THESIS

CONSTRAINTS ON MECHANICAL FUEL REDUCTION TREATMENTS IN USFS WILDFIRE CRISIS STRATEGY PRIORITY LANDSCAPES

Submitted by

George Woolsey

Department of Forest and Rangeland Stewardship

In partial fulfillment of the requirements

For the Degree of Master of Science

Colorado State University

Fort Collins, Colorado

Spring 2024

Master's Committee:

Advisor: Chad M. Hoffman
Co-Advisor: Wade T. Tinkham

Mike A. Battaglia
Matthew R.V. Ross

ABSTRACT

CONSTRAINTS ON MECHANICAL FUEL REDUCTION TREATMENTS IN USFS WILDFIRE CRISIS STRATEGY PRIORITY LANDSCAPES

The US Forest Service recently launched a Wildfire Crisis Strategy outlining objectives to safeguard communities and other values at risk by substantially increasing the pace and scale of fuel reduction treatment. This analysis quantified layered operational constraints to mechanical fuel reduction treatments including existing vegetation, protected areas, steep slopes, and administrative boundaries in prioritized landscapes. A Google Earth Engine workflow was developed to analyze the area where mechanical treatment is allowed and operationally feasible under three scenarios representing a range of management alternatives under current standards. Results suggest that a business-as-usual approach to mechanical fuel reduction is unlikely in most landscapes to achieve the 20-40% of high-risk area treatment objective using mechanical methods alone. Increased monetary spending to overcome physical constraints to mechanical treatment (e.g., steep slopes and road access) opens sufficient acreage to meet treatment objectives in 18 of 21 priority landscapes. Achieving treatment objectives in the remaining landscapes will require both increased spending and navigating administrative complexities within reserved land allocations to implement fuels treatments at the pace and scale needed to moderate fire risk to communities. Broadening the land base available for treatment allows for flexibility to develop treatment plans that optimize across the multiple-dimensions of effective

landscape-scale fuel treatment design. Spatial identification of the constraints to mechanical operability allows managers and policymakers to effectively prioritize mechanical and managed fire treatments.

TABLE OF CONTENTS

CHAPTER 1: SPATIAL IDENTIFICATION OF MECHANICALLY AVAILABLE AREA IN THE 21 PRIORITY LANDSCAPES OUTLINED IN THE 2022 USFS WILDFIRE CRISIS STRATEGY

1 Introduction

Despite broad agreement in scientific and policy arenas that proactive management actions are needed to foster fire- and climate-adapted forests in the western United States ([US]; Hessburg et al., 2021; Prichard et al., 2021), the pace and scale of treatments has been inadequate to address the immense management challenge (North et al., 2012; Liang et al., 2018; Kolden, 2019). In response, the US Department of Agriculture, Forest Service (USFS) recently launched a Wildfire Crisis Strategy (USFS, 2022a), hereafter called the Strategy, with the goal to substantially increase the extent of forest health and risk reduction fuel treatments over the next decade to match the scale of wildfire risk across the landscape. The Strategy proposes to implement treatments on up to an additional 20.2 million hectares (50 million acres) over ten years using an all-lands approach across the western US. To meet the goals of the Strategy, the US federal government appropriated just over $5 billion through the Infrastructure Investment and Jobs Act of 2021 (P.L. 117-58) and an additional $1.8 billion in funding for fuels treatments via the Inflation Reduction Act of 2022 (P.L. 117-169). This proactive approach represents a land management paradigm shift from a reactive approach centered on aggressive wildfire suppression which cost the USFS over $1.9 billion per year from 2016 to 2020 (USFS, 2022a).

The Strategy prioritizes 21 landscapes for initial investment in fuels and forest health treatment projects across ten western states targeting federal, state, tribal, and private lands where wildfire ignitions will potentially impact communities (Figure 1.1). The selection criteria for these 21 priority landscapes included potential wildfire exposure to buildings, infrastructure, and critical watersheds with additional consideration for underserved communities, Indigenous peoples and lands, fish and wildlife habitat, and other values (USFS, 2023a). Areas with ongoing projects that could be scaled in their extent while operating under existing authorities were prioritized to maximize the area of impact (USFS, 2023a). The boundaries of the 21 priority landscapes roughly follow the boundaries of "firesheds" prioritized to reduce wildfire transmission to developed areas (Figure 1.1). Firesheds are geographic delineations averaging approximately 100,000 hectares (250,000 acres) that were created to organize the landscape into units for managing wildfire risk to communities. Wildfire simulation data from the national FSim library (Short et al. 2020) was intersected with building locations to quantify source of fire risk to communities at the fireshed level (Ager et al. 2021a). Nested within firesheds are project areas of approximately 10,000 hectares (25,000 acres) in size which represent the geographic unit at which vegetation and fuel management projects are planned. The full process for delineating fireshed boundaries and determining risk across the continental US is described in detail in Ager et al. (2021a).

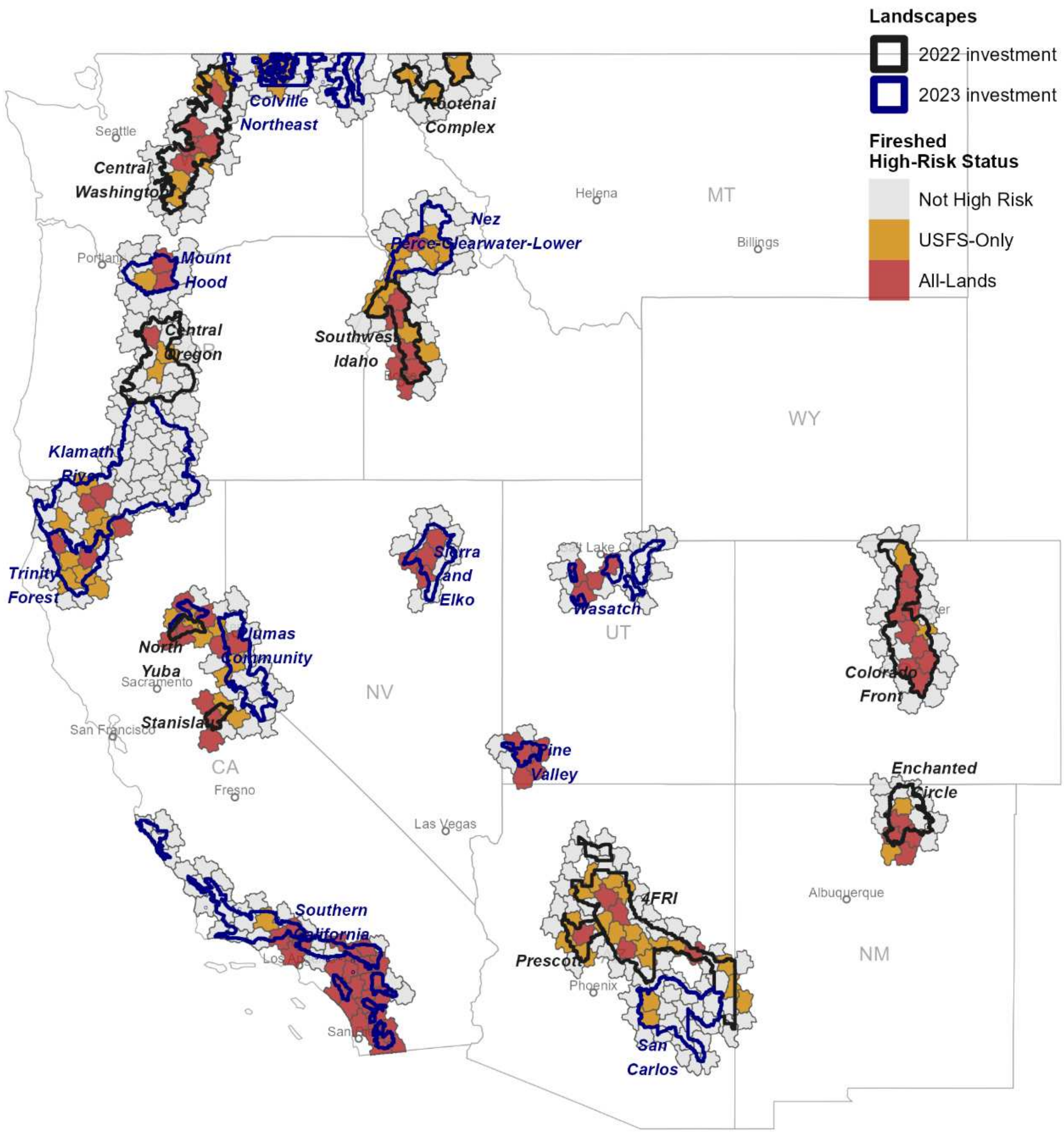

Figure 1.1. 2022 USDA, Forest Service Wildfire Crisis Strategy 21 landscapes prioritized for fuel reduction treatments in Arizona, California, Colorado, Idaho, Nevada, New Mexico, Montana, Oregon, Utah, and Washington. Ten landscapes outlined in black and 11 outlined in navy blue represent 2022 and 2023 Strategy investments, respectively. Firesheds intersecting priority landscapes are shaded by risk to communities with the highest risk firesheds as determined by the Strategy shaded red (multiple ownerships) and orange (USFS ownership only). Firesheds shaded in gray are still at-risk to potential wildfire impacts but were not classified as high-risk by the Strategy.

The size of each priority landscape does not represent total planned treatment acres. Rather, the Strategy has set a goal to treat 20-40% of “high-risk” fireshed areas within the 21 priority landscapes where community exposure to potential wildfire is the greatest (USFS, 2022b; Figure 1.1). The 20-40% treatment level follows science showing that fuels reduction at this scale can effectively reduce fire size and severity (e.g., Finney, 2007; Schmidt et al., 2008). The total area of the 21 priority landscapes is approximately 19 million hectares (47 million acres), of which 9.6 million hectares (23.7 million acres) are in high-risk firesheds; an objective of treating 20-40% would indicate the need to treat 1.9 to 3.8 million hectares (4.7 to 9.5 million acres). The Strategy prioritizes treatment in forest and shrubland systems across the western US where increases in wildfire frequency, area burned, and area burned at high severity have been observed in recent decades (Syphard et al., 2018; Singleton et al., 2019; Parks and Abatzoglou, 2020; Hagmann et al., 2021). Fuels reduction treatments are implemented with the intent to “alter the fuel complex in such a way as to modify fire behavior and thereby minimize the potential negative impacts of future wildfires on ecosystem goods and services, cultural resources, and human communities” (Hoffman et al., 2020). Land managers consider landscape condition, ecology, and objectives to design fuel treatments which typically include mechanical thinning of trees, mastication of woody material, prescribed fire, managed wildfire, grazing or herbicide to reduce herbaceous fuels, or a combination of approaches (Monsen et al., 2004; Agee and Skinner, 2005; Jain et al., 2012; Jain et al., 2018).

Prior research from the fire science community evaluating fuel treatment effectiveness at achieving desired outcomes provides guidance on how to design and implement treatments at broad spatial scales (Collins et al., 2010). A thorough review of fuel treatment effectiveness based on studies using simulation approaches exists in Ott et al. (2023), while McKinney et al. (2022) focus on empirical studies and Urza et al. (2023) review case studies involving actual fires. These studies generally indicate that fuel treatment effectiveness at the landscape scale is positively related to: i) the amount of area treated (i.e., treatment extent); ii) the size of individual treatment units; iii) use of a placement prioritization scheme (e.g., based on fire threat) or optimization algorithm (e.g., treatment optimization model [Finney et al., 2007]); and iv) recency of treatment. However, maximizing the effectiveness of fuel treatments is hindered by a complex web of regulations and other constraints which limit the extent, intensity, and location of treatment application (Van Deusen et al., 2012; North et al., 2015; Lydersen et al., 2019). While increased use of managed fire (i.e., prescribed burning and managed wildfires) has been touted as a strategy for increasing treatment pace and scale (e.g., Kolden, 2019), the use of managed fire in the western US is significantly limited by risk-related concerns (air quality, liability, safety), resources (funding and workforce), and regulations (Ryan et al., 2013; Miller et al., 2020). Fuel reduction via mechanical means represents an alternative but cost, legal (e.g., wilderness and roadless areas), operational (e.g., steep slopes, distance to roads), and administrative (e.g., sensitive species habitat, riparian buffers) factors alone or in combination affect whether mechanical equipment is practical or allowed in different areas (North et al., 2015). A recent study encompassing the 58 million hectares (143 million acres) of the 76 USFS-managed national forests in 15 western and central US states (USFS regions 1-6) found that protected areas where mechanical equipment is prohibited made up 50% of the total area (Ager et al., 2021b). Prior work considering layered legal, operational, and administrative constraints found that only 25% of the total land area and 44% of productive forest area was available for mechanical treatment on USFS land across the Sierra Nevada Bioregion (North et al., 2015). Even with substantial funding allocated to complete the fuels reduction work needed across the western US, there could be major challenges to completing the proposed work. The extent of the Strategy's priority landscapes that overlap with land on which mechanical fuels reduction treatment is practical or allowed is unknown.

The objective of this study is to spatially identify the mechanically treatable area and the constraints on management activities in the 21 priority landscapes outlined in the USFS Wildfire Crisis Strategy to inform plan implementation and future policy-making efforts. We took a tiered approach to understand the constraints to mechanical treatment. Specifically, at the scale of each of the 21 landscapes, we asked the following questions: (1) What is the spatial extent of the landscape on which ground-based equipment is allowed and operationally feasible? (2) Which constraining factor(s) — legal, operational, administrative — is most limiting to mechanical fuel reduction treatment? In practice, the arrangement of mechanically available land is crucial for planning and implementing fuel treatments at broad spatial scales by enabling flexibility in design for a specific configuration (e.g., Finney 2007; Schmidt et al. 2008). To characterize the spatial arrangement of mechanically available land we used the nested spatial framework for firesheds and asked the questions: (3) How are fireshed project areas distributed based on level of mechanical constraint? (4) Is 20-40% of high-risk fireshed area mechanically available in moderately and lightly constrained fireshed project areas? (5) Are lightly constrained fireshed project areas spatially aggregated such that extensive treatments could be implemented using primarily mechanical methods? To address these questions, three scenarios of operational constraints were analyzed to represent a range of management alternatives under current standards for implementing mechanical treatment.

2 Methods

This study combines readily available datasets in a Google Earth Engine workflow to quantify the amount and spatial arrangement of land available for mechanical forest health and risk reduction fuel treatments after considering layered operational constraints within the 21 landscapes prioritized in the USFS Wildfire Crisis Strategy (USFS, 2023a). A hierarchy of constraints that affect mechanical operability (Figure 1.2) starting with fixed limitations and progressing to less rigid constraints was implemented in a manner similar to North et al. (2015). This type of planning analysis has been utilized in recent western national forest plan revisions to identify strategic fire-management zones (North et al., 2021) and to estimate the costs of alternative forest management strategies (Holland et al., 2022).

2.1 Management Scenarios Used to Quantify Mechanically Available Acreage

Using this hierarchical approach, areas within the boundary of each priority landscape that were not classified as forest or shrubland based on the 2019 National Land Cover Database ([NLCD]; Dewitz and USGS, 2021) were removed as a first-level constraint (Figure 1.2B) and to identify the total acreage available for treatment given no constraints. With combined forest and shrubland area as the base layer, protected areas such as wilderness (Wilderness Act, 16 U.S.C. §§ 1131–1136 [2006 & Supp. II 2008]) and inventoried roadless areas (Roadless Area Conservation Rule [36 Code of

Federal Regulations § 294]) where mechanical equipment is not allowed were identified and removed (Figure 1.2C) using GAP Status Code 1 areas and inventoried roadless area (IRA) designation in the USGS Protected Areas Database (PAD-US [USGS, 2018]).

To account for various operability constraints for mechanical equipment, we developed three scenarios (Table 1.1) to represent a gradient in funding, policy, and management options. With combined forest and shrubland area as the base layer and protected areas removed, four constraining factors to mechanical operability — slope, road access, riparian buffers, and administrative designation — were varied over these three scenarios (Table 1.1). Scenario 1 reflects the status-quo approach to mechanical fuel reduction treatments based on USFS operations in recent years where mechanical treatments occur on slopes <40% within 1,000 feet (305 m) of existing road infrastructure and are excluded within 100 ft (30 m) of waterways and all specialty administrative designations (North et al., 2015). Scenario 2 represents a management approach characterized by increased monetary spending which enables working on steeper slopes up to 60% and increases the use of temporary roads by extending the distance to existing roads to 2,000 feet (610 m), with no changes to riparian buffers and administrative designations (further described below). This scenario would be indicative of management actions that emphasize utilizing recent innovations in mechanized harvesting systems, such as tethered or cable-assisted equipment, that have been designed to operate on steep slopes (e.g., 40-60%) and may extend mechanical management opportunities to previously inoperable areas (Sessions et al., 2016; Belart et al., 2019). Scenario 3 is the least restrictive scenario considered in this analysis and represents an aggressive approach to fuel reduction work that is characterized by both increased monetary spending and expanded treatment near riparian areas and within administratively designated areas. Administrative designations such as sensitive species habitat, wildlife refuges, and riparian buffers do not prohibit mechanical treatment by law, but in practice these areas are commonly left untreated by land managers who wish to avoid administrative hurdles and litigation concerns (Stephens and Ruth, 2005; Charnley et al., 2015; Gosnell et al., 2020).

Table 1.1. Hierarchy of constraints used to determine whether mechanical equipment was allowed and operationally feasible for this analysis, where spatial analysis was overlaid from L1 through L5 to attribute the cause of constraint.

	Constraint type	**Scenario 1 Most Constrained**	**Scenario 2**	**Scenario 3 Least Constrained**
L0:	NLCD Cover Type	Forest or Shrubland	Forest or Shrubland	Forest or Shrubland
L1:	Protected or IRA Status	Not Protected	Not Protected	Not Protected
L2:	Slope	<40%	<60%	<60%
L3:	Distance to Nearest Road	<1,000 ft <305 m	<2,000 ft <610 m	<2,000 ft <610 m
L4:	Riparian Buffer	>100 ft >30 m	>100 ft >30 m	>50 ft >15 m
L5:	Administrative Designation	No Designation	No Designation	Any Designation

Slope constraints to mechanically treatable areas were calculated using 3D Elevation Program (3-DEP [USGS, 2020]) data at 10 m resolution (Figure 1.2D). Remote areas distant from existing road infrastructure were removed using the US

Census Bureau TIGER/Line road dataset (USCB, 2016) and the USFS Forest Activity Tracking System database (FACTS [USFS, 2023b]) tables including the motor vehicle use map for trails and roads and the national forest system trail and road map (Figure 1.2E). Administrative boundaries were removed from the treatable area (Figure 1.2F-G) using GAP Status Code 2 in PAD-US, the US Fish and Wildlife Survey Threatened and Endangered Species Active Critical Habitat Report (USFWS, 2023), and riparian buffers identified using the National Hydrography Dataset (NHD [USGS, 2022]). At each level of constraint, the reduction in area and percentage was calculated based on the area remaining after considering the cumulative impact of prior constraints compared to the total area of forest and shrubland in each of the 21 landscapes.

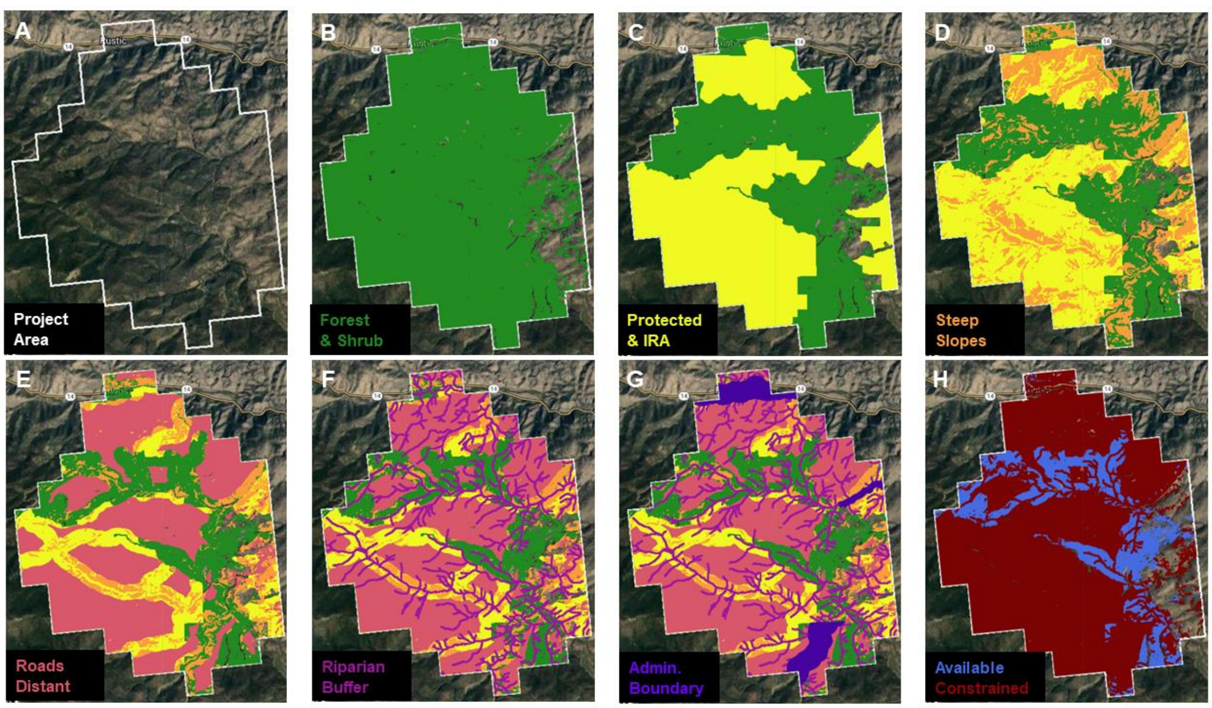

Figure 1.2. Workflow used to quantify the amount of land available for mechanical forest health and risk reduction fuel treatments by considering layered operational constraints. This example illustrates scenario 2 for a (A) 10,252 hectare (25,000 acre) fireshed project area near Rustic, Colorado in the Colorado Front Range priority landscape. The analysis identifies (B) all forest and shrubland areas, (C) removes protected and inventoried roadless areas, (D) classifies land as mechanically operable based on terrain slope, (E) buffers existing roads according to equipment haul distance,

(F) removes areas within riparian buffers, (G) removes areas within administrative boundaries, and (H) determines what land is mechanically available or constrained and by what factor.

