United States Department of Agriculture

Teton Interagency Fire Quantitative Wildfire Risk Assessment

Methods and Results

Horse Thief Canyon Fire 2012 **Photo: Andy Norman, USDA Forest Service**

Prepared by:

Don Helmbrecht and Chris Mallek – USDA Forest Service Enterprise Program

Julie W. Gilbertson-Day, Kevin C. Volger, April Brough, and Joe H. Scott – Pyrologix LCC

For:

Teton Interagency Fire Program

April 9, 2021

Contents

Tables

Figures

1. Assessment Overview:

1.1 Purpose and Background of the Assessment

This report provides an overview of wildfire hazard and risk to highly valued resources and assets (HVRAs) within and adjacent to the Bridger-Teton National Forest and Grand Teton National Park. The assessment was conducted to identify and quantify the risks posed by wildfire (i.e., unplanned ignitions; NWCG 2010) to HVRAs and is a fundamental step in the development of risk mitigation strategies.

Assessing wildfire risk requires quantifying the likelihood of wildfires occurring, the intensity at which those wildfires are likely to occur, and the potential exposure and effects to HVRAs (Finney 2005; Thompson and Calkin 2011; Miller and Ager 2012; Scott et al. 2013). Wildfire risk assessment provides baseline information on how risk is distributed across the assessment area and which HVRAs face the greatest expected loss (or benefit) from wildfire. This information may be used in the planning, prioritization, and implementation of wildfire prevention, preparedness, and risk mitigation strategies. Applying a methodologically-consistent, risk-based approach to wildland fire management is a cornerstone of the National Cohesive Wildland Fire Management Strategy (Calkin et al. 2011; USDA Forest Service and USDI 2011) and adheres to the direction presented in Chapter 5140 of the Forest Service Manual—Hazardous Fuels Management and Prescribed Fire.

This quantitative wildfire risk assessment was completed by the USDA Forest Service, Enterprise Program and Pyrologix LLC following the wildfire risk assessment framework described in United States Department of Agriculture General Technical Report RMRS-GTR-315: *A Wildfire Risk Assessment Framework for Land and Resource Management* (Scott et al. 2013). This report provides details about the analysis methods and an overview of results.

1.2 Analysis Area

The 3.5 million-acre Bridger-Teton National Forest and 330,000-acre Grand Teton National Park/John D. Rockefeller Jr. Memorial Parkway are located in western Wyoming, USA (Figure 1). For the purposes of this assessment the Park and Memorial Parkway will be considered a single management unit.

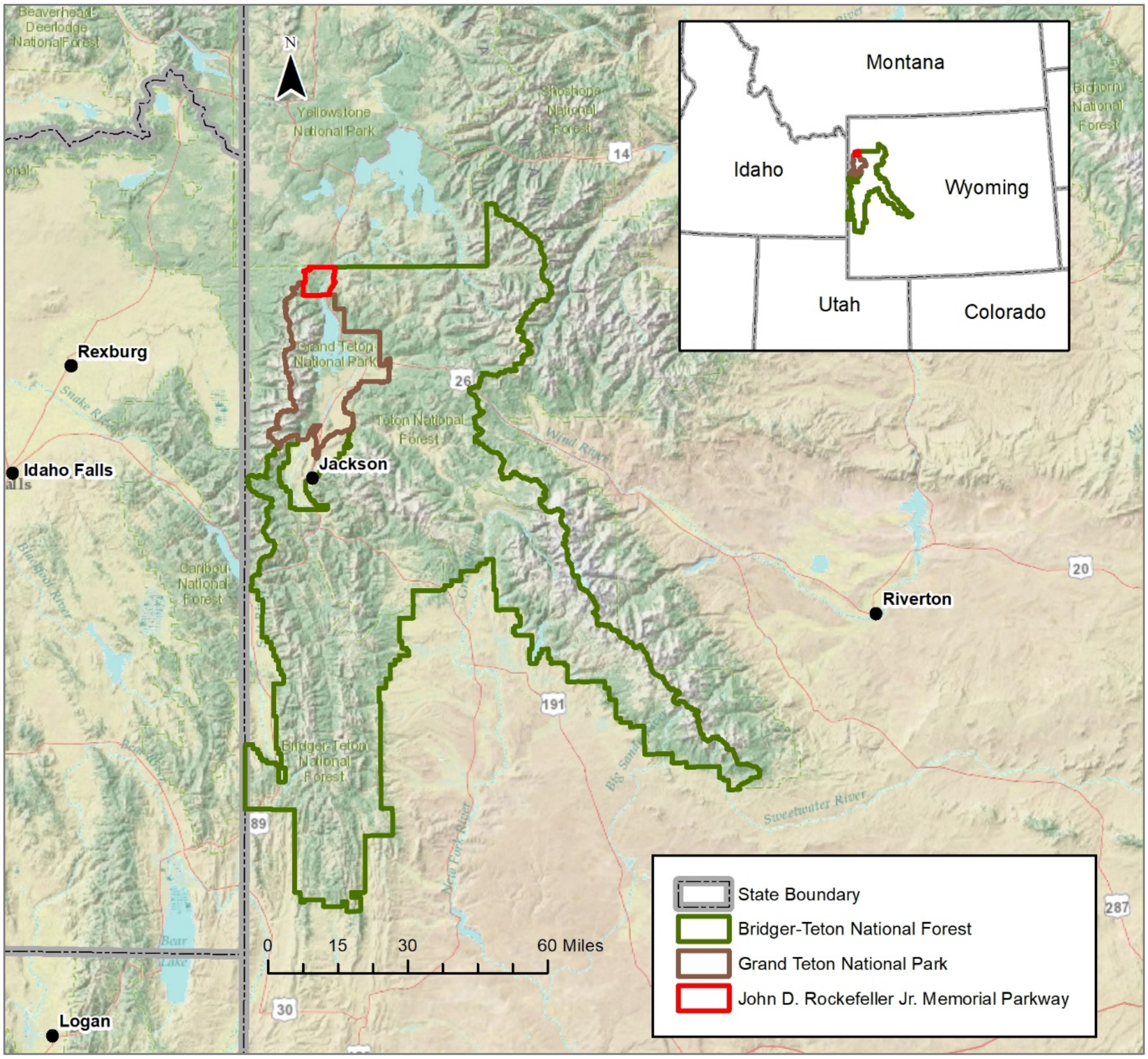

Figure 1. Vicinity map of the Bridger-Teton National Forest and Grand Teton National Park/John D. Rockefeller Jr. Memorial Parkway.

1.3 Wildfire Risk Assessment Concepts

Wildfire risk assessment is an appraisal of the interaction between wildfire hazard, exposure, and effects to a given set of HVRAs in an analysis area (Scott et al. 2013). Whereas hazard refers to a physical situation with the potential to cause harm to people or damage to resources and assets; risk refers to the potential for realization of consequences due to a hazard. Risk assessment therefore further requires information on HVRA *exposure* and susceptibility to *effects*. Most professional disciplines that utilize risk assessment focus on potential losses. However, since many natural resources benefit from exposure to fire, we expand our definition of risk to include beneficial as well as adverse effects in the context of wildland fire.

A quantitative framework for assessing wildfire risk to HVRAs was first introduced by Finney (2005). The framework measures wildfire risk as the probabilistic expectation of net value change (NVC) to HVRAs. NVC captures both fire-related losses and benefits in relative terms on a percentage basis (for example, complete loss = -100 percent), allowing for a common currency in evaluating wildfire risk across market and non-market resources and assets. Continued development of the framework led to its formalization in United States Department of Agriculture General Technical Report RMRS-GTR-315: *A Wildfire Risk Assessment Framework for Land and Resource Management* (Scott et al. 2013). The primary analytical components of the framework are the simulation of wildfire hazard, identification and characterization of HVRAs, and quantification of risk—all in a geospatial context that explicitly considers the location of HVRAs with respect to estimates of wildfire likelihood and intensity (Figure 2). The following paragraphs provide a brief overview of each component.

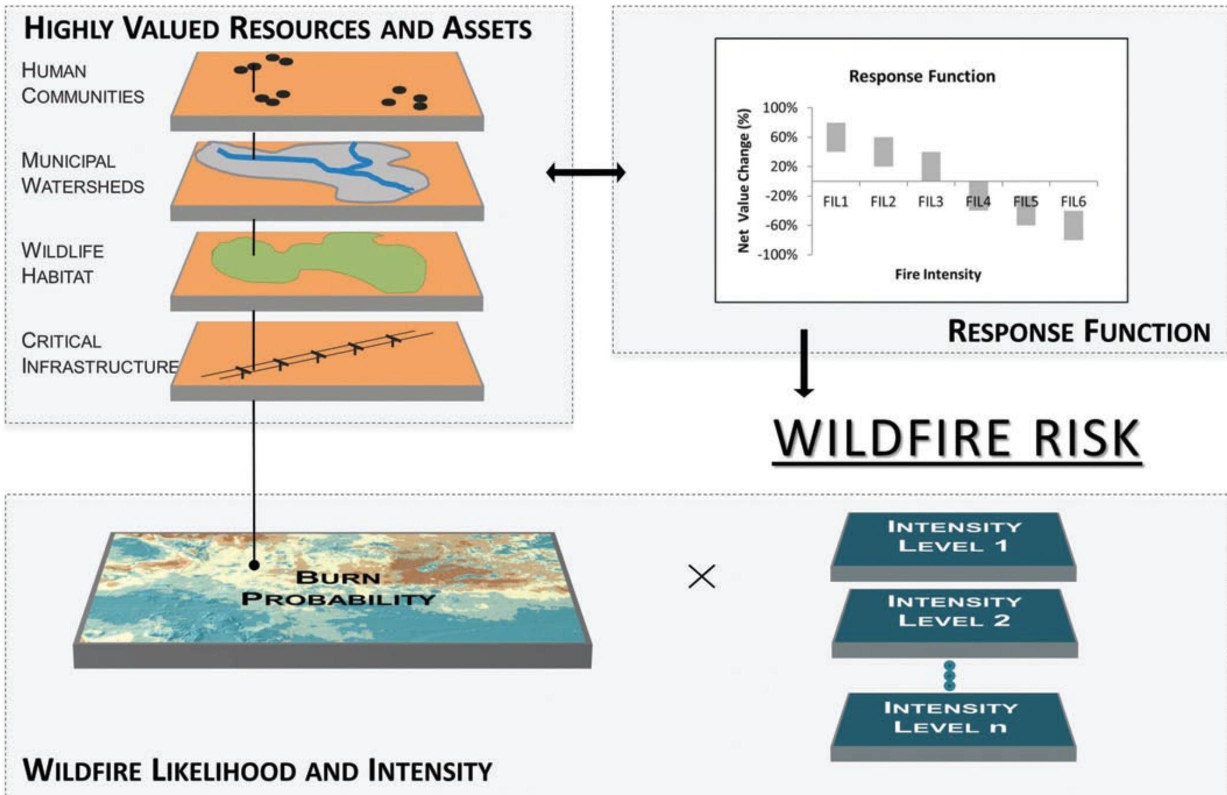

Figure 2. Geospatial context of the wildfire risk assessment framework (From Scott et al. 2013).

Spatial wildfire hazard simulation

In quantitative wildfire risk assessment, two components of wildfire hazard—likelihood and intensity—are estimated through application of a spatially-explicit, stochastic wildfire simulation system. A stochastic system is one in which multiple iterations of potential scenarios are simulated to create probabilistic outputs based on the random variation in one or more of the inputs. In this assessment we used the FSim, large-fire simulation system (Finney et al. 2011) to produce spatially explicit estimates of wildfire hazard. FSim is a comprehensive simulation system that integrates models of wildfire weather, occurrence, growth (Finney 2002), and containment (Finney et al. 2009) to simulate the full range of wildfire hazard over a fire season. FSim provides two critical probabilistic outputs for quantifying wildfire risk: annual burn probability and conditional flame-length probability. Annual burn probability is the probability that a fire will burn a particular location on the landscape during a single calendar year; conditional flame-length probability is the probability of burning at different intensity levels given that a fire occurs.

Identification and characterization of HVRAs

Resources and assets are generally considered ‘highly valued’ in wildfire risk assessments based on their influence on fire management decision making. Three characteristics must be determined for each HVRA identified: spatial extent, response (i.e., degree of loss or benefit) to wildfire of varying intensity levels, and relative importance. The mapped spatial extent of an HVRA is dependent on the properties of the HVRA that are affected by fire. Assets (i.e., human-made objects of value) are typically mapped directly, sometimes with a buffer to depict the area in which fire would have an effect. Resources (i.e., objects of value found in nature), such as wildlife habitat, drinking water, or other ecosystem services may require the modeling and/or mapping of additional landscape variables that effect HVRA response indirectly. For example, Thompson et al. (2013a) mapped erosion potential as a factor of soil type and slope steepness to characterize water quality as a high-value resource in the Rocky Mountain Region of the USDA Forest Service. Scott et al. (2014) modeled vegetation departure from historical conditions to characterize vegetation condition as a high-value resource on the Bridger-Teton National Forest.

Response to wildfire is based on the susceptibility of HVRAs to varying levels of fire intensity. Characterizing the response to wildfire involves quantifying the relationship between relative change in HVRA value and fire intensity. In the quantitative wildfire risk assessment framework, this relationship is quantified as a tabular response function—positive values indicate a net increase in value; negative values indicate a net decrease in value (Calkin et al. 2010; Scott et al. 2013). Response functions represent the near-term effects on HVRAs. This time period may include both first-order (e.g., tree mortality) and second-order (e.g., habitat loss) fire effects but does not include effects due to dynamic landscape processes that may take place in the future, such as, successional processes, disturbances, and climate change (Scott et al. 2013). Response functions are typically based on expert judgement or some combination of expert judgement and fire effects modeling.

The wildfire risk assessment framework accommodates a variety of HVRAs using a common measure (i.e., NVC), however the final step in HVRA characterization is to assign a relative importance value to each HVRA. This step is unnecessary for assessing wildfire risk to a single HVRA but important when integrating risk across overlapping HVRAs or comparing risk among multiple HVRAs on a landscape. The intent of relative importance weighting is to capture broader social values and reflect fire and land management objectives and priorities (Scott et al. 2013; Thompson et al. 2013b). For example, crown fire may be considered to have beneficial effects in ecological systems or plant communities where it is typical of the fire regime (e.g., lodgepole pine, jack pine, and chaparral) but result in adverse effects to other resources or assets collocated with those plant communities, such as municipal watersheds or human communities. Adverse and beneficial effects would offset one another when integrated across these HVRAs. Assigning relative importance allows the NVC of certain HVRAs to be weighted more heavily—based on the social values, legal requirements, policies, and priorities of land managers—in the final calculation of integrated risk.

Quantification of risk

The final analytical component of the wildfire risk assessment framework is the quantification of risk. Full quantification of wildfire risk incorporates information on wildfire hazard, exposure, and fire effects to HVRAs as the expected net-value-change (eNVC). eNVC integrates the probability of burning at different intensity levels (i.e., conditional flame-length probability), HVRA susceptibility (i.e., response functions), and the overall probability of burning in a given fire season (i.e., annual burn probability) into a single, comprehensive metric of wildfire risk. eNVC is the foundational metric of quantitative wildfire risk assessment.

2. Wildfire Hazard Simulation

2.1 Landscape Zones

Three primary landscape zones were delineated for the wildfire hazard simulation (Figure 3). The analysis area (AA) is the area for which wildfire hazard and risk results are desired and consequently the area for which valid burn probability results are required. The AA was defined as a 10-kilometer buffer around the combined Bridger-Teton National Forest and Grand Teton National Park (including the John D. Rockefeller Jr. Memorial Parkway) boundaries. To ensure valid burn probability results in the AA and prevent edge effects, it is necessary to allow FSim to start fires outside of this area that may burn into it. This larger area where simulated fires are started is called the Fire Occurrence Area (FOA). We established the FOA extent as a 30-km buffer on the AA. The FOA buffer provides sufficient area to ensure that all fires that could reach the AA are simulated. The FOA covers roughly 13.7-million acres characterized by diverse topographic and vegetation conditions. To more accurately model wildfire hazard across this large area, we divided the overall fire occurrence area into two individual FOAs to account for variability in historical fire occurrence and fire weather. The boundary between the two FOAs roughly separates the Teton and Absaroka ranges in the north from the Wyoming and Wind River mountain ranges in the south (For consistency with other FSim projects, we numbered these FOAs nine and ten). Historical wildfire occurrence analysis, historical weather analysis, and wildfire hazard simulations were conducted independently for each of the two FOAs. The wildfire hazard results were then compiled into a single, integrated set of results.

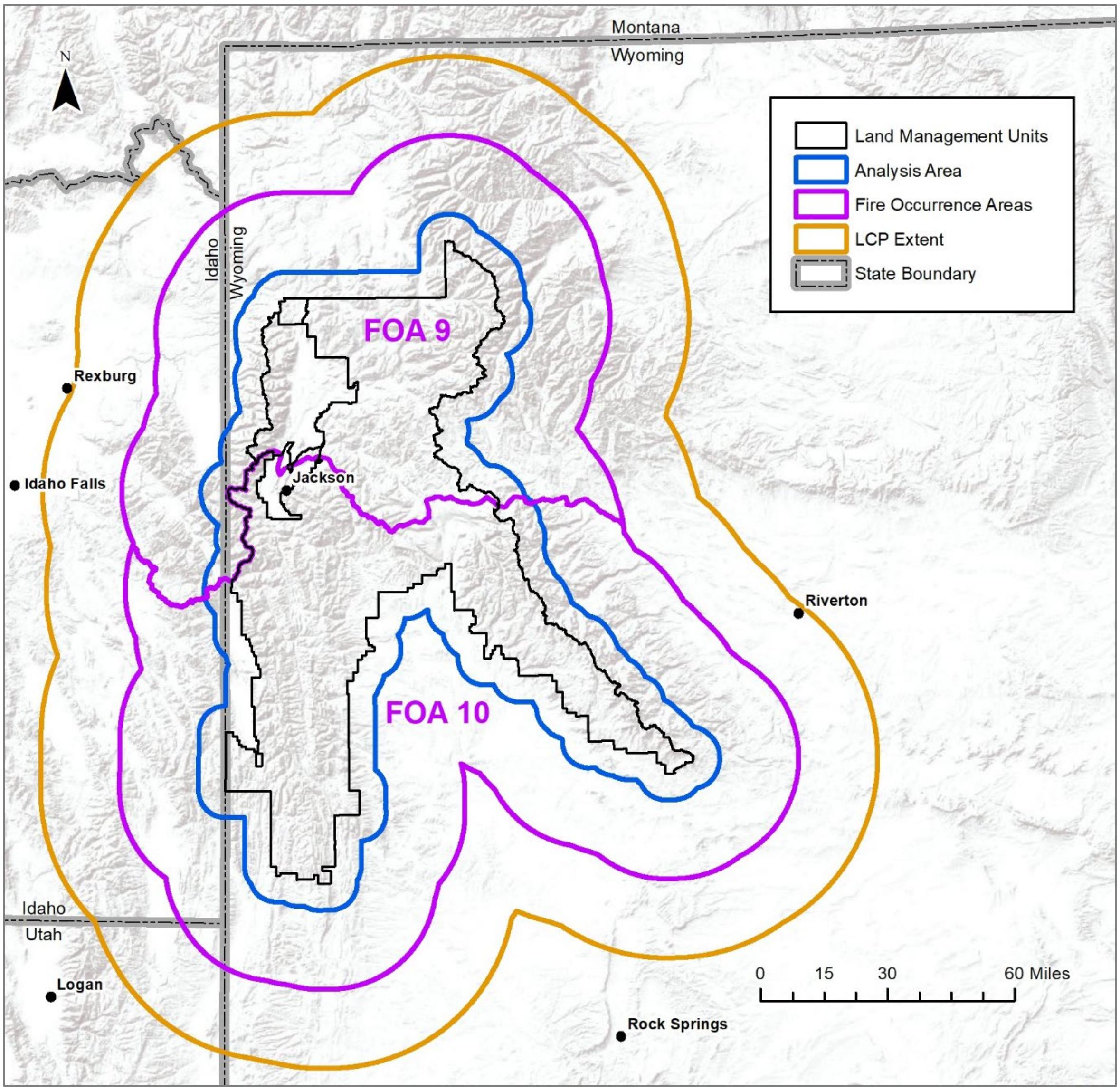

Figure 3. Extents of the analysis area, fire occurrence areas (FOAs), and fire modeling landscape (LCP) used to simulate wildfire hazard for the Teton Interagency Quantitative Wildfire Risk Assessment.

Although FSim is constrained to starting fires only within the FOAs, it is necessary that the extent of the fire modeling landscape is large enough so that simulated fires can spread outward from all parts of an individual FOA. This buffer allows fires starting within the FOA to grow unhindered by the edge of the fuelscape, which would otherwise truncate fire growth and affect the simulated fire-size distribution and potentially introduce errors in the calibration process. This final zone is referred to as the fire modeling landscape, or LCP extent (Figure 3). The LCP extent was delineated by adding an additional 30-km buffer to the combined FOA extent. It covers roughly 21.8-million acres.

2.2 Fire Modeling Landscape

A fire modeling landscape (LCP) is a combination of gridded geospatial data layers that represent the surface fuel (fire behavior fuel model), canopy fuel (canopy base height and canopy bulk density), vegetation (forest canopy cover and height), and topographic (slope steepness, aspect, and elevation) characteristics required for modeling spatial wildfire behavior. We generated the Teton Interagency LCP using the LANDFIRE Total Fuel Change Toolbar (LFTFCT). The LFTFCT allows users to input existing vegetation and disturbance data, define fuel rulesets, and generate fuel grids. See the LFTFCT Users Guide for more information (Smail et al. 2011). The resulting LFTFCT output fuel grids can then be combined into a single landscape file (LCP) and used as a fuelscape input in various fire modeling programs. Additional information can be found in the LANDFIRE data modification guide (Helmbrecht and Blankenship 2016).

Our LFTFCT vegetation and disturbance inputs were derived from LANDFIRE 2014b 30-m raster data (a precursor to LANDFIRE v2.0 “fuel vegetation” products). Both the surface and canopy inputs were updated to reflect fuel disturbances occurring between 2015 and 2018. Wildfire fuel disturbances were incorporated using three different sources: Monitoring Trends in Burn Severity (MTBS) data, Rapid Assessment of Vegetation Condition after Wildfire (RAVG) data, and GeoSpatial Multi-Agency Coordination (GeoMAC) perimeter data. We gathered severity data as available from MTBS, then RAVG, and where severity data were unavailable, we relied on final perimeters from GeoMAC. We crosswalked MTBS and RAVG severity to the appropriate disturbance codes for use in the LFTFCT corresponding with fire disturbances of low, moderate, or high severity, occurring in the past one to five years. GeoMAC perimeters were assigned a uniform severity of moderate. We also incorporated non-wildfire fuel disturbances from three different sources: The Forest Service Activity Tracking System (FACTS), the National Fire Plan Operations and Reporting System (NFPORS), and the Bureau of Land Management (BLM) activity data. All non-wildfire fuel disturbance datasets were provided by local resource staff. Finally, a fuelscape review involving input from Bridger-Teton National Forest and Grand Teton National Park fire and fuels staff and others familiar with fuels and fire behavior in the LCP extent was held remotely on December 12, 2018 to refine the LFTFCT fuel rulesets for this project. The resulting fuelscape generated by the LFTFCT is shown by fuel model group in Figure 4. Additional documentation on the fuelscape processing and edits to LANDFIRE default rules are included in Appendix A.

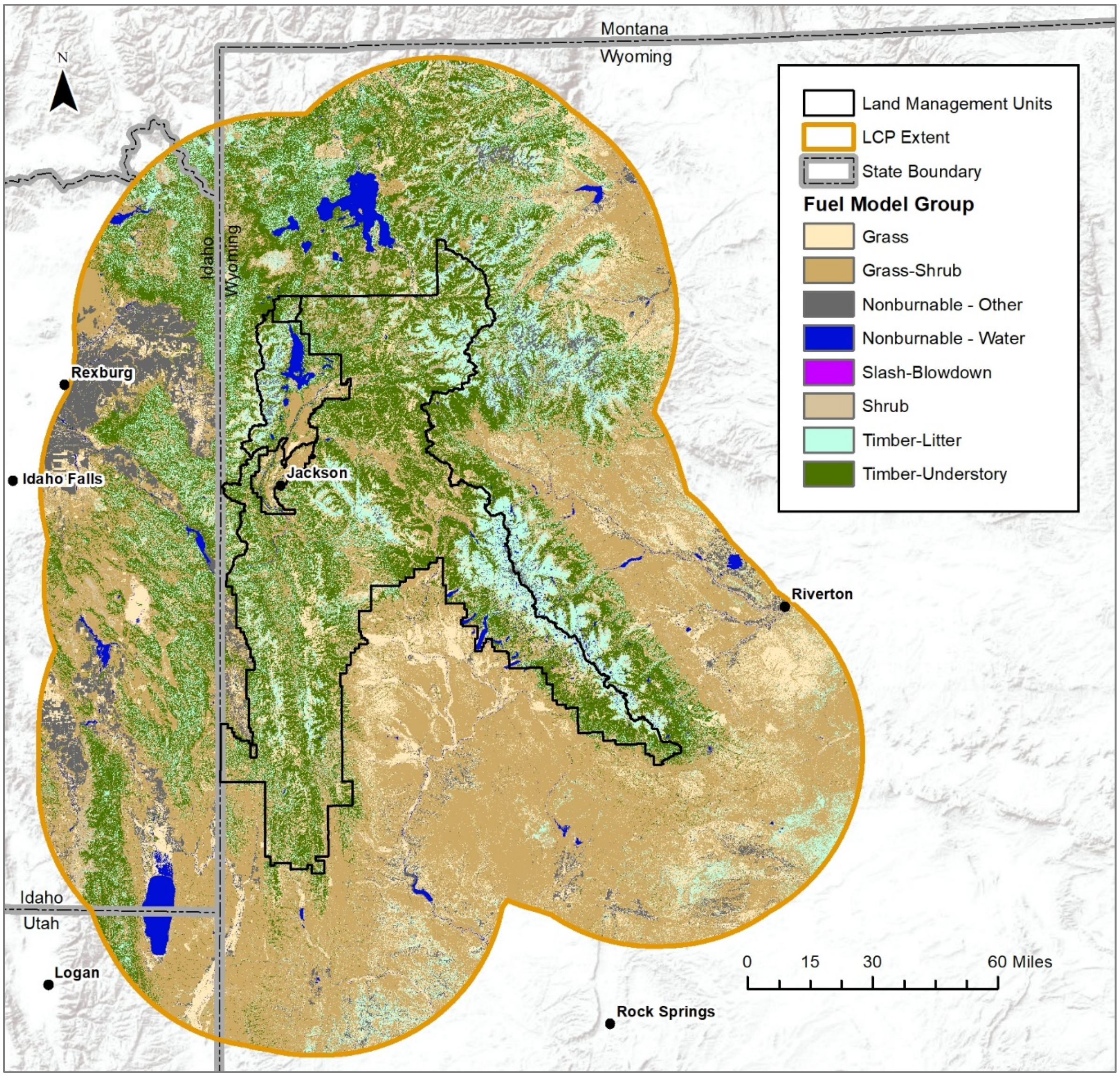

Figure 4. Fuel model groups (Scott and Burgan 2005) across the Teton Interagency Risk Assessment fire modeling landscape.

2.3 Analysis of Historical Wildfire Occurrence

FSim is called the large-fire simulation system because it focuses on the relatively small fraction of wildfires that escape initial attack and become "large." This is not to imply that small fires are unimportant to fire management, rather it is to reflect that burn probability is heavily influenced by large fires because they account for most of the area burned (Strauss et al. 1989). For example, Calkin et al. (2005) found for the period between 1970 through 2002, that fires 300 acres or larger accounted for only 1.1% of all fires but 97.5% of the area burned. In the context of FSim simulations, the term *large* is used in a general way to describe fires that escape initial attack, irrespective of their actual size (Finney et al. 2011). A user-defined large-fire size is required for statistical purposes in the simulation of wildfire occurrence and model calibration. The system still simulates fires that never meet that threshold size; however, they have a negligible effect on overall burn probability. For this assessment we used a large-fire size threshold of 100 hectares (247.1 acres).

