Addressing Wildfire Hazard in Mount Spokane State Park

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Abstract

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Keywords: wildfire, land management, fire regime, forest vegetation simulator, FFE-FVS, woody fuels, fire hazard, fire behavior, eastern Washington, Mount Spokane, state parks

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As the climate warms, extreme disturbance events are demarcating a new normal which is apparent when looking at the change in fire regimes from historical conditions. With the prevalence of wildfire across the West, land managers like the Washington State Parks and Recreation Commission (WSPRC) are concerned about the implications this new normal brings to the table. Mt. Spokane State Park, one of the largest under their jurisdiction, is a park of concern for wildfire not only because of its size and location, but its diversity in forests and human usage. Over the course of two summer field seasons, 151 plots were established across the park to address the historical context, current risk and future implications wildfire brings to Mt. Spokane State Park. To question: (1) What is the historical context of fire in the area and what past fire events have happened in and around the park?; (2) What does the park look like on the ground currently?; and (3) How would that change over time under different fire and management scenarios? To answer these questions site, ground fuel, tree, and tree core data were collected at every plot when able to be used with a family of forest simulator models developed by the USFS, the Forest Vegetation Simulator otherwise known as FVS with the Fire and Fuel Extension (FFE-FVS). With FVS, simulations were run on plot data both individually and in USNVC groupings to look at what would happen when you do or do not add fire to two different approaches, do nothing or do something with a management prescription over the course of 60 years on potential wildfire. Through analysis of structural, fuel, and fire outputs of interest over time as well as literature research and tree cores, presence of past fire activities, areas of high fire hazard and treatment effectiveness were identified. Of the 62 tree cores harvested across the

park, only four had fire scars indicating the park has had small fire events in the last 100 years, but due to thorough past harvesting, determining historical fire conditions through just this methodology was not possible. The plots belonging to USNVC grouping, Northern Rocky Mountain Mesic Montane Mixed Conifer Forest, are of priority for management treatments due to high flame lengths and higher potential for crown fires. This grouping was also statistically different in many of the FVS outputs of interest when compared to the other groupings. Simulated thinning and slash treatments can reduce the probability of active crown fires, especially after removing at least 40% of the basal areas of trees under 20 inches in dbh with its effects lasting decades. It was not as effective when looking at stand structure and fuel variables over time when comparing fire scenarios that did and did not include management as many of the variables that were significantly different in 2039 were not so 20 to 40 years later indicating a need for recurring management. Mt. Spokane's simulated dominant fire type over time following the do nothing scenario was conditional crown fire. It indicates two outcomes for stands with this fire type; surface fire behavior, if fire were to enter the stand as a surface fire; or active crown fire, if fire were to enter the stand as a passive or active crown fire. The goal of this work is to provide land managers information on fire hazard and forest conditions through on the ground data, modeling with FVS, and satellite imagery, which can assist with future management decisions.

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Meiner Mutter, meinem Vater und meiner Familie gewidmet, denn ohne sie wäre nichts davon möglich gewesen.

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Introduction

As the climate warms, extreme disturbance events are demarcating a new normal which is apparent when looking at the change in historical fire regimes (Agee, 1998; Higuera et al., 2021; Morgan et al., 2001). With the prevalence of wildfire across the West, land managers are concerned about the implications this new normal brings to the table (DNR, 2019). Those in the Washington State Parks and Recreation Commission (WSPRC) are looking ahead to the future for how they can manage their parks in an ever changing world with the many different elements needed for consideration. One of those parks that managers are concerned with is Mt. Spokane State Park, one of the largest and heavily visited in the state, located in the Selkirk Mountains just north of the city of Spokane, Washington (WSPRC, n.d.). WSPRC was founded in 1913 making it older than the National Park Service and has grown to over 140 state parks, historic sites, trails, marine parks and properties that they manage across the state (WTA, n.d.). WSPRC mission is catered more to the needs of Washingtonians and described as to care, "...for Washington's most treasured lands, waters, and historic places. State parks connect all Washingtonians to their diverse natural and cultural heritage and provide memorable recreational and educational experiences that enhance their lives" (WSPRC, n.d.). In this mission, a responsibility to protect significant natural, cultural, and recreational resources within the park as well as the safety of its visitors.

With record fire seasons in the last two decades, efforts have been made to have effective and cohesive management to create resilient landscapes, fire-adapted communities, and prevent and/or reduce severity of wildfires (DNR, 2019; Lasko, 2010; Schoennagel & Cara, 2011). The awareness to manage fire both inside and outside protected areas like Mt. Spokane has grown (DeMeo et al., 2018). Described in the 20-Year Forest Health Strategic Plan for Eastern Washington published by Washington State Department of Natural Resources (DNR), Mt. Spokane State Park is located in a higher priority planning area for potential treatment to improve ecosystem resilience and reduce risks of uncharacteristic wildfires labeled under Tier 1, Forest Health, and Tier 2, Values at Risk (DNR, 2018). This priority planning area, the Mt. Spokane Planning Area, encompasses 121,767 total acres, with over 93,000 acres of that considered forested. Being so many acres, the planning area has a variety of stakeholders divided up as follows with small private (60%) and private-industrial (24%) being the predominant owners along with some Washington State Parks (10%), and DNR trust lands (6%) ownership of forest lands (DNR, 2018; Figure 1). Four priorities were established for this area taking into account all stakeholders as follows… "1) Increase safety and fire protection for homes and communities; 2) Increase resilience to drought and wildfire by creating open canopy forest with resistant tree species and a large tree component; 3) Sustain wood production objectives on private and DNR land; 4) Enhance habitat and recreational values in Mt. Spokane State Park" (DNR, 2018). For the forests in and around Mt. Spokane State Park, there was a recommendation of treating an estimated 5,500-10,000 acres to break up the large dense forest patches to reduce crown fire risk and assist in fostering forests that can adapt to climate change To do so, a combination of treatments would be necessary (DNR, 2018).

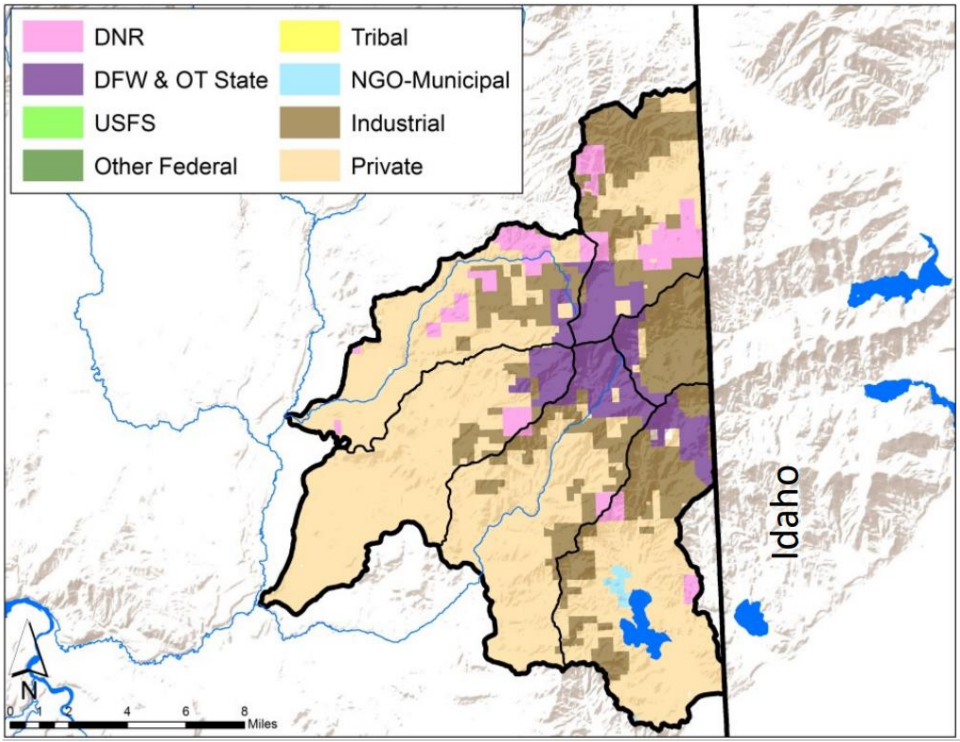

Figure 1. Land ownerships across the Mount Spokane Planning Area established by the Washington Department of Natural Resources calling for 27-41% of the forested acres within to be treated to achieve established priorities and landscape goals (DNR, 2018).

These priorities become even more important with the increasing number of people moving into the wildland urban interface and the relative closeness of the park to the city of Spokane (Robbins & Wolf, 1994; Figure 2). This increase in population is a concern as not only worldwide human activities are responsible for most wildfire ignitions, but if a fire started, there could be significant loss to property and life (FAO, 2007; Gude et al., 2008). Any fire events happening in and around the park could have a significant impact on the inhabitants around near and far. Even without wildfires happening close by, Spokane still gets inundated with smoke for a few days nearly every year causing unhealthy air quality conditions from fires all across the state along with Canada, Oregon, and Idaho as well (Glover, 2017). These fires have unequal impacts to vulnerable populations like the elderly, disabled, and people of color within Spokane county. This is a concern as Spokane, Washington, the largest city in the county, has a higher wildfire hazard potential than 93% of communities in the state with the county itself having a wildfire risk greater than 70% of counties in the U.S. (Headwater Economics, 2021; Scott et al., 2020). This makes fuel-reduction treatments catered to how complex fire and our forested landscapes are more and more important (Stephens et al., 2012).

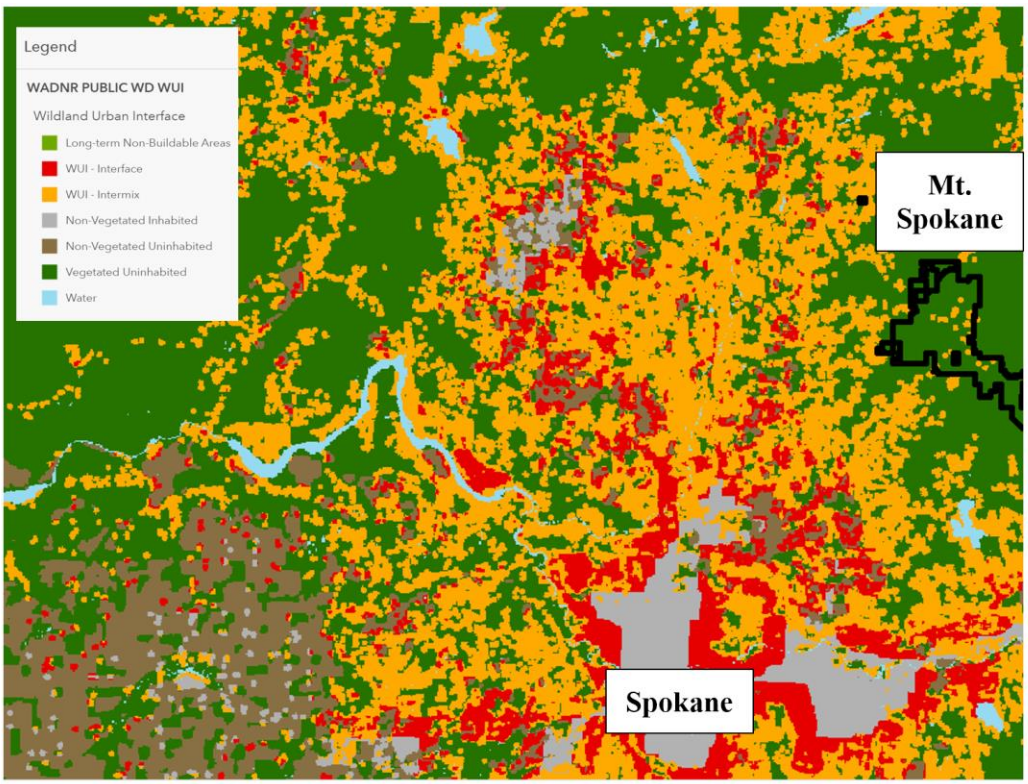

Figure 2. Wildland Urban Interface (WUI) of the landscapes surrounding Mt. Spokane State Park (OpenData WADNR, 2020).

To do so, knowing the past is important as it explains why eastern Washington's forests and more specifically Mt. Spokane's are in need of fuel-reduction treatments to prevent similar outcomes from the large wildfire events that have happened across Washington state (Wilma, 2023). Fire exclusion, land use practices and development across the West has led to great changes in the landscape in a relatively short period of time due to population increases and technological advances (Lehmkuhl, 1994; Robbins & Wolf, 1994). Before the presence of settlers, the Inland Northwest region had fire events caused primarily by lightning and indigenous burning that were often of low and mixed severity, but could be large in size with the effects varying by forest type (Arno, 1998; Wilma, 2003). Fire history data in this region primarily from fire scars suggested fire activity was prolific every decade or two from the mid-1500s until fire suppression policies were implemented in the early 20th Century (Barrett et al., 1997). Fire chronologies in the Northern Rockies based upon old-growth fire scars indicated that fire intervals were shorter in areas of high indigenous use and even augmented lightning fires in some forests (Barrett & Arno, 1982). In the Northern Rockies in particular, climate is a strong driver for these widespread historical fire events that occurred in years that had warm springs followed by warm, dry summers. These widespread events were in years with positive Pacific Decadal Oscillation and with future climate projections, years of widespread fire are likely to continue to occur (Morgan et al., 2006; Morgan et al., 2008). Through this intensive land use change though, this relationship between drought and fire occurrence was disrupted (Mckenzie et al., 2004).

With eastern Washington's forests being so diverse ranging from the high return interval ponderosa pine dominated forests to the low return interval subalpine fir forests higher in elevation with fire exclusion, these changes have overloaded many forests with fuels (Arno, 1998). From the suppression of fire and intensive harvesting practices of the past, the threat of even-aged stands and encroachment of species moving into spaces they were not in before, such as grand fir, can make the forests more susceptible to larger and more severe fires (Arno, 1998). Even with this increased wildfire activity happening though, there is still a fire deficit in this country due to the intensive fire suppression efforts, widespread livestock grazing, and lack of traditional burning starting in the late 1800s impacting fire regimes with the additional stressor of climate change (DeMeo et al., 2018; Haugo et al., 2019; Marlon et al., 2012). One such event contributed to changing the course of fire management practice to complete suppression. That was the Big Blowup in 1910 which over the course of two days devastated the west burning over three million acres of forests. Parts of this large fire event occurred close to Mt. Spokane in nearby Newport, Washington and Coeur d' Alene, Idaho right across the state line (Spencer, 1956; Yablonski, 2022).

In the context of Mt. Spokane, knowing the human history of the park is important as it assists in explaining how it became a priority planning area for potential treatment to improve ecosystem resilience and reduce risks of uncharacteristic wildfires (DNR, 2018). Before Mt. Spokane was the state park that it is known as today, it was and still is an important gathering place for local indigenous peoples for beargrass and huckleberry. The summit of the mountain is also regarded as a spiritual pilgrimage site (Luttrell, 2000). With the settlement of the west, federal land grants were given to railroad companies starting in the 1860s to finance the lines with Northern Pacific being the one to own much of what is considered to be the state park today (Arksey, 2006; Robbins & Wolf, 1994). Much of it remained in its hands until the turn of the century when it started to be sold to settler, corporate, and timber industry interests. In this turnover, most of the lower elevation forests were harvested over a thirty year period with the largest timber owner, the Panhandle Lumber Company out of Spirit Lake Idaho, harvesting much of the eastern flank (Arksey, 2006). The mountain received its current name of Mt. Spokane in 1912 after the purchase of the summit from Francis Cook in 1909 who began building the first road to the summit (Rebstock, n.d.). Mt. Spokane later became a state park in 1927 being the first east of the Cascades with an initial size of 1,500 acres steadily growing in size over the years.

The Civilian Conservation Corps (CCC) had a heavy presence in the park between 1936-1940 building roads, trails, and structures that are still in use today (Arksey, 2006).

With winter sports becoming more popular and visiting the mountain more accessible, there was a conservation push in the 1930s to reduce timber harvesting with one of the concerns being the impacts of slash left behind in regard to wildfire after the devastating destruction caused by the 1910 fire aided by slash. Residents in Spokane also still had the devastating fires of 1889 that burned over thirty blocks of the downtown area in their minds on top of other devastating fires events happening in Seattle and the forests close by in and around nearby Coeur d'Alene that same year (Arksey, 2006; Graham et al., 1999; Harbine, n.d.). Fire monitoring and reducing potential fire risk became more popularized. In 1932, a fire lookout was constructed at Mt. Spokane with its final iteration staffed until 1994 reporting record amounts of wildfires with its panoramic views of the city of Spokane, Canada, and Northern Idaho (Willhite Webs, 2023; Arksey, 2006). It could not come at a better time when a lightning strike caused fire broke out on the east flank of the mountain, escaping park boundaries and taking out the Panhandle Lumber Company's Spirit Lake Sawmill in 1939 (Arksey, 2006; Cowles, 1939). Outside of this fire event, available records show Mt. Spokane State Park has only had small escaped campfires and lightning-caused fires in the last 100 years that were quickly extinguished. One close call in which the park escaped harm was from the 92 separate predominately grass fire event called the Spokane Firestorm in 1991 that burned several homes (Wilma, 2023). Although not as close to the park as the Spokane Firestorm was, another wind driven fire event happened just this past summer in Spokane County with 20,000 acres burned and 265 structures destroyed (Wohlfeil & Sanford, 2023) Around Mt. Spokane State Park, the forests surrounding the park near and far have unfortunately not been as lucky in not having large fire events which is why it is such a concern for the park currently and in the future (Figure 3).

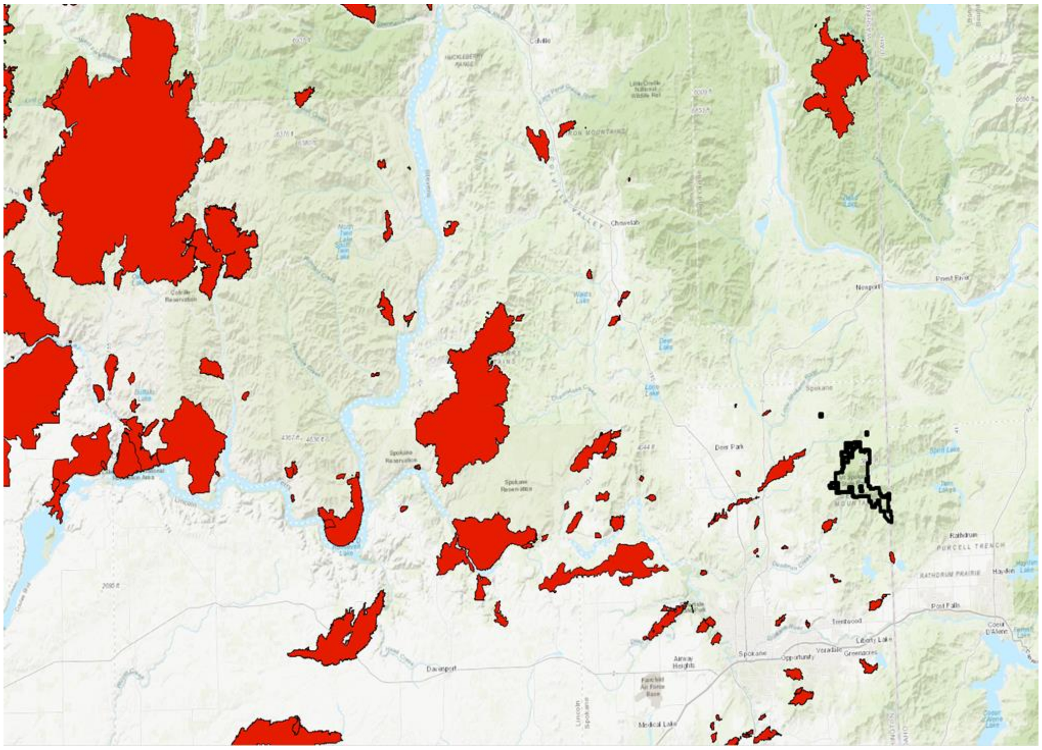

Figure 3. Washington wildfires that have burned more than 100 acres around Mt. Spokane State Park from 1973-2019 (OpenData WADNR, 2019).

As Mt. Spokane State Park is located in a priority planning area and with the increasing threat of large fires, there is a need to have more information related to potential wildfire specific to the park to inform future management decisions (DNR, 2018). Limited studies have been done related to fuel and fire risk in Mt. Spokane State Park. One past study used geospatial and field data to use the Fuel Characteristic Classification System (FCCS) software to determine fire risk and fuel load potentials. The results of that work determined Mt. Spokane had a high fuel load and fire risk potential (Alvarado & Blazina, 2017). In terms of past fuel reduction treatments, small scale treatments have occurred in the park with a focus along North Mt. Spokane Drive

(Highway 206), with the goal of moving treated stands to be healthier and fire safe as well as ensuring the ability to evacuate more easily if a fire event did occur. Enacting large scale treatments are often difficult, especially with the unnatural forest structures and high fuel loads due to fire exclusion because of cost and public perception with how actively used the park is (Calkin & Gebert, 2006; Stephens et al., 2012). Planning them though is hard because forest types and their treatment needs vary, requiring site specific prescriptions (Vrablick, 2009). With the lack of studies in the park related to wildfire to better inform future management decisions, an effort has been made to map fire hazard in Mt. Spokane utilizing fire analysis tools (Miller & Ager, 2013).

In this study, the overarching objective was determining the historical context, current risk and future implications wildfire brings to Mt. Spokane State Park. In doing so, informing managers of fire hazard in the park through on the ground data, modeling, and satellite imagery that can assist in future management decisions to improve forest resilience and prevent a catastrophic fire event going through park property and potentially adjacent WUI (Figure 2). Three research questions were asked based on this objective: (1) What is the historical context of fire in the area and what past fire events have happened in and around the park; (2) What does park forest structure and composition look like on the ground?; (3) How would that potentially change over time under different fire and management scenarios?

Methods

The methods for this work are presented below, separated into five main sections: (1) First section introduces the study site, Mt. Spokane State Park, including location, general information, and vegetation found in the park.; (2) Data collection, detailing plot design, site selection, and what was collected at every plot.; (3) Data preparation, outlining the process to turn paper datasheets into usable data for analysis.; (4) Data analysis section introducing the Forest Vegetation Simulator (FVS), what parameters were set to run four different scenarios, and the outputs of interests chosen from running these simulations; (5) Statistical analysis methods used for output data produced by using FVS.

Study Site

Mt. Spokane is one of the largest state parks in the state of Washington and is located right along the Washington-Idaho border, approximately 30 miles north from downtown Spokane (WSPRC, n.d.; Figure 4). The mountain itself is the southernmost in the Selkirk range, which is older than that of the Cascades or Rocky Mountains giving it a more rounded shape due to the thousands of years of weathering that it has endured (Arksey, 2006). Mt. Spokane has a summit of 5,883 feet (1793.138 meters) and a size encompassing approximately 12,444 acres. This state park provides a variety of outdoor activities all year round and forest types to see with its over 100 miles of trails (WSPRC, n.d.). The mountain houses Mt. Spokane Ski and Snowboard Park with facilities and ski runs down multiple sides of the mountain. Even with the year round outdoor activities offered that keep visitors frequenting the park, it is home to large mammal species like moose, deer, cougars, coyotes, and black bears of which many were seen during the collection of data for this study.

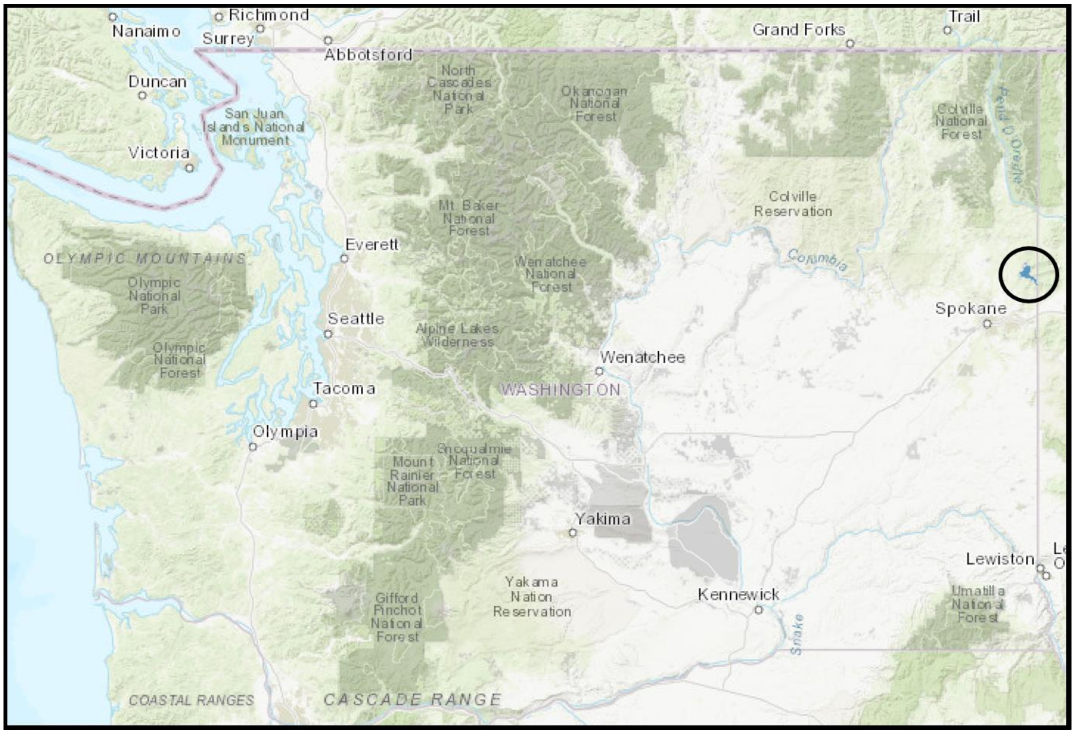

Figure 4. Mount Spokane State Park (circled) located in northeastern Washington along the Washington-Idaho border.

