Forest Service
Region 5 Ecology Program
Sierra Cascade Province

Post-fire Restoration Opportunities for Conifer Forest, Plumas NF Fires 2017-2020

North Complex (2020), Sheep (2020), Walker (2019), Camp (2018), and Minerva (2017)

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Cover photo: Mosaic of burn severities within the 2020 North Complex Fire on the Plumas National Forest. Photo credit: Kyle Merriam, Region 5 Ecology Program.

Summary

This document provides an overview of the process used to identify restoration opportunities for mixed conifer forests within and adjacent to five large (> 200 acre) fires that occurred at least partially on the Plumas National Forest (PNF) between 2017 and 2020. This analysis considers 1.25 million acres across all ownerships within watersheds that contain the North Complex Fire (2020), Sheep Fire (2020), Walker Fire (2019), Camp Fire (2018) and Minerva Fire (2017). It uses the science-based approach outlined in the "Postfire Restoration Framework for National Forests in California" (GTR-270, Meyer et al. 2021) to identify a broad range of potential restoration opportunities to increase, maintain, and restore resilience on 396,548 acres of conifer forest. Approximately 60% of these acres are in areas directly impacted by the five focal fires, while the remainder are outside of the fire perimeters, but within affected watersheds. Analysis results are captured within a geodatabase (**GTR270_PNF_5Fire.gdb**) to assist with post-fire restoration planning on the Plumas and Lassen National Forests. A description of geodatabase contents is contained in **Appendix A**.

This assessment does not provide site-specific proposed actions. Therefore, development of future restoration projects will require additional refinement and prioritization using an interdisciplinary approach, as well as further analyses, field surveys, and ground-truthing. A portion of the analysis area subsequently burned in the 2021 Dixie Fire. These areas are included in the analysis but excluded from final restoration opportunities. Restoration opportunities for all areas within the Dixie Fire perimeter are found in "Post-fire Restoration Opportunities for Conifer Forest in the 2021 Dixie and Sugar Fires" (USDA FS 2022).

Overview of Focal Fires

Between 2017 and 2020, five large fires burned at least partially on the Plumas National Forest (Table 1). Individual fires ranged in size from the 4,339-acre Minerva Fire (2017) to the 318,168-acre North Complex (2020). The Camp Fire (2018) totaled 153,575 acres, the Walker Fire (2019) 58,790 acres, and the Sheep Fire (2020) 29,545 acres. Together, these fires burned 558,483 acres, impacting 24% (292,648 acres) of lands administered by the Plumas National Forest, as well as acreage on the Lassen National Forest (4,512 acres), and private, state-owned, or BLM lands (261,283 acres).

Table 1. Distribution of focal fire acres across Plumas (PNF) and Lassen (LNF) National Forests, and other ownerships.

Fire	Year	PNF Acres	LNF Acres	Other Acres	Total Acres
Minerva	2017	4,251	0	88	4,339
Camp	2018	32,343	0	121,232	153,575
Walker	2019	57,432	0	1,358	58,790
North	2020	197,372	0	120,796	318,168
Sheep	2020	4,627	4,512	20,406	29,545
Total Acres		**292,648**	**4,512**	**261,323**	**558,483**