2.2 Spatial Arrangement of Mechanically Available Land

2.2.1 Distribution of Fireshed Project Areas by Level of Mechanical Constraint (Question 3)

We used the nested spatial framework delineating firesheds developed by Ager et al. (2021a) and described above to characterize the spatial arrangement of mechanically available land within the 21 priority landscapes (Figure 1.3). The level of analysis used for this study was the fireshed project area approximately 10,000 hectares (25,000 acres) in size which represents the area at which planning and implementation of forest and fuel management treatments on western national forests typically occurs. Fireshed project areas were classified as high-risk USFS lands, high-risk all land ownerships, or not high-risk based on the parent fireshed in the Strategy (Figure 1.1; Figure 1.3A). Fireshed project areas were included for analysis if 25% or more of the project area was within the boundary of a priority landscape (Figure 1.3B). For each fireshed project area included in this analysis, the entire project area, including area outside of the priority landscape boundary, was used to calculate the percent of forest and shrubland mechanically available. The fireshed project areas were then divided into three classes of mechanical constraint: high (81–100% constrained; 0–19% available for mechanical treatment), medium (60–80% constrained; 20–40% available), and low (0–59% constrained; 41–100% available) based on the methodology outlined for subwatersheds by North et al. (2015).

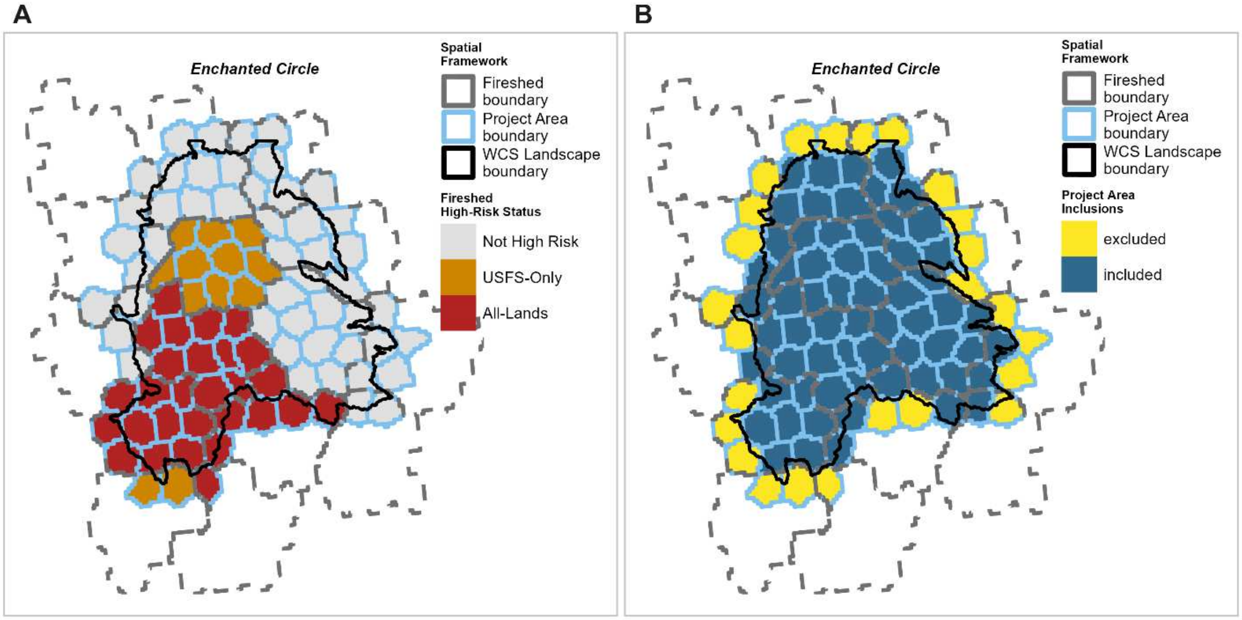

Figure 1.3. (A) Nested spatial framework of the Enchanted Circle priority landscape (New Mexico; black outline) delineating firesheds (gray dashed outline) approximately 100,000 hectares (250,000 acres) in size which are the broad scale unit of prioritization and nested fireshed project areas (light blue outline) approximately 10,000 hectares (25,000 acres) in size which are used for planning and conducting fuel management projects. Fireshed project areas are shaded by risk to communities of the parent fireshed with the highest risk firesheds as determined by the Strategy shaded red (multiple ownerships) and orange (USFS ownership only). (B) Fireshed project areas that did not have at least 25% of area within the boundary of the Strategy priority landscape were excluded (shaded yellow) from this analysis.

2.2.2 Mechanically Available Acreage to Meet Treatment Area Objective of 20-40% (Question 4)

In areas with high mechanical constraint, fuels reduction will principally need to rely on some type of managed fire but in areas with low mechanical constraint, wildfire risk could be mitigated using primarily mechanical methods (North et al., 2015; North et al., 2021). In project areas with medium mechanical constraint levels, fuel reduction work using primarily mechanical methods may or may not be feasible based on local constraining factors not considered in our analysis and the configuration of available acreage which influence real-world treatment planning. These moderately constrained project areas potentially have a suboptimal distribution of mechanically available land and could use a combination of mechanical thinning and fire treatment to reduce risk and moderate fire behavior (North et al., 2015; North et al., 2021). The priority landscapes with the highest likelihood of achieving the objective of treating 20-40% of high-risk acreage include those landscapes where mechanical methods are lightly constrained across a majority of planning areas while moderately constrained planning areas could provide supplemental treatment acreage to meet objectives. To assess the likelihood of achieving Strategy objectives, the amount of mechanically available area within lightly and moderately constrained, high-risk fireshed planning areas was aggregated and compared against the total area of high-risk fireshed planning areas included for analysis (Figure 1.3).

2.2.3 Spatial Aggregation of Fireshed Project Areas by Level of Mechanical Constraint (Question 5)

To quantify the spatial aggregation of fireshed project areas by level of mechanical constraint, we created patch boundaries by combining spatially adjacent fireshed project areas of the same class of mechanical constraint until all other adjacent project areas were of a different class. For each landscape, we then selected the largest patch of interconnected fireshed project areas by constraint class and calculated the proportion of the total area of all project areas represented by this patch (i.e., largest patch index). Extensive, lightly mechanically constrained patches represent opportunities for land managers to design plans that incorporate the principles of effective landscape-scale fuel treatments (Collins et al., 2010).

3 Results

3.1 Mechanically Available Acreage in the Strategy's Priority Landscapes

The total area of the 21 priority landscapes selected in the USFS Wildfire Crisis Strategy is approximately 19 million ha (48 million acres) of which 16.1 million ha (39.8 million acres) is classified as forest or shrubland (83%; Table 1.2). The Central Washington Initiative landscape has the lowest proportion of combined forest and shrubland cover at 70% and the North Yuba (California) landscape has the highest proportion of forest and shrubland cover at 97% (Table A.1). Four landscapes have a majority of area that is classified as shrubland — Prescott (Arizona), San Carlos Apache Tribal Forest Protection (Arizona), Southern California Fireshed Risk Reduction Strategy, and Sierra and Elko Fronts (Nevada) — while the remaining 17 landscapes are primarily forested (Figure A.1).

On the combined forest and shrub area across all 21 priority landscapes, 29% is available to mechanical treatment under scenario 1 constraints, 42% is available under scenario 2 constraints, and 53% is available under scenario 3 constraints (Table 1.2). Mechanically available forest and shrubland acreage at the individual landscape level ranged from a low of 10% to a high of 60% under scenario 1, 20 to 70% under scenario 2, and 24 to 83% under scenario 3 (Table A.1; Figure A.2). A detailed report of the data describing the extent of mechanically available acreage within the boundary of each priority landscape by scenario and the reductions by constraining factor is presented in Appendix A.

Table 1.2. Combined forest and shrubland area across the 21 priority landscapes and the percent reduction of different types of constraints on mechanical treatment based on the three scenarios of operational constraints considered in this analysis. Scenario 1 represents the status-quo with mechanical fuel reduction treatments occurring on slopes <40% within 1,000 feet (305 m) of existing road infrastructure and are excluded within 100 ft (30 m) of waterways and all specialty administrative designations. Scenario 2 allows working on slopes up to 60% and use of temporary roads to allow operation within 2,000 feet (610 m) of existing roads. Scenario 3 expands on Scenario 2 by allowing mechanical treatment near riparian areas and within administratively designated areas.

			Constraint Least Flexible to Most Flexible						
	Forest & Shrub (ha)	Forest & Shrub (%)	Protected & IRA	Slope Steepness	Road Distance	Riparian Buffer	Administrative Boundary	Mechanically Available (ha)	Mechanically Available (%)
Overall Landscape Area									
Scenario 1	16.1 M	82.9%	-22.0%	-16.9%	-19.8%	-7.0%	-5.6%	4.6 M	28.7%
Scenario 2	16.1 M	82.9%	-22.0%	-5.2%	-12.0%	-10.5%	-8.4%	6.8 M	41.9%
Scenario 3	16.1 M	82.9%	-22.0%	-5.2%	-12.0%	-7.5%	0.0%	8.6 M	53.3%

3.2 Spatial Arrangement of Mechanically Available Land

3.2.1 Distribution of Fireshed Project Areas by Level of Mechanical Constraint (Question 3)

Under the status-quo approach to mechanical fuel reduction treatments represented by scenario 1, the resulting classification of fireshed project areas by level of mechanical constraint is: 42% of project areas (n = 896) are highly constrained (81–100% constrained; 0–19% available for mechanical treatment), 29% of project areas (n = 622) are moderately constrained (60–80% constrained; 20–40% available), and 29%

of project areas (n = 613) are lightly constrained (0–59% constrained; 41–100% available) across the 21 priority landscapes (Figure 1.4B). There was an increase in the proportion of lightly constrained fireshed project areas between scenarios 1 and 2 (adding steeper slopes and expanding temporary road construction) from 29% to 53% of all fireshed project areas considered in this analysis and from 28% to 58% of high-risk firesheds (Figure 1.4B). Under the most aggressive approach to fuel reduction work using scenario 3, the combined impact of operating on steep slopes, expanding the use of temporary roads, and expanding treatment near riparian areas and within administratively designated areas further increased the proportion of lightly mechanically constrained fireshed project areas to 68% of all fireshed project areas and to 76% of high-risk firesheds (Figure 1.4B).

The distribution of fireshed project areas by level of mechanical constraint shifted considerably at the individual landscape level as constraints were relaxed. Under the operational constraints represented by scenario 1, four landscapes had a plurality of project areas lightly constrained to mechanical access while eight landscapes had a plurality of project areas highly constrained to mechanical access (Figure B.1). Allowing mechanical operations on steeper slopes and expanding the use of temporary roads using scenario 2 resulted in all but seven priority landscapes (i.e., 14 landscapes) having a majority (>50%) of project areas classified as lightly constrained (Figure B.1). Relaxing constraints to mechanical operations in administratively designated areas (scenario 3) in addition to operating on steeper slopes and further away from existing roads resulted in all but three priority landscapes — San Carlos Apache Tribal Forest Protection (Arizona), Southern California Fireshed Risk Reduction Strategy, and Pine

Valley (Utah) — or 18 landscapes having a majority (>50%) of project areas classified as lightly constrained (Figure B.1).

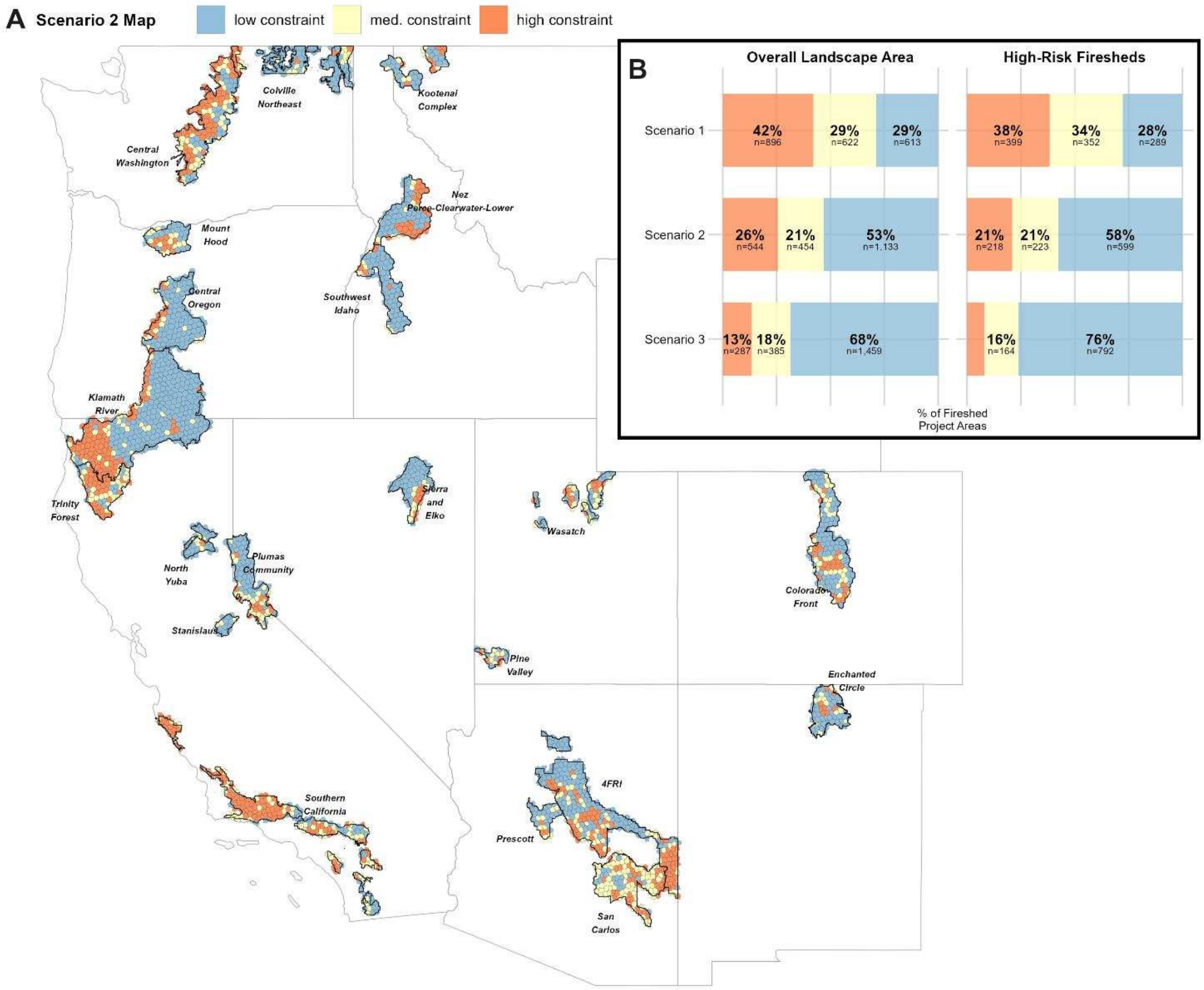

Figure 1.4. Fireshed project areas were divided into three classes of mechanical constraint: high (81–100% constrained; 0–19% available for mechanical treatment), medium (60–80% constrained; 20–40% available), and low (0–59% constrained; 41–100% available). (A) Fireshed project areas in USFS Wildfire Crisis Strategy priority landscapes were mapped and shaded by level of constraint under scenario 2 mechanical constraints. (B) The distribution of fireshed project areas by level of constraint was determined within the overall landscape area and within high-risk firesheds only.

3.2.2 Mechanically Available Acreage to Meet Treatment Area Objective of 20-40% (Question 4)

In fireshed project areas classified as lightly constrained, mechanically treatable areas are likely large enough to achieve effective fuel reductions by mechanical methods alone. Under the status-quo approach to mechanical fuels reduction treatment (scenario 1) there are four priority landscapes where over 20% of high-risk acreage is mechanically available in lightly constrained project areas while an additional ten landscapes may meet the 20% minimum target of high-risk acreage by pooling low and medium constraint areas (Figure 1.5; Table B.1). However, seven landscapes have less than 20% of high-risk area mechanically available in combined low and medium constraint planning areas based on scenario 1 operational constraints. Increasing slope and road access under scenario 2 resulted in 15 priority landscapes with over 20% of high-risk acreage mechanically available in lightly constrained areas and an additional three landscapes with over 20% of high-risk acreage mechanically available in combined low and medium constraint areas (Figure 1.5; Table B.1). Under scenario 2 operational constraints, there are only three landscapes with less than 20% of high-risk area mechanically available in combined low and medium constraint planning areas: Central Washington Initiative (13.2% available), Trinity Forest Health and Fire-Resilient Rural Communities (California; 17.1% available), and Mount Hood Forest Health and Fire-Resilient Communities (Oregon; 19.9% available). Under the most aggressive approach to fuel reduction work considered in this analysis (scenario 3), the combined impact of operating on steep slopes, expanding the use of temporary roads, and allowing treatment near riparian areas and within administratively designated areas resulted in all 21 priority landscapes with sufficient available acreage in lightly constrained areas to meet the objective of treating over 20% of high-risk acreage using mechanical methods alone (Figure 1.5; Table B.1).

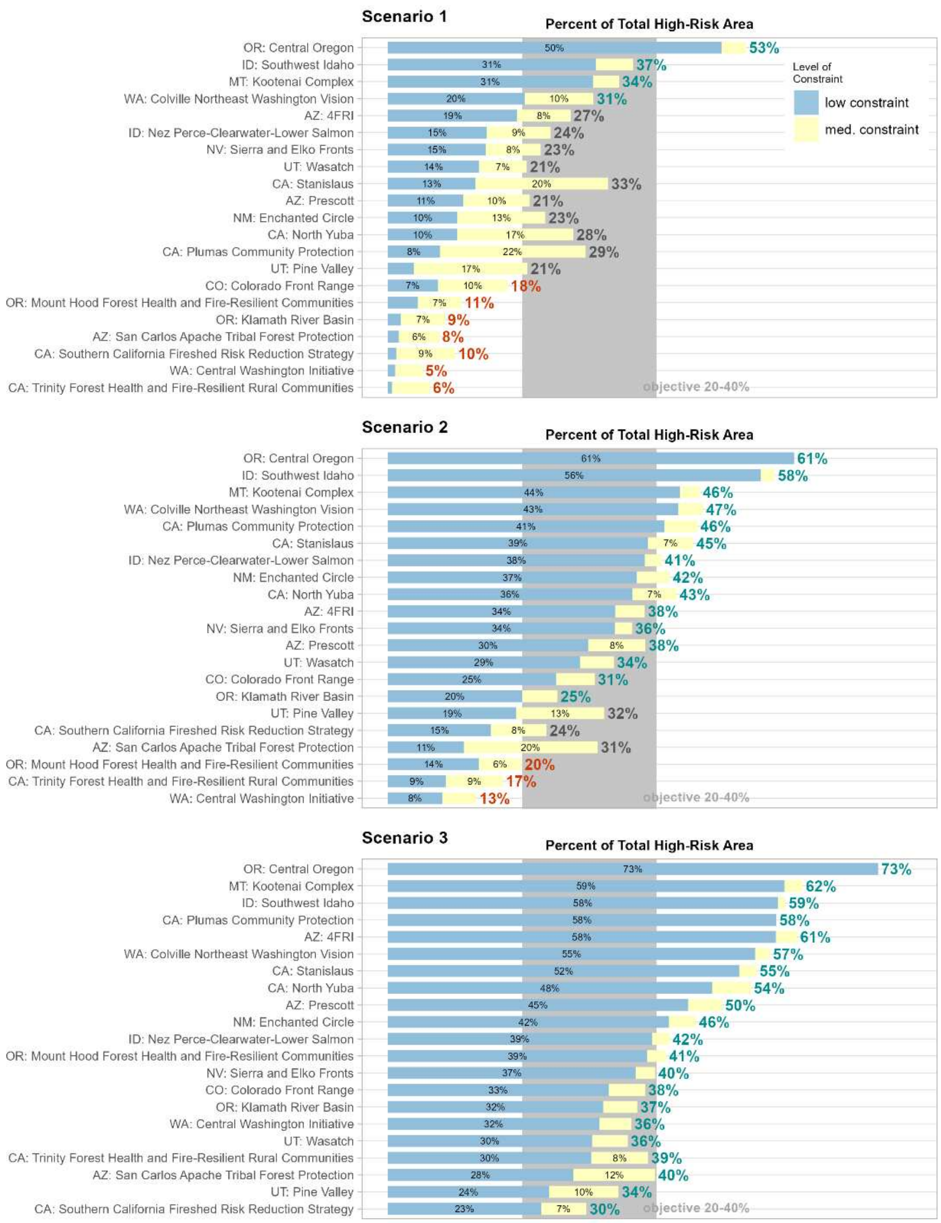

Figure 1.5. Percent of total area within high-risk firesheds where there exists the ability to create effective, extensive fuels treatments by mechanical methods alone (low constraint areas: 0–59% constrained; 41–100% available for mechanical treatment) or in combination with managed fire (medium constraint areas: 60–80% constrained; 20–40% available). The gray area in the plot represents the Strategy objective of treating 20-40% of high-risk fireshed acreage.