The National Fire Occurrence Database (FOD; Short 2017) was used as the foundation for summarizing large-fire occurrence within each of the two FOAs (Table 1; Figure 3). For each FOA, fires spanning the 24-year period of 1992-2015 were selected from the National FOD based on their start location to create FOA-specific FODs for analysis. The mean annual number of large fires and mean large-fire size statistics were later used to calibrate the FSim simulations, such that the mean simulated fire occurrence was within the 70% confidence interval of the historical mean.

FOA 9 experienced slightly more fires per million acres over the 24-year historical period than FOA 10. These fires are also larger, burning twice as much area annually per million acres, contributing to a burn probability in FOA 9 that is twice as high as FOA 10.

Table 1. Historical large-fire occurrence, 1992-2015, in the Teton Interagency Risk Assessment Fire Occurrence Areas (FOAs).

FOA	Mean Annual Number of Large Fires	Mean Large-Fire Size (acres)	FOA Area (millions of acres)	Mean Annual Number of Large Fires (per million acres)	Mean Annual Large-Fire Area Burned (per million acres)	Mean Annual Burn Probability
9	2.9	5,705	5.33	0.539	3,077	0.0031
10	3.5	3,481	8.37	0.418	1,456	0.0015

To account for the spatial variability in historical wildfire occurrence across the landscape, we used the ignition locations from the FOD to build an ignition density grid (IDG) representing the relative density of large-fire ignitions within the fire modeling landscape. FSim uses the IDG to weight the placement of, the otherwise random, simulated ignitions based on the relative density of the historical ignitions. The IDG was generated using a mixed-methods approach by averaging the two grids resulting from the Kernel Density tool and the Point Density tool within ArcGIS for a 2-km cell size and 75-km search radius. All fires equal to or larger than 247.1 acres (100 ha) reported in the FOD were used as inputs to the IDG. The IDG was divided up for each FOA by setting to zero all area outside of the fire occurrence boundary of that FOA. This allows for a natural blending of results across adjacent FOA boundaries by allowing fires to start only within a single FOA but burn onto adjacent FOAs. The IDG enables FSim to produce a spatial pattern of large-fire occurrence consistent with what was observed historically. Figure 5 shows the ignition density grid for the fire occurrence area.

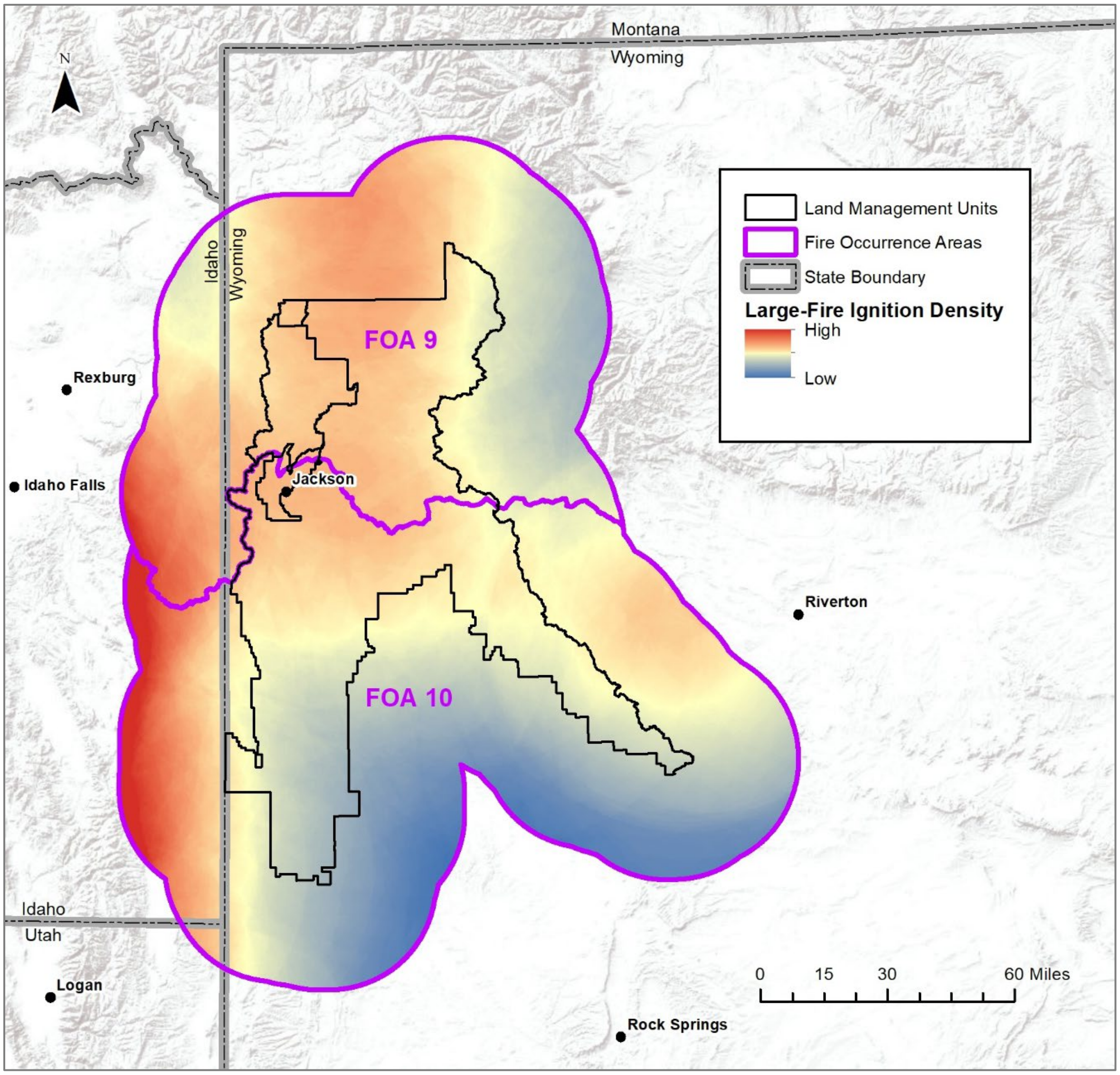

Figure 5. Large-fire (≥ 247.1 acres) ignition density used in the Teton Interagency Risk Assessment.

2.4 Analysis of Historical Weather

2.4.1 Energy Release Component

FSim's weather module uses the Energy Release Component (ERC) fire danger rating index as a proxy for the influence of fuel moisture on large-fire occurrence and growth (Finney et al. 2011). The ERC index represents the amount of energy released from the flaming spread of a wildfire and varies based on fuel moisture for a given fuel type. FSim uses the ERC index for National Fire Danger Rating System fuel model "G" because it reflects both short- and long-term variations in fuel moisture caused by precipitation and changes in temperature and humidity.

As the source of historical ERC data, we used ERC(G) values sampled from historical ERC rasters created by Dr. Matt Jolly at the USDA Forest Service, Rocky Mountain Research Station, Fire Sciences Lab. Historical ERCs were sampled at an advantageous location within each FOA (Figure 6). Acquiring historical ERC values in this way is preferred because recorded values from Remote Automated Weather

Stations (RAWS) are often sporadic and/or have limited years of observations. The location of the RAWS may also not be ideal (e.g., at the border of two FOAs with different fire regimes and weather). The spatial data provide a consistent, uniform source from which to extract historical ERC values in the most ideal location for the analysis.

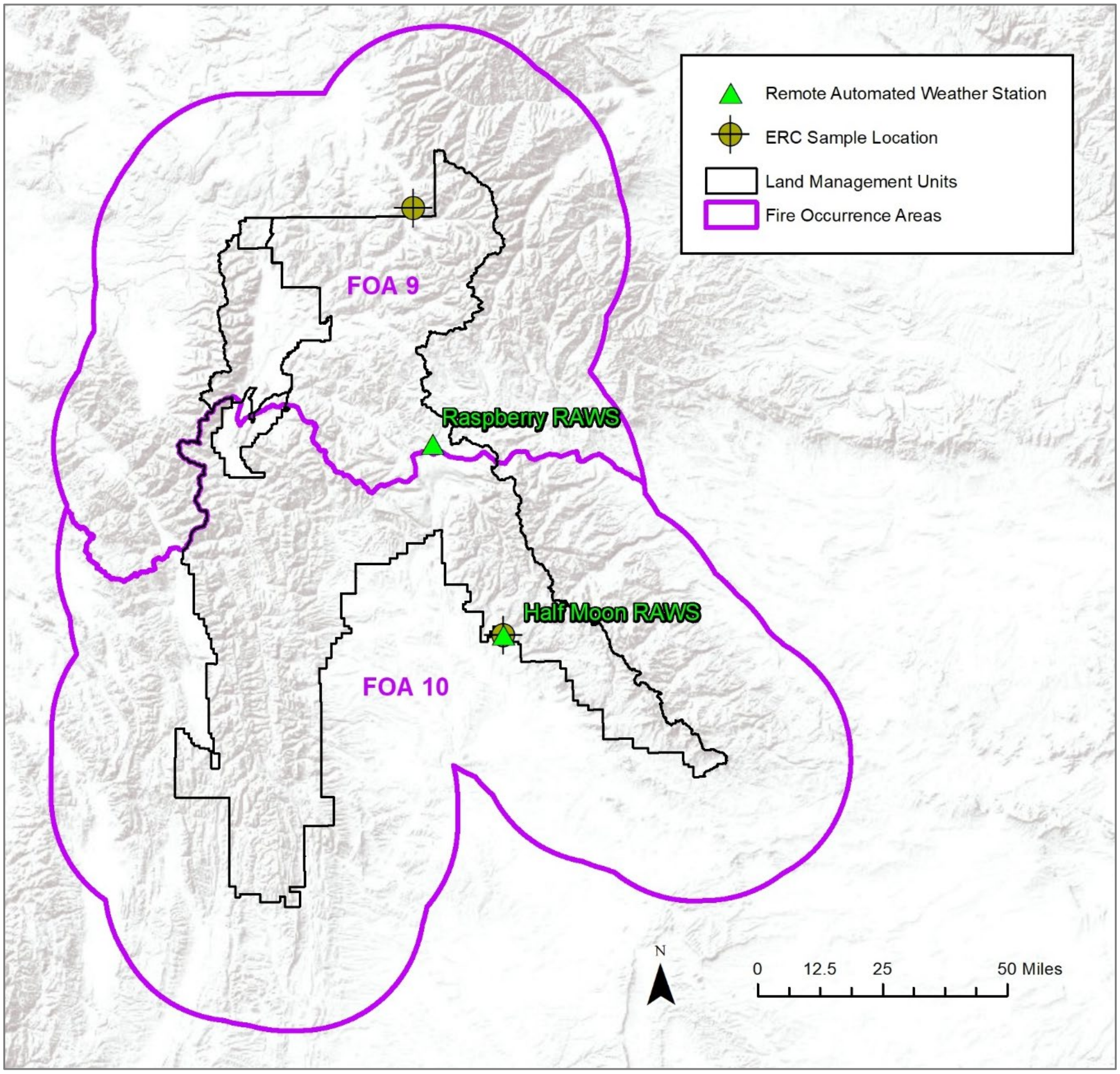

Figure 6. Energy release component (ERC) sample sites and remote automated weather stations (RAWS) used for weather analysis. RAWS were used to acquire hourly, 10-min average, wind speed and direction.

The historical ERC values were used in conjunction with the FOA FODs to generate FSim Fire-Day Distribution (FDist) input files. The FDist file provides the FSim fire occurrence module with two statistics for simulating large-fire occurrence: the probability of at least one large-fire ignition, based on the historical relationship between large fires and ERC, and the probability of more than one large-fire ignition occurring simultaneously on the same day, based on the historical distribution of large fire ignitions. Historical ERC(G) raster data were available for the years 1979-2015 and historical fire occurrence data were available for 1992-2015. We used the overlapping years of 1992-2015 to develop a logistic regression of probability of a large-fire day in relation to ERC(G). The final FDist files used in the wildfire hazard simulations are included with the project deliverables from Pyrologix.

FSim's fire growth module uses time-series analysis of historical daily ERC(G) values to account for daily and seasonal variability in live and dead fuel moisture (Finney et al. 2011). This time-series analysis captures the average daily trend, standard deviation, and temporal autocorrelation of the historical ERC values. Isaac Grenfell, statistician at the USDA Forest Service, Rocky Mountain Research Station, Fire Sciences Lab, has generated 1,000 years of spatial, daily ERC values (365,000 ERC values) based on this analysis. We sampled Grenfell's spatial data at the same FOA locations as the historical data (Figure 6) to create an ERC-stream input file for FSim. Using Grenfell's simulated ERC streams allows for analysis of fire-year information across FOAs because the spatial data are "coordinated" in that a given year and day, for one FOA, corresponds to the same year and day in all other FOAs—their values only differ due to their location on the landscape. FSim's FRISK file summarizes weather information from the simulated ERC streams. Combined with wind speed and wind direction, tens of thousands of hypothetical fire seasons may be simulated. The final FRISK files used in the wildfire hazard simulations are included with the project deliverables from Pyrologix.

2.4.2 Wind Speed and Direction

Hourly sustained wind data (10-minute average), for the time period of 1200 to 2000 hours were acquired from the Raspberry and Half Moon RAWS (Figure 7). These stations were selected based on their ability to represent general wind patterns within each FOA. To prevent edge effects between FOAs and allow for representative wildfire potential it is occasionally necessary to adjust the wind speed record from individual RAWS stations. The recorded mean wind speed for the Raspberry and Half Moon RAWS is 9.0 and 8.1 mph, respectively. The mean wind speed for both FOAs was adjusted upwards to 9.5 mph to prevent introducing data seamlines between FOAs and meet historical calibration targets. Wind directions from the recorded observations were maintained. The joint probability of wind speed and wind direction are summarized by month in the FSim FRISK file. These data are sampled at random by FSim and combined with the Grenfell simulated ERC streams to create the weather scenarios for simulating wildfire hazard.

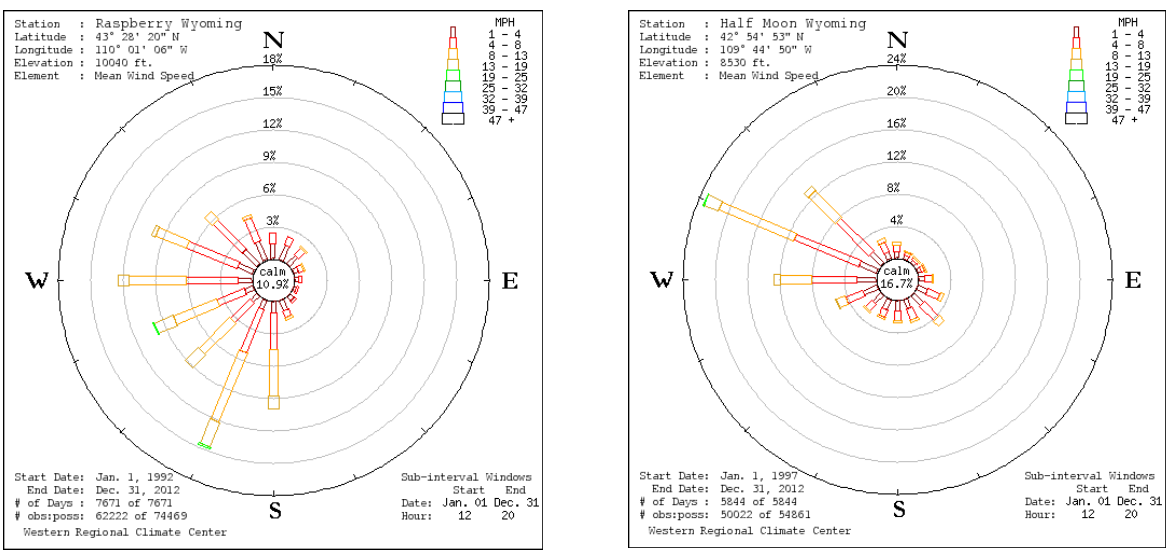

Figure 7. Wind rose charts for the Raspberry and Half Moon remote automated weather stations.

2.4.3 Fuel Moisture

The same set of stylized fuel moisture input files (representing the 80th, 90th, and 97th percentile ERC conditions) were used for both FOAs. This set allows for higher moisture content where fuel is presumed to be sheltered by a forest canopy (i.e., timber-litter, timber-understory, and slash-blowdow fuel models), and lower moisture content for the drier ERC classes (i.e., higher percentile values) (Table 2).

Table 2. Dead and live percent fuel moisture content values used for each energy release component (ERC) percentile bin.

ERC Percentile	Sheltered[1]			Exposed			Live Herbaceous	Live Woody
	1-hr	10-hr	100-hr	1-hr	10-hr	100-hr		
80th	7	8	9	5	6	7	90	110
90th	6	7	8	4	5	6	65	100
97th	5	6	7	3	4	5	45	90

[1] Fuels are presumed to be sheltered where the fire behavior fuel model is a timber-liter, timber-understory, or slash-blowdown type (Scott and Burgan 2005).

2.5 Wildfire Hazard

The large-fire simulator (Finney et al. 2011), FSim, was used to quantify wildfire hazard across the analysis area. FSim is particularly well suited to wildfire risk assessment because it simulates wildfire occurrence on an annualized basis; accounts for seasonal variability in fuel moisture, wind speed, and wind direction; and incorporates wildfire suppression. Although we cannot know with absolute certainty when and where wildfires will occur, FSim provides an informed estimate of the contemporary likelihood and intensity of wildfires across the analysis landscape based on locally-relevant data of historical climate and weather patterns, historical fire frequency and pattern, and fuel and topological conditions.

Each of the two FOAs was calibrated independently over multiple calibration runs until the simulated mean annual number of large fires and mean large-fire size were within the 70% confidence interval of the historical mean (Table 3). The final simulations were run at 90-m (2-acre) resolution, for 20,000 iterations each. The individual FOA results were then integrated using the natural weighting method described in Thompson et al. (2013a). With this method, the results for pixels located well within the boundary of a FOA will be influenced only by the simulation parameters used for that FOA. The results for pixels near the border with another FOA will be influenced by both FOAs

Table 3. Comparison of historical and simulated wildfires by fire occurrence area (FOA).

	Historical (1992 – 2015)		Simulated	
FOA	Mean annual number of large fires	Mean large-fire size (acres)	Mean annual number of large fires	Mean large-fire size (acres)
9	2.9	5,705	2.9	5,995
10	3.5	3,481	3.6	3,665

Two measures of wildfire hazard—annual burn probability and conditional flame length—are summarized by land management unit in Table 4. The John D. Rockefeller Jr. Memorial Parkway is combined with Grand Teton National Park for all wildfire hazard and risk summaries. Additionally, all FSim-derived wildfire hazard results presented as deliverables are described in further detail in Appendix B.

Table 4. Mean annual burn probability and conditional flame length by land management unit (Park, Forest, and Districts).

Management Unit	Burnable Area (Acres)	Mean Annual Burn Probability	Mean Annual Burn Probability (Odds)	Mean Conditional Flame Length (ft.)
Grand Teton National Park[1]	284,659	0.0018	1-in-567	3.4
Bridger-Teton National Forest	3,393,820	0.0028	1-in-358	3.8
Big Piney Ranger District	446,693	0.0024	1-in-417	3.8
Blackrock Ranger District	708,767	0.0040	1-in-250	3.7
Greys River Ranger District	482,620	0.0023	1-in-443	3.8
Jackson Ranger District	685,929	0.0032	1-in-313	3.9
Kemmerer Ranger District	285,177	0.0024	1-in-417	4.2
Pinedale Ranger District	784,634	0.0021	1-in-487	3.8

[1]Includes the John D. Rockefeller Jr. Memorial Parkway.

Annual burn probability is calculated for each pixel on the landscape as the number of iterations that resulted in the pixel burning divided by the total number of iterations (20,000). Burn probability varies widely both within and across the land management units (Figure 8). Mean annual burn probability is highest for the Blackrock and Jackson Ranger Districts. In general, the northern two-thirds of the analysis area have the highest annual burn probability with the exception of Grand Teton National Park, where the rocky peaks of the Tetons limit wildfire spread from the west and the flat terrain and large lakes that compose the eastern half of the Park limit fire size—both reducing the overall burn probability within the Park.

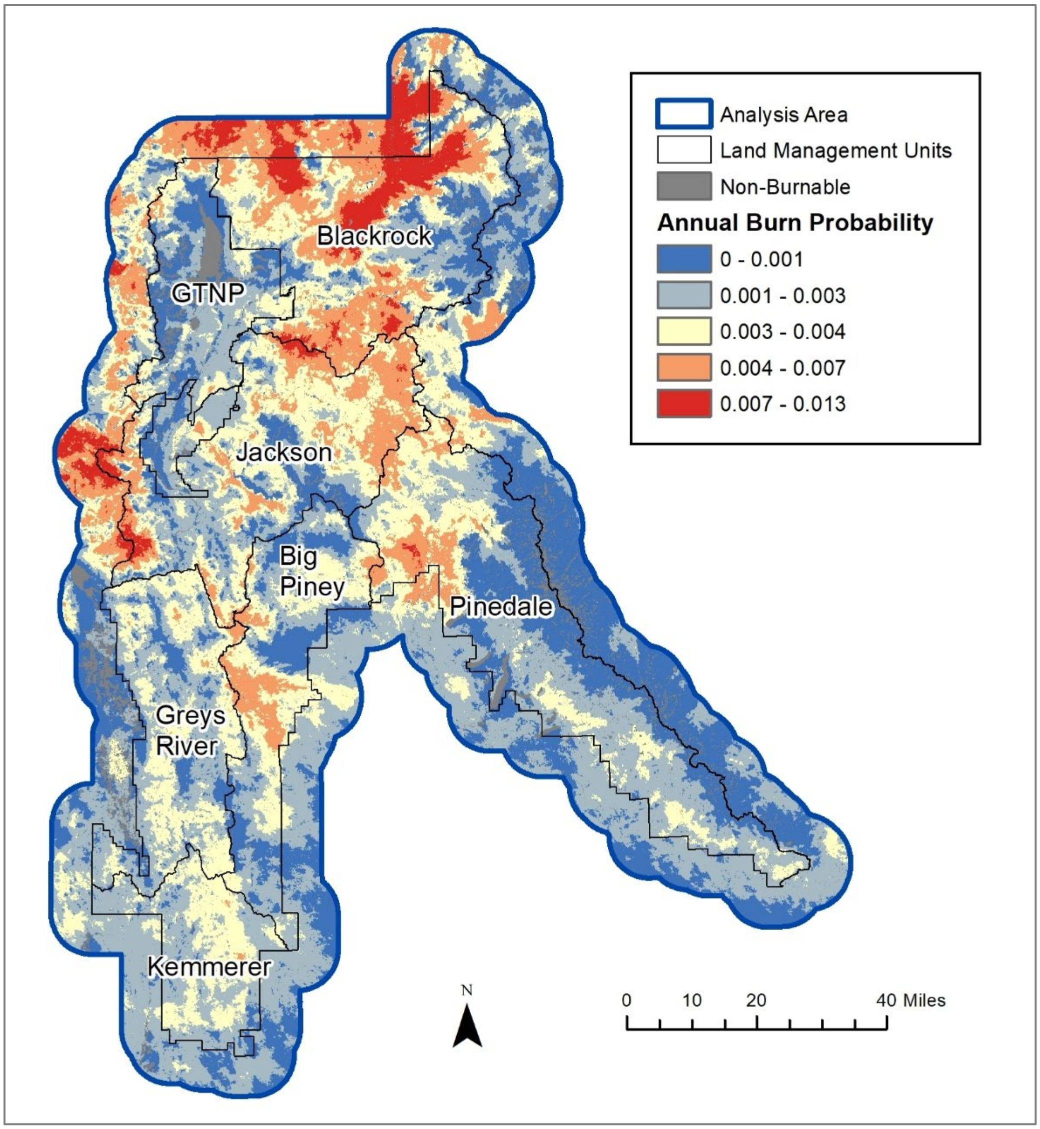

Figure 8. Annual burn probability within the Teton Interagency Risk Assessment analysis area.

Conditional flame length is an estimate of the mean flame length of the iterations that burned the pixel—that is, under all weather and fire spread directions (heading, flanking, backing). It is a measure of the central tendency of flame length. Much of the analysis area has a conditional flame length of less than four feet and management unit means are similar (Table 4). Areas where higher flame-length potential exists within land management units can be seen in Figure 9. Conditional flame length is calculated as the sum-product of the probability of burning in each of the six fire intensity levels and the mid-point flame length for that fire intensity level (Table 5). For FIL6 (> 12 ft. flame length), for which there is no midpoint, we used a surrogate flame length of 100 ft. to represent torching trees.

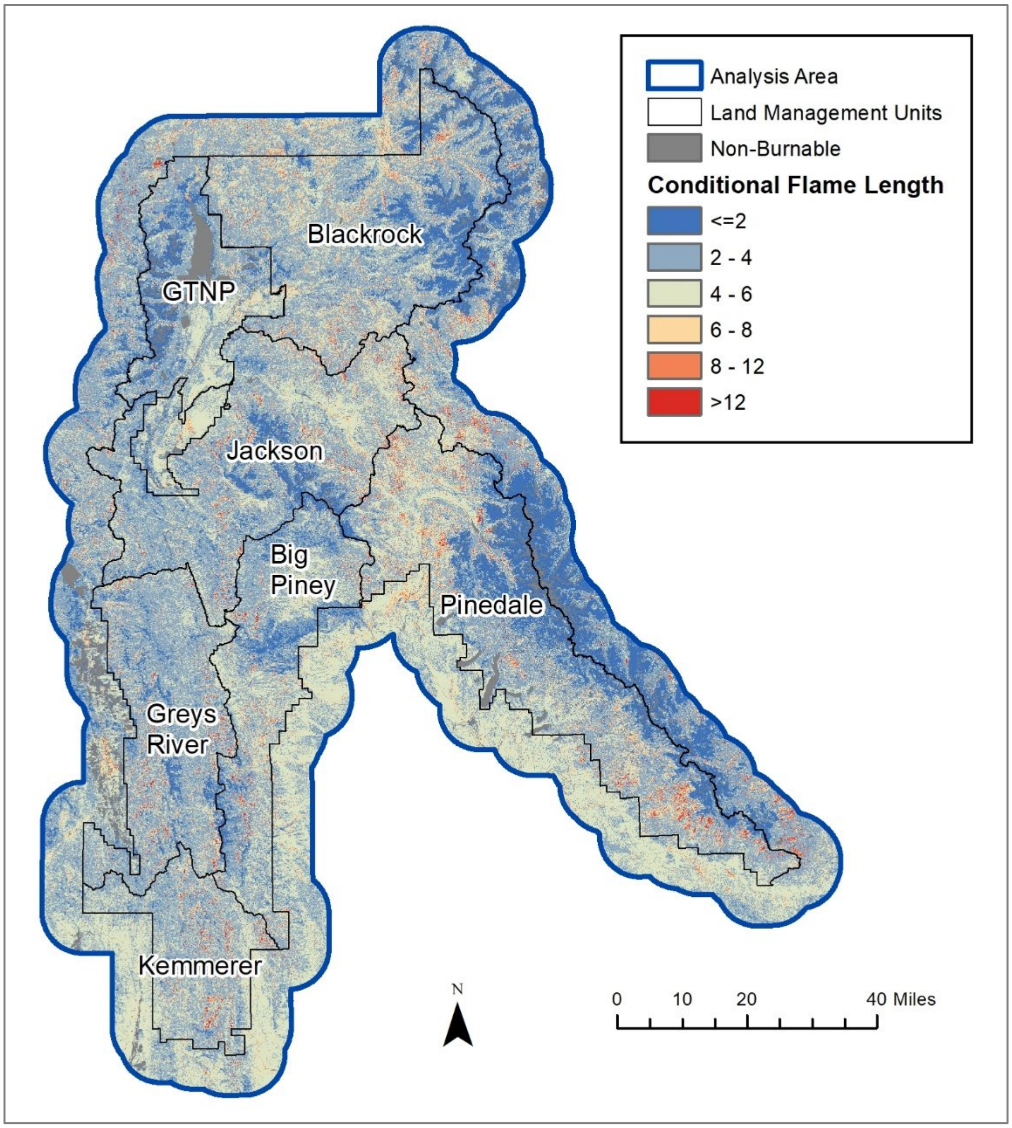

Figure 9. Conditional flame length within Teton Interagency Risk Assessment analysis area.

