Appendix B8

Forest Carbon Change Analysis

1.0 Forest Vegetation Simulator and LEMMA Data

This analysis utilized the Forest Vegetation Simulator (FVS) software package to model the effects of fuels reduction treatments. FVS is a computer-based model utilized in forest management, carbon and greenhouse gas accounting, and wildfire impact analysis. Developed and maintained by the USDA Forest Service, FVS is designed to simulate the complex dynamics of forest ecosystems over time. It integrates empirical equations, statistical models, and algorithms to replicate key processes such as tree growth, mortality, regeneration, and competition for resources. Users input data on initial stand conditions and management activities, enabling FVS to generate detailed predictions of stand development, including tree growth rates, carbon sequestration, and stand structure. FVS is the industry standard tool for understanding and predicting the effects of management decisions on forest ecosystems and timber resources.

FVS requires forest stand structure input data to simulate forest growth over time. This analysis utilized the LEMMA forest structure data (Landscape Ecology, Modeling, Mapping, and Analysis) created through a partnership with the US Forest Service/Oregon State University. This dataset uses gradient nearest neighbor (GNN) methods to impute forest characteristics to 30-meter grid cells across California, Oregon, and Washington, based on over 50,000 field plots and a host of explanatory variables. The GNN method integrates vegetation measurements from regional grids of field plots, mapped environmental data, and Landsat Thematic Mapper (TM) imagery to spatially predict forest structure (Ohmann and Gregory 2002). The GNN Structure dataset provides detailed forest structure data representing forest conditions in 2017. LEMMA is commonly used by other entities such as CAL FIRE and the California Air Resources Board to predict the impacts of forest treatments on greenhouse gases.

1.1 Processing LEMMA Data

The Project proposes to conduct forest fuels treatments on roughly 85,779 (see Section 1.2.3.1) annually across both the Lassen and Keystone Project areas. Due to the very large spatial scale of the Project, a scaling approach was chosen to model the effects of these treatments. This process involved modelling effects of forest treatments within representative, smaller, subsets of the Project area, and scaling these results to account for the larger, Project-wide treatable area. Forest structure diversity within sample areas is crucial to effectively account for forest heterogeneity across the Project area. Therefore, representative subsets (sample areas) were selected by Forest Type and Stand Density Index (SDI).

1.1.1 Removal of Areas Burned Since 2017

FVS models forest growth over time based on the initial date associated with the input data. Because the LEMMA GNN Structure data provides forest structure conditions in 2017, simulated forest growth after 2017 is unable to account for changes in forest structure that have resulted from wildland fire occurring between 2017 and the present. Therefore, the Project's *Treatable Area* layer was modified to remove forest lands that that have experienced wildfire since 2017. This does not imply that the Project will not conduct fuels reduction activities in areas that have experienced wildfire since 2017. Instead, this step ensures that representative sample areas will not be selected where existing conditions (post-fire) are not accurately represented in the 2017 forest structure LEMMA data. The *Modified Treatable Area* is provided in Figure 1.

1.1.2 Dominant Forest Types

Given that fuels treatment standards and forest dynamics differ across forest types, the dominant forest types by species were identified across the Project area. The USFS National Forest Inventory and Analysis (FIA) program's National Forest Type dataset was clipped to the Project's *Modified Treatable Area* polygon. It was determined that California Mixed Conifer, Ponderosa Pine, and White Fir forest types represented the majority (~80%) of forest types across the Project's treatable areas (Table 1). These forest types were selected from the total Project area and were clipped to the Project's Modified *Treatable Area* polygon (Figure 2)

Table 1. Dominant forest types in the Project Area

Forest Type	Percent of Treatable Area
California Mixed Conifer	43%
Ponderosa Pine	28%
White Fir	9%
Total:	**80%**

Source: USFS National Forest Type Dataset

1.1.3 Forest Density

To further account for forest structure diversity within the dominant forest types, dominant forest types were divided based on their Stand Density Index (SDI). SDI is a measure used in forestry to quantify the density or crowding of trees within a stand. SDI is calculated based on the number of trees per unit area and the average diameter of those trees. Stand density measurements assist managers in identifying the degree of competition among trees and the utilization of the site, aiding in the determination of appropriate management strategies to achieve specific objectives.

Existing forest structure and stand density influences the level of benefits from forest treatments. For example, overcrowded, high density stands may experience great benefits from fuels reduction/thinning treatments due to substantial reductions in tree-tree competition for resources. However, treatments in lower density stands may result in less substantial effects given their already present condition of low tree-tree competition. Therefore, dominant forest types were further classified based on existing SDI to account for variable effects of fuel treatments.