3.2.3 Spatial Aggregation of Fireshed Project Areas by Level of Mechanical Constraint (Question 5)

Examination of a map of project areas shaded by constraint level under scenario 2 (Figure 1.4A; Figure 1.6A; Figures B.3-22) reveals that mechanically constrained and mechanically available areas tend to be clustered. For example, in the Central Washington Initiative (Washington; Figure 1.6A) landscape under scenario 2 constraints, fireshed planning areas in the western portion of the landscape are mostly highly mechanically constrained while fireshed planning areas in the eastern portion are mostly lightly constrained. The largest patch of fireshed project areas classified as lightly mechanically constrained covered between 10 and 20% of the total landscape for most priority landscapes (i.e., 11 out of 21) under scenario 1 (Figure B.2). Three landscapes had a significant proportion of total area covered by the largest lightly constrained patch in which managers would have broad flexibility to optimize fuel treatment design: Central Oregon (73%), Southwest Idaho (60%), and Klamath River Basin (Oregon; 47%). Allowing access to steeper slopes and areas more distant from existing roads under scenario 2 increased the proportion of the total landscape covered by the largest patch of lightly constrained area to 25% or greater in 15 of the 21 priority landscapes (Figure B.2). Under the most aggressive approach we considered for expanding fuel reduction treatments, scenario 3, the largest lightly mechanically constrained patch comprised 35% or greater of the total landscape in all but four priority landscapes (i.e., 17 landscapes; Figure B.2). The Southern California Fireshed Risk Reduction Strategy and San Carlos Apache Tribal Forest Protection (Arizona) landscapes were among the priority landscapes with the lowest proportion of total landscape acreage covered by the largest lightly mechanically constrained patch under all three mechanical constraint scenarios considered. On the Southern California Fireshed Risk Reduction Strategy landscape, the proportion of total landscape area comprised by the largest patch of lightly mechanically constrained project areas was 1% for scenario 1, 6% in scenario 2, and 8% under scenario 3 (Figure B.2; Figure B.8). Conversely on this priority landscape, the proportion of total landscape area comprised by the largest patch of highly mechanically constrained project areas was 39% under scenario 1, 24% under scenario 2, and 20% under scenario 3 (Figure B.2; Figure B.8).

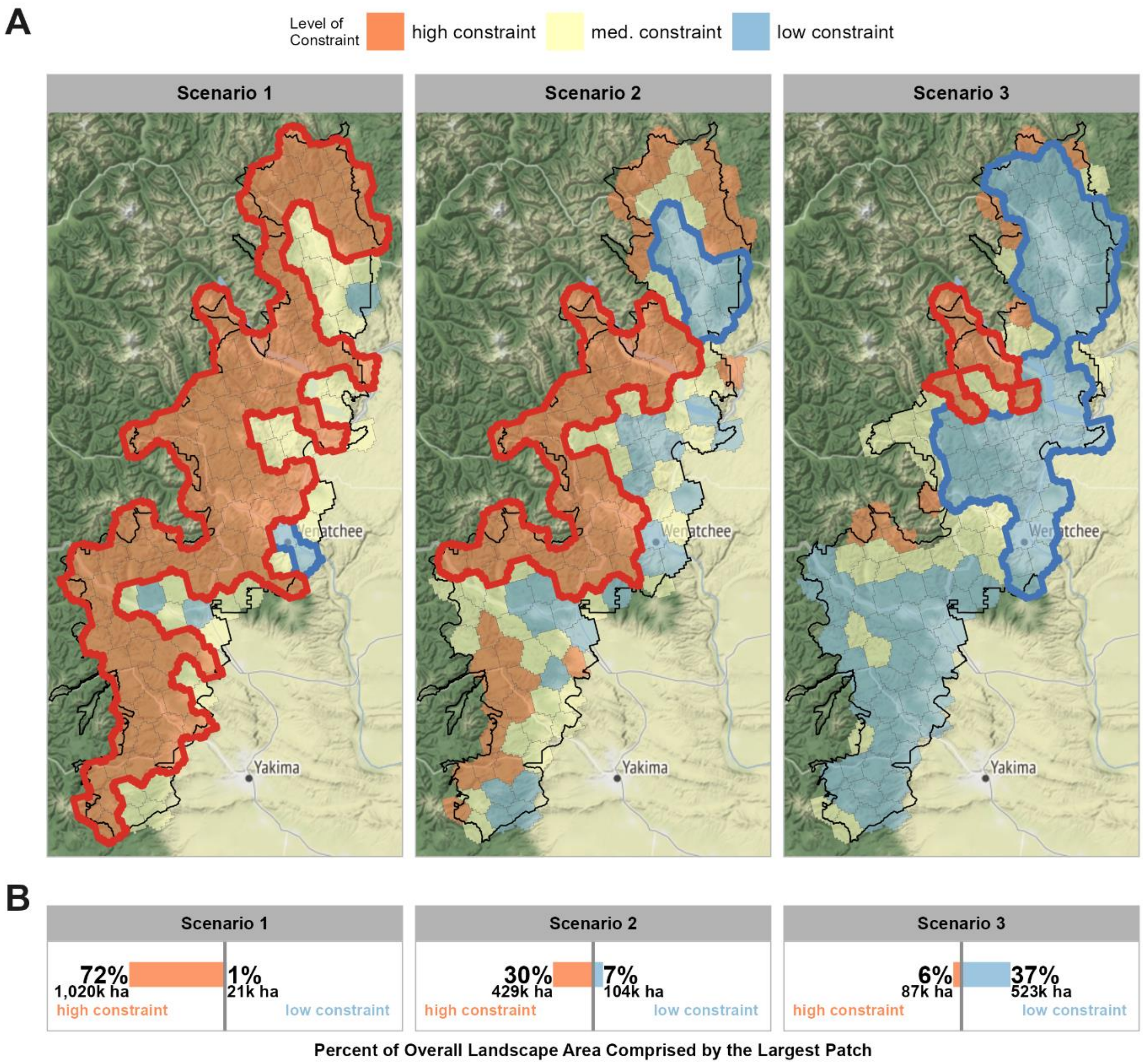

Figure 1.6. (A) Central Washington Initiative (Washington) priority landscape divided into fireshed project areas. Shadings indicate percentages of the total combined forest and shrubland acres that are available for mechanical treatment: high (81–100% constrained; 0–19% available for mechanical treatment), medium (60–80% constrained; 20–40% available), and low (0–59% constrained; 41–100% available). The largest patch of interconnected fireshed project areas classified as highly and lightly constrained are outlined. (B) Proportion of the total area of the overall landscape comprised by the largest patch of interconnected fireshed project areas of similar levels of mechanical constraint. Comparison is made between the largest patch of project areas classified as high constraint and the largest patch of project areas classified as low constraint.

4 Discussion

4.1 Constraints on Meeting Strategy Objectives using Mechanical Methods

The USFS Wildfire Crisis Strategy plan prioritizes 21 landscapes across ten states in the western US for initial funding to accomplish fuels reduction treatments with the objective to treat 20-40% of high-risk acreage where community exposure to potential wildfire is the greatest (USFS, 2022a; USFS 2022b; USFS, 2023a). The Strategy highlights the use of mechanical treatment as a primary tool for fuels reduction treatments yet mechanical operability is limited by factors including legal, operational, and administrative constraints (North et al., 2015). Our analysis suggests the status-quo approach to mechanical fuel reduction treatments based on USFS operations in recent years (scenario 1) could prevent attainment of Strategy objectives in seven of the 21 priority landscapes (Figure 1.5; Table B.1). By working on steeper slopes (up to 60%) and increasing the use of temporary roads (scenario 2), operations under the Strategy have an opportunity to achieve the objective of treating 20-40% of high-risk acreage by mechanical methods alone on all but three of the 21 priority landscapes (Figure 1.5; Table B.1). Construction of temporary roads and operations on steep slopes (e.g., 40-60%) using tethered mechanized harvesting systems, for example, increase the cost of treatment compared to operations on gentle slopes using untethered equipment. A recent study of tether-equipped systems used for fuel reduction treatment in the Klamath Basin in southern Oregon and northern California found that operation costs were about 1.47 times the cost of non-tethered operations, though the authors note the cost estimates for tethered operations may be inflated due to factors unassociated with tethered operations (Petitmermet et al., 2019). However, tethered mechanization improves operator safety, minimizes soil impacts, and reduces costs compared to manual chainsaw labor typically used for treatments on steep slopes (Visser and Stampfer, 2015; West et al., 2022). While cable-assisted and tethered mechanical harvesting systems are becoming more commonly used for fuel reduction treatments in the western US, the literature on costs, operational productivity, and implementation differences across variable site conditions is sparse (Petitmermet et al., 2019; Chang et al., 2023). Steep slope mechanical operations for fuel reduction treatment could significantly extend Strategy management opportunities to previously inoperable areas and present an opportunity to enhance our understanding of the potential of these systems.

The most aggressive approach to fuel reduction work considered in this analysis (scenario 3) included working on steeper slopes (up to 60%), increasing the use of temporary roads, and expanding mechanical treatment within administrative boundaries (e.g., riparian zones and sensitive species habitat). Under these least restrictive mechanical constraints, there is sufficient opportunity to achieve Strategy objectives of treating 20-40% of high-risk fireshed area using mechanical methods alone on all 21 priority landscapes (Figure 1.5; Table B.1). While fuel reduction treatments constrained to the area outside of administratively designated areas (e.g., scenarios 1 and 2 in this analysis) can reduce the risk of severe wildfire effects within the administrative boundary, recent simulation studies of spotted owl (*Strix occidentalis*) habitat, for example, have found even greater fire hazard reductions when fuel reduction work is allowed within owl habitat (Chiono et al., 2017; Jones et al., 2022). Administratively withdrawn lands such as habitat of species listed under the Endangered Species Act and late-successional reserves of the Northwest Forest Plan represent “fine-filter” conservation strategies focused on protecting individual resources or species (Stephens and Ruth, 2005; Spies et al., 2019). While administrative reserves are core to conservation efforts under climate change (Watson et al., 2014), focusing management on iconic landscapes and wildlife can lead to a tunnel vision that discounts diversity in social-ecological systems and limits management flexibility in the face of emerging threats (Stephens et al., 2016; Spies et al., 2019). Achieving the biodiversity goals of administrative reserves often requires active management (Lindenmayer et al., 2000; Pressey et al., 2007; Watson et al., 2014), especially in disturbance-dependent ecosystems such as dry, historically frequent-fire (e.g., <50 years) forests where restoring fire and implementing mechanical restoration treatments promote ecological integrity (Hessburg et al., 2015; Stephens et al., 2016; Spies et al., 2018). Proposals for creating new protected areas and enhancing protective measures in existing administrative reserves such as those under consideration for mature and old-growth forests (Exec. Order No. 14072, 2022) would most effectively meet conservation and policy goals if designed and actively managed to account for threats from climate change, altered disturbance regimes, and invasive species (Lindenmayer et al., 2000; Stephenson, 2014; Spies et al., 2018).

4.2 Broadening the Treatment Land Base to Enhance Management Flexibility

Research from the fire science community on maximizing the effectiveness of landscape-scale fuel treatments highlights five dimensions of fuel treatment design: extent, placement, size, prescription, and timing (Collins et al., 2010; McKinney et al., 2022; Ott et al., 2023; Urza et al., 2023). Extensive patches of land available for mechanical treatment represent opportunities for land managers to design broad-scale treatment plans that optimize across these dimensions by expanding the total area treated, adjusting the size of individual treatment units, using placement prioritization schemes, and maintaining treatment effectiveness over time (Collins et al., 2010). Our analysis indicates that when mechanical treatments are limited to modest slopes near existing roads outside of administratively designated areas (scenario 1), contiguous patches where operations may effectively create extensive fuels treatments by mechanical methods alone comprise at least 20% of total landscape acreage in only six of the 21 priority landscapes (Figure B.2). Increasing slope and road access for mechanical equipment (scenario 2) results in contiguous patches with low mechanical constraint that represent at least 25% of total landscape acreage in 15 of the 21 priority landscapes (Figure B.2). Further expanding mechanical access to administratively designated areas in addition to increasing slope and road access (scenario 3) results in contiguous patches of land where mechanical treatment alone could effectively influence potential wildfire behavior comprising at least 35% of total landscape acreage in 17 of the 21 priority landscapes (Figure B.2). Broadening the land base available for treatment allows treatment design flexibility, enabling land managers to integrate local knowledge and account for constraints not considered in this analysis. Flexibility in the design of landscape-scale management strategy has been identified as key to achieving convergence of the objective to mitigate negative impacts of potential wildfire to human communities with the objective to restore ecosystem resilience to future disturbance by promoting heterogeneity in forest and shrubland structure (Stephens et al., 2021).

Climate models suggest that wildfire activity will likely continue to increase under hotter and drier conditions (Krawchuk et al., 2009; Moritz et al., 2012; Bowman et al.,

2020) and that the reintroduction of fire as a key ecosystem process is essential to create wildfire-resilient landscapes (Larson and Churchill, 2012; North et al., 2012; Churchill et al., 2013). While this analysis focused on mechanical fuel treatments which, when implemented alone, have been shown to effectively mitigate negative wildfire effects (e.g., Prichard and Kennedy, 2014; Prichard et al. 2020), an approach that combines mechanical thinning with prescribed fire may be most effective, especially in seasonally dry pine and mixed-conifer forests common across the western US (Fulé et al., 2012; Kalies and Kent, 2016). For long-term fuel treatment effectiveness at lower cost, initial entry mechanical thinning can be used to reduce high fuel loads with periodic fire reintroduction (i.e., prescribed burning or managed wildfire) for maintenance (North et al. 2012; Stephens et al., 2021). Furthermore, mechanically thinning dense forests to reintroduce Indigenous cultural burning could extend social-ecological benefits to tribal communities while recovering opportunities for tribal engagement in resource management in ancestral lands across all jurisdictions (Lake et al., 2017; Long et al., 2018). To meet Strategy objectives of substantially increasing the pace and scale of fuel treatments over the next decade, North et al. (2021) suggest a "pyrosilviculture" approach which strategically implements mechanical thinning operations to: i) create fuel-reduced anchors from which to expand prescribed fire and managed wildfire operations; ii) precisely execute fuel-reduction work in areas where sensitive resources and assets (e.g., wildlife habitat and homes) are at risk; and iii) generate revenue from forest products to support jobs and economic returns.

4.3 Alternatives to Mechanical Treatment in Highly Constrained Areas

This analysis found that many of the high-risk fireshed project areas with high levels of mechanical constraint are directly adjacent to urban areas such as Salt Lake

County, Utah and Orange County, California, for example, while project areas that are lightly mechanically constrained are located relatively far from centers of population (Figures B.2-22). When mechanical fuel reduction treatments are highly constrained by physical-environment, legal, or other constraints in the wildland-urban interface (WUI), it is unlikely that prescribed fire will be a feasible risk-reduction alternative due to air quality, liability and safety concerns, and other regulations (Ryan et al., 2013; Miller et al., 2020). While fire suppression and strategic fuel breaks (e.g., Massada et al., 2011; Gannon et al., 2023) will continue to play a role in WUI fire management, continued emphasis on treating wildland fuels to reduce the probability of wildfire exposure to buildings is unlikely to be successful without managing for the susceptibility of buildings to ignitions (Gibbons et al., 2012; Calkin et al., 2014; Calkin et al., 2015). Fuel treatments do not stop or eliminate fires and it is well documented that building destruction from wildfire is primarily determined by the space immediately around structures (30-60 m) and building construction materials (Cohen, 2000; Syphard et al., 2014; Syphard et al., 2017). Even with significant funding for the Strategy, the USFS has limited capacity and authority to influence community protection under threat of increasing fire activity with climate change (Schoennagel et al., 2009). A “shared stewardship” approach (USFS, 2018; Kooistra et al., 2022) will be required to achieve land management objectives across boundaries and jurisdictions as communities aim to build social-ecological resilience for adapting to changing climate and socioeconomic conditions (McWethy et al., 2019). Coordinated efforts between governments (federal, state, local, tribal) and the people at risk (homeowners) to implement sustainable land-use planning and mitigate building ignition susceptibility are likely to produce the most effective long-term solutions (Gill and Stephens, 2009; Stephens et al., 2009; Calkin et al., 2014; Moritz et al., 2014; Keeley and Syphard, 2019).

4.4 Study Limitations

Although our analysis utilized methods which have been used in recent western national forest plan revisions and prior research, several limitations still exist. This analysis spans the broad extent of ten western US states and requires simplifying assumptions about the conditions and factors that constrain mechanical treatment which may not apply given locality differences. For example, soil conditions are not equally suitable for ground-based equipment at a given slope steepness across all areas (Robitaille et al., 2015). While mechanical treatments (e.g., chaining, harrowing, and mastication) are among the most commonly implemented fuel reduction treatments in shrublands (Monsen et al., 2004), with mastication requiring a carrier machine, cutting head, and mounting system similar to forest harvesting systems (Jain et al., 2018), this analysis did not consider how mechanical treatments in shrublands might differ from treatments in forests. In shrubland areas where mechanical treatment and prescribed fire are constrained, aerial application of herbicide and livestock grazing can be effective fuel-reduction alternatives (Monsen et al., 2004). Coordinating land management practices across multiple ownerships and jurisdictions with differing values and perceptions about managing the wildfire crisis (Gill and Stephens, 2009; Charnley et al., 2015; Kooistra et al., 2022) also presents unique challenges which were not considered in this analysis. Additionally, this analysis did not consider economic constraints to mechanical treatment given the substantial Congressional funding for fuels reduction work available through the Strategy in these areas. Economic constraints including funding for treatment, workforce capacity (Hartsough et al., 2008), and the net economic benefit of mechanical thinning or harvesting based on the value of potential forest products and the costs of harvesting and transporting those products (e.g., Prestemon et al., 2012) pose significant challenges to risk reduction fuel treatments in the western US. Fuel reduction projects often remove small-diameter trees and produce biomass residue, yet infrastructure is lacking in many regions to process this material and barriers exist to the creation of long-term economically sustainable markets (Han et al., 2004; Hjerpe et al., 2009; Nicholls et al., 2018).

References

Agee, J. K., & Skinner, C. N. (2005). Basic principles of forest fuel reduction treatments. *Forest ecology and management, 211*(1-2), 83-96.

Ager, A.A., Day, M. A., Ringo, C., Evers, C. R., Alcasena, F. J., Houtman, R. M., Scanlon, M., Ellersick, T. (2021a). *Development and application of the fireshed registry*. Gen. Tech. Rep. RMRS-GTR-425. Fort Collins: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 47 p.

Ager, A. A., Evers, C. R., Day, M. A., Alcasena, F. J., & Houtman, R. (2021b). Planning for future fire: Scenario analysis of an accelerated fuel reduction plan for the western United States. *Landscape and Urban Planning, 215*, 104212.

Belart, F., Leshchinsky, B., Sessions, J., Chung, W., Green, P., Wimer, J., & Morrissette, B. (2019). Sliding stability of cable-assisted tracked equipment on steep slopes. *Forest Science, 65*(3), 304-311.

Bowman, D. M., Kolden, C. A., Abatzoglou, J. T., Johnston, F. H., van der Werf, G. R., & Flannigan, M. (2020). Vegetation fires in the Anthropocene. *Nature Reviews Earth & Environment, 1*(10), 500-515.

Calkin, D. E., Cohen, J. D., Finney, M. A., & Thompson, M. P. (2014). How risk management can prevent future wildfire disasters in the wildland-urban interface. *Proceedings of the National Academy of Sciences, 111*(2), 746-751.

Calkin, D. E., Thompson, M. P., & Finney, M. A. (2015). Negative consequences of positive feedbacks in US wildfire management. *Forest Ecosystems, 2*, 1-10.

Chang, H., Han, H. S., Anderson, N., Kim, Y. S., & Han, S. K. (2023). The cost of forest thinning operations in the western United States: a systematic literature review and new thinning cost model. *Journal of Forestry, 121*(2), 193-206.

Charnley, S., Poe, M. R., Ager, A. A., Spies, T. A., Platt, E. K., & Olsen, K. A. (2015). A burning problem: social dynamics of disaster risk reduction through wildfire mitigation. *Human Organization, 74*(4), 329-340.

Chiono, L. A., Fry, D. L., Collins, B. M., Chatfield, A. H., & Stephens, S. L. (2017). Landscape-scale fuel treatment and wildfire impacts on carbon stocks and fire hazard in California spotted owl habitat. *Ecosphere, 8*(1), e01648.

Churchill, D. J., Larson, A. J., Dahlgreen, M. C., Franklin, J. F., Hessburg, P. F., & Lutz, J. A. (2013). Restoring forest resilience: from reference spatial patterns to silvicultural prescriptions and monitoring. *Forest Ecology and Management, 291*, 442-457.

Cohen, J. D. (2000). Preventing disaster: home ignitability in the wildland-urban interface. *Journal of forestry, 98*(3), 15-21.

Dewitz, J., & USGS (US Geological Survey). (2021). National Land Cover Database (NLCD) 2019 Products;(Ver. 2.0, June 2021). *US Geological Survey: Reston, Virginia, USA*.

Finney, M. A. (2007). A computational method for optimising fuel treatment locations. *International Journal of Wildland Fire, 16*(6), 702-711.

Fulé, P. Z., Crouse, J. E., Roccaforte, J. P., & Kalies, E. L. (2012). Do thinning and/or burning treatments in western USA ponderosa or Jeffrey pine-dominated forests help restore natural fire behavior?. *Forest Ecology and Management, 269*, 68-81.

Gannon, B., Wei, Y., Belval, E., Young, J., Thompson, M., O'Connor, C., ... & Dunn, C. (2023). A quantitative analysis of fuel break effectiveness drivers in southern California national forests. *Fire, 6*(3), 104.

Gibbons, P., Van Bommel, L., Gill, A. M., Cary, G. J., Driscoll, D. A., Bradstock, R. A., ... & Lindenmayer, D. B. (2012). Land management practices associated with house loss in wildfires. *PloS one, 7*(1), e29212.

Gill, A. M., & Stephens, S. L. (2009). Scientific and social challenges for the management of fire-prone wildland–urban interfaces. *Environmental Research Letters, 4*(3), 034014.

Gosnell, H., Kennedy, R., Harris, T., & Abrams, J. (2020). A land systems science approach to assessing forest governance and characterizing the emergence of social forestry in the Western Cascades of Oregon. *Environmental Research Letters, 15*(5), 055003.