Table 5. Example of conditional flame length calculation.

Fire Intensity Level	Flame-Length Range (ft.)	Mid-Point Flame Length (ft.)	Flame-Length Probability (fraction)	Mid-point flame length X flame-length probability
1	0 – 2	1	0.0	0.0
2	2 – 4	3	0.1	0.3
3	4 – 6	5	0.3	1.5
4	6 – 8	7	0.4	2.8
5	8 – 12	10.5	0.1	1.05
6	> 12	100*	0.1	10.0
			Conditional Flame Length:	**15.65**

* Because there is no midpoint for fire intensity level 6, a surrogate flame length of 100 feet was used to represent torching trees.

Flame-length exceedance probability represents the conditional probability of exceeding a nominal flame-length value. We produced five flame-length exceedance probability rasters, one for each flame-length value of 2, 4, 6, 8, and 12 feet (Figure 10). There is no raster for exceeding a flame length of zero because, by definition, for all burnable pixels there is a 100 percent probability that flame length will exceed zero, given that a fire occurs. Flame length exceedance probability is useful in describing fire behavior potential, especially in identifying areas where specific flame length thresholds are likely to be met.

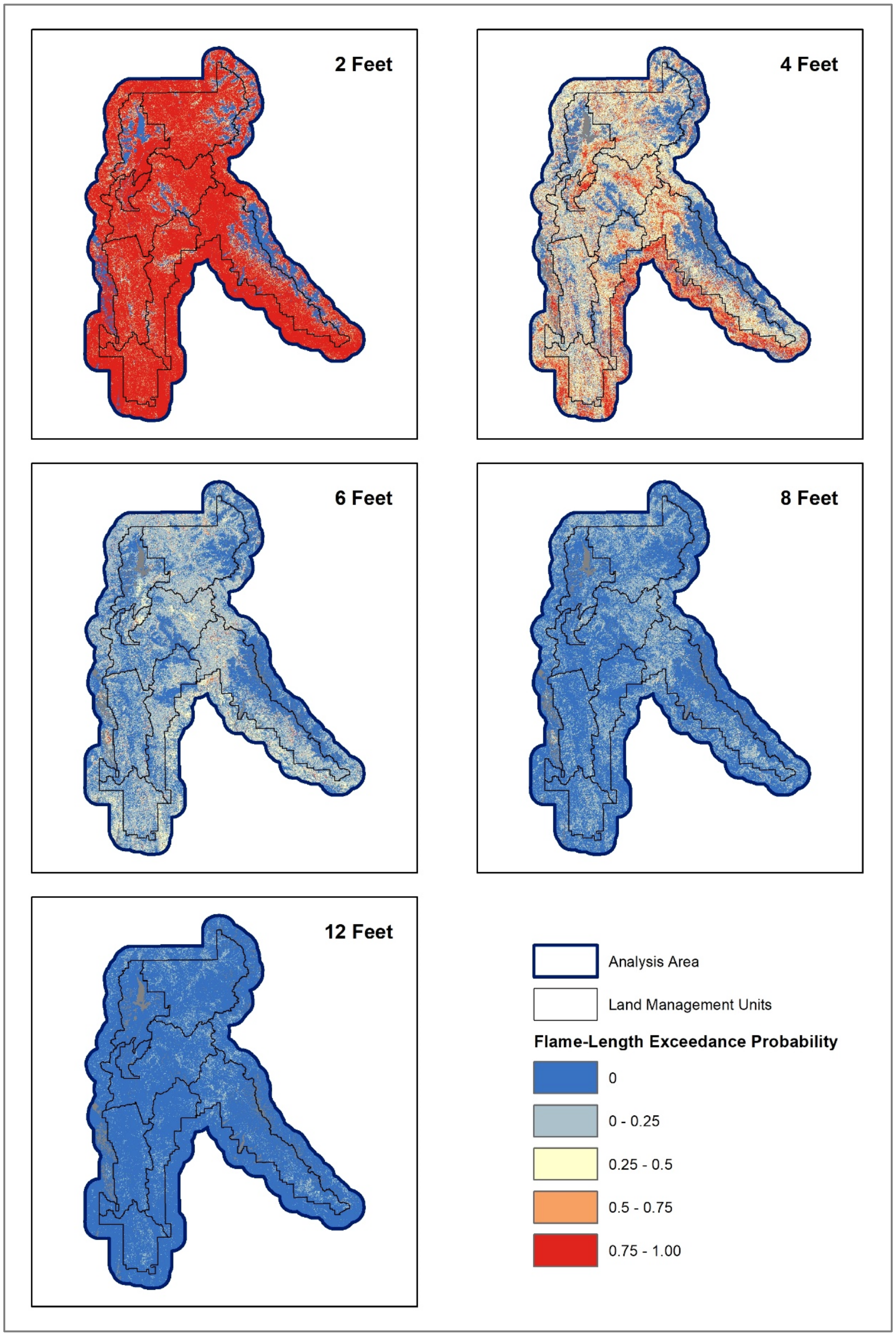

Figure 10. Flame length exceedance probability for five flame-length values within the Teton Interagency Risk Assessment analysis area.

3. Characterization of Highly Valued Resources and Assets

3.1 HVRA Identification

We asked Line Officers and Resource Specialists from the Bridger-Teton National Forest and Grand Teton National Park to identify the suite of highly valued resources and assets (HVRAs) to be analyzed in this assessment. Resources and assets were deemed 'highly valued' for the purposes of the assessment based on their importance to wildland fire and land management decision making. The identification process proceeded hierarchically, in that primary HVRA categories were identified first, followed by articulation of sub-HVRAs to differentiate between similar resources or assets that may have differences in importance and/or susceptibility to wildfire. For example, wildlife habitat was identified as an HVRA with multiple sub-HVRAs representing the habitat of individual species. In some cases, a covariate was also identified as an important characteristic affecting an HVRA's or sub-HVRA's response to wildfire without affecting its relative importance. For example, in addition to species composition, the susceptibility of timber is influenced by the size-class of the trees. Nine primary HVRAs with 37 sub-HVRAs were identified (Table 6). Covariates were identified for the ecological integrity, municipal watershed, timber, and wildlife habitat HVRAs.

Table 6. Highly valued resources and assets (HVRAs), sub-HVRAs, and covariates of the Teton Interagency Quantitative Wildfire Risk Assessment.

HVRA	Sub-HVRA	Covariate
Ecological Integrity	Aspen Forest and Woodland	Custom (see Appendix C)
	Douglas-Fir Forest and Woodland	
	Subalpine Dry-Mesic Spruce-Fir Forest and Woodland	
	Subalpine Mesic-Wet Spruce-Fir Forest and Woodland	
	Subalpine Woodland and Parkland	
	Sagebrush	
Heritage Resources	Historic Buildings	None
	Historic Districts (Grand Teton Only)	
	Historic Campgrounds (Grand Teton Only)	
Human Habitation	Below Density Rating	None
	Very Low Density	
	Low Density	
	Medium Density	
	Medium-High Density	
	High Density	
	Very High Density	
Municipal Watersheds	Low Complexity	Slight/Low Erosion Hazard
		Moderate Erosion Hazard
		High Erosion Hazard

HVRA	Sub-HVRA	Covariate
	Moderate Complexity	Slight/Low Erosion Hazard
		Moderate Erosion Hazard
		High Erosion Hazard
	High Complexity	Slight/Low Erosion Hazard
		Moderate Erosion Hazard
		High Erosion Hazard
Recreation and Administrative Infrastructure	Buildings	None
	Low-Development Recreation Sites	
	Moderate-Development Recreation Sites	
	High-Development Recreation Sites	
Special Uses	Elk Feed Ground Facilities	None
	Oil and Gas Leases	
	Ski Areas	
	Recreation Residences and Resorts	
Production Timber	Sub-merchantable (<5" DBH, all species)	None
	Aspen-Conifer Mix	5"-9.9" diameter
		10"-19.9" diameter
		≥20" diameter
	Douglas-Fir Mix	5"-9.9" diameter
		10"-19.9" diameter
		≥20" diameter
	Lodgepole Pine Mix	5"-9.9" diameter
		10"-19.9" diameter
		≥20" diameter
	Spruce-Fir Mix	5"-9.9" diameter
		10"-19.9" diameter
		≥20" diameter
	Whitebark Pine Mix	5"-9.9" diameter
		10"-19.9" diameter
		≥20" diameter
Utilities Infrastructure	Communication Sites	None
	Distribution Lines	
	Transmission Lines	
Wildlife Habitat	Elk Winter Range (Crucial)	Herb/Shrub
		Aspen
		Conifer
	Elk Winter Range (General)	Herb/Shrub
		Aspen
		Conifer

HVRA	Sub-HVRA	Covariate
	Lynx Habitat - lodgepole regen	
	Lynx Habitat - spruce/fir forest	Regen
		Young
		Mature
	Sage Grouse Habitat	

3.2 HVRA Mapping and Response to Wildfire

The spatial extent of each sub-HVRA was defined based on the characteristics of the resource or asset that are affected by wildfire. All vector-based source data were converted to raster format at a 30-m pixel resolution for use in the risk calculations. Non-burnable pixels were removed from the final extent as they do not contribute to wildfire risk.

Response to wildfire was characterized as tabular response functions based on consensus-based professional judgement of Bridger-Teton National Forest and Grand Teton National Park Resource Specialists. The response functions quantify the susceptibility of HVRAs to each of six fire intensity levels (FILs) as a percentage change in value due to exposure. Values range numerically from -100 (total loss) to +100 (greatest possible benefit), with zero indicating a neutral response.

Professional input on HVRA mapping and response to wildfire was provided by the following resource specialists: Diane Abendroth, Kate Birmingham, Dun Cochrane, Chip Collins, Dave Cottle, Don Delong, Ashley Egan, Brian Goldberg, Randy Griebel, Dave Gustine, Laura Jones, Tobin Kelley, Erik Kramer, Rusty Mizelle, Andy Norman, Hector Ortiz (Regional Office), Kelly Owens, Trevi Robertson, JP Schubert, Justin Snyder, Cindy Stein, and John Stephenson.

3.2.1 Ecological Integrity

The Ecological Integrity HVRA recognizes naturally functioning terrestrial ecosystems as an important natural resource influencing wildland fire and land management decisions. The 2012 Forest Service Planning Rule defines ecological integrity as:

> *"The quality or condition of an ecosystem when its dominant ecological characteristics (for example, composition, structure, function, connectivity, and species composition and diversity) occur within the natural range of variation and can withstand and recover from most perturbations imposed by natural environmental dynamics or human influence (36 CFR 219.19)."*

Characterization of ecological integrity as an HVRA was a multi-step process that involved first assessing ecological departure across the analysis area and then developing response functions that characterize the effect of wildfire on departure (Appendix C). Resource specialists identified six LANDFIRE biophysical settings (BpSs) for inclusion in the assessment as sub-HVRAs. Each BpS was mapped to the full analysis area extent with the exception of sagebrush (Figure 11). Sagebrush was mapped to the land management units only due to the unavailability of cheatgrass data for the full analysis area extent. The cheatgrass data were necessary for mapping a covariate of cheatgrass susceptibility used in the response functions (see below).

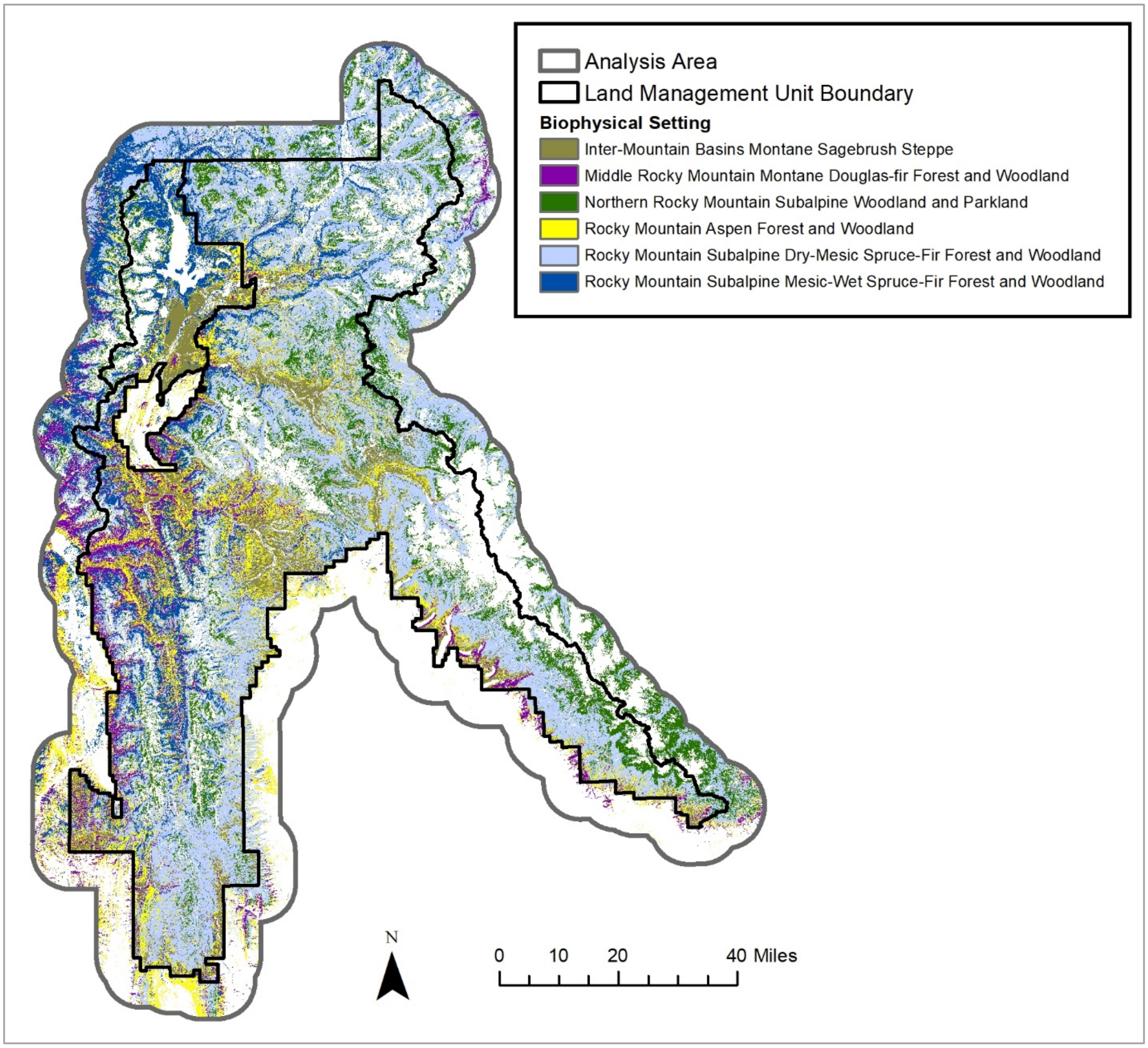

Figure 11. Spatial extent of the Ecological Integrity sub-HVRAs.

LANDFIRE BpSs represent potential vegetation communities based on both the biophysical environment and an approximation of the historical disturbance regime (Barrett et al. 2010). Corresponding to each BpS is a set of vegetation development stages referred to as succession classes (S-Classes). S-Classes are defined by species composition and structure. To account for disturbances occurring between 2015 and 2018, and ensure consistency with the wildfire hazard modeling outputs, we manually mapped S-Class by applying LANDFIRE S-Class mapping rules for each BpS to the updated vegetation data used to create the fire modeling landscape (Section 2.2). We additionally updated S-Class for the presence of cheatgrass (i.e., uncharacteristic-exotic S-Class) in the sagebrush BpS using locally derived spatial data (Egan 2019).

Next, we delineated landscape units within each BpS. Each BpS/landscape unit combination defines a stratum for assessing S-Class departure. Strata vary in size based on the biophysical setting's historical fire regime and spatial distribution on the landscape. To be meaningful, strata need to be sufficiently broad to encompass the major disturbance regimes of each BpS and to have a realistic expectation of containing a natural distribution of conditions in response to the ecological drivers inherent in them. Generally speaking, BpSs associated with longer return interval and higher severity fire regimes should be evaluated across larger landscapes than BpSs driven by shorter return interval and lower severity regimes.

For all but the Subalpine Woodland and Parkland BpS, we utilized the US Forest Service Ecomap Subsections (McNab et al. 2007) as a first approximation of landscape stratification. Ecomap follows the National Hierarchical Framework for Ecological Units and provides a nested and hierarchical delineation of ecological units. In applying the Ecomap polygons to define strata, small polygons of adjacent subsections were combined with core subsections to ensure adequate minimum scales for analysis for each BpS. In combining portions of subsections and delineating analysis strata, consideration was given to the overarching geographic and topographic influences on the BpSs rather than relying purely on length of shared border. The elevational setting of the Subalpine Woodland and Parkland BpS did not align well with Ecomap Subsection delineations. To avoid artificial delineations in connected systems, a manual delineation was developed.

Each BpS is associated with a vegetation dynamics model. The model is used to estimate the natural, range of variation in the relative abundance of S-Classes under the historical disturbance regime. The average relative abundance of S-Classes for each BpS is referred to as the reference condition. It is assumed that ecological integrity is intact when current conditions are similar to the reference condition—the greater the departure from the reference condition, the less resiliency to current and future stressors. We applied the standard LANDFIRE vegetation departure methodology (Barrett et al. 2010) to quantify the degree of departure as the percent difference between the current and reference condition S-Class relative abundance.

Finally, we reclassified the S-Class departure as one of three covariates: deficit (-100 to -33 percent difference from the reference amount), similar (-33 to 33 percent difference from the reference amount), or surplus (33 to 100 percent difference from the reference amount). Positive or negative response to fire was then characterized as a function of whether fire causes a transition from one S-Class to another (Appendix C) and the departure status of both the pre- and post-fire S-Class (Table 7). For example, if fire causes a change in S-Class where the pre-fire S-Class was in surplus and the post-fire S-Class was in deficit, we assign a benefit of +75 to ecological integrity—both the surplus and deficit were lessened as a result of the fire. For the sagebrush BpS we mapped an additional covariate representing areas with high susceptibility for post-fire cheatgrass establishment using a local cheatgrass susceptibility model (Egan 2019). It was assumed that wildfire in these areas would result in a conversion to cheatgrass and a response function value of -75 was assigned at all fire intensity levels.

Table 7. Ecological Integrity HVRA response functions.

		Post-Fire Status			No Transition
		Deficit	**Similar**	**Surplus**	
Pre-Fire Status	**Deficit**	0	-50	-75	0
	Similar	25	-25	-50	0
	Surplus	75	25	0	0
	Sagebrush with high susceptibility to cheatgrass (any status)	-75	-75	-75	-75

3.2.2 Heritage Resources

Much of the built infrastructure within the Bridger-Teton National Forest and Grand Teton National Park consists of historic buildings and structures that continue to be functionally used by the two government agencies and the public. Not only does federal law, agency mission, and management direction dictate protection of cultural resources, but historic buildings and districts provide a tangible connection between our current use of public lands with past settlement and management of the landscape, and provide a sense of grounding and value to the American people.

The Heritage Resources HVRA was split into three sub-HVRAs: historic buildings, historic districts, and historic campgrounds. Both the Forest and Park mapped historic buildings using available agency data (Figure 12). These are buildings currently on, or eligible for listing on, the National Register of Historic Places. Grand Teton National Park also included dilapidated historic structures that are intended for future restoration and modern buildings that contain historic art collections as part of the historic buildings sub-HVRA, despite their not being on or eligible for the National Register. We converted the point location of the historic buildings spatial data to raster at 30-m resolution, expanded by a one-pixel buffer, and masked out non-burnable pixels.

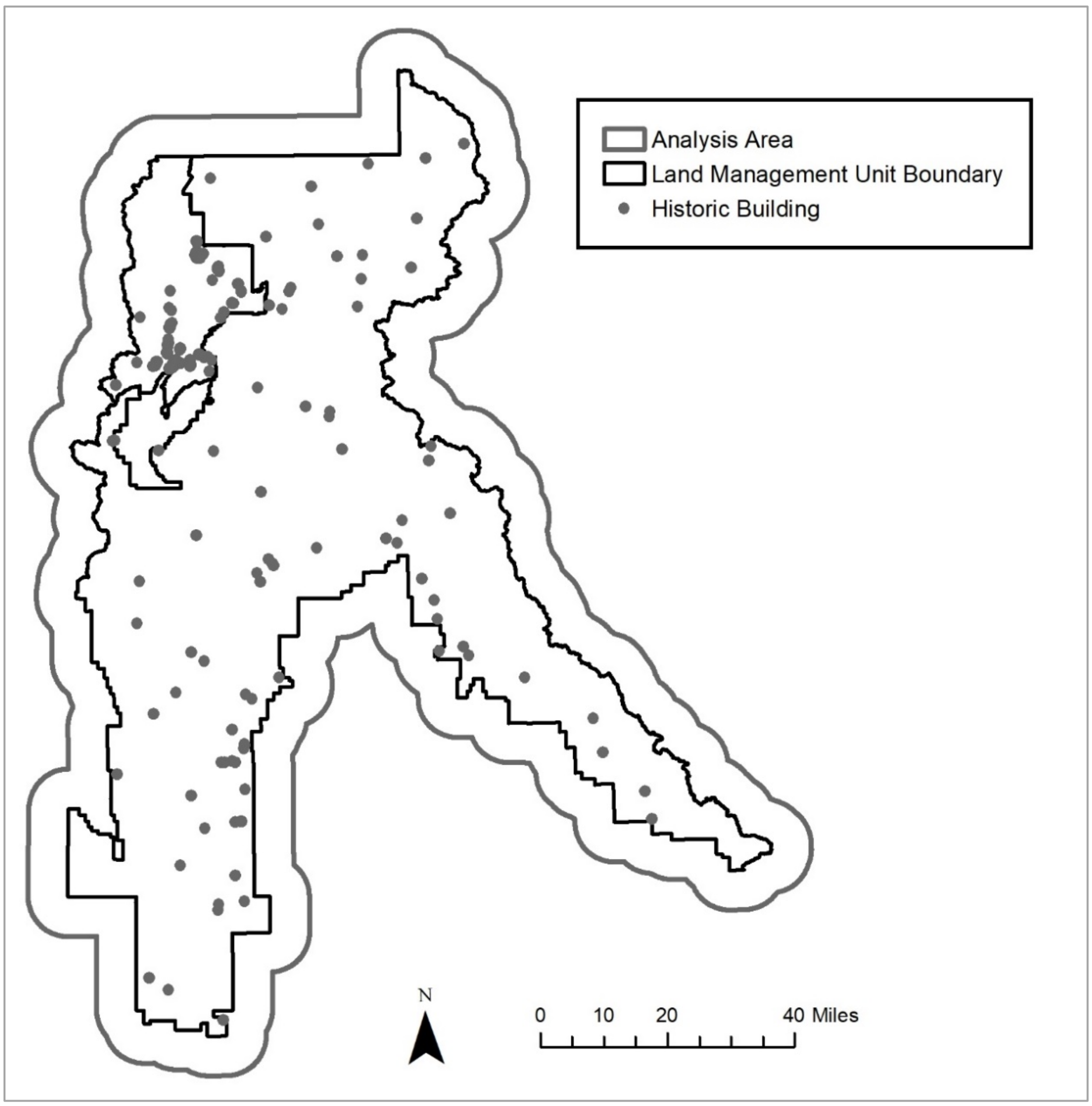

Figure 12. Spatial extent of the Historic Buildings sub-HVRA.

Historic districts and campgrounds are mapped only in Grand Teton National Park (Figure 13). Historic districts encompass areas with a culturally significant landscape, often with historic buildings contained within. Examples include homestead-era settlements and dude ranches. Landscape elements, constructed features, and a broad distribution of artifacts across these areas all contribute to the significance of historic districts. Historic Campgrounds are a specific type of historic district that was listed as a separate sub-HVRA so that it could be assigned a different relative importance value (Section 3.3). We converted the district and campground polygons delineated by Park staff to raster at 30-m resolution and masked out non-burnable pixels.

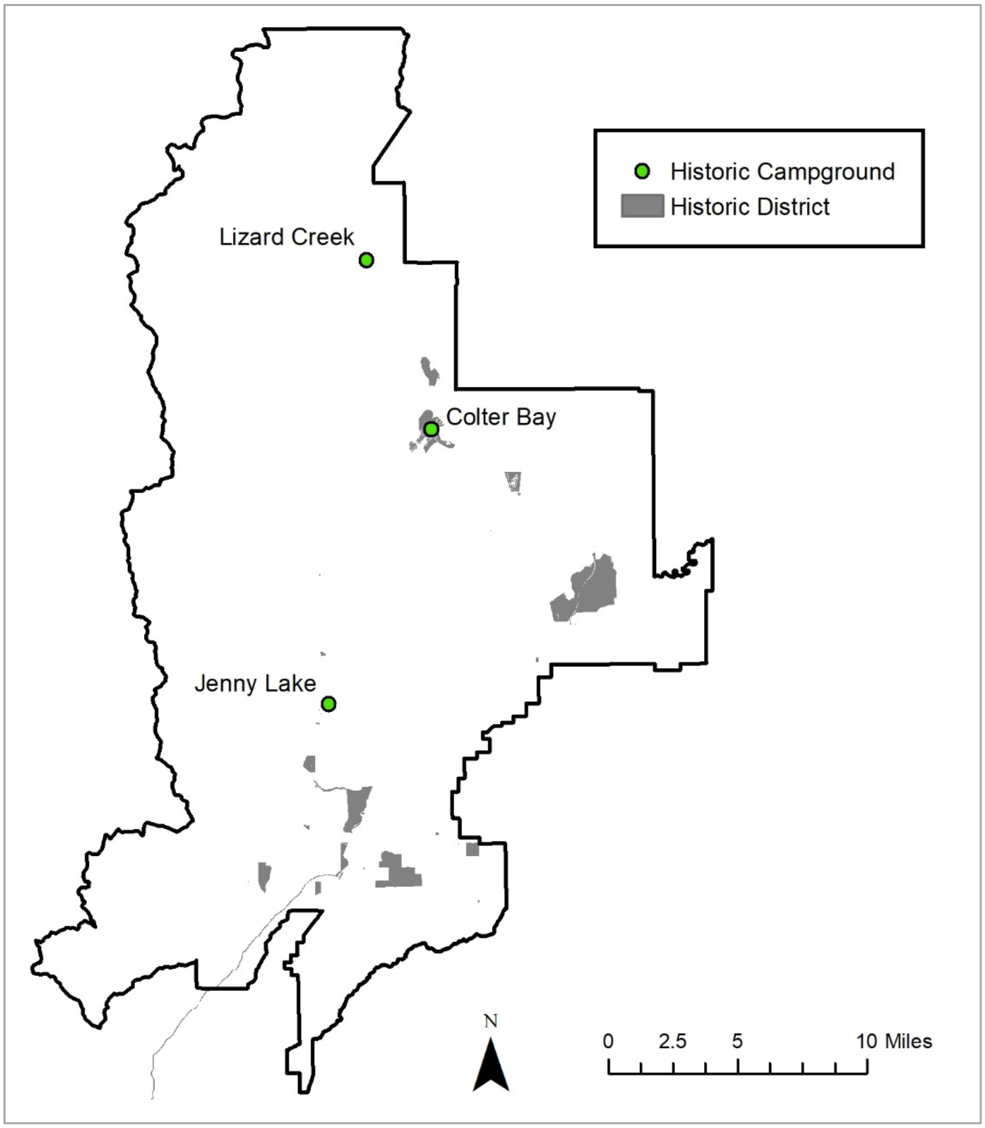

Figure 13. Spatial extent of the Historic Districts and Historic Campgrounds sub-HVRAs.

The same response function was assigned to each of the three sub-HVRAs by resource specialists (Table 8). Most of the historic buildings are rustic log and wooden buildings that are surrounded by native vegetation up to the foundations making them susceptible to damage from even low-intensity fire. The primary effect to historic districts and campgrounds is alteration or loss of the surrounding vegetation that characterizes the setting, and in the case of districts, scattered artifacts. At lower fire intensity levels herbaceous and shrub vegetation would be expected to recover quickly and most trees would survive. At moderate to high fire intensity levels herbaceous and shrub vegetation would be temporarily altered and trees would be lost, taking decades to recover.