The LEMMA GNN Structure data *Stand Density Index (SDI)* attribute was utilized to divide dominant forest types into three categories: *High SDI, Moderate SDI, and Low SDI*. Categorical breaks for High, Moderate, and Low SDI were determined using the natural breaks classification in ArcGIS Pro which accounts for non-uniform distributions, providing unequal class widths with varied levels of observations per class. This process resulted in a total of nine forest stand types, encompassing three levels of SDI across the three dominant forest types. The distribution of these forest stand types across the Project area is provided below in Table 2.

Table 2. Distribution of dominant stand types across the Project area

Forest Stand Type	Acres	Proportion of Assessment Area
White Fir	**621,958**	
High	131,698	2.3%
Mod	278,681	4.9%
Low	205,765	3.6%
California Mixed Conifer	**3,048,147**	
High	662,294	11.7%
Mod	1,317,049	23.2%
Low	1,027,649	18.1%
Ponderosa Pine	**1,994,744**	
High	82,076	1.4%
Mod	677,317	12.0%
Low	1,223,591	21.6%
	Total:	**100%**

Source: USFS National Forest Type Dataset, LEMMA 2017

1.1.4 Selecting Representative Forest Stands

In order to randomly select sample representative forest stands within the nine forest stand types, each forest stand type was subdivided into 500-acre latitudinal strips using the *Subdivide Polygons Tool* in ArcGIS Pro. Latitudinal strips allowed for the impacts of elevation on forest growth and structure to be accounted for within each 500-acre polygon. Six 500-acre polygons for each forest stand type were randomly selected resulting in a 3,000-acre representative sample area for each of the nine forest stand types. These representative sample areas are presented graphically in Figure 3.

1.1.5 Data Processing

The 30-meter grid cell LEMMA GNN Structure raster dataset was clipped to each 3,000-acre representative sample area and exported into a CSV file including unique forest stands, their structure attributes, and total acreage. The CSV files were then imported into a Microsoft Access Database to convert the input data into a format compatible with FVS.

1.2 Forest Vegetation Simulator (FVS) Modelling

Forest structure data for the nine representative forest stand type sample areas was imported into FVS. FVS modelling was conducted in four main scenarios for each forest stand type.

1. **Not treated, No Wildfire**
2. **Treated, No Wildfire**

3. **Not treated, With Wildfire**
4. **Treated, With Wildfire**

Each scenario was assigned a start date of 2024, allowing forest growth to be simulated from current forest structure conditions. Forest growth was modelled over 60 years (2024-2084) for all scenarios.

1.2.1 Treated Scenarios

For scenarios where forest treatments occurred, treatment parameters were dependent on the forest type. A Stand Density Index (SDI) treatment approach was chosen as it was determined this method most accurately reflects how the Project will conduct forest treatments across different forest types to reach a desired post-treatment condition. For each forest type, a desired residual SDI was determined as presented below in Table 3. Through a review of relevant research and expert opinion from career foresters, these residual SDI values were determined to achieve desired forest conditions conducive to wildfire resilience and overall forest health (Sherlock 2007, Long and Shaw, 2012).

Table 3. Desired Residual Stand Density Index after treatment by forest type

Forest Type	Residual SDI after Treatment
California Mixed Conifer	225
Ponderosa Pine	200
White Fir	300

Treatment scenarios were assigned a treatment date of 2024. The *Thin From Below* cutting control parameter was selected within the *ThinSDI* treatment method to align with the Project's goal of prioritizing the removal of small diameter forest materials.

1.2.2 Wildfire Scenarios

In scenarios where wildfire was modelled to occur, model inputs for wildfire were set to the following conditions.

- **Time of Wildfire:** 5 years after treatment (2029)[1]
- **Wind Speed:** 20 miles/hour
- **Moisture Level:** Very Dry
- **Temperature:** 80 degrees Fahrenheit
- **Mortality Code:** FFE
- **Percentage of stand area burned:** Variable depending on forest stand type (See Table 5)
- **Season of Fire:** After greenup (before Fall)

Historical wildfire perimeter data was analyzed to predict the percentage of the Project Area likely to experience wildfire across the Project's 20-year lifespan. Historic wildfire perimeter data was obtained from CAL FIRE's Fire and

1 Simulating wildfire 5 years after treatment, or at the midpoint of the effective period for fuels reduction, is common as seen in other greenhouse gas assessment methods (CARB, 2020, Climate Forward, 2022).