Hagmann, R. K., Hessburg, P. F., Prichard, S. J., Povak, N. A., Brown, P. M., Fulé, P. Z., ... & Waltz, A. E. M. (2021). Evidence for widespread changes in the structure, composition, and fire regimes of western North American forests. *Ecological applications, 31*(8), e02431.

Han, H. S., Lee, H. W., & Johnson, L. R. (2004). Economic feasibility of an integrated harvesting system for small-diameter trees in southwest Idaho. *Forest Products Journal, 54*(2).

Hartsough, B. R., Abrams, S., Barbour, R. J., Drews, E. S., McIver, J. D., Moghaddas, J. J., ... & Stephens, S. L. (2008). The economics of alternative fuel reduction treatments in western United States dry forests: Financial and policy implications from the National Fire and Fire Surrogate Study. *Forest Policy and Economics, 10*(6), 344-354.

Hessburg, P. F., Churchill, D. J., Larson, A. J., Haugo, R. D., Miller, C., Spies, T. A., ... & Reeves, G. H. (2015). Restoring fire-prone Inland Pacific landscapes: seven core principles. *Landscape Ecology, 30*, 1805-1835.

Hessburg, P. F., Prichard, S. J., Hagmann, R. K., Povak, N. A., & Lake, F. K. (2021). Wildfire and climate change adaptation of western North American forests: a case for intentional management. *Ecological applications, 31*(8), e02432.

Hoffman, C. M., Collins, B., & Battaglia, M. (2020). Wildland fuel treatments. In *Encyclopedia of wildfires and wildland-urban interface (WUI) fires* (pp. 1159-1166). Cham: Springer International Publishing.

Hjerpe, E., Abrams, J., & Becker, D. R. (2009). Socioeconomic barriers and the role of biomass utilization in southwestern ponderosa pine restoration. *Ecological Restoration, 27*(2), 169-177.

Holland, T. G., Evans, S. G., Long, J. W., Maxwell, C., Scheller, R. M., & Potts, M. D. (2022). The management costs of alternative forest management strategies in the Lake Tahoe basin. *Ecology and Society, 27*(4).

Jain, T. B., Battaglia, M. A., Han, H. S., Graham, R. T., Keyes, C. R., Fried, J. S., & Sandquist, J. E. (2012). *A comprehensive guide to fuel management practices for dry mixed conifer forests in the northwestern United States*. Gen. Tech. Rep. RMRS-GTR-292. Fort Collins: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 331 p.

Jain, T. B., Sikkink, P., Keefe, R., & Byrne, J. (2018). *To masticate or not: useful tips for treating forest, woodland, and shrubland vegetation*. Gen. Tech. Rep. RMRS-GTR381. USDA Forest Service, Rocky Mountain Research Station, Fort Collins, Colorado, USA. 55 p.

Jones, G. M., Keyser, A. R., Westerling, A. L., Baldwin, W. J., Keane, J. J., Sawyer, S. C., ... & Peery, M. Z. (2022). Forest restoration limits megafires and supports species conservation under climate change. *Frontiers in Ecology and the Environment, 20*(4), 210-216.

Kalies, E. L., & Kent, L. L. Y. (2016). Tamm Review: Are fuel treatments effective at achieving ecological and social objectives? A systematic review. *Forest Ecology and Management, 375*, 84-95.

Keeley, J. E., & Syphard, A. D. (2019). Twenty-first century California, USA, wildfires: fuel-dominated vs. wind-dominated fires. *Fire Ecology, 15*(1), 1-15.

Kolden, C. A. (2019). We're not doing enough prescribed fire in the Western United States to mitigate wildfire risk. *Fire, 2*(2), 30.

Kooistra, C., Schultz, C., Abrams, J., & Huber-Stearns, H. (2022). Institutionalizing the United States Forest Service's shared stewardship strategy in the western United States. *Journal of Forestry, 120*(5), 588-603.

Krawchuk, M. A., Moritz, M. A., Parisien, M. A., Van Dorn, J., & Hayhoe, K. (2009). Global pyrogeography: the current and future distribution of wildfire. *PloS one, 4*(4), e5102.

Lake, F. K., Wright, V., Morgan, P., McFadzen, M., McWethy, D., & Stevens-Rumann, C. (2017). Returning fire to the land: celebrating traditional knowledge and fire. *Journal of Forestry, 115*(5), 343-353.

Larson, A. J., & Churchill, D. (2012). Tree spatial patterns in fire-frequent forests of western North America, including mechanisms of pattern formation and implications for designing fuel reduction and restoration treatments. *Forest Ecology and Management, 267*, 74-92.

Liang, S., Hurteau, M. D., & Westerling, A. L. (2018). Large-scale restoration increases carbon stability under projected climate and wildfire regimes. *Frontiers in Ecology and the Environment, 16*(4), 207-212.

Lindenmayer, D. B., Margules, C. R., & Botkin, D. B. (2000). Indicators of biodiversity for ecologically sustainable forest management. *Conservation biology, 14*(4), 941-950.

Long, J., Lake, F.K., Lynn, K., & Viles, C. (2018). *Tribal ecocultural resources and engagement*. In: Spies, T.A., Stine, P.A., Gravenmier, R., et al. (Tech Coord). Synthesis of science to inform land management within the Northwest Forest Plan area. Gen. Tech. Rep. PNWGTR-966. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Lydersen, J. M., Collins, B. M., & Hunsaker, C. T. (2019). Implementation constraints limit benefits of restoration treatments in mixed-conifer forests. *International Journal of Wildland Fire, 28*(7), 495-511.

Massada, A. B., Radeloff, V. C., & Stewart, S. I. (2011). Allocating fuel breaks to optimally protect structures in the wildland–urban interface. *International Journal of Wildland Fire, 20*(1), 59-68.

McWethy, D. B., Schoennagel, T., Higuera, P. E., Krawchuk, M., Harvey, B. J., Metcalf, E. C., ... & Kolden, C. (2019). Rethinking resilience to wildfire. *Nature Sustainability, 2*(9), 797-804.

Miller, R. K., Field, C. B., & Mach, K. J. (2020). Barriers and enablers for prescribed burns for wildfire management in California. *Nature Sustainability, 3*(2), 101-109.

Monsen, S.B., Stevens, R., Shaw, N.L. (2004). *Restoring Western Ranges and Wildlands, vol. 2*. Gen. Tech. Rep. RMRS-GTR-136-vol-2. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. Pages 295-698 plus index.

Moritz, M. A., Batllori, E., Bradstock, R. A., Gill, A. M., Handmer, J., Hessburg, P. F., ... & Syphard, A. D. (2014). Learning to coexist with wildfire. *Nature, 515*(7525), 58-66.

Moritz, M. A., Parisien, M. A., Batllori, E., Krawchuk, M. A., Van Dorn, J., Ganz, D. J., & Hayhoe, K. (2012). Climate change and disruptions to global fire activity. *Ecosphere, 3*(6), 1-22.

Nicholls, D. L., Halbrook, J. M., Benedum, M. E., Han, H. S., Lowell, E. C., Becker, D. R., & Barbour, R. J. (2018). Socioeconomic constraints to biomass removal from forest lands for fire risk reduction in the western US. *Forests, 9*(5), 264.

North, M., Brough, A., Long, J., Collins, B., Bowden, P., Yasuda, D., ... & Sugihara, N. (2015). Constraints on mechanized treatment significantly limit mechanical fuels reduction extent in the Sierra Nevada. *Journal of Forestry, 113*(1), 40-48.

North, M., Collins, B. M., & Stephens, S. (2012). Using fire to increase the scale, benefits, and future maintenance of fuels treatments. *Journal of Forestry, 110*(7), 392-401.

North, M. P., York, R. A., Collins, B. M., Hurteau, M. D., Jones, G. M., Knapp, E. E., ... & Tubbesing, C. L. (2021). Pyrosilviculture needed for landscape resilience of dry western United States forests. *Journal of Forestry, 119*(5), 520-544.

Parks, S. A., & Abatzoglou, J. T. (2020). Warmer and drier fire seasons contribute to increases in area burned at high severity in western US forests from 1985 to 2017. *Geophysical Research Letters, 47*(22), e2020GL089858.

Petitmermet, J., Sessions, J., Bailey, J., & Zamora-Cristales, R. (2019). Cost and productivity of tethered cut-to-length systems in a dry-forest fuel-reduction treatment: A case study. *Forest Science, 65*(5), 581-592.

Pressey, R. L., Cabeza, M., Watts, M. E., Cowling, R. M., & Wilson, K. A. (2007). Conservation planning in a changing world. *Trends in ecology & evolution, 22*(11), 583-592.

Prestemon, J. P., Abt, K. L., & Barbour, R. J. (2012). Quantifying the net economic benefits of mechanical wildfire hazard treatments on timberlands of the western United States. *Forest Policy and Economics, 21*, 44-53.

Prichard, S. J., Hessburg, P. F., Hagmann, R. K., Povak, N. A., Dobrowski, S. Z., Hurteau, M. D., ... & Khatri-Chhetri, P. (2021). Adapting western North American forests to climate change and wildfires: 10 common questions. *Ecological Applications, 31*(8), e02433.

Prichard, S. J., & Kennedy, M. C. (2014). Fuel treatments and landform modify landscape patterns of burn severity in an extreme fire event. *Ecological Applications, 24*(3), 571-590.

Prichard, S. J., Povak, N. A., Kennedy, M. C., & Peterson, D. W. (2020). Fuel treatment effectiveness in the context of landform, vegetation, and large, wind-driven wildfires. *Ecological Applications, 30*(5), e02104.

Robitaille, A., Saucier, J. P., Chabot, M., Côté, D., & Boudreault, C. (2015). An approach for assessing suitability for forest management based on constraints of the physical environment at a regional scale. *Canadian Journal of Forest Research, 45*(5), 529-539.

Ryan, K. C., Knapp, E. E., & Varner, J. M. (2013). Prescribed fire in North American forests and woodlands: history, current practice, and challenges. *Frontiers in Ecology and the Environment, 11*(s1), e15-e24.

Sessions, J., Leshchinsky, B., Chung, W., Boston, K., & Wimer, J. (2016). Theoretical stability and traction of steep slope tethered feller-bunchers. *Forest Science, 63*(2), 192-200.

Schmidt, D. A., Taylor, A. H., & Skinner, C. N. (2008). The influence of fuels treatment and landscape arrangement on simulated fire behavior, Southern Cascade range, California. *Forest Ecology and Management, 255*(8-9), 3170-3184.

Schoennagel, T., Nelson, C. R., Theobald, D. M., Carnwath, G. C., & Chapman, T. B. (2009). Implementation of National Fire Plan treatments near the wildland–urban interface in the western United States. *Proceedings of the National Academy of Sciences, 106*(26), 10706-10711.

Short, K. C., Finney, M. A., Vogler, K. C., Scott, J. H., Gilbertson-Day, J. W., & Grenfell, I. C. (2020). *Spatial datasets of probabilistic wildfire risk components for the United States (270m)*. Forest Service Research Data Archive.

Singleton, M. P., Thode, A. E., Meador, A. J. S., & Iniguez, J. M. (2019). Increasing trends in high-severity fire in the southwestern USA from 1984 to 2015. *Forest ecology and management, 433*, 709-719.

Spies, T. A., Hessburg, P. F., Skinner, C. N., Puettmann, K. J., Reilly, M. J., Davis, R. J., ... & Shaw, D. C. (2018). Old growth, disturbance, forest succession, and management in the area of the Northwest Forest Plan. *Synthesis of science to inform land management within the Northwest Forest Plan area, 1*.

Spies, T. A., Long, J. W., Charnley, S., Hessburg, P. F., Marcot, B. G., Reeves, G. H., ... & Raphael, M. G. (2019). Twenty-five years of the Northwest Forest Plan: what have we learned?. *Frontiers in Ecology and the Environment, 17*(9), 511-520.

Stephens, S. L., Adams, M. A., Handmer, J., Kearns, F. R., Leicester, B., Leonard, J., & Moritz, M. A. (2009). Urban–wildland fires: how California and other regions of the US can learn from Australia. *Environmental Research Letters, 4*(1), 014010.

Stephens, S. L., Battaglia, M. A., Churchill, D. J., Collins, B. M., Coppoletta, M., Hoffman, C. M., ... & Stevens, J. T. (2021). Forest restoration and fuels reduction: Convergent or divergent?. *Bioscience, 71*(1), 85-101.

Stephens, S. L., Collins, B. M., Biber, E., & Fulé, P. Z. (2016). US federal fire and forest policy: emphasizing resilience in dry forests. *Ecosphere, 7*(11), e01584.

Stephens, S. L., & Ruth, L. W. (2005). Federal forest-fire policy in the United States. *Ecological applications, 15*(2), 532-542.

Stephenson, N. L. (2014, January). Making the transition to the third era of natural resources management. In: *The George Wright Forum* (Vol. 31, No. 3, pp. 227-235). George Wright Society.

Syphard, A. D., Brennan, T. J., & Keeley, J. E. (2014). The role of defensible space for residential structure protection during wildfires. *International Journal of Wildland Fire, 23*(8), 1165-1175.

Syphard, A. D., Brennan, T. J., & Keeley, J. E. (2017). The importance of building construction materials relative to other factors affecting structure survival during wildfire. *International journal of disaster risk reduction, 21*, 140-147.

Syphard, A. D., Brennan, T. J., & Keeley, J. E. (2018). Chaparral landscape conversion in southern California. *Valuing chaparral: Ecological, socio-economic, and management perspectives*, 323-346.

Urza, A. K., Hanberry, B. B., & Jain, T. B. (2023). Landscape-scale fuel treatment effectiveness: lessons learned from wildland fire case studies in forests of the western United States and Great Lakes region. *Fire Ecology, 19*(1), 1-12.

[USCB] United States Census Bureau. (2016). *2016 TIGER/Line Shapefiles*. U.S. Census Bureau, 2016. https://www2.census.gov/geo/pdfs/maps-data/data/tiger/tgrshp2016/TGRSHP2016_TechDoc.pdf.

[USFS] United States Department of Agriculture, Forest Service. (2018). *Toward shared stewardship across landscapes: An outcome-based investment strategy*. FS-1118, August 2018. Available at: https://www.fs.usda.gov/sites/default/files/toward-shared-stewardship.pdf [Accessed May 11, 2023]

[USFS] United States Department of Agriculture, Forest Service. (2022a). *Confronting the Wildfire Crisis: A Strategy for Protecting Communities and Improving Resilience in America's Forests*. FS-1187a, January 2022. Available at: https://www.fs.usda.gov/sites/default/files/Confronting-Wildfire-Crisis.pdf [Accessed February 27, 2023]

[USFS] United States Department of Agriculture, Forest Service. (2023a). *Confronting the Wildfire Crisis: Expanding Efforts To Deliver on the Wildfire Crisis Strategy*. S-1187f, January 2023. Available at: https://www.fs.usda.gov/sites/default/files/fs_media/fs_document/WCS-Second-Landscapes.pdf [Accessed February 27, 2023]

[USFS] United States Department of Agriculture, Forest Service. (2022b). *Confronting the Wildfire Crisis: Initial Landscape Investments to Protect Communities and Improve Resilience in America's Forests*. FS-1187d, April 2022. Available at: https://www.fs.usda.gov/sites/default/files/fs_media/fs_document/WCS-Initial-Landscapes.pdf [Accessed February 27, 2023]

[USFS] United States Department of Agriculture, Forest Service. (2023b). Forest Service Activity Tracking System (FACTS): Motor Vehicle Use Map: Roads; Motor Vehicle Use Map: Trails; National Forest System Roads; National Forest System Trails. Geospatial Technology and Applications Center, Salt Lake City, Utah, USA. Available at: http://data.fs.usda.gov/geodata/edw/datasets.php [Accessed May 14, 2023].

[USFWS] United States Fish and Wildlife Service. (2023). USFWS Threatened & Endangered Species Active Critical Habitat Report. Available at:

https://ecos.fws.gov/ecp/report/table/critical-habitat.html [Accessed February 5, 2023].

[USGS] United States Geological Survey. (2017). Watershed Boundary Dataset. Available at: https://www.usgs.gov/national-hydrography/watershed-boundary-dataset [Accessed April 23, 2017].

[USGS] United States Geological Survey. (2020). 3D Elevation Program 10-Meter Resolution Digital Elevation Model (published 2020-05-06).

[USGS] United States Geological Survey. (2022). National Hydrography Dataset (ver. USGS National Hydrography Dataset Best Resolution (NHD)). Available at: https://www.usgs.gov/national-hydrography/access-national-hydrography-products [Accessed April 29, 2022].

[USGS] United States Geological Survey Gap Analysis Project (GAP). (2018). Protected Areas Database of the United States (PAD-US): U.S. Geological Survey data release, doi:10.5066/P955KPLE.

Van Deusen, P., Wigley Jr, T. B., & Lucier, A. A. (2012). Cumulative effects of constraints on forest management. *Journal of Forestry, 110*(3), 123-128.

Visser, R., & Stampfer, K. (2015). Expanding ground-based harvesting onto steep terrain: A review. *Croatian Journal of Forest Engineering: Journal for Theory and Application of Forestry Engineering, 36*(2), 321-331.

Vorster, A. G., Stevens-Rumann, C., Young, N., Woodward, B., Choi, C. T. H., Chambers, M. E., ... & West, A. (2023). Metrics and Considerations for Evaluating How Forest Treatments Alter Wildfire Behavior and Effects. *Journal of Forestry*, fvad036.

Watson, J. E., Dudley, N., Segan, D. B., & Hockings, M. (2014). The performance and potential of protected areas. *Nature, 515*(7525), 67-73.

West, T., Sessions, J., & Strimbu, B. M. (2022). Steep Slope Harvest System Models for Small to Large Trees. *Forests, 13*(2), 305.

APPENDIX A: EXTENT OF MECHANICALLY AVAILABLE AREA BY SCENARIO AND REDUCTIONS BY CONSTRAINING FACTOR

On the combined forest and shrubland area, protected area and inventoried roadless area status reduced mechanically available area by 22% overall (Table 1.2). There was considerable variation in the protected area constraints across the 21 landscapes. The Plumas Community Protection (California) landscape contained no protected or inventoried roadless area and four other priority landscapes had less than 10% of area classified as protected and inventoried roadless (Table A.1). By contrast, the Southern California Fireshed Risk Reduction Strategy landscape had mechanical operability reduced by 57% due to protected area constraints while an additional three priority landscapes had over 35% of area classified as protected and inventoried roadless (Table A.1).

A.1 Status-quo Approach (Scenario 1)

Under the operational constraints represented by scenario 1, 29% of the combined forest and shrub area across all 21 priority landscapes is available to mechanical treatment (Table 1.2). Mechanically available forest and shrubland acreage ranged from a low of 10% in the Southern California Fireshed Risk Reduction Strategy landscape to a high of 59% in the Central Oregon landscape (Table A.1; Figure A.2). Four landscapes have less than 20% of combined forest and shrubland acreage available while two landscapes have greater than 40% of area available for mechanical fuel treatment (Table A.1; Figure A.2). After removing protected areas, slopes >40% reduced mechanical availability by 17% across all landscapes (Table 1.2) and by 30%

or more on three landscapes including a 38% reduction on the Trinity Forest Health and Fire-Resilient Rural Communities (California) landscape and a 33% reduction on the North Yuba (California) landscape (Table A.1; Figure A.2). Removal of remote forest and shrubland acreage >1,000 feet (305 m) from existing roads reduced mechanically available acreage by 20% across all landscapes (Table 1.2) and by over 30% on two landscapes including a 50% reduction on the San Carlos Apache Tribal Forest Protection (Arizona) landscape and a 33% reduction on the Enchanted Circle (New Mexico) landscape (Table A.1; Figure A.2). Administrative designations reduced mechanically available land by 25% or more on the 4FRI (Arizona), Stanislaus (California), and Mount Hood Forest Health and Fire-Resilient Communities (Oregon) but by less than 10% on nine landscapes (Table A.1; Figure A.2).

A.2 Increased Slope and Road Access (Scenario 2)

Changing operational constraints from the status-quo approach represented by scenario 1 to scenario 2 which allows mechanical operations on steeper slopes up to 60% and expands the use of temporary roads increased mechanical acreage by 13% across all 21 landscapes bringing total treatable combined forest and shrub area to 42% (Table 1.2). The extent of mechanically available forest and shrubland acreage under scenario 2 constraints ranged from a low of 20% in the Southern California Fireshed Risk Reduction Strategy landscape to a high of 70% in the Central Oregon and Southwest Idaho landscapes (Table A.1; Figure A.2). Increasing slope and road access to combined forest and shrubland increased mechanically available acreage by 24% in the Southwest Idaho landscape (70% available overall) and by 18% in both the Enchanted Circle (New Mexico; 45% available overall) and Colville Northeast

Washington Vision (52% available overall) landscapes (Table A.1; Figure A.2). Comparatively, there was just a 10% increase in four landscapes including Southern California Fireshed Risk Reduction Strategy (20% available overall), Central Washington Initiative (23% available overall), Trinity Forest Health and Fire-Resilient Rural Communities (California; 23% available overall), and Central Oregon (70% available overall). Some of the gains to mechanically treatable acreage made by working on steeper slopes and increasing the use of temporary roads were offset by corresponding increases in the proportion of land constrained by administrative factors. That is, mechanical operations on slopes 40-60% and/or within 1,000-2000 feet (305-610 m) from existing roads were still constrained by other, administrative designations (e.g., sensitive species habitat, riparian buffers).