Table 8. Heritage Resources HVRA response functions.

HVRA	Sub-HVRA	FIL1	FIL2	FIL3	FIL4	FIL5	FIL6
Heritage Resources	Historic Buildings	-30	-40	-60	-100	-100	-100
	Historic Districts (Grand Teton Only)	-30	-40	-60	-100	-100	-100
	Historic Campgrounds (Grand Teton Only)	-30	-40	-60	-100	-100	-100

Historic and prehistoric archaeological sites are also vulnerable to damage from wildland fire, however due to the sensitive nature of these site locations, they are reviewed for possible impacts during an incident and are not included in this assessment.

3.2.3 Human Habitation

We used the national housing-unit density raster (HUDen) to represent the spatial extent of the Human Habitation HVRA. HUDen was created using a combination of 2018 U.S. Census Bureau data and Microsoft building footprint data. More detailed information on the methodology used to create HUDen can be found in Scott et al. (2020).

The HUDen data included many non-residential structures within Grand Teton National Park that we are accounting for in the Heritage Resources and Recreation and Administrative Infrastructure HVRAs. To mitigate the potential double counting we clipped the HUDen raster to within private inholdings within the Park. No modification was made to the HUDen data outside of the Park. Finally, we classified the HUDen data into the same seven density classes (Figure 14) used in the West Wide Wildfire Risk Assessment (Sanborn Map Company 2016). Each class represents a sub-HVRA for use in distinguishing relative importance (Section 3.3).

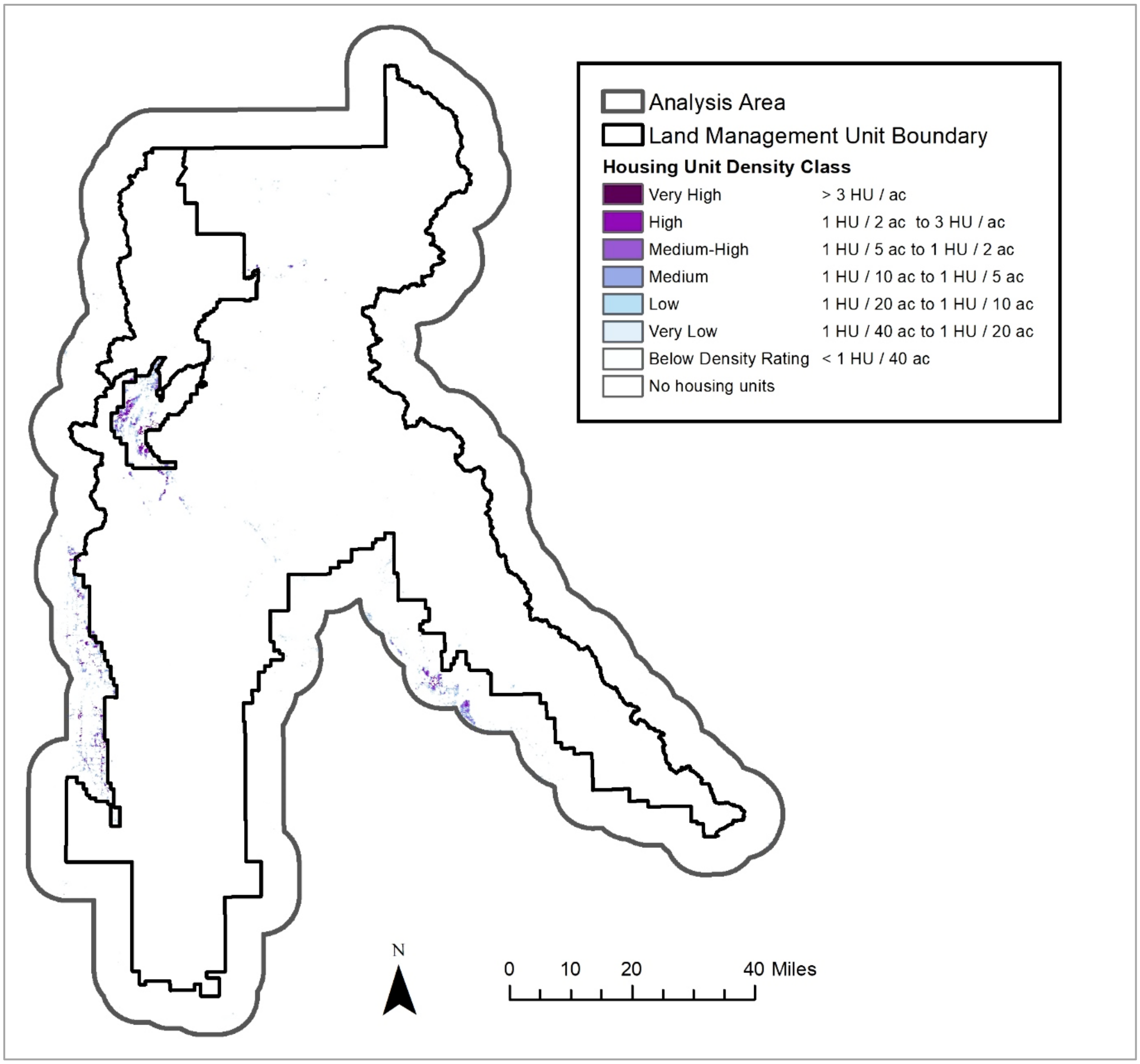

Figure 14. Spatial extent of the Human Habitation sub-HVRAs.

Characterizing the susceptibility of housing units to damage or destruction from wildfire is extremely challenging. Susceptibility is influenced by many factors—building materials, road access, defensible space, proximity to suppression resources, availability of resources, etc.—and quantitative information on the susceptibility of individual structures is not available at most spatial scales for which wildfire risk assessment is conducted. Furthermore, our fire behavior modeling systems don't account for the ignitability of homes from home-to-home spread or embers lofted from remote wildland fuels. For these reasons, we used a single response function to characterize wildfire effects for all housing unit density classes (Table 9). This response function assumes there is potential for loss even at low fire intensity levels and that the potential for loss increases with fire intensity—both as a result of more radiant heat and an increased potential for exposure to fire brands. Residential structures exposed to wildfire typically suffer complete loss or no loss at all (Cohen and Butler 1996). It may therefore be more convenient to think of the response function values as the chance of complete loss, rather than a percent loss in value.

Table 9. Human Habitation HVRA response functions.

HVRA	Sub-HVRA	FIL1	FIL2	FIL3	FIL4	FIL5	FIL6
Human Habitation	Below Density Rating	-10	-20	-60	-80	-100	-100
	Very Low Density	-10	-20	-60	-80	-100	-100
	Low Density	-10	-20	-60	-80	-100	-100
	Medium Density	-10	-20	-60	-80	-100	-100
	Medium-High Density	-10	-20	-60	-80	-100	-100
	High Density	-10	-20	-60	-80	-100	-100
	Very High Density	-10	-20	-60	-80	-100	-100

3.2.4 Municipal Watersheds

Municipal watersheds[1] provide water to the public for human consumption through pipes or other constructed conveyances. Spatial data of municipal watersheds on the Bridger-Teton National Forest were provided by the Forest Hydrologist/Water Rights Coordinator. The spatial extent was expanded to the sub-watershed (6th level hydrologic unit) as the scale for estimating fire effects. We converted the sub-watershed polygons to raster at 30-m resolution and masked out non-burnable pixels (Figure 15). Municipal watersheds are not present in Grand Teton National Park.

Each municipal watershed was assigned a ranking of low, moderate, or high complexity based on the number of persons served and infrastructure replacement cost. These categories represent municipal watershed sub-HVRAs (Table 10).

A covariate of erosion hazard was added by intersecting Bridger-Teton soil survey spatial data with the sub-watersheds. Erosion hazard refers to the likelihood of erosion and potential damage resulting from disturbances that expose the soil surface. Erosion hazard ratings are based on slope, k-factor (a measure of inherent soil erodibility), and rock fragments on the surface layer. Slight/low hazard refers to soils where erosion is unlikely under ordinary climatic conditions. Moderate hazard refers to soils where some erosion is likely and control measures may be needed to mitigate damage. Severe hazard refers to soils where erosion is very likely and control measures for vegetation re-establishment on bare areas and structural measures are advised.

[1] The term watershed is used here in a generic sense. All the municipal watersheds in the analysis area were smaller than the USDA, Natural Resources Conservation System, Watershed Boundary Dataset definition of a watershed (i.e., 5th level hydrologic unit).

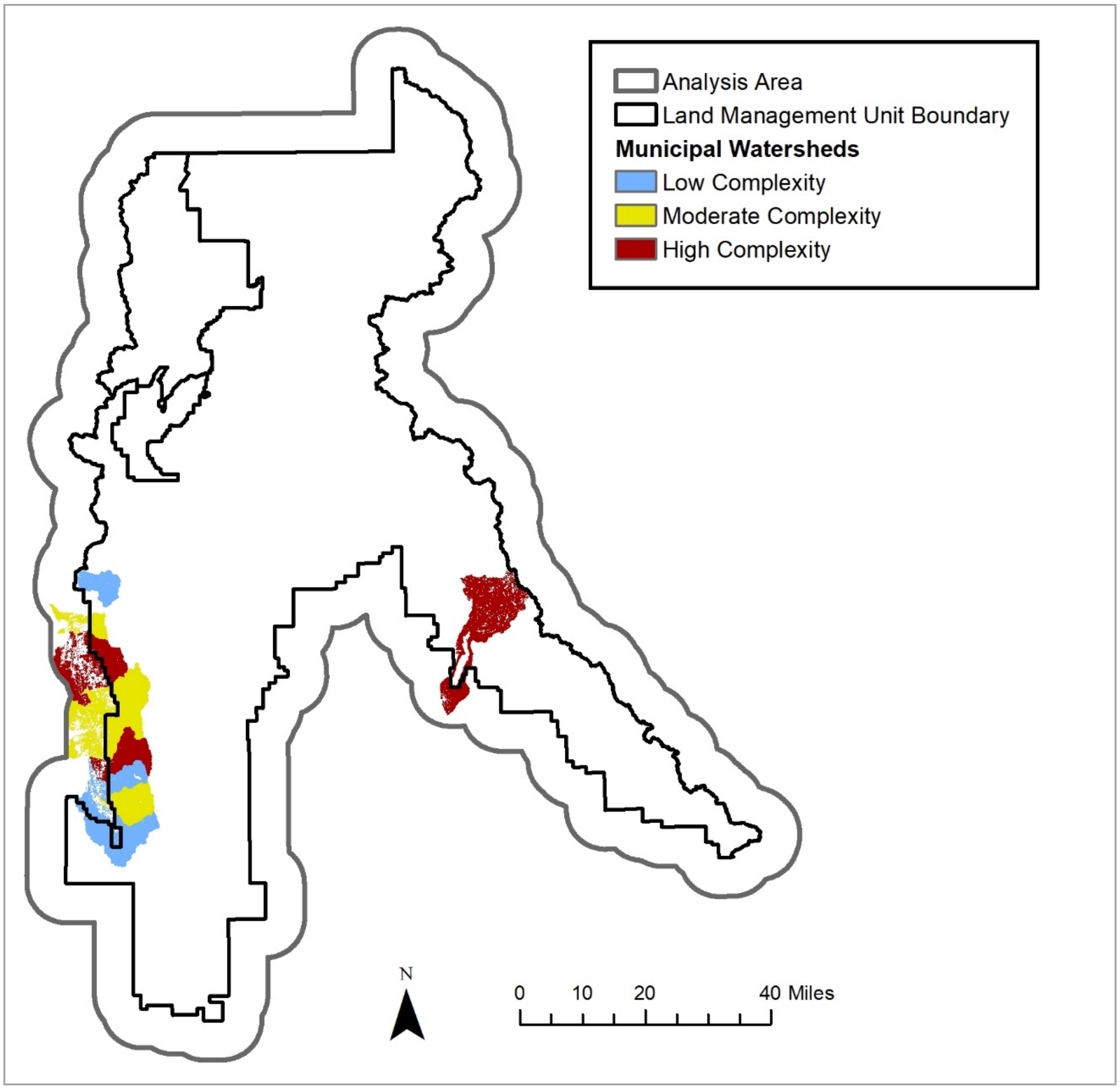

Figure 15. Spatial extent of the Municipal Watershed sub-HVRAs.

The potential for soil exposure increases with fire intensity. Response functions reflect the potential effect of erosion-induced sedimentation on water intake developments and filtration systems as a factor of fire intensity and erosion hazard (Table 10). No effect is expected for flame lengths less than 2 ft., a loss in value of 10% to 50% is estimated for wildfire burning in low erosion hazard areas, 20% to 80% in moderate erosion hazard areas, and 30% to 100% in high erosion hazard areas.

Table 10. Municipal Watersheds HVRA response functions.

HVRA	Sub-HVRA	Covariate	FIL1	FIL2	FIL3	FIL4	FIL5	FIL6
Municipal Watersheds	Low Complexity	Slight/Low Erosion Hazard	0	-10	-20	-30	-40	-50
		Moderate Erosion Hazard	0	-20	-30	-50	-70	-80
		High Erosion Hazard	0	-30	-50	-75	-100	-100
	Moderate Complexity	Slight/Low Erosion Hazard	0	-10	-20	-30	-40	-50
		Moderate Erosion Hazard	0	-20	-30	-50	-70	-80
		High Erosion Hazard	0	-30	-50	-75	-100	-100
	High Complexity	Slight/Low Erosion Hazard	0	-10	-20	-30	-40	-50
		Moderate Erosion Hazard	0	-20	-30	-50	-70	-80
		High Erosion Hazard	0	-30	-50	-75	-100	-100

3.2.5 Recreation and Administrative Infrastructure

Recreation is a primary use of the Bridger-Teton National Forest and Grand Teton National park. The Recreation and Administrative Infrastructure HVRA was split into four sub-HVRAs characterizing recreation-based assets. Buildings used for recreational and/or administrative purposes represent a single sub-HVRA. Recreation sites were classified into three additional sub-HVRAs based on the level of development and replacement value of the site. The Bridger-Teton National Forest included both picnic areas and campgrounds as recreation sites; Grand Teton National Park included only non-historic campgrounds—the Park's historic campgrounds are included in the Heritage Resources HVRA. Spatial data were acquired from agency databases (Figure 16) and converted to raster at 30-m resolution. Buildings and Forest Service recreation sites, which were represented as points, were expanded by a one-pixel buffer. All non-burnable pixels were masked out.

Response functions characterizing the susceptibility of recreation sites were adopted from the Forest Service, Intermountain Region, Quantitative Wildfire Risk Assessment (Helmbrecht et al. 2019). Effects vary by the level of development of the sites and fire intensity (Table 11). High-development sites are expected to better withstand effects of low-intensity fire (FILs 1 & 2) as they are often newer and constructed with more fire-resistant materials (concrete toilets/vaults – less wood construction), are more likely to have received some level of vegetation management or hazardous fuel reduction, and have more access to firefighting resources. In most cases, low-intensity ground fire would not create substantial effects to high-development recreation sites. Moderate impacts are estimated at FILs 3 & 4, though high-standard facilities would be more likely to withstand with minimal damage.

Medium-development sites are estimated to receive incrementally more negative effects to FILs 1 & 2 than high-development sites due to the site's facilities sometimes being older and constructed with more wood and non-fire-resistant materials (wood toilets, wood shingled roofs), having less active vegetation management and defendable space, less access, and often being more remote. In most cases, low-intensity ground fire would not create substantial effects to medium-developed recreation sites, though additional impacts would be expected to sites that are on the lower end of this scale of development. Like high-development sites, impacts of FILs 3 & 4 would be incrementally higher due to lower-standard buildings (more wood) and less access.

Low-development sites are estimated to have an incrementally more negative response to FILs 1 & 2 than moderate-development sites as all aspects identified above lead to more susceptibility, including wood structures, older facilities, lack of defendable space, remote locations, and less access. Low-development sites would likely receive significant damage from FILs 3 & 4 due to the types of structures (mostly wood) and the remoteness and limited access to resources.

High-intensity fire would have a devastating effect on all development levels of recreation sites. Most sites, as well as the surrounding landscape, would likely be severely burned and damaged, with many facilities destroyed. Some would likely never be rebuilt; others may be closed for years for rebuilding as budgets permit. Once hazard trees have been removed, there may be a substantial change in the quality of the recreation experience, especially in campgrounds and picnic areas.

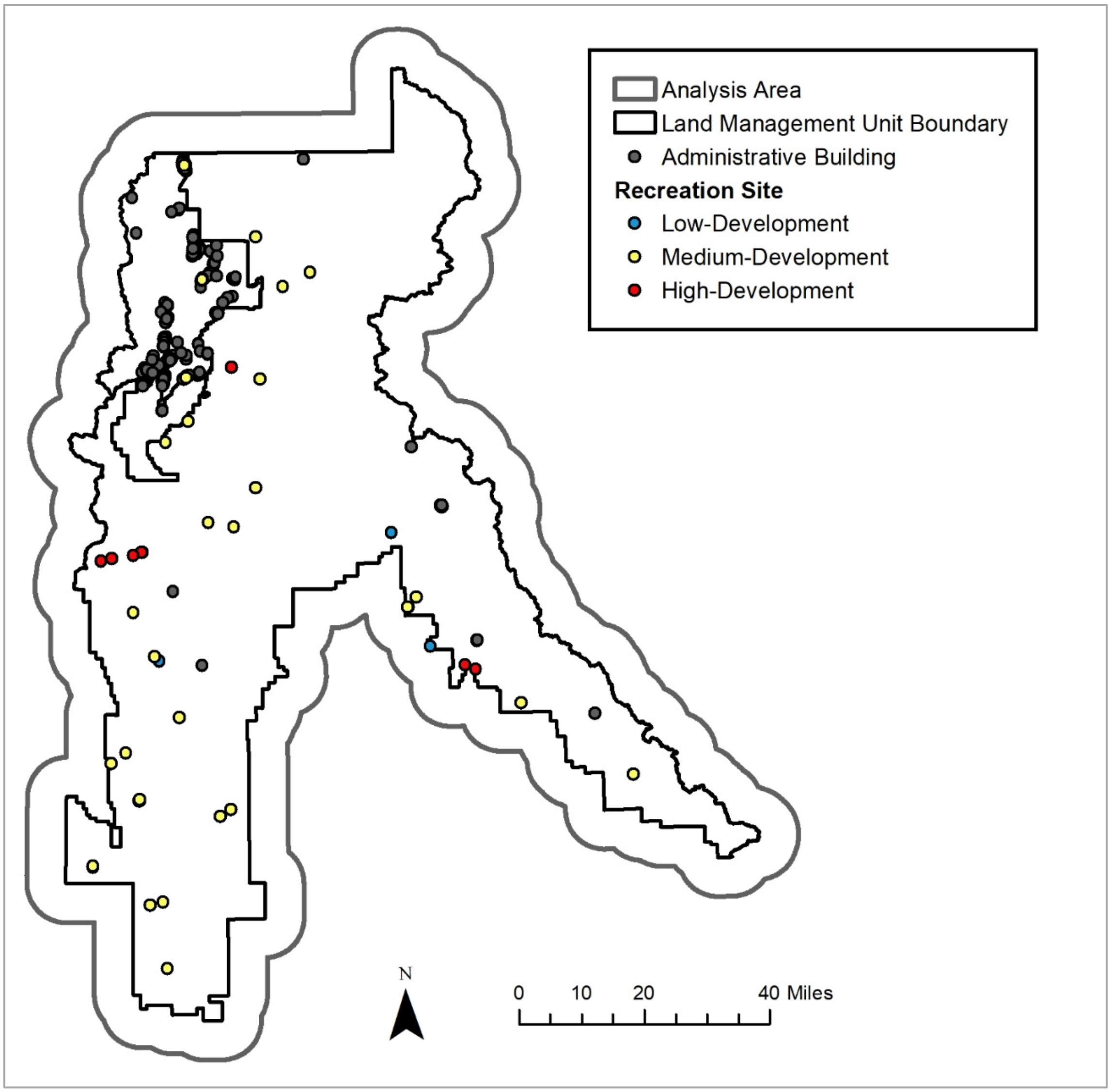

Figure 16. Spatial extent of the Recreation and Administrative Infrastructure sub-HVRAs.

Table 11. Recreation and Administrative Infrastructure HVRA response functions.

HVRA	Sub-HVRA	FIL1	FIL2	FIL3	FIL4	FIL5	FIL6
Recreation and Administrative Infrastructure	Buildings	-20	-30	-50	-90	-100	-100
	Low-Development Recreation Sites	-25	-50	-75	-75	-100	-100
	Moderate-Development Recreation Sites	-10	-25	-50	-75	-100	-100
	High-Development Recreation Sites	0	-20	-50	-50	-100	-100

3.2.6 Special Uses

The Special Uses HVRA includes Forest Service long-term permitted private structures and associated operations. These permitted operations meet Forest Plan goals and objectives to provide recreational opportunities, Wyoming Game and Fish Department wildlife objectives, and provide oil/gas resources. Wildland fire has the potential to both damage capital improvements as well as impact activities within the permitted area. Spatial data were acquired from Bridger-Teton National Forest databases (Figure 17) and converted to raster at 30-m resolution. Elk feed-ground structures, which were represented as points, were expanded by a one-pixel buffer. All non-burnable pixels were masked out.

Four sub-HVRAs were identified based on the size, scope, and purpose of the special use permit (Table 12). Recreation residences, resorts, and outfitter cabins that are permitted on Forest Service System land make up the Recreation Residences and Resorts sub-HVRA. Although many of the structures are older, of wooden construction, and minimally fire resistant, permittees are required to minimize fire susceptibility. Additionally, the Forest Service has completed some level of hazardous fuels reduction within and adjacent to many of the building sites. Given these considerations, low to moderate losses are expected at FILs 1 & 2. At FIL 3, spotting and torching may occur, and suppression efforts will become more difficult leading to increased susceptibility of the less fire-hardened structures. At FILs 4 – 6 structures will very likely be lost.

Winter feed ground facilities are permitted to the Wyoming Game and Fish Department. The facilities consist of large open pasture with covered hay sheds and a few associated cabins and outbuildings. The primary value is in the cabins and hay that is stored in the sheds during the summer in preparation for winter feeding.

FILs 1 – 3 are expected to result in increasing loss to the hay sheds and associated buildings, especially if the hay is well cured. If adequate firefighter response is available, suppression action using water and hand tools will likely be effective at mitigating loss. Exposure to FILs 4 – 6 is expected to result in a complete loss.

The infrastructure associated with oil and gas leases includes wells, manifolds, and pipelines. Although the majority of infrastructure is located in open areas and is not susceptible to damage from wildfires, the major impact to these sites is if they were required to shut down production for a period of time during wildland fire operations. For this reason, we characterized the sub-HVRA as the area within a 0.5-mile buffer of the infrastructure. FILs 1 – 3 are expected to have minimal impacts to oil and gas operations, while the greater rate of spread and potential for spotting into, or adjacent to, infrastructure associated with FILs 4 – 6 is expected to have moderate impacts.

Three ski areas are permitted on the Bridger-Teton National Forest. Infrastructure includes ski lifts, snow making and maintenance equipment, and buildings. All three facilities have completed some degree of recent hazardous fuels mitigation within and adjacent to the permit area. FILs 1 & 2 are expected to have minimum impacts on vegetation and infrastructure. Infrastructure will be more susceptible to damage or loss at FIL 3. Older buildings and other structures located adjacent to forested areas may be damaged and torching and spotting, especially from subalpine fir stands, may throw embers into and around developed areas. High loss is expected at FILs 4 – 6, any resulting crown fire activity can damage ski lifts, even higher up at the top of the towers.

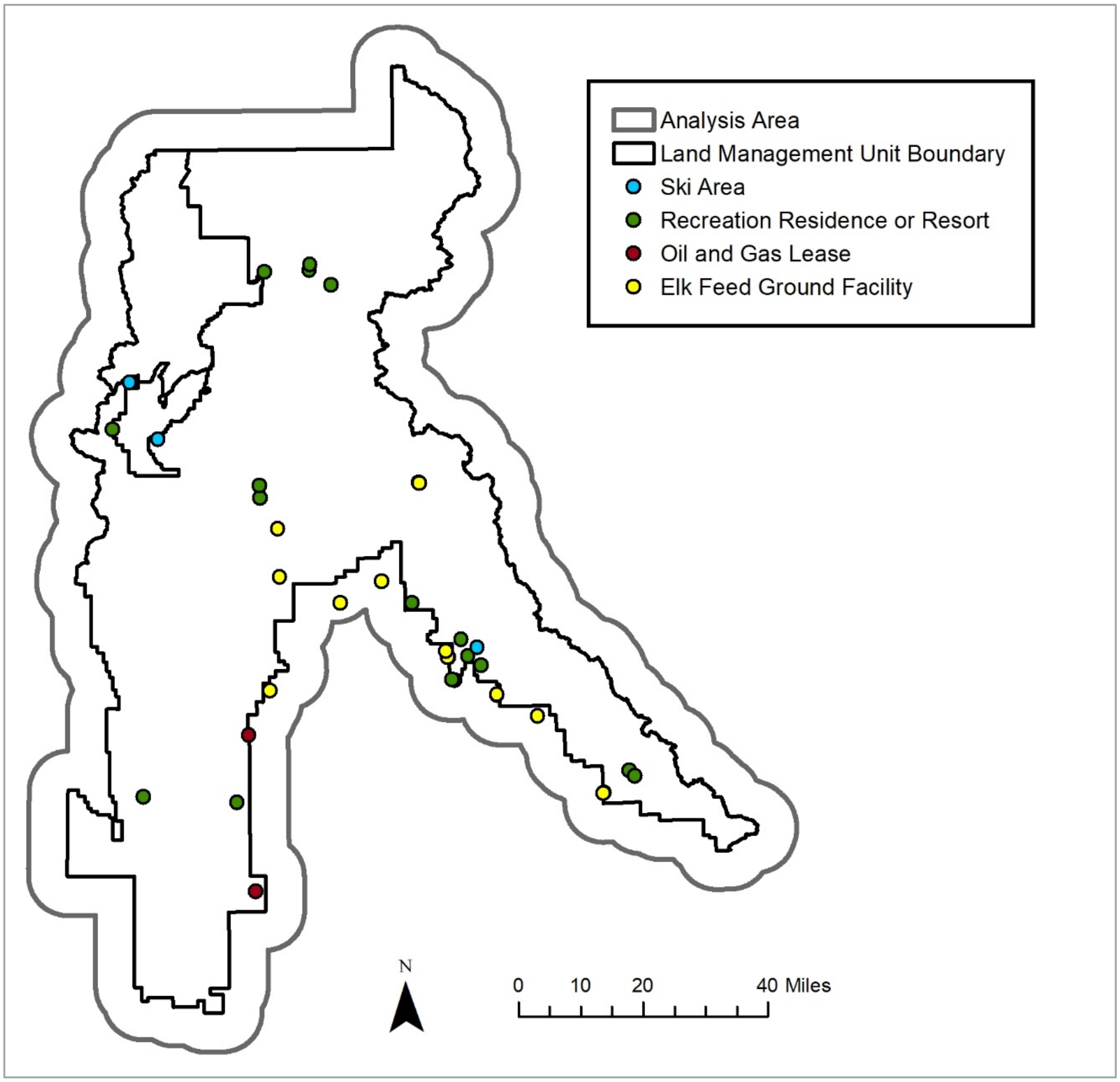

Figure 17. Spatial extent of the Special Uses sub-HVRAs.

Table 12. Special Uses HVRA response functions.

HVRA	Sub-HVRA	FIL1	FIL2	FIL3	FIL4	FIL5	FIL6
Special Uses	Recreation Residences and Resorts	-20	-30	-50	-90	-100	-100
	Elk Feed Ground Facilities	-30	-40	-60	-100	-100	-100
	Oil and Gas Leases	0	-5	-20	-40	-50	-70
	Ski Areas	-5	-15	-35	-75	-90	-90

3.2.7 Production Timber

The Production Timber HVRA represents the Bridger-Teton National Forest's suitable timber base within the 1990 Forest Plan's Desired Future Condition (DFC) Area 1B—Substantial Commodity Resource Development with Moderate Accommodation of Other Resources. Although the harvest of timber as a management tool is allowed in other DFC Areas, timber as a commodity is a primary objective in 1B.

