replicates of four treatments were installed: prescribed fire, site-specific mechanical treatment, prescribed fire combined with mechanical treatment, and untreated controls. Multiple response variables were then measured at each site, including but not limited to vegetation response, macroinvertebrate activity, soil chemistry, fuel loading, and predicted fire behavior. For sites in the western US, fire behavior was predicted using the Fire and Fuels Extension of the Forest Vegetation Simulator (FFE-FVS) (Bernal et al. 2025). This western-centric fire behavior model has not yet been utilized for the Green River Game Land (GRGL) in North Carolina to understand its utility or effectiveness therein. Following the impacts of

Hurricane Helene and a large wildfire that occurred two decades after the intial installation of the treatments, GRGL presents a unique opportunity to assess fire behavior and burn severity.

2.6 Major storms in the southern Appalachians

While tropical and extratropical storms are not unheard of in the southern Appalachian Mountains, they are significantly less frequent and/or impactful there than in the Coastal Plain. Since 1850, Polk and Henderson Counties, North Carolina, have been impacted by just 39 of these storms, while more than 150 storms have impacted coastal Craven County, NC (NOAA 2026, https://coast.noaa.gov/hurricanes. Accessed: 25 March 2026). Though infrequent and generally understudied, major storms in the region can have significant impacts on forest structure, composition, and ecology from high wind and precipitation (McNab et al. 2004). In the past 40 years, eight major storms in the region – Hugo in September 1989 (Doggett 1993), Opal in October 1995 (Greenberg and McNab 1998, Clinton and Baker 2000), Frances, Jeanne, and Ivan in 2004, and now Helene – have resulted in significant windthrow, altering forest structure and composition (Greenberg 2021). The effects of the interaction between wind disturbance and fire are less understood, but available research suggests that, in addition to potential increases in fuel load, the aforementioned changes in structure and composition can have significant influence on fuel dynamics and potential fire behavior (Cannon et al. 2014).

2.7 Managing post-storm fuel loads

Hurricanes can drastically alter both the structure and composition of forests (Cannon et al. 2023). Reduction in overstory density of mature forests increases light penetration to the forest floor, creating conditions that favor shade-intolerant species (Diaz et al. 2021). Methods of forest management, including prescribed fire, may be hampered by the volume of heavy fuels present following a major storm, further complicating vegetation dynamics and compounding fuel loading issues for managers seeking to mitigate hazardous fuel accumulation. Pre-emptive forest management for major natural disturbances may forestall these negative impacts.

2.8 Summary

Evidence gathered by a variety of methods suggests that, from pre-settlement times through the mid-20th century, the southern Appalachian Mountains experienced regular, low intensity fires (Lafon et al. 2017). An uptick in higher severity fires following the logging boom of the late-19th and early-20th century, which threatened the timber supply conservationists sought to protect, prompted a widespread suppression policy which sought to exclude wildfire entirely. The result of this policy was widescale alteration of forest structure and composition, and a decades-long buildup of wildland fuels.

Wildland fuel loading is a key factor in potential wildfire intensity and burn severity (Keane 2015). While fuel structure and loading have been studied extensively, as with most things wildfire-related, the bulk of their study has been focused on fuel types of the western United States, where most high intensity wildfires occur (Hiers et al. 2020). Further study of fuels dynamics in the eastern United States, and the Southeast in particular, is needed.

The knowledge gleaned from this thesis project should be useful to Appalachian forest and fire managers. Silviculturists and ecologists benefit from a more thorough understanding of the impacts of fuels on fire effects and numerous ecological responses, and fire suppression managers require accurate fuel volume and mass estimates to predict fire behavior. In 2001, the National Fire and Fire Surrogate Study sought to evaluate the efficacy of fire and fire surrogate treatments in achieving multiple ecological objectives, including fuels and fire behavior, in various ecosystems across the United States (Bernal et al. 2025). In some cases, prescribed fire alone may be impractical or ineffective in mitigating hazardous fuels or achieving specific management goals where forests have been drastically altered by the historic suppression of fire. While generally uniform in nature, treatments were sometimes adapted to local conditions. At GRGL, mechanical felling operations were tailored to local cover types, removing ericaceous shrubs that benefitted from historic fire suppression (Waldrop et al. 2016). In addition to its historically regular fire return interval, the southeastern US also experiences regular tropical cyclones. In the 180 years of recorded weather data, the region surrounding Green River has been impacted by 39 such storms (NOAA 2026, https://coast.noaa.gov/hurricanes. Accessed: 25 March 2026). These impacts now exacerbate the suppression policy-related fuel buildup, posing additional challenges for managers. While these storms are relatively common, as compared to other regions of the US which experience regular wildfires, the interaction between storms and fuels is not well understood.

Chapter 3. Post-Hurricane Helene Wildfire Fuels of the Fire and Fire Surrogate Study at Green River Game Land, North Carolina, USA

3.1 Introduction

Following a period of frequent, extensive, and intense wildfires during the logging boom of the early-20th century, a policy of fire exclusion was adopted in the United States, in part to protect and support forest regeneration but to also reduce property losses and deaths resulting from wildfires (Pyne 1981, Schullery 1989, Lafon et al. 2017). Prescribed and cultural burning were often restricted in many places, and government organizations sought to suppress wildfires as quickly as possible through direct attack (Pyne 1981). In the eastern US, these suppression practices resulted in widescale alteration of forest composition, structure, and fuels that continue to impact forest management today (Nowacki and Abrams 2008, Vaughan et al. 2022). Fire exclusion along with reduced light resources and high white-tailed deer (*Odocoileus virgnianus*) populations, contributes to a process known as “mesophication” (Nowaki and Abrams 2008, Kreye et al. 2013). In the southern Appalachian Mountains as fire-adapted species, such as oaks (*Quercus* spp.) and pines (*Pinus* spp.), face replacement by mesophytic competitors that are no longer constrained by frequent low to medium intensity fires (Waldrop et al. 2016).

After decades of mesophication, southern Appalachian Mountain forests are dense and contain large quantities of wildland fuels that are often continuous, both horizontally and vertically (Vaughan et al. 2021). Forests whose stand structure previously had been patchy and heterogeneous prior to industrial logging’s spread into the Southeast in the 1920s have become vastly more even-aged and homogenized (Lydersen 2013). With increased tree density and fuel continuity, both important drivers of fire behavior (Keane 2015), comes the increased risk of high intensity and severity wildfires at longer intervals in lieu of low severity fires at shorter intervals. This risk has been actualized in several fire seasons within the last decade, particularly during the southeastern US's Fall 2016 fire season, when the region experienced 51% of the nation's wildfire ignitions, a total of over 34,000 for that year, burning approximately 647,497 ha across 13 states (NICC 2016).