Resource Assessment Program (FRAP) database. FRAP summarizes fire perimeter data from the late 1800s to 2022 and includes fires 10 acres or greater. Given this dataset only provides fire history data for California, the National Interagency Fire Center Interagency Fire Perimeter History database was utilized where the Project's Treatable Area extends into Southern Oregon. Both datasets were merged and clipped to the forest stand type layer. Given wildfire occurrences and their sizes have fluctuated throughout history, wildfire perimeters prior to 2002 were removed to better understand the prese and future fire regime within the Project area. The proportion of areas burned for each forest stand type from 2002-2022 was used to estimate future wildfire burn areas across the different forest stand types. These values are provided below in Table 4. Because many argue that both the size and frequency of wildfires in the Western United States will continue to increase, the values provided below are assumed to be conservative estimates for wildfire impacts during the Project's lifespan.

Table 4. Fire History from 2002-2002 across the dominant forest types

Forest Stand Type	Percentage of Stand Type Burned (2002-2022)	Percentage of Stand Type Burned Annually (2002-2022)
White Fir		
High	19.4%	1.0%
Mod	13.6%	0.7%
Low	13.7%	0.7%
California Mixed Conifer		
High	10.1%	0.5%
Mod	31.0%	1.5%
Low	32.0%	1.6%
Ponderosa Pine		
High	41.0%	2.0%
Mod	37.42%	1.9%
Low	19.0%	1.0%

Source: FRAP, 2023, NIFC, 2023

1.2.3 Outputs

FVS model outputs for forest carbon, mortality, and smoke production were used to determine the impact of the Project's forest treatments related on greenhouse gases.

1.2.3.1 Determining Acres Treated Annually

The Project's feedstock requirements from GSNR biomass only thinning projects for both sites were used to determine the number of acres required to be treated annually. In total, a total feedstock volume of **509,740 Bone Dry Tons (BDT)** per year from GSNR biomass only thinning projects was determined from a separate and prior analysis. This value was used to determine how many treated acres are necessary to satisfy the feedstock requirement.

FVS provides an output for the amount of total biomass removed from treatment. Total removed green biomass from treatment across the forest stand types was calculated and scaled to each forest stand type's relative distribution. As provided below in Table 5, it was determined that **85,779 acres** are required to be treated annually to supply the necessary feedstock supply from GSNR biomass only thinning projects.

Table 5. Acres required to be treated annually to achieve feedstock requirements

Forest Stand Type	Acres	Biomass Removed/ Acre (Green tons)	Biomass Removed/ Acre (Bone dry tons)[2]	Percent Distribution	Required Feedstock Supply	Acres Required to be Treated Annually
White Fir	**621,958**					
High	131,698	14.9	7.45	2%	12413	1666
Moderate	278,681	12.32	6.16	5%	25027	4063
Low	205,765	4.97	2.49	4%	18479	7436
California Mixed Conifer	**3,048,147**					
High	662,294	19.46	9.73	12%	59478	6113
Moderate	1,317,049	11.75	5.88	23%	120190	20458
Low	1,027,649	12.52	6.26	18%	94158	15041
Ponderosa Pine	**1,994,744**					
High	82,076	15.41	7.71	1%	7371	957
Moderate	677,317	16.42	8.21	12%	60827	7409
Low	1,223,591	9.79	4.90	22%	110803	22636
				Total:	508,740	85,779

1.2.3.2 Forest Carbon Sequestration

Changes in above ground, live carbon over time was used to calculate rates of carbon sequestration in both untreated and treated stands. A sixty-year time scale was chosen to measure changes in carbon sequestration. This time scale allows the impacts of forest treatments to be accounted for during and beyond the Project's lifespan. Differences in carbon sequestration rates for untreated and treated stands both with and without the occurrence of wildfire are provide below in Table 6.

[2] 1 BDT = 2 GT (assuming a moisture content on a wet basis of 50%) (UC Berkely, 2007)

Table 6. Forest Carbon Sequestration

Forest Stand Type	2024 Carbon/ acre (untreated, no fire)	2024 Carbon/acre (treated, no fire)	2084 Carbon/acre (untreated, no fire)	2084 Carbon/acre (treated, no fire)	2084 Carbon/ acre (untreated, with fire)	2084 Carbon/acre (treated, with fire)
White Fir						
High	83.92	70.75	136.64	137.89	136.38	137.56
Moderate	86.31	74.76	144.37	144.03	144.33	143.89
Low	55.19	50.15	123.54	124.8	123.57	124.68
California Mixed Conifer						
High	73.83	56.74	116.74	107.65	116.66	107.55
Moderate	48.25	40.04	104.82	93.14	104.65	92.95
Low	60.8	49.51	110.74	102.52	110.65	102.25
Ponderosa Pine						
High	57.15	42.15	107.42	91.65	107.38	91.1
Moderate	55.16	41.81	109.2	93.51	109.02	93.25
Low	52.12	36.31	98.58	88.01	97.44	87.86