The Forest's 2018 existing vegetation data were filtered for conifer and deciduous map groups containing commercial timber species. Pure aspen, whitebark pine, and limber pine types were removed from consideration as those species do not provide any commercial products for the timber industry within the region. Stands with slopes greater than 40 percent were also removed as timber harvest is not implemented on slopes above this threshold. The data were then clipped to DFC 1B. To ensure consistency with LANDFIRE vegetation-fuel assignments, we applied a mask when converting to raster so that only pixels representing the LANDFIRE tree lifeform would be included in the final spatial extent (Figure 18). The Production Timber HVRA was split into six sub-HVRAs and three covariates based on species composition and tree size class to allow for the characterization of relative importance and fire effects (Table 13).

Non-merchantable stands (i.e., those with an average diameter at breast height of less than five inches) of any species composition were grouped into a single sub-HVRA. Some of these stands have regenerated naturally after disturbance while others have been planted. Many are currently in an overstocked condition and have reached a level of stagnation where tree growth and vigor has begun to decline. Fire at lower FILs is beneficial as a mechanism to thin overstocked stands and create stand heterogeneity. At moderate and high FILs these stands are highly susceptible to mortality resulting in a loss of investment in planting and/or in future timber value.

Merchantable stands were split into five sub-HVRAs based on species composition. Additionally, three covariates were assigned representing different size classes to further differentiate between fire effects. Lodgepole pine, Engelmann spruce, and subalpine fir are the commercially viable species found on the Forest. Aspen has little to no commercial value, and although considered a commercially viable species, Douglas-fir has limited value on the Bridger-Teton due to its open-grown nature resulting in a high proportion of limbs contributing to poor wood quality.

Lodgepole pine is the primary commercial species found in each of the merchantable sub-HVRAs except for the spruce-fir mix, where it is less common. As such, we applied the same response functions to each of the remaining four sub-HVRAs. Lodgepole is a fire-intolerant tree species and susceptible to mortality even at lower fire intensity levels. As lodgepole matures it becomes slightly less susceptible as bark thickens and lower branches are self-pruned but there is little difference in susceptibility in trees ten inches or greater in size. Loss was capped at -80 for the ten inch and greater size classes to account for the potential recovery of timber value through salvage sales.

Engelmann spruce and subalpine fir are the primary commercial species in the spruce-fir mix sub-HVRA. Like lodgepole pine both are fire-intolerant species and susceptible to mortality from even low fire intensity levels. Spruce and fir are more susceptible to mortality in the 10- to 20-inch size class than lodgepole. Subalpine fir also has less post-fire salvage potential because wood quality degrades quickly. However, fire-killed spruce holds value as house logs or firewood. Loss was thus capped at -90 for the ten inch and greater size classes.

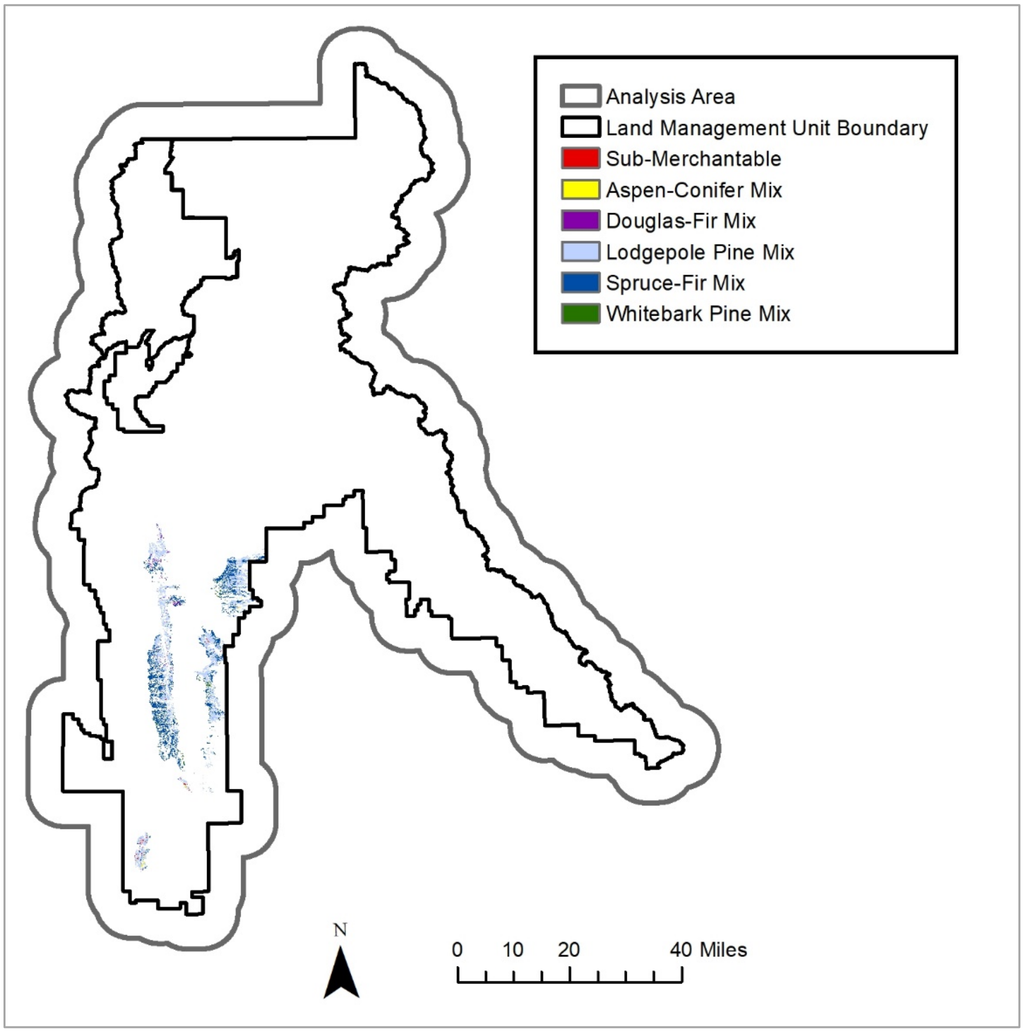

Figure 18. Spatial extent of the Production Timber sub-HVRAs.

Table 13. Production Timber HVRA response functions.

HVRA	Sub-HVRA	Covariate	FIL1	FIL2	FIL3	FIL4	FIL5	FIL6
Timber	Sub-merchantable (<5" DBH, all species)	None	50	-50	-80	-100	-100	-100
	Aspen-conifer mix	5"-9.9"	-50	-70	-80	-100	-100	-100
		10"-19.9"	-25	-50	-70	-80	-80	-80
		≥20"	-25	-50	-70	-80	-80	-80
	Douglas-fir mix	5"-9.9"	-50	-70	-80	-100	-100	-100
		10"-19.9"	-25	-50	-70	-80	-80	-80
		≥20"	-25	-50	-70	-80	-80	-80
	Lodgepole pine mix	5"-9.9"	-50	-70	-80	-100	-100	-100
		10"-19.9"	-25	-50	-70	-80	-80	-80
		≥20"	-25	-50	-70	-80	-80	-80
	Spruce-Fir mix	5"-9.9"	-50	-70	-80	-100	-100	-100
		10"-19.9"	-50	-70	-75	-90	-90	-90
		≥20"	-25	-50	-75	-90	-90	-90
	Whitebark pine mix	5"-9.9"	-50	-70	-80	-100	-100	-100
		10"-19.9"	-25	-50	-70	-80	-80	-80
		≥20"	-25	-50	-70	-80	-80	-80

3.2.8 Utilities Infrastructure

The Utilities Infrastructure HVRA was split into three sub-HVRAs: communication sites, distribution lines (< 230 kV), and transmission lines (≥ 230 kV) to account for differences in fire effects and relative importance. Communication sites spatial data were acquired from Bridger-Teton National Forest and Grand Teton National Park databases. These data include the locations of agency radio repeaters and other state, local government, and private communication infrastructure on National Forest System land. Distribution and transmission line data were compiled from Forest and Park spatial databases and Homeland Infrastructure Foundation-Level Data within the open public domain. The point and line spatial data were converted to raster at 30-m resolution and expanded by one pixel. All non-burnable pixels were removed (Figure 19).

Although the components susceptible to damage from wildfire for each sub-HVRA are similar, the physical arrangement of those components and their distance from wildland fuel differ thus affecting their overall susceptibility to damage (Table 14). The electronics of communication sites generally include solder—which can be destroyed at temperatures of 382 degrees Fahrenheit—and copper wire—which can be destroyed at temperatures of 900 degrees Fahrenheit (Ortiz per. comm. May 2019). Communication sites are generally located 20 meters or greater from burnable fuels and therefore the amount of radiant heat generated by flame lengths of 4 feet or less reaching these components is unlikely to damage or destroy much of the infrastructure. The level of damage increases with fire intensity and we estimate that flame lengths greater than 8 feet are generating enough heat to cause a complete loss of the infrastructure.

The components associated with low-voltage distribution lines are generally the same as communication sites—solder and copper wire—however the lines are generally located in closer proximity to burnable fuels and therefore the amount of radiant heat generated by flame lengths of 4 feet or less reaching these components is more likely to damage or degrade the infrastructure than with communication sites. The level of damage increases with fire intensity and we estimate that flame lengths greater than 6 feet are generating enough heat to cause a complete loss of the infrastructure.

The copper wire associated with high-voltage transmission lines is generally able to withstand more heat than that in distribution lines—1,800 degrees Fahrenheit—and the lines are located further from burnable fuels. For these reasons it was estimated that the amount of radiant heat generated by flame lengths of 6 feet or less reaching these components is unlikely to do much damage or degrade the infrastructure and that it would require flame lengths greater than 8 feet to cause a significant loss of operational capability or infrastructure.

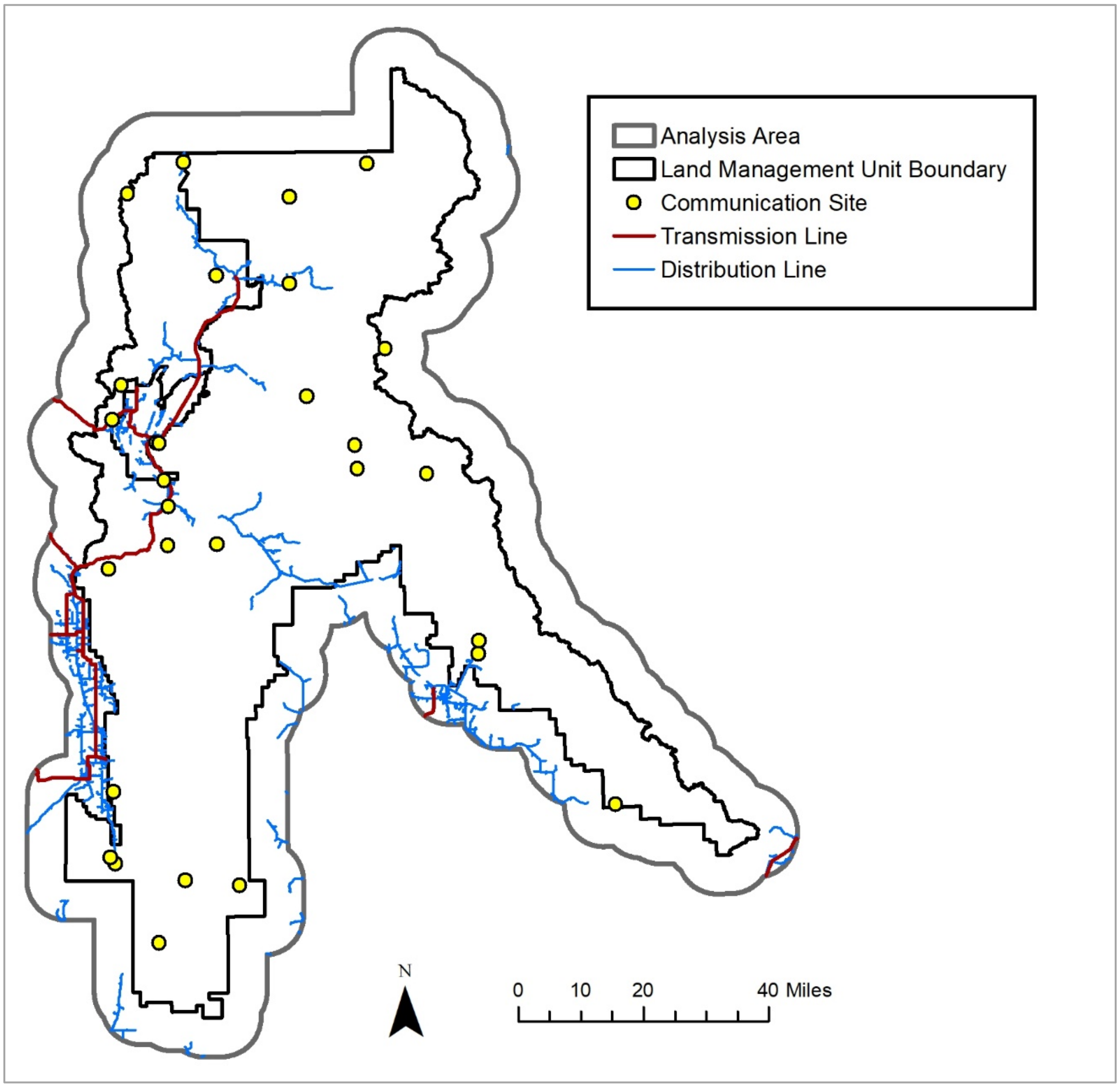

Figure 19. Spatial extent of the Utilities Infrastructure sub-HVRAs.

Table 14. Utilities Infrastructure HVRA response functions.

HVRA	Sub-HVRA	FIL1	FIL2	FIL3	FIL4	FIL5	FIL6
Utilities Infrastructure	Communication Sites	-5	-30	-60	-80	-100	-100
	Distribution Lines	-5	-10	-40	-60	-100	-100
	Transmission Lines	0	0	-10	-25	-80	-100

3.2.9 Wildlife Habitat

The Ecological Integrity HVRA provides a surrogate for assessing wildfire risk to the habitat of many wildlife species. Elk winter range, Canada lynx, and sage grouse habitat were identified to be analyzed independently given their socio-economic importance, Endangered Species Act status, or local rarity.

Elk are an important wildlife species in Tetons, contributing to local economies through wildlife viewing and hunting opportunities. Wildfire plays an important role in maintaining and/or enhancing native elk winter range. Two categories of elk winter range are identified and mapped by the Wyoming Game and Fish Department. Crucial winter range has been documented as the determining factor in a population's ability to maintain itself at or above the Department's population objective. General winter range provides forage that remains accessible under snowy conditions in sufficient quantity and quality to aid in the winter survival of elk. We intersected the Bridger-Teton National Forest's 2018 existing vegetation data with the Wyoming Game and Fish spatial data to define covariates that further differentiate fire effects to elk winter range based on three classes of vegetation: herbaceous/shrub, aspen, and conifer. We converted the resulting polygons to raster at 30-m resolution and masked out non-burnable pixels (Figure 20).

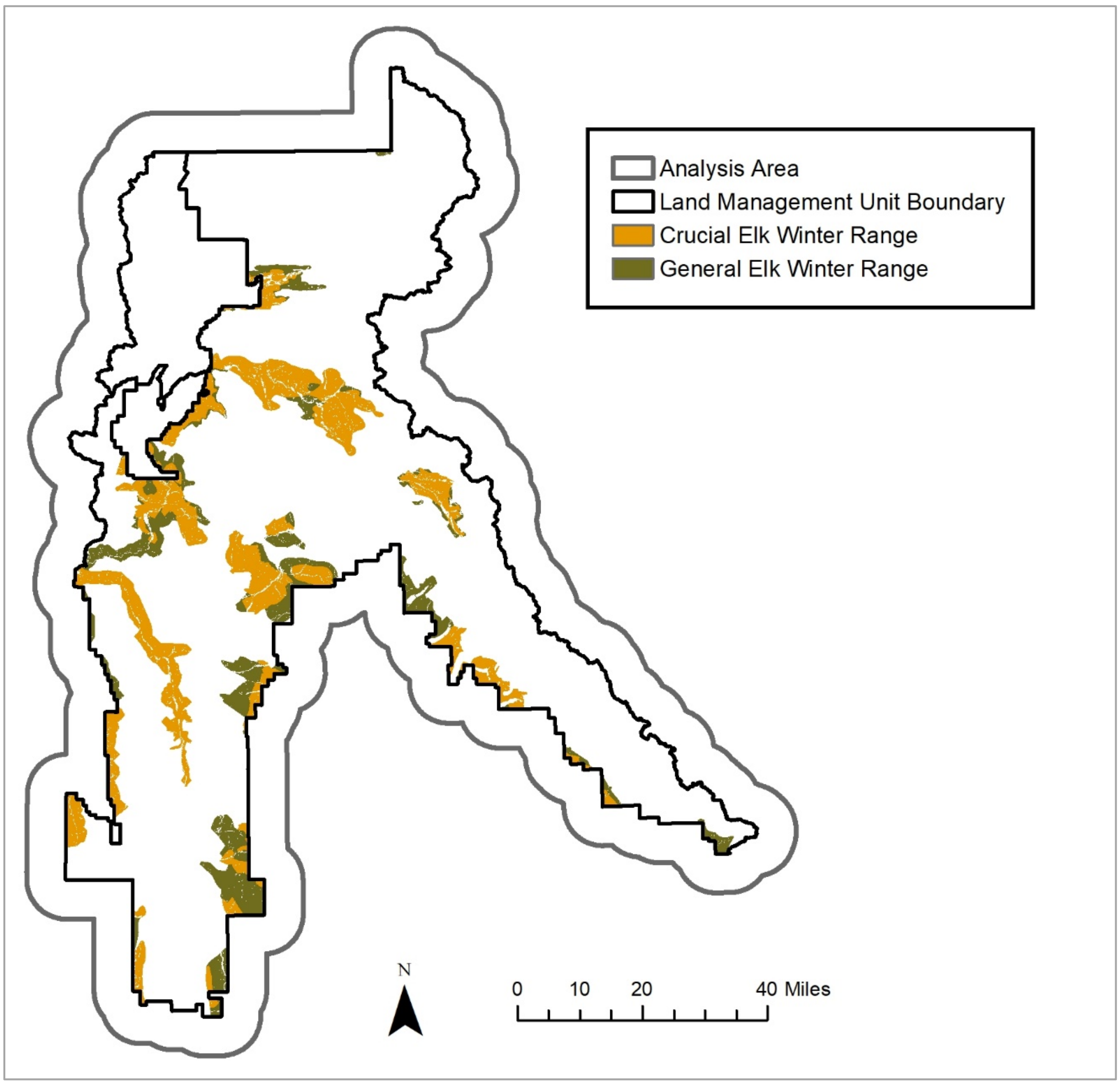

Figure 20. Spatial extent of the Elk Winter Range sub-HVRAs.

FIL 1 would enhance herbaceous vegetation in the herbaceous/shrub and aspen vegetation types providing a benefit to available forage over current conditions (Table 15). In conifers, there would be no forage enhancement and little to no change in condition at these flame lengths.

FILs 2 – 6 would lead to losses to shrubs, which are an important winter food source for elk, but an increase in herbaceous vegetation. The overall net response would be neutral in the herbaceous/shrub vegetation type. As burn severity increases in aspen, mature trees are scorched and suckering increases, providing an important winter food source for elk. It is expected that at FILs 4 – 6, mortality of mature aspen trees may continue to increase but the subsequent suckering of young trees would be similar. Most conifer establishment on winter range is the result of encroachment into aspen and herbacerous/shrub sites. Conifer does not provide winter forage and any decrease in conifer encroachment subsequently results in an increase of either aspen or herbaceous/shrub type habitat. At FIL6 understory recovery may be delayed, which is why the response at FIL 6 is slightly less beneficial than at FILs 4 – 5.

Canada lynx were designated federally threatened under the Endangered Species Act in 2000. The Bridger-Teton National Forest is considered ‘occupied, core habitat’ and contains designated ‘critical habitat’. The most important habitat for lynx corresponds to the winter foraging habitat of its primary prey—the snowshoe hare—which, consists of spruce-fir forest and young/regenerating lodgepole pine. Mid- to late-seral lodgepole pine provides poor snowshoe hare habitat. Resource specialists characterized lynx habitat as two sub-HVRAs, one for each vegetation type, using the Bridger-Teton National Forest’s 2018 existing vegetation data. To account for differences in fire effects, the spruce-fir type was further split into three covariates based on development stage: young/regenerating forest (less than 5 inch diameter at breast height), young forest (5 – 9.9 inch diameter at breast height), and mature forest (10 inches or greater diameter at breast height) structural stages. We converted the resulting polygons to raster at 30-m resolution and masked out non-burnable pixels (Figure 21).

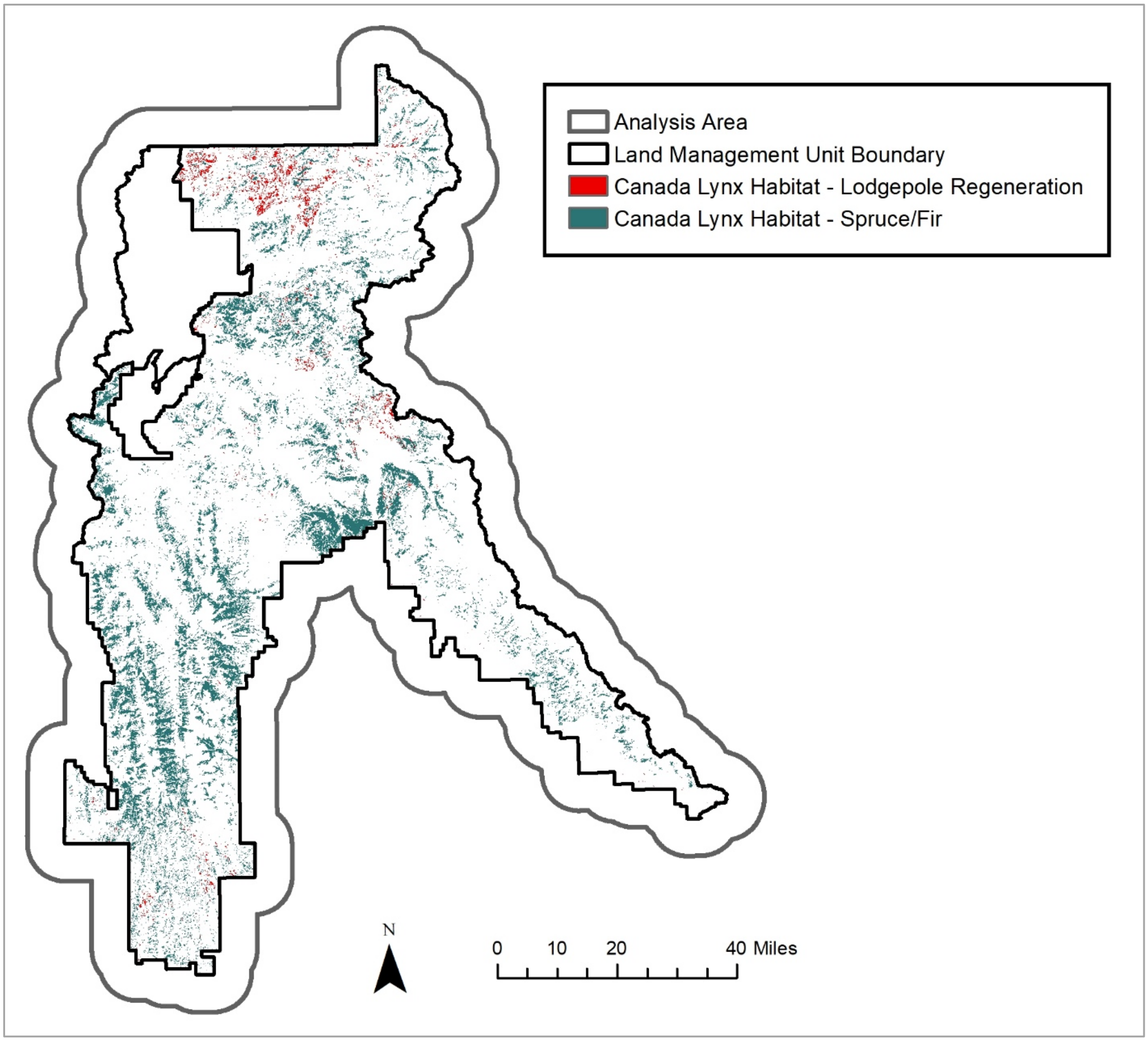

Figure 21. Spatial extent of Canada Lynx Habitat sub-HVRAs.

The young/regenerating forest in both the spruce-fir and lodgepole pine vegetation types is characterized by high-density, fire-intolerant, seedlings, saplings, and small trees that are old enough to protrude above the snow providing forage and cover for hares. Fire at FILs 1 & 2 would create openings but not significantly reduce the stand's value as winter snowshoe hare habitat (Table 15). FILs 3 & 4 would result in an increasing level of mortality thus reducing the stand's habitat value. It is expected that FILs 5 & 6 would result in stand replacement, eliminating the habitat entirely.

Young spruce-fir forest has typically entered a phase of stem exclusion where little light reaches the forest floor and there is limited understory vegetation. Trees begin to self-prune resulting in live crowns that are out of reach to foraging hares. These stands are poor snowshoe hare habitat but are a necessary successional stage on the pathway to mature spruce-fir forest. It is expected that FILs 1 – 3 would not change the current condition of these stands and therefore not improve or degrade their quality as habitat. FILs 4 – 6 would result in moderate- to high-mortality degrading their habitat potential.

Mature spruce-fir forests provide multi-storied structure that is ideal snowshoe hare and lynx habitat. Mature forests are where lynx appear to hunt most effectively (Holbrook et al. 2019). In their work in

Colorado, Ivan and Shenk (2016) found that mature, uneven-aged Engelmann spruce and subalpine fir stands naturally provide patches of dense and open habitats in close juxtaposition, which facilitate high hare densities and accessibility to hares by lynx. A continuous fuelbed of litter, small woody debris, forbs, shrubs, and small trees allows fire to spread through mature stands where FILs 1 – 4 result in a loss of the understory vegetation contributing to the high quality of the habitat. FILs 5 & 6 are expected to result in stand replacement and loss of the habitat.

Greater sage grouse are rare in the Tetons and relatively unique in that they occupy high-elevation sagebrush communities. Given this rarity and uniqueness, there is a real concern for localized extirpations from several factors including habitat loss, or degradation, from fire. Wyoming's Greater sage-grouse Core Area Protection Strategy protects significant quantity and quality of Greater sage-grouse habitat across the state and has been shown to represent approximately 84% of Wyoming's Greater sage-grouse population. Leks outside of core habitat are also important and the area around leks typically incorporates nesting and breeding habitat in Wyoming.

Greater sage-grouse habitat was mapped to both the Bridger-Teton National Forest and Grand Teton National Park (Figure 22). Resource specialists used the Bridger-Teton National Forest's 2018 existing vegetation data to characterize the mapped extent as contiguous sagebrush greater than 200 acres on slopes less than 30% within the Wyoming version 4 core habitat designation or a 5.3 mile buffer around active leks.