Mt. Spokane also houses a plethora of vegetation communities with young to mature mixed conifer forests being the dominant cover type (DNR, 2018). *Pinus ponderosa* Lawson & C. Lawson var. *ponderosa* C. Lawson (ponderosa pine) dominates the forests seen along the drive to the park entrance, but most stands within the park are a mix of several species with only a splattering of ponderosa pine located on the western side of the park. In Mt. Spokane, the most common tree species are *Larix occidentalis* Nutt. (western larch), *Thuja plicata* Donn ex D. Don (western red cedar), *Tsuga heterophylla* (Raf.) Sarg. (western hemlock), *Pseudotsuga menziesii* (Mirb.) Franco var. *Menziesii (*Douglas-fir), *Abies grandis* (Douglas ex D. Don) Lindl. (grand fir), *Pinus monticola* Douglas ex D. Don (western white pine), *Pinus contorta* Douglas ex Loudon (lodgepole pine), *Picea engelmannii* Parry ex Engelm. (Engelmann spruce), *Abies lasiocarpa* (Hook.) Nutt. (subalpine fir), *Acer glabrum* Torr. (Rocky Mountain maple), *Alnus* *viridis* (Chaix) DC. ssp. *sinuata* (Regel) Á. Löve & D. Löve (Sitka alder), and *Populus tremuloides* Michx. (quaking aspen) (Franklin & Dyrness, 1973; USDA, 2023; Van Pelt, 2018). Vegetation and habitat assessments have been done in the past on some of the unique communities within the park like the high elevation conifer meadows. Only five meadows greater than 5 acres in size occur within the park, while next to none occur outside the park in the region (Smith IV, 2009). In 2010 before a ski run expansion, biological surveys were conducted to assess vegetation composition and habitat conditions for wildlife in an approximate study area of 3,814 acres. They found over 258 vascular plant species and 55 different plant associations (Morrison & Wooten, 2010). With the diversity in vegetation communities, elevation, and aspect, it does not have one historically based fire return interval or fire intensity expected for the whole park. With forest ecosystems representative of the Northern Rocky Mountain region, higher elevations stands are classified as a stand replacement fire and lower elevation stands being more likely to be mixed-severity fire with return intervals from 35 to 400 years range due to this diversity. (Agee, 1993; Campbell & Liegel, 1996; FEIS Staff, 2012; Heinselmann, 1981; DeMeo et al., 2018). Having this diversity in historical fire regime variability has promoted the growth of multi-aged stands in Mt. Spokane although that has been impacted by past intensive harvesting activities and development in the park (Arksey, 2006; Arno et al., 2000).

Data Collection

To collect data, I established 151 plots across the park looking at site, ground fuel, tree, and tree core data with a permanent rebar plot center. The data collected was primarily dependent on FVS as well as to provide a baseline if plots were remeasured in the future. To determine where to put these plots, 2000 random points were generated across the park with the parameters of having to be at least 100 feet from the park boundaries and 200 feet away from each other (Figure 5). This was done to prevent any unintentional overlapping of plots as well as to not to work outside the park boundary to reduce potential edge-effect from neighboring properties (Porensky & Young, 2013). The 151 plots established from the 2000 randomly generated ones were selected based on three different criteria: accessibility and safe access, having plots located in varied locations within park boundaries, and plots that represented the different dominant U.S National Vegetation Classification (USNVC) types located within the park.

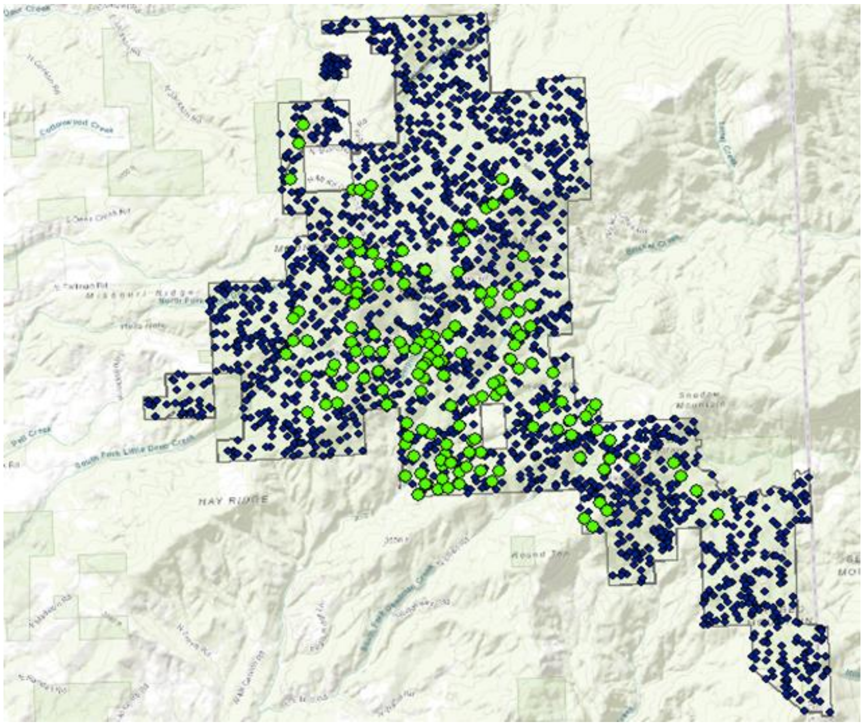

Figure 5. 2000 randomized points (purple squares) were generated across the study site of Mt. Spokane State Park with 151 points (green circles) selected to create plots looking at site, tree, and fuel variables.

A nested plot design concept similar to Forest Inventory Analysis (FIA) protocols was selected to reduce the sampling effort for smaller trees in favor of larger trees as they contribute a greater share to the total volume of the plot. This was also done to reduce the time needed to sample each plot (Kershaw, 2016; USFS, 2005). The three nested plot sizes were a circular microplot (6.8ft radius) looking at seedlings below breast height by species, a subplot (18.6ft radius), and a macroplot (37.2ft radius) plot with diameter at breast height (dbh) thresholds of less than or equal to 5 inches and greater than 5 inches respectively were used to collect tree data (Figure 6). The threshold between the subplot and macroplot was chosen because trees larger are classified as either pole timber, and smaller trees are classified as seedlings or saplings in the FIA program (Lin et al., 2020). Then from every plot center, three 72ft fuel transects were laid out 120° apart from one another with an initial random azimuth selected using a compass (Figure 6). At every plot center, slope, azimuth, aspect, GPS location, elevation, two plot photos, five dominant understory vegetation species, and notes descriptive of the plot were recorded. Some of the site data recorded at each plot was used as inputs in FVS, but more importantly was used as a reference to have more detailed information on site conditions.

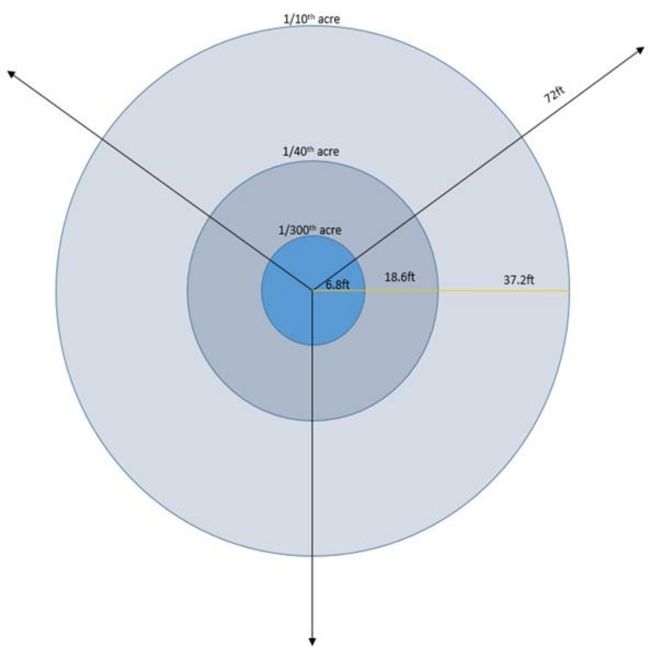

Figure 6. Nested plot design used in the 151 plots established across the park.

After the plots were laid out by the three fuel transect tapes and site data was collected, ground fuel data was next to be collected to maintain minimum disturbance to the fuels located on the transect line to provide an accurate estimate following protocols modified from Brown (Brown, 1974). Seedling counts were the first to be done in the microplot (6.8ft radius) distinguishing them by tree species. Along each fuel transect line, 1000-hour (72-6ft), 100-hour (72-60ft), 10-hour (72-66ft), and 1-hour (72-66ft) fuels were tallied using a clicker to count each size class accurately. A Go-No-Go gage was used to distinguish the different standard size classes when counting, as established by Brown (Brown, 1973). 1000-hours fuels had their tree species, dbh (in), decay class, and notes if there were any signs of past fire activity recorded. The time-lag value represents the approximate time that size class of fuel takes to reach 63% in the way to reach equilibrium between its initial moisture content and its current environment. The shorter the time lag, the more responsive the fuel is to changing weather conditions (Wade, 2013). Decay class values ranged from 1 to 5 with class 1 being a freshly downed log and class 5 being buried under the litter layer log that has lost its structural integrity (Maser et al., 1979). Litter and duff measurements were taken in millimeters at 62 ft and 52 ft measurement at each transect line. These measurements were taken at the end of the transect line furthest from the plot center going in to prevent trampling of fuels and repeated for each fuel transect. A total of 423 fuel transects were measured with 10 plots not having their ground fuels measured due to early snowy conditions in the 2019 field season.

In the established circular subplot (18.6ft radius) all trees were measured while in the macroplot (37.2ft radius) only trees with a diameter at breast height (dbh) greater than 5 inches were measured. A laser hypsometer was used to check horizontal distance from plot center to the tree to validate if a tree was in or out of the plot. For every tree measured, species code, dbh (in), status (live/dead), decay class if dead, height, canopy base height (cbh), crown ratio (%), and notes were recorded. Decay classes were assigned with numbers ranging from 2 (declining) to 7 (decomposed) (Maser et al., 1979). Tree measurements taken were based on the basic requirements needed for FVS which included species, dbh, and height along with additional variables to provide a baseline for potential remeasurements in the future for monitoring the forests of Mt. Spokane (Dixon, 2002; Johnson et al., 2007; Kershaw et al., 2016). A total of 6275 trees were sampled in the 151 plots established.

At every plot, there was an effort to core one tree although it was not always successful. This was due to decay of the tree center, below freezing temperatures that made coring difficult, and no trees that were larger than 20 inches in dbh in the plot of the preferred coring species. Trees were cored at diameter breast height (4.5ft) on the upslope side of the tree with a Haglof increment borer aiming for the pith (Figure 7). Douglas fir, western larch, and true firs with a dbh of 20 inches or greater were the intended targets to core to look for signs of previous fire activity due to ease of coring and were more successful in producing a full core without a break. After tree cores were harvested, they were stored into paper straws and later glued and mounted. For each core, information recorded included plot number, species code, dbh, what side was the bark and what side was the pith, and if any of the core had disintegrated due to the tree being rotten in the center. Tree coring protocols were similarly followed as described in Stokes & Smiley (1996) in the field. Additional measures were taken as well to prevent the risk of disease spread between trees in addition to reducing the need for additional coring (Dean et al., 1973, Stokes & Smiley, 1996; Tsen et al., 2016). All tree cores were mounted and aged on site at Mt. Spokane and then sanded using the facilities at the University of Washington's Pack Forest with

62 complete tree cores aged (Figure 7).

Figure 7. Images illustrating the tree coring process by taking initial measurements of the tree of interest which was a western larch in this case, using a Haglof increment borer to collect the core, and finally sanding the mounted and labeled core at Pack Forest in Eatonville, Washington. Photo Credit: Mark Stone.

Data Preparation

After all the data was collected at Mt. Spokane State Park on paper datasheets in the field, that data had to be organized and prepared in a way to be able to be entered in FVS and for general evaluation. To do so, data was recorded into excel datasheets to start the preparation process. Due to the use of paper data forms, field data had to be confirmed for correctness, completeness, and consistency everyday after data collection as well as when transferring the data to a digital format. Field technicians were provided methodology guides along with keys to limit mistakes out in the field related to collection protocol and how data was to be recorded into the datasheet. To get the digitized data ready for FVS, plots were placed into USNVC groupings, woody fuel loadings were calculated for each fuel size class, and data formatted in a way that it could be run through FVS successfully.

USNVC Groupings

Plots were placed into grouping based off of the United States Vegetation Classification System (USNVC). Plots were stratified into sample groups based on the USNVC, parsing the data to better match the many vegetative communities and fire regimes represented in the park and allowing more site-specific data analysis and recommendations (Hoyt & Mercker, 2021). The four dominant vegetation groupings located in Mt. Spokane State Park were Northern Rocky Mountain Mesic Montane Mixed Conifer Forest, Northern Rocky Mountain Dry- Mesic Montane Mixed Conifer Forest, Rocky Mountain Subalpine Dry-Mesic Spruce-Fir Forest and Woodland, and Rocky Mountain Lodgepole Pine Forest in their prominence within the park from most to least (Figure 8; Table 1; Appendix A). Plots were placed into a grouping based on three factors. The number one factor is where the plot fell on the LANDFIRE's (LF) Existing Vegetation Type National Vegetation Classification (NVC) Remap 2016 layer (LANDFIRE Team, 2016). For this layer, the vegetation grouping selected for an area was determined by past field data collected, Landsat satellite imagery, and other inputs like elevation. The issue is that it is not always accurate when looking at the finer scale if there is no local field data associated for the area interested in (LANDFIRE Team, 2016). The two other factors looked at because of this issue were the tree data collected as well as the images that were taken in each plot to ensure it was representative of the descriptions for each vegetation grouping (Crawford & Rocchio, 2015).

Table 1. Plot distribution for the four dominant USNVC groupings within Mt. Spokane State Park with designated grouping number.

Grouping Title	Grouping Number	Plots
Northern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest	1	1948, 1968, 1977, 1998, 542, 543, 547, 556, 557, 6915, 6921 6922, 6923, 6924, 6934, 6936, 6951, 6952, 6948, 6958: **20 plots**
Northern Rocky Mountain Mesic Montane Mixed Conifer Forest	2	1944, 1945, 1946, 1947, 1949, 1950, 1952, 1954, 1955, 1956 1961, 1962, 1963, 1964, 1965, 1959, 1960, 1967, 1969, 1970 1971, 1958, 1976, 1978, 1979, 1980, 1992, 1993, 1994, 1995 1996, 1997, 1999, 2000, 526, 528, 527, 529, 530, 531, 532, 533, 534, 1981, 1982, 1983, 1984, 1985, 1986, 1987, 1988 1989, 1990, 535, 536, 537, 538, 539, 540, 541, 544, 545, 546 548, 549, 550, 552, 554, 555, 558, 559, 560, 561, 562, 563 1991, 6901, 6907, 6902, 6903, 6904, 6908, 6905, 6906, 6909 6910, 6911, 6913, 6914, 6926, 6927, 6928, 6929, 6932, 6930 6938, 6939, 6940, 6945, 6947, 6942, 6954, 6955, 6937, 6953 6956: **106 plots**
Rocky Mountain Lodgepole Pine Forest	3	1951, 1974, 551, 6916, 6919, 6920, 6912, 6946: **8 plots**
Rocky Mountain Subalpine Dry-Mesic Spruce-Fir Forest and Woodland	4	1953, 1957, 1966, 1973, 1975, 553, 564, 565, 6917, 6918, 6941, 6943, 6944, 6949, 6950, 6957, 1972: **17 plots**

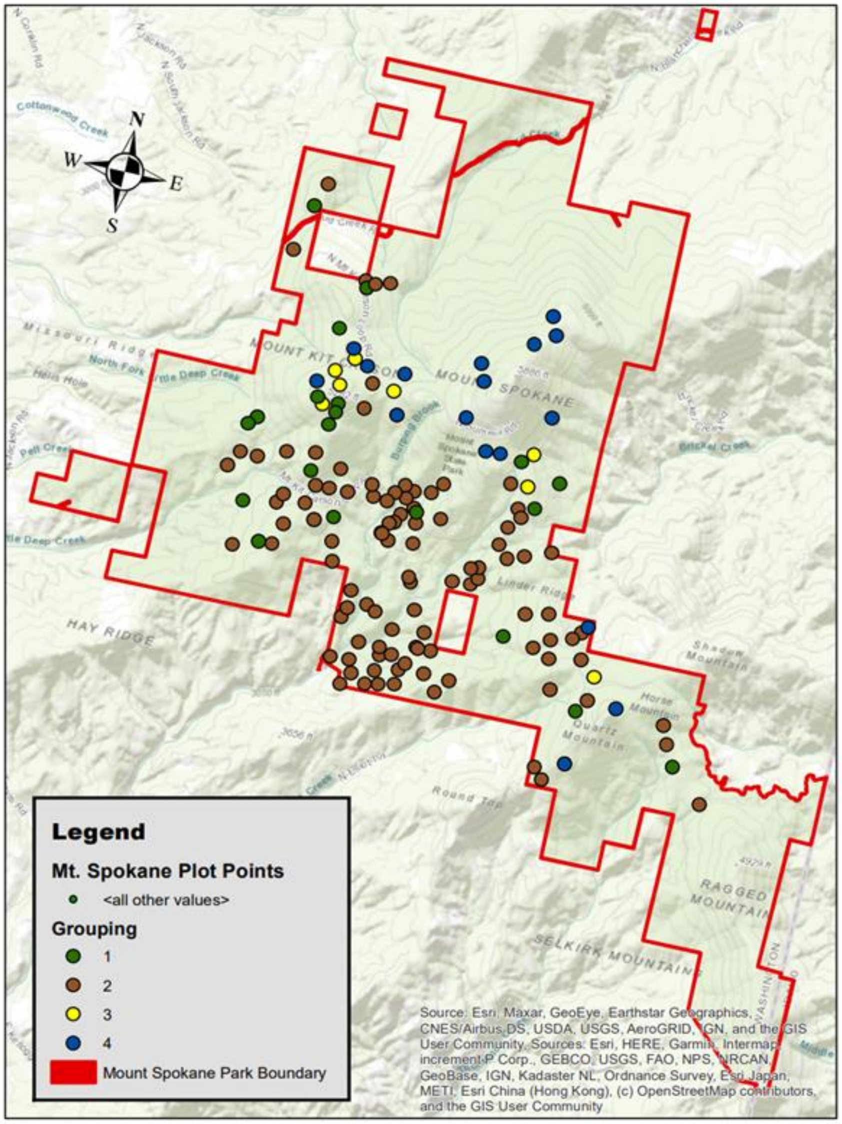

Figure 8. Plot distribution for the four dominant USNVC groupings within Mt. Spokane State Park. Grouping 2 plots are located primarily in the lower elevation forests. Grouping 1 plots are located more on the western slopes of the mountain. Grouping 4 plots dominated by subalpine fir were located at the highest elevations. Grouping 3 plots are located in higher elevation dominated by lodgepole pine.

Calculating Woody Fuel Loading

To include field measurements of surface fuels into FVS, fuel measurements for every plot needed to have their mean loading (ton/acre) calculated for each size and condition class. To do so, fuel data was organized into three different excel files to be run through the Woody Fuels

Calculator created by the Fire and Environmental Research Applications (FERA) team within the USDA Forest Service. Those excel files separated the fuel data into fine woody fuels (1-hour, 10-hour, and 100-hour fuels), course woody fuels(1000-hour fuels), and litter and duff measurements. A total of 141 plots of data were able to be analyzed in this method out of the 151 established due to snowfall preventing accurate fuel measurements for 10 of the plots in 2019. This calculator took equations from Brown (1974) as well as species-specific wood gravity values from Miles and Smith (2009). It was used to calculate mean fuel loadings (tons/acre) for each plot separated by their size and condition classes which is used in FVS (Anderson et al. 2003; Brown, 1974; Miles & Smith, 2009). This calculator also produces outputs looking at the number of fuel pieces total, mean quadratic mean diameter, and pieces per acre for each size and condition class as supplemental information that could be used for future analysis.

Formatting for FVS

To be able to enter plot data into the Forest Vegetation Simulator (FVS), it was formatted into an Access database and then linked to a suppose.loc file. The graphical interface used was Suppose v2.08 for FVS (FVS Staff, 2021). Collected data was organized into three different tables labeled FVS_PlotInit, FVS_StandInit, and FVS_TreeInit within the Access database that could be read into FVS (Seymour, 2007; Crookston, et al. 2022). Two Access databases were created with the plot data organized individually while the other organized in their USNVC groupings. Grouping 2 was split in half in the Access database using basal area as the variable to do so as FVS can only run 3000 trees in a single grouping and it had 4037 trees. The outputs of these two parts of Grouping 2 were later combined together and then averaged.

Data Analysis

After plot data was organized into Access databases, it was then ready to be entered into FVS. The Forest Vegetation Simulator (FVS) with the Fire and Fuels Extension(FFE) is what was primarily used for analysis (Rebain et al., 2022). FVS is a forest vegetation simulator growth model for predicting forest dynamics. It has been used for a variety of purposes which includes interactions with disturbance events like wildfire and insect outbreaks, determining suitable wildlife habitat, and looking at how wildfire or management has an impact on forest structure and composition over time (Dixon, 2002; Johnson et al., 2007, Johnson et al., 2020).

The FVS Fire and Fuels Extension (FFE) calculates potential fire intensity over time as a measure of fire hazard based on the tree and fuels data inputted (Beukema et al., 2003). With FFE-FVS, effects that fire and different management prescriptions have on fire potential and forest structure were simulated (Peterson et al., 2007). Out of all the tools available to manage and analyze vegetation and fuels, FVS was selected for the analysis due to its small spatial scale, flexibility, high data requirements to incorporate as much on the ground data as possible, and the many outputs to choose from (Anderson et al., 2020; Peterson et al., 2007). It has also been used intensively in studies simulating impacts of management both pre and post fire (Johnson et al., 2020). Finally, when looking at fire hazard, behavior models are often what is used for predicting surface and crown fire spread, propagation, and fire effects which FFE-FVS utilizes to do so (Miller & Ager, 2013; Rothermel, 1972; Van Wagner, 1977). Predicting when and where a large fire would happen in the park is impossible, but being able to determine where in the park is at most risk and what treatments would work best at reducing that risk is an option with the software (Thompson, 2012).

The Inland Empire variant was selected which determines which of the 14 established fuel models are used based on the fuel loadings and stand characteristics provided (Johnson et al., 2007; Burgan & Scott, 2005; Rothermel, 1972). The Inland Empire variant was originally developed in 2003 and it takes tree growth, mortality, and volume equations representing eastern Washington, western Montana, and northern Idaho tree species. This variant recognizes 21 different species plus two other composite species categories. Any species not recognized in this variant, of which there are a few measured in this work, are mapped to a similar species in the variant (FVS Staff, 2021).

Organized into the proper Access database file both in groupings and the plots singularly, plot data was put under four different scenarios. These scenarios were all looked at over a 60 year time scale in 20 year time increments at 2019, 2039, 2059, and 2079. Instead of choosing a 90th or 99th percentile weather condition determined by data from a weather station, a standard temperature and wind speed was selected to represent moderate and severe potential fire weather conditions. This was done as the closest weather stations do not accurately represent weather conditions for the whole park due to the elevation gradient and distance of those stations from the park (Black & Opperman, 2005). The closest weather stations still operational and measuring temperature were located in Deer Park, which was a good distance to the west of the park in much lower elevation, and Quartz Peak, located in the southeast corner of the park. The Fire and Fuels summary post processor was chosen to get moderate and severe fire potential variable values for all scenarios at each year of interest, with moderate being a temperature of 70°F and a wind speed of 6 mph and severe being a temperature of 90°F with a wind speed of 30 mph. These four scenarios were selected to look at how Mt. Spokane could change over time and are described below.

Scenario: Do Nothing

In this scenario, no management or fire event was simulated in the 60 year period looked at. The scenario was used as a baseline to compare to the other three to see what would happen to the outputs of interest if nothing was done. FVS is an individual-tree growth and yield model that is determined by the inputs provided so this scenario simulated how the forests of Mt. Spokane would change in response to natural succession and mortality simulated in this model (Dixon, 2022; Johnson et al, 2007).