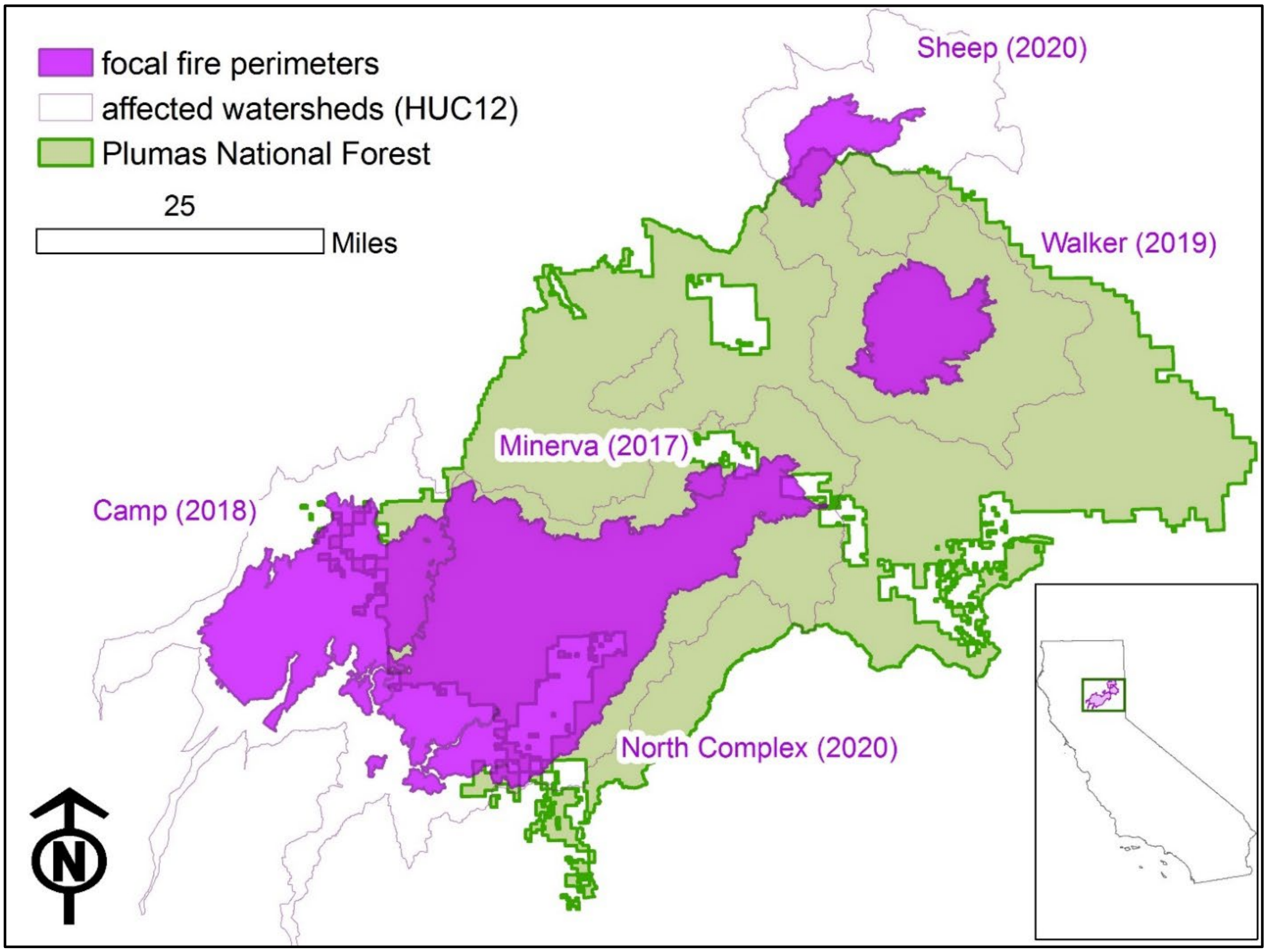


Figure 1. Location of focal fires in northern California and on the Plumas NF.

The five focal fires span a broad elevational gradient from 300 ft. to 7,400 ft. traversing the Sierra crest from the Central Valley to the Great Basin. Fire areas support a mosaic of vegetation types, including conifer forest, oak woodlands, aspen stands, montane and foothill chaparral, annual grassland, meadow, and riparian habitats (**Figure 2**).

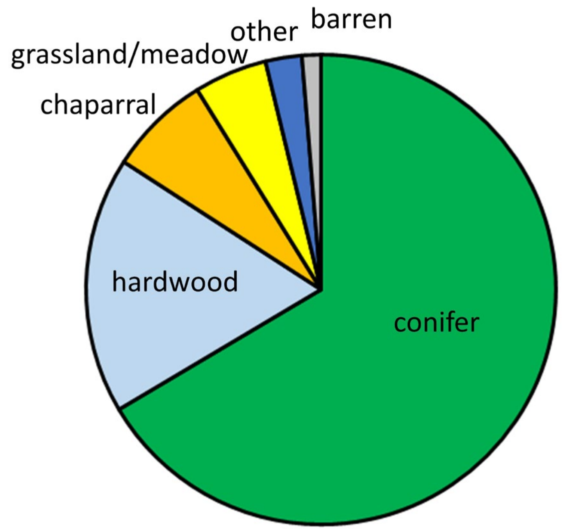


Figure 2. Vegetation type proportions within focal fires. Source: CalVeg (2022).

We obtained fire perimeter and satellite-derived estimates of fire severity for the five focal fires from the USDA Forest Service Rapid Assessment of Vegetation Condition after Wildfire (RAVG) program. For this analysis, we combined RAVG severity estimates from all five fires into one data layer. Where the fires overlapped, the higher of severities was utilized. We chose basal area loss as our metric of fire severity, which will be used throughout this analysis (**Table 2**).