In response to the increased risk of high intensity and severity wildfires throughout the country, the National Fire and Fire Surrogate Study was launched in 2000 to determine the effects of prescribed fire and other potential fuel reduction practices, such as commercial thinning and mechanical felling, on a host of ecosystem properties and processes (Schwilk et al. 2009). Thirteen sites were selected for this study, including one in the southern Appalachian Mountains near Hendersonville, North Carolina. Situated along the Green River on the North Carolina Game Commission's Green River Game Land (GRGL), this site presented not only potentially hazardous wildland fuel conditions, but it also faced many of the forest management issues of declining oak and pine regeneration and mesophication favoring less commercially and wildlife-valuable tree species that are consistent throughout the region. Treatments at this site were first conducted in 2001, and subsequent treatments were conducted through May 2024. These treatments included: mechanical (chainsaw) felling of shrubs and midstory stems less than 10 cm diameter at breast height (DBH) (M), prescribed burning (B), a combination of mechanical felling and prescribed burning (MB), and an untreated control (C) (Stephens et al. 2009).

Many refereed journal articles have been produced to highlight the impacts of these treatments over time at GRGL, including Bernal et al. (2025) and Taylor et al. (2025). Bernal et al. (2025) evaluated fuel load changes in ground fuels (GF), fine woody debris (FWD) (0-7.5 cm diameter), and coarse woody debris (CWD) (≥7.6 cm diameter) from 2001-2014 suggesting that the greatest alteration to fuel loading was an increase in CWD in the MB treatment. This fuel class increased during the 13-year period, largely due to delayed overstory mortality resulting from the use of multiple low to moderate severity prescribed fires. Taylor et al. (2025) evaluated tree responses to these treatments from the onset of the study through 2018. The authors found that desired tree species regeneration was most positively improved with the MB treatment.

In September 2024, Hurricane Helene produced unprecedented impacts throughout parts of the southern Appalachian Mountains (Dale et al. 2025). In addition to widespread historic flooding, in North Carolina alone, hurricane and near-hurricane force winds far inland toppled approximately 332,652 ha of timber, generating an exponential increase in both wildland fuel loading and vertical continuity across the region (FEMA 2025, Dale et al. 2025). Windthrow and stem breakage placed a large volume of mature stems on the ground just prior to the start of the Southeast's Fall wildfire season. These fuels, along with other wind-, rain-, and flood-related damage to infrastructure, limited access to remote areas throughout the region, setting the stage for potentially catastrophic wildfires. Subsequently, these conditions and a prolonged dry period following Hurricane Helene resulted in numerous wildfires throughout the region in March 2025. The southern Appalachian Fire and Fire Surrogate Study site was one of the locations impacted by both Hurricane Helene and the March 2025 wildfires, most notably the Black Cove Wildfire Complex (NCAGR, 2025. https://www.ncagr.gov/news/press-releases/2025/04/03/daily-update-black-cove-complex. Accessed 25 March 2026) (Figure 3.1).

Due to the intensity of both management and research at GRGL and the unprecedented combination of disturbances at the site from Fall 2024 - Spring 2025, we conducted research in Summer 2025 to better understand how both Hurricane Helene and the Black Cove Wildfire Complex impacted the fuels of the southern Appalachian Fire and Fire Surrogate Study. We formed several hypotheses: 1. Overall, Hurricane Helene and the Black Cove Wildfire Complex increased total fuel mass in all treatments from 2014-2025; 2. Change in fuel loading from 2014-2025 was greatest in the control (C) treatment due to the presence of greater fuel loads in the absence of active treatments since 2001; 3. The MB treatment displayed the least change in fuel loading from 2014-2025; 4. Wildfire spread was reduced in the burn-only (B) and MB treatments due to the prior reduction in GF. This research provides critical information for other portions of the Appalachian Mountains that have similar management histories and similar impacts from both Hurricane Helene and recent wildfires.

3.2 Methods

3.2.1 Study location

The North Carolina Wildlife Resources Commission (NCWRC) manages approximately 800,000 ha for hunting, fishing, and recreation under the state's Game Lands Program (NCwildlife.gov, 2026). This includes GRGL, which covers 6,159 ha in NCWRC's Mountain Region across Henderson and Polk counties, North Carolina, USA (Figure 3.2). Green River was selected as the location of the southern Appalachian Mountain research site because it was representative of a forest with a historically short-interval, low to moderate severity fire regime and a high risk of uncharacteristically severe wildfire (Witherspoon et al. 2000).

At GRGL, elevation range is 366-793 m and the topography is mountainous. The climate is warm continental with mean annual precipitation of 1,638 mm. Mean annual temperature is 17.6ºC. Soils at the study site are moderately deep, well-drained Ultisols (Typic Hapludults), primarily from the Evard (Replications 1 and 2) and Cliffield (Replication 3) soil series (Dukes et al. 2020). At the time of study implementation in 2001, forest stand ages were approximately 80-120 years (Waldrop et al. 2010, Keenan 1998). Fire history of the region suggests a mean fire return interval of 10 years prior to 1940 (Harmon 1982), however no evidence was present of previous wildfires or agricultural activity at GRGL (Waldrop et al. 2010).

Forests of GRGL are mixed oak-pine. On dry, xeric ridges, pitch pine (*Pinus* rigida Mill.) and Table Mountain pine (*Pinus pungens* Lamb.) are the dominant pine species in the overstory. Eastern white pine (*Pinus strobus* L.) is the dominant pine species in the overstory in moist coves. A mixture of oaks, including black (*Quercus velutina* Lam.), chestnut (*Quercus montana* L.), northern red (*Quercus rubra* L.), scarlet (*Quercus coccinea* Muenchh.), and white (*Quercus alba* L.), are dominant in the overstory throughout. Depending on site characteristics, blackgum (*Nyssa sylvatica* Marsh.), mockernut hickory (*Carya tomentosa* [Poir] Nutt.), red maple (*Acer rubrum* L.), sourwood (*Oxydendrum arboreum* [L.] DC), and yellow-poplar (*Liriodendron tulipifera* L.) are also present (Waldrop et al. 2010).

A mixture of ericaceous shrubs occurs at GRGL, as well, accounting for 35% cover or greater within many plots at the time of study implementation in 2001 (Waldrop et al. 2007). These shrubs include mountain laurel (*Kalmia latifolia*) and and blueberry (*Vaccinium* spp. L.) on drier sites, rhododendron (*Rhododendron maximum* L. and *Rhododendron minus* Michx.) in riparian areas and moist coves, and flame azalea (*Rhododendron calendulaceum* [Michx.] Torr.) in submesic to subxeric sites. While native to the region, these species may greatly increase vertical fuel structure, aiding in the formation of ladder fuels that may increase fire intensity and crown mortality in the event of a wildfire under dry conditions (Coates and Ford 2022, Reilly et al. 2022, Waldrop and Brose 1999). They also impede tree regeneration due to the increased shade presented by their dense canopies (Elliott and Miniat 2021, Bolstad et al. 2018, Nilsen et al. 1999).

3.2.2 Treatments

The southern Appalachian Fire and Fire Surrogate Study was implemented in a randomized complete block design, consisting of four treatments and three replications.