Forest Stand Type	Acres	Sequestered Carbon (tons/acre) 2024-2084			
		Untreated, no fire	Treated, no fire	Untreated, with fire	Treated, with fire
White Fir	621,958				
High	131,698	52.72	67.14	52.46	66.81
Moderate	278,681	58.06	69.27	58.02	69.13
Low	205,765	68.35	74.65	68.38	74.53
California Mixed Conifer	3,048,147				
High	662,294	42.91	50.91	42.83	50.81
Moderate	1,317,049	56.57	53.1	56.4	52.91
Low	1,027,649	49.94	53.01	49.85	52.74
Ponderosa Pine	1,994,744				
High	82,076	50.27	49.5	50.23	48.95
Moderate	677,317	54.04	51.7	53.86	51.44
Low	1,223,591	46.46	51.7	45.32	51.55

Forest Stand Type	Acres	Relative Distribution	Sequestered Carbon (tons) 2024-2084			
			Untreated, no fire	Treated, no fire	Untreated, with fire	Treated, with fire
White Fir	621,958					
High	131,698	2.4%	6,943,119	8,842,204	6,908,877	8,798,743
Moderate	278,681	4.9%	16,180,219	19,304,233	16,169,072	19,265,218
Low	205,765	3.6%	14,064,038	15,360,357	14,070,211	15,335,665
California Mixed Conifer	3,048,147					
High	662,294	11.7%	28,419,036	33,717,388	28,366,052	33,651,158
Moderate	1,317,049	23.6%	7,405,462	69,935,302	74,281,564	69,685,063
Low	1,027,649	18.5%	51,320,791	54,475,673	51,228,303	54,198,208
Ponderosa Pine	1,994,744					
High	82,076	1.4%	4,125,960	4,062,762	4,122,677	4,017,620
Moderate	677,317	12.0%	36,602,211	35,017,289	36,480,294	34,841,186
Low	1,223,591	21.8%	56,848,038	63,259,655	55,453,144	63,076,116
		Total Tons C (Entire Project Area):	289,008,873	303,974,862	287,080,193	302,868,978
		Total Tons C (treatment areas):	87,525,344	92,057,742	86,941,250	91,722,830
		Sequestered Carbon/acre:	51.02	53.66	50.68	53.46

1.2.3.3 Total Carbon Impact

The total carbon impact of GSNR biomass only thinning projects utilized the Above ground, live carbon FVS output. Above ground, live carbon totals were compared across non-treated and treated scenarios at the time of treatment (2024). As provide below in Table 7, carbon removed annually equates to **11.89 tons/acre.**

Table 7. Carbon removed annually by GSNR only thinning projects

Forest Stand Type	Acres	2024 Carbon/ acre (non-treated)	2024 Carbon/ acre (treated)	Difference in Carbon/ acre	Acres Required to be Treated annually	Carbon/ acre Removed Annually
White Fir	**621,958**					
High	131,698	83.92	70.75	13.17	1666	0.26
Moderate	278,681	86.31	74.76	11.55	4063	0.55
Low	205,765	55.19	50.15	5.04	7436	0.44
California Mixed Conifer	**3,048,147**					
High	662,294	73.83	56.74	17.09	6113	1.22
Moderate	1,317,049	48.25	40.04	8.21	20458	1.96
Low	1,027,649	60.8	49.51	11.29	15041	1.98
Ponderosa Pine	**1,994,744**					
High	82,076	57.15	42.15	15	957	0.17
Moderate	677,317	55.16	41.81	13.35	7409	1.15
Low	1,223,591	52.12	36.31	15.81	22636	4.17
					Total:	**11.9**
					Carbon Tons/year :	1,020,770
					CO_2e – Metric tons/year	3,398,519
					Carbon - Total tons (20 yr) Project Life	20.4 million
					CO_2e – Total metric tons (20 yr) Project Life	67,913,288

However, as provided in Table 8, treated forest stands were found to sequester carbon at a greater rate over the course of the 60-year period. This increase is carbon sequestration is considered a carbon benefit and was therefore reduced from the total carbon impact.