Table 2. Fire severity categories and definitions used in this assessment. Data provided by the USDA FS RAVG program.

Fire severity category	Definition
Unchanged	0% basal area mortality
Low	0 < basal area mortality < 25%
Moderate	25 ≤ basal area mortality < 75%
High	> 75% basal area mortality

Approximately 47% of the focal fire area experienced high severity fire effects (i.e., more than 75% of the pre-fire basal area was killed), most of which occurred in large contiguous patches. By contrast, 14% burned at moderate severity (25-75% basal area mortality) and 19% burned at low severity (0-25% basal area mortality), while the remainder (20%) was characterized as unchanged by the fire (**Figure 3**).

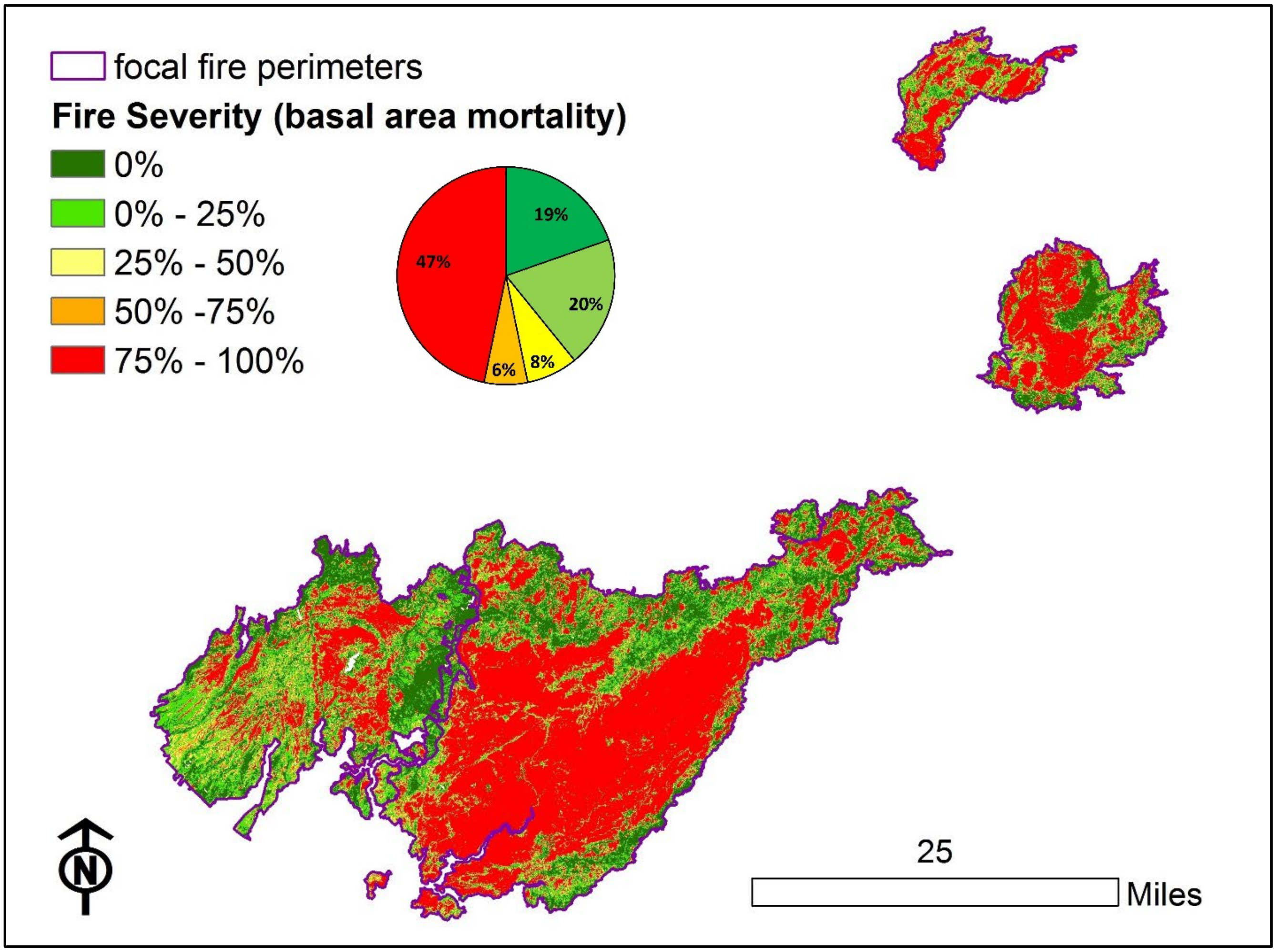


Figure 3. Burn severities of focal fires. Burn severity is expressed as percent basal area loss, as determined from post-fire imagery (Rapid Assessment of Vegetation).