Scenario: Management

To introduce management into these 151 plots, a standard approach was applied for all of them. Although certain vegetation groupings in the park do not see much in terms of management for reduction of fire risk like high elevation stands dominated by subalpine fir for example, the same management prescription was applied to all stands as a standard of comparison (Taylor & Fonda, 1990). The prescription decided upon was based on management already done by park managers in the past as well as with the intention of reduction in wildfire risk and creation of late successional reserves. A thinning prescription was chosen that reduces the risk of a stand replacement fire, protects legacy trees, and furthers the development of late successional, fire-resistant forests (Kittrel & Stone, 2003). In doing so, reducing ladder fuels, ground fuels, and overly dense stands (Agee & Skinner, 2005; Bardon & Carter, 2001; Bennet, 2010). The prescription chosen to do so was thin throughout a diameter range from 0-20 inches harvesting 40% of the basal area of the stand with an after harvest slash removal leaving only the branchwood behind in the year in 2021. The thinning treatment was chosen to follow the objectives wanted, but also not be so intensive that it would be impractical for managers of the park to enact. Surface fuels were treated as well after the thinning treatments as there is a higher opportunity to have intense surface wildfires negating what management could have done on reducing the crown fire potential by just treating the overstory (Graham et al., 1999).

Scenario: Do Nothing and Fire

In this scenario, a fire event was simulated in the year of 2039 with no management prescription. The parameters of that fire event were to have it happen after greenup before the fall season, have very dry fuel conditions, a temperature of 90°F, and a wind speed of 30 mph twenty feet above vegetation with the whole entire plot burned. This could be edited in FFE-FVS under the SimFire keyword.

Scenario: Management and Fire

In this last scenario, the same management prescription in 2021 and fire event in 2039 was done to see how and if treatment had long term impacts on reducing wildfire hazard. Removing different percentages of basal area with the same slash treatment with and without the fire event in 2039 was also simulated to see what was the optimal amount of removal to reduce active crown fire behavior .Those percentages were 5, 10, 15, 20, 30, 35, 40, 60, 80, and 100 to examine if having a more or less intensive management prescription impacted flame length and fire behavior type variables over time.

After doing these four scenario runs in FVS, the outputs needed to be verified just to confirm that the model was working the way it should be. To be able to do so, FVS run outputs were saved into an Access databases by selecting database extension under model outputs for easier reviewal which separated out the outputs into different tables. Those tables being, FVS_Cases, FVS_Fuels, FVS_PotFire, FVS_SnagSum, and FVS_Summary. These tables are determined by the post processors and outputs of interest that are selected in FVS. For this work, summary statistics and all fire and fuel extensions reports were chosen. Each Access database was labeled by scenario and if it was singular plot or group run.

A simple way of verifying the model was working was confirming the general trends that stand basal area (BA; ft2/acre) and stand quadratic mean diameter (QMD) increases through time while stand density (TPA) decreases through time. This though can be impacted temporarily depending on what you put your stand data through (Cawrse et al. 2010). Outside of determining if general simulation trends were working, outliers of the determined outputs of interest were looked at to make sure data was not entered into the access database incorrectly. Trees per acre for some plots for example were simulated with initially very high values. That is due to the subplot having many small diameter trees and then those values being multiplied reflective of its plot size, 1/40th of an acre, to output a value equal to an acre. This information was located in the summary table where it was easy to see the changes of these variables for each year of interest.

Statistical Analysis

Of all the outputs produced from running FFE-FVS with the specified scenarios, the outputs chosen for statistical analyses and visualization were stand structure, fuels, and fire related variables. For stand structure, trees per acre, basal area (square feet per acre), quadratic mean diameter (inches), and total cubic foot volume (cubic feet). For fuel variables, surface total (tons per acre), standing total (tons per acre), snags less than or equal to three inches (tons per acre) and snags greater than three inches (tons per acres). Finally and most importantly, the fire variables which included potential flame lengths (ft) and the assigned four potential fire types indicative of different fire behaviors. The four potential fire types in order of increasing fire intensity are surface fire, passive crown fire, conditional crown fire and active crown fire. Surface fires are fires that do not go into the canopy, but rather burn the surface layer of the forest floor which includes loose needles, saplings, shrubs, grasses, and small trees. Passive crown fires are fires where individuals or groups of tree crowns burn, but there is no solid flame front consistently in the canopy layer known as torching. Conditional crown fires are a rarer event where the type of fire observed in the stands depends on what the fire was before coming into the stand. In other words, a surface fire will continue to be a surface fire and a crown fire will continue to be a crown fire. Active crown fires are when a solid frame front occurs from the surface to the canopy moving one tree to the next (Johnson et al., 2007; Reinhardt & Scott, 2001; Rebain et al., 2022; Scott, 2006; Van Wagner, 1977). These varying types of fire are determined by the variables entered into FFE-FVS such as slope, fuel quantities represented by the tree and fuel transect data entered, and environmental conditions set such as wind speed, temperature, and time of fire (Rebain et al., 2022).

All statistical analyses and visualizations were performed on Rstudio (R Development Core Team, 2022, version 4.2.2) using ggplot2 (version 3.4.1), and stats package (version 4.2.2) (R Development Core Team, 2019). Statistical significance was tested after a one-way analysis of variance (ANOVA) using the Tukey Honest Significant Difference (HSD) Test. Comparisons were considered significant at a p-value < 0.05. The comparisons looked at for each stand and fuel variable of interest were (1) if the means were significantly different between plots in their USNVC groupings and (2) if the means were significantly different between scenarios for the years 2039, 2059, and 2079. The Tukey's HSD test was used as it compares the means of every scenario or grouping to the means of every other scenario and grouping in one go, family-wise comparisons. To use this test, the assumptions made are that the means must be normally distributed and what was tested are independent from each other (Everitt & Hothorn, 2011; Appendix B & C). Descriptive statistics like mean and standard deviation were calculated and displayed in graph formats using RStudio to look at how different scenarios impacted outputs of interests over time both singularly and in groupings as well.

Results

General Site Data Information

Across the 151 plots established at Mt. Spokane State Park, 6275 trees and 423 fuel transects were measured. With those plots, the average slope was 25.68% (s.d. 12.29) with an elevation of 4308.35 ft (s.d. 601.23). These values help explain the different vegetation communities found in the park compared to what is found outside of the park which is timber plantations and ponderosa pine dominated stands. For average and standard deviation (s.d.) values of all the trees measured at Mt. Spokane, dbh was 7.71 in (s.d. 6.99), height 37.73 ft (s.d. 33.92), and crown ratio 32.44% (s.d. 20.54) which showed smaller trees held a dominating presence across the park (Table 2). The largest tree measured in terms of diameter was a western hemlock with a dbh of 70.4 in while the smallest trees measured were grand firs and Rocky Mountain maples with a dbh of 1in.

Table 2. Average and standard deviations values of all 151 plots for slope (%), elevation (ft), dbh (in), height (ft), and crown ratio (%).

	Slope (%)	**Elevation (ft)**	**DBH (in)**	**Height (ft)**	**Crown Ratio (%)**
Average	25.68	4308.35	7.71	37.73	32.44
Standard Deviation	12.29	601.23	6.99	33.92	20.54

When looking at plots in grouping in regards to elevation, Grouping 4 (5198 ft, s.d. 323.91) had the highest elevation values followed by Grouping 3 (5004.38 ft, s.d. 195.01), Grouping 1 (4487.3 ft, s.d. 475.55), and Grouping 2 (4070.4 ft, s.d. 477.49). Elevation of plots established in the park had a range of 2446 ft from 3236 ft to 5682 ft. Grouping 2, Northern Rocky Mountain Dry- Mesic Montane Mixed Conifer Forest, had the most variation among elevation values while Grouping 3, Rocky Mountain Lodgepole Pine Forest, had the least (Figure 9).

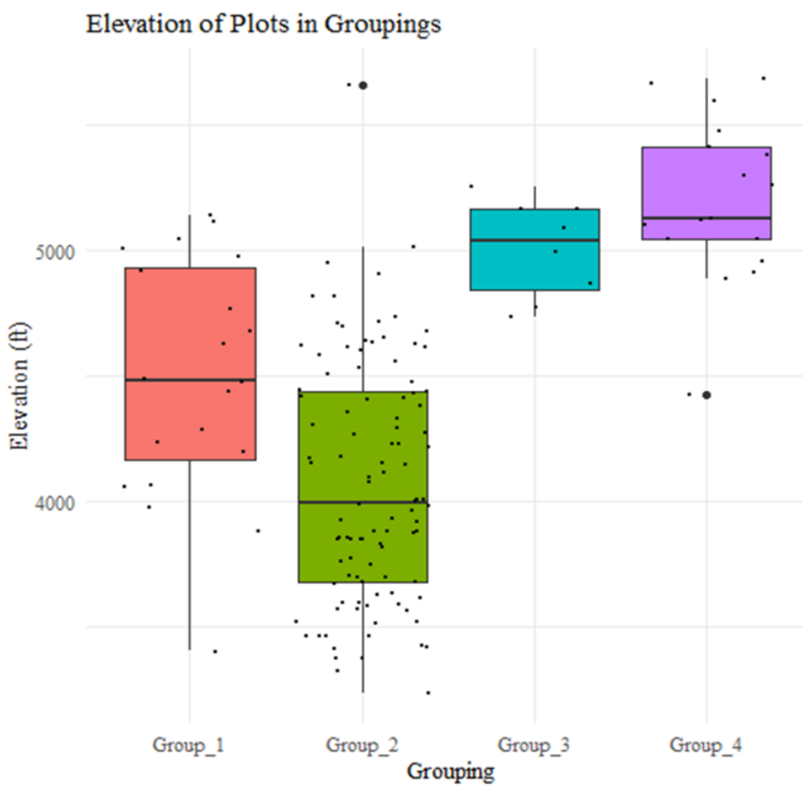

Figure 9. Elevation of plots in their assigned groupings.

Mt. Spokane is diverse in the variety of tree species it holds. Eighteen different species were measured across the 151 plots with 16 unknown individuals (Figure 10). The three most common tree species measured were grand fir (ABGR) at 2039 (32.5%), followed by subalpine fire (ABLA) at 1052 (16.7%), and finally Douglas fir (PSME) at 646 (10.3%). In Grouping 2 alone, 4037 trees were measured in the 108 plots belonging to it, giving an average trees per nested plot value of 37.38 trees. This was then followed by Grouping 1 with 1011 tree measured and an average of 50.55 trees per nested plot, Grouping 4 with 947 measured and an average of 55.71 trees per nested plot, and lastly with Grouping 3 with 280 trees measured with an average of 35 trees per nested plot.

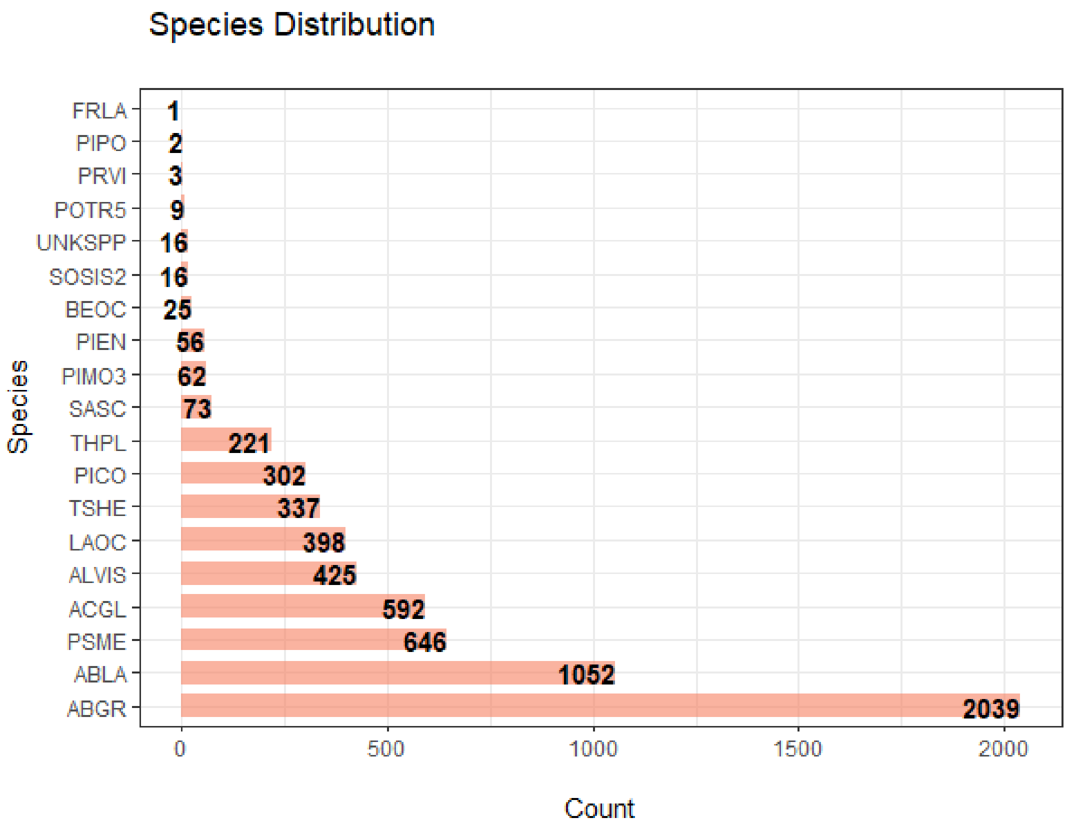

Figure 10. A tree species frequency distribution of trees measured across 151 plots at Mt. Spokane. A key for the tree species codes used here relative to their scientific and common names is located in the appendix (Appendix F).

Tree Core Results

Sixty two complete tree cores were taken in the field with their ages ranging from 27 years to 200 years (Table 3). The average age of the trees was 98.06 years old. Of the 62 cores collected, only four had fire scars, all of which were collected in the 2020 field season taken from plots belonging to Grouping 2 (Figure 11). The first fire scar corresponded to a Douglas fir with a dbh of 21 in that was aged at 81 years old with a fire event that happened 52 years ago from the year of collection. It dates this tree getting damaged by fire approximately in 1968. The next tree was a grand fir with a dbh of 26 in. It was approximately 77 years old with a fire event happening 35 years ago dating the fire event happening in 1985. Next, another Douglas fir with dbh of 25.3 in that was aged at approximately 100 years old and 81 years since fire. It dates this tree getting damaged by fire approximately 1939. The fourth collected core with a fire scar was a western larch with a dbh of 11.9 in. It unfortunately was partially rotten that caused part of the core to disintegrate, but it still could be determined that it had a fire event when it was approximately 30 years old. Seven different tree species were cored (Table 3). The tree species cored the most was Douglas fir (PSME) with 41 different individuals aged with lodgepole pine (PICO), Engelmann spruce (PIEN), and western hemlock (TSHE) the least at only one individual each.

Table 3. Average, minimum and maximum ages by tree species from collected tree cores.

Tree Species	Average	Minimum	Maximum	Total Collected
ABGR	79.6	59	100	5
ABLA	188	187	189	2
PICO	114	-	-	1*
PIEN	97	-	-	1*
PSME	96.71	27	161	41
LAOC	98.12	58	200	11
TSHE	43	-	-	1*

A key for the tree species codes used here relative to their scientific and common names is located in the appendix (Appendix F). An asterisk* indicates only one of the species was collected out in the field.

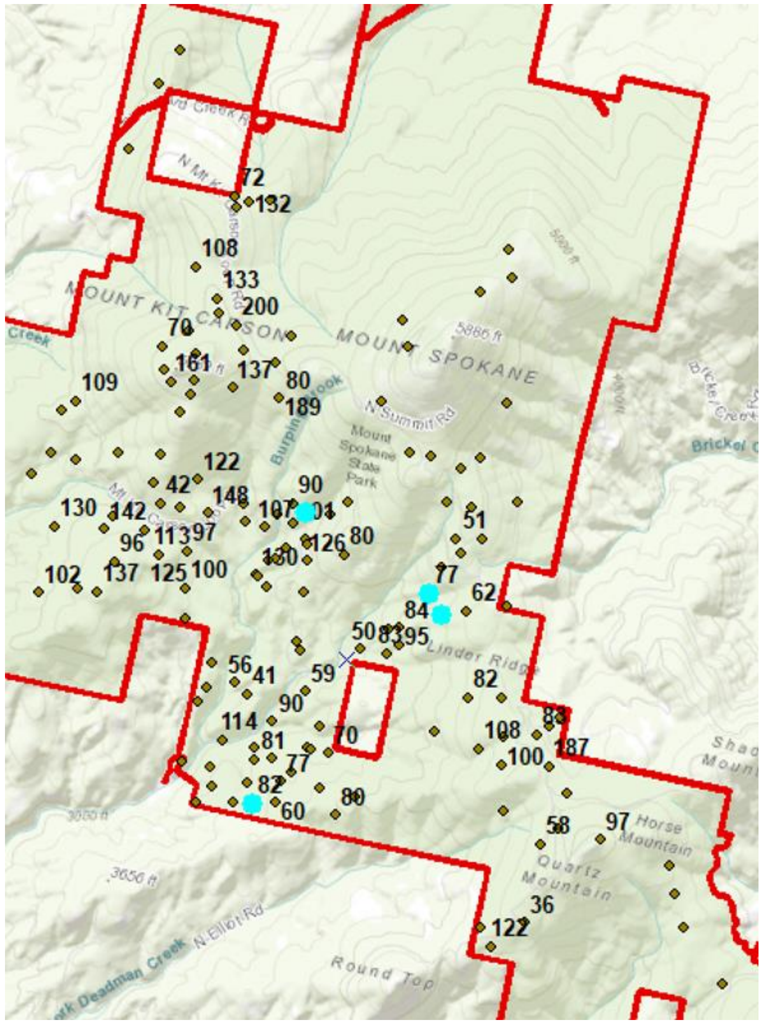

Figure 11. Map image showing the 151 plots (brown) established across the park with the 62 that had complete tree cores labeled with age of the core taken. Only four cores had fire scars indicated in the highlighted blue circles.

Stand Structure Variables

Stand structure and fuel variables were looked at over time (2019, 2039, 2059, 2079) for the four scenarios to see general trends, if USNVC grouping differed from each other initially, and how scenarios differed from each other over time.

Trees per acre (TPA) decrease over time in all scenarios only increasing in 2079 for the fire involved scenarios when trees finally regenerate after the fire event in 2039 (Figure 12). TPA values were higher in the do nothing fire scenario compared to the management and fire scenarios in 2079. The do nothing and management scenarios for grouping 1 maintained the most trees per acre over time. Under initial 2019 conditions, grouping 2 and 3 had significantly different TPA values to grouping 4 (Appendix B: B.1; B.9). When comparing scenario's TPA mean values over time, only in 2059 were the do nothing and fire and management and fire scenarios significantly different to the do nothing and management scenarios. This shows that the fire event was the defining factor in impacting TPA values. Otherwise, all scenario's TPA values were not significantly different from each other in 2039 and 2079. (Appendix B: B.1; B.10)

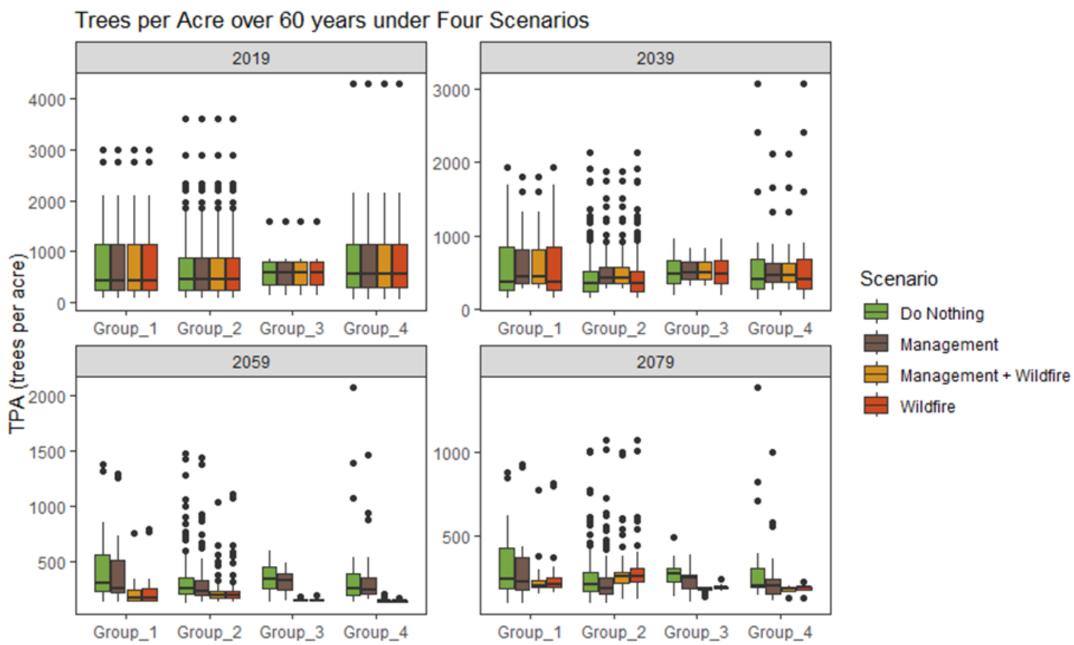

Figure 12. Trees per acre over a 60-year period under four different scenarios separated by groupings.

Basal area increases over time in all scenarios with temporary large decreases after management and fire events. The do nothing and management scenarios for grouping 2 maintained the highest basal area values (Figure 13). Grouping 2 had significantly different basal area mean values to the three other groupings (Appendix B: B.3; B.9). When comparing scenario's basal area values over time, 2039, 2059, and 2079 all had significant values. In 2039, the do nothing scenario's basal area values were significantly different to management and management and fire scenarios. Also, the management scenario was significantly different to the management and fire and do nothing and fire scenarios. In 2059, all scenarios were significantly different from each other except management and fire and do nothing and fire were not. In 2079, the same differences as in 2059 were sustained (Appendix B: B.4; B.10).

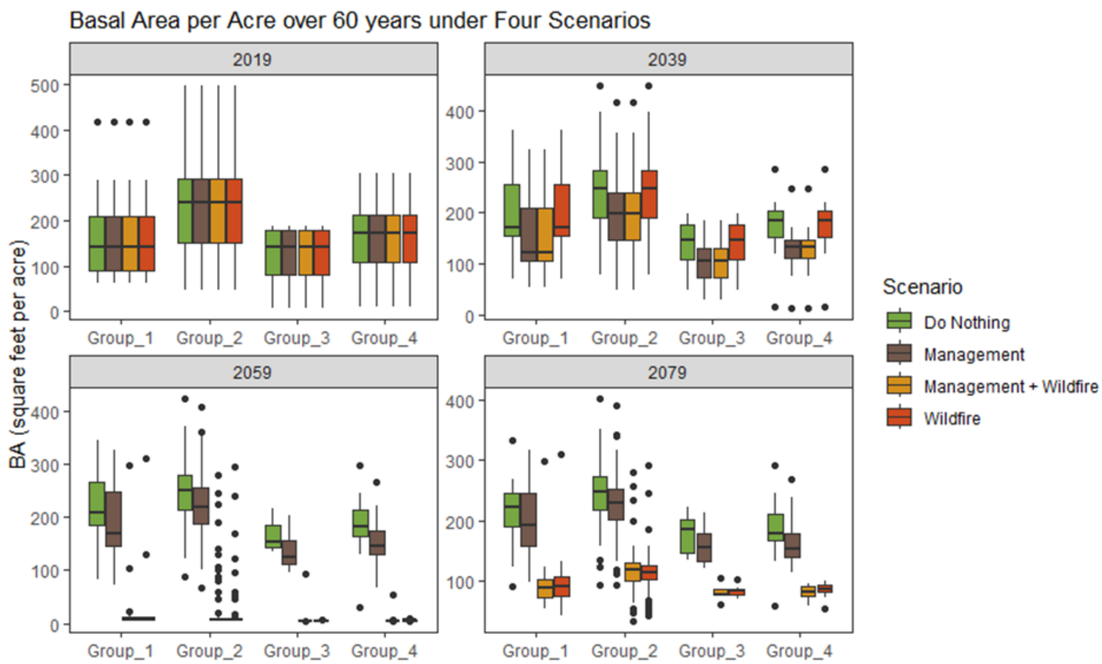

Figure 13. Basal area (square feet per acre) over a 60-year period under four different scenarios separated by groupings.

Quadratic mean diameter followed the same trends as basal area with increases over time in all scenarios with temporary large decreases after management and fire events followed with grouping 2 having the largest diameter trees and grouping 3 the smallest on average (Figure 14). Grouping 2 also had significantly different quadratic mean diameter mean values when compared to the three other groupings (Appendix B: B.5; B9). When comparing scenario's quadratic mean values over time, 2039, 2059, and 2079 all had significant differences with all scenario differences being the same as basal area except for in 2059 and 2079, management and do nothing were not significantly different from each other. (Appendix B: B.6; B10).