A.3 Increasing Slope, Road, and Administrative Access (Scenario 3)

Under the most aggressive approach we considered for expanding fuel reduction treatments, scenario 3, an additional 25% across all 21 priority landscapes would become available for mechanical treatment compared to the status-quo approach represented by scenario 1, bringing total treatable combined forest and shrub area to 53% (Table 1.2). Expanding mechanical treatment near riparian areas and within administratively designated areas increased mechanical access to combined forest and shrubland by 11% across all 21 priority landscapes after allowing mechanical operations on steeper slopes and expanding the use of temporary roads using scenario 2 (Table 1.2). The extent of mechanically available forest and shrubland acreage under scenario 3 constraints ranged from a low of 24% in the Southern California Fireshed Risk Reduction Strategy landscape to a high of 83% in the Central Oregon landscape (Table

A.1; Figure A.2). After increasing slope and road access to combined forest and shrubland (scenario 2), expanding access to administratively designated areas increased mechanically available acreage by 26% in the Central Washington Initiative (49% available overall) landscape, 24% in the 4FRI (Arizona; 62% available overall) landscape, 24% in the Mount Hood Forest Health and Fire-Resilient Communities (Oregon; 59% available overall) landscape, and 23% in the Trinity Forest Health and Fire-Resilient Rural Communities (California; 46% available overall) landscape. By contrast, less than 10% of additional acreage would become available for mechanical treatment by expanding access to administratively designated areas in 11 landscapes after relaxing slope and road access constraints (Table A.1; Figure A.2).

Table A.1. Combined forest and shrubland area of each of the 21 priority landscapes and the percent reduction of different types of constraints on mechanical treatment based on the three scenarios of operational constraints considered in this analysis.

			Constraint Least Flexible to Most Flexible						
	Forest & Shrub (ha)	Forest & Shrub %	Protected & IRA	Slope Steepness	Road Distance	Riparian Buffer	Administrative Boundary	Mechanically Available (ha)	Mechanically Available (%)
AZ: 4FRI									
Scenario 1	2,128k	90.4%	-12.4%	-7.5%	-26.7%	-10.2%	-15.5%	589k	27.7%
Scenario 2	2,128k	90.4%	-12.4%	-2.1%	-13.3%	-14.0%	-19.9%	813k	38.2%
Scenario 3	2,128k	90.4%	-12.4%	-2.1%	-13.3%	-9.9%	0.0%	1,325k	62.3%
AZ: Prescott									
Scenario 1	275k	87.2%	-12.9%	-16.1%	-25.1%	-11.9%	-4.2%	82k	29.8%
Scenario 2	275k	87.2%	-12.9%	-3.3%	-13.2%	-18.6%	-6.8%	124k	45.2%
Scenario 3	275k	87.2%	-12.9%	-3.3%	-13.2%	-13.2%	0.0%	158k	57.4%
AZ: San Carlos Apache Tribal Forest Protection									
Scenario 1	1,119k	91.7%	-9.3%	-19.7%	-49.8%	-5.8%	-1.1%	161k	14.4%
Scenario 2	1,119k	91.7%	-9.3%	-5.0%	-46.6%	-10.1%	-2.2%	300k	26.8%
Scenario 3	1,119k	91.7%	-9.3%	-5.0%	-46.6%	-7.3%	0.0%	357k	31.9%
CA: North Yuba									
Scenario 1	139k	96.5%	-11.6%	-33.4%	-7.8%	-14.7%	-2.3%	42k	30.2%
Scenario 2	139k	96.5%	-11.6%	-13.9%	-3.2%	-23.0%	-3.3%	63k	45.0%
Scenario 3	139k	96.5%	-11.6%	-13.9%	-3.2%	-16.7%	0.0%	76k	54.6%
CA: Plumas Community Protection									
Scenario 1	101k	93.3%	0.0%	-23.2%	-19.8%	-21.5%	-1.9%	34k	33.6%
Scenario 2	101k	93.3%	0.0%	-5.2%	-8.1%	-33.9%	-2.9%	50k	49.9%
Scenario 3	101k	93.3%	0.0%	-5.2%	-8.1%	-24.4%	0.0%	63k	62.3%
CA: Southern California Fireshed Risk Reduction Strategy									
Scenario 1	1,408k	86.0%	-57.0%	-21.0%	-8.3%	-2.3%	-1.4%	139k	9.9%
Scenario 2	1,408k	86.0%	-57.0%	-9.6%	-6.5%	-4.2%	-3.0%	278k	19.7%
Scenario 3	1,408k	86.0%	-57.0%	-9.6%	-6.5%	-3.0%	0.0%	336k	23.9%
CA: Stanislaus									
Scenario 1	116k	94.3%	-2.9%	-26.7%	-10.6%	-24.7%	-0.6%	40k	34.5%
Scenario 2	116k	94.3%	-2.9%	-10.7%	-3.9%	-35.8%	-0.8%	53k	46.0%
Scenario 3	116k	94.3%	-2.9%	-10.7%	-3.9%	-26.1%	0.0%	66k	56.5%
CA: Trinity Forest Health and Fire-Resilient Rural Communities									
Scenario 1	554k	83.5%	-21.4%	-37.8%	-10.4%	-8.7%	-9.2%	69k	12.4%
Scenario 2	554k	83.5%	-21.4%	-12.4%	-7.8%	-17.3%	-18.5%	126k	22.7%
Scenario 3	554k	83.5%	-21.4%	-12.4%	-7.8%	-12.5%	0.0%	254k	45.9%

Table A.1 (continued).

			Constraint						
			Least Flexible to Most Flexible						
	Forest & Shrub (ha)	Forest & Shrub %	Protected & IRA	Slope Steepness	Road Distance	Riparian Buffer	Administrative Boundary	Mechanically Available (ha)	Mechanically Available (%)
CO: Colorado Front Range									
Scenario 1	1,052k	72.6%	-20.4%	-19.9%	-20.0%	-11.3%	-1.6%	281k	26.7%
Scenario 2	1,052k	72.6%	-20.4%	-5.6%	-12.0%	-17.3%	-3.2%	436k	41.4%
Scenario 3	1,052k	72.6%	-20.4%	-5.6%	-12.0%	-12.3%	0.0%	522k	49.6%
ID: Nez Perce-Clearwater-Lower Salmon									
Scenario 1	700k	89.0%	-43.0%	-19.7%	-9.1%	-1.4%	-0.3%	185k	26.5%
Scenario 2	700k	89.0%	-43.0%	-6.7%	-5.5%	-2.3%	-0.7%	293k	41.8%
Scenario 3	700k	89.0%	-43.0%	-6.7%	-5.5%	-1.6%	0.0%	302k	43.2%
ID: Southwest Idaho									
Scenario 1	611k	87.6%	-13.3%	-28.2%	-10.4%	-2.0%	-0.3%	279k	45.8%
Scenario 2	611k	87.6%	-13.3%	-7.0%	-6.6%	-2.8%	-0.8%	425k	69.5%
Scenario 3	611k	87.6%	-13.3%	-7.0%	-6.6%	-2.0%	0.0%	435k	71.2%
MT: Kootenai Complex									
Scenario 1	372k	91.4%	-21.4%	-15.0%	-7.8%	-6.9%	-10.6%	142k	38.3%
Scenario 2	372k	91.4%	-21.4%	-3.6%	-2.1%	-8.6%	-13.8%	188k	50.6%
Scenario 3	372k	91.4%	-21.4%	-3.6%	-2.1%	-6.1%	0.0%	249k	66.9%
NM: Enchanted Circle									
Scenario 1	506k	85.6%	-8.5%	-21.5%	-33.4%	-7.5%	-2.2%	136k	26.8%
Scenario 2	506k	85.6%	-8.5%	-5.2%	-25.7%	-11.7%	-3.7%	229k	45.2%
Scenario 3	506k	85.6%	-8.5%	-5.2%	-25.7%	-8.2%	0.0%	265k	52.3%
NV: Sierra and Elko Fronts									
Scenario 1	1,001k	73.1%	-26.6%	-9.8%	-26.8%	-6.2%	-0.9%	297k	29.6%
Scenario 2	1,001k	73.1%	-26.6%	-2.0%	-15.7%	-8.9%	-1.5%	453k	45.3%
Scenario 3	1,001k	73.1%	-26.6%	-2.0%	-15.7%	-6.3%	0.0%	495k	49.4%
OR: Central Oregon									
Scenario 1	959k	87.1%	-7.0%	-2.8%	-15.3%	-5.4%	-10.0%	571k	59.5%
Scenario 2	959k	87.1%	-7.0%	-0.6%	-5.0%	-6.4%	-11.3%	669k	69.7%
Scenario 3	959k	87.1%	-7.0%	-0.6%	-5.0%	-4.5%	0.0%	796k	83.0%
OR: Klamath River Basin									
Scenario 1	2,675k	77.0%	-19.3%	-14.9%	-17.7%	-5.4%	-4.4%	1,023k	38.3%
Scenario 2	2,675k	77.0%	-19.3%	-4.9%	-7.9%	-8.3%	-7.8%	1,386k	51.8%
Scenario 3	2,675k	77.0%	-19.3%	-4.9%	-7.9%	-5.9%	0.0%	1,659k	62.0%
OR: Mount Hood Forest Health and Fire-Resilient Communities									
Scenario 1	326k	76.3%	-20.1%	-14.3%	-17.1%	-9.0%	-15.7%	78k	23.8%
Scenario 2	326k	76.3%	-20.1%	-4.1%	-7.5%	-13.2%	-20.1%	114k	35.0%
Scenario 3	326k	76.3%	-20.1%	-4.1%	-7.5%	-9.5%	0.0%	191k	58.8%

Table A.1 (continued).

	Forest & Shrub (ha)	Forest & Shrub %	Constraint Least Flexible to Most Flexible Protected & IRA	Slope Steepness	Road Distance	Riparian Buffer	Administrative Boundary	Mechanically Available (ha)	Mechanically Available (%)
UT: Pine Valley									
Scenario 1	153k	94.2%	-37.2%	-6.9%	-21.5%	-6.7%	0.0%	43k	27.8%
Scenario 2	153k	94.2%	-37.2%	-1.4%	-10.5%	-9.2%	0.0%	64k	41.7%
Scenario 3	153k	94.2%	-37.2%	-1.4%	-10.5%	-6.5%	0.0%	68k	44.4%
UT: Wasatch									
Scenario 1	381k	89.5%	-43.0%	-12.1%	-14.8%	-4.9%	-0.3%	95k	25.0%
Scenario 2	381k	89.5%	-43.0%	-3.7%	-7.9%	-6.7%	-0.5%	146k	38.3%
Scenario 3	381k	89.5%	-43.0%	-3.7%	-7.9%	-4.8%	0.0%	155k	40.7%
WA: Central Washington Initiative									
Scenario 1	893k	69.8%	-25.0%	-29.5%	-11.5%	-8.1%	-12.7%	117k	13.1%
Scenario 2	893k	69.8%	-25.0%	-9.5%	-7.0%	-13.4%	-22.2%	204k	22.9%
Scenario 3	893k	69.8%	-25.0%	-9.5%	-7.0%	-9.7%	0.0%	436k	48.8%
WA: Colville Northeast Washington Vision									
Scenario 1	656k	92.8%	-20.1%	-18.5%	-16.0%	-10.1%	-1.2%	223k	34.1%
Scenario 2	656k	92.8%	-20.1%	-3.8%	-7.5%	-14.4%	-2.0%	342k	52.2%
Scenario 3	656k	92.8%	-20.1%	-3.8%	-7.5%	-10.4%	0.0%	382k	58.3%

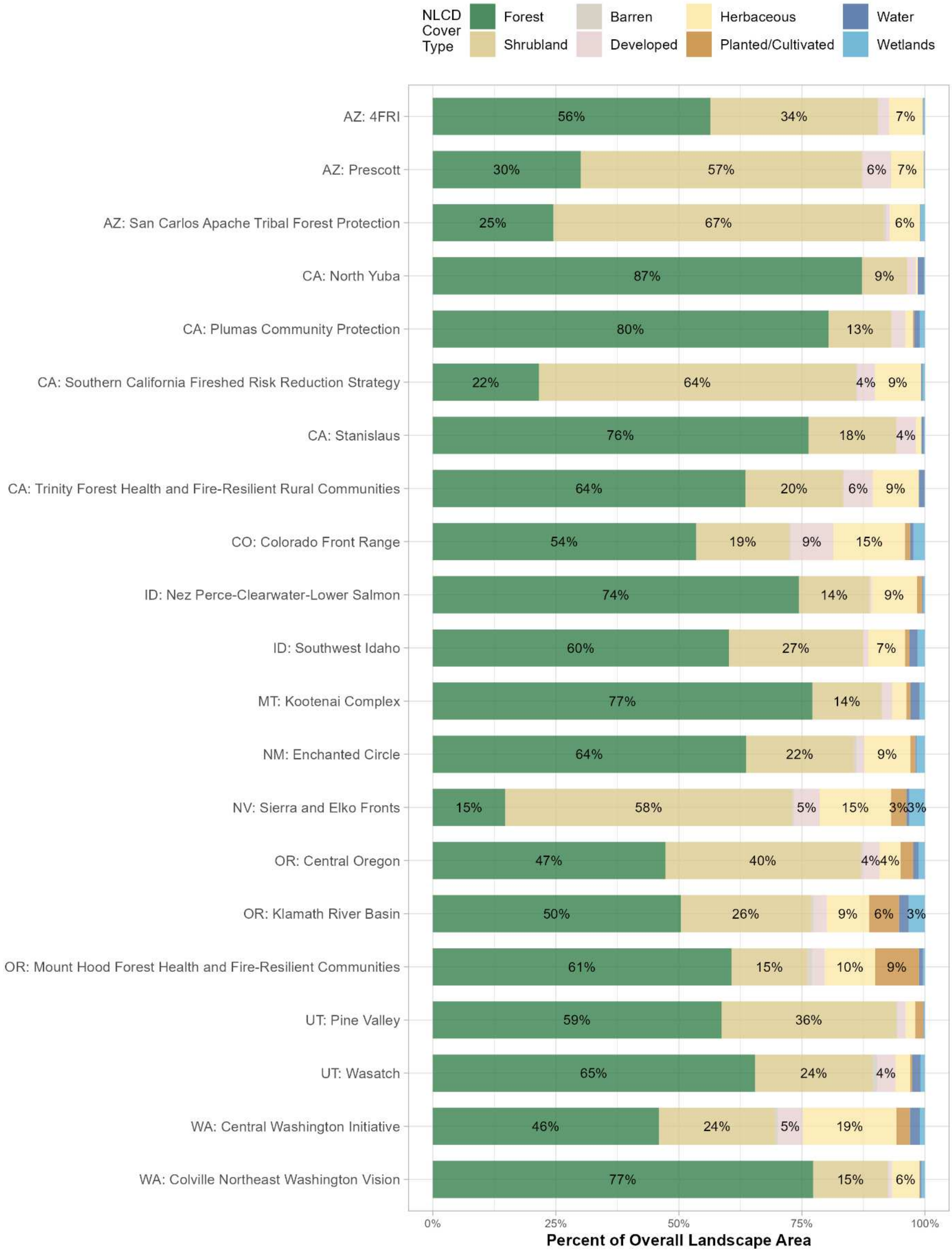

Figure A.1. National Land Cover Database (NLCD) classification within the boundaries of the 21 priority landscapes.

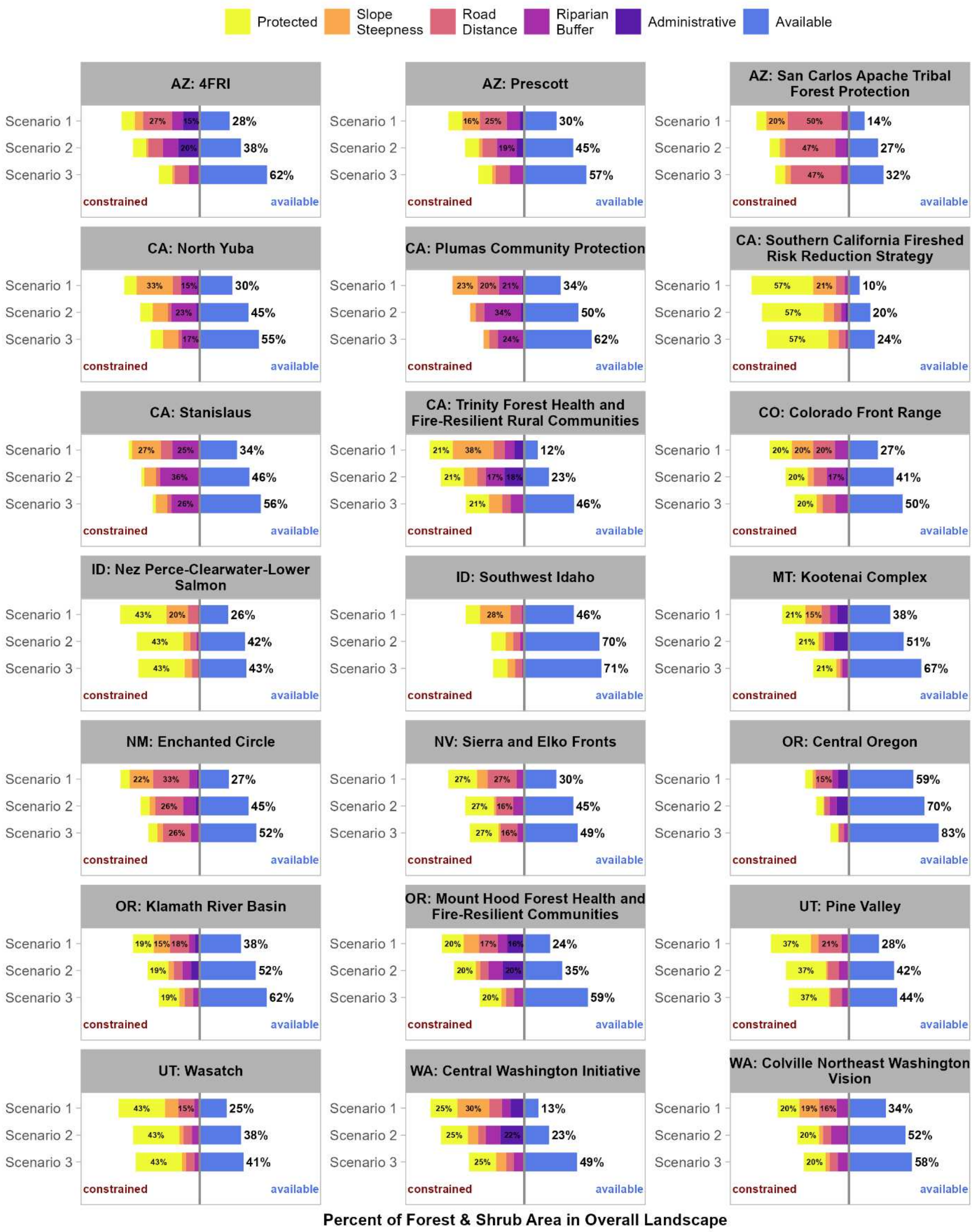

Figure A.2. Percent of combined forest and shrubland area in the overall landscape that is available to mechanical fuel reduction treatment and the percent reduction of different types of constraints.

APPENDIX B: SPATIAL ARRANGEMENT OF MECHANICALLY AVAILABLE ACREAGE - TABLES AND FIGURES

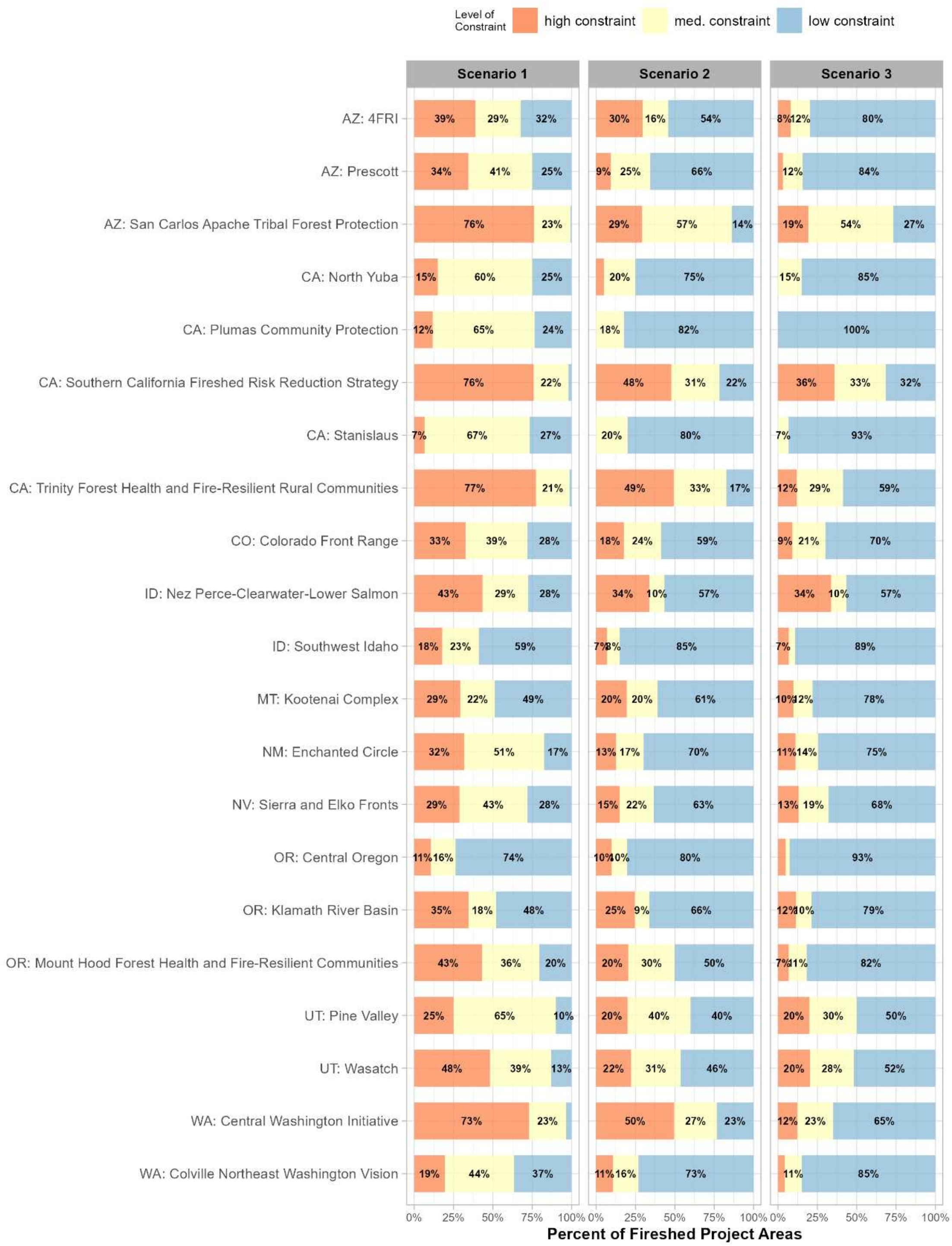

Figure B.1. Classification of fireshed project areas within each priority landscape by level of mechanical constraint: high (81–100% constrained; 0–19% available for mechanical treatment), medium (60–80% constrained; 20–40% available), and low (0–59% constrained; 41–100% available).