Table 8. Changes in carbon storage due to GSNR only thinning projects

	Untreated, Without Fire	Treated, No Fire	Untreated, With Fire	Treated, With Fire
Sequestered Tons Carbon/acre 2024-2084	51.02	53.66	50.68	53.46
Increase from Treatment:		2.64 (4.9%)		2.79 (5.2 %)
Total Carbon Impact (Total Carbon Removed – Increase in Sequestered Carbon after Treatment):		**9.25**		**9.1**

1.2.3.4 Greenhouse Gas Emissions from Wildfire

FVS provides emissions outputs that can be used to compare the impact of forest treatments on greenhouse gas emissions from wildfire. The *Potential Smoke* output was used to calculate $PM_{2.5}$ emissions from wildfire 5 years after treatment in tons/acre using the high severity fire option. $PM_{2.5}$ emissions were then cross walked to the Fire Order Fire Effects Model (FOFEM) to quantify other emission types. Currently, FOFEM provides quantitative fire effects information for tree mortality, fuel consumption mineral soil exposure, smoke, and soil heating. Estimated emissions are included for CO_2, CH_4, and other pollutants not included in this analysis. Table 9 provides the cross walk from forest stand type to the FOFEM cover type.

Table 9. Crosswalk for determining FOFEM Cover Types from forest stand types

Forest Stand Type	FOFEM Cover Type
White Fir	
High	SAF 211 – White Fir (H)*
Moderate	SAF 211 – White Fir (T)**
Low	SAF 211 – White Fir (L)***
California Mixed Conifer	
High	SAF 243 – Sierra Mixed Conifer (H)
Moderate	SAF 243 – Sierra Mixed Conifer (T)
Low	SAF 243 – Sierra Mixed Conifer (L)
Ponderosa Pine	
High	SAF 245 – Pacific Ponderosa Pine (H)
Moderate	SAF 245 – Pacific Ponderosa Pine (T)
Low	SAF 245 – Pacific Ponderosa Pine (L)

*H= High fuel load adjustment, **T=No fuel load adjustment, ***L= Low fuel load adjustment

Emissions outputs for CO_2 and CH_4 were calculated for each forest stand type. FOFEM utilizes emission factors (Ward and Hardy 1991) and applies these to the fuel consumed in flaming and smoldering combustion to calculate for particulate and chemical emissions. Because of these defined emissions factors, CO_2 and CH_4, emissions were determined from the known $PM_{2.5}$emissions calculated in FVS. The factors used to determine emission types in relation to $PM_{2.5}$ emissions are provided below in Table 10.

Table 10. Emissions factors for determining air pollutants from known $PM_{2.5}$ emissions

Forest Stand Type	Emissions Factor (*$PM_{2.5}$)	
	CO_2	CH_4
White Fir	68.30	0.60
California Mixed Conifer	65.00	0.60
Ponderosa Pine	73.58	0.60

Total emissions over the Project's lifespan were calculated by multiplying predicted annual emissions in treated areas by 20 years. Reduction in wildfire emissions after treatment were determined by subtracting wildfire emissions from fires occurring within treated stands by the emissions that would occur in those same stands without treatment (Table 11).

Table 11. Emissions from wildfires in untreated and treated stands

Emission Type	Untreated Stands (tons)	Treated Stands (tons)	Emissions Reduction (tons)
CO_2	32,276,328	28,309,811	3,966,517
CH_4	335,967	294,371	41,597
$PM_{2.5}$	474,530	415,778	58,752

Emission types were converted into CO_2 equivalent (CO_2e) by applying Global Warming Potential (GWP) conversion factors. These conversion factors are provided below in Table 12

GWP is a measure used to compare the impact of different greenhouse gases on global warming relative to carbon dioxide (CO_2). It is a way to express the ability of each greenhouse gas to trap heat in the atmosphere over a specific time period. GWP is dimensionless and indicates how much heat a greenhouse gas will trap compared to CO2.

Carbon dioxide has a GWP of 1, which serves as the baseline. The term "CO_2 equivalent" (CO_2e) is used to describe the amount of greenhouse gases emitted, accounting for their GWP. It allows for the combined effect of different gases to be expressed as a single number, simplifying comparisons and reporting. This way, the combined impact of various greenhouse gases can be expressed in terms of the equivalent amount of CO_2.