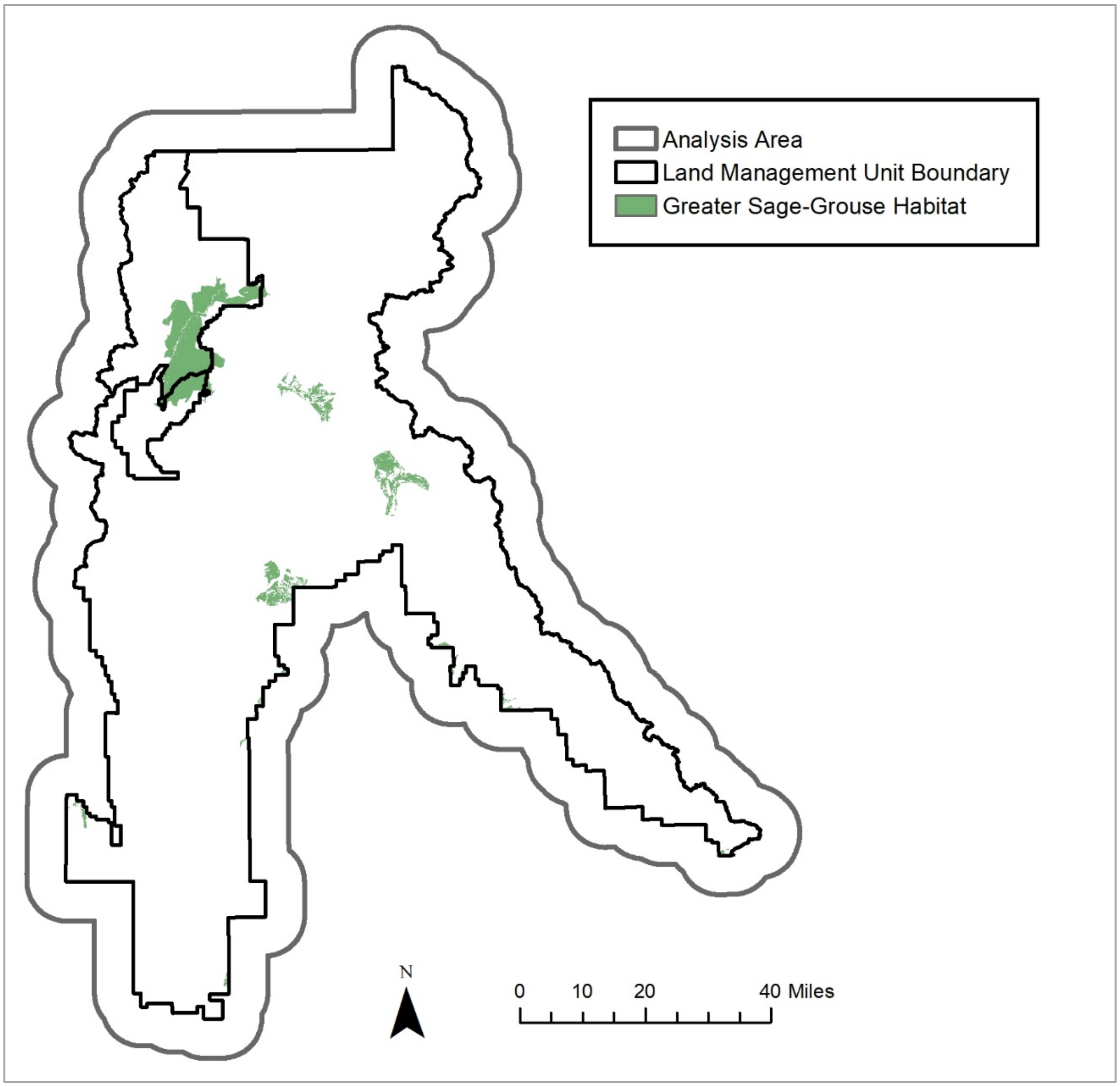

Figure 22. Spatial extent of the Greater Sage Grouse Habitat sub-HVRA.

Sage grouse habitat is highly vulnerable to fire. The main concern is not simply the loss of sagebrush but also the reality that cheatgrass may infest recently burned areas and result in a more frequent fire return interval, which could severely impact sagebrush recovery post-fire. The value of Greater sage-grouse habitat is expected to be degraded even at low FILs (Table 15). A complete loss of habitat was assumed for FILs 3 – 6.

Table 15. Wildlife Habitat HVRA response functions.

HVRA	Sub-HVRA	Covariate	FIL1	FIL2	FIL3	FIL4	FIL5	FIL6
Wildlife Habitat	Elk Winter Range (Crucial)	Herb/Shrub	50	0	0	0	0	0
		Aspen	25	50	75	100	100	100
		Conifer	0	25	50	75	75	50
	Elk Winter Range (General)	Herb/Shrub	50	0	0	0	0	0
		Aspen	25	50	75	100	100	100
		Conifer	0	25	50	75	75	50
	Canada Lynx (Lodgepole Regen)		0	0	-25	-50	-100	-100
	Canada Lynx (Spruce/Fir)	Regen	0	0	-25	-50	-100	-100
		Young	0	0	0	-50	-75	-75
		Mature	-50	-50	-50	-75	-100	-100
	Sage Grouse		-50	-75	-100	-100	-100	-100

3.3 HVRA Relative Importance

Relative importance ranking is necessary when wildfire risk is to be compared or integrated across multiple HVRAs. Without this step all HVRAs and sub-HVRAs are considered equally important (e.g., a picnic area, a residential structure, and the habitat of an endangered species). Bridger-Teton National Forest and Grand Teton National Park Line Officers and Resource Specialists established relative importance weights across HVRAs and sub-HVRAs within the context of existing law, regulation, policy, and the established managerial priorities of each agency. The relative importance weights were then used to create a weighting factor that incorporates the spatial extent of the mapped sub-HVRAs. This approach spreads the importance over the full extent of the sub-HVRAs, such that those covering few acres will have high per-unit-area importance and the importance of those covering many acres will not be overemphasized. Relative importance weights were then iteratively adjusted until there was consensus that the overall and per-unit-area relative importance across HVRAs and sub-HVRAs reflected the mandates and priorities of the respective agencies.

The Human Habitation HVRA received the greatest share of relative importance for the Bridger-Teton National Forest at 35%, followed closely by Ecological Integrity at 32% (Figure 23). The Municipal Water and Wildlife Habitat HVRAs received a similar amount of relative importance at 14% and 11%, respectively. Finally, the Utilities Infrastructure, Production Timber, Special Uses, Heritage Resources, and Recreation and Administrative Infrastructure HVRAs received a relatively small share of the overall HVRA importance, in part due to their limited spatial extent.

For Grand Teton National Park, the Heritage Resources HVRA received the greatest share of relative importance at 36%, followed closely by Ecological Integrity at 33%. The Wildlife Habitat and Human Habitation HVRAs each received 11% of the overall importance. The Recreation and Administrative Infrastructure and Utilities Infrastructure HVRAs received 5% and 4% of the importance, respectively.

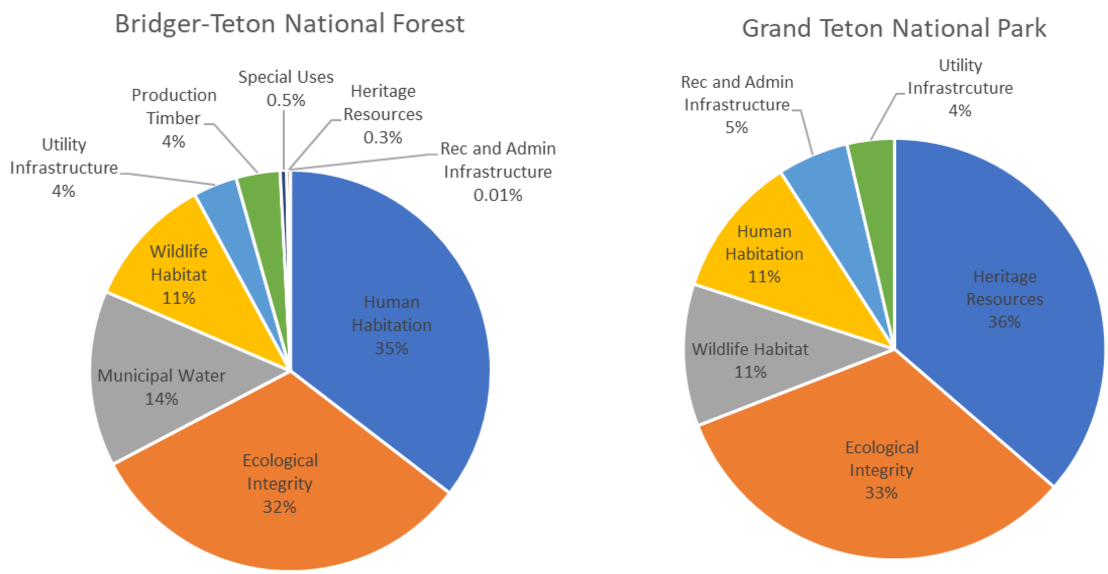

Figure 23. Bridger-Teton National Forest and Grand Teton National Park overall share of HVRA importance.

Table 16 and Table 17 show the final share of within-HVRA and overall relative importance of each sub-HVRA after adjusting for relative extent. The relative-importance-per-pixel weighting factor used in the effects analysis calculations (Section 4.1) is also shown to provide further context for interpreting the relationship between spatial extent, overall importance, and per-unit-area importance. For instance, sub-HVRAs covering few acres and contributing to a relatively small share of the overall importance, such as Historic Buildings, can receive a relatively high per-unit-area importance.

Table 16. Bridger-Teton National Forest's share of within-HVRA and overall relative importance by sub-HVRA.

HVRA	Sub-HVRA	Acres	Share of Within-HVRA Importance	Share of Overall Importance	Relative Importance per Pixel
Ecological Integrity	Aspen Forest and Woodland	514,074	20%	6%	0.028
	Douglas-Fir Forest and Woodland	274,788	13%	4%	0.034
	Subalpine Dry-Mesic Spruce-Fir Forest and Woodland	1,678,052	13%	4%	0.006
	Subalpine Mesic-Wet Spruce-Fir Forest and Woodland	486,416	13%	4%	0.019
	Subalpine Woodland and Parkland	546,509	20%	6%	0.026
	Sagebrush	416,821	20%	6%	0.034
Heritage Resources	Historic Buildings	166	100%	0.3%	3.798
Human Habitation	Below Density Rating	40,093	3%	1%	0.068
	Very Low Density	19,472	4%	2%	0.181
	Low Density	20,367	9%	3%	0.340

HVRA	Sub-HVRA	Acres	Share of Within-HVRA Importance	Share of Overall Importance	Relative Importance per Pixel
	Medium Density	17,348	15%	5%	0.679
	Medium-High Density	13,648	25%	9%	1.449
	High Density	5,686	34%	12%	4.663
	Very High Density	333	10%	3%	22.637
Municipal Watersheds	Low Complexity	77,893	10%	1%	0.042
	Moderate Complexity	104,400	32%	5%	0.098
	High Complexity	128,657	57%	8%	0.140
Recreation and Administrative Infrastructure	Buildings	22	43%	0.003%	0.312
	Low-Development Rec Sites	8	2%	0.0001%	0.031
	Moderate-Development Rec Sites	58	24%	0.002%	0.065
	High-Development Rec Sites	16	31%	0.002%	0.312
Special Uses	Elk Feed Ground Facilities	38	1%	0.003%	0.192
	Oil and Gas Leases	7,398	32%	0.2%	0.051
	Ski Areas	3,317	45%	0.2%	0.160
	Recreation Residences and Resorts	818	22%	0.1%	0.321
Production Timber	Sub-merchantable (<5" DBH, all species)	544	0%	0.01%	0.054
	Aspen-Conifer Mix	562	1%	0.02%	0.086
	Douglas-Fir Mix	1,654	2%	0.1%	0.080
	Lodgepole Pine Mix	45,258	62%	2%	0.107
	Spruce-Fir Mix	31,780	35%	1%	0.086
	Whitebark Pine Mix	1,248	1%	0.05%	0.080
Utilities Infrastructure	Communication Sites	51	0.2%	0.01%	0.299
	Distribution Lines	28,417	67%	2%	0.187
	Transmission Lines	6,837	32%	1%	0.374
Wildlife Habitat	Elk Winter Range (Crucial)	405,631	15%	2%	0.009
	Elk Winter Range (General)	220,594	5%	1%	0.005
	Lynx Habitat - lodgepole regen	38,322	5%	1%	0.031
	Lynx Habitat - spruce/fir forest	490,770	25%	3%	0.012
	Sage Grouse Habitat	45,896	50%	5%	0.257

Table 17. Grand Teton National Park's share of within-HVRA and overall relative importance by sub-HVRA.

HVRA	Sub-HVRA	Acres	Share of Within-HVRA Importance	Share of Overall Importance	Relative Importance per Pixel
Ecological Integrity	Aspen Forest and Woodland	79,568	18%	6%	0.165
	Douglas-Fir Forest and Woodland	35,767	15%	5%	0.311
	Subalpine Dry-Mesic Spruce-Fir Forest and Woodland	188,824	15%	5%	0.059
	Subalpine Mesic-Wet Spruce-Fir Forest and Woodland	225,204	15%	5%	0.049
	Subalpine Woodland and Parkland	53,683	18%	6%	0.244
	Sagebrush	80,062	18%	6%	0.164
Heritage Resources	Historic Buildings	372	46%	17%	100.117
	Historic Districts	6,346	47%	17%	6.007
	Historic Campgrounds	109	7%	2%	50.059
Human Habitation	Below Density Rating	4,396	1%	0.1%	0.067
	Very Low Density	3,407	2%	0.2%	0.157
	Low Density	4,384	6%	1%	0.315
	Medium Density	4,256	11%	1%	0.630
	Medium-High Density	3,644	20%	2%	1.350
	High Density	1,857	39%	4%	5.061
	Very High Density	224	21%	2%	22.495
Recreation and Administrative Infrastructure	Buildings	600	92%	5%	18.528
	Moderate-Development Rec Sites	109	8%	0.5%	9.264
Utilities Infrastructure	Communication Sites	6	0.2%	0.01%	2.151
	Distribution Lines	6,225	50%	2%	0.645
	Transmission Lines	2,357	50%	2%	1.721
Wildlife Habitat	Sage Grouse Habitat	79,652	100%	11%	0.305

4. Wildfire Risk to Highly Valued Resources and Assets

4.1 Effects Analysis Methods

FSim is computationally intensive and can result in long simulation run times on large landscapes. To achieve a reasonable balance between simulation time and detail of fuel and terrain features, we chose to resample the native LANDFIRE fire modeling inputs from 30-m (~0.25 acre) to 90-m (~2 acre) resolution. To maintain a 30-m resolution for mapped HVRA extents and subsequent wildfire risk results, we then applied a downscaling approach to interpolate the wildfire hazard results into areas where burnable pixels at 30-m resolution were coincident with non-burnable pixels at 90-m resolution.

First, the original 90-m annual burn probability (BP) and flame length probability (FLP) results were resampled to 30 m. Next, we applied the focal statistics function in ArcGIS software to calculate the mean BP and FLP of all 30-m burnable pixels in a 7-pixel by 7-pixel moving window. Finally, the mean BP and FLP values were used to backfill burnable pixels at 30-m resolution that were coincident with non-burnable pixels at 90-m resolution. The final "smoothed" rasters resulted in original FSim values for pixels that were burnable at both 90 m and 30 m and mean values in pixels that were burnable at 30 m but non-burnable at 90 m.

The downscaled hazard data were then used to quantify wildfire risk to both individual HVRAs and integrated across all HVRAs. We quantify risk as the expected net-value-change (eNVC) through application of an effects analysis (Scott et al. 2013). Effects analysis integrates the wildfire hazard results with the HVRA response functions and relative importance ranking discussed in Section 3.

First, a relative importance per pixel (RIPP) value was calculated as a function of the overall HVRA importance, sub-HVRA importance, and sub-HVRA extent. Next, the response function and RIPP values were combined with the FLP results to calculate the conditional net-value-change. Conditional net-value-change (cNVC) is calculated as the sum-product of FLP and response function (RF) value over all six flame-length classes, weighted by RIPP, as follows:

$$cNVC_j = \sum_{i}^{n} FLP_i * RF_{ij} * RIPP_j$$

where i refers to flame length class (n = 6), j refers to each HVRA, and RIPP is the weighting factor based on the relative importance and relative extent (number of pixels) of each HVRA. The cNVC calculation shown above places each pixel of each resource and asset on a common scale, allowing them to be summed across all resources and assets to produce the total cNVC at every pixel in the landscape.

Finally, eNVC is calculated as the product of cNVC and annual BP:

$$eNVC = cNVC * BP$$

Both cNVC and eNVC provide valuable information about wildfire risk to resources and assets. Their interpretation differs in that cNVC is conditional on a wildfire occurring. In other words, it describes the likely effects, if a wildfire were to occur. eNVC estimates the potential for realization of those effects because it also integrates the probability of burning, thus identifying areas with both the greatest likelihood of burning and the greatest consequence. The conditional results are most applicable to wildfire response planning, whereas the eNVC results are most applicable to wildfire risk mitigation planning, hazardous fuels treatment prioritization, and budget and resource allocation. We only present the eNVC results in the remainder of this report but include the cNVC results with the project deliverables for future analysis and applications.

4.2 Bridger-Teton National Forest

The integrated eNVC across the Bridger-Teton National Forest is shown in Figure 24. Integrated results represent the sum of the results across all sub-HVRAs at the pixel level. That is, the net losses or benefits of multiple sub-HVRAs located in the same place (pixel) will augment or offset one another into a single, integrated, pixel-level result. To reiterate, eNVC incorporates burn probabilities, response functions, and relative importance into a single value. The integrated eNVC results may then be summarized by HVRA, sub-HVRA, management units (e.g., ranger districts, watersheds, potential operational delineations), or combinations thereof.

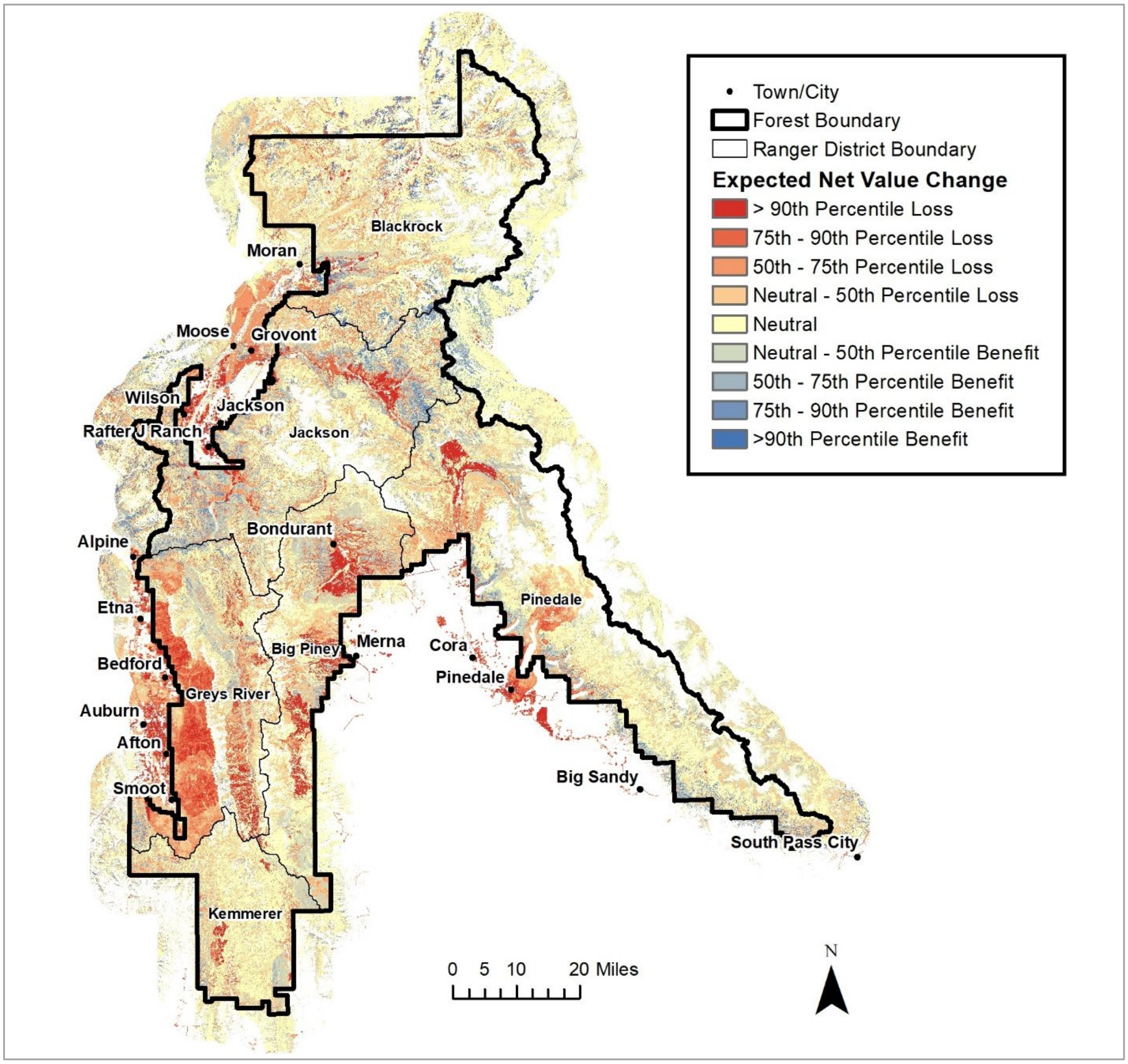

Figure 24. Expected net value change across the Bridger-Teton National Forest analysis area.

Both losses and benefits from wildfire are expected throughout the Bridger-Teton National Forest and adjacent land. Areas with the greatest expected loss are those where communities, sage grouse habitat, municipal watersheds, and production timber are found. Areas with the greatest expected benefit are primarily associated with concentrations of elk winter range but also areas of subalpine, aspen, and Douglas-fir vegetation. A significant amount of the analysis area shows a neutral response to wildfire, which indicates either a neutral response to the expected fire intensity or where expected losses and benefits balance each other out. These spatial data of wildfire risk may be used to inform the development of potential operational delineations and strategic response zones (Thompson et al. 2016), facilitate pre-season wildfire incident planning (O'Connor and Calkin 2019), and identify and prioritize hazardous fuel and risk mitigation opportunities.

The cumulative and mean integrated eNVC are summarized by ranger district in Table 18. All values are negative indicating an expected net loss from wildfire at the district scale. The amount of HVRA area is a factor in the cumulative results—the greater the land area, the greater the potential for loss to be accumulated. Mean results are a factor of the wildfire hazard and consequences to HVRAs irrespective of how much of the HVRA there is.

The Greys River District received the greatest cumulative loss despite not having the most area with mapped HVRAs. A contributing factor is that Greys River is the only district to include both production timber and municipal water—two resources with a largely negative response to wildfire. The Jackson District received 94% of the cumulative loss as Greys River, followed by Big Piney (89%), Pinedale (76%), Blackrock (37%), and Kemmerer (15%). The three districts with the greatest cumulative loss are the same as those with the greatest mean loss, however the order is different. Big Piney has the greatest mean loss, followed by Greys River, Jackson, Pinedale, Blackrock, and Kemmerer.

Table 18. Cumulative and mean integrated expected net-value-change (eNVC) by ranger district.

Ranger District	HVRA Area (Acres)	Cumulative eNVC	Mean eNVC	Cumulative eNVC Scaled	Mean eNVC Scaled
Greys River	437,654	-8,833	-0.0045	100%	99%
Jackson	590,595	-8,343	-0.0031	94%	70%
Big Piney	387,966	-7,883	-0.0045	89%	100%
Pinedale	619,989	-6,733	-0.0024	76%	53%
Blackrock	550,664	-3,286	-0.0013	37%	29%
Kemmerer	263,329	-1,329	-0.0011	15%	25%

Losses and benefits may also be summed independently across HVRAs and sub-HVRAs to provide insight on how individual resources and assets contribute to the overall picture of wildfire risk. Figure 25 shows the cumulative expected loss and benefit from wildfire by HVRA and ranger district. Values are scaled to the HVRA with the greatest net response (i.e., Human Habitation). The net eNVC is shown in parentheses to the right of the HVRA name.

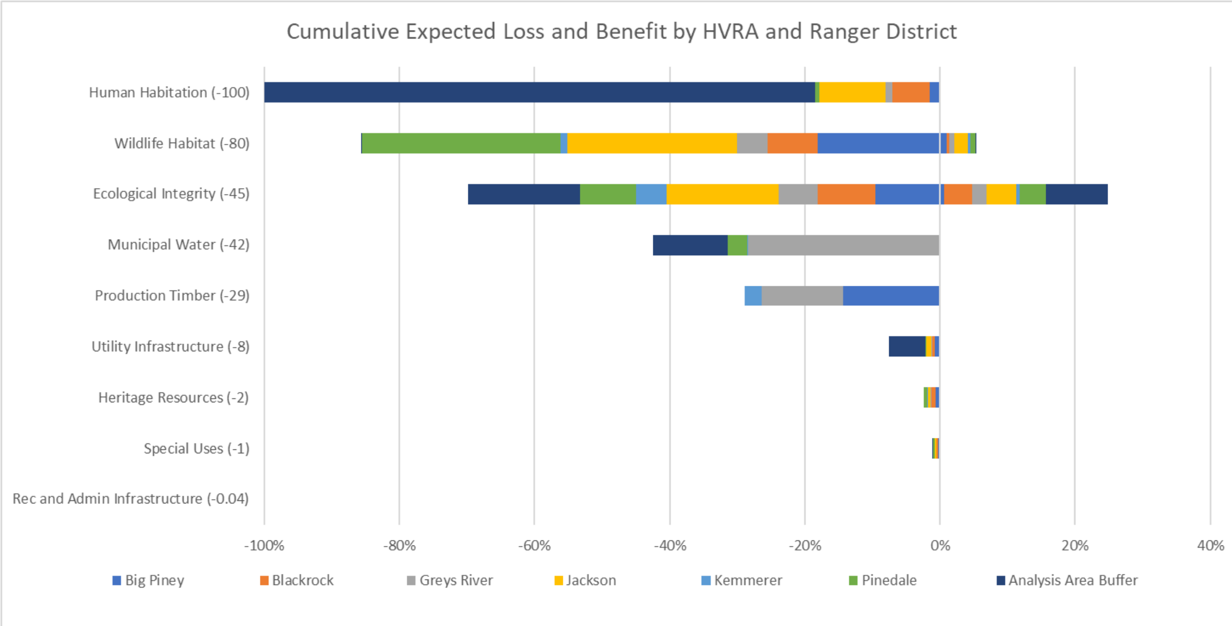

Figure 25. Cumulative expected loss and benefit from wildfire by HVRA and ranger district.

A great deal of information can be extracted from Figure 25. Human habitation accounts for the greatest expected loss from wildfire, however, most of that loss is adjacent to the national forest within the analysis area buffer. Eighteen percent of the risk to human habitation is found within the ranger district boundaries. This occurs where there are private inholdings or communities within the Forest's mapped administrative boundary and where the housing unit density data "bleeds" into the administrative boundary (Section 3.2.3).

Wildlife habitat is expected to incur 86% the cumulative loss as human habitation with the greatest amounts on the Pinedale, Jackson, and Big Piney Districts. These three districts contain expansive sage grouse habitat, which is negatively affected by wildfire at all intensity levels. Wildlife habitat is also expected to benefit from wildfire on a portion of the landscape due to the positive effect of wildfire on elk winter range.

The ecological integrity HVRA is expected to benefit the most from wildfire, however the net eNVC is still -45. Losses to ecological integrity may occur where wildfire is expected to move the distribution of vegetation succession classes away from the natural range of variability and in areas with high post-fire cheatgrass susceptibility within the sagebrush biophysical setting (Section 3.2.1; Appendix C).

Municipal water and production timber are expected to incur 42% and 29% as much loss, respectively, as human habitation. Risk to municipal water is shown outside the Bridger-Teton because the HVRA was mapped to the full extent of the subwatershed within the analysis area (Section 3.2.4). The Greys River District includes all the municipal watersheds except for Upper and Lower Pine Creek residing on the Pinedale District. The remaining four HVRAs account for less than 12% as much expected loss combined as is expected for human habitation.

In interpreting Figure 25 it is important to reiterate that cumulative effects are influenced by HVRA extent—the greater the extent, the greater the potential for losses and benefits to be accumulated. HVRAs with small spatial extents, such as Utility Infrastructure, Heritage Resources, Special Uses, and Recreation and Administrative Infrastructure cannot accumulate as much risk as the more expansive HVRAs. This does not negate the value of looking at cumulative results. For example, the Human

Habitation HVRA accounts for only 9.7% the area of the Wildlife Habitat HVRA but still shows the most cumulative expected loss because of its relative importance, susceptibility to damage, and exposure to wildfire.

Finally, expected NVC is the product of the conditional NVC (i.e., the response to expected fire intensity given the pixel burns) and the annual probability of burning. Plotting HVRAs by their mean conditional NVC and mean annual burn probability provides a graphical representation of eNVC (Figure 26). Differences in burn probability are driven by ignition density and spread-rate potential within and adjacent to sub-HVRAs, whereas differences in conditional NVC are driven by wildfire intensity and the susceptibility and relative importance of the sub-HVRA. Plotting the results in this way shows the influence of these different factors on the overall risk.