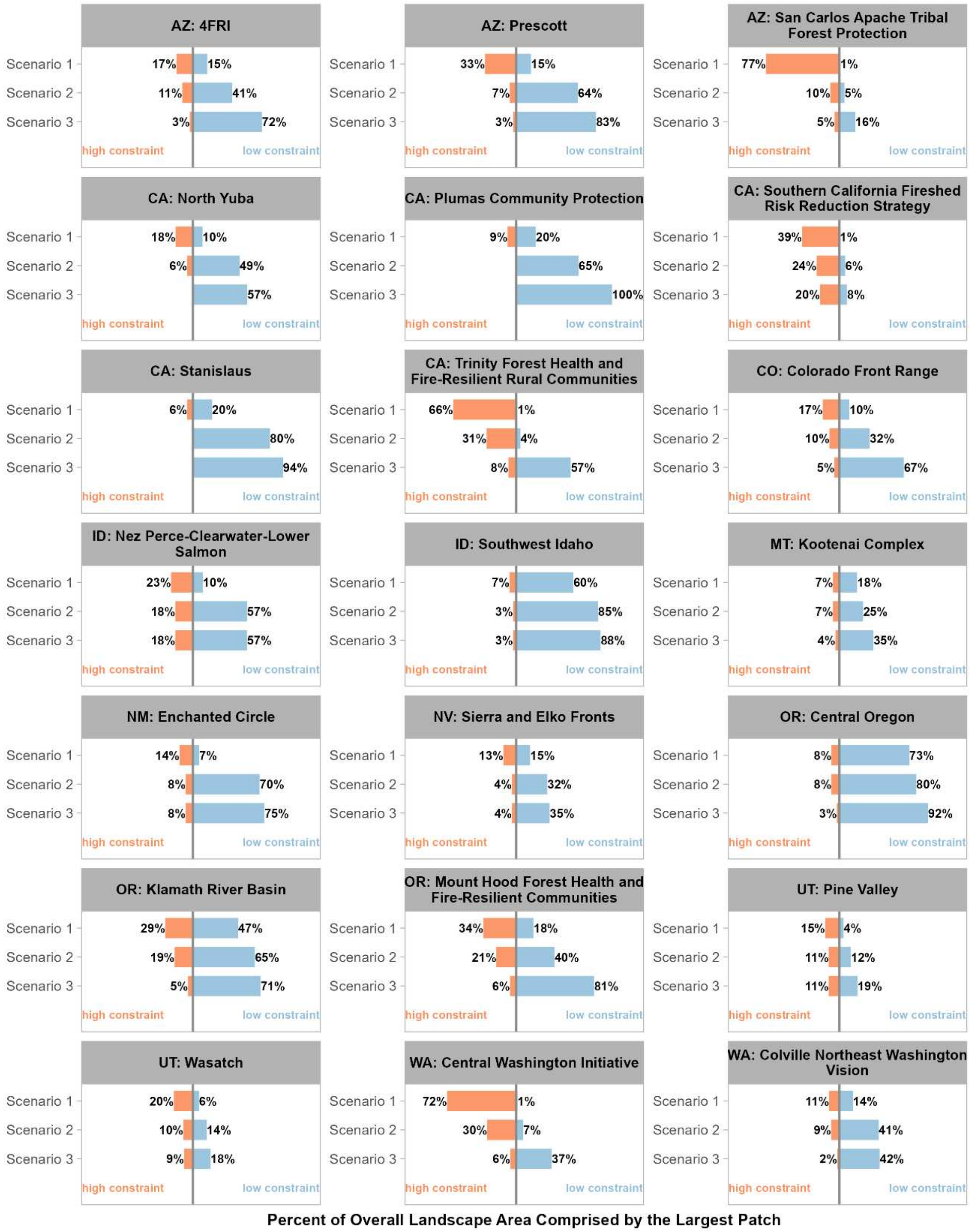

Figure B.2. Percent of the total area of the overall landscape comprised by the largest patch of interconnected fireshed project areas of similar levels of mechanical constraint. Comparison is made between the largest patch of project areas classified as high constraint (100–81% constrained; 0–19% available for mechanical treatment) and the largest patch of project areas classified as low constraint (0–59% constrained; 41–100% available).

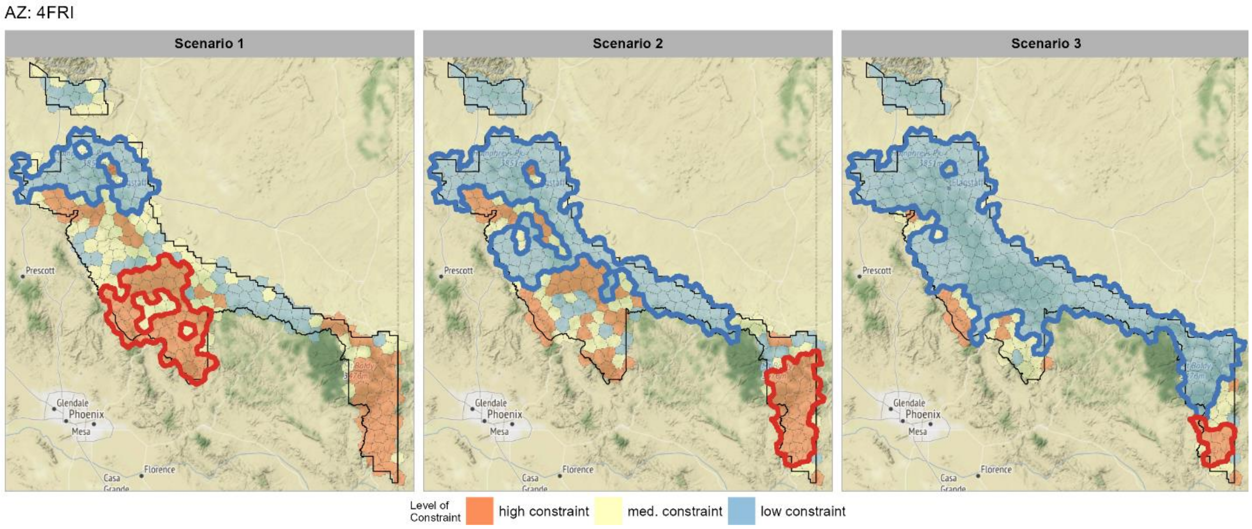

Figure B.3. 4FRI (Arizona) priority landscape divided into fireshed project areas. Shadings indicate percentages of the total combined forest and shrubland acres that are available for mechanical treatment: high (81–100% constrained; 0–19% available for mechanical treatment), medium (60–80% constrained; 20–40% available), and low (0–59% constrained; 41–100% available). The largest patch of interconnected fireshed project areas classified as highly and lightly constrained are outlined.

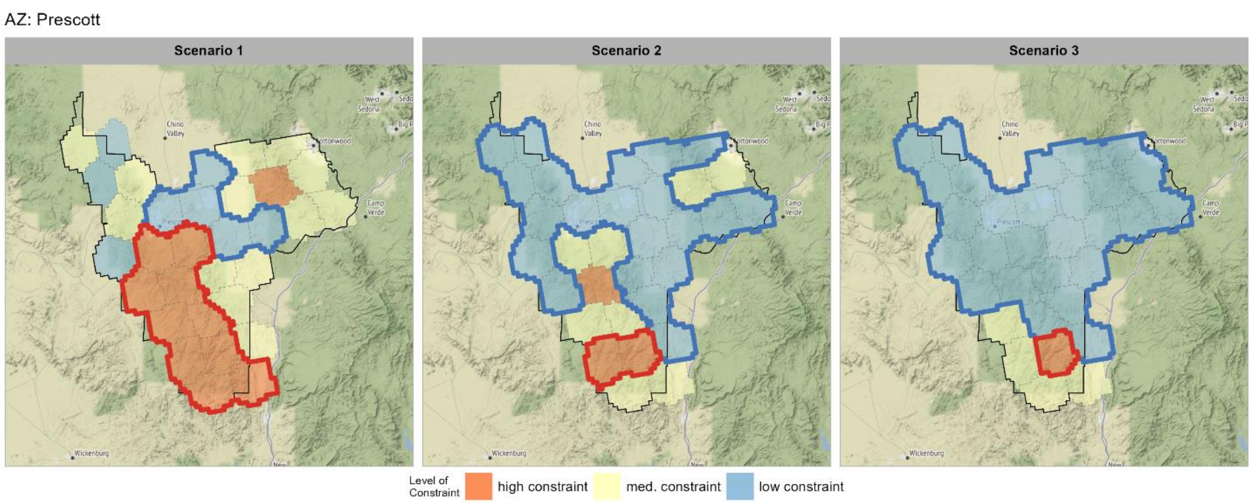

Figure B.4. Prescott (Arizona) priority landscape divided into fireshed project areas. Shadings indicate percentages of the total combined forest and shrubland acres that are available for mechanical treatment: high (81–100% constrained; 0–19% available for mechanical treatment), medium (60–80% constrained; 20–40% available), and low (0–59% constrained; 41–100% available). The largest patch of interconnected fireshed project areas classified as highly and lightly constrained are outlined.

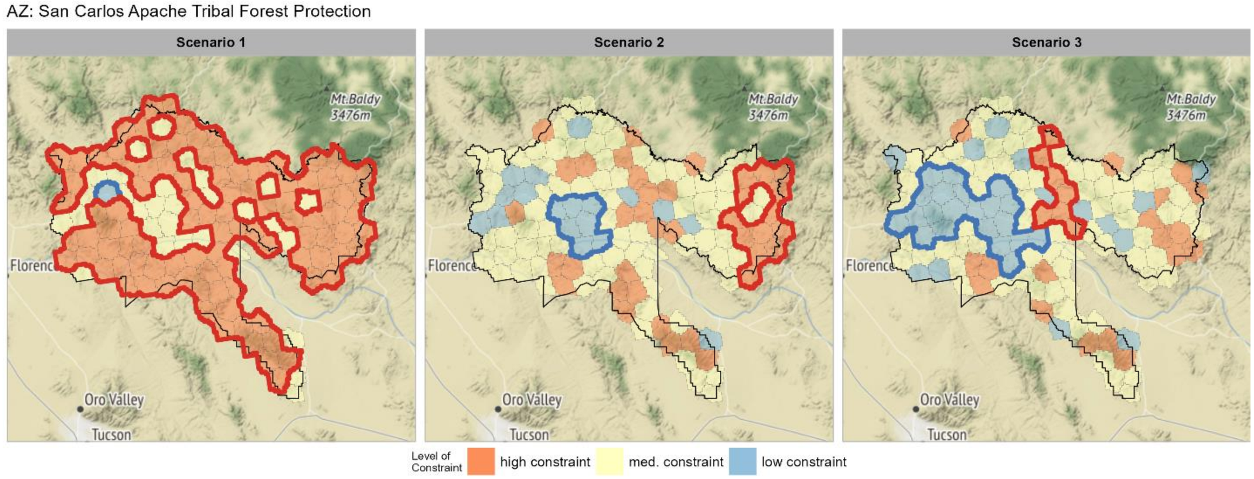

Figure B.5. San Carlos Apache Tribal Forest Protection (Arizona) priority landscape divided into fireshed project areas. Shadings indicate percentages of the total combined forest and shrubland acres that are available for mechanical treatment: high (81–100% constrained; 0–19% available for mechanical treatment), medium (60–80% constrained; 20–40% available), and low (0–59% constrained; 41–100% available). The largest patch of interconnected fireshed project areas classified as highly and lightly constrained are outlined.

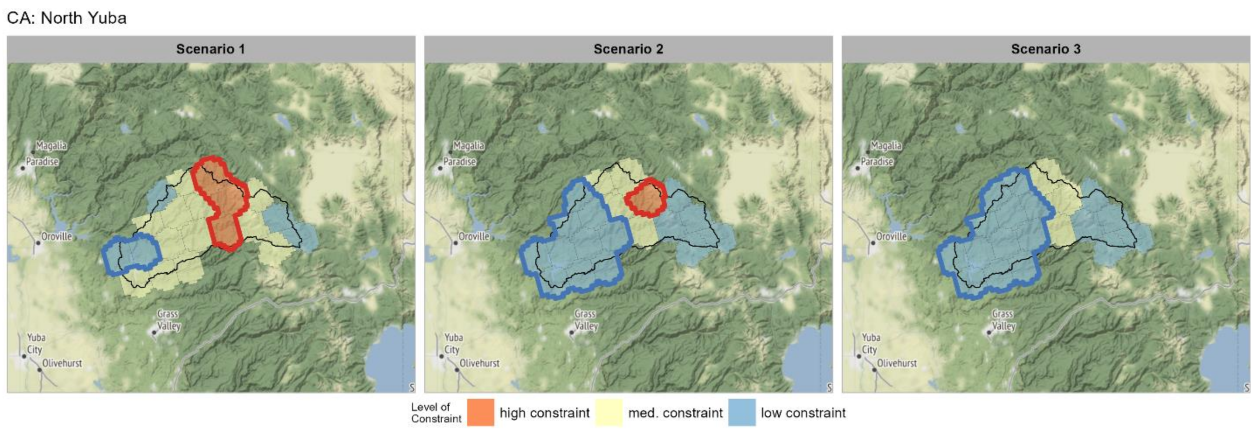

Figure B.6. North Yuba (California) priority landscape divided into fireshed project areas. Shadings indicate percentages of the total combined forest and shrubland acres that are available for mechanical treatment: high (81–100% constrained; 0–19% available for mechanical treatment), medium (60–80% constrained; 20–40% available), and low (0–59% constrained; 41–100% available). The largest patch of interconnected fireshed project areas classified as highly and lightly constrained are outlined.

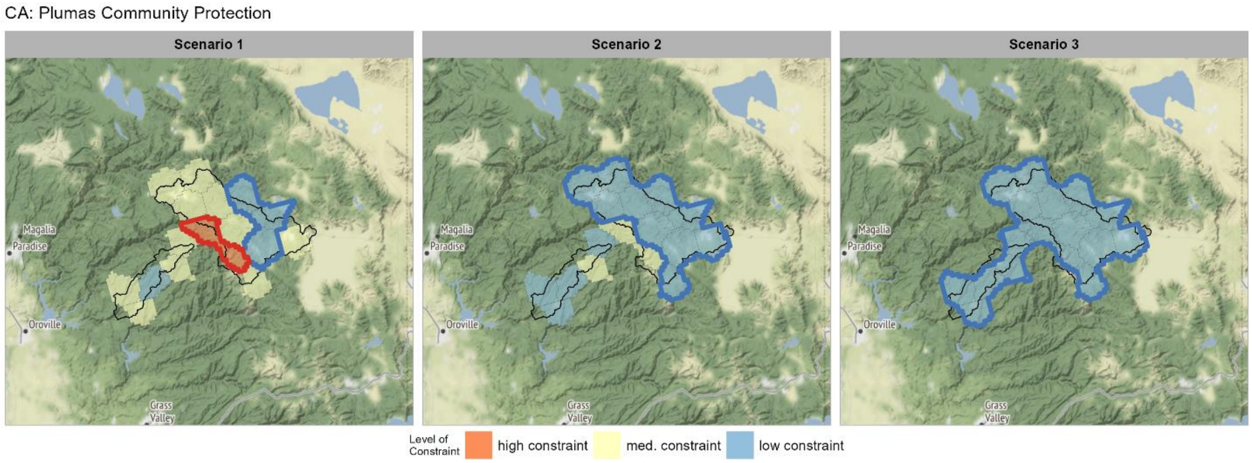

Figure B.7. Plumas Community Protection (California) priority landscape divided into fireshed project areas. Shadings indicate percentages of the total combined forest and shrubland acres that are available for mechanical treatment: high (81–100% constrained; 0–19% available for mechanical treatment), medium (60–80% constrained; 20–40% available), and low (0–59% constrained; 41–100% available). The largest patch of interconnected fireshed project areas classified as highly and lightly constrained are outlined.

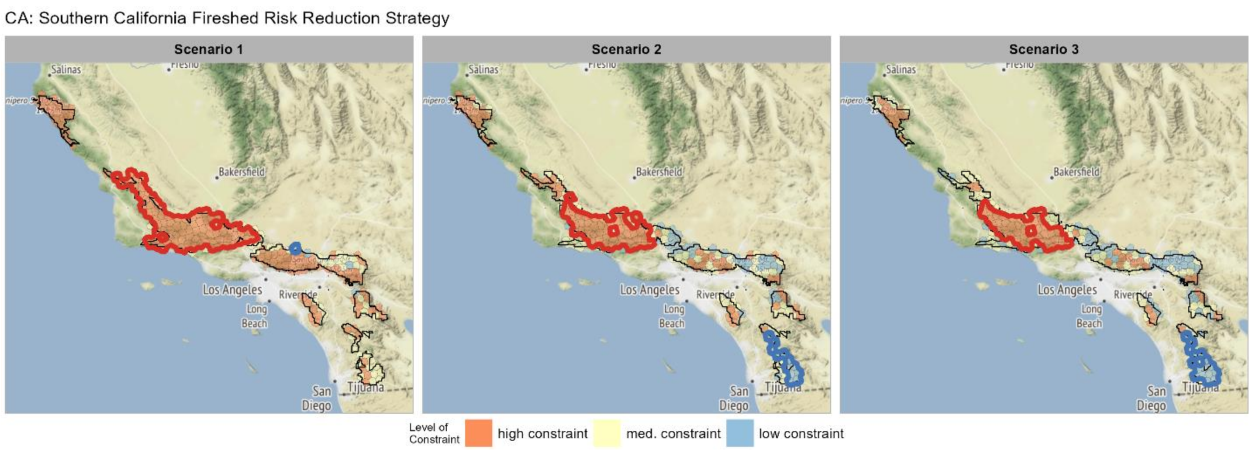

Figure B.8. Southern California Fireshed Risk Reduction Strategy (California) priority landscape divided into fireshed project areas. Shadings indicate percentages of the total combined forest and shrubland acres that are available for mechanical treatment: high (81–100% constrained; 0–19% available for mechanical treatment), medium (60–80% constrained; 20–40% available), and low (0–59% constrained; 41–100% available). The largest patch of interconnected fireshed project areas classified as highly and lightly constrained are outlined.

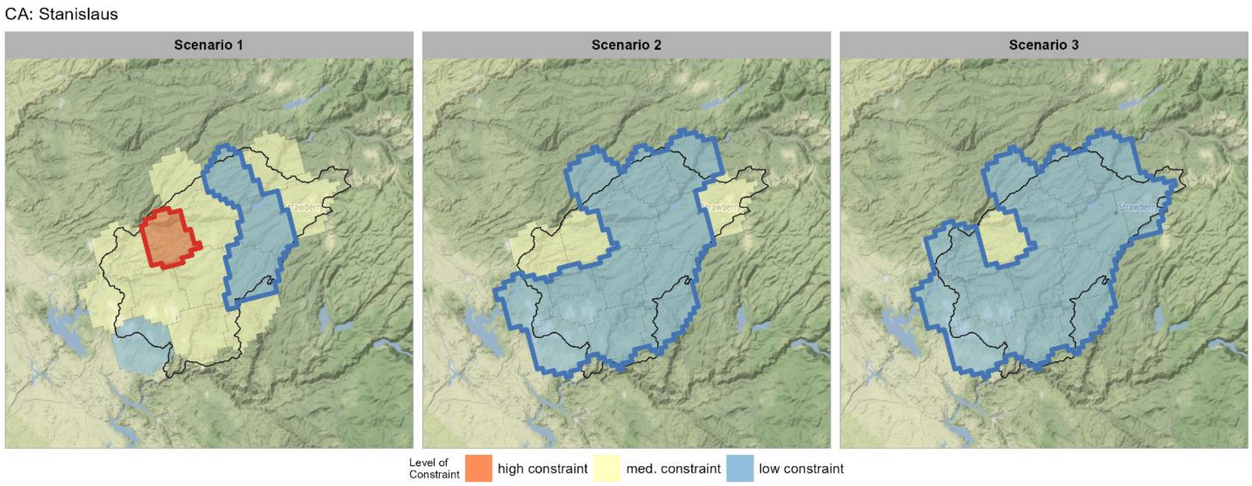

Figure B.9. Stanislaus (California) priority landscape divided into fireshed project areas. Shadings indicate percentages of the total combined forest and shrubland acres that are available for mechanical treatment: high (81–100% constrained; 0–19% available for mechanical treatment), medium (60–80% constrained; 20–40% available), and low (0–59% constrained; 41–100% available). The largest patch of interconnected fireshed project areas classified as highly and lightly constrained are outlined.