Table 12. Global Warming Potential of wildfire emissions in untreated and treated stands

Emission Type	GWP Conversion Factor[3]	CO_2e Untreated	CO_2e Treated	CO_2e Reduction
CO_2	1	32,276,328	28,309,811	3,966,517
CH_4	28	335,967	294,371	943,381
			Total	**4,541,745**

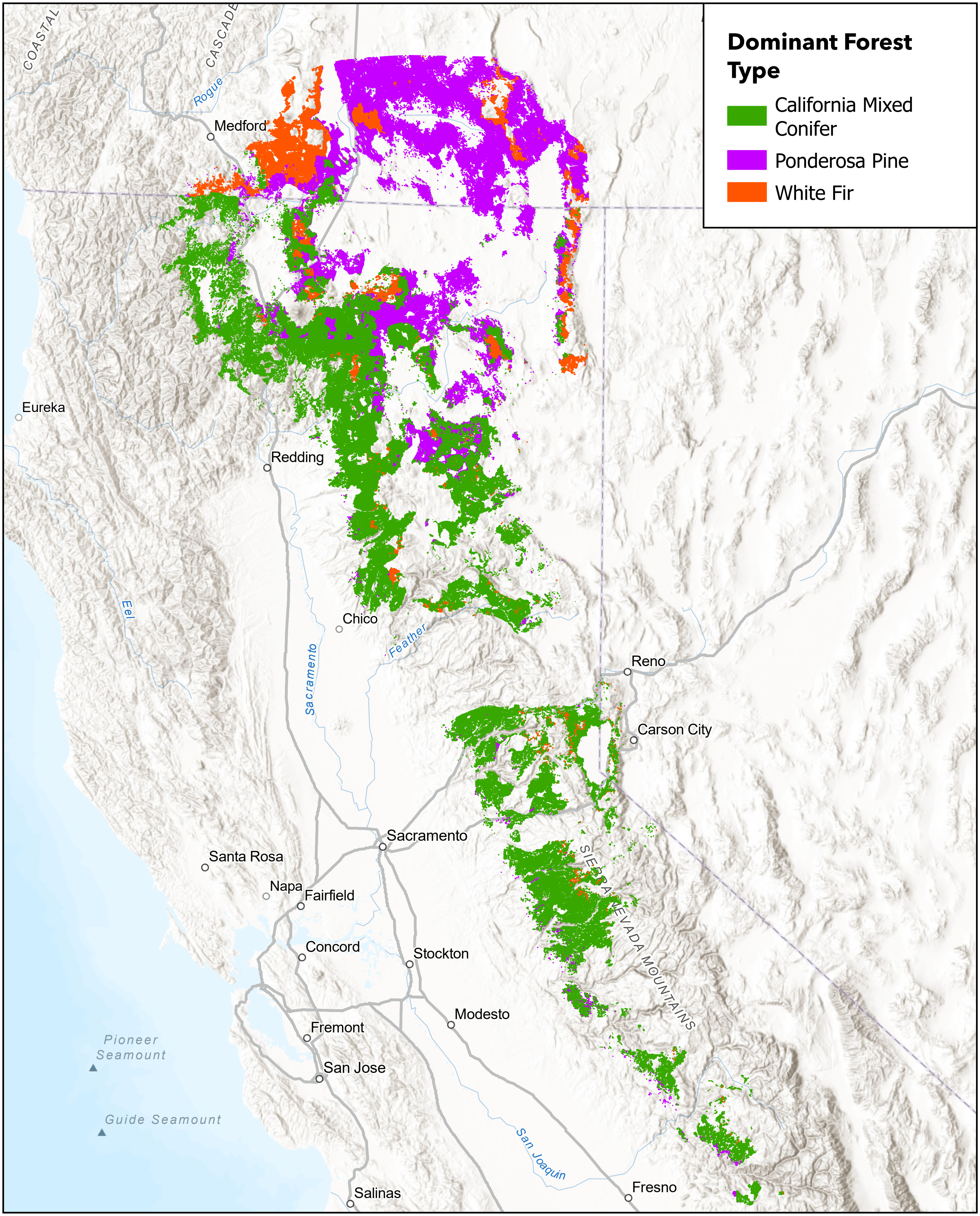
[3] Values for; values for CH_4 from IPCC, AR5.

1.2.3.5 Mortality From Wildfire

FVS provides outputs to predict wildfire related mortality. The *Potential Mortality – Percent Basal Area* output was chosen to estimate mortality. This output provides the proportion of total basal area subject to mortality from wildfire occulting 5 years after treatment during high severity wildfire conditions. Reductions in wildfire related mortality after treatment were determined by subtracting mortality estimates from fires occurring within treated stands by the mortality that would occur in those same stands without treatment Table 13.