Treatments included: mechanical (chainsaw) felling of shrubs and midstory stems less than 10 cm diameter at breast height (DBH) (M), prescribed fire (B), a combination of mechanical felling and prescribed fire (MB), and an untreated control (C) (Taylor et al. 2025, Stephens et al. 2009). Mechanical felling within the M and MB treatments was conducted at the inception of the study at GRGL, between December 2001 and February 2002 (Dukes et al. 2020). An additional felling was conducted in the M replications in 2012. No additional felling was conducted in the MB replications in 2012 because it was determined they were not necessary (Waldrop et al. 2016). Prescribed burns were implemented five times (2003, 2006, 2012, 2015, and 2024) prior to 2025 in both B and MB.

3.2.3 Fuels inventory

Ten 20 m x 50 m modified Whittaker plots were installed within each of the twelve treatment-replications to conduct vegetation inventories (Waldrop et al. 2016). A modified version (Coates et al. 2019, Coates and Ford 2022) of Brown's Planar Intercept Method (Brown 1974) was utilized in each corner of the ten 10 m x 10 m subplots to tally and measure fuels on the ground (n=480). Due to limitations of time and funding in 2025, 25% of the original fuel sampling locations were revisited. Specifics for the layout of the planar intercepts and the formulas used to convert the tallies of down-and-dead woody fuels to volume and mass can be found in Coates et al. (2019) and Coates and Ford (2022). Masses of 1-hr (0-0.64 cm), 10-hr (0.65-2.54 cm), 100-hr (2.55-7.61 cm), and 1000-hr (≥7.62 cm) fuels were obtained from the tallies. Depths of litter (Oi Horizon) and duff (Oe+Oa Horizons) were measured using rulers (mm) along the planar intercepts (Coates et al. 2019; Coates and Ford 2022) and were converted to masses using the following depth to mass conversions (Ottmar and Andreu 2007):

Litter mass: 1.22 Mg per ha per cm

Duff mass: 4.27 Mg per ha per cm

For our analyses, we followed the methods of Bernal et al. (2025) and evaluated: 1. The sum of the litter and duff masses as *Ground Fuels* (GF); 2. The sum of the 1-, 10-, and 100-hr fuel masses as *Fine Woody Debris* (FWD); 3. 1000-hr fuel mass as *Coarse Woody Debris* (CWD), 4. The sum of GF, FWD, and CWD as *Total fuel mass* (TFM). Plots that displayed no evidence of wildfire impacts were excluded from our statistical analyses (Figure 3.3).

3.2.4 Statistical analyses

Means of GF, FWD, CWD, and TFM were determined for 2001 (pre-treatment), 2014, and 2025. The significance of mean fuel load changes for each of the fuel loading categories from 2014-2025 was assessed using a Kruskal-Wallis Test (one-way analysis of variance [ANOVA] for non-parametric data) (Conover, 1984). When differences between treatments were significant ($\alpha=0.05$), a Steel-Dwass All Pairs test was utilized to distinguish those differences. All statistical analyses were conducted using JMP Student Edition 19 (SAS; Cary, NC, USA).

3.3 Results

Means of the fuel loads in 2001, 2014, and 2025 are listed in Table 3.3 and are visually displayed in Figure 3.4. In 2001, 52-58% of TFM was accounted for by GF in each of the treatments. By 2014, only 18% and 37% of TFM was accounted for by GF in the MB and B treatments, respectively. Masses of GF accounted for 52% of TFM for both the C and M treatments in 2014. In 2025, only 4-9% of TFM was accounted for by GF in all treatments. In all years, FWD accounted for 8-27% of TFM. Loads of CWD were 25-38% of TFM in 2001. By 2014, 43% and 67% of TFM was accounted for by CWD in the B and MB treatments, respectively, while CWD remained nearly constant in the C treatment at 29%. In the M treatment, 23% of TFM in 2014 was accounted for by CWD, a decrease of 15% from 2001. In 2025, CWD loads accounted for 64-78% of all TFM loads in all treatments.

From 2014-2025, the mean reduction in GF loads differed between treatments ($p<0.01$) (Table 3.2) and was greatest in the C treatment. This reduction was not significantly different from the M treatment, but it did differ from the B and MB treatments. No significant differences between the means of the treatments existed for FWD ($p=0.19$, CWD ($p=0.06$), or TFM ($p=0.33$) (Table 3.2). However, while not statistically significant: 1. CWD increased in both the C and M treatments, but decreased in the B and MB treatments; 2: TFM decreased in all treatments except the M treatment from 2014-2025; 3. In 2025, TFM was 26.93 Mg ha^{-1} in the B treatment, representing only 53-61% of TFM in the other treatments.

3.4 Discussion

3.4.1 Impacts of treatments prior to 2024

As previously stated by Bernal et al. (2025) and as shown in Figure 3.4 (Table 3.1), the implementation of the B and MB treatments reduced GF on the GRGL from 2001-2014. The reduction in GF, which serves as the primary fuel source for mixed oak-pine forests in the eastern United States (Waldrop and Goodrick 2016), was the result of repeated prescribed fires. The implementation of these fires in these long-unburned stands caused delayed mortality of overstory stems (Taylor et al. 2025, Waldrop et al. 2016), leading to subsequent increases in CWD (>200% in B, >400% in MB). Changes in overstory light conditions promoted desired tree regeneration, with the most positive outcomes aligning with the MB treatment, followed by the B treatment (Taylor et al. 2025). These positive outcomes steered management objectives toward continued burning at the site prior to 2024. Potential innovations of the treatments were discussed prior to October 2024, such as the use growing season prescribed fires (Vaughan et al. 2022) and experimentation with herbicides. These innovations would be targeted to reduce ericaceous shrub cover and constrain regeneration of red maple and other less desired tree species.

3.4.2 Impacts of Hurricane Helene and the Black Cove Wildfire Complex

In October 2024, plans for potential next steps at GRGL were paused due to the impacts of Hurricane Helene. Several months later in March 2025, the Black Cove Wildfire Complex further confounded future planning. Impacts from both Hurricane Helene and the Black Cove Wildfire Complex varied widely between plots within treatments, and between treatments within replications (Figure 3.5). Overstory blowdowns throughout GRGL were patchy in distribution, with some areas seeing nearly 100% of overstory trees toppled by storm winds and others seeing 0%. In some cases, the fuel transects were oriented within patches of forest apparently unaffected by the storm and completely excluded from the wildfire. In others, transects were placed within dense, “jack-strawed” timber. In some of the more severely burned sites, no O Horizon was present, whereas in unburned areas of the M, B, and MB treatments, litter depth sometimes matched or exceeded pre-treatment levels. The spread of the Black Cove Wildfire Complex, largely unchecked within the bounds of natural and constructed control features, immensely complicated this controlled experiment as it crossed FFSS treatment boundaries.