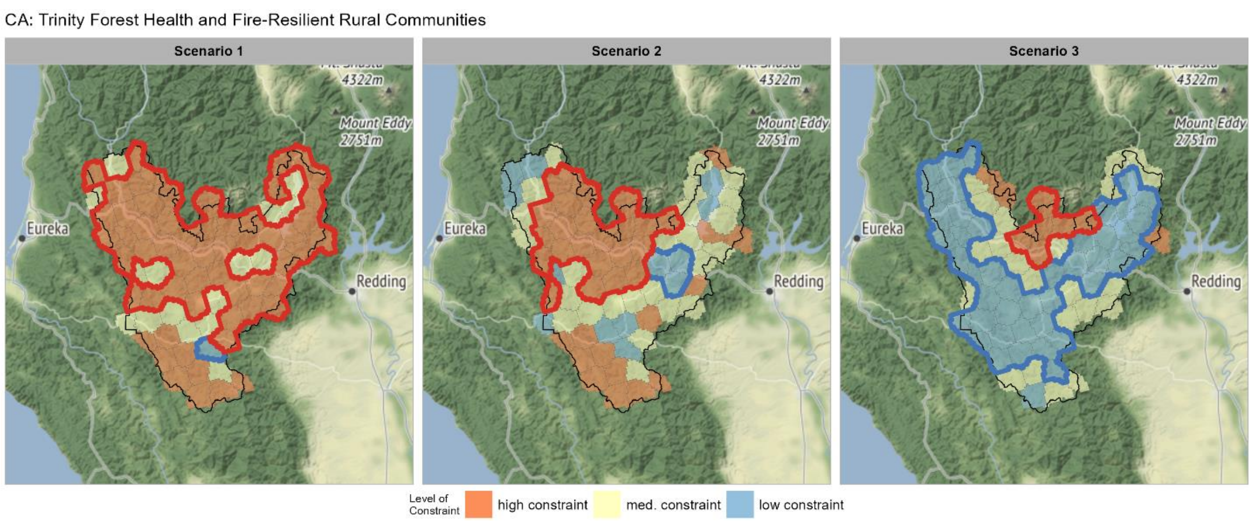

Figure B.10. Trinity Forest Health and Fire-Resilient Rural Communities (California) priority landscape divided into fireshed project areas. Shadings indicate percentages of the total combined forest and shrubland acres that are available for mechanical treatment: high (81–100% constrained; 0–19% available for mechanical treatment), medium (60–80% constrained; 20–40% available), and low (0–59% constrained; 41–100% available). The largest patch of interconnected fireshed project areas classified as highly and lightly constrained are outlined.

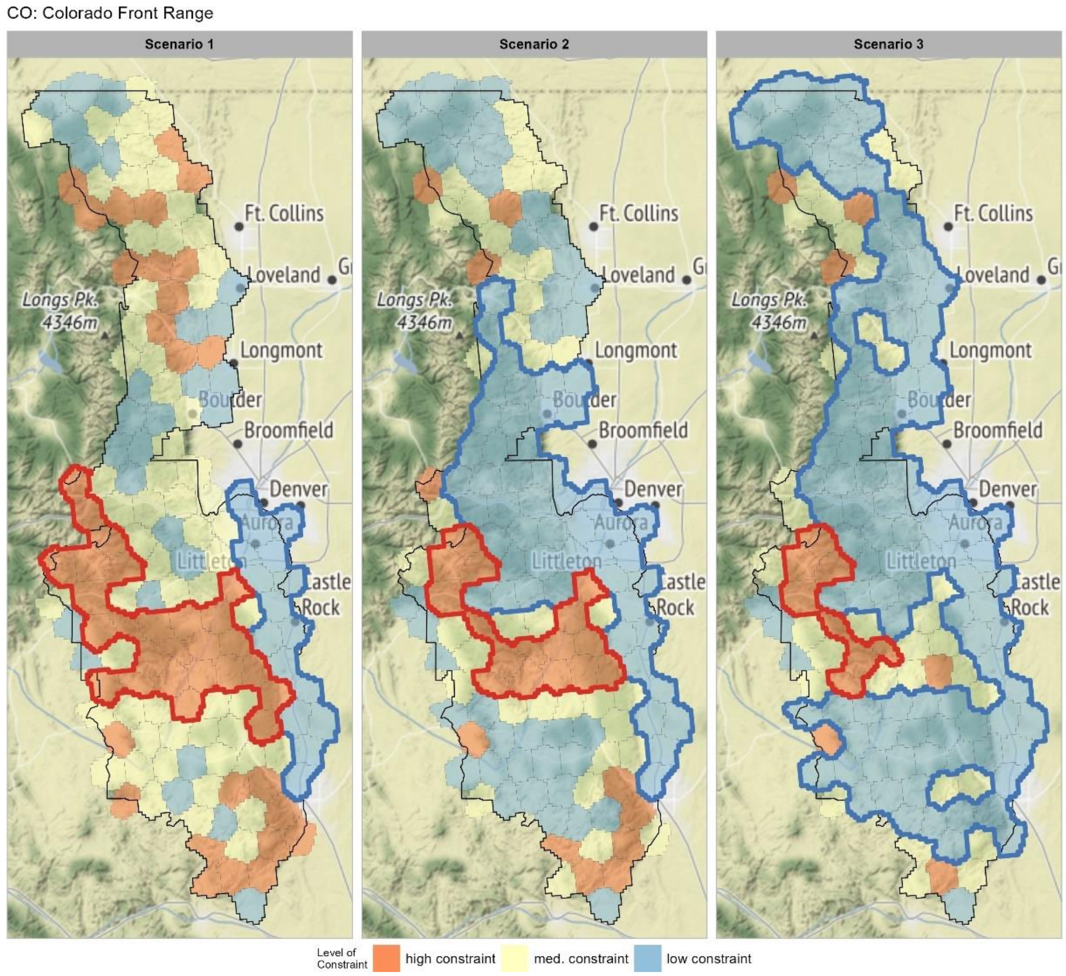

Figure B.11. Colorado Front Range (Colorado) priority landscape divided into fireshed project areas. Shadings indicate percentages of the total combined forest and shrubland acres that are available for mechanical treatment: high (81–100% constrained; 0–19% available for mechanical treatment), medium (60–80% constrained; 20–40% available), and low (0–59% constrained; 41–100% available). The largest patch of interconnected fireshed project areas classified as highly and lightly constrained are outlined.

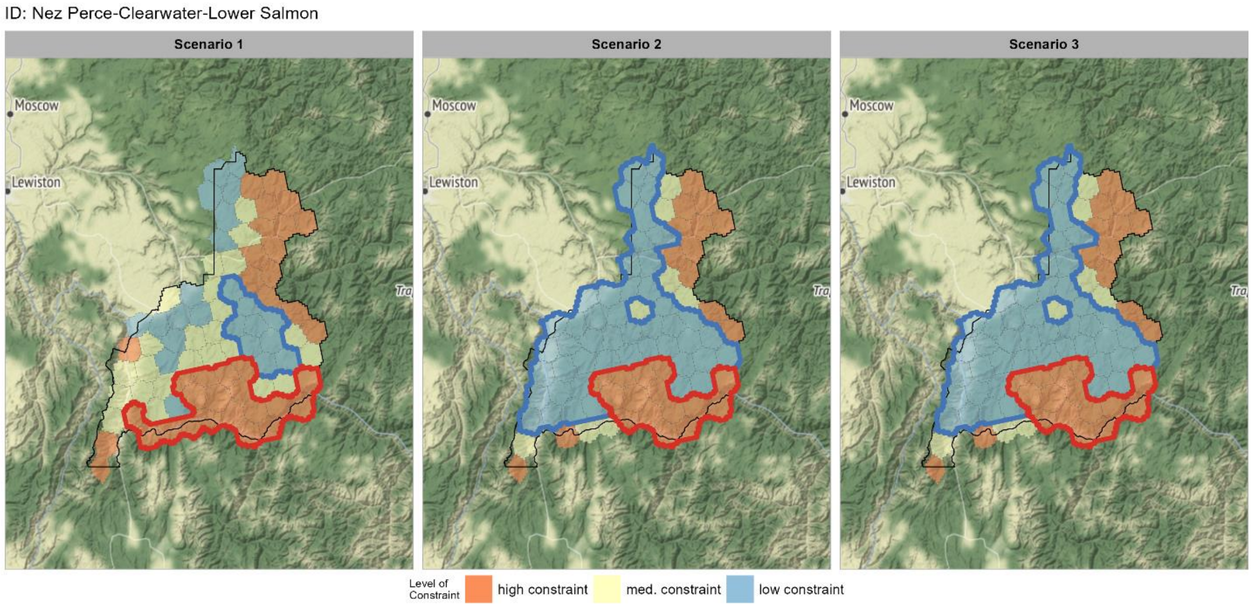

Figure B.12. Nez Perce-Clearwater-Lower Salmon (Idaho) priority landscape divided into fireshed project areas. Shadings indicate percentages of the total combined forest and shrubland acres that are available for mechanical treatment: high (81–100% constrained; 0–19% available for mechanical treatment), medium (60–80% constrained; 20–40% available), and low (0–59% constrained; 41–100% available). The largest patch of interconnected fireshed project areas classified as highly and lightly constrained are outlined.

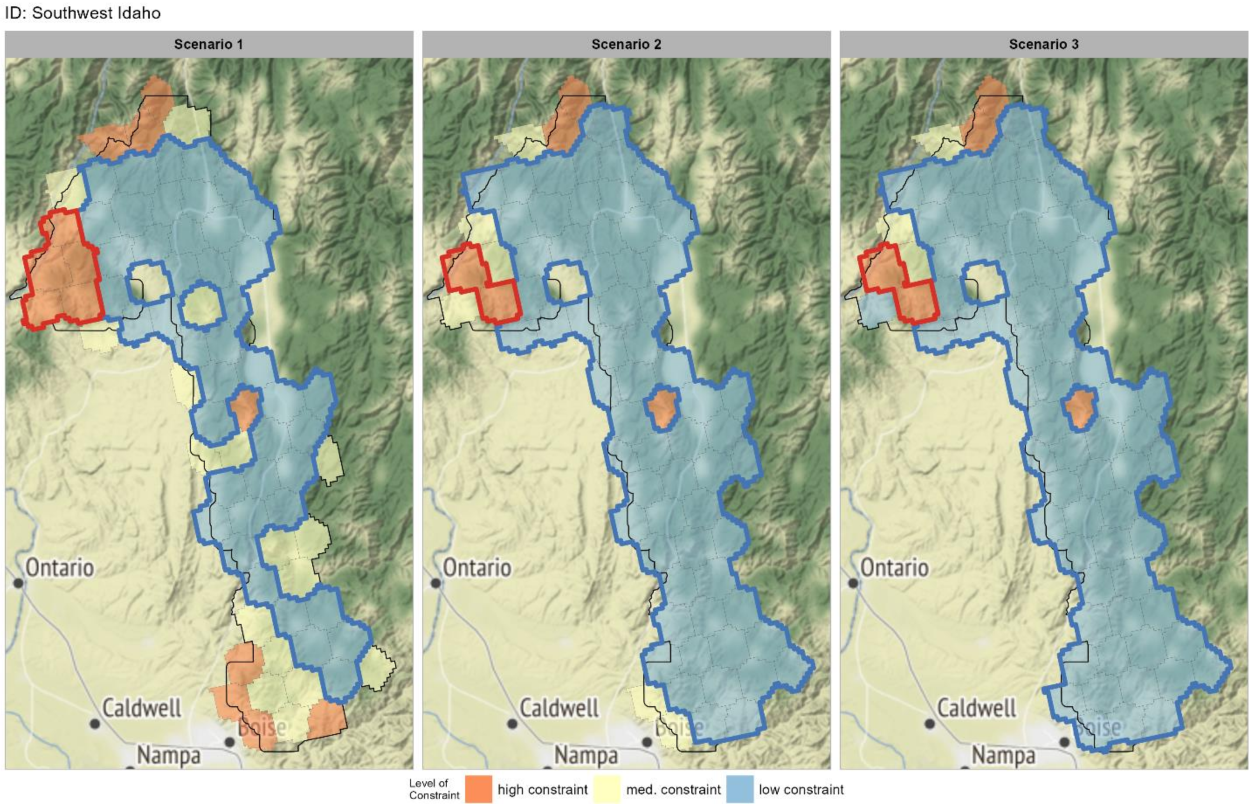

Figure B.13. Southwest Idaho (Idaho) priority landscape divided into fireshed project areas. Shadings indicate percentages of the total combined forest and shrubland acres that are available for mechanical treatment: high (81–100% constrained; 0–19% available for mechanical treatment), medium (60–80% constrained; 20–40% available), and low (0–59% constrained; 41–100% available). The largest patch of interconnected fireshed project areas classified as highly and lightly constrained are outlined.

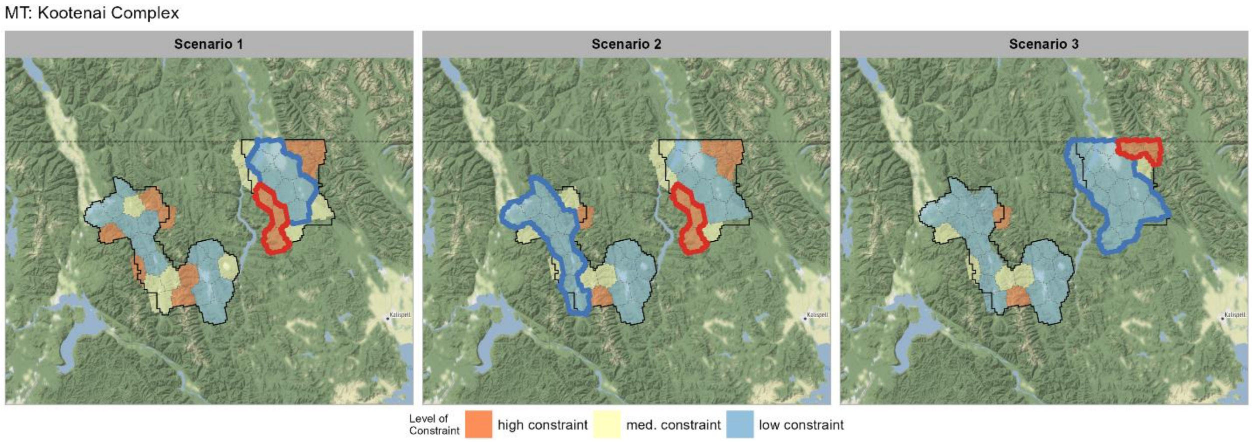

Figure B.14. Kootenai Complex (Montana) priority landscape divided into fireshed project areas. Shadings indicate percentages of the total combined forest and shrubland acres that are available for mechanical treatment: high (81–100% constrained; 0–19% available for mechanical treatment), medium (60–80% constrained; 20–40% available), and low (0–59% constrained; 41–100% available). The largest patch of interconnected fireshed project areas classified as highly and lightly constrained are outlined.

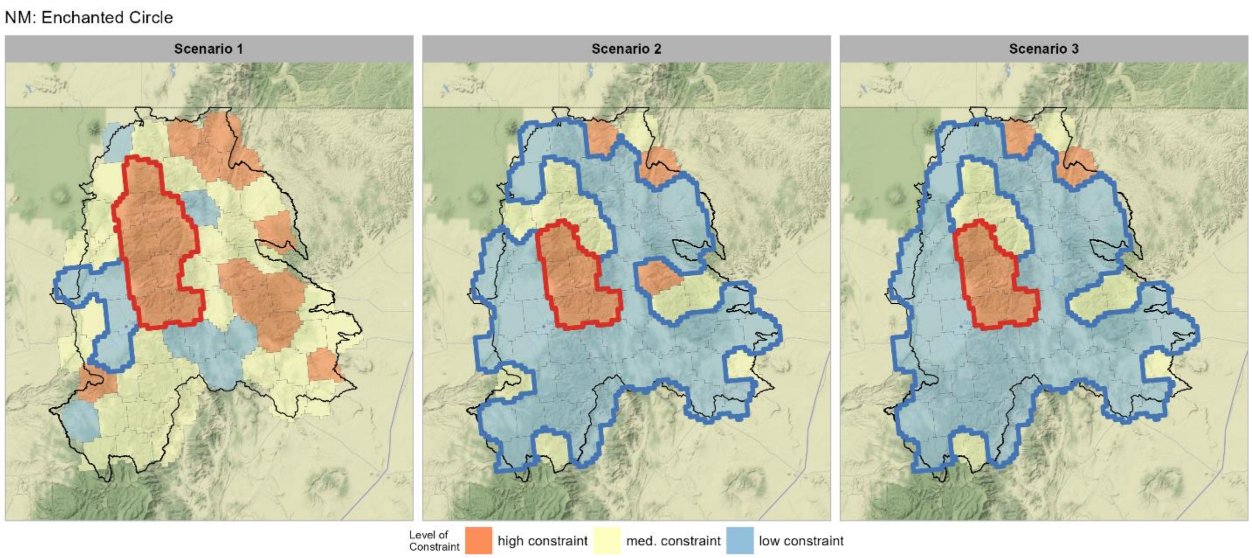

Figure B.15. Enchanted Circle (New Mexico) priority landscape divided into fireshed project areas. Shadings indicate percentages of the total combined forest and shrubland acres that are available for mechanical treatment: high (81–100% constrained; 0–19% available for mechanical treatment), medium (60–80% constrained; 20–40% available), and low (0–59% constrained; 41–100% available). The largest patch of interconnected fireshed project areas classified as highly and lightly constrained are outlined.

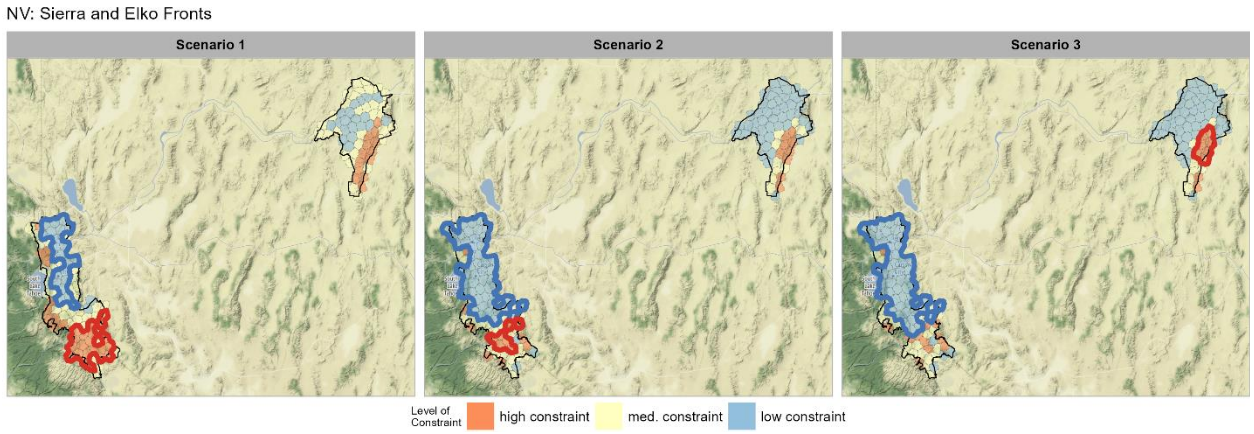

Figure B.16. Sierra and Elko Fronts (Nevada) priority landscape divided into fireshed project areas. Shadings indicate percentages of the total combined forest and shrubland acres that are available for mechanical treatment: high (81–100% constrained; 0–19% available for mechanical treatment), medium (60–80% constrained; 20–40% available), and low (0–59% constrained; 41–100% available). The largest patch of interconnected fireshed project areas classified as highly and lightly constrained are outlined.

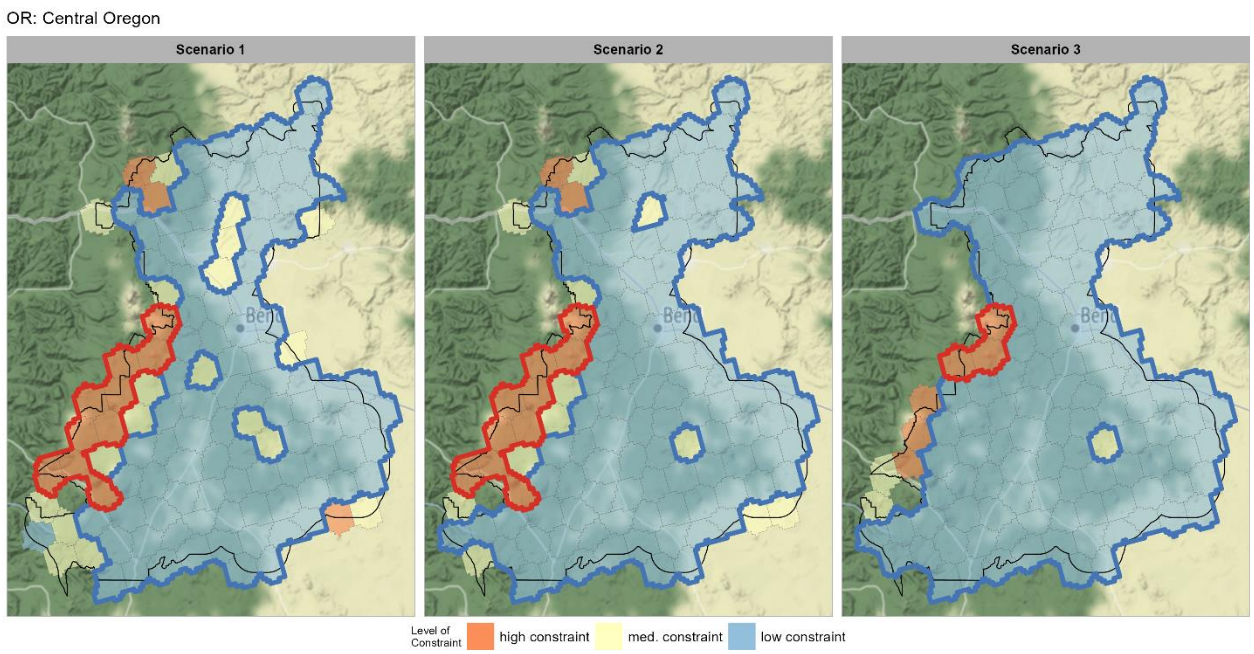

Figure B.17. Central Oregon (Oregon) priority landscape divided into fireshed project areas. Shadings indicate percentages of the total combined forest and shrubland acres that are available for mechanical treatment: high (81–100% constrained; 0–19% available for mechanical treatment), medium (60–80% constrained; 20–40% available), and low (0–59% constrained; 41–100% available). The largest patch of interconnected fireshed project areas classified as highly and lightly constrained are outlined.