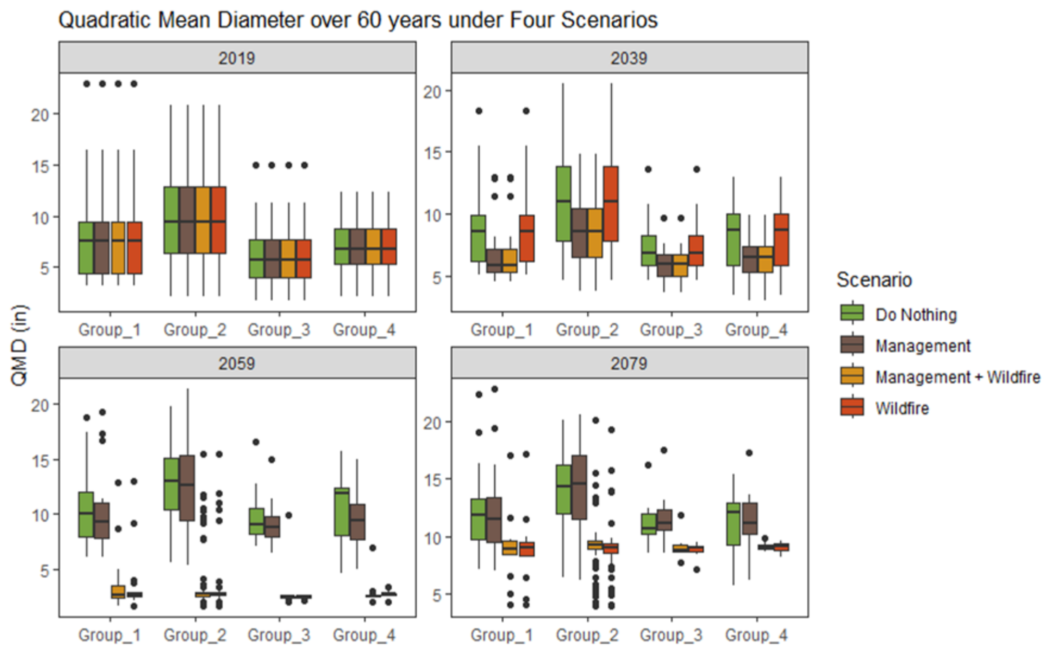

Figure 14. Quadratic mean diameter (in) over a 60-year period under four different scenarios separated by groupings.

Total cubic foot volume followed similar trends and significant differences between groups and scenarios as quadratic mean diameter (Figure 15). Those differences being grouping 2 having significantly different total cubic foot volume mean values when compared to the three other groupings (Appendix B: B.7; B.9). When compared to quadratic mean diameter, the only change was that the same significant differences in the year 2039 were not as great between the do nothing scenario when compared to the two management ones as well as the fire scenario against both management scenarios (Appendix B: B.8; B.10).

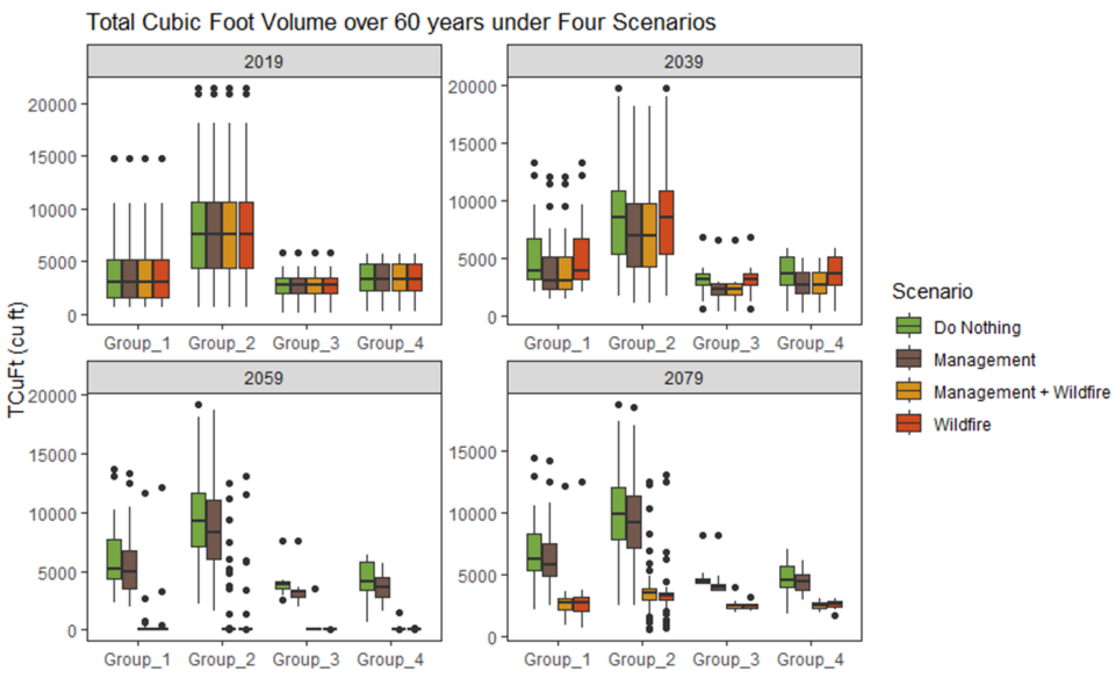

Figure 15. Total cubic foot volume (cu ft) over a 60-year period under four different scenarios separated by groupings.

Fuel Variables

When compared to forest stand structure variables that follow similar trends and significant differences, fuel outputs are more variable. Surface fuel total, otherwise referred to as surface fuel loading, remained generally unchanged reducing slightly over time under do nothing scenarios with the management scenarios having slightly less surface fuels due to the slash removal after the basal area removal treatment. For groupings 2 and 4, scenarios with fire had more surface fuels than the do nothing and management scenarios in the year 2079 (Figure, 16). For 2059, the fire scenario had the highest surface fuel total values for all groupings which carries over in the year 2079 for groupings 2 and 3. Grouping 3 had significantly different surface fuel total mean values to groupings 1 and 2 (Appendix C: C.1; C.9). When comparing scenario's mean surface fuel totals over time, only 2039 and 2059 had significant differences. In 2039, the do nothing scenario's surface fuel total mean values were significantly different to do nothing and fire and management and fire scenarios. Also, the management scenario was significantly different to the management and fire and do nothing and fire scenarios. In 2059, there were only slight significant differences between the do nothing and fire scenarios against the management and management and fire scenarios (Appendix C: C.2; C.10). This indicates that management had a significant impact on reducing the mean total surface fuels.

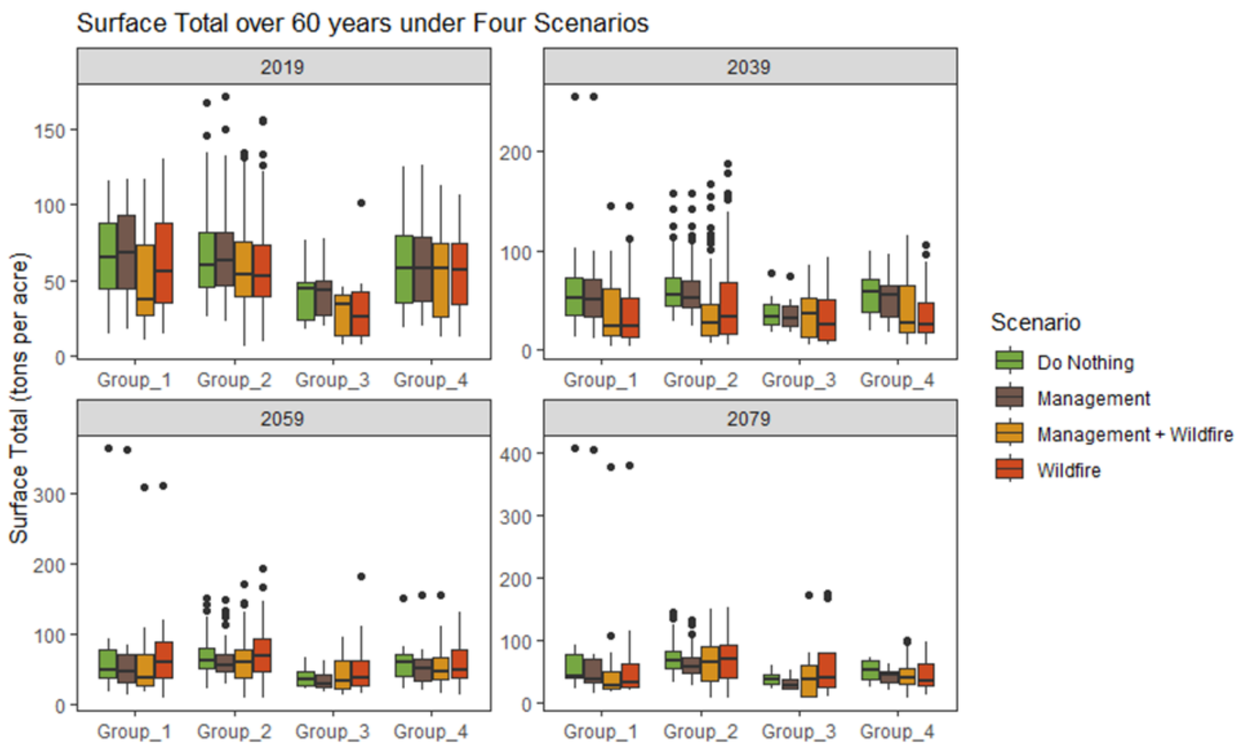

Figure 16. Surface fuel total (tons per acre) over a 60-year period under four different scenarios by groupings.

The general trend for standing fuel total under the do nothing scenario was to have a slight increase in fuel loading over time with wide variability between the groups in the amount of standing total. There was greater variability in the years of 2059 and 2079 especially for groupings 1 and 2. The management and wildfire scenario produced the most variable changes in 2079 in Grouping 3. Grouping 2 under the do nothing and management scenarios had the most standing total over time (Figure, 17). Groupings 1 and 2 had significantly different standing fuel total mean values when compared to groupings 3 and 4. (Appendix C: C.3; C.9). When comparing scenario's standing fuel totals over time, years 2039, 2059, and 2079 all had significant differences. In 2039, the do nothing scenario's standing fuel total values were significantly different to the three other scenarios. Also, the management scenario was significantly different to the management and fire scenarios. In 2059, this same trend followed through with an additional significant comparison with the management and do nothing and fire scenarios. In 2079, the same significant differences between scenarios were seen as in 2059 (Appendix C: C.4; C.10).

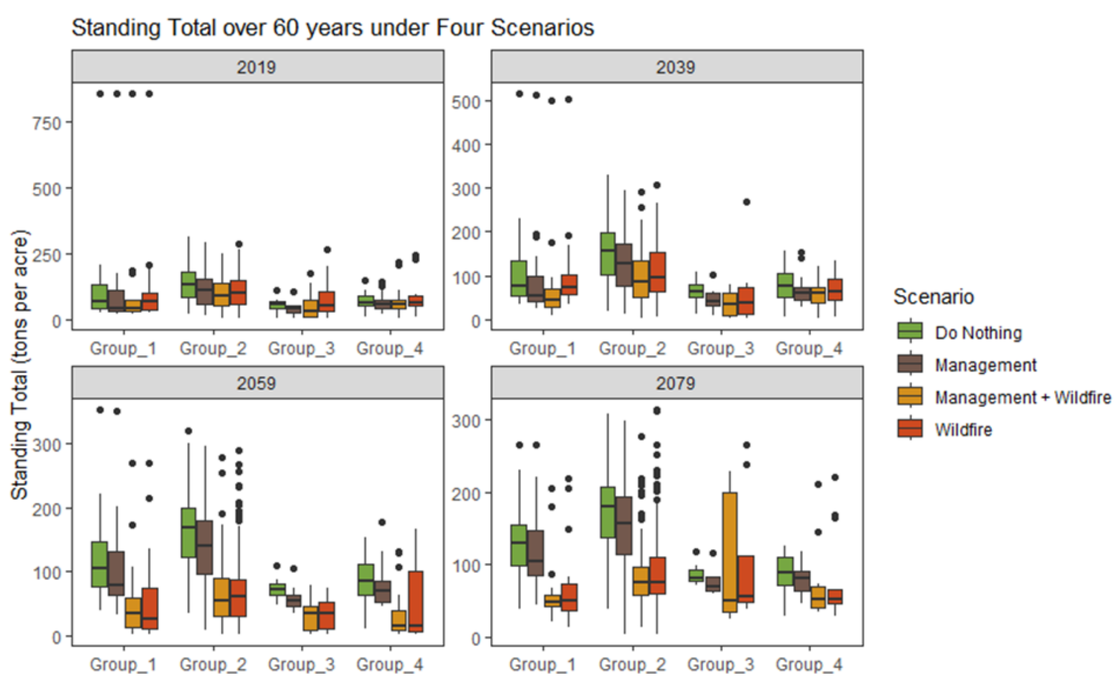

Figure 17. Standing fuel total (tons per acre) over a 60-year period under four different scenarios by groupings.

Both snag variables, snags ≤ 3 inches and snags > 3 inches, generally followed the same trends with grouping 2 initially having the most snags on average compared to the other groupings in the year 2019. After fire events, there was a big increase in snags that decreased sharply as they fell down over time (Figures 18 & 19). When looking if any groupings were significantly different from each other with their snags ≤ 3 inches, none were significantly different (Appendix C: C.5; C.9). For the case of snags > 3 inches, grouping 1 was significantly different to groupings 2 and 4 (Appendix C: C.7; C.9). When comparing scenario's snags ≤ 3 mean values over time, all three years had significant differences. In 2039, all scenarios were significantly different from each other except do nothing and management. In 2059, all scenarios were significantly different from each other except management and fire compared to the do nothing and fire scenario. In 2079, this changed even more with management and fire becoming statistically different to the do nothing, management, and do nothing and fire scenarios (Appendix C: C.6; C.10). Snags ≤ 3 and snags > 3 outputs were significantly different between scenarios for all three years. In 2039, the do nothing and management scenarios were significantly different to both fire scenarios. In 2059, that still stayed true except for the do nothing and management and fire scenario not being different anymore. In 2079, only the management and do nothing and fire scenarios were significantly different from each other (Appendix C: C.8; C.10).

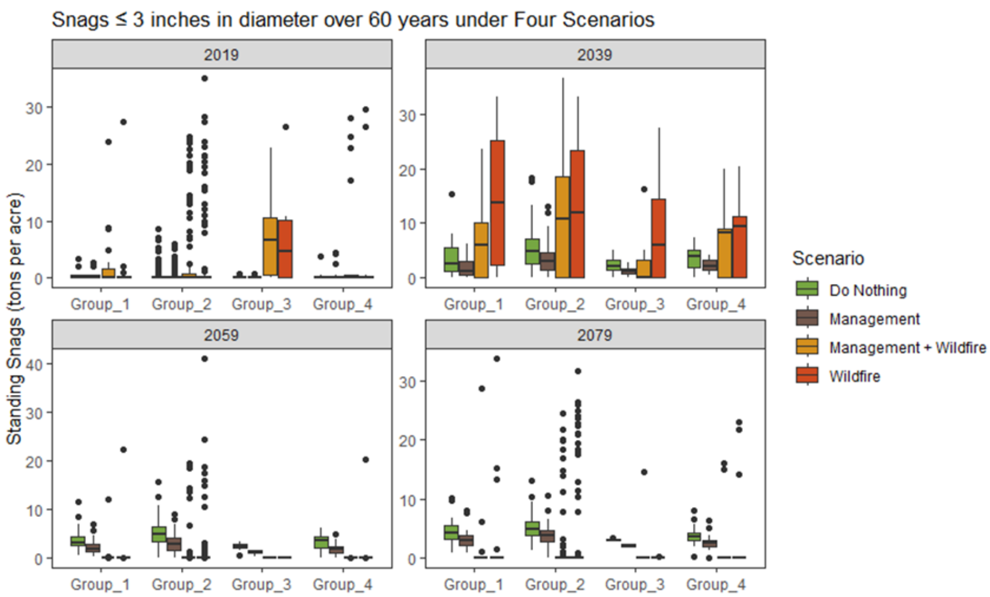

Figure 18. Standing snags ≤ 3 inches (tons per acre) over a 60-year period under four different scenarios separated by groupings.

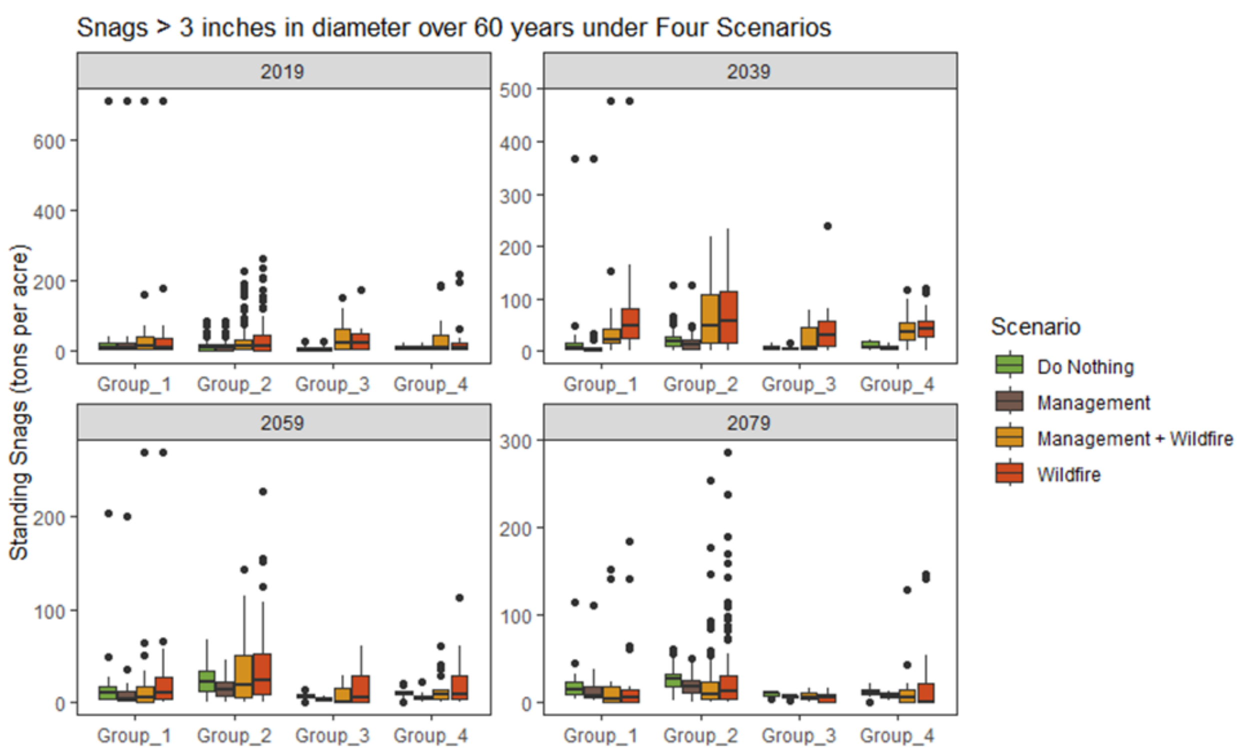

Figure 19. Standing snags > 3 inches (tons per acre) over a 60-year period under four different scenarios separated by groupings.

Moderate and Severe Potential Fire Hazard

Potential fire hazard was looked at over time under the established moderate and severe fire conditions. To set baseline conditions for the 151 plots, potential moderate and severe fires were simulated in the year 2019. Under moderate conditions, a 20 foot wind speed of 6 mph and temperature of 70° F, there was low fire hazard in the park with only 8% of plots presenting as passive crown fires with the remaining 82% being surface fire. Under severe conditions, a 20 foot wind speed of 30mph and temperature of 90° F, fire types were much different with 44% of plots having active crown behavior, 44% conditional crown fires, 7% passive crown fires, and 5% being surface fires (Figure 22). Most of the park is expected to experience crown fire of varying intensity. Both surface and total flame length values were relatively low under moderate conditions with all surface flame length less than 5 ft and total flame length values much under 84 ft (Figures 20 & 21). When looking at severe fire conditions for those same values, there were still some plots remaining in the 0-4.8 ft and 0-84 ft bins for surface flame length and total flame length respectively. Higher fire hazard is seen throughout the park with high flame lengths and active crown fire as the fire type. Plots with high fire hazard values were seen at Mt. Kit Carson, around the parking lot used for the Mt. Kit Carson Loop Road hike, the ski runs, and the trail to access Ragged Ridge, a natural area preserve within the park (Figures 20, 21 & 22).

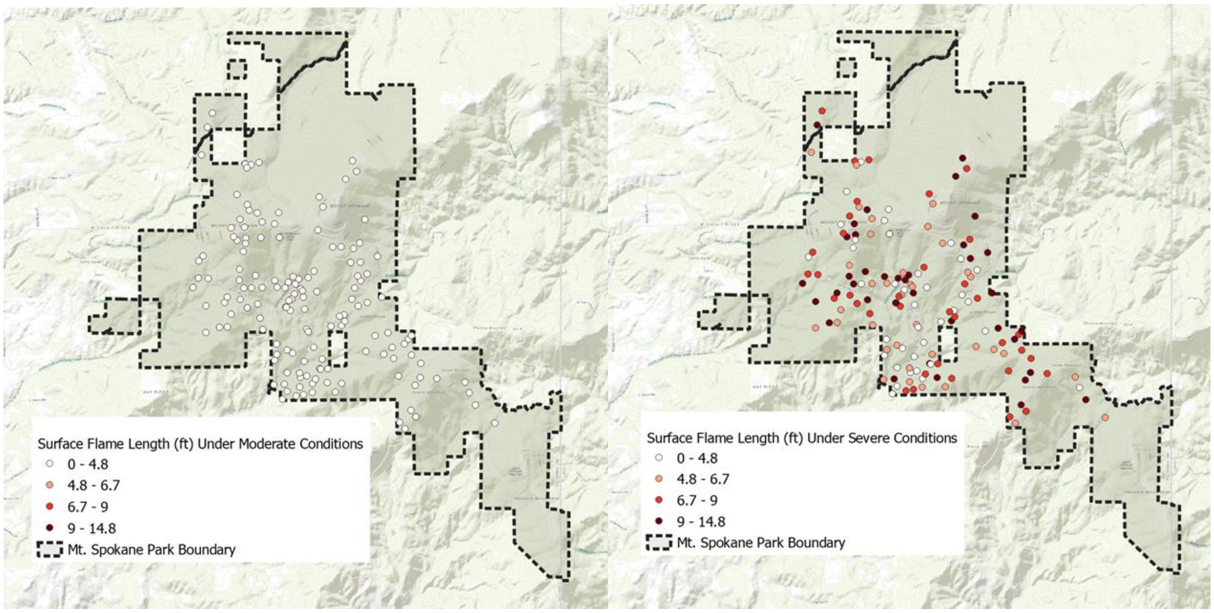

Figure 20. Potential surface flame length (ft) values for all 151 plots under moderate and severe conditions in 2019.

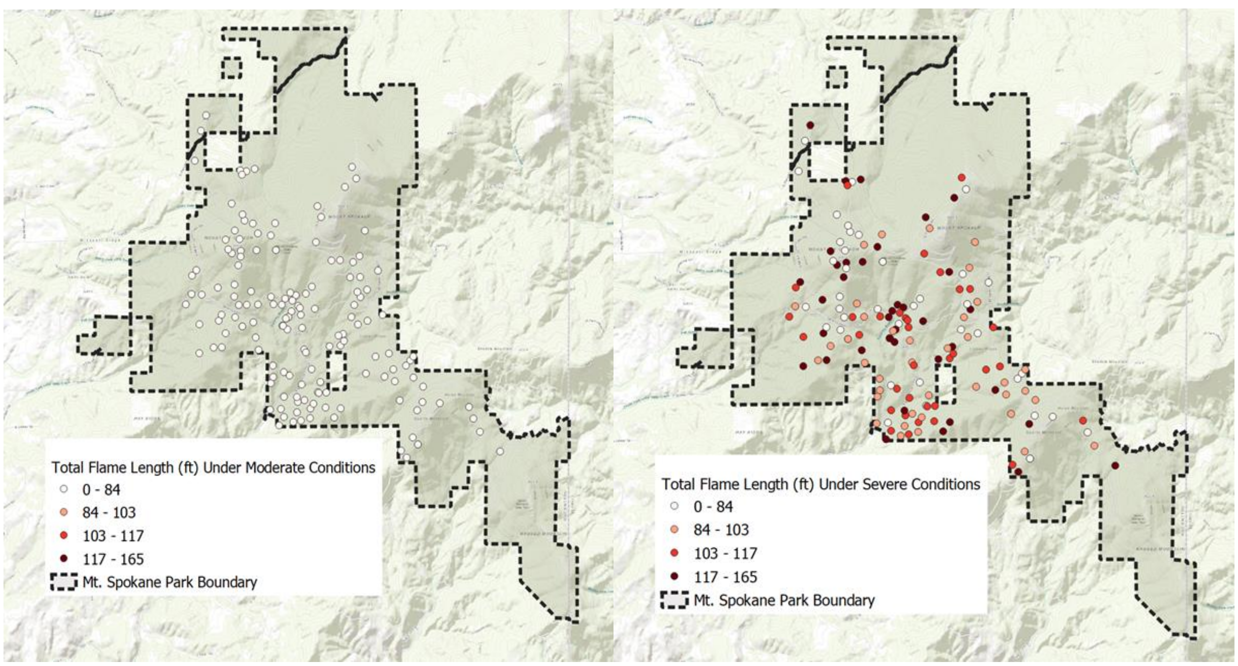

Figure 21. Potential total flame length (ft) values for all 151 plots under moderate and severe conditions in 2019.