Changes in mean fuel load from 2014-2025 differed by treatment for GF (Table 3.2). This reduction was greatest for C, but did not differ significantly from the M treatment. This result is logical because fire had not been present in these sites previously. Fire ignition and spread through those treatment areas was aided by fuel complexes that were likely 52% GF, based upon the 2014 values (Table 3.1). Due to the high degree of variability of impacts from Hurricane Helene and the high variability in fuel loads within each sampling location, the CWD change was not significant between the treatments. However, CWD decreased in the B and MB treatments, but increased in the C and M treatments. In the B and MB treatments, some of the CWD that had been added as a result of overstory mortality induced by the treatments prior to 2024 was likely consumed in the wildfire. In the C and M treatments, new CWD was likely added as a direct result of Hurricane Helene, the Black Cove Wildfire Complex, or both events. Although both treatments experienced reductions in CWD in 2025, the remaining CWD in the MB treatment was double that of the B treatment.

3.4.3 Fuels and wildfire management

While we have no documented photographs or measurements of fire behavior within each plot, we hypothesize that fire behavior likely differed in the B and MB treatments from the C and M treatments due to the differences in both fuel loading and fuel structure. This brings to light a critical consideration for fuel treatments: TFM may stay constant despite changes in fuel structure. When fuel structure is altered, both vertical and horizontal fuel continuity may be impacted. Alterations to horizontal continuity may impact surface fire spread, and alterations to vertical continuity may impact ladder fuels and the potential for crown fires (Keane 2015). When the fuel reduction treatments were coupled with another natural disturbance, such as Hurricane Helene, overstory stems that may have maintained resilience to repeated burning may have succumbed to inundation with heavy rains and strong winds. Additional work is being conducted to further investigate those dynamics specifically at GRGL (Weise 2026, in preparation).

From a practical standpoint of wildfire management following the fuel reduction treatments, we do know that the Black Cove Wildfire Complex did not fully spread throughout all of the study area (Figure 3.5). For example, in replication 1, the wildfire only spread through a portion of the B treatment. In replicate 3, the majority of the M treatment was unaffected. All of replication 2 was part of the wildfire complex, regardless of treatment designation.

Unfortunately, we are not certain of the points of ignition nor the tactical decisions that were made to constrain the boundaries of the wildfire. Wildland firefighters often make tactical suppression decisions to insure the protection of lives and property, therefore we cannot directly state that some of the treatments promoted more or less spread of the wildfire. However, we have evidence that the fuel reduction treatments did not provide “wildfire-proof conditions” at GRGL. The notion that fuel mitigation treatments completed remove any risk of wildfires is a faulty assumption and further affirms that changes in fire behavior may be expected following alterations to fuel loading and structure rather than complete wildfire resistance. Fuels mitigation in the southern Appalachian Mountains may target the reduction of hazardous wildfire conditions to reduce threats to lives and property if and when wildfires occur, but the potential for wildfires in systems that are managed with prescribed fires will still be present under certain conditions because fuels must be present to ignite and sustain a prescribed fire regime. Areas managed with prescribed fire benefit from the fuel breaks and fire perimeters that are often created and maintained to sustain frequent prescribed burning, and those assets may provide benefits when and if wildfires occur in areas that have been treated with prescribed fires.

3.5 Conclusion

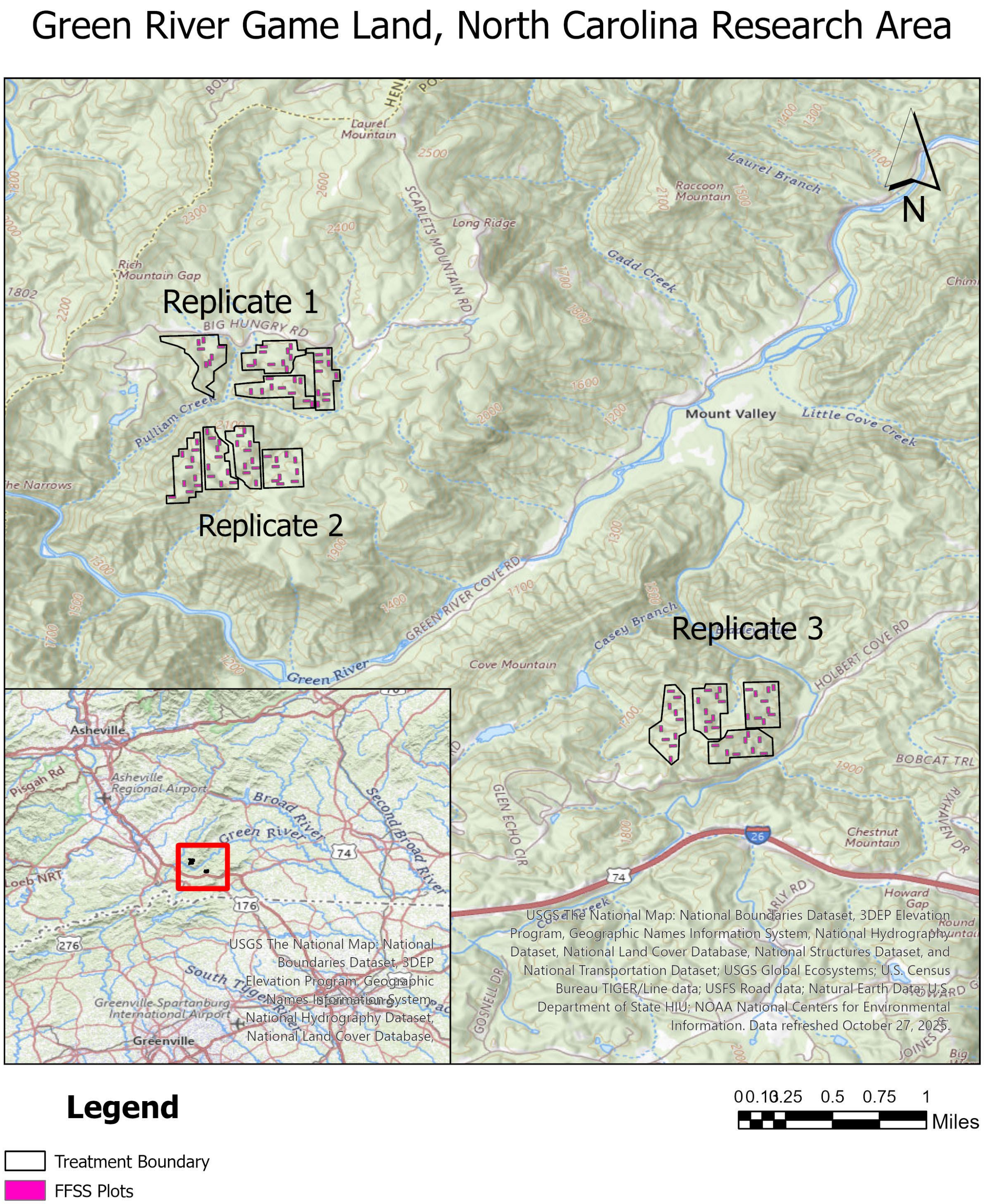
Next steps for GRGL began in May 2025. A prescribed fire was administered in that month to include all locations within replication 1 that had not been impacted by the wildfire. We anticipate the installation of additional treatments at the site to target objectives for both wildfire risk reduction and the long-term management of a mixed oak-pine forest. The additional treatments may include herbicides and the use of prescribed fire in the growing season to potentially alter fuel composition and subsequent fire behavior. In the southern Appalachian Mountains, prescribed fire is being used more frequently to target a variety of objectives, including but not limited to fuel hazard reduction, vegetation restoration and maintenance, and wildlife habitat restoration and maintenance (Waldrop and Goodrick 2012). Many locations within the region have now been burned numerous times. Findings from GRGL of use to managers include: 1. Long-term use of B and MB treatments does not ensure that a forest will resist impacts from disturbances such as wildfires, windstorms, and hurricanes; and 2. Achievement of long-term land management objectives may require multiple entries of multiple treatments over time.