POST-FIRE RESTORATION ASSESSMENT PROCESS

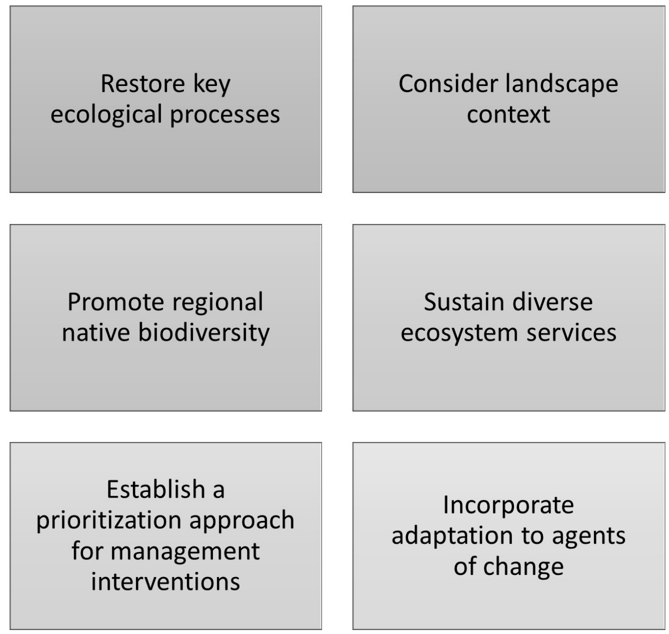


Figure 4. The six ecological principles that provide the foundation for the post-fire assessment process. From Meyer et al. 2021.

This assessment follows the process outlined in the "Postfire restoration framework for National Forests in California" (Meyer et al. 2021). This framework provides a science-based approach for developing restoration opportunities across large landscapes that have been impacted by wildfire. It is rooted in a set of ecological principles (**Figure 4**) and uses a five-step assessment process (**Figure 5**) to guide development of potential restoration opportunities (**Figure 6**), which can ultimately be used to inform post-fire project planning and monitoring efforts. The focus of this document is to describe the goals and objectives, methods, and broad restoration opportunities identified for mixed conifer forests within focal fires (e.g., steps 1-3, **Figure 5**). Site-specific management actions, which are not included in this assessment, will require additional refinement and prioritization, as well as further analyses, field surveys, and ground-truthing.

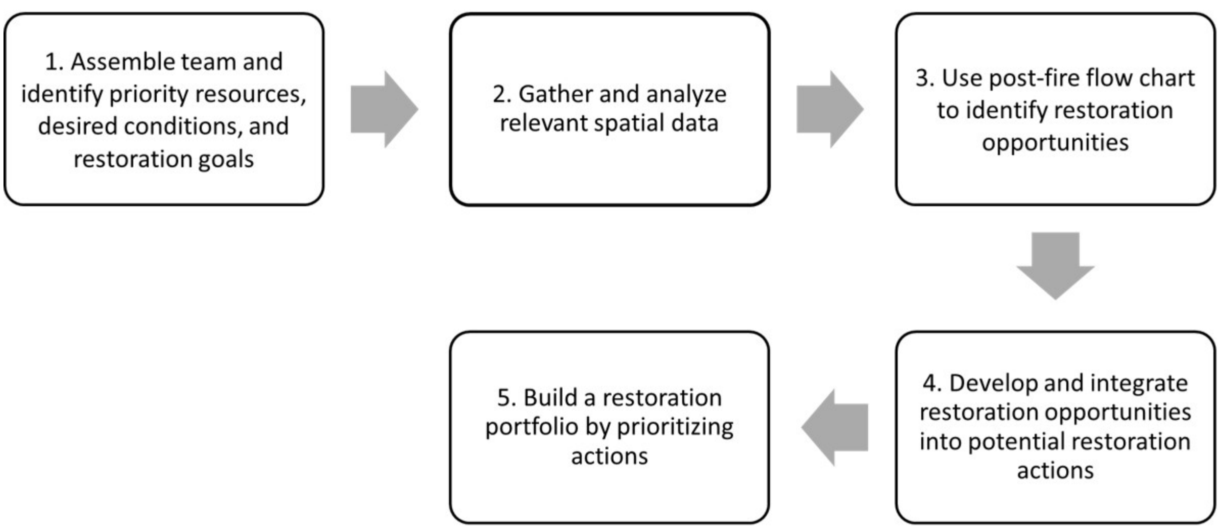


Figure 5. The five-step process used in the post-fire restoration framework. From Meyer et al. 2021.