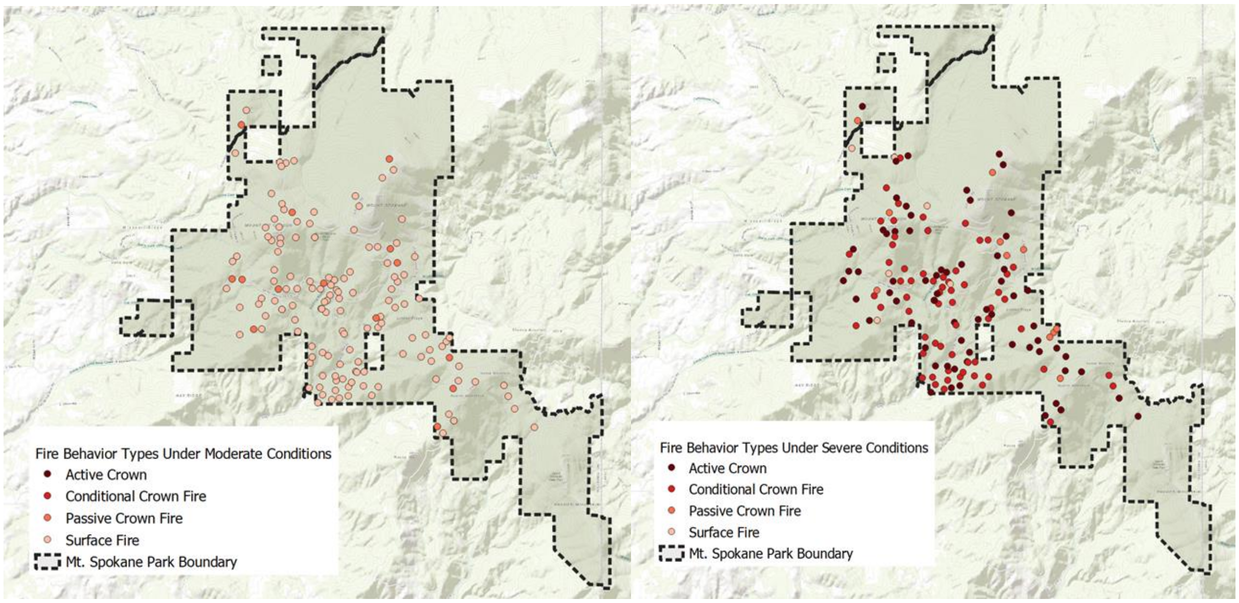

Figure 22. Potential fire types for all 151 plots under moderate and severe conditions in 2019.

The results for the do nothing scenario in 2079 show a steep reduction in active crown fire with increases in surface and conditional crown fires (Table 4). Conditional crown fires now were 62% of all plots, an 18% increase from sixty years ago. Active crown fires went down to 12% of all plots, a 32% decrease from sixty years ago (Table 4). Surface fires increased from 5% to 22% of all plots in sixty years. The average total flame length for all 151 plots in this scenario was 81.67 ft with the remaining active crown fires mostly persisting in the same general areas stated under the 2019 potential fire results (Figure 23).

Table 4. Potential fire types in a do nothing scenario under severe fire conditions by total plot numbers in the year 2079.

Scenario	Surface Fire	Passive Crown Fire	Conditional Crown Fire	Active Crown Fire
Do Nothing	33	6	94	18

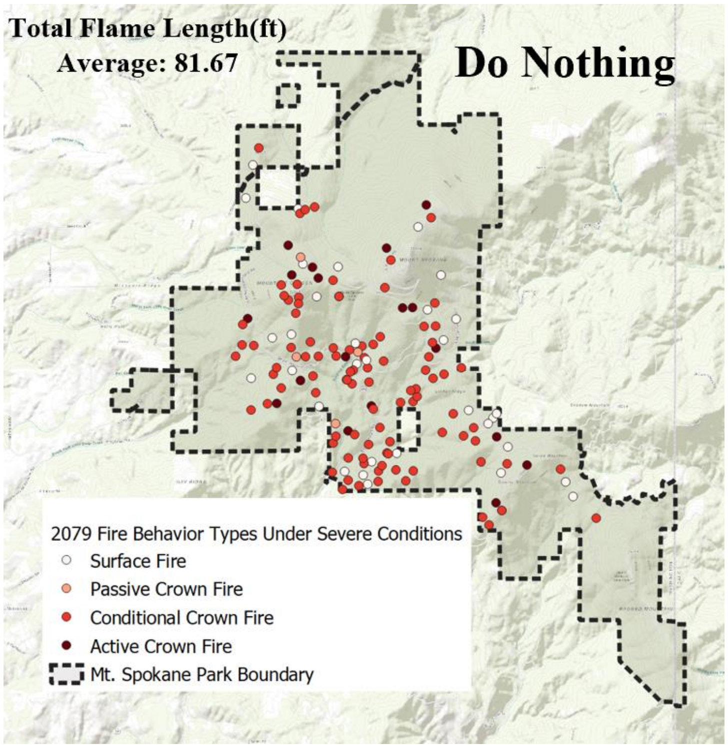

Figure 23. Potential fire types under severe fire conditions for all 151 plots under the do nothing scenario in the year 2079. The average total flame length was 81.67 ft.

For the management or no management scenarios, fire is predicted to be surface fires in all the plots for the severe and moderate conditions in 2039 after the simulated fire event with 2059 being a mix of surface and passive crown fires. A significant impact is expected in 2079 where the management and fire scenario still continues to reduce the potential of severe crown fire risk. Compared to the do nothing scenario which had many more plots that were conditional crown fires and only 12% of plots that were active crown fires in 2079, scenarios in which a past fire event happened resulted in reduction of conditional crown to almost nonexistence with an increase in active and passive crown fires (Tables 4 & 5). The management and fire scenario had an average total flame length of 61.7 ft compared to the do nothing and fire scenario that had a total flame length of 74.14 ft. Both were less than the do nothing scenario average total flame length of 81.67 ft. Active crown fires were prevalent in the lower elevations of Mt. Spokane in both fire scenarios particularly on the south facing slope (Figure 24).

Table 5. Potential fire types in a management and fire scenario versus a do nothing and fire scenario under severe fire conditions in the year 2079 by total plot numbers. The management prescription happened in 2021 while the fire event in 2039.

Scenario	Surface Fire	Passive Crown Fire	Conditional Crown Fire	Active Crown Fire
Management and Fire	41	52	3	55
Do Nothing and Fire	24	56	1	70

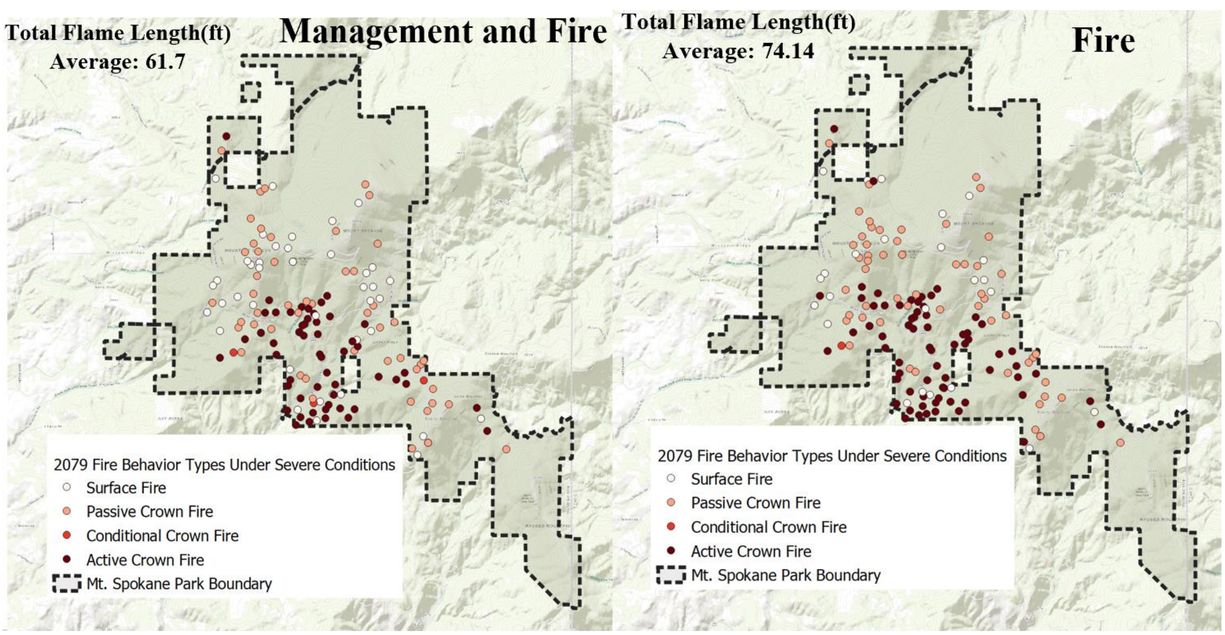

Figure 24. Potential fire types under severe fire conditions for all 151 plots under the management and fire scenario versus the do nothing and fire scenario in the year 2079. Management prescription happened in 2021 with the simulated fire event occurring in 2039.

Simulated Fire Event Hazard

FFE-FVS fire outputs were looked at related to the 2039 simulated fire event in regards to the management and fire and do nothing and fire scenarios individually and in groupings. This was done to see if introducing a management prescription would impact fire hazard. Under the simulated fire event in 2039 looking at individual plots, management and fire scenario types were as follows with conditional crown fire (49%), active crown fire (24%), passive crown fire (15%), and surface fire (12%) in order of prominence. Under the do nothing and fire scenario, fire types were conditional crown fire (51%), active crown fire (36%), surface fire (7%), and passive crown fire (6%) in order of prominence (Table 6). When comparing crown fire hazard between the two scenarios, 88% of the plots were determined to express crown fire behaviors for the management and fire scenario and 93% in the do nothing and fire scenario. Although this is not statistically different between the two, there was a reduction in the number of active crown fires by 12% when management was done before the fire event.

In the management and fire scenario, of the plots designated as active crown fires (24%), were split as 72% from Grouping 2, 14% from Grouping 1, 11% from Grouping 4, and 3% from Grouping 3. When looking at the percentage of plots that had active crown fire within their own USNVC grouping for this scenario, 24.5% for Grouping 2, 25% for Grouping 1, 23.5% for Grouping 4, and 12.5% for Grouping 3. In the do nothing and fire scenario, of the plots designated active crown fires (36%), were split as 69% from Grouping 2, 15% from Grouping 4, 13% from Grouping 1, and 4% from Grouping 3. When looking at the percentage of plots that had active crown fire within their own USNVC grouping for this scenario, 36% for Grouping 2, 47% for Grouping 4, 35% for Grouping 1, and 25% for Grouping 3. Many of the same plots continued to exhibit active crown fire behavior between the two scenarios.

Table 6. Fire types in the simulated 2039 fire event for the management and fire scenario versus a do nothing and fire scenario.

Scenario	Surface Fire	Passive Crown Fire	Conditional Crown Fire	Active Crown Fire
Management and Fire	18	23	74	36
Do Nothing and Fire	10	9	77	55

When looking at flame length values individually in their groupings, there was a range of flame lengths produced under the management and fire and the do nothing and fire scenarios (Figure 25). Under the management and fire scenario, plots total flame length values belonging to Grouping 1 ranged from 3.92 ft to 133.55 ft, Grouping 2 from 1.48 ft to 129.05 ft, Grouping 3 from 7.74 ft to 71.34 ft, and Grouping 4 from 6.22 ft to 110.98 ft. Under the do nothing and fire scenarios, plots belonging to Grouping 1 flame length values ranged from 4.01 ft to 139.58 ft, Grouping 2 from 3.47 ft to 141.73 ft, Grouping 3 from 54.10 ft to 98.01 ft, and Grouping 4 from 10.21 ft to 120.15 ft. There is much variability with the flame length values between the fire behavior types except for those designated as surface fires (Figure 25).

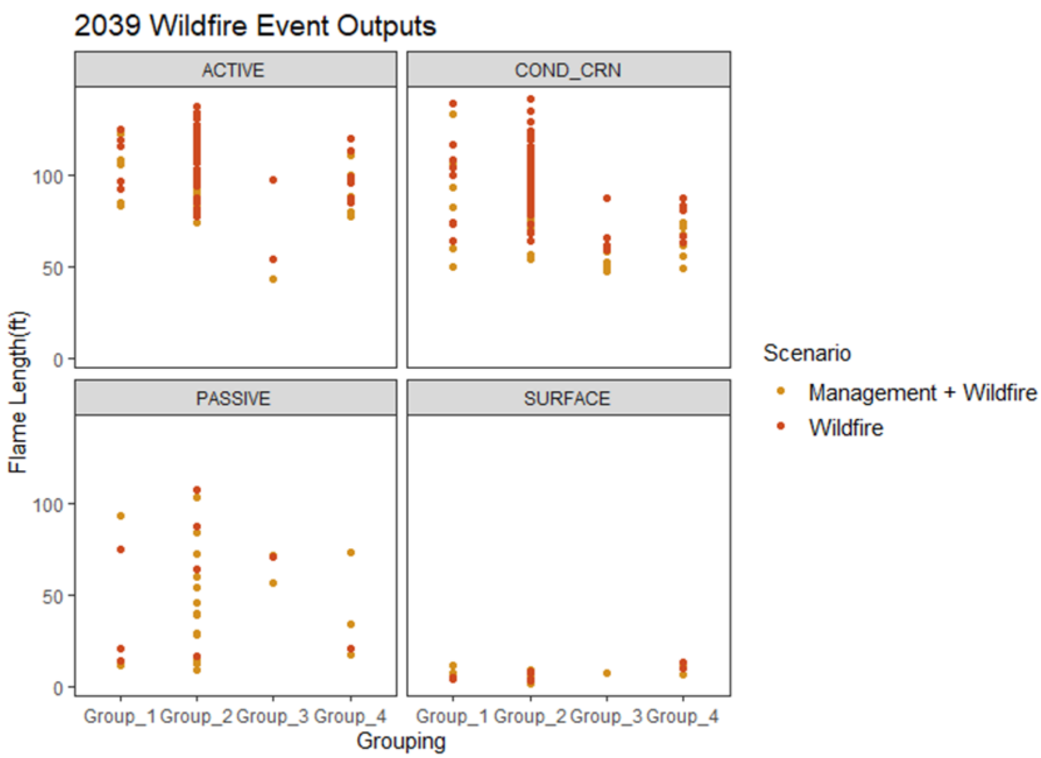

Figure 25. Total flame length (ft) values for the management and wildfire and the do nothing and fire scenarios in 2039, per grouping using individual plot data, separated by fire types.

When looking at fire outputs from the 2039 simulated fire event produced by FFE-FVS through groupings, management had an average fire type of passive crown fire for all groupings (Table 7; Figure 26). On the other hand, during the simulated fire event without any previous management decisions, the median fire type for all grouping was an active crown fire with only Grouping 3, Rocky Mountain Lodgepole Pine Forest, presenting as a passive crown fire. When comparing flame length values between the two scenarios, the average flame length value reduced as follows: Grouping 1: 24.03 ft (24.5%), Grouping 2: 34.43 ft (32.6%), Grouping 3: 34.31 ft (51.4%), and Grouping 4: 30.49 ft (33.8%).

Table 7. Average fire types and flame length (ft) values for the four vegetation groupings in the simulated 2039 fire event for the management and fire scenario versus do nothing and fire scenario.

Scenario	Grouping	Flame Length (ft)	Fire Type
Management and Fire	1	74.63	Passive Crown Fire
Management and Fire	2	70.95	Passive Crown Fire
Management and Fire	3	32.39	Passive Crown Fire
Management and Fire	4	59.71	Passive Crown Fire
Do Nothing and Fire	1	98.66	Active Crown Fire
Do Nothing and Fire	2	105.38	Active Crown Fire
Do Nothing and Fire	3	66.70	Passive Crown Fire
Do Nothing and Fire	4	90.20	Active Crown Fire

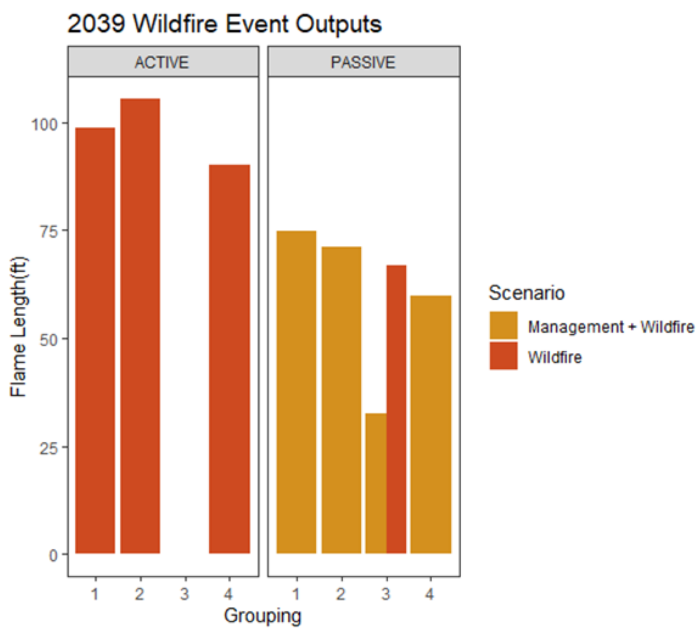

Figure 26. Total flame length (ft) averages for the management and wildfire and the do nothing and fire scenarios in 2039, per grouping, with active crown fire (left) versus passive crown fire (right) types separated.

Variable Basal Area Removal Prescriptions Impact on Fire Hazard

The sensitivity of the model to forest management activities during the model run period was tested by varying the intensity and timing. This helped determine management prescriptions that would achieve the desired modification of fire behavior. One test was to vary the percentages of basal area removed to see how basal area reduction made a difference on the severity of the simulated fire event in 2039 (Table 8). With no management, the simulated fire event had an average 91.31 ft total flame length with fire behavior types divided up in order of prominence with conditional crown fires (51%), active crown fires (36%), surface fires (7%), and passive crown fires (6%). With this, 93% of the plots measured at Mt. Spokane were expected to have a crown fire of some sort with the simulated fire event of 2039. When including a management prescription in 2021, conditional crown fires continued being the dominating fire behavior type for the 151 plots measured peaking at 30% basal area removal. Conditional crown fires only started to decline after the removal of more than 40% basal area and loses its dominance when more than 60% of the basal area is removed from the thinning selection of 0-20 inches dbh. Along with conditional crown fires, plots that are expected to have surface fires are rather stagnant until removing more than 40% basal area. Many plots need a higher basal area percentage removal for there to be a change from the baseline fire behavior type represented in the do nothing and fire scenario.

Table 8. Fire types and total flame length (ft) average values in a management and fire scenario versus a do nothing and fire scenario under severe fire conditions for the simulated fire event in 2039 after a variable basal area removal management prescription in 2021.

Scenario	Flame Length (ft)	Surface Fire	Passive Crown Fire	Conditional Crown Fire	Active Crown Fire
5% Mng_Fire	88.94	13	11	75	53
10% Mng_Fire	87.02	14	13	74	51
15% Mng_Fire	85.48	14	13	75	50
20% Mng_Fire	84.13	13	15	75	49
30% Mng_Fire	80.28	14	20	77	41
35% Mng_Fire	77.51	17	22	76	37
40% Mng_Fire	74.42	19	23	74	36
60% Mng_Fire	57.83	41	25	65	21
80% Mng_Fire	38.12	67	35	43	6
100% Mng_Fire	25.00	78	46	25	2
Do Nothing and Fire	91.31	11	9	77	55

The second sensitivity test looked at removing variable percentages of basal area to see if management had long term impacts in reducing fire hazard by way of reducing potential flame length and crown fire type in the year 2079 with a simulated fire event in 2039 (Table 9). With no management and a simulated fire event in 2039, a potential fire in 2079 would have an average total flame length of 74.14 ft with fire behavior types divided up in order of prominence with active crown fires (46%), passive crown fires (37%), surface fires (16%), and conditional crown fires (<1%). With the management and fire scenario, active crown fires were the dominant fire behavior type peaking at 73 (48%) with 5% basal area removal. That was flipped when there was more than 40% basal area removal with surface fire dominating. A sharp increase is seen in the number of potential surface fires when removing more than 40% basal area. Passive crown fire numbers are not more greatly impacted until more than 40% removal as well. In this scenario, there are next to no conditional crown fire behavior plots peaking at 60% basal area removal at 4.

Table 9. Potential fire types and total flame length (ft) average values in a management and fire scenario versus a do nothing and fire scenario under severe fire conditions in the year 2079 after a variable basal area removal management prescription in 2021 and fire event in 2039.

Scenario	Flame Length (ft)	Surface Fire	Passive Crown Fire	Conditional Crown Fire	Active Crown Fire
5% Mng_Fire	74.00	25	52	1	73
10% Mng_Fire	71.51	29	56	1	65
15% Mng_Fire	70.46	31	51	1	68
20% Mng_Fire	69.79	33	50	1	67
30% Mng_Fire	67.05	37	51	1	62
35% Mng_Fire	64.70	38	51	2	60
40% Mng_Fire	61.70	41	52	3	55
60% Mng_Fire	49.34	59	44	4	44
80% Mng_Fire	36.10	83	34	4	30
100% Mng_Fire	27.11	101	26	2	22
Do Nothing and Fire	74.14	24	56	1	70

The last sensitivity test looked at removing variable percentages of basal area to see if the management scenario was still impactful in reducing fire hazard by way of reducing potential flame length and crown behavior in the year 2079 if no fire even happened until that point (Table 10). Management is not as impactful when compared to including the simulated fire in 2039 in the run, but it does start to be if removing more than 40%. Conditional crown fires are the dominant fire type followed by surface fire which is flipped when removing more than 60% basal area. Removing 100% of the basal area of trees 0-20 inches in diameter still produces crown fires separated to passive crown fires (9%), conditional crown fires (32%), and active crown fires (8%) with surface fires still dominant at 51%. Removing more than 80% of basal area caused an inverse reaction for crown fire behavior and with higher flame lengths.

Table 10: Potential fire types and total flame length (ft) average values in a management scenario under severe fire conditions in the year 2079 after a variable basal area removal management prescription in 2021.

Scenario	Flame Length (ft)	Surface Fire	Passive Crown Fire	Conditional Crown Fire	Active Crown Fire
5% Management	81.30	32	7	96	16
10% Management	79.94	33	6	93	19
15% Management	77.72	35	7	94	15
20% Management	77.27	33	7	97	14
30% Management	74.69	33	7	100	11
35% Management	70.34	40	6	97	8
40% Management	67.28	43	6	94	8
60% Management	53.40	61	8	77	5
80% Management	37.81	84	10	52	5
100% Management	41.27	77	13	49	12

Discussion

Impact of Scenarios on Variables of Interests over Time

Fire exclusion, different historical management in the park, and climate change have amplified the natural structural diversity, fuels and potential fires across Mt. Spokane State Park.

This is a condition that has been shown to be prevalent through the Northern Rockies in the United States and Canada (Cansler, 2011; Parisien, 2023). This study shows a general trend given by future scenarios simulated for the park in which stand structure variables over time without management or a fire event, having basal area and quadratic mean diameter increasing while stand density (trees per acre) and total cubic foot volume decreasing over time. The management scenario followed the same trends with slightly lower mean output values. General trends for fuels were more variable than stand structure with surface fuel total remaining stable for the most part with slight decline in standing fuel total increasing over time. Snags fluctuated each simulation of future scenarios as more were created and fell down over time with fire events causing a sharp increase right after (Morris et al., 2007).

Plots belonging to grouping 2, Northern Rocky Mountain Mesic Montane Mixed Conifer Forest, were significantly different from others structurally in basal area, quadratic mean diameter, and total cubic foot volume. The subalpine forests represented by grouping 4 were significantly different in trees per acre to grouping 2, moist mixed-conifer forests and 3, lodgepole pine dominated forests. Similar patterns have been reported in forests of similar makeups located in the Northern Rockies (Cansler et al., 2018; Stine et al., 2014) Grouping 2 had the largest diameter trees, much of which belong to only a few common species in the park. This vegetation type of mixed-conifers is important as it holds a lot of the biomass and its loss through fire could not only release a lot of carbon, but reduce the structural heterogeneity within the park (Lutz, et al., 2018). With fuel hazard, it was much more variable. The lodgepole pine dominated stands were significantly different to the other vegetation groupings in surface fuel total while the dry and mesic mixed-conifer groupings of 1 and 2 were both significantly different to the higher elevation groupings of 3 and 4 in standing fuel total. For snags smaller than or equal to 3 inches diameter snags, no vegetation groupings were significantly different while the snags greater than 3 inches had grouping 1 significantly different to groupings to 2 and 4.