Table 13. Differences in tree mortality in untreated and treated stands

Forest Stand Type	Relative Distribution	Mortality – Percent Basal Area (Untreated)	Mortality – Percent Basal Area (Treated)	Mortality Reduction (Unscaled)	Mortality Reduction (Scaled)
White Fir					
High	2.4%	94.85%	65.17%	29.7%	0.7%
Moderate	4.9%	73.10%	46.67%	26.4%	1.30%
Low	3.6%	80.10%	72.30%	7.8%	0.3%
California Mixed Conifer					
High	11.7%	69.02%	28.20%	40.8%	4.8%
Moderate	23.6%	46.95%	26.99%	20.0%	4.7%
Low	18.5%	56.42%	30.61%	25.8%	4.8%
Ponderosa Pine					
High	1.4%	64.43%	31.00%	33.4%	0.5%
Moderate	12.0%	49.99%	26.80%	23.2%	2.8%
Low	21.8%	52.25%	32.80%	19.5%	4.2%
				Total:	**24.1%**



DUDEK

Source: USFS National Forest Type Dataset

FIGURE 1

Dominant Forest Types

Forest Resiliency Program

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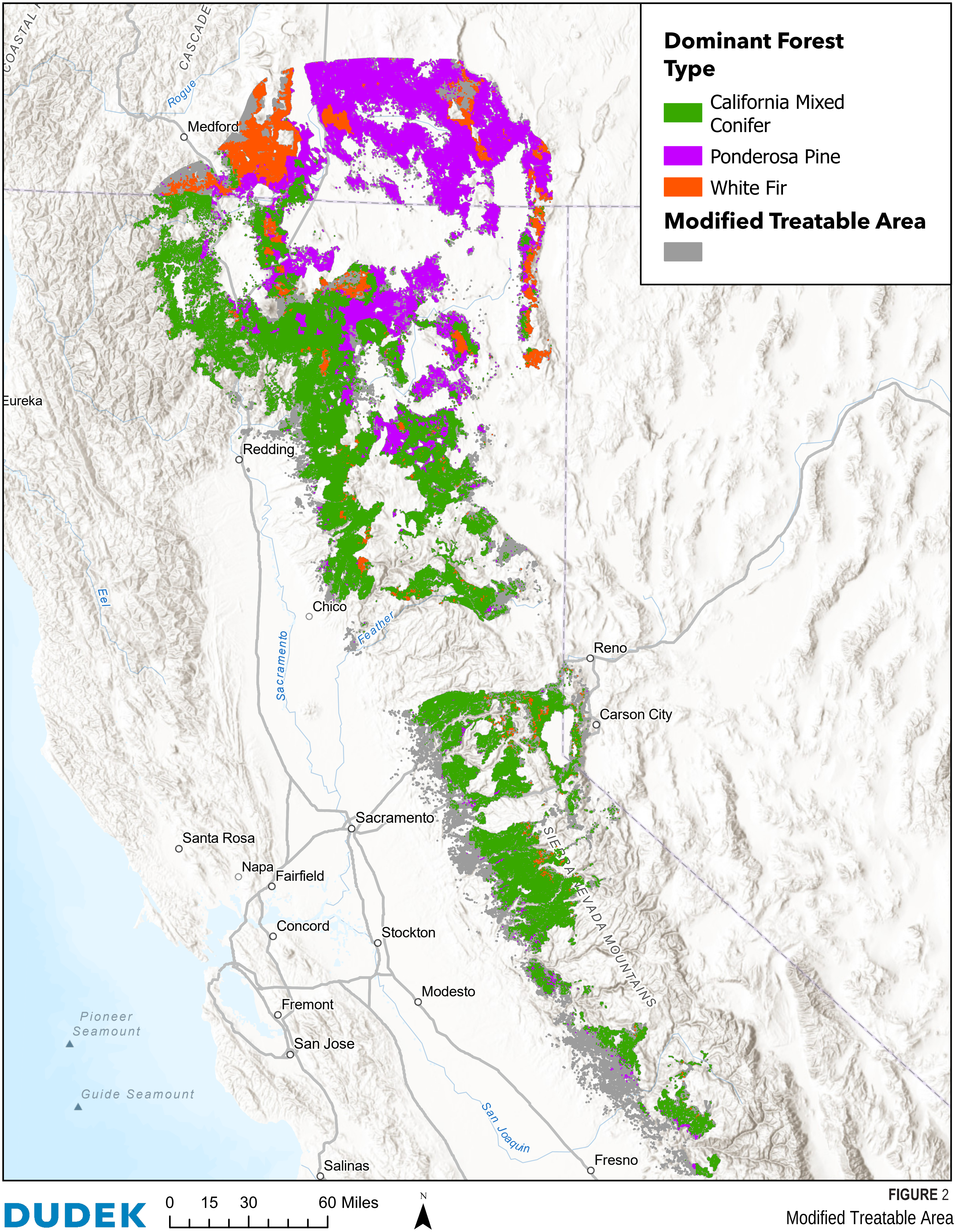