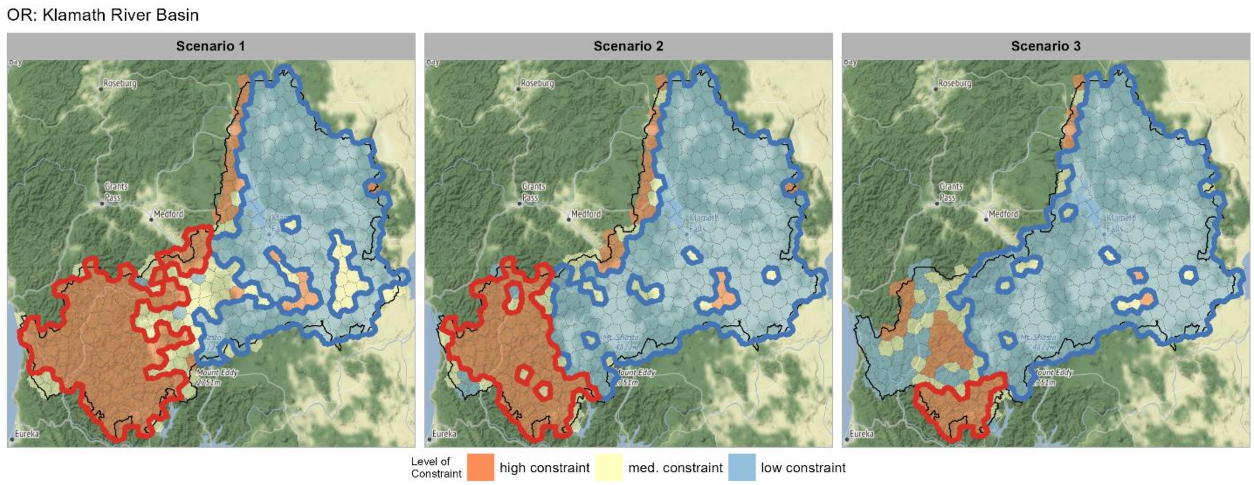

Figure B.18. Klamath River Basin (Oregon) priority landscape divided into fireshed project areas. Shadings indicate percentages of the total combined forest and shrubland acres that are available for mechanical treatment: high (81–100% constrained; 0–19% available for mechanical treatment), medium (60–80% constrained; 20–40% available), and low (0–59% constrained; 41–100% available). The largest patch of interconnected fireshed project areas classified as highly and lightly constrained are outlined.

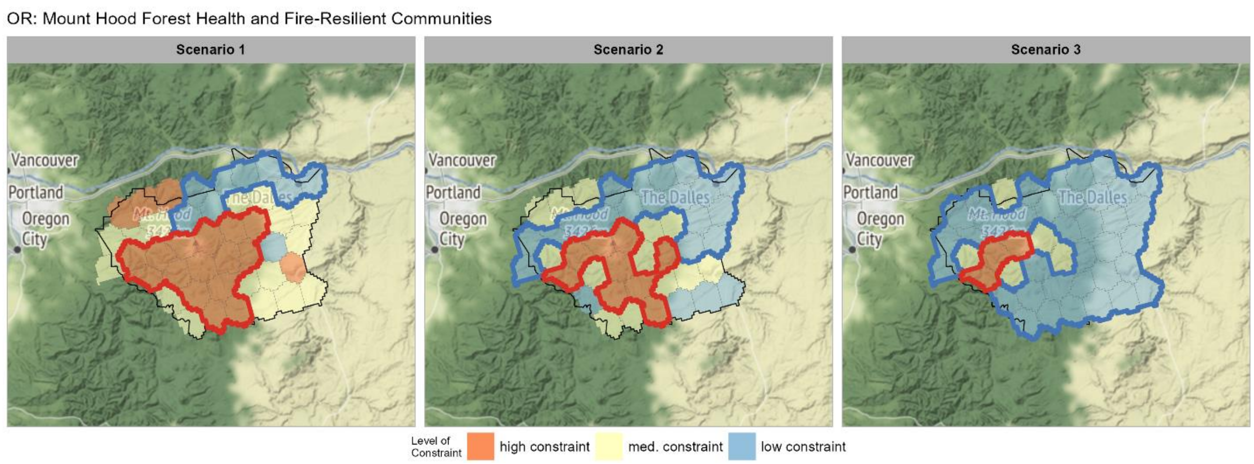

Figure B.19. Mount Hood Forest Health and Fire-Resilient Communities (Oregon) priority landscape divided into fireshed project areas. Shadings indicate percentages of the total combined forest and shrubland acres that are available for mechanical treatment: high (81–100% constrained; 0–19% available for mechanical treatment), medium (60–80% constrained; 20–40% available), and low (0–59% constrained; 41–100% available). The largest patch of interconnected fireshed project areas classified as highly and lightly constrained are outlined.

UT: Pine Valley

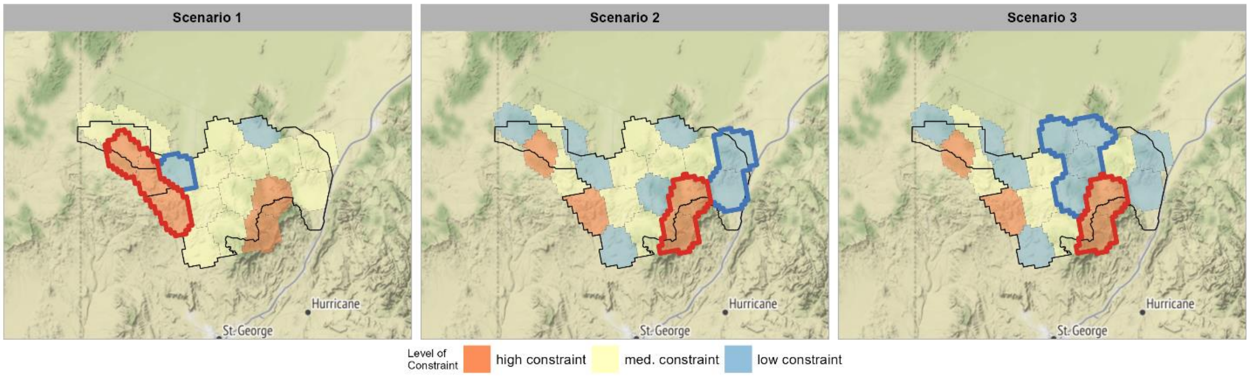

Figure B.20. Pine Valley (Utah) priority landscape divided into fireshed project areas. Shadings indicate percentages of the total combined forest and shrubland acres that are available for mechanical treatment: high (81–100% constrained; 0–19% available for mechanical treatment), medium (60–80% constrained; 20–40% available), and low (0–59% constrained; 41–100% available). The largest patch of interconnected fireshed project areas classified as highly and lightly constrained are outlined.

UT: Wasatch

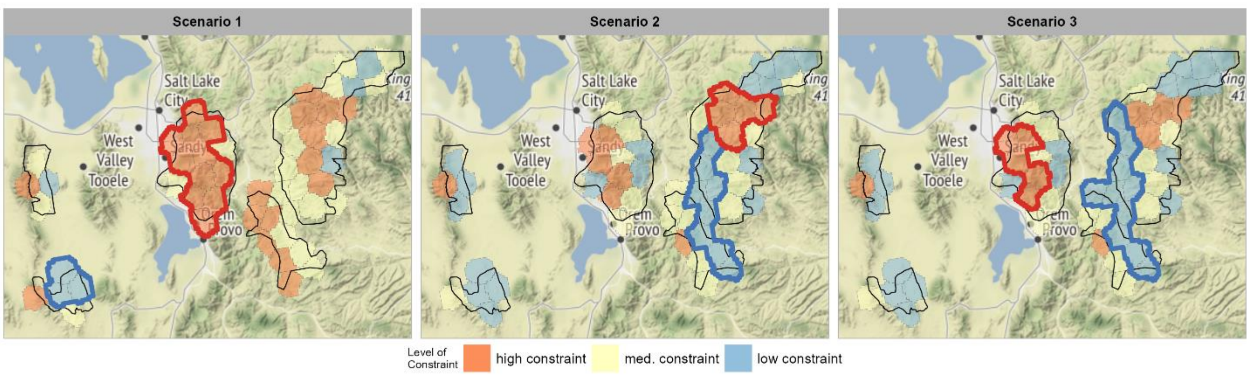

Figure B.21. Wasatch (Utah) priority landscape divided into fireshed project areas. Shadings indicate percentages of the total combined forest and shrubland acres that are available for mechanical treatment: high (81–100% constrained; 0–19% available for mechanical treatment), medium (60–80% constrained; 20–40% available), and low (0–59% constrained; 41–100% available). The largest patch of interconnected fireshed project areas classified as highly and lightly constrained are outlined.

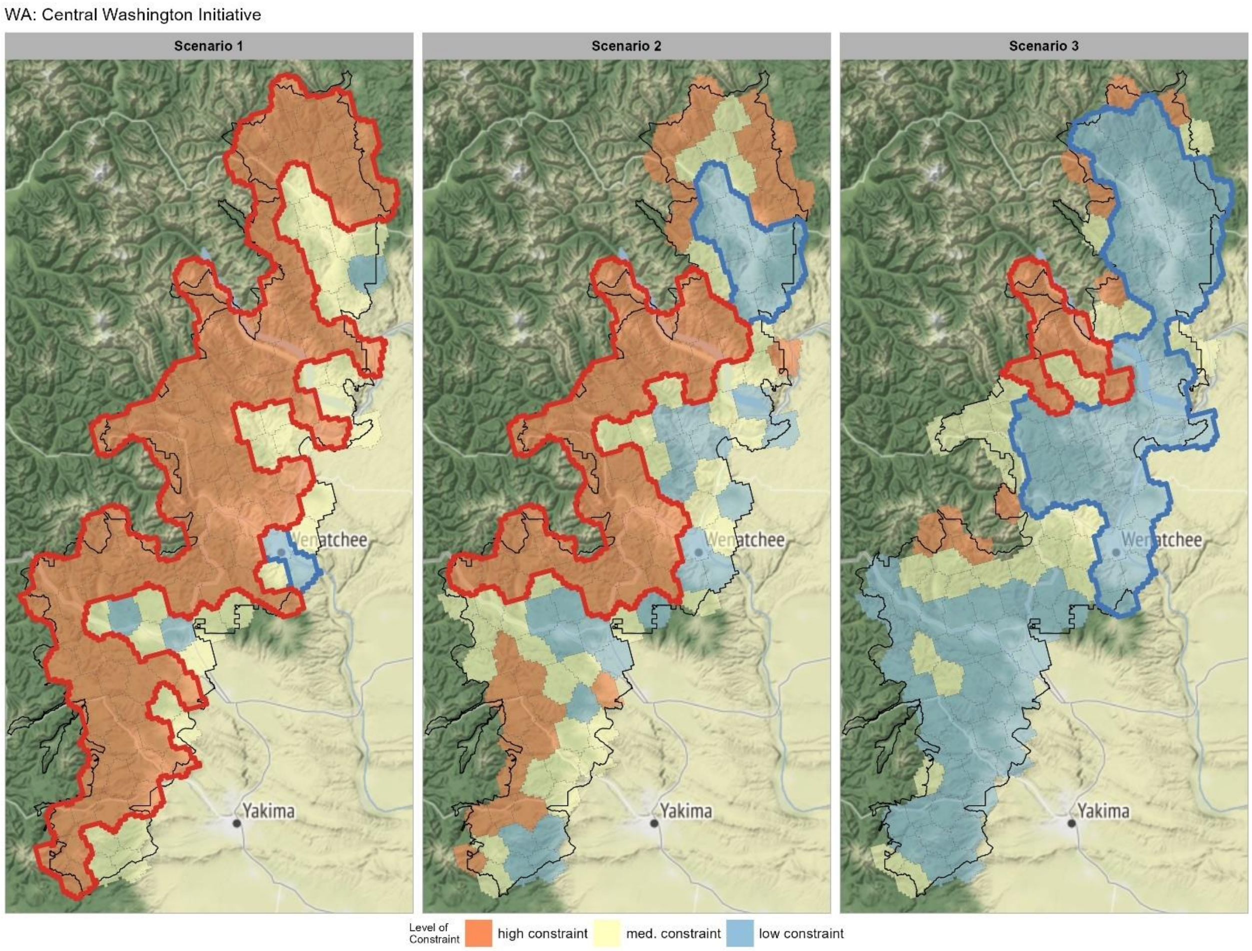

Figure B.22. Central Washington Initiative (Washington) priority landscape divided into fireshed project areas. Shadings indicate percentages of the total combined forest and shrubland acres that are available for mechanical treatment: high (81–100% constrained; 0–19% available for mechanical treatment), medium (60–80% constrained; 20–40% available), and low (0–59% constrained; 41–100% available). The largest patch of interconnected fireshed project areas classified as highly and lightly constrained are outlined.

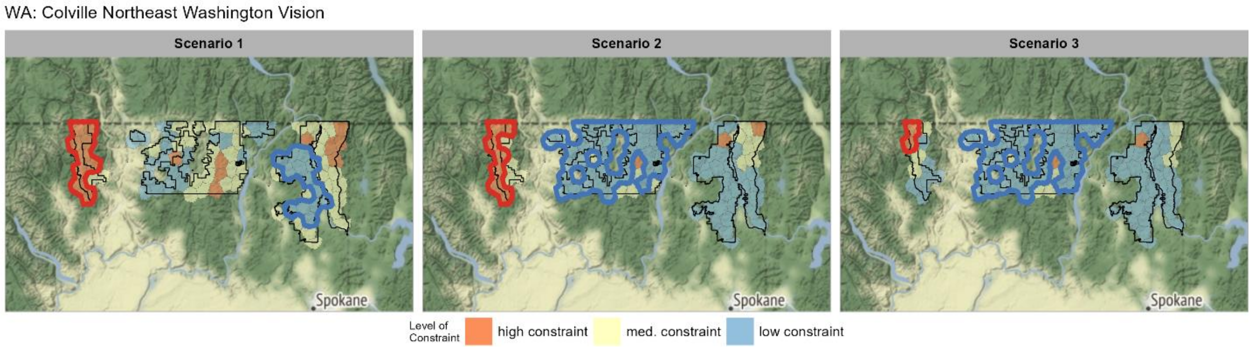

Figure B.23. Colville Northeast Washington Vision (Washington) priority landscape divided into fireshed project areas. Shadings indicate percentages of the total combined forest and shrubland acres that are available for mechanical treatment: high (81–100% constrained; 0–19% available for mechanical treatment), medium (60–80% constrained; 20–40% available), and low (0–59% constrained; 41–100% available). The largest patch of interconnected fireshed project areas classified as highly and lightly constrained are outlined.

Table B.1. Area and percent of area within high-risk firesheds that is mechanically available in combined low (0–59% constrained; 41–100% available for mechanical treatment) and medium (60–80% constrained; 20–40% available) constraint planning areas compared to the Strategy objective of treating 20-40% of high-risk fireshed acreage.

	High-Risk Fireshed Project Areas		Treatable High-Risk Area (ha)			Treatable High-Risk Percent (%)		
	Total Area (ha)	Forest+Shrub Area (ha)	Lightly Constrained	Moderately Constrained	Total	Lightly Constrained	Moderately Constrained	Total
AZ: 4FRI								
Scenario 1	1,579k	1,436k	304k	126k	430k	19.3%	8.0%	27.2%
Scenario 2	1,579k	1,436k	535k	69k	605k	33.9%	4.4%	38.3%
Scenario 3	1,579k	1,436k	913k	50k	963k	57.8%	3.2%	61.0%
AZ: Prescott								
Scenario 1	300k	263k	34k	30k	63k	11.3%	9.9%	21.1%
Scenario 2	300k	263k	90k	25k	115k	29.9%	8.5%	38.4%
Scenario 3	300k	263k	134k	15k	150k	44.8%	5.0%	49.8%
AZ: San Carlos Apache Tribal Forest Protection								
Scenario 1	250k	230k	4k	15k	19k	1.6%	6.1%	7.7%
Scenario 2	250k	230k	28k	50k	78k	11.3%	19.9%	31.2%
Scenario 3	250k	230k	69k	31k	100k	27.6%	12.2%	39.8%
CA: North Yuba								
Scenario 1	206k	197k	21k	36k	57k	10.4%	17.3%	27.6%
Scenario 2	206k	197k	75k	13k	88k	36.5%	6.5%	43.0%
Scenario 3	206k	197k	99k	12k	111k	48.4%	5.7%	54.1%
CA: Plumas Community Protection								
Scenario 1	157k	148k	12k	34k	46k	7.8%	21.7%	29.5%
Scenario 2	157k	148k	65k	8k	72k	41.2%	4.9%	46.1%
Scenario 3	157k	148k	91k	0k	91k	57.9%	0.0%	57.9%
CA: Southern California Fireshed Risk Reduction Strategy								
Scenario 1	1,053k	854k	13k	92k	105k	1.3%	8.7%	10.0%
Scenario 2	1,053k	854k	162k	87k	249k	15.3%	8.3%	23.7%
Scenario 3	1,053k	854k	241k	71k	311k	22.8%	6.7%	29.6%
CA: Stanislaus								
Scenario 1	153k	143k	20k	30k	50k	13.1%	19.8%	32.8%
Scenario 2	153k	143k	59k	10k	70k	38.8%	6.7%	45.5%
Scenario 3	153k	143k	80k	4k	84k	52.4%	2.5%	54.9%
CA: Trinity Forest Health and Fire-Resilient Rural Communities								
Scenario 1	565k	488k	3k	32k	36k	0.6%	5.7%	6.3%
Scenario 2	565k	488k	49k	48k	97k	8.6%	8.5%	17.1%
Scenario 3	565k	488k	171k	48k	219k	30.3%	8.5%	38.8%

Table B.1 (continued).

	High-Risk Fireshed Project Areas		Treatable High-Risk Area (ha)			Treatable High-Risk Percent (%)		
	Total Area (ha)	Forest+Shrub Area (ha)	Lightly Constrained	Moderately Constrained	Total	Lightly Constrained	Moderately Constrained	Total
CO: Colorado Front Range								
Scenario 1	1,138k	823k	85k	118k	203k	7.5%	10.4%	17.8%
Scenario 2	1,138k	823k	286k	65k	351k	25.1%	5.7%	30.8%
Scenario 3	1,138k	823k	374k	62k	436k	32.9%	5.4%	38.3%
ID: Nez Perce-Clearwater-Lower Salmon								
Scenario 1	520k	444k	77k	49k	126k	14.8%	9.5%	24.2%
Scenario 2	520k	444k	199k	13k	212k	38.3%	2.5%	40.8%
Scenario 3	520k	444k	205k	14k	218k	39.4%	2.6%	42.0%
ID: Southwest Idaho								
Scenario 1	734k	632k	228k	41k	268k	31.0%	5.5%	36.5%
Scenario 2	734k	632k	408k	15k	423k	55.6%	2.1%	57.6%
Scenario 3	734k	632k	427k	8k	435k	58.1%	1.1%	59.2%
MT: Kootenai Complex								
Scenario 1	322k	294k	98k	12k	111k	30.6%	3.9%	34.4%
Scenario 2	322k	294k	140k	9k	149k	43.5%	2.9%	46.4%
Scenario 3	322k	294k	190k	9k	199k	59.1%	2.7%	61.8%
NV: Sierra and Elko Fronts								
Scenario 1	678k	453k	99k	55k	154k	14.6%	8.2%	22.8%
Scenario 2	678k	453k	229k	17k	247k	33.8%	2.6%	36.4%
Scenario 3	678k	453k	250k	20k	270k	36.9%	2.9%	39.9%
NM: Enchanted Circle								
Scenario 1	318k	285k	33k	42k	75k	10.4%	13.1%	23.5%
Scenario 2	318k	285k	118k	16k	134k	37.1%	4.9%	42.0%
Scenario 3	318k	285k	133k	13k	146k	41.9%	4.0%	45.9%
OR: Central Oregon								
Scenario 1	278k	232k	138k	10k	149k	49.7%	3.6%	53.4%
Scenario 2	278k	232k	169k	0k	169k	60.5%	0.0%	60.5%
Scenario 3	278k	232k	203k	0k	203k	73.1%	0.0%	73.1%
OR: Klamath River Basin								
Scenario 1	684k	557k	13k	45k	59k	2.0%	6.6%	8.6%
Scenario 2	684k	557k	137k	36k	173k	20.0%	5.2%	25.3%
Scenario 3	684k	557k	220k	35k	254k	32.1%	5.1%	37.2%
OR: Mount Hood Forest Health and Fire-Resilient Communities								
Scenario 1	339k	244k	15k	22k	37k	4.5%	6.5%	11.0%
Scenario 2	339k	244k	46k	21k	67k	13.6%	6.3%	19.9%
Scenario 3	339k	244k	131k	10k	141k	38.6%	2.8%	41.5%

Table B.1 (continued).

	High-Risk Fireshed Project Areas		Treatable High-Risk Area (ha)			Treatable High-Risk Percent (%)		
	Total Area (ha)	Forest+Shrub Area (ha)	Lightly Constrained	Moderately Constrained	Total	Lightly Constrained	Moderately Constrained	Total
UT: Pine Valley								
Scenario 1	187k	173k	7k	32k	39k	3.9%	16.9%	20.8%
Scenario 2	187k	173k	36k	24k	60k	19.1%	13.1%	32.2%
Scenario 3	187k	173k	45k	19k	64k	24.0%	10.3%	34.4%
UT: Wasatch								
Scenario 1	156k	126k	21k	11k	32k	13.6%	7.1%	20.7%
Scenario 2	156k	126k	45k	8k	52k	28.6%	5.0%	33.7%
Scenario 3	156k	126k	47k	8k	56k	30.4%	5.3%	35.7%
WA: Central Washington Initiative								
Scenario 1	903k	654k	10k	37k	47k	1.1%	4.1%	5.2%
Scenario 2	903k	654k	73k	46k	119k	8.1%	5.1%	13.2%
Scenario 3	903k	654k	285k	43k	328k	31.6%	4.7%	36.3%
WA: Colville Northeast Washington Vision								
Scenario 1	272k	244k	55k	28k	83k	20.4%	10.2%	30.6%
Scenario 2	272k	244k	118k	10k	128k	43.3%	3.6%	46.9%
Scenario 3	272k	244k	149k	6k	155k	54.7%	2.2%	56.9%