Different scenarios caused different trajectories for the vegetation groupings in regards to their stand structure, fuel, and fire variables over time. Management affected variables differently with some benefits not holding over time when comparing the do nothing versus management and management and fire versus do nothing and fire scenarios outputs. It did have a significant impact during the simulated fire event in 2039. The forests of Mt. Spokane had an average fire type of passive crown when management was done before the fire event. When compared to the fire event alone without management, the average fire type was active crown fire for all groupings outside of plots representing the lodgepole pine dominated stands continuing to have passive crown fire. Benefits of structural fuels management did not hold over time indicating a need for recurring management although flame length and the number of crown fire behaviors types were reduced even 60 years post management.

Due to how diverse the forests are in the park caused by past human actions and variations in elevation and aspect, the forests of Mt. Spokane as a whole were shown to have mixed-severity fire over time based on the variations of assigned crown fire types and fire behavior flame lengths seen across the 151 plots (Appendix D). Mixed-conifer forests which are representative of most of the park are also shown to follow a mixed-severity fire regime across their range. The variation in needed management in these forests has not been well characterized and hampers the development of appropriate management (Franklin, & Dyrness, 1973; Merschel et al., 2014; Stine et al., 2014). Compared to initial conditions in 2019 where both conditional crown and active crown fires had similar high values under severe conditions, over time there was an expected fire regime shift to conditional crown being the overarching dominant behavior type followed by surface fires without intervention after 60 years even with management. This was not the case if a fire event occurred in the past though with active crown fire dominating followed by passive crown fires and surface fires for the potential fire behavior types in 2079. Thinning can be effective in reducing torching potential thus more intense fires, but with intense winds as simulated under potential severe fire conditions, it is not as effective (Agee & Lolley, 2006).

Conditional crown fires continued to be the dominant fire behavior type except in scenarios that included a simulated fire both with or without a management prescription. Conditional crown fires are situations in which the model predicts an active crown fire is possible in the stand, but it cannot initiate (Scott, 2006; Van Wagner, 1977). In other words, more extreme conditions are required to initiate crown fire than to maintain active crown fire. This is often caused by high canopy base height and canopy bulk density values in the park making the crowning index less than the torching index (Reinhardt and Scott, 2001; Van Wagner 1977). Conditional crown fires are supposed to be a rare event, but it was the prevalent behavior type when looking at the base conditions of the plot data (Reinhardt & Scott, 2001; Johnson et al., 2007). This indicates two outcomes for stands with this behavior type; surface fire behavior, if fire were to enter the stand as a surface fire; or active crown fire, if fire were to enter the stand as a passive or active crown fire (Scott, 2006). This is a concern as crown fire behavior types were much more prevalent than surface fire behavior types throughout the park meaning most of these plots would be active crown fires. Even before utilizing FFE-FVS to assign a fire behavior type in the simulated fire event in 2039 with no management prescription, looking over plot photos are a good first indicator of assigned fire behavior type (Appendix E).

Management Implications

After a century of forest management and fire exclusion across eastern Washington's landscapes, forests have had their successional and disturbance dynamics altered which was seen at Mt. Spokane State Park. Current efforts to mitigate these effects have not been enough when looking at the numerous large wildfires that have occurred across eastern Washington. Moreover, often these management efforts emphasize small scale treatments when having a more large-scale approach would be more effective (Hessburg et al. 2015). Eastern Washington's moist mixed-conifer, subalpine fir, and lodgepole pine dominated forests have numerous management considerations with some presented here incorporating the results of this study (DeMeo et al., 2012; Stine et al, 2014)

When looking at historical range of variation (HRV), returning to it may not be feasible anymore in changing climate and past timber harvesting activities that have altered structure and composition across the park. These forests are also more vulnerable to high severity fire especially as disturbance regimes have been altered (DeMeo et al., 2018; Hessburg et al., 2015; Hessburg et al. 2016; Stine et al, 2014.) Outputs from FFE-FVS indicated high fire hazard in much of the park with high flame lengths and crown fire behavior types under the do nothing scenario. Thinning from a diameter range of 0-20 inches with at least 40% basal area removal did have long term impacts on reducing crown fire activity, but more intensive or recurring management would be needed for more long-term reduction in crown fires. This was seen looking at comparisons between the do nothing and fire and management and fire scenarios as for most structure and fuel variables, the scenarios were not significantly different from each other except for 2039. This was due to this year having a simulated fire event. Trees per acre were not significantly different between the scenarios in any year (Appendix B). To maintain the significant differences between scenarios, management needs to be recurring with recommendations of 20-30 years in some plots as significance between scenarios was lost in that timeframe as well as for many of the variables (Jain et al., 2011; Schoennagel, et al. 2017; Stephens et al., 2012). Even with the scenarios not being significantly different from each other when looking at the variables selected in 2079, management prescriptions still have long term impacts on the plots they were simulated in (Agee & Skinner, 2005; Appendix G). Another consideration to make is when looking at plots that are presented as potential surface fires even under severe fire conditions. These stands can still have crown fires with the right conditions of high surface fuel outside the plot, a low fuel moisture content, and strong winds.

Northern Rocky Mountain Mesic Montane Mixed Conifer Forest, grouping 2, is of most concern for management efforts to reduce wildfire hazard due to its dominance in the park, the density of its stands, and high potential crown fires. These are the lower elevations stands that line the park entrance and roadways. In the lower elevation mixed-conifer plots, grand fir was the dominant tree species measured and these are a species of concern for park managers. Grand fir encroachment is a concern as they are a species more susceptible to fire which can contribute to forming unhealthy stands prone to large-scale wildfires. Historically, this species was largely absent or transient from the mixed-conifer forests represented in this study (Graham et al., 1999; Merschel et al., 2014). Of the over 6000 trees measured, only two were ponderosa pines. Even though the park is higher in elevation than the surrounding forest, fire suppression and the removal of large ponderosa pine in the lower elevation parts of the park through commercial timber harvest in the past has impacted the park and surrounding private and timber property (Graham et al., 1999; McCool et al., 1997). Some of the land acquired to increase the size of Mt. Spokane were Douglas fir planted stands which historically used to be more of a mix of ponderosa pine and Douglas fir on the western border of the park (Merschel et al., 2014). This has caused these communities to become multistoried, denser, and dominated by younger trees (Fryer, 2016). Ponderosa pines are fire resistant species due to many reasons, with some being their deep roots, thick bark, self-pruning lower branches, and more open crown structure. In the Northern Rockies, only one other species is more fire resistant than ponderosa pine which is the western larch (Arno, 1980; Flint, 1925; Fryer, 2016). Maintaining species that are fire resistant, especially on the borders if a fire were to come from outside of the park, is important.

Due to the diversity in topography, fuel conditions, and vegetation composition and structure found in Mt. Spokane State Park, fire behavior varies across the park (Cansler, 2011; Jain et al., 2012). This variation caused by both natural and human disturbances in the past has created a mosaic pattern of fire effects which makes it more resilient to large fire events not burning the whole entire park (Agee, 1993; Morgan et al., 2001). Conversely, complete suppression of any fire events in the future could have negative implications, by simplifying the forests reducing the spatial heterogeneity it already has which could increase the chance for disease and insect outbreaks (Lehmkuhl et al., 1994; Raffa et al., 2008).

With FFE-FVS estimating potentially high fire hazard over time for much of the park under severe fire conditions, a question comes up as to why the park has not had more major fire events in the over 100 years since its establishment with such high potential flame lengths and predicted crown fire behavior types. Quick to extinguish responses in the past might be the answer, but the climate of the mountain is unique in the landscape it is in (Halofsky et al., 2018). The park has a short fire season as it is covered in snow for over half of the year with only a few months of dry enough conditions to sustain a crown fire. That fire season could extend with climate change, as fire seasons across the west are expected to be longer and the wildfire activity within them more extreme which is something to consider when looking at future management decisions in the park (Abatzoglou, 2021; Coop et al., 2022). Increase in fire season and drought conditions can limit future management options available like prescribed fire under future conditions. It can decrease favorable conditions for prescribed fire along with moving the window of when they can occur (Littell, 2016).

As WSPRC has complex land management goals outside of just reducing wildfire hazard, managing for resilience within the park will look more site-specific than an overarching timber management approach represented here with varied basal area removal (Mina et al., 2022; Raymond et al., 2023). The approach used in this work may not be the best option for the entire park, but variable-density thinnings with remnant logs and snags could promote increases in biological diversity and accelerate the growth of old growth characteristics promoting vertical and horizontal diversity in stands (Binkley et al., 2007; Carey et al., 2002). From the results of this study, implementing programmatic fuel treatments along with individual site-specific fuel treatments looked at a landscape level would be beneficial. Also, the initial treatment may actually cause an increase in surface total and snags over the treatment location (Hessburg et al., 2016; Reinhardt et al., 2008). That is something to take into account if management prescriptions were used across high fire hazard areas of the park to reduce fire hazard. If a severe fire event were to occur outside of the park, large fires could still burn in treated stands under extreme weather conditions especially as the park is surrounded by timber property and more fire prone ponderosa pine dominated stands (Agee, 1998).

Cohesive planning with all stakeholders involved in fuel-reduction management will improve outcomes as fires move throughout the landscape (DNR, 2019; Hessburg et al., 2015). Improving collaboration between all stakeholders of the priority planning area is essential in building and improving relationships that will promote more comprehensive approaches that remove divisions which limit effective wildfire risk reduction (Wildland Fire Mitigation and Management Commission, 2023). As Mt. Spokane State Park is unique to its a priority planning area and 10% of the land in that planning area, its management is important yet differing from the surrounding landscape (DNR, 2018). Numerous factors make it unique to the rest of the planning area which include its high variability and representation of tree species, elevation gradient that contributes to its unique climate when compared to the surrounding lowland areas promoting much cooler conditions, and even with intensive human recreation use, less developed than the surrounding area (Figures 2, 9 & 10). With this uniqueness, applying fuel reduction treatments that are sized appropriately to restore multi-level landscape patterns, processes, and dynamics is vital (Hessburg et al., 2015; Hessburg et al. 2016; Jain et al., 2012; Stine et al., 2014).

Other management prescriptions like prescribed fire can be simulated in FFE-FVS, even if implementation is often constrained by social, administrative, and financial issues (Stephens et al., 2012; Kolden, 2019). Both thinning and prescribed burning will impact fuel variables, but prescribed fire can be much more spotty in effectiveness and does not significantly reduce canopy closure and basal area while also promoting canopy base height (Agee & Lolley, 2006). Due to the varying forest structures in the park, prescribed fire would not be recommended in most stands without pre-thinning and slash operations due to potential escaped containment. Due to this, if prescribed fire were to be chosen by managers as an option in the park, it is recommended that easier places to apply it be chosen first. Some of those places are the higher elevation conifer meadows which would have plentiful ecological payoffs and be easier to contain if a prescribed fire were to occur catered to the meadow conditions. As this is such a unique community in this region, targeted tree removal during the earliest stages of encroachment along with light burning could be beneficial (Haugo et al., 2015; Smith IV, 2009; Swanson et al., 2007).

Most of the fire work in mixed-conifer forests relies on using remote sensing, aerial photography or extrapolation of forest inventory data. Little work has been conducted based on ground data collection. This study shows the complexity of this type of approach. Nevertheless, there is much more that could be done with the plethora of data produced through this type of work for any future analysis with some examples described in a following discussion section. With FFE-FVS, there are countless possibilities on how and what to look at with the stand data not presented here which includes, but not limited to adding recurring treatments, different management prescription types, and testing for optimal basal area removal within vegetation classes. Continued monitoring of the established 151 plots or placing additional ones to represent forest types in the park with little coverage in this study following the protocol established would be valuable in having the continual knowledge of status, trends, and condition of Mt. Spokane's forests on how it changes over time as well as more information for FFE-FVS (USFS, 2023).

Limitations of Field Work, Sampling, and FVS Simulations

Restrictions due to COVID-19, weather, and poor or no road access caused the north and southeast parts of the park to have limited coverage. For the northern half of the park, there was limited access due to closed gates, washouts on roads, and private properties surrounding all sides by state park. Some parts of the north face of the mountain were especially steep with rock fields making hiking to plots too hazardous. With the southeastern part of the park where the Ragged Ridge Natural Area Preserve is located closest to the Idaho state line, it was extremely steep on either side of the trail with pitfalls informed by park staff. To have addressed some of these limitations of access before the first day of data collection, more scoping of the forest types and access points should have been done beforehand. One instance where this would have been beneficial is in the effort to find trees that have fire scars as much of the lower elevation stands in the park were young to middle-aged forests due to past logging activity making that difficult.

Although wildlife did not stop collection of data in the park, it was a safety concern if not prepared properly for encounters. There were several moose and bear encounters when out in the field, especially on days where the summit was closed to the public as well when working in plots far from roads and trails. Of the 151 plots established to collect data from, 10 of the plots did not have fuel data collected due to early snowfall in September 2019. The ground was not clearly visible and on some days the snow was deeper than a foot making counting of fuels not possible without actively disturbing original conditions.

Whilst there is a lot that can be done with FVS, there are a lot of limitations and unknowns from the outputs simulated with the program. FVS is a useful tool to make broad estimations, but it is still a simulation that does not account for environmental changes and factors that happen outside of the stand data that is entered (Johnson et al., 2007). With the base model not accounting for environmental changes, that means possibly in 60 years certain tree species initially measured in the plots in the field seasons of 2019 and 2020 might no longer be compatible where they are currently with changing climatic conditions (Crookston & Dixon, 2005). Trees can become maladapted to local environments when climate changes with instances of different species establishing dominance where not before. High elevation species like subalpine fir for example are experiencing their tree line shift higher and higher in elevation (Cansler et al., 2018; Krawchuk et al., 2009; Higuera, 2021). Another concern for this species outside of the upward shift of their range is these subalpine dominated forests represented in grouping 4, Rocky Mountain Subalpine Dry-Mesic Spruce-Fir Forest, in this study are now burning more than at any point in the past 2,000 years (Higuera, 2021). Bringing this back to the implications of management, with this shift of ranges and increase in burning seen in higher elevation forests, management decisions will need to account for the effect of climate change on species distribution and fire regimes (Mckenzie et al., 2004; Demeo et al., 2012). Some of those effects include a water deficit in the summer with warmer and drier conditions as well as water not being stored as long as snowpack in the region (Littell et al., 2013; Littell et al., 2016). These effects lead to patterns of warming and drought which makes uncertain the benefits of fuel treatments over time. These treatments are also often costly so having these projected worsening conditions will need to be accounted for as this investment may not pay off or have a limited time window as large fires are still occurring in treated stands (Schoennagel, et al. 2017). Looking at the already high fire hazard in the park under the simulated severe fire conditions, the impacts of wind and temperature coupled with projected drought would have devastating effects (Littell et al, 2016).

Changes in climate or disturbances, natural or human, can cause multiple pathways of succession for plant communities (Donato et al., 2012; Fastie, 1995; Moritz et al., 2012). The forest's of Mt. Spokane may have looked different in the past or will in the future as both small or transient environmental changes and human-caused disturbances can have large and long-lasting vegetation changes (Littell, et al., 2010; Spruegel, 1991; Tepley et al., 2013).

FVS is not able to accurately predict the successional structural complexity of stands over time, especially as stands are so diverse in their ages and species makeup in Mt. Spokane. There is an extension for the software, Climate-FVS, which takes inputs that define current and future climate as well as tree viability scores into account for the equations that define growth, mortality and regeneration potential although there are limitations as well (Crookston, 2014).

FFE-FVS also nominally represents the shrub and herbaceous regeneration with their contribution to smoke and fuel when in reality they contribute significantly to fire behavior due to the software basing it off of the fuel model selected and not actual conditions (Rebain et al., 2022; Stephan et al., 2010). While the FVS model simulates growth and mortality in cycles of 10 years with 20 years being selected in this study to look further into the future, FFE is on a 1-year cycle (Johnson et al., 2007). This is an issue when combining the two steps and may not accurately represent what would happen when adding in a fire event (Reinhardt & Crookston, 2003). In the future, choosing a shorter cycle can somewhat compensate for the problem of having two different cycle lengths between the base program and extension (Johnson et al., 2007). Another weakness of the models used within FFE-FVS is that they have limited ability to predict consumption of specific fuel bed categories like litter and duff, downed logs, and tree crowns if interested in their greenhouse gas contribution during a fire event (Ottmar, 2014). This is important especially when looking at small woody fuels as they influence fire's rate of spread and intensity as they carry the flame front. This is due to their size as they lose their moisture fast in warmer conditions making them start and burn more easily (Agee, 1993; Prichard et al., 2010).

Outside of these limitations, there are the ones directly related to fire variables that are outputted. Slope, aspect, vegetation structure and composition are primary influences on fire behavior when combined with wind which was seen with fire hazard under moderate and severe fire conditions (Butler et al., 2007; Keane et al., 2011). FFE-FVS is a stand level model and is not sensitive to spatially dependent fire behavior meaning it's only looking at what you inputted and not how fire would move outside of it (Reinhardt & Crookston, 2003). With many of the vegetation communities in the park expected to have longer fire-return intervals, topography has a strong influence as to the spatial variation that is seen in historical fire regimes of the Northern Rockies (Cansler, 2011; McKenzie, 2004). Slope and aspect were included in the FVS runs for each plot, but with FFE-FVS being a stand level model, this means it is not looking at what would happen if a fire moved into the plot. The outside influences presented before can greatly impact how fire enters the plots meaning FFE-FVS may be underestimating the impacts of fire on plots. For example, if the plot was on a flatter piece of ground higher in elevation than a steeper part of the park (Johnson et al., 2007). If a fire were to come from below up the steeper slope, it would result in a faster moving fire with taller flame lengths which could have a devastating impact on that plot that would not be recognized in FFE-FVS (Butler et al., 2007).

Potential Future Work

With over 151 plots of data, there is additional work that can be done to explore the historical context, current conditions, and future of wildfire in Mt. Spokane State Park. When looking at the historical context of fire in the park, more work could have been done with tree coring. As only four cores collected had fire scars, an effort could be made to core trees that predispose harvesting in the park even on trees located outside of plots. By doing so, getting more observations to reconstruct a more localized fire regime as they can vastly vary across short distances (Heyerdahl, et al. 1995). It can also be used as a reference to show how humans have impacted the dynamics of natural fire regimes within the park as the cores collected in this study only had an average age of just under 100 even when intentionally coring larger diameter trees (Mckenzie, 2015).

Tree growth is affected by variations in climate which can be seen in the size and width between rings (Fritts, 1976). Additional work could be done in the future with the 62 mounted tree cores to match the tree ring patterns among them which is called crossdating and examining the widths of the rings to compare with meteorological records to reconstruct the climate of Mt. Spokane. In doing so, following a more established dendrochronology protocol for future coring such as coring trees twice from opposing radii to look at climatic information taken from examining the rings more thoroughly outside of just aging (Dean et al., 1973; Johnston et al., 2017).

Tree seedlings were recorded as supplemental data, but no analysis was done with them. They can be entered into FFE-FVS if their biomass estimates were included as part of the surface and canopy fuels inputted, but there are issues when doing so. One example of those issues is including them as canopy fuel can lower average cbh values increasing the tendency of making all potential fires crowns fires. That can be unrealistic if there was a large gap in heights between the measured seedings and trees (Brown, 1982; Noonan-Wright & Vaillant, 2014). Something that could be looked at is seeing if there is a relationship between species found and their abundance relative to the density of the plot they were recorded in (Gray & Spies, 1996).

Finally, another worthwhile endeavor is looking outside just wildfire hazard which in this study is determined by potential crown fire and flame length. Wildfire risk could be addressed by looking at the interactions among how fire would spread outside of the stand level approach that FFE-FVS takes by including interest values like proximity to roads and buildings and/or prime wildlife habitat for example (Calkin et al. 2010). There are a lot of different fire models out there attempting to address the variety of concerns surrounding wildfire and the tools utilizing them are continually being modified so a lot can still be done with the data collected to take a more landscape approach than what was done in this study that focused only on the park (Stephens et al., 2012).

Conclusion

Through the interpretation of historical records, tree cores, and collected plot data, the historical context, the current risk and future implications wildfire brings to Mt. Spokane State Park was addressed. When looking at the historical context of fire within the park, wildfire has helped shape the landscape in and around Mt. Spokane with this study showing smaller fire events have occurred in the last 100 years through tree coring. Past harvesting activities complicated finding trees that had experienced fire events before the park was established. Furthermore, for conditions in the park under the do nothing scenario, most of the park is expected to experience crown fires of varying intensity under severe fire conditions over time. This is due to the diversity in topography, fuel conditions, and vegetation composition and structure found in Mt. Spokane State Park. This variation caused by both natural and human disturbances in the past has created a mosaic pattern of fire effects which can be further amplified by projected climate change effects in the future.

Although there were varying fire types expressed across the park, the dominant fire type was conditional crown fire for plots in Mt. Spokane under the do nothing and management scenarios with a shift to active crown fire in 2079 if a fire event were to happen 40 years prior. The dominance of conditional crown fires seen at this park is due to the high canopy base height and canopy bulk density of the stands. FFE-FVS outputs also indicated that removing at least 40% basal area from trees 0-20 inches did have an impact on reducing active crown fire and flame length over time, but additional fuel treatments may be necessary 20-30 years after initial treatment. This is due to many fuel and stand variables losing significance in that timeframe when the management and fire and do nothing and fire scenarios were compared. The treatment selected for this work has potential to inform management decisions aimed at reducing the risk of a stand replacement fire, but managing for resilience along with other WSPRC management goals will look more varied and site-specific than the approach taken here.

When determining where to prioritize future management, the lower elevation mixed-conifer forests represented in grouping 2 are a priority for future management due to their high flame lengths, crown fire type, and location along the main road of the park. These forests were also statistically different to the other vegetation groupings of Mt. Spokane when examining stand structure variables of interest although fuels were much more variable across the park. The information presented in this study along with the establishment of permanent monitoring plots across Mt. Spokane State Park can inform managers of potential fire hazard and forest conditions across the park over time as well as assist in where to prioritize future management for reduction of wildfire hazard. To further the work in this study, prioritizing future coring in remaining mature and old growth stands to determine a more localized historical fire regime as well as testing other types of management in FVS over time would be beneficial.