Roberto Di Giovine | U.S. Army National Guard via AP

AP Photo / Allison Joyce

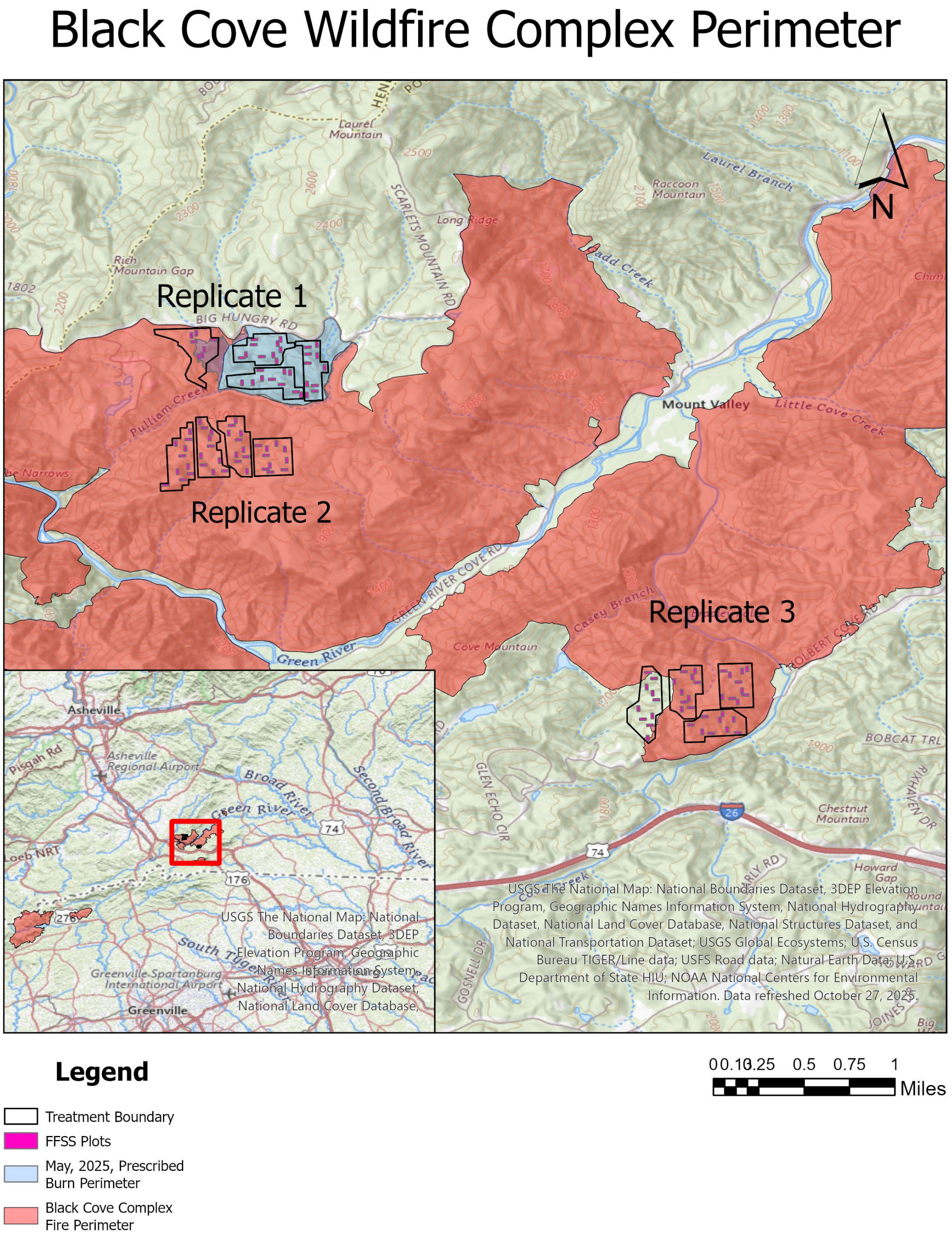
Polk County Govt.

Figure 3.1 The Black Cove Wildfire Complex (March 2025) burned approximately 3,076 ha in Henderson and Polk Counties, North Carolina.



USGS The National Map: National Boundaries Dataset, 3DEP Elevation Program, Geographic Names Information System, National Hydrography Dataset, National Land Cover Database, National Structures Dataset, and National Transportation Dataset; USGS Global Ecosystems; U.S. Census Bureau TIGER/Line data; USFS Road data; Natural Earth Data; U.S. Department of State HIU; NOAA National Centers for Environmental Information. Data refreshed October 27, 2025.

Figure 3.2 Location of the Southern Appalachian Fire and Fire Surrogate Study on the Green River Game Land near Hendersonville, North Carolina, USA



USGS The National Map: National Boundaries Dataset, 3DEP Elevation Program, Geographic Names Information System, National Hydrography Dataset, National Land Cover Database, National Structures Dataset, and National Transportation Dataset; USGS Global Ecosystems; U.S. Census Bureau TIGER/Line data; USFS Road data; Natural Earth Data; U.S. Department of State HIU; NOAA National Centers for Environmental Information. Data refreshed October 27, 2025.

Figure 3.3 Extent of impact of the Black Cove Wildfire Complex within the Southern Appalachian Fire and Fire Surrogate Study, Green River Game Land, North Carolina, USA. Note that three treatment units in Replication 1 and one treatment unit within Replication 3 were not completed impacted by the wildfire.

Figure 3.4 Means (±standard error of the mean) for the masses of ground fuels (GF), fine woody fuels (FWD), coarse woody debris CWD), and total fuels (TF) in 2001, 2014, and 2025 for each of the treatments (C = control, B = burn-only, M = mechanical-only, and MB = mechanical+burn) of the Southern Appalachian Fire and Fire Surrogate Study, North Carolina, USA. Plots not observably impacted by wildfire were excluded from this analysis.