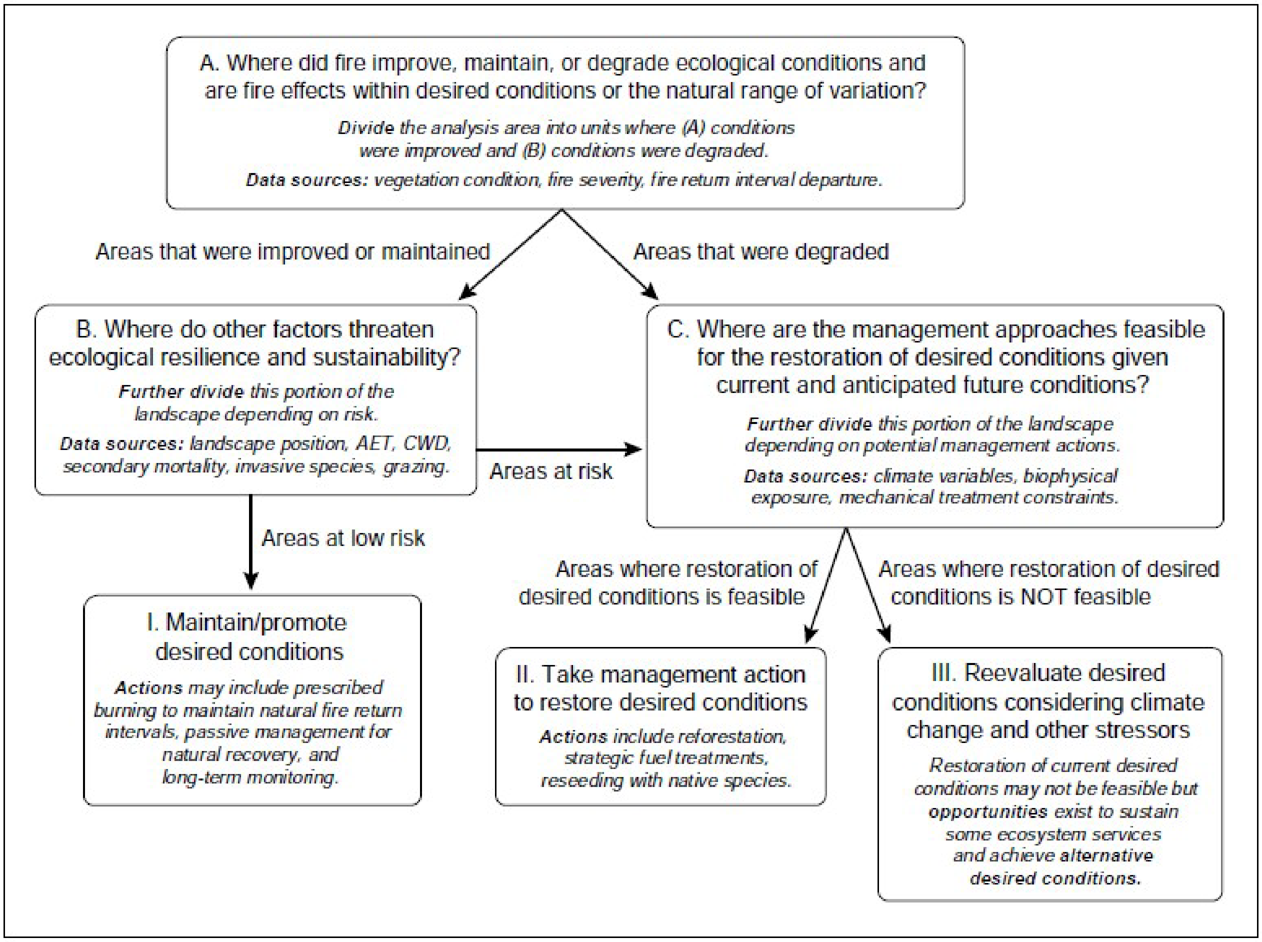


Figure 6. The post-fire flow chart from Meyer et al. 2021. This process uses three questions (A, B, and C) to identify management responses or "restoration opportunities" (1,2, and 3) in different portions of the post-fire landscape.