The results show a wide range of both exposure and effects to sub-HVRAs. The Human Habitation sub-HVRAs are among the least likely to be exposed to wildfire although the consequences of exposure are among the highest. Elk winter range, along with the ecological integrity of the aspen, Douglas-fir, and subalpine woodland and parkland biophysical settings, are all expected to benefit from wildfire on average. All other sub-HVRAs experience a mean net loss when exposed to wildfire. Analyzing the mean results, as opposed to the cumulative, also provides a different perspective on wildfire risk. For instance, historic buildings (the only Heritage Resources sub-HVRA) account for relatively little cumulative loss (Figure 25), however, the mean loss to historic buildings is greater than that of all other sub-HVRAs except for very-high density human habitation, and historic buildings are three times more likely to burn than very-high density human habitation.

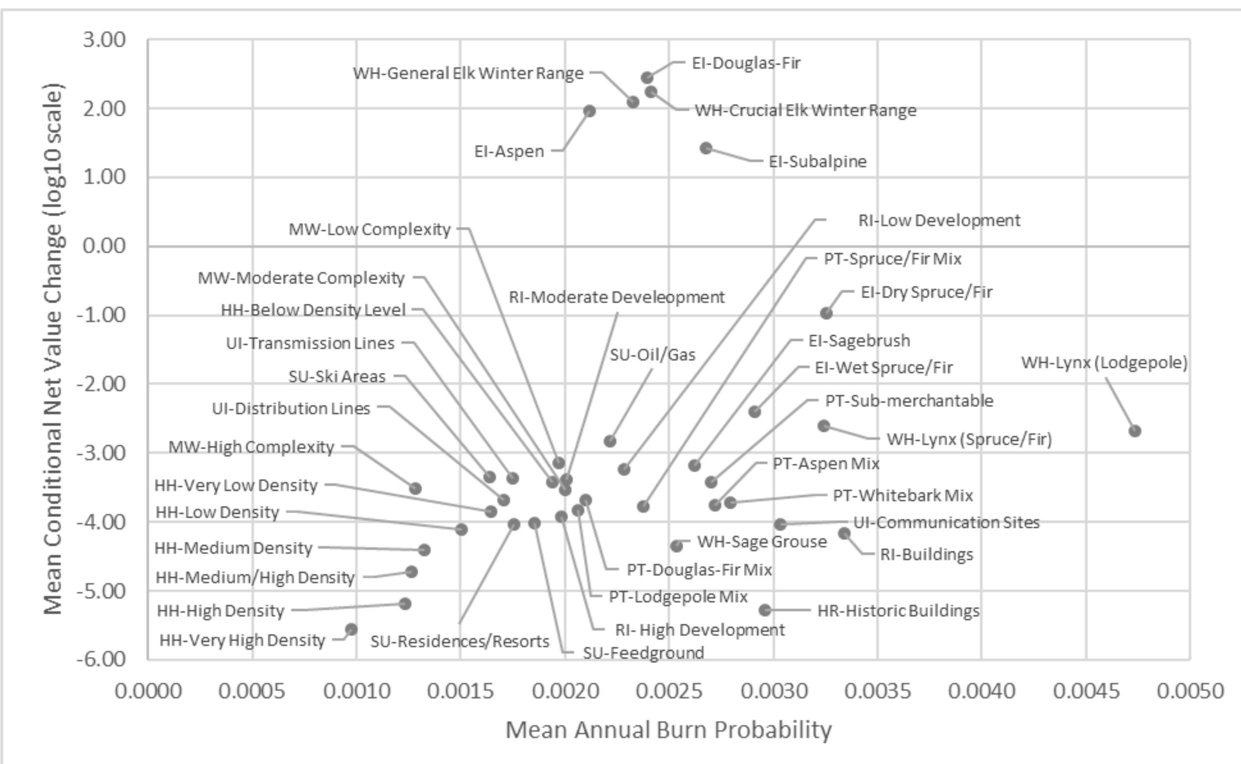

Figure 26. Mean burn probability and mean conditional net value change of sub-HVRAs on the Bridger-Teton National Forest. Values are plotted on the y-axis as the base 10 logarithm of the mean cNVC x 1,000 to account for the wide variation across sub-HVRAs. Data labels use HVRA abbreviations—EI: Ecological Integrity, HH: Human Habitation, HR: Heritage Resources, MW: Municipal Watersheds, PT: Production Timber, RI: Recreation and Administrative Infrastructure, SU: Special Uses, UI: Utilities Infrastructure, and WH: Wildlife Habitat.

The results presented in this report are meant to provide a broad look and different representations of wildfire risk on the Bridger-Teton National Forest. The best representation of quantitative wildfire risk results is dependent on the analysis question being asked. Further analysis may be conducted with the spatial data that accompany this report to address specific questions and inform management actions.

4.3 Grand Teton National Park

The integrated eNVC across Grand Teton National Park is shown in Figure 27. Integrated results represent the sum of the results across all sub-HVRAs at the pixel level. That is, the net losses or benefits of multiple sub-HVRAs located in the same place (pixel) will augment or offset one another into a single, integrated, pixel-level result. To reiterate, eNVC incorporates burn probabilities, response functions, and relative importance into a single value. The integrated eNVC results may then be summarized by HVRA, sub-HVRA, management units (e.g., watersheds, potential operational delineations), or combinations thereof.

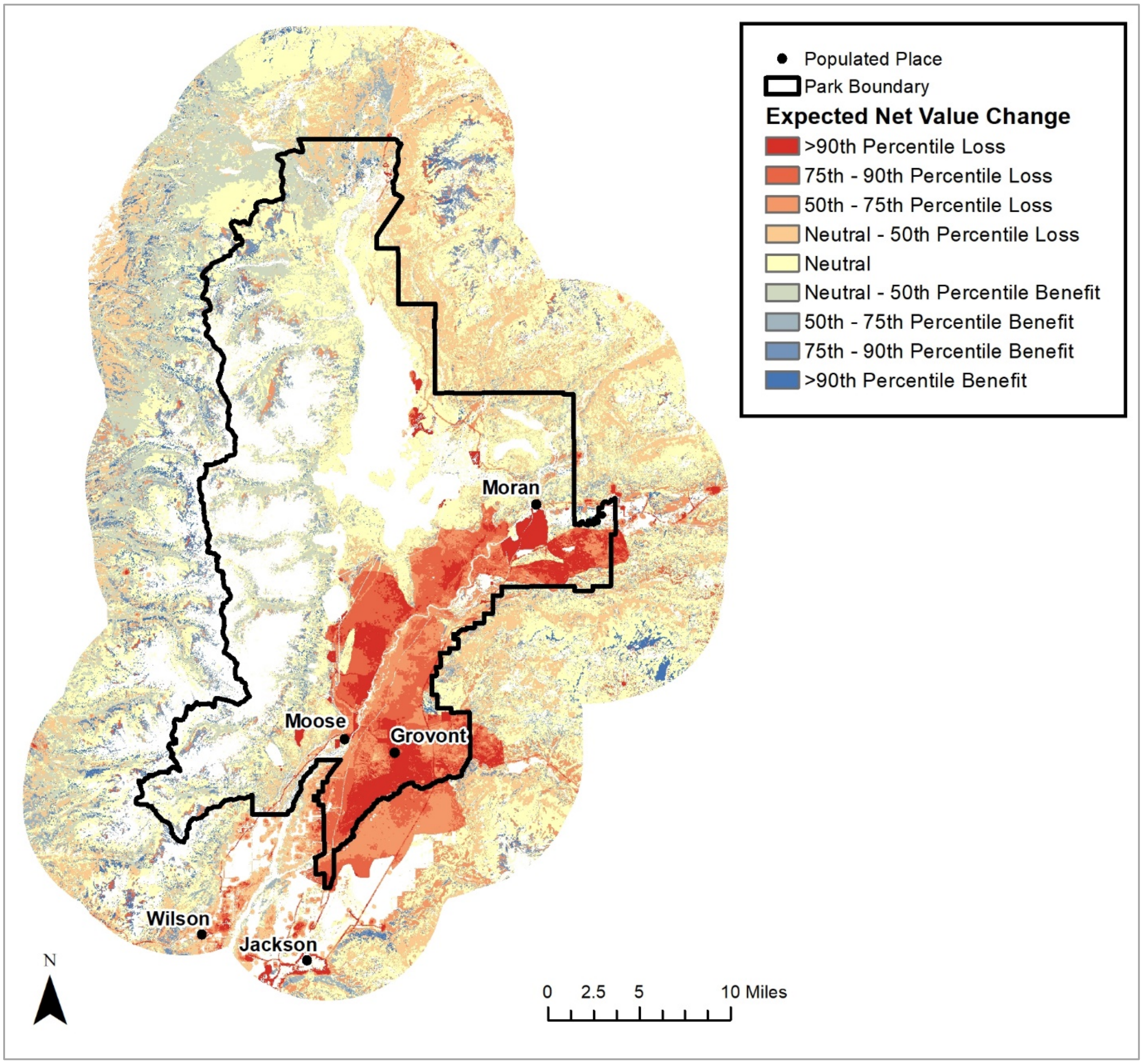

Figure 27. Expected net value change across the Grand Teton National Park analysis area.

Both losses and benefits from wildfire are expected throughout the Park and adjacent land within the analysis area. The greatest expected losses are found along the Snake River valley floor, as most of the Park's HVRAs are concentrated there, and except for ecological integrity, all have a neutral or negative response to burning. Additional concentrations of high loss are associated with heritage resources and administrative infrastructure along Jackson Lake and in the Headwaters/Flagg Ranch area, and the communities outside the Park's boundary. Except for a couple of patrol cabins and utility infrastructure the only HVRA mapped to the rest of the analysis area is Ecological Integrity. The Snake River valley floor is primarily sagebrush steppe with high susceptibility to post-fire cheatgrass establishment and subsequent loss to ecological integrity—further augmenting the integrated loss found there. However, the expected wildfire effects on ecological integrity of the forested biophysical settings vary widely (positive, negative, and neutral) throughout the rest of the analysis area. These spatial data of wildfire risk may be used to inform the development of potential operational delineations and strategic response zones (Thompson et al. 2016), facilitate pre-season wildfire incident planning (O'Connor and Calkin 2019), and identify and prioritize hazardous fuel and risk mitigation opportunities.

Losses and benefits may also be summed independently across HVRAs and sub-HVRAs to provide insight on how individual resources and assets contribute to the overall picture of wildfire risk. Figure 28 shows the cumulative expected loss and benefit from wildfire by HVRA within and adjacent to the Park's administrative boundary. Values are scaled to the HVRA with the greatest net response (i.e., Heritage Resources). The net eNVC is shown in parentheses to the right of the HVRA name.

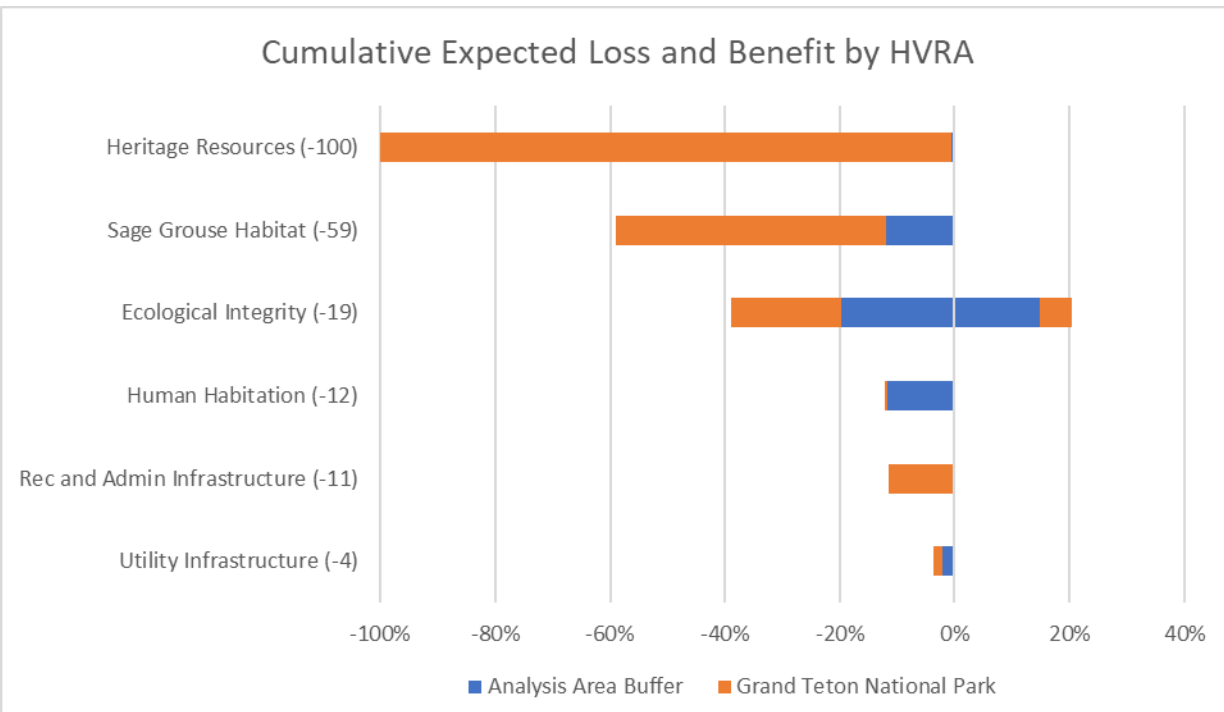

Figure 28. Cumulative expected loss and benefit from wildfire by HVRA.

Heritage resources account for the greatest expected loss from wildfire. This HVRA has the highest relative importance among HVRAs and responds negatively to fire at all intensity levels. Sage grouse habitat is expected to incur 59% the cumulative loss as heritage resources. Sage grouse habitat has the third highest relative importance among HVRAs but also only responds negatively to fire. Ecological integrity is the second most important HVRA within the Park and about one-third of the cumulative response to wildfire is beneficial. The small amount of loss to human habitation shown within the Park is a result of the housing unit density data “bleeding” into the Park as a result of the mapping methodology (Section 3.2.3). Finally, the Recreation and Administrative Infrastructure and Utility Infrastructure HVRAs are expected to incur 11% and 4% as much loss, respectively, as Heritage Resources.

In interpreting Figure 28 it is important to reiterate that cumulative effects are influenced by HVRA extent—the greater the extent, the greater the potential for losses and benefits to be accumulated. HVRAs with small spatial extents, such as the Recreation and Administrative Infrastructure and Utility Infrastructure HVRAs cannot accumulate as much risk as the more expansive HVRAs. This does not negate the value of looking at cumulative results. For example, the Heritage Resources HVRA accounts for only 8.6% the area of the Sage Grouse Habitat HVRA but still shows the most cumulative expected loss because of its relative importance, susceptibility to damage, and exposure to wildfire.

Finally, expected NVC is the product of the conditional NVC (i.e., the response to expected fire intensity given the pixel burns) and the annual probability of burning. Plotting HVRAs by their mean conditional NVC and mean annual burn probability provides a graphical representation of eNVC (Figure 29). Differences in burn probability are driven by ignition density and spread-rate potential within and adjacent to sub-HVRAs, whereas differences in conditional NVC are driven by wildfire intensity and the susceptibility and relative importance of the sub-HVRA. Plotting the results in this way shows the influence of these different factors on the overall risk.

The results show a wide range of both exposure and effects to sub-HVRAs. The ecological integrity of the aspen, Douglas-fir, and subalpine woodland and parkland biophysical settings all are expected to benefit from exposure to wildfire. Historic campgrounds are the least likely to be exposed to wildfire although the consequences of exposure are, on average, second only to those of historic buildings. Analyzing the mean results, as opposed to the cumulative, also provides a different perspective on wildfire risk. For instance, moderate development recreation infrastructure (i.e., non-historic campgrounds) accounts for relatively little cumulative loss (Figure 28), however, the mean loss to campgrounds, which cover only 109 acres, is the same as that to historic districts, which cover 6,346 acres. However, the campgrounds are 1.3 times more likely to burn than the historic districts and therefore, on average, are at greater risk.

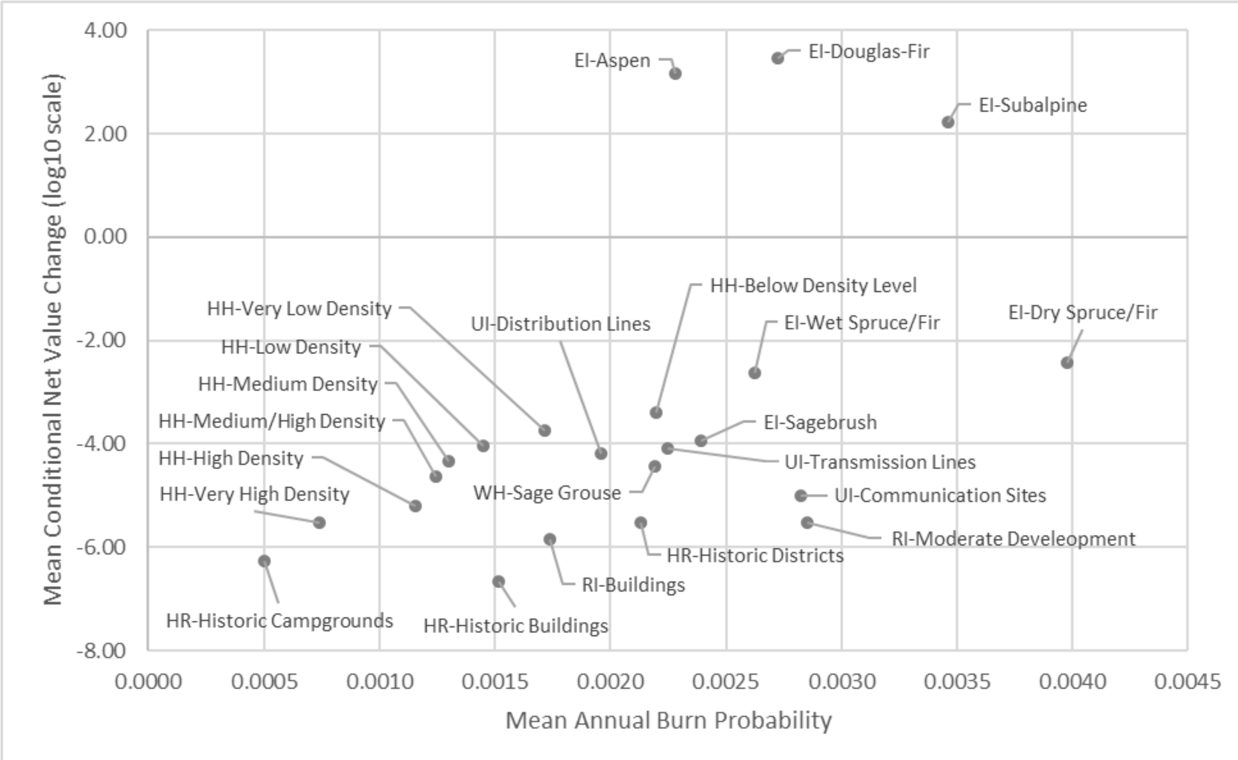

Figure 29. Mean burn probability and mean conditional net value change of sub-HVRAs in Grand Teton National park. Values are plotted on the y-axis as the base 10 logarithm of the mean cNVC x 1,000 to account for the wide variation across sub-HVRAs. Data labels use HVRA abbreviations—EI: Ecological Integrity, HH: Human Habitation, HR: Heritage Resources, RI: Recreation and Administrative Infrastructure, UI: Utilities Infrastructure, and WH: Wildlife Habitat.

The results presented in this report are meant to provide a broad look and different representations of wildfire risk in Grand Teton National Park. The best representation of quantitative wildfire risk results is dependent on the analysis question being asked. Further analysis may be conducted with the spatial data that accompany this report to address specific questions and inform management actions.

5. Summary

This report presents the methods and a general overview of results from the Teton Interagency Quantitative Wildfire Risk Assessment. The spatial and tabular data accompanying this report may be used to inform planning, prioritization, and implementation of management actions. Wildfire risk assessment identifies where on the landscape risk can be mitigated or alternatively where fire may play a benign or beneficial role and could be promoted. In addition, the definition of HVRA response functions in relation to fire intensity can aid in the design of fuel treatments to target intensity levels that lead to a desired response. This report provides transparency about the assumptions and rationale used in mapping and characterizing the effects to HVRAs and the assignment of relative importance enabling future external review of the results.

While this report was generated by the USDA Forest Service's Enterprise Program and Pyrologix LLC, the overall analysis was developed as a collaborative effort with the Bridger-Teton National Forest's and Grand Teton National Park's wildland fire and resource-management staff. This assessment provides a snapshot in time of wildfire hazard and risk across the Forest and Park. Landscape changes due to future natural disturbances and management activities will affect the overall picture of wildfire hazard and risk. Periodic updates to the fuelscape and HVRA mapping will be required to keep the information presented in this assessment current. Through these updates, trends in wildfire risk to HVRAs may be quantified and monitored.

6. References

Barrett, S.; Havlina, D.; Jones, J.; Hann, W.; Frame, C.; Hamilton, D.; Schon, K.; Demeo, T.; Hutter, L.; Menakis, J. 2010. Interagency Fire Regime Condition Class Guidebook. Version 3.0 [Interagency Fire Regime Condition Class website, USDA Forest Service, U.S. Department of the Interior, and The Nature Conservancy]. Online: https://landfire.cr.usgs.gov/frcc/frcc_guidebooks.php. [Verified January 2019]

Calkin DE, Gebert KM, Jones G, Neilson RP. 2005. Forest service large fire area burned and suppression expenditure trends 1970–2002. J For 103(4):179–183.

Calkin, David E.; Ager, Alan A.; Gilbertson-Day, Julie, eds. 2010. Wildfire risk and hazard: procedures for the first approximation. Gen. Tech. Rep. RMRS-GTR-235. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 62 p.

Calkin, David E.; Ager, Alan A.; Thompson, Matthew P., eds. 2011. A comparative risk assessment framework for wildland fire management: the 2010 cohesive strategy science report. Gen. Tech. Rep. RMRS-GTR-262. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 63 p.

Cohen, J. D., & Butler, B. W. 1996. Modeling potential structure ignitions from flame radiation exposure with implications for wildland/urban interface fire management. In Thirteenth Fire and Forest Meteorology Conference, Lorne, Australia.

Egan, Ashley. 2019. The current distribution and invasion susceptibility of cheatgrass on the Bridger-Teton National Forest. Unpublished report. On file at U.S. Department of Agriculture, Bridger-Teton National Forest.

Finney, M. A. 2002. Fire growth using minimum travel time methods. Canadian Journal of Forest Research. 32(8): 1420-1424.

Finney, M. A. 2005. The challenge of quantitative risk analysis for wildland fire. Forest Ecology and Management. 211(1): 97-108.

Finney, Mark; Grenfell, Isaac C.; McHugh, Charles W. 2009. Modeling containment of large wildfires using generalized linear mixed-model analysis. Forest Science. 55(3): 249-255.

Finney, M. A.; McHugh, C. W.; Grenfell, I. C.; Riley, K. L.; Short, K. C. 2011. A simulation of probabilistic wildfire risk components for the continental United States. Stochastic Environmental Research and Risk Assessment. 25(7): 973-1000.

Helmbrecht, Donald J. and Kori Blankenship. 2016. Modifying LANDFIRE Geospatial Data for Local Applications. Available: http://www.conservationgateway.org/ConservationPractices/FireLandscapes/LANDFIRE/Pages/landfire.aspx. [Verified May 2019].

Helmbrecht, Don; Hawks, Michelle; Gilbertson-Day, Julie W.; Volger, Kevin C.; Brough, April, and Scott, Joe H. 2019. Intermountain Region Quantitative Wildfire Risk Assessment, Methods and Results. Unpublished report. U.S. Department of Agriculture, Forest Service, Intermountain Region.

Holbrook, J.D., Squires, J.R., Bollenbacher, B., Graham, R. Olson, L.E., Hanvey, G., Jackson, S., Lawrence, R.L., and Savage, S.L. 2019. Management of forests and forest carnivores: Relating landscape mosaics to habitat quality of Canada lynx at their range periphery. Forest Ecology and Management 437.

Ivan, J.S. and Shenk, T.M. (2016), Winter diet and hunting success of Canada lynx in Colorado. Jour. Wild. Mgmt., 80: 1049-1058. https://doi.org/10.1002/jwmg.21101

McNab, W.H.; Cleland, D.T.; Freeouf, J.A.; Keys, Jr., J.E.; Nowacki, G.J.; Carpenter, C.A., comps. 2007. Description of ecological subregions: sections of the conterminous United States [CD-ROM]. Gen. Tech. Report WO-76B. Washington, DC: U.S. Department of Agriculture, Forest Service. 80 p.

Miller, C.; Ager, A. A. 2012. A review of recent advances in risk analysis for wildfire management. International Journal of Wildland Fire. 22: 1-14.

National Wildfire Coordinating Group. 2010. Memorandum Attachment A. Terminology Updates Resulting from Release of the Guidance for the Implementation of Federal Wildland Fire Management Policy (2009). Reference number: NWCG#024-2010.

O'Connor, Christopher D.; Calkin, David E. 2019. Engaging the fire before it starts: A case study from the 2017 Pinal Fire (Arizona). Wildfire. 28(1): 14-18.

Ortiz, Hector. [Personal communication] May 2019. OIG/GAO Audit Liaison, USDA Forest Service, Intermountain Region.

Sanborn Map Company. 2016. West wide wildfire risk assessment: Final report. Prepared for the Oregon Department of Forestry, Western Forestry Leadership Coalition, Council of Western State Foresters, and funded by the USDA Forest Service. 106 p. https://www.thewflc.org/sites/default/files/WWA_FinalReport_3-6-2016-1.pdf.

Scott, J. H. 1999. NEXUS: a system for assessing crown fire hazard. Fire Management Notes, v. 59, no. 2, p. 20-24.

Scott, Joe H.; Burgan, Robert E. 2005. Standard fire behavior fuel models: a comprehensive set for use with Rothermel's surface fire spread model. Gen. Tech. Rep. RMRS-GTR-153. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 72 p.

Scott, Joe H.; Thompson, Matthew P.; Calkin, David E. 2013. A wildfire risk assessment framework for land and resource management. Gen. Tech. Rep. RMRS-GTR-315. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 83 p.

Scott, J. H.; Helmbrecht, D. J.; Thompson, M. P. 2014. Assessing the expected effects of wildfire on vegetation condition on the Bridger-Teton National Forest, Wyoming, USA. Res. Note: RMRS-RN-71. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 36 p.

Scott, Joe H.; Brough, April M.; Gilbertson-Day, Julie W.; Dillon, Gregory K.; Moran, Christopher. 2020. Wildfire Risk to Communities: Spatial datasets of wildfire risk for populated areas in the United States. Fort Collins, CO: Forest Service Research Data Archive. https://doi.org/10.2737/RDS-2020-0060

Scott, J. H. [Personal communication] 2005 - 2019. Senior Wildfire Analyst/Owner, Pyrologix LLC.

Short, Karen C. 2017. Spatial wildfire occurrence data for the United States, 1992-2015 [FPA_FOD_20170508]. 4th Edition. Fort Collins, CO: Forest Service Research Data Archive. Available at https://doi.org/10.2737/RDS-2013-0009.4. [Verified January 2019]

Smail, T., Martin, C., Napoli, J., 2011. The LANDFIRE Total Fuel Change Tool User's Guide. Available: https://www.landfire.gov/documents/LFTFC_Users_Guide.pdf. [Verified May 2019].

Strauss D, Bednar L, Mees R (1989) Do one percent of forest fires cause ninety-nine percent of the damage? For Sci 35(2):319–328.

Thompson, M. P.; Calkin, D. E. 2011. Uncertainty and risk in wildland fire management: a review. Journal of Environmental Management. 92(8): 1895-1909.

Thompson, Matthew P.; Scott, Joe; Langowski, Paul G.; Gilbertson-Day, Julie W.; Haas, Jessica R.; Bowne, Elise M. 2013a. Assessing watershed-wildfire risks on National Forest System lands in the Rocky Mountain Region of the United States. Water. 5(3): 945-971.