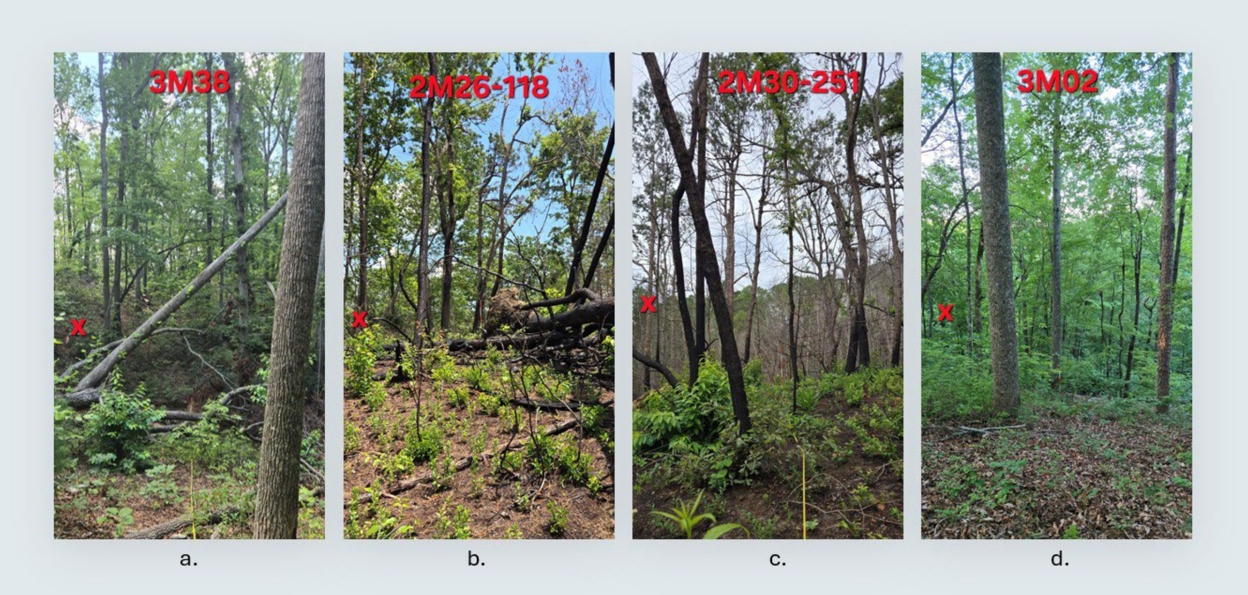


Figure 3.5 Variable impacts of Hurricane Helene and the Black Cove Wildfire Complex at the Green River Game Land, North Carolina, USA as observed in June-July 2025. This panel depicts mechanical-only treatments under four observed conditions: a.) impacted by the storm; b.) impacted by the storm and the wildfire; c.) impacted only by the wildfire; d.) not significantly impacted by the storm and excluded from the wildfire.

Table 3.1a – 3.1c Means (±standard error of the mean) for the fuel loading variables in 2001, 2014, and 2025 for each of the treatments of the Southern Appalachian Fire and Fire Surrogate Study, North Carolina, USA. The percentage of total fuel mass represented by ground fuels, fine woody fuels, and coarse woody debris is listed below the mean (±standard error of the mean).

Table 3.1a 2001

Fuel Mass (Mg ha^{-1})	**Control (n=19)**	**Burn-only (n=22)**	**Mechanical-only (n=12)**	**Combination (n=16)**
Ground Fuels	21.04 (1.74) 58%	23.78 (1.71) 58%	18.66 (1.75) 54%	20.00 (1.92) 52%
Fine Woody Fuels	5.77 (0.75) 16%	6.97 (0.94) 17%	2.89 (0.53) 8%	6.35 (0.91) 17%
Coarse Woody Debris	9.75 (2.27) 27%	10.19 (3.27) 25%	12.94 (4.30) 38%	11.96 (4.18) 31%
Total	36.56 (2.71)	40.93 (3.25)	34.49 (4.63)	38.31 (5.46)

Table 3.1b 2014

Fuel Mass (Mg ha^{-1})	**Control (n=19)**	**Burn-only (n=22)**	**Mechanical-only (n=12)**	**Combination (n=16)**
Ground Fuels	26.00 (1.40) 52%	19.31 (1.11) 37%	23.28 (1.96) 52%	13.86 (1.13) 18%
Fine Woody Fuels	9.36 (1.80) 19%	10.39 (0.81) 20%	11.18 (1.10) 25%	10.87 (1.26) 14%
Coarse Woody Debris	14.53 (3.35) 29%	22.57 (5.36) 43%	10.55 (2.21) 23%	50.40 (14.90) 67%
Total	49.90 (3.94)	52.27 (5.69)	45.01 (3.54)	75.14 (15.24)

Table 3.1c 2025

Fuel Mass (Mg ha^{-1})	**Control (n=19)**	**Burn-only (n=22)**	**Mechanical-only (n=12)**	**Combination (n=16)**
Ground Fuels	2.24 (0.19) 5%	2.53 (0.52) 9%	3.70 (0.69) 7%	1.92 (0.38) 4%
Fine Woody Fuels	7.97 (0.85) 18%	7.15 (0.71) 27%	7.51 (0.92) 15%	8.65 (1.41) 19%
Coarse Woody Debris	33.78 (10.75) 77%	17.25 (4.36) 64%	39.39 (15.40) 78%	34.76 (11.36) 77%
Total	43.98 (10.94)	26.93 (4.35)	50.60 (16.11)	45.32 (12.30)

Table 3.2 Mean fuel mass change (±standard error of the mean) from 2014-2025 for each of the treatments of the Southern Appalachian Fire and Fire Surrogate Study, North Carolina, USA. Negative values indicate fuels were added over the time period.

Fuel Mass Change ($Mg\ ha^{-1}$)	**Control (n=19)**	**Burn-only (n=22)**	**Mechanical-only (n=12)**	**Combination (n=16)**	**p-value**
Ground Fuels	23.76 (1.37) A	16.77 (1.01) B	19.58 (1.93) AB	11.94 (0.97) C	<0.01
Fine Woody Fuels	1.40 (1.90)	3.24 (1.02)	3.67 (1.25)	2.23 (2.01)	0.19
Coarse Woody Debris	-19.25 (11.29)	5.32 (4.66)	-28.84 (14.95)	15.64 (11.55)	0.06
Total	5.92 (11.93)	25.34 (5.33)	-5.59 (16.47)	29.81 (12.61)	0.33

Chapter 4. Conclusion

4.1 Fuels summary

As the climate changes, and the frequency and severity of storms like Hurricane Helene are projected to increase, effective management for fire-adapted and resilient forests becomes even more vital. Managers must seek not only to mitigate the results of broad-scale fire exclusion in restoring our forests' natural resilience, but to increase that resilience to a level sufficient to withstand higher temperatures and more frequent and intense events. Therefore, this thesis represents timely work addressing a topic of interest to many within the Appalachian Mountain region.

Results from the study of post-Helene, post-Black Cove Wildfire fuels at GRGL suggest that long-term alteration of both fuel loading and fuel structure is challenging. Areas receiving the fuel reduction treatments were not invincible to wildfire ignition and spread. While we have no recorded evidence to illustrate differences in fire behavior during the Black Cove Wildfire Complex in the B and MB treatments versus the C and M treatments, it appears likely that fire behavior differed between these treatments based upon the differences in the fuel components that would have been present prior to the wildfire and their distribution. Similarly, we cannot be 100% certain of the tactical fire suppression decisions that may have encouraged or stifled fire spread and residence time in each treatment-replicate.