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Appendix A: Plot Photos Representative of the Four Dominate USNVC Groupings

Grouping 1: Northern Rocky Mountain Dry- Mesic Montane Mixed Conifer Forest

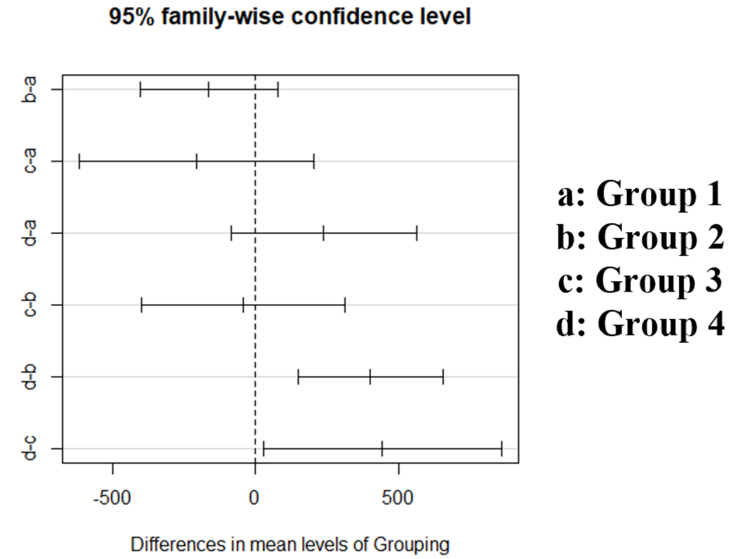
Grouping 2: Northern Rocky Mountain Mesic Montane Mixed Conifer Forest

Grouping 3: Rocky Mountain Lodgepole Pine Forest

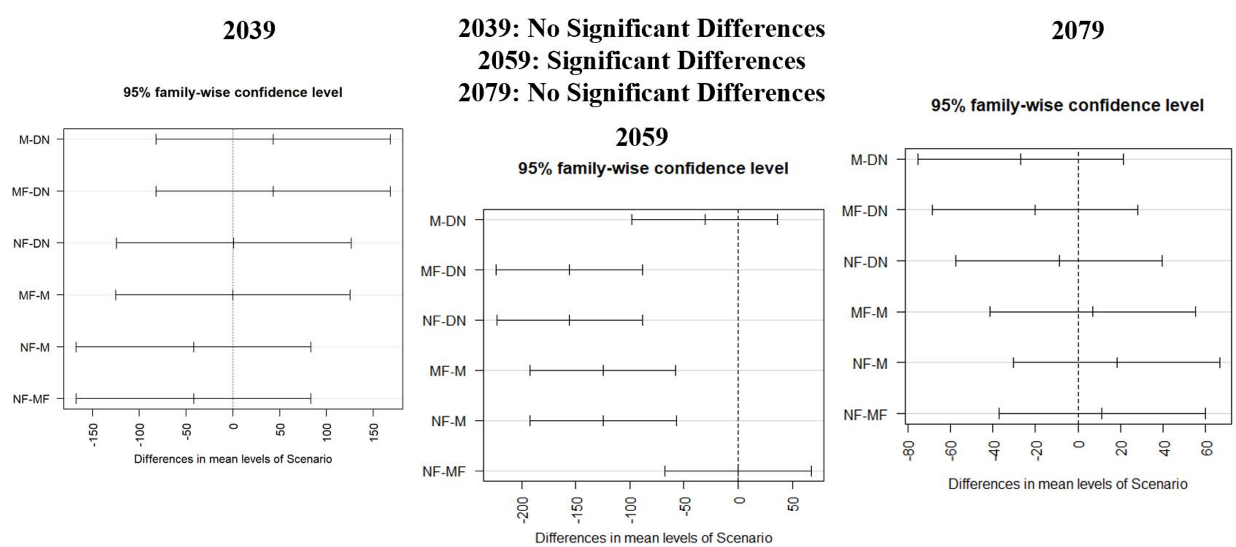
Grouping 4: Rocky Mountain Subalpine Dry-Mesic Spruce-Fire Forest and Woodland

Appendix B: Stand Structure Variables Significance Between Groups and Treatments

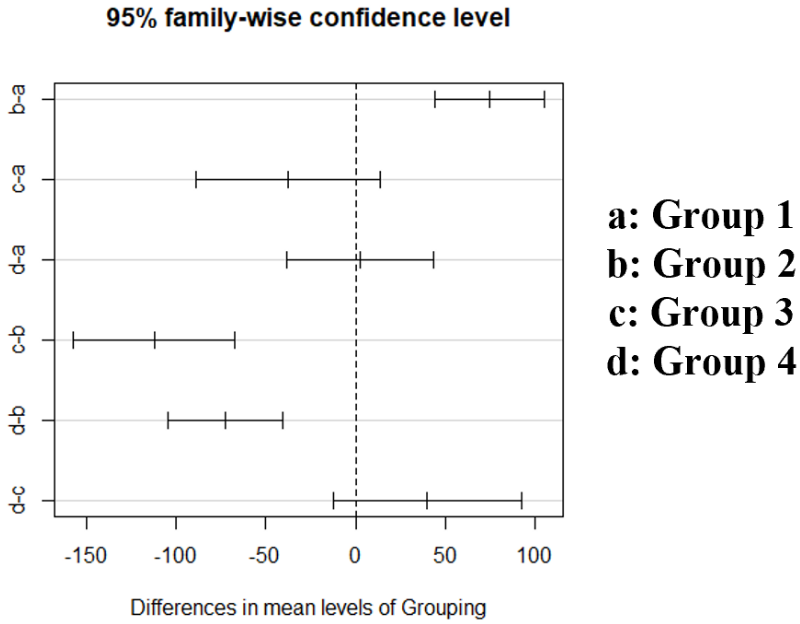
Figures and Tables



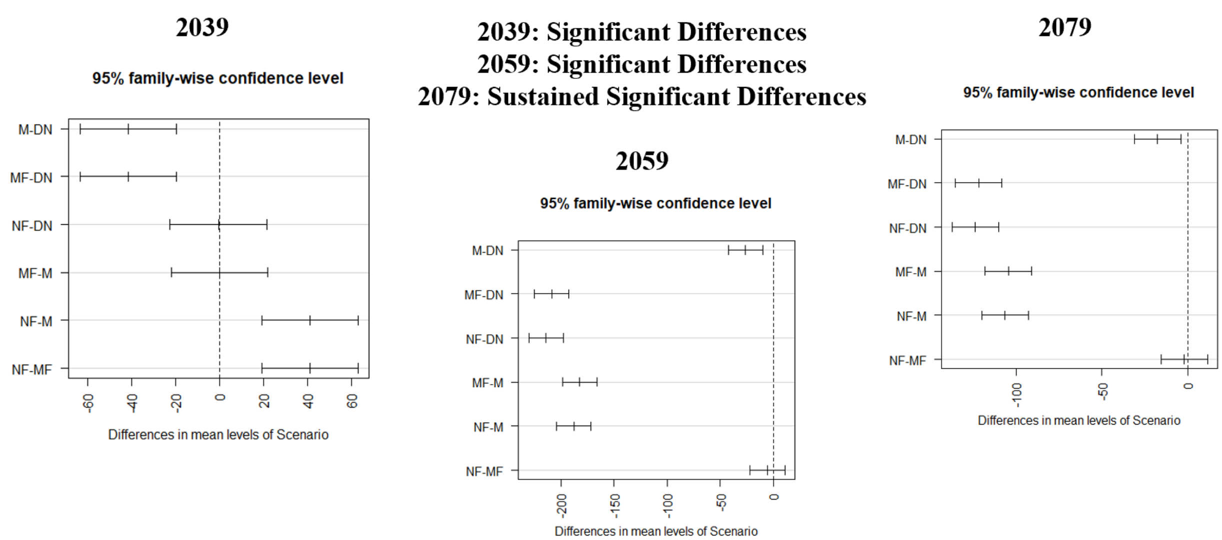
B.1 TPA. Tukey Honest Significant Difference (HSD) Test with multiple comparisons between USNVC groupings to determine if the means between trees per acre values are significantly different in 2019.



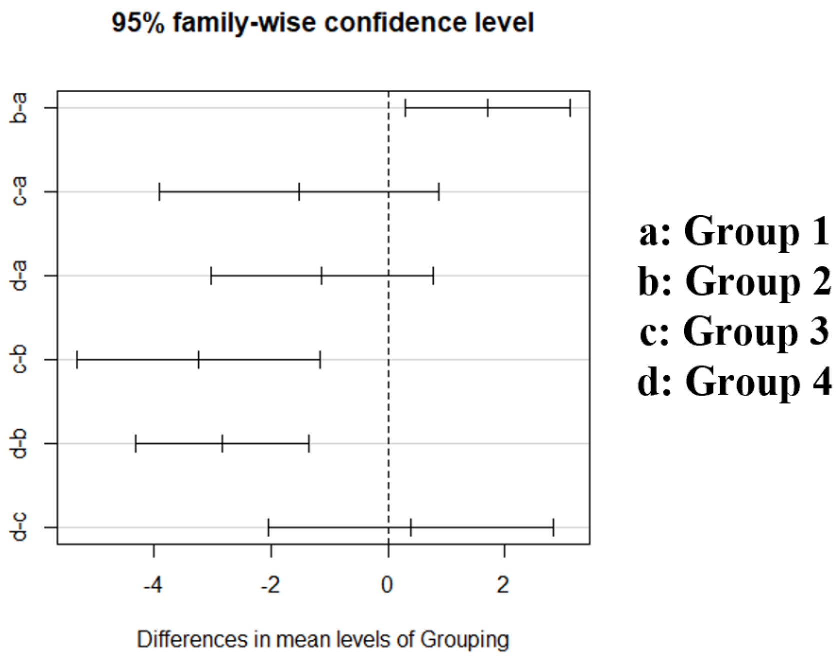
B.2 TPA. Tukey Honest Significant Difference (HSD) Test with multiple comparisons between scenarios to determine if the means between trees per acre values are significantly different in the years 2039, 2059, and 2079. Scenarios are as what follows: DN=Do Nothing, M=Management, MF= Management + Fire, NF= Do Nothing + Fire.



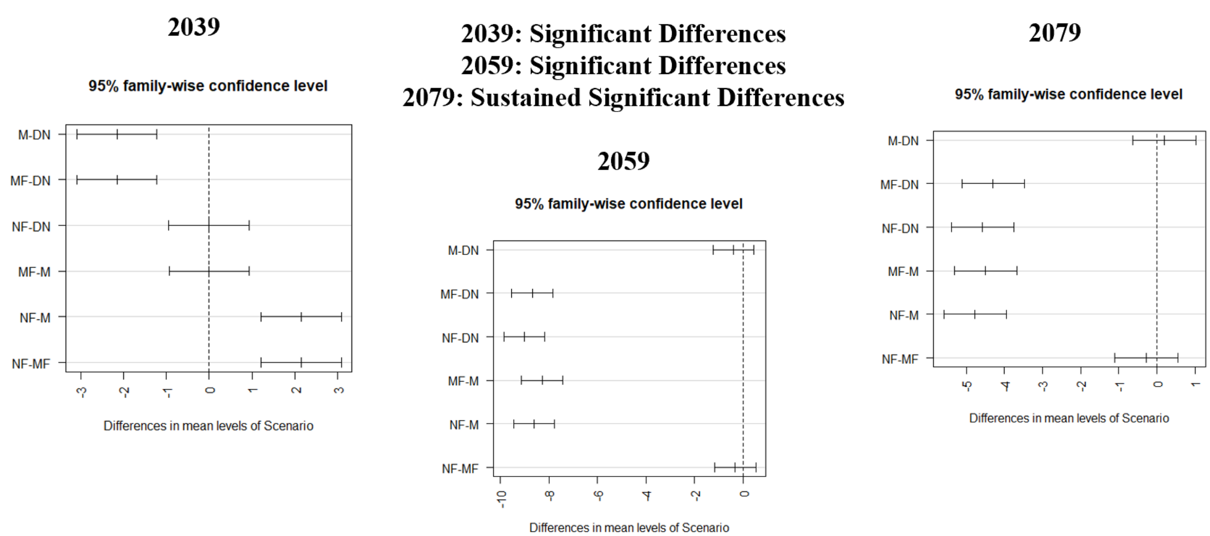
B.3 Basal Area. Tukey Honest Significant Difference (HSD) Test with multiple comparisons between USNVC groupings to determine if the means between basal area (ft2/acre) values are significantly different in 2019.



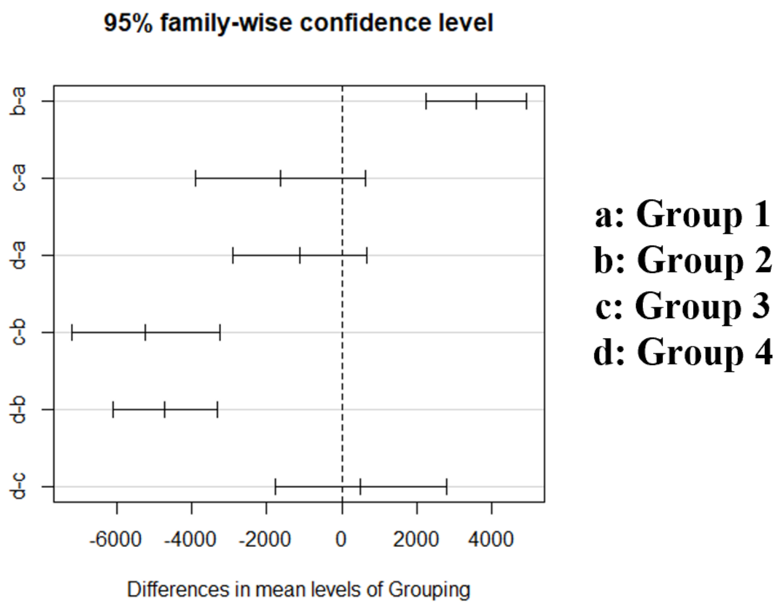
B.4 Basal Area. Tukey Honest Significant Difference (HSD) Test with multiple comparisons between scenarios to determine if the means between basal area (ft2/acre) values are significantly different in the years 2039, 2059, and 2079. Scenarios are as what follows: DN=Do Nothing, M=Management, MF= Management + Fire, NF= Do Nothing + Fire.



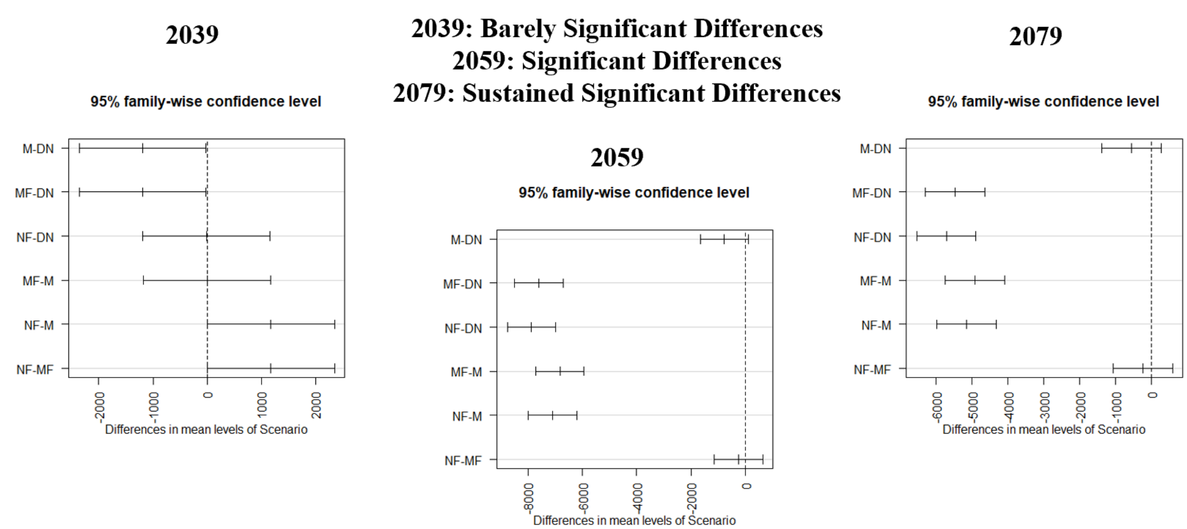
B.5 Quadratic Mean Diameter. Tukey Honest Significant Difference (HSD) Test with multiple comparisons between USNVC groupings to determine if the means between quadratic mean diameter values are significantly different in 2019.



B.6 Quadratic Mean Diameter. Tukey Honest Significant Difference (HSD) Test with multiple comparisons between scenarios to determine if the means between quadratic mean diameter values are significantly different in the years 2039, 2059, and 2079. Scenarios are as what follows: DN=Do Nothing, M=Management, MF= Management + Fire, NF= Do Nothing + Fire.



B.7 Total Cubic Foot Volume. Tukey Honest Significant Difference (HSD) Test with multiple comparisons between USNVC groupings to determine if the means between total cubic foot volume (cu ft) values are significantly different in 2019.



B.8 Total Cubic Foot Volume. Tukey Honest Significant Difference (HSD) Test with multiple comparisons between scenarios to determine if the means between total cubic foot volume (cu ft) values are significantly different in the years 2039, 2059, and 2079. Scenarios are as what follows: DN=Do Nothing, M=Management, MF= Management + Fire, NF= Do Nothing + Fire.

B.9 Table. Tukey Honest Significant Difference (HSD) Test outputs with multiple comparisons between USNVC groupings to determine if structure variables values are significantly different in 2019.

Stand Structure Variable	Grouping Comparisons	Difference in Means	Lower	Upper	p-value
Trees Per Acre	b-a	-162.47	-404.31	79.37	0.31
	c-a	-204.93	-614.36	204.50	0.57
	d-a	238.08	-86.24	562.40	0.23
	c-b	-42.46	-398.53	313.60	0.99
	d-b	400.55	146.91	654.19	0.00*
	d-c	443.01	26.51	859.52	0.03*
Basal Area	b-a	74.52	44.13	104.91	0.00*
	c-a	-37.59	-89.04	13.86	0.24
	d-a	2.33	-38.42	43.09	1.00
	c-b	-112.11	-156.86	-67.37	0.00*
	d-b	-72.19	-104.06	-40.31	0.00*
	d-c	39.93	-12.41	92.27	0.20
Quadratic Mean Diameter	b-a	1.70	0.29	3.12	0.01*
	c-a	-1.52	-3.92	0.87	0.36
	d-a	-1.13	-3.02	0.77	0.42
	c-b	-3.23	-5.31	-1.15	0.00*
	d-b	-2.83	-4.31	-1.35	0.00*
	d-c	0.40	-2.03	2.83	0.97
Total Cubic Foot Volume	b-a	3592.95	2260.17	4925.73	0.00*
	c-a	-1632.04	-3888.36	624.28	0.25
	d-a	-1121.38	-2908.65	665.90	0.37
	c-b	-5224.99	-7187.23	-3262.74	0.00*
	d-b	-4714.33	-6112.10	-3316.56	0.00*
	d-c	510.66	-1784.65	2805.97	0.94

Significance at p<0.05 displayed with an asterisk, a= Grouping 1, b= Grouping 2, c= Grouping 3, and d= Grouping 4.

B.10 Table. Tukey Honest Significant Difference (HSD) Test with multiple comparisons between scenarios to determine if the means of structure variable values are significantly different in the years 2039, 2059, and 2079.

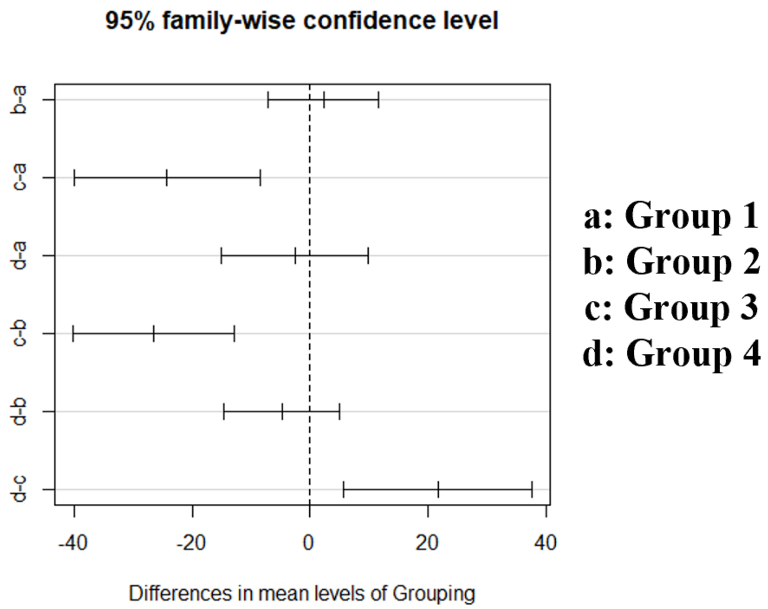
Stand Structure Variable	Year	Scenario Comparisons	Difference in Means	lower	upper	p-value
Trees Per Acre	2039	M-DN	4.30E+01	-82.248	168.209	0.813
	2039	MF-DN	4.30E+01	-82.248	168.209	0.813
	2039	NF-DN	1.03E+00	-124.409	126.465	1.000
	2039	MF-M	-1.14E-13	-125.229	125.229	1.000
	2039	NF-M	-4.20E+01	-167.389	83.485	0.825
	2039	NF-MF	-4.20E+01	-167.389	83.485	0.825
	2059	M-DN	-30.940	-98.473	36.592	0.640
	2059	MF-DN	-155.954	-223.486	-88.421	0.000*
	2059	NF-DN	-155.735	-223.268	-88.202	0.000*
	2059	MF-M	-125.013	-192.546	-57.481	0.000*
	2059	NF-M	-124.795	-192.327	-57.262	0.000*
	2059	NF-MF	0.219	-67.314	67.751	1.000
	2079	M-DN	-30.940	-98.473	36.592	0.640
	2079	MF-DN	-155.954	-223.486	-88.421	0.000*
	2079	NF-DN	-155.735	-223.268	-88.202	0.000*
	2079	MF-M	-125.013	-192.546	-57.481	0.000*
	2079	NF-M	-124.795	-192.327	-57.262	0.000*
	2079	NF-MF	0.219	-67.314	67.751	1.000
Basal Area	2039	M-DN	-4.15E+01	-63.376	-19.684	0.000*
	2039	MF-DN	-4.15E+01	-63.376	-19.684	0.000*
	2039	NF-DN	-4.56E-01	-22.338	21.427	1.000
	2039	MF-M	1.14E-13	-21.846	21.846	1.000
	2039	NF-M	4.11E+01	19.192	62.956	0.000*

	2039	NF-MF	4.11E+01	19.192	62.956	0.000*
	2059	M-DN	-26.245	-42.554	-9.936	0.000*
	2059	MF-DN	-206.775	-255.084	-192.466	0.000*
	2059	NF-DN	-214.185	-230.494	-197.876	0.000*
	2059	MF-M	-182.530	-198.839	-166.221	0.000*
	2059	NF-M	-187.940	-204.249	-171.631	0.000*
	2059	NF-MF	-5.411	-21.720	10.898	0.828
	2079	M-DN	-17.470	-31.043	-3.897	0.005*
	2079	MF-DN	-121.801	-135.374	-108.229	0.000*
	2079	NF-DN	-123.781	-137.354	-110.209	0.000*
	2079	MF-M	-104.331	-117.904	-90.758	0.000*
	2079	NF-M	-106.311	-119.884	-92.738	0.000*
	2079	NF-MF	-1.980	-15.553	11.593	0.982
Quadratic Mean Diameter	2039	M-DN	-2.15E+00	-3.091	-1.216	0.000*
	2039	MF-DN	-2.15E+00	-3.091	-1.216	0.000*
	2039	NF-DN	-1.03E-02	-0.949	0.929	1.000
	2039	MF-M	3.55E-15	-0.938	0.938	1.000
	2039	NF-M	2.14E+00	1.204	3.082	0.000*
	2039	NF-MF	2.14E+00	1.204	3.082	0.000*
	2059	M-DN	-0.403	-1.253	0.446	0.613
	2059	MF-DN	-8.690	-9.540	-7.841	0.000*
	2059	NF-DN	-9.020	-9.869	-8.171	0.000*
	2059	MF-M	-8.287	-9.136	-7.438	0.000*
	2059	NF-M	-8.617	-9.466	-7.767	0.000*
	2059	NF-MF	-0.330	-1.179	0.520	0.749
	2079	M-DN	0.198	-0.623	1.020	0.925
	2079	MF-DN	-4.292	-5.114	-3.471	0.000*

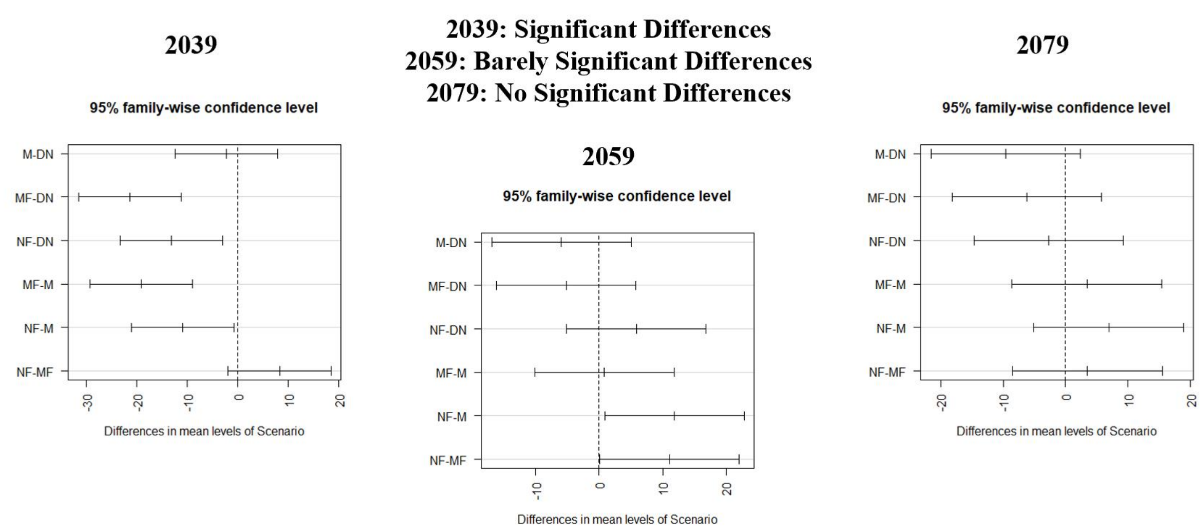
	2079	NF-DN	-4.571	-5.392	-3.749	0.000*
	2079	MF-M	-4.491	-5.312	-3.669	0.000*
	2079	NF-M	-4.769	-5.591	-3.947	0.000*
	2079	NF-MF	-0.279	-1.100	0.543	0.819
Total Cubic Foot Volume	2039	M-DN	-1.19E+03	-2364.111	-15.995	0.046*
	2039	MF-DN	-1.19E+03	-2364.111	-15.995	0.046*
	2039	NF-DN	-1.33E+01	-1189.274	1162.752	1.000
	2039	MF-M	1.82E-12	-1174.058	1174.058	1.000
	2039	NF-M	1.18E+03	0.779	2352.805	0.050*
	2039	NF-MF	1.18E+03	0.779	2352.805	0.050*
	2059	M-DN	-779.748	-1671.639	112.142	0.111
	2059	MF-DN	-7604.007	-8495.897	-6712.116	0.000*
	2059	NF-DN	-7863.795	-8755.685	-6971.904	0.000*
	2059	MF-M	-6824.258	-7716.149	-5932.368	0.000*
	2059	NF-M	-7084.046	-7975.937	-6192.156	0.000*
	2059	NF-MF	-259.788	-1151.679	632.102	0.876
	2079	M-DN	-555.894	-1383.699	271.911	0.309
	2079	MF-DN	-5477.636	-6305.441	-4649.831	0.000*
	2079	NF-DN	-5718.940	-6546.745	-4891.135	0.000*
	2079	MF-M	-4921.742	-5749.547	-4093.937	0.000*
	2079	NF-M	-5163.046	-5990.851	-4335.241	0.000*
	2079	NF-MF	-241.305	-1069.110	586.501	0.876

Significance at $p<0.05$ displayed with an asterisk. Scenarios are as what follows: DN=Do Nothing, M=Management, MF= Management and Fire, NF= Do Nothing and Fire.