STEP 1: ASSEMBLE TEAM, IDENTIFY PRIORITY RESOURCES AND RESTORATION GOALS

Assessment Team

Our first step was to assemble a small team of specialists with the following attributes: familiarity with the burned landscape; knowledge of silviculture, fire, and forest ecology; familiarity with National Forest priorities and constraints; and would ultimately be involved in post-fire restoration efforts. Team members include Kirsten Bovee (project lead, UC Davis Research Associate), Michelle Coppoletta (Associate Province Ecologist, USFS), and Will Brendecke (Plumas NF Silviculturist).

Priority resource: Conifer Forest

The focus of our assessment is conifer forest vegetation. We selected this resource because of its dominance within the impacted landscape, its ecological significance (e.g., for forest-dependent wildlife species), and because it is often a priority for forest restoration and fuel reduction activities in this region. Prior to these focal fires, conifer forest vegetation types occupied 67% of the landscape (Figure 7).

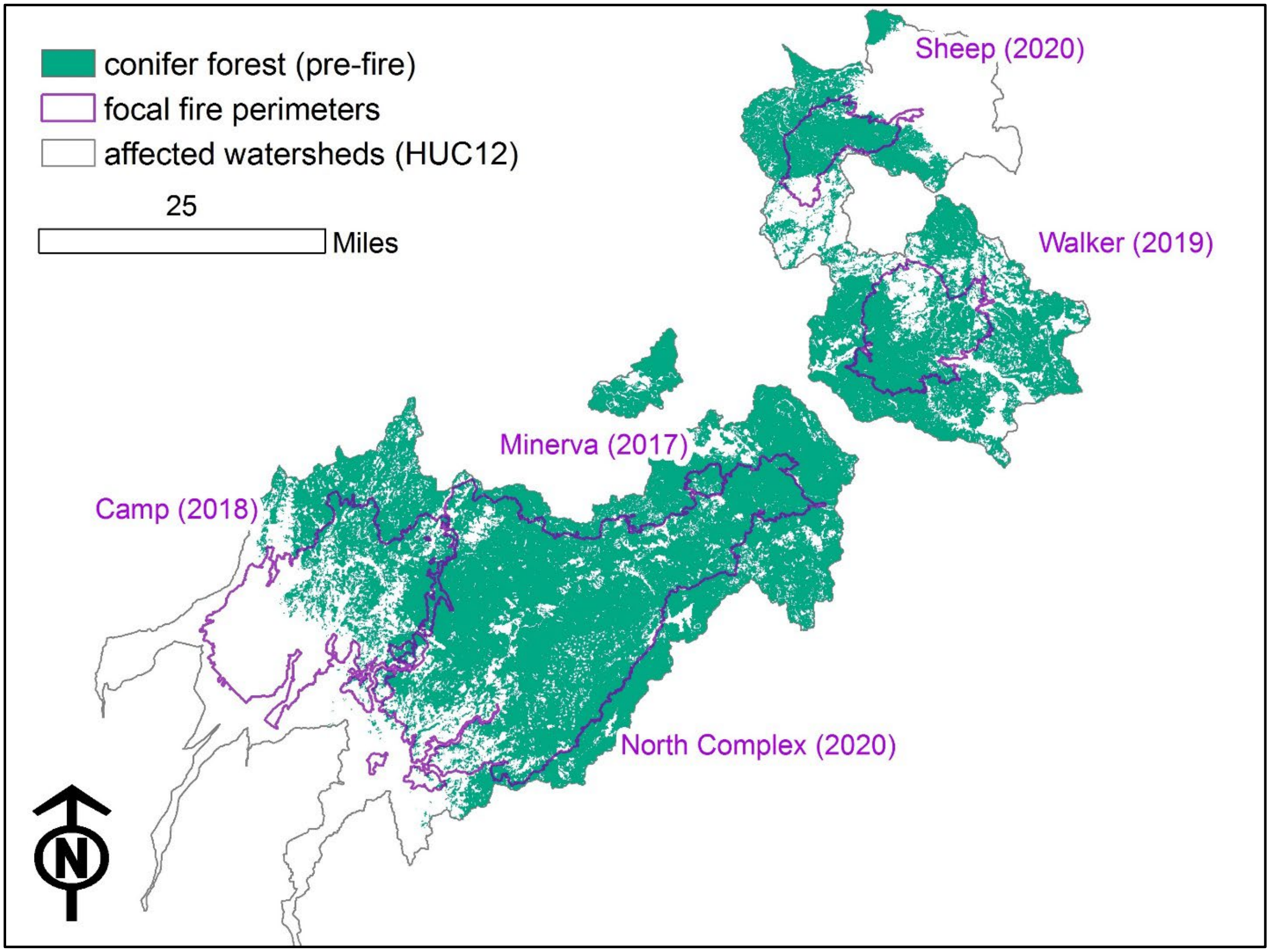


Figure 7. Extent of conifer forest within the analysis area prior to focal fires (CalVeg).

Apart from red fir forests, most of the conifer forest types in the assessment area are characterized by a mixture of pine, white fir, Douglas fir, incense-cedar, and some component of California black oak (Table 3). Fires in these stands were historically frequent, occurring at mean intervals of 11-16 years and resulting in predominantly low-moderate severity fire effects (Safford and Stevens 2017). Conifer stands dominated by red fir are generally found at higher elevations and on moister sites within the assessment area, however red fir vegetation types comprise a minor component of the analysis area. These forest types were historically characterized by longer and more varied fire return intervals but were also generally dominated by low-moderate severity fire effects (Meyer and North 2019, Coppoletta et al. 2021).