4.2 Additional preliminary analyses

4.2.1 Hurricane Helene impacts

Additional work is needed to fully characterize the impacts of the fuel reduction treatments on hurricane resistance at GRGL. Data from Christie and Norman's (2024) HiForm Hurricane Helene Rapid Assessment datasets were used to perform a cursory analysis of storm damage severity at GRGL. The HiForm assessment used 10 m Sentinel-2 imagery to determine NDVI change, and this was combined with documentation from field observations to assess storm damage to forests and other lands along the length of Helene’s impact area, from its landfall in the Florida Panhandle to its eventual dissipation in southern West Virginia. Impact severity was classified into four types:

- Type 1: Extreme NDVI change (<= -20) and in patches greater than 0.1 ha; typically associated with complete stand blowdown, or partially blown down stands with a major increase in CWD.
- Type 2: Moderate NDVI change (<= -13); may include small gaps of extreme blowdown <= -20.
- Type 3: Low NDVI change (-6 to –12); normally an indication of isolated gaps and/or minor crown damage, may also represent leaf stripping from wind.
- Type 4: No or minor impacts from the storm.

We overlaid HiForm’s raster dataset with the GRGL raster and plot map in ArcGIS Pro, and a spatial join was used to associate storm damage severity with individual plot locations. Data from this join function was then extracted for analysis.

We found that most Hurricane Helene impacts to plots at GRGL (54%) were classified as Type 4, with little or no apparent damage (Table 4.1). Impacts to 31% of plots were classified as Type 3, displaying isolated gaps and/or minor crown damage at the time of assessment. The most severe impacts within GRGL treatments were classified as Type 2, and impacted 15% of the study area. Thirty-two percent of MB plots had Type 2 damage, and 56% percent of plots with Type 2 damage were MB. No Type 1 impacts were located within the study area at GRGL. For the purposes of this study, the term “storm-impacted” shall refer to plots assessed at impact severity Type 2. Therefore, 15% of the GRGL site is considered “storm-impacted” as pertains to fuel loading.

At GRGL, damage severity was greatest within treatments with the lowest overstory density and least in treatments with the greatest overstory density (p=<0.0001). The MB treatment was broadly occupied by early successional forest vegetation in late 2024 and saw the highest incidence of high severity impacts. Thirty-two percent of MB plots had Type 2 damage, and 56% percent of plots with Type 2 damage were MB. The C treatment remains mostly mature, closed canopy forest, which experienced little to no severe storm damage.

4.2.2 Black Cove Wildfire Complex impacts

Impacts of the Black Cove Wildfire Complex at GRGL were preliminarily assessed by overlaying the North Carolina Forest Service (NCFS) fire progression map with our treatment and plot map in ArcGIS Pro. A spatial join was then used to classify plots as either burned or not burned based on their inclusion or exclusion from the wildfire perimeter, and this classification was checked against field observations of conditions at each plot. The progression map provided the dates during which specific areas were impacted by the wildfire, allowing extraction of substantial information regarding weather and fire danger conditions at the time of impact for each plot (Table 4.2).

Following the wildfire, in May 2025, efforts were made to complete the wildfire’s work in some of the areas excluded by suppression operations. The majority of Replication 1, which had been excluded from the Black Cove Wildfire Complex, was treated with low intensity prescribed fire on May 6, 2025, under less volatile weather conditions than occurred during the Black Cove Wildfire Complex. In addition to burn status, each plot was classified by burn type. Plots confirmed to be impacted by wildfire were classified with burn type WF in our dataset, while those within the prescribed burn perimeter, and confirmed to have been impacted by that burn, were classified with burn type RX.

The SDA Fire Environment Mapping System (FEMS) provides fire weather and fire danger data from over 2,000 Remote Autonomous Weather Stations (RAWS) across the United States (Wildfire.gov). For fire weather and fire danger analysis, we selected the Guion Farm RAWS, located approximately 24.1 km from the site, in Hendersonville, NC. Fire weather and fire danger data were extracted for each date during which our plots were impacted by fire, and that data was associated with each plot based on its date of burn. To facilitate percentile analysis of these metrics, we extracted hourly weather and fire danger data from the station for every day of every year since 2005. This data was used to determine 80th percentile weather conditions in keeping with those considered for FFSS objectives (Stevens 2009). The same 80th percentile threshold was considered for common National Wildfire Coordinating Group (NWCG) fire danger metrics at each site.

Among the plots measured, 89% were confirmed to have experienced either wildfire or prescribed fire in 2025 (Figure 4.2, Table 4.3). Sixty-four percent of fire-impacted plots were confirmed to have burned by wildfire, while 25% were burned by the May 2025 prescribed fire. Of the remaining plots, 8% experienced no fire at all, and 3% of all plots were observed to have been partially burned. Fuel transects in partially burned plots generally did not include a significant portion of the burned area within these plots.