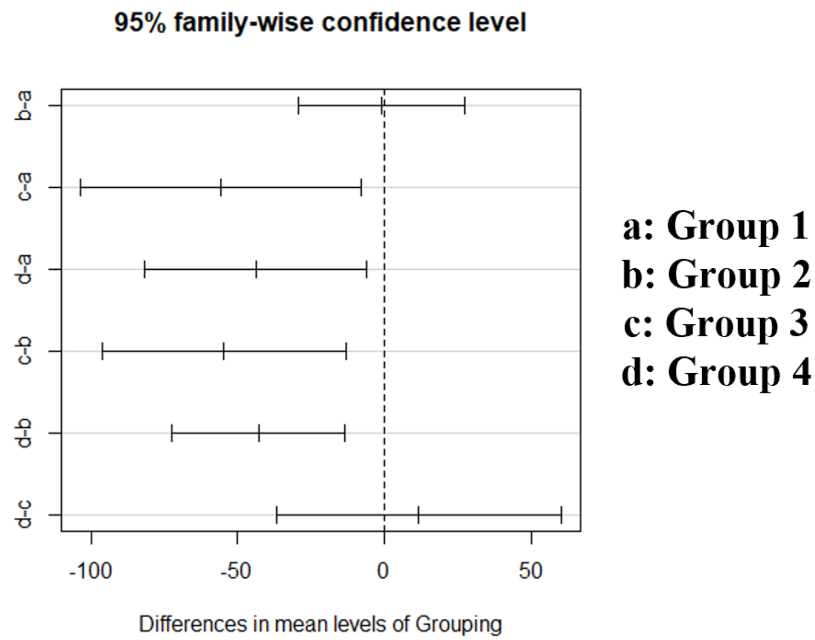
Appendix C: Fuel Variables Significance Between Groups and Treatments Figures and Tables



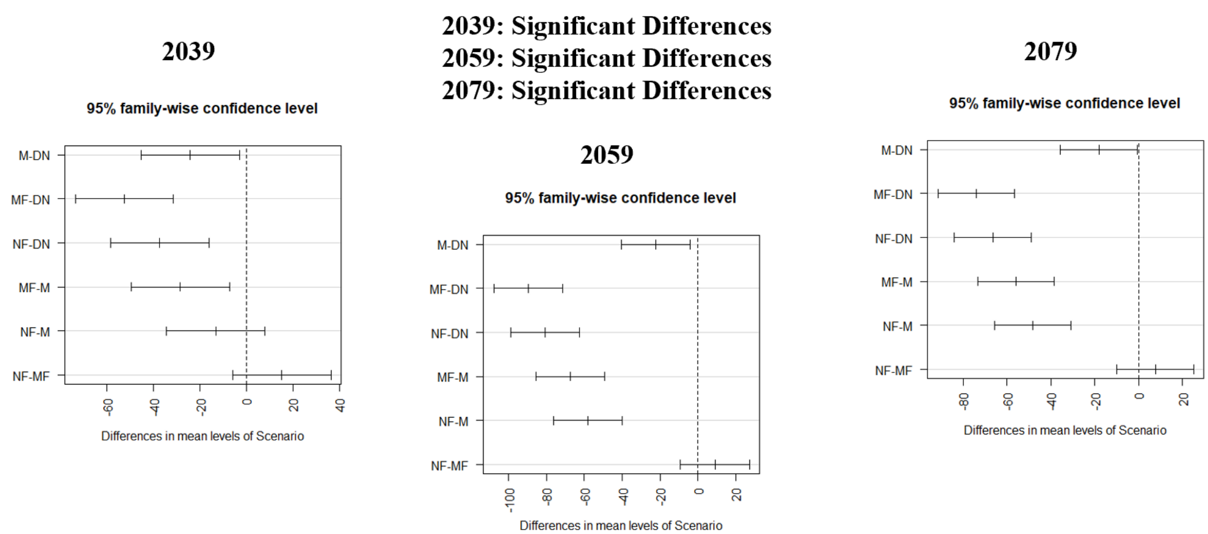
C.1 Surface Total. Tukey Honest Significant Difference (HSD) Test with multiple comparisons between USNVC groupings to determine if the means between surface total (tons/acre) values are significantly different in 2019.



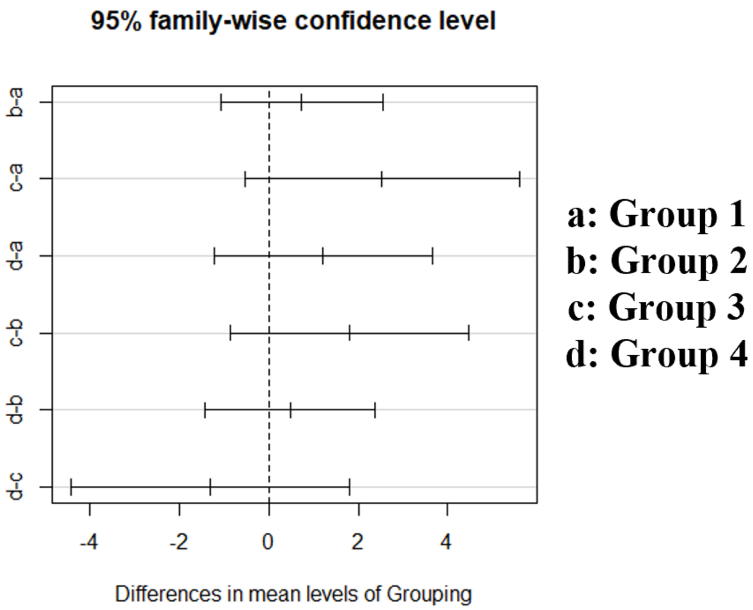
C.2 Surface Total. Tukey Honest Significant Difference (HSD) Test with multiple comparisons between scenarios to determine if the means between surface total (tons/acre) values are significantly different in the years 2039, 2059, and 2079. Scenarios are as what follows: DN=Do Nothing, M=Management, MF= Management + Fire, NF= Do Nothing + Fire.



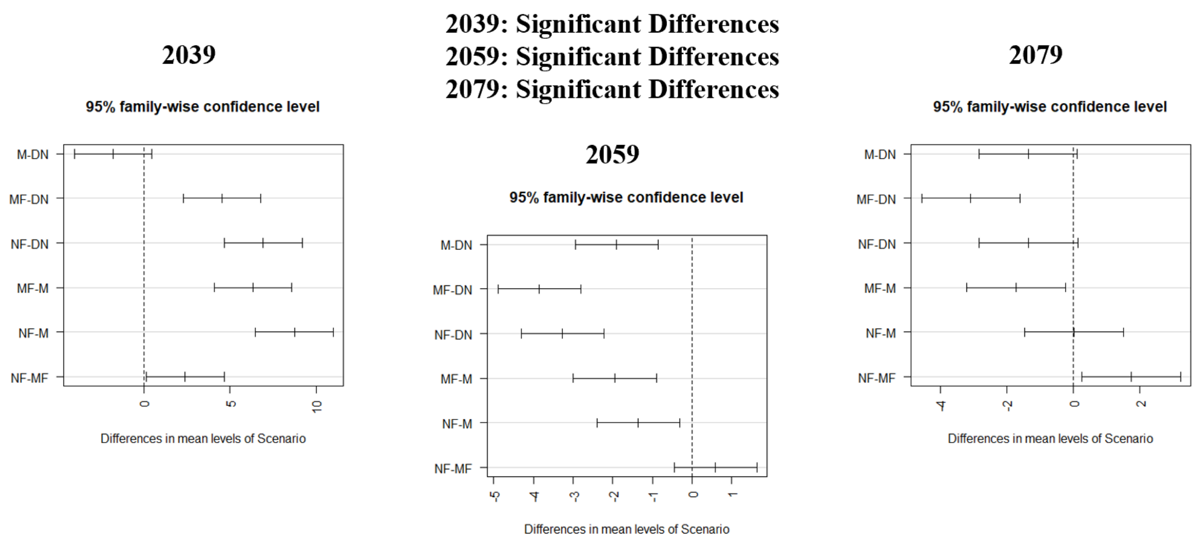
C.3 Standing Total. Tukey Honest Significant Difference (HSD) Test with multiple comparisons between USNVC groupings to determine if the means between standing total (tons/acre) values are significantly different in 2019.



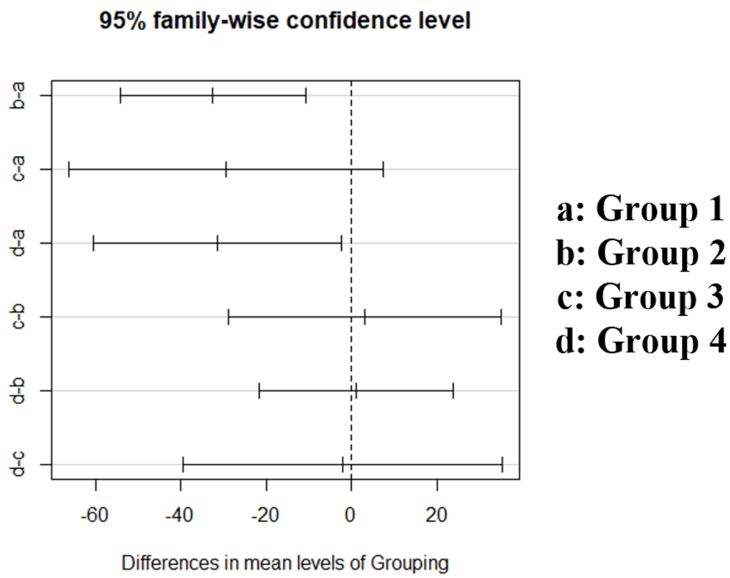
C.4 Standing Total. Tukey Honest Significant Difference (HSD) Test with multiple comparisons between scenarios to determine if the means between standing total (tons/acre) values are significantly different in the years 2039, 2059, and 2079. Scenarios are as what follows: DN=Do Nothing, M=Management, MF= Management + Fire, NF= Do Nothing + Fire.



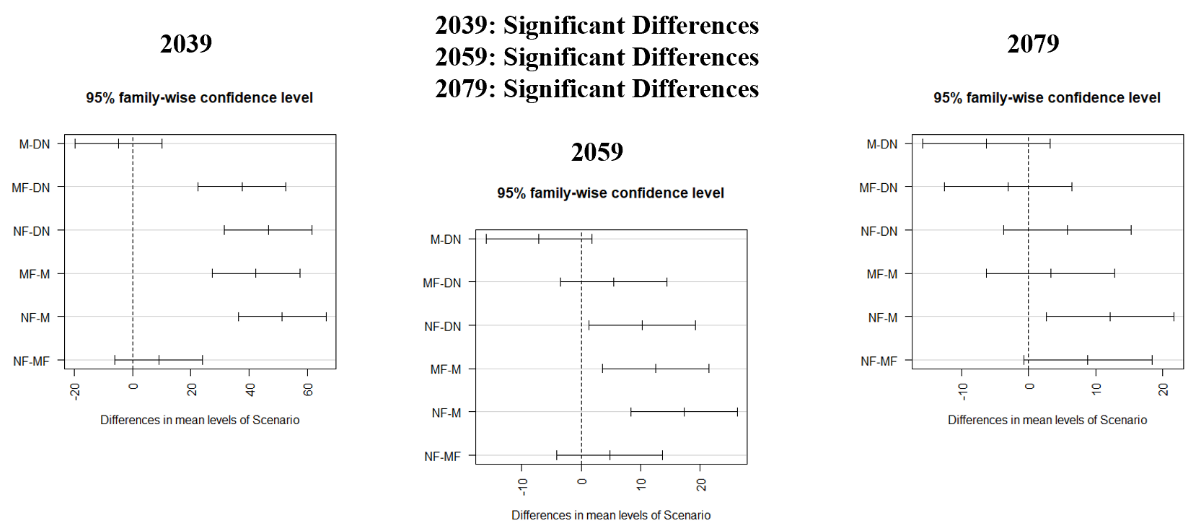
C.5 Snags ≤ 3in. Tukey Honest Significant Difference (HSD) Test with multiple comparisons between USNVC groupings to determine if the means between snags ≤ 3 inches (tons/acre) values are significantly different in 2019.



C.6 Snags ≤ 3in. Tukey Honest Significant Difference (HSD) Test with multiple comparisons between scenarios to determine if the means between snags ≤ 3 inches (tons/acre) values are significantly different in the years 2039, 2059, and 2079. Scenarios are as what follows: DN=Do Nothing, M=Management, MF= Management + Fire, NF= Do Nothing + Fire.



C.7 Snags > 3in. Tukey Honest Significant Difference (HSD) Test with multiple comparisons between USNVC groupings to determine if the means between snags > 3 inches (tons/acre) values are significantly different in 2019.



C.8 Snags > 3in. Tukey Honest Significant Difference (HSD) Test with multiple comparisons between scenarios to determine if the means between snags > 3 inches (tons/acre) values are significantly different in the years 2039, 2059, and 2079. Scenarios are as what follows: DN=Do Nothing, M=Management, MF= Management + Fire, NF= Do Nothing + Fire.

C.9 Table. Tukey Honest Significant Difference (HSD) Test outputs with multiple comparisons between USNVC groupings to determine if fuel variables are significantly different in 2019.

Fuel Variable	Grouping Comparisons	Difference in Means	Lower	Upper	p-value
Surface Total	b-a	2.250	-7.039	11.538	0.924
	c-a	-24.246	-39.971	-8.521	0.000*
	d-a	-2.564	-15.020	9.892	0.952
	c-b	-26.495	-40.171	-12.820	0.000*
	d-b	-4.813	-14.555	4.928	0.581
	d-c	21.682	5.686	37.678	0.003*
Standing Total	b-a	-0.936	-29.188	27.316	1.000
	c-a	-55.564	-103.393	-7.736	0.015*
	d-a	-43.776	-81.661	-5.890	0.016*
	c-b	-54.628	-96.223	-13.033	0.001*
	d-b	-42.840	-72.469	-13.210	0.001*
	d-c	11.789	-36.866	60.444	0.924
Snags ≤ 3in	b-a	0.735	-1.076	2.545	0.723
	c-a	2.534	-0.531	5.598	0.145
	d-a	1.221	-1.207	3.648	0.566
	c-b	1.799	-0.866	4.464	0.304
	d-b	0.486	-1.412	2.385	0.912
	d-c	-1.313	-4.431	1.804	0.699
Snags > 3in	b-a	-32.574	-54.292	-10.856	0.001*
	c-a	-29.450	-66.217	7.317	0.166
	d-a	-31.499	-60.623	-2.375	0.028*
	c-b	3.124	-28.851	35.099	0.994
	d-b	1.075	-21.702	23.852	0.999
	d-c	-2.049	-39.451	35.354	0.999

Significance at $p<0.05$ displayed with an asterisk, a= Grouping 1, b= Grouping 2, c= Grouping 3, and d= Grouping 4.

C.10 Table. Tukey Honest Significant Difference (HSD) Test with multiple comparisons between scenarios to determine if the means of fuel variables are significantly different in the years 2039, 2059, and 2079.

Fuel Variable	Year	Scenario Comparisons	Difference in Means	Lower	Upper	p-value
Surface Total	2039	M-DN	-2.237	-12.401	7.927	0.942
	2039	MF-DN	-21.410	-31.574	-11.246	0.000*
	2039	NF-DN	-13.136	-23.317	-2.955	0.005*
	2039	MF-M	-19.174	-29.338	-9.009	0.000*
	2039	NF-M	-10.899	-21.080	-0.718	0.030*
	2039	NF-MF	8.274	-1.907	18.456	0.156
	2059	M-DN	-5.968	-16.948	5.013	0.500
	2059	MF-DN	-5.172	-16.152	5.808	0.618
	2059	NF-DN	5.879	-5.101	16.859	0.513
	2059	MF-M	0.795	-10.185	11.775	0.998
	2059	NF-M	11.847	0.867	22.827	0.029*
	2059	NF-MF	11.052	0.071	22.032	0.048*
	2079	M-DN	-9.610	-21.576	2.355	0.164
	2079	MF-DN	-6.205	-18.171	5.760	0.540
	2079	NF-DN	-2.704	-14.670	9.261	0.937
	2079	MF-M	3.405	-8.561	15.371	0.884
	2079	NF-M	6.906	-5.060	18.872	0.446
	2079	NF-MF	3.501	-8.465	15.467	0.875
Standing Total	2039	M-DN	-24.146	-45.295	-2.996	0.018*
	2039	MF-DN	-52.543	-73.693	-31.393	0.000*
	2039	NF-DN	-37.276	-58.461	-16.091	0.000*
	2039	MF-M	-28.397	-49.547	-7.248	0.003*
	2039	NF-M	-13.131	-34.316	8.054	0.381
	2039	NF-MF	15.267	-5.918	36.452	0.248

	2059	M-DN	-22.358	-40.589	-4.126	0.009*
	2059	MF-DN	-89.768	-107.999	-71.537	0.000*
	2059	NF-DN	-80.662	-98.893	-62.431	0.000*
	2059	MF-M	-67.411	-85.642	-49.179	0.000*
	2059	NF-M	-58.305	-76.536	-40.074	0.000*
	2059	NF-MF	9.106	-9.125	27.337	0.572
	2079	M-DN	-18.132	-35.594	-0.670	0.038*
	2079	MF-DN	-74.113	-91.575	-56.651	0.000*
	2079	NF-DN	-66.503	-83.965	-49.041	0.000*
	2079	MF-M	-55.980	-73.442	-38.518	0.000*
	2079	NF-M	-48.371	-65.833	-30.909	0.000*
	2079	NF-MF	7.609	-9.853	25.071	0.676
Snags ≤ 3in	2039	M-DN	-1.805	-4.056	0.445	0.165
	2039	MF-DN	4.532	2.281	6.782	0.000*
	2039	NF-DN	6.937	4.683	9.192	0.000*
	2039	MF-M	6.337	4.086	8.587	0.000*
	2039	NF-M	8.742	6.488	10.997	0.000*
	2039	NF-MF	2.406	0.151	4.660	0.031*
	2059	M-DN	-1.907	-2.951	-0.862	0.000*
	2059	MF-DN	-3.854	-4.899	-2.810	0.000*
	2059	NF-DN	-3.266	-4.311	-2.222	0.000*
	2059	MF-M	-1.948	-2.992	-0.903	0.000*
	2059	NF-M	-1.360	-2.404	-0.315	0.005*
	2059	NF-MF	0.588	-0.456	1.633	0.468
	2079	M-DN	-1.358	-2.839	0.122	0.085
	2079	MF-DN	-3.078	-4.558	-1.597	0.000*
	2079	NF-DN	-1.342	-2.822	0.138	0.091

	2079	MF-M	-1.719	-3.200	-0.239	0.015*
	2079	NF-M	0.016	-1.464	1.497	1.000
	2079	NF-MF	1.736	0.255	3.216	0.014*
Snags > 3in	2039	M-DN	-4.820	-19.797	10.158	0.841
	2039	MF-DN	37.584	22.606	52.561	0.000*
	2039	NF-DN	46.594	31.592	61.596	0.000*
	2039	MF-M	42.403	27.426	57.380	0.000*
	2039	NF-M	51.413	36.411	66.415	0.000*
	2039	NF-MF	9.010	-5.992	24.012	0.410
	2059	M-DN	-7.077	-16.009	1.855	0.174
	2059	MF-DN	5.460	-3.473	14.392	0.394
	2059	NF-DN	10.251	1.318	19.183	0.017*
	2059	MF-M	12.537	3.604	21.469	0.002*
	2059	NF-M	17.328	8.395	26.260	0.000*
	2059	NF-MF	4.791	-4.141	13.724	0.511
	2079	M-DN	-6.336	-15.870	3.197	0.318
	2079	MF-DN	-3.060	-12.593	6.473	0.842
	2079	NF-DN	5.813	-3.721	15.346	0.396
	2079	MF-M	3.277	-6.257	12.810	0.812
	2079	NF-M	12.149	2.616	21.683	0.006*
	2079	NF-MF	8.873	-0.661	18.406	0.079

Significance at $p<0.05$ displayed with an asterisk. Scenarios are as follows: DN=Do Nothing, M=Management, MF= Management and Fire, NF= Do Nothing and Fire.

Appendix D: Flame Length Averages Under Moderate and Severe Fire Conditions Across All Four Scenarios Over Time Table

Average Values					
	Year	Surface Flame Sev (ft)	Surface Flame Mod (ft)	Total Flame Sev (ft)	Total Flame Mod (ft)
Baseline	**2019**	**7.06**	**2.56**	**97.64**	**2.72**
Do Nothing	2039	6.66	2.38	91.31	2.33
Do Nothing	2059	7.36	2.66	89.72	2.63
Do Nothing	2079	7.42	2.69	81.67	2.78
Management	2039	6.76	2.35	74.42	2.3
Management	2059	6.91	2.4	74.61	2.34
Management	2079	7.45	2.59	67.28	2.37
Management and Fire	2039	7.39	2.51	6.57	2.28
Management and Fire	2059	10.56	3.54	21.36	3.78
Management and Fire	2079	7.78	2.81	61.7	2.8
Do Nothing and Fire	2039	8.04	2.86	6.40	2.29
Do Nothing and Fire	2059	10.79	3.69	24.46	4.37
Do Nothing and Fire	2079	8.07	2.96	74.14	3.25

Appendix E: Plot Photos Representative of Baseline Conditions for the Different Fire Types Expected During the Simulated Fire Event in 2039

Surface Fire

Passive Crown Fire

Conditional Crown Fire

Active Crown Fire

Appendix F: Tree Species Code Key

Species Code	Scientific Name	Common Name
FRLA	*Fraxinus latifolia*	Oregon ash
PIPO	*Pinus ponderosa*	ponderosa pine
PRVI	*Prunus virginiana*	common chokecherry
POTR5	*Populus tremuloides*	quaking aspen
UNKSPP	-	unknown species
SOSIS2	*Sorbus sitchensis*	western mountain ash
SASC	*Salix scouleriana*	Scouler's willow
BEOC	*Betula occidentalis*	water birch
PIEN	*Picea Engelmannii*	Englemann spruce
PIMO3	*Pinus monticola*	western white pine
THPL	*Thuja plicata*	western red cedar
PICO	*Pinus contorta*	lodgepole pine
TSHE	*Tsuga heterophylla*	western hemlock
LAOC	*Larix occidentalis*	western larch
ALVIS	*Alnus viridis* ssp. *sinuata*	Sitka alder
ACGL	*Acer glabum*	Rocky Mountain maple
PSME	*Pseudotsuga menziesii*	Douglas fir
ABLA	*Abies lasiocarpa*	subalpine fir
ABGR	*Abies grandis*	grand fir

Appendix G: Stand Visualization System (SVS) Plot 1987 Example

USNVC Grouping 2: Northern Rocky Mountain Mesic Montane Mixed Conifer Forest

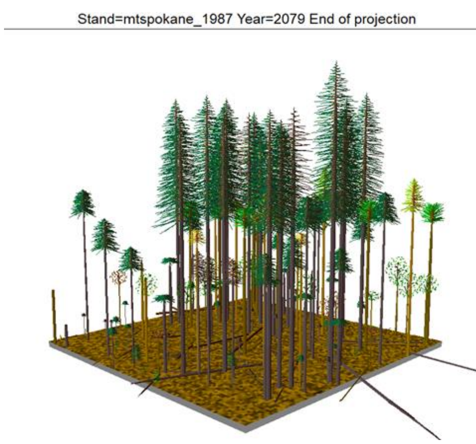
Elevation: 3565ft

Site Notes: In between two streams only there when wet. Very dense and diverse understory with old harvest stumps. Fairly open stand dominated by grand fir, Douglas fir, and western hemlock.

Tree Core: Douglas fir with a dbh of 21in. Approximately 82 years old with a fire scar about 52 years ago (1968).

2079 Visualization Outcomes

Do Nothing / Management



Do Nothing and Fire / Management and Fire