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Source: USFS National Forest Type Dataset

FIGURE 2
Modified Treatable Area
Forest Resiliency Program

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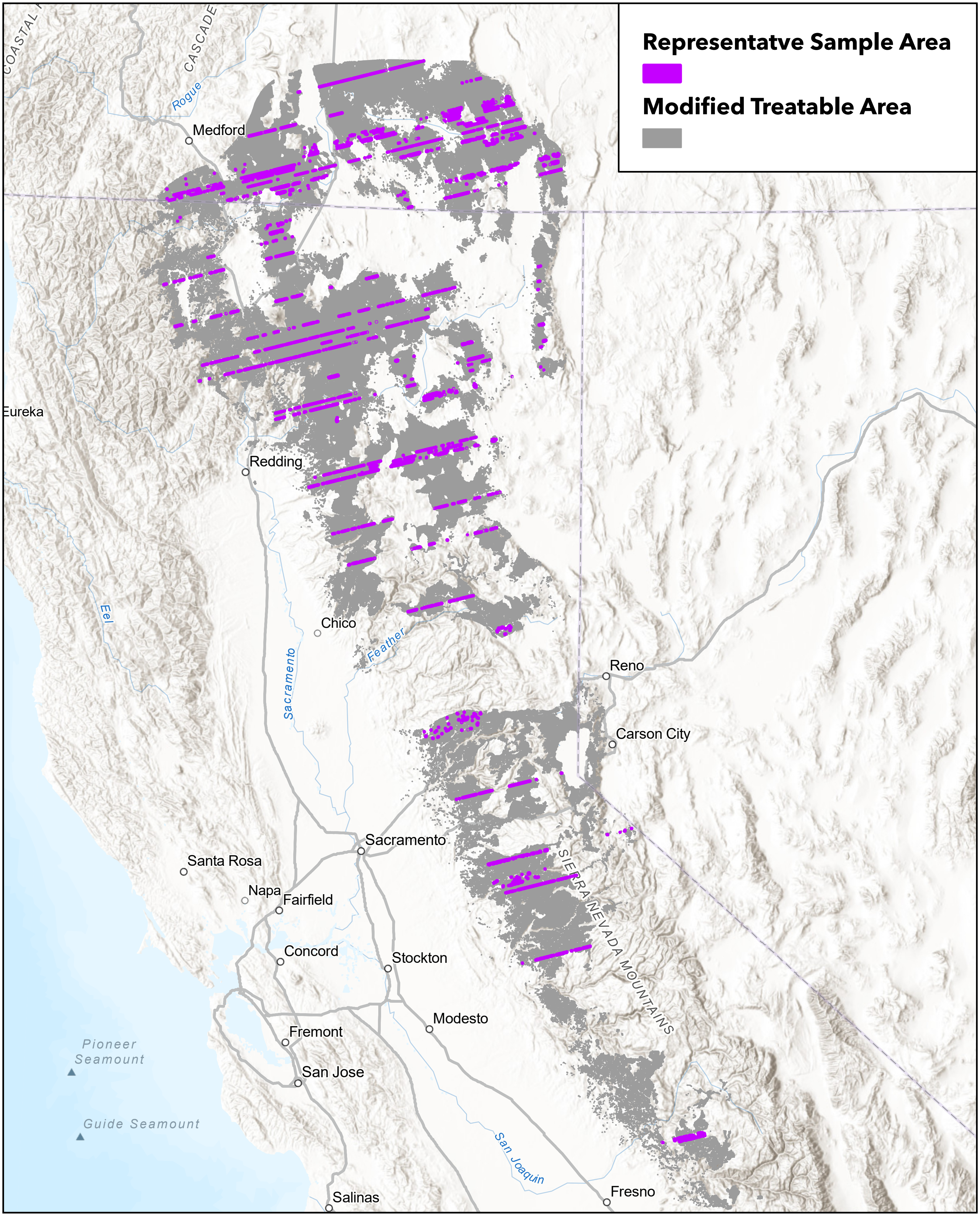

DUDEK

Source: USFS National Forest Type Dataset

FIGURE 3
Representative Sample Area
Forest Resiliency Program

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