Table 3. California Wildlife Habitat Relationship (CWHR) vegetation types included in our assessment of conifer forest, and number of acres of each forest type within the focal fire footprint and affected watersheds.

Forest Type	Primary Species	Acres within focal fires (%)	Acres outside of focal fires (%)
Sierran Mixed Conifer (SMC)	Douglas fir, ponderosa pine, white fir	208,044 (56%)	209,249 (56%)
Montane Hardwood-Conifer (MHC)	ponderosa pine, incense cedar, California black oak	61,555 (16%)	15,614 (4%)
White Fir (WFR)	white fir, Douglas fir, sugar pine	49,073 (13%)	49,031 (13%)
Ponderosa Pine (PPN)	ponderosa pine, Jeffrey pine, Douglas fir	29,967 (8%)	21,957 (6%)
Eastside Pine (EPN)	ponderosa pine, Jeffrey pine, white fir	18,038 (5%)	60,077 (16%)
Red Fir (RFR)	red fir, white fir, lodgepole pine	3,193 (<1%)	12,298 (3%)
Jeffrey Pine (JPN)	Jeffrey pine, ponderosa pine, sugar pine	2,513 (<1%)	3,400 (1%)
Douglas fir (DFR)	Douglas fir, tanoak, ponderosa pine	2,058 (<1%)	15 (<1%)
Total Conifer Forest Types		374,441 acres	371,640 acres

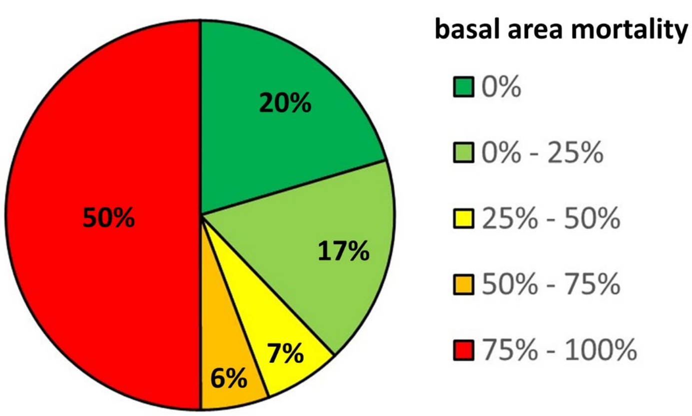


Figure 8. Proportion of conifer forest that experienced varying intervals of basal area mortality.

Approximately 50% of conifer forest experienced high severity fire effects (i.e., more than 75% of the pre-fire basal area was killed), most of which occurred in large contiguous patches. By contrast, 13% burned at moderate severity (25-75% basal area mortality) and 17% burned at low severity (0-25% basal area mortality), while the remainder (20%) was characterized as unchanged by the fire (Figure 8).