Thompson, M.P., Scott, J., Helmbrecht, D., Calkin, D.E., 2013b. Integrated wildfire risk assessment: framework development and application on the Lewis and Clark National Forest in Montana, USA. Integr. Environ. Assess. Manage. 9 (2), 329–342.

Thompson, Matthew P.; Bowden, Phil; Brough, April; Scott, Joe H.; Gilbertson-Day, Julie; Taylor, Alan; Anderson, Jennifer; Haas, Jessica R. 2016. Application of Wildfire Risk Assessment Results to Wildfire Response Planning in the Southern Sierra Nevada, California, USA. Forests. 7(3): 64. https://doi.org/10.3390/f7030064

U.S. Department of Agriculture, Forest Service; Department of the Interior, Office of Wildland Fire Coordination. 2011. A national cohesive wildland fire management strategy. Washington, DC: Wildland Fire Leadership Council. 43 p.

Appendix A: Fuelscape Edits

The LANDFIRE program assigns fuel model and canopy characteristics using two primary input layers: Existing Vegetation Type (EVT) and Map Zone (MZ). Using these inputs (and information about the fuel disturbance(s), vegetation height and cover, and biophysical setting), a rule is queried from the LANDFIRE ruleset database to assign surface fuel model and, if applicable, canopy characteristics for the given EVT and MZ. When working with a larger project extent, such as TIARA, multiple MZs are present. The challenge in fuelscape calibration is to produce a set of output grids without artificial seamlines across multiple MZs. To do so, the rules from many MZs must be reconciled and filtered to allow only one ruleset per EVT across the entire fuelscape. As an unbiased way to reconcile rules from multiple MZs, we determined which MZ holds the greatest share of each EVT on the landscape and imported those rules to apply across the landscape.

The landscape resulting from that filtered collection of rulesets was used in a preliminary FSim modeling effort and used to run gNexus – the spatial implementation of the fire behavior calculator software, NEXUS (Scott 1999). The gNexus process produces maps of Rate of Spread (ROS), Heat Per Unit Area (HPUA), Flame Length (FL), Fireline Intensity (FIL), Crown Fraction Burned (CFRB), Torching Index (TI), and Crowning Index (CI). These maps can then be summarized by each rule of the LANDFIRE Total Fuel Change Tool database for landscape critique and evaluation (Smail et al. 2011).

The set of EVTs reviewed in fuel calibration were identified as being among the top ten most abundant EVTs, EVTs that encompass a large portion of the Analysis Area, and EVTs with issues in Torching Index (i.e. one part of the rule allows torching at all windspeeds and another portion of the rule never allows for torching). The sections below list EVTs that were modified due to an issue with Torching Index, along with their original rule, modified rule, and rationale for change.

An important note of consideration in reviewing the fuel model revisions, though TU2 is named a “humid climate” fuel model, it has a fuel moisture of extinction of 30 percent – only 5 percent greater than TU5 which is named a “dry climate” fuel model. Fuel models should be selected based solely on the fire behavior they produce and not on the name, climate description, or photograph included in the fuel model publication (Scott 2005-2019, personal communication).

EVT 2046: Northern Rocky Mountain Subalpine Woodland and Parkland

- Original rule

Fuel Model for FDIST 000	CL	CH	HL	HH	BPS	CG	CBH	FDIST0
GR1 / 101	101	101	108	111	any	1	9999	101
GS2 / 122	102	102	108	111	any	1	9999	122
TU5 / 165	103	109	108	111	any	1	9999	165

- Final rule

Fuel Model for FDIST 000	CL	CH	HL	HH	BPS	CG	CBH	FDIST0
GR1 / 101	101	101	108	111	any	1	9999	101
GS2 / 122	102	102	108	111	any	1	9999	122
TU2 / 162	103	109	108	111	any	1	9999	162

- Rationale for change:
  - The original rule for TU5 produced an average Torching Index of 0 mi/h which signifies constant torching in FSim. We replaced TU5 with TU2 which allows for occasional non-torching.

EVT 2050: Rocky Mountain Lodgepole Pine Forest

- Original rule

Fuel Model for FDIST 000	CL	CH	HL	HH	BPS	CG	CBH	FDIST0
GS2 / 122	101	109	108	108	any	0	9999	122
TU5 / 165	101	103	109	111	any	1	9999	165
TL3 / 183	104	109	109	111	any	1	9999	183

- Final rule

Fuel Model for FDIST 000	CL	CH	HL	HH	BPS	CG	CBH	FDIST0
GS2 / 122	101	109	108	108	any	0	9999	122
TU2 / 162	101	103	109	109	any	1	3	162
TU2 / 162	101	103	110	111	any	1	6	162
TL5 / 185	104	109	109	109	any	1	2	185
TL5 / 185	104	109	110	111	any	1	3	185

- Rationale for change:
  - The original rule for TU5 with a default CBH produced an average Torching Index of 0 mi/h, which signifies constant torching in FSim. We replaced TU5 with TU2 and modified the CBH to 3 or 6 meters respective to height, which allows for occasional non-torching.
  - The original rule for TL3 with a default CBH produced an average Torching Index of 99 mi/h, which is too high to ever be produced by FSim. We replaced TL3 with TL5 and modified the CBH to 2 or 3 meters respective to height, which allows for occasional torching.

EVT 2055: Rocky Mountain Subalpine Dry-Mesic Spruce-Fir Forest and Woodland

- Original rule

Fuel Model for FDIST 000	CL	CH	HL	HH	BPS	CG	CBH	FDIST0
GS2 / 122	101	109	108	108	any	0	9999	122
TU1 / 161	101	103	109	111	any	1	9999	161
TU5 / 165	104	109	109	111	any	1	9999	165

- Final rule

Fuel Model for FDIST 000	CL	CH	HL	HH	BPS	CG	CBH	FDIST0
GS2 / 122	101	109	108	108	any	0	9999	122
TU1 / 161	101	103	109	111	any	1	9999	161
TU2 / 162	104	109	109	111	any	1	5	162

- Rationale for change:
  - The original rule for TU5 with a default CBH produced an average Torching Index of 0 mi/h, which signifies constant torching in FSim. We replaced TU5 with TU2 and modified the CBH to 5 meters, which allows for occasional non-torching.

EVT 2056: Rocky Mountain Subalpine Mesic-Wet Spruce-Fir Forest and Woodland

- Original rule

Fuel Model for FDIST 000	CL	CH	HL	HH	BPS	CG	CBH	FDIST0
GS2 / 122	101	108	108	108	any	0	9999	122
GS2 / 122	101	102	109	111	any	1	9999	122
TU1 / 161	103	103	109	111	any	1	9999	161
TU1 / 161	104	108	109	110	any	1	9999	161
TU5 / 165	104	108	111	111	any	1	9999	165

- Final rule

Fuel Model for FDIST 000	CL	CH	HL	HH	BPS	CG	CBH	FDIST0
GS2 / 122	101	108	108	108	any	0	9999	122
GS2 / 122	101	102	109	111	any	1	9999	122
TU1 / 161	103	103	109	111	any	1	9999	161
TU1 / 161	104	108	109	110	any	1	9999	161
TU2 / 162	104	108	111	111	any	1	5	162

- Rationale for change:
  - The original rule for TU5 with a default CBH produced an average Torching Index of 0 mi/h, which signifies constant torching in FSim. We replaced TU5 with TU2 and modified the CBH to 5 meters, which allows for occasional non-torching.

EVT 2166: Middle Rocky Mountain Montane Douglas-fir Forest and Woodland

- Original rule

Fuel Model for FDIST 000	CL	CH	HL	HH	BPS	CG	CBH	FDIST0
GS2 / 122	101	102	108	111	any	1	9999	122
TU5 / 165	103	103	108	111	any	1	9999	165
TL4 / 184	104	109	108	111	any	1	9999	184

- Final rule

Fuel Model for FDIST 000	CL	CH	HL	HH	BPS	CG	CBH	FDIST0
GS2 / 122	101	102	108	111	any	1	9999	122
TU2 / 162	103	103	108	109	any	1	3	162
TU2 / 162	103	103	110	111	any	1	6	162
TL7 / 187	104	109	108	111	any	1	9999	187

- Rationale for change:
    - The original rule for TU5 with a default CBH produced an average Torching Index of 0 mi/h, which signifies constant torching in FSim. We replaced TU5 with TU2 and modified the CBH to 3 or 6 meters respective to height, which allows for occasional non-torching.
    - The original rule for TL4 produced an average Torching Index of 99 mi/h which is too high to ever be produced by FSim. We replaced TL4 with TL7, which allows for occasional torching.

EVT 2227: Pseudotsuga menziesii Forest Alliance

- Original rule

Fuel Model for FDIST 000	CL	CH	HL	HH	BPS	CG	CBH	FDIST0
GS2 / 122	101	109	108	108	any	0	9999	122
TL4 / 184	101	103	109	111	any	1	9999	184
TU5 / 165	104	109	109	111	any	1	9999	165

- Final rule

Fuel Model for FDIST 000	CL	CH	HL	HH	BPS	CG	CBH	FDIST0
GS2 / 122	101	109	108	108	any	0	9999	122
TL7 / 187	101	103	109	109	any	1	2	187
TL7 / 187	101	103	110	111	any	1	3	187
TU2 / 162	104	109	109	109	any	1	3	162
TU2 / 162	104	109	110	111	any	1	6	162

- Rationale for change:
    - The original rule for TL4 with a default CBH produced an average Torching Index of 86 mi/h, which is too high to ever be produced by FSim. We replaced TL4 with TL7 and modified the CBH to 2 or 3 meters respective to height, which allows for occasional torching.

- The original rule for TU5 with a default CBH produced an average Torching Index of 0 mi/h, which signifies constant torching in FSim. We replaced TU5 with TU2 and modified the CBH to 3 or 6 meters respective to height, which allows for occasional non-torching.

Appendix B: Data Dictionary

A large amount of geospatial and tabular data accompanies this report. The following describes the data organization and naming conventions used.

HVRA Characterization

1. **RF_Rationale** – This folder includes the original documentation from the resource specialists providing their rationale for HVRA characterization, including sub-HVRA and covariate classification, mapping rules, and response function assignment. These documents were summarized in the body of this report.

2. **hvraFinal_Features.gdb** – Processed feature data before being converted to raster format for risk calculations.

3. **TIARAv2_VCA_Final.gdb** – This geodatabase contains the input and output data of the vegetation condition assessment used to create the Ecological Integrity HVRA. The data may be used to do further analysis of vegetation departure.

    a. **BpS** – LANDFIRE v1.4 biophysical settings (BpSs) reclassified to final TIARA VCA BpS groups—BpS models 2210110 (aspen), 2211660 (Douglas-fir), and 2211260 (sagebrush) were reclassified as the map zone 21 model. BpS model 2111240 (Columbia Plateau low sagebrush steppe) was reclassified to 2111260 (Inter-Mountain Basins montane sagebrush steppe) based on local knowledge.

    b. **SClass** – Succession class, mapped using LANDFIRE 2.0 BpS model mapping rules.

    c. **SClass_pctDifference** – The succession class percent difference calculated for each stratum on a scale from -100 to 100.

    d. **SClass_Status** – SClass status calculated for each stratum. This represents the SClass percent difference in three classes: deficit (-100 to -33 percent difference from the reference amount), similar (-33 to 33 percent difference from the reference amount), or surplus (33 to 100 percent difference from the reference amount).

    e. **Strata** – Unique strata ID for each BpS.

    f. **Strata_[BpS]** – The strata polygons for delineated for each BpS (Aspen, Douglas-fir, dry spruce/fir, sagebrush, subalpine, and wet spruce/fir).

    g. **StratumDeparture** – Vegetation departure across all succession classes within a stratum as a single value on a scale from zero (indicating no departure) to 100 (indicating full departure).

    h. **StratumVCC** – Vegetation condition class. Stratum departure classified into three classes: 1: within the natural range of variability (NRV; ≤ 33% stratum departure), 2: moderately departed from the NRV (>33% to ≤ 66% stratum departure), 3: highly departed from the NRV (>66% departure).

4. **TIARA2_vcaCalc.xlsx** – This spreadsheet was used to calculate the vegetation condition assessment results.

Wildfire Risk

1. **[BTNF/GRTE]_Conditional.gdb** – These geodatabases contain the conditional net value change results for the Bridger-Teton National Forest (BTNF) and Grand Teton National Park (GRTE). HVRA abbreviations: EI: Ecological Integrity, HH: Human Habitation, HR: Heritage Resources, MW: Municipal Watersheds, PT: Production Timber, RI: Recreation and Administrative Infrastructure, SU: Special Uses, UI: Utilities Infrastructure, and WH: Wildlife Habitat.
    a. **HVRA_wcNVC_*** – Conditional NVC results summed to the HVRA level.
    b. **icNVC** – Conditional NVC results integrated across all HVRAs.
    c. **wcNVC_*** – Conditional NVC results at the sub-HVRA level.
2. **[BTNF/GRTE]_Expected.gdb** – These geodatabases contain the expected net value change results for the Bridger-Teton National Forest (BTNF) and Grand Teton National Park (GRTE). HVRA abbreviations: EI: Ecological Integrity, HH: Human Habitation, HR: Heritage Resources, MW: Municipal Watersheds, PT: Production Timber, RI: Recreation and Administrative Infrastructure, SU: Special Uses, UI: Utilities Infrastructure, and WH: Wildlife Habitat.
    a. **HVRA_weNVC_*** – Expected NVC results summed to the HVRA level.
    b. **ieNVC** – Expected NVC results integrated across all HVRAs.
    c. **weNVC_*** – Expected NVC results at the sub-HVRA level.
3. **[BTNF/GRTE]_HVRA.gdb** – These geodatabases contain the final sub-HVRA level raster data used in the risk calculations for the Bridger-Teton National Forest (BTNF) and Grand Teton National Park (GRTE). HVRA abbreviations: EI: Ecological Integrity, HH: Human Habitation, HR: Heritage Resources, MW: Municipal Watersheds, PT: Production Timber, RI: Recreation and Administrative Infrastructure, SU: Special Uses, UI: Utilities Infrastructure, and WH: Wildlife Habitat.
4. **DownscaledHazard.gdb** – This geodatabase contains the downscaled 30-m resolution hazard data used in the risk calculations (Section 4.1).
    a. **BP** – Annual burn probability.
    b. **FLP1** – Flame-length probability for FIL1.
    c. **FLP2** – Flame-length probability for FIL2.
    d. **FLP3** – Flame-length probability for FIL3.
    e. **FLP4** – Flame-length probability for FIL4.
    f. **FLP5** – Flame-length probability for FIL5.
    g. **FLP6** – Flame-length probability for FIL6.
5. **LayerFiles** – The layer files (.lyr) in this folder may be used to display the risk results by percentile breaks.

Appendix C: Characterizing Ecological Integrity as an HVRA

Ecological integrity is defined in the 2012 Forest Service Planning Rule as:

> *"The quality or condition of an ecosystem when its dominant ecological characteristics (for example, composition, structure, function, connectivity, and species composition and diversity) occur within the natural range of variation and can withstand and recover from most perturbations imposed by natural environmental dynamics or human influence (36 CFR 219.19)."*

Ecological integrity is commonly quantified as the degree of departure from the natural range of variation by comparing the current relative abundance of vegetation succession classes (S-Classes) to that of a historical reference (Barrett et al. 2010). Integrating a metric of ecological integrity into the quantitative wildfire risk assessment framework provides insight to the beneficial, as well as, adverse effects of wildfire on ecosystems and the tradeoffs with other resources and assets. Characterization of ecological integrity as a highly valued resource and asset (HVRA) in the Scott et al. (2013) wildfire risk assessment framework, requires a more involved approach than with standard HVRAs. This appendix summarizes that approach.

HVRA characterization requires mapping the characteristics of the HVRA that are susceptible to change from wildfire. Unlike an asset, such as a residential structure or powerline, which may sustain some static level of damage from wildfire, ecological integrity is spatially interdependent—the transitioning from one S-Class to another affects the overall proportion of both S-Classes. It is therefore necessary to first map the 'pre-fire' departure from the natural range of variability and then identify the fire intensity levels that would transition one S-Class to another.

Given that the quantitative wildfire risk assessment framework focuses on relatively near-term fire effects (Scott et al. 2013), this methodology for integrating ecological integrity as an HVRA quantifies fire effects as the effect on relative abundance of both the current and post-fire S-Class, without consideration of long-term successional changes. That is, if the effect of fire is to move the relative abundance of an S-Class towards the reference condition it is considered beneficial, if the effect is to move the relative abundance away from the reference condition it is considered a loss. The approach does not consider, for instance, the effect of fire "setting up" an S-Class for vegetation succession into an S-Class that may be in deficit status (e.g., fire maintaining an open structure of mid-seral vegetation to grow into a deficit of late-seral, open structure). If fire does not result in a transition between S-Classes its effect is considered neutral. The approach used to characterize ecological integrity of biophysical settings (BpS) as an HVRA in this assessment is discussed in the following sections.

Landscape Delineation

Assessment landscapes were delineated for each BpS. Each BpS/landscape unit combination defines a stratum for assessing S-Class departure. Strata vary in size based on the biophysical setting's historical fire regime and spatial distribution on the landscape. To be meaningful, strata need to be sufficiently broad to encompass the major disturbance regimes of each BpS and to have a realistic expectation of containing a natural distribution of conditions in response to the ecological drivers inherent in them. Generally speaking, BpSs associated with longer return interval and higher severity fire regimes should be evaluated across larger landscapes than BpSs driven by shorter return interval and lower severity regimes.

For all but the Subalpine Woodland and Parkland BpS, we utilized the US Forest Service Ecomap Subsections (McNab et al. 2007) as a first approximation of landscape stratification. Ecomap follows the National Hierarchical Framework for Ecological Units and provides a nested and hierarchical delineation of ecological units. In applying the Ecomap polygons to define strata, small polygons of adjacent subsections were combined with core subsections to ensure adequate minimum scales for analysis for each BpS. In combining portions of subsections and delineating analysis strata, consideration was given to the overarching geographic and topographic influences on the BpSs rather than relying purely on length of shared border. The elevational setting of the Subalpine Woodland and Parkland BpS did not align well with Ecomap Subsection delineations. To avoid artificial delineations in connected systems, a manual delineation was developed. The spatial landscape units for each BpS are provided in the final deliverables.

Mapping S-Class Status

Each BpS is associated with a vegetation dynamics model. The model is used to estimate the natural, range of variation in the relative abundance of S-Classes under the historical disturbance regime. The average relative abundance of S-Classes for each BpS is referred to as the reference condition. It is assumed that ecological integrity is intact when current conditions are similar to the reference condition—the greater the departure from the reference condition, the less resiliency to current and future stressors. We applied the standard LANDFIRE vegetation departure methodology (Barrett et al. 2010) to quantify the degree of departure as the percent difference between the current and reference condition S-Class relative abundance.

S-Class percent difference was calculated as:

$$\text{S-Class percent difference} = \frac{\text{CP-RP}}{\max(\text{RP,CP})} * 100$$

where, CP is the current proportion of the S-Class within the landscape unit and RP is the reference proportion. Positive values of this measure indicate that the current proportion of the S-Class exceeds the reference proportion; negative values indicate that the current is less than the reference proportion. For example, if the current proportion is twice the reference proportion, the S-Class percent difference is +50%; if the current proportion is half of the reference, then percent difference is -50%.

S-Class percent difference was then reclassified as one of three covariates: deficit (-100 to -33 percent difference from the reference amount), similar (-33 to 33 percent difference from the reference amount), or surplus (33 to 100 percent difference from the reference amount).

S-Class transition matrix

A prerequisite to applying response functions under this framework is the characterization of transitions between S-Classes based on fire intensity through the development of a transition matrix. Transitions were assigned by the Grand Teton National Park and Enterprise Program Fire Ecologists based on professional knowledge of fire ecology in the assessment area and experience with application to quantitative wildfire risk assessment (Table C-1).

C-1. Teton Interagency Risk Assessment transition matrix.

Biophysical Setting (Model Number)	From Succession Class		To Succession Class						Rationale
	Succession Class	Succession Class Label	FIL1	FIL2	FIL3	FIL4	FIL5	FIL6	
Rocky Mountain Aspen Forest and Woodland (10110_21)	Early Development 1 - All Structures	A	A	A	A	A	A	A	
	Mid Development 1 - All Structures	B	B	A	A	A	A	A	Young aspen is very fire-intolerant due to thin bark.
	Late Development 1 - Closed	C	C	A	A	A	A	A	FIL1 unlikely to kill all overstory aspen. Regeneration will maintain higher cover of S-Class C.
	Late Development 2 - Open	D	C	A	A	A	A	A	Partial mortality at FIL1 will increase cover to that characterizing S-Class C due to regeneration.
	Late Development 3 - Closed	E	C	A	A	A	A	A	Conifer component would torch while aspen would partially survive at FIL1. Aspen regeneration would increase cover to S-Class C.
Northern Rocky Mountain Subalpine Woodland and Parkland (10460_21)	Early Development 1 - All Structures	A	A	A	A	A	A	A	
	Mid Development 1 - Closed	B	C	A	A	A	A	A	These species are easily killed by surface fire except for whitebark pine. Regen trees easily killed regardless of species. Partial survival likely at FIL1 leading to lower canopy cover of S-Class C.
	Mid Development 1 - Open	C	C	A	A	A	A	A	All trees would be killed because of thin bark or torching at FILs 2-6.
	Late Development 1 - Open	D	D	A	A	A	A	A	This S-Class is most likely to have a mature whitebark pine component. FILs 2-6 would transition to early seral.
	Late Development 1 - Closed	E	D	A	A	A	A	A	Partial mortality in FIL1 would reduce canopy cover to S-Class D.

Biophysical Setting (Model Number)	From Succession Class		To Succession Class						Rationale
	Succession Class	Succession Class Label	FIL1	FIL2	FIL3	FIL4	FIL5	FIL6	
Rocky Mountain Subalpine Dry-Mesic Spruce-Fir Forest and Woodland (10550_21_22)	Early Development 1 - All Structures	A	A	A	A	A	A	A	
	Mid Development 1 - All Structures	B	B	A	A	A	A	A	Some survival at FIL1.
	Late Development 1 - Closed	C	C	C	A	A	A	A	Some survival at FILs 1 & 2 due to fewer ladder fuels in lodgepole pine stands.
	Late Development 2 - Closed	D	D	D	A	A	A	A	This S-Class represents a mature spruce-fir stand, where lodgepole would be an incidental species. Partial mortality is expected at FILs 1 & 2 but not conversion to lodgepole.
Rocky Mountain Subalpine Mesic-Wet Spruce-Fir Forest and Woodland (10560_21_22)	Early Development 1 - All Structures	A	A	A	A	A	A	A	
	Mid Development 1 - Closed	B	C	A	A	A	A	A	Easily killed species. Partial mortality in FIL1 would reduce canopy cover to S-Class C.
	Mid Development 1 - Open	C	C	A	A	A	A	A	FIL1 maintains open structure. FILs 2-6 transition to early seral.
	Late Development 1 - Open	D	D	D	A	A	A	A	Slightly more fire tolerant than mid-development S-Classes. FILs 1 & 2 maintain open structure.
	Late Development 1 - Closed	E	D	D	A	A	A	A	Slightly more fire tolerant than mid-development S-Classes. FILs 1 & 2 open canopy to S-Class D. Even FIL can cause significant mortality through root damage.
Inter-Mountain Basins Montane Sagebrush Steppe (11260_21)	Early Development 1 - All Structures	A	A	A	A	A	A	A	Fire maintains the dominance by herbaceous species (< 10% shrub cover).
	Mid Development 1 - Open	B	B	A	A	A	A	A	Partial survival of shrubs at FIL1. Probably a mosaic of burned and unburned but at 30 m pixels would stay B. 2-4 ft flame length is "crown" fire in our sagebrush.
	Late Development 1 - Closed	C	B	A	A	A	A	A	FIL1 opens canopy cover to S-Class B.

Biophysical Setting (Model Number)	From Succession Class		To Succession Class						Rationale
	Succession Class	Succession Class Label	FIL1	FIL2	FIL3	FIL4	FIL5	FIL6	
	Uncharacteristic - Native	UN	B	B	A	A	A	A	UN in this BpS is characterized by > 50% shrub cover or > 10% tree cover. FILs 1 and 2 will open the stand and kill encroaching trees but result in a mosaic of mortality.
Middle Rocky Mountain Montane Douglas-fir Forest and Woodland (11660_21)	Early Development 1 - All Structures	A	A	A	A	A	A	A	
	Mid Development 1 - Closed	B	C	C	A	A	A	A	Young Douglas-fir is easily killed by surface fire. FILs 1 & 2 will open canopy to S-Class C.
	Mid Development 1 - Open	C	C	C	A	A	A	A	FILs 1 & 2 maintain open structure.
	Late Development 1 - Open	D	D	D	D	A	A	A	Late development Douglas-fir is more tolerant of higher fire intensity than mid-development S-Classes.
	Late Development 1 - Closed	E	D	D	D	A	A	A	Late development Douglas-fir is more tolerant of higher fire intensity than mid-development S-Classes.
	Uncharacteristic - Native	UN	E	D	D	A	A	A	UN in this BpS is characterized by > 90% canopy cover. FIL1 will not open to S-Class D but FILs 3 & 4 could.

Response functions

After transitions between S-Classes have been identified, the final step is to characterize the response of these transitions in the context of effects on ecological integrity. As stated above, a transition that moves the relative abundance of an S-Class towards the reference condition is considered a benefit to ecological integrity, a transition that moves the relative abundance away from the reference condition is considered a loss to ecological integrity. The effect of these transitions on S-Class status is shown in Table C-2. If a transition occurs between S-Classes, the relative abundance (number of pixels) of the S-Classes on both sides of the transition are affected. For example, if fire transitioned an S-Class currently in a surplus to an S-Class currently in a deficit, the relative amount of the surplus S-Class would be reduced (moved towards similar; a benefit) and the relative amount of the deficit S-Class would be increased (also moved towards similar; a benefit). This would be the best-case scenario, as the S-Classes on both sides of the transition are moving towards the reference condition. Conversely, if fire transitioned an S-Class currently in deficit status to an S-Class currently in surplus status, it would be the worst-case scenario, as the S-Classes on both sides of the transition would be moving away from the reference condition. If no transition occurs between S-Classes as a result of burning there is no change in ecological integrity.

C-2. Effect on succession class status by transition type.

		Transition Occurs		No Transition Occurs
		Pixels Removed	Pixels Added	
Current Status	Deficit	Further deficit	Towards similar	No change
	Similar	Towards deficit	Towards surplus	No Change
	Surplus	Towards similar	Further surplus	No change

To quantify the effects due to transitions between S-Classes, we assigned numeric values ranging from -75 to +75 (Table C-3). We chose not to use the full range of -100 to +100 under the assumption that no transition would result in a complete loss or complete restoration of ecological integrity. This highlights one of the limitations of this methodology—we don't know how many pixels (i.e., area) are moving in any of these transitions during any given simulation. That is, we only know the relative direction the change is taking and not whether enough pixels would transition in order to cause a change in status, or whether so many pixels would transition that the current status could change from a surplus to a deficit or a deficit to a surplus. Results should therefore be interpreted within the context of potential relative change, with an expectation that future analyses will be conducted with updated vegetation and fuel conditions to monitor trends over time.

C-3. Numeric response for transitions between departure status categories.

		Post-Fire Status			**No Transition**
		Deficit	**Similar**	**Surplus**	
Pre-Fire Status	**Deficit**	0	-50	-75	0
	Similar	25	-25	-50	0
	Surplus	75	25	0	0
	Sagebrush with high susceptibility to cheatgrass (any status)	-75	-75	-75	-75

The magnitude of loss or benefit assigned in Table C-3 is less for transitions to or from a similar status. The premise being that moving away from similar, either from an addition or removal of pixels, has a lesser effect because it will require less acres of change to restore the status than if an S-Class was already in deficit or surplus status and moved further into that status—further away from the reference. Each transition identified within a BpS represents a covariate of the sub-HVRA. For the sagebrush BpS we mapped an additional covariate representing areas with high susceptibility for post-fire cheatgrass establishment using a local cheatgrass susceptibility model (Egan 2019). It was assumed that wildfire in these areas would result in a conversion to cheatgrass and a response function value of -75 was assigned at all fire intensity levels.