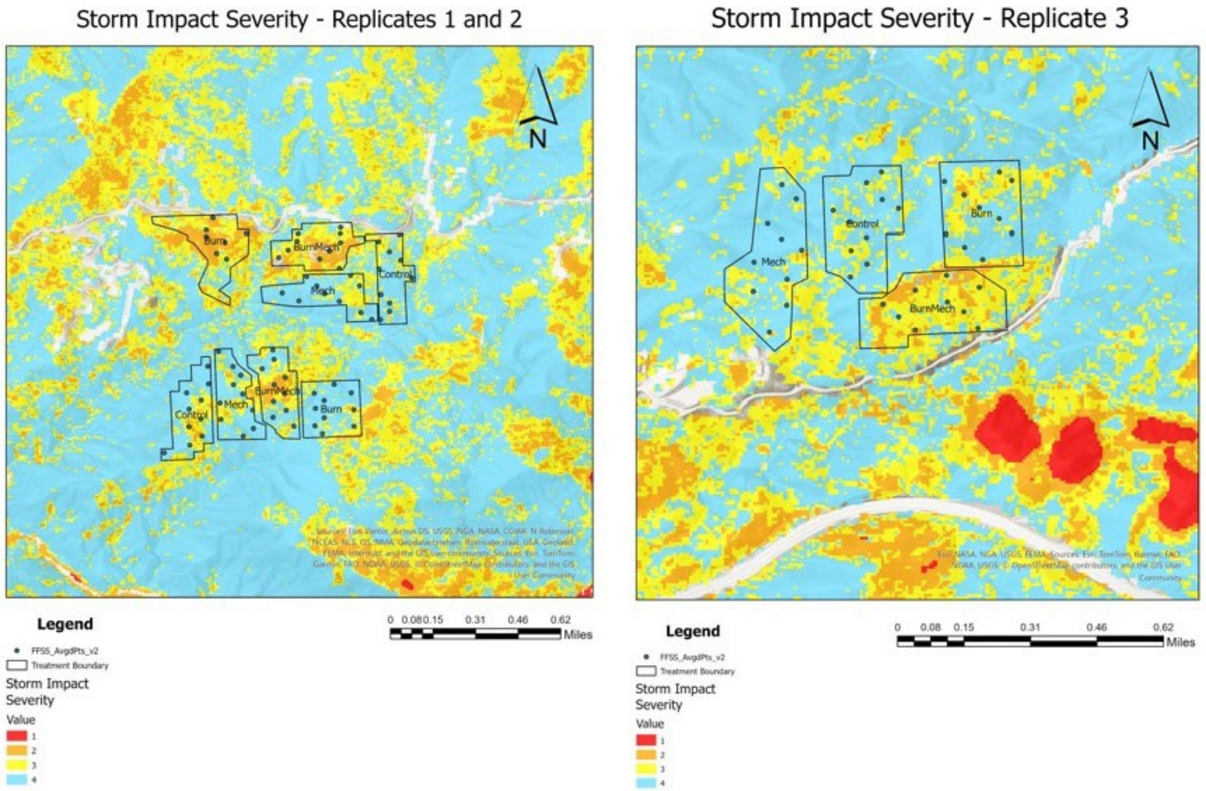


Figure 4.1 Hurricane Helene impact severity within the treatment area of the Green River Game Land, Hendersonville, NC, USA.

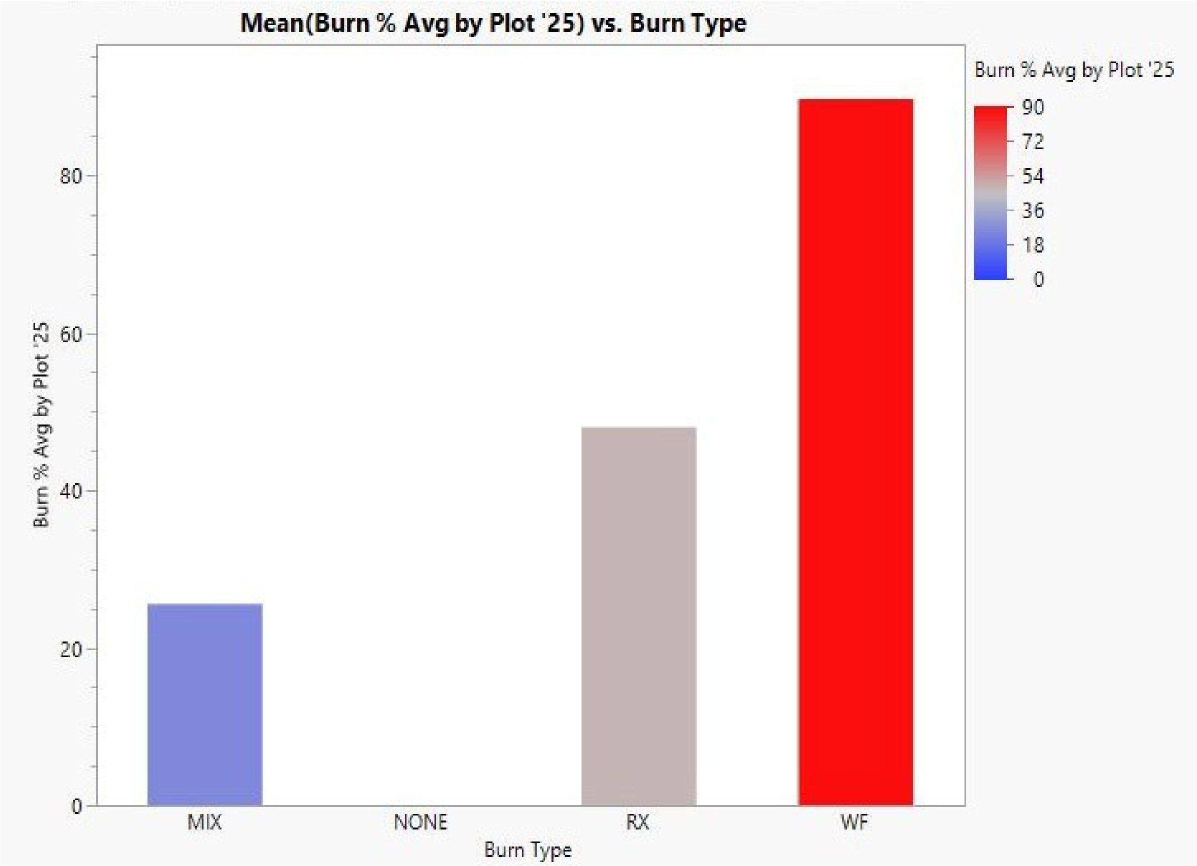


Figure 4.2 The percentage of plot area impacted by burn type the Green River Game Lands, Hendersonville, North Carolina, USA. 'WF' represents plots burned by wildfire. 'RX' represents plots burned only by prescribed fire. 'MIX' represents plots partially burned by wildfire.

Table 4.1 The percentage of plots located at the Green River Game Land (Hendersonville, NC, USA) affected by the storm severity types produced by Hurricane Helene (HiForm Hurricane Helene Rapid Assessment - Christie & Norman, 2024)

Storm Severity Type	**Percentage of Plots Impacted (%) n=111**
1 (Highest)	0
2	15
3	31
4 (Lowest)	54

Table 4.2 Mean fire weather and fire danger values for the Green River Game Land during the Black Cove Wildfire Complex (March 2025) and the May 2025 prescribed fire. Values meeting the Fire and Fire Surrogate Study 80th percentile thresholds are shown in red.

Fuel/Weather Parameter	**March 22**	**March 24**	**March 28**	**March 29**	**May 6**
Keetch-Byram Drought Index (KBDI)	55.00	70.33	102.00	111.33	22.33
Energy Release Component (ERC)	31.00	26.02	35.20	30.80	13.09
Burning Index (BI)	19.03	12.17	19.30	16.07	8.03
Spread Component (SC)	1.82	1.03	1.64	1.24	0.88
1-hr Fuel Moisture (%)	7.98	17.09	9.34	14.88	19.29
10-hr Fuel Moisture (%)	9.65	16.17	9.80	13.45	17.43
100-hr Fuel Moisture (%)	13.87	12.97	12.34	12.38	18.77
Live Woody Fuel Moisture (%)	60.00	69.67	87.67	93.33	174.00
Live Herb Fuel Moisture (%)	30.67	46.33	73.67	83.00	209.33
Temperature (°C)	10.83	13.73	14.72	15.63	12.80
Relative Humidity (%)	27.04	56.17	35.88	60.50	69.54
Wind Gust Speed (km h^{-1})	19.52	19.44	14.89	18.51	11.88

Table 4.3. The percentage of plots impacted by wildfire or prescribed fire in 2025 on the Green River Game Land, Hendersonville, NC, USA.

Burn Status and Type	**Percentage of Plots Affected (%) n=111**
Burned	89
Not Burned	8
Partially Burned	3
Burned by Prescribed Fire	25
Burned by Wildfire	64

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