Restoration goals

The assessment team identified the following three restoration goals for conifer forests impacted by the five focal fires:

1. Reduce the risk of uncharacteristically severe wildfire, particularly in and adjacent to high value resources (i.e., rural communities, late-seral conifer forest habitat, remnant conifer stands, etc.).
2. Increase the resilience of surviving forests to future disturbance (i.e., fire, drought, insects, and disease).
3. Facilitate forest recovery through reforestation and natural regeneration.

Scale

The 1.26-million-acre assessment area includes the combined footprint of the five focal fires, as well as the sub watersheds (HUC12) that subtend the fire areas (**Figure 9**). It encompasses burned and unburned forest vegetation across all ownerships including the National Forest System (Plumas and Lassen National Forests), and other ownerships (BLM, state, private lands). There are no wilderness areas within the analysis area.

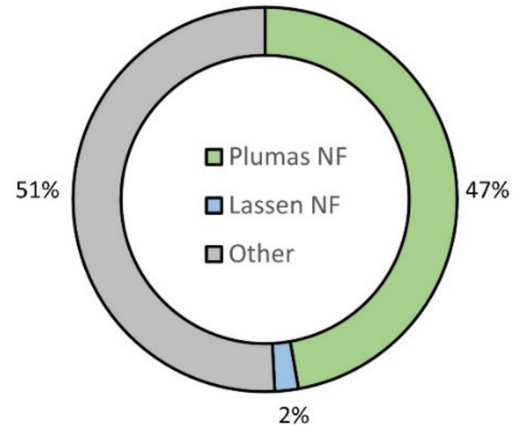


Figure 9. Proportion of analysis area on the Plumas NF, Lassen NF, and other ownerships.

STEP 2: GATHER AND ANALYZE RELEVANT SPATIAL DATA TO INFORM DECISION FRAMEWORK

To conduct this analysis at a broad scale with consistency across fires, we relied on spatial data that were available across the analysis landscape, rather than information collected from post-fire field surveys. The spatial datasets used in this assessment are listed in **Table 4**.

Table 4. Spatial data used in the Plumas 5 Fire assessment.

Data type	Data source	Description/Source
Fire severity	Rapid Assessment of Vegetation Condition after Wildfire (RAVG) program; USDA Forest Service, Geospatial Technology and Applications Center (https://burnseverity.cr.usgs.gov/ravg/)	Reclassified the 7-class basal area mortality layer (rdnbr_ba7.tif) into a 5-class basal area mortality layer for 5 focal fires, as well as past fires (1997-2019); includes fire perimeter data
Pre-fire vegetation	Existing vegetation; CALVEG, USDA Forest Service, Pacific Southwest Region. (https://www.fs.usda.gov/detail/r5/landmanagement/resourcemanagement/?cid=stelprdb5347192)	Used California Wildlife Habitat Relationships (CWHR) in the Calveg layer to identify vegetation type.
Conifer regeneration	Outputs from the Post-fire Spatial Conifer Regeneration Prediction Tool (POSCRPT) (https://stewartecology.shinyapps.io/POSCRPT_dev_version/)	Used mean seed availability and mean precipitation outputs (Stewart et al. 2021) to identify areas with potential natural conifer regeneration

Data type	Data source	Description/Source
Pre-fire management	Forest Activity Tracking System (FACTS), USDA Forest Service (https://data.fs.usda.gov/geodata/edw/)	Filtered to only include vegetation and fuels treatments completed between 1997-2021
Stand density index (SDI), Basal Area	Landscape Ecology Modeling, Mapping, and Analysis (LEMMA) Team. Gradient Nearest Neighbor (GNN) raster dataset modeled forest vegetation data. https://lemma.forestry.oregonstate.edu/data	Continuous cover of SDI (Reinecke) at 30-m resolution as modelled pre-fire (2016). Basal area estimates for sugar pine (SP), Jeffery pine (JP); ponderosa pine (PP), white fir (WF), red fir (RF), Shasta fir (SH), Douglas fir (DF), and total BA.

STEP 3. USE POST-FIRE FLOW CHART TO IDENTIFY RESTORATION OPPORTUNITIES

We used the post-fire decision process, described in **Figure 6** (Meyer et al. 2021), to spatially partition the burned landscape and identify potential opportunities for restoration. This process involved answering a series of four questions for each stand within the analysis area to determine where post-fire stand conditions were within or departed from NRV (**Figure 10**):

1. Were fire effects within the natural range of variation (NRV)?
2. Are conifers predicted to regenerate naturally post-fire?
3. Was stand structure and composition within NRV prior to focal fires?
4. Are high volumes of fire-generated fuels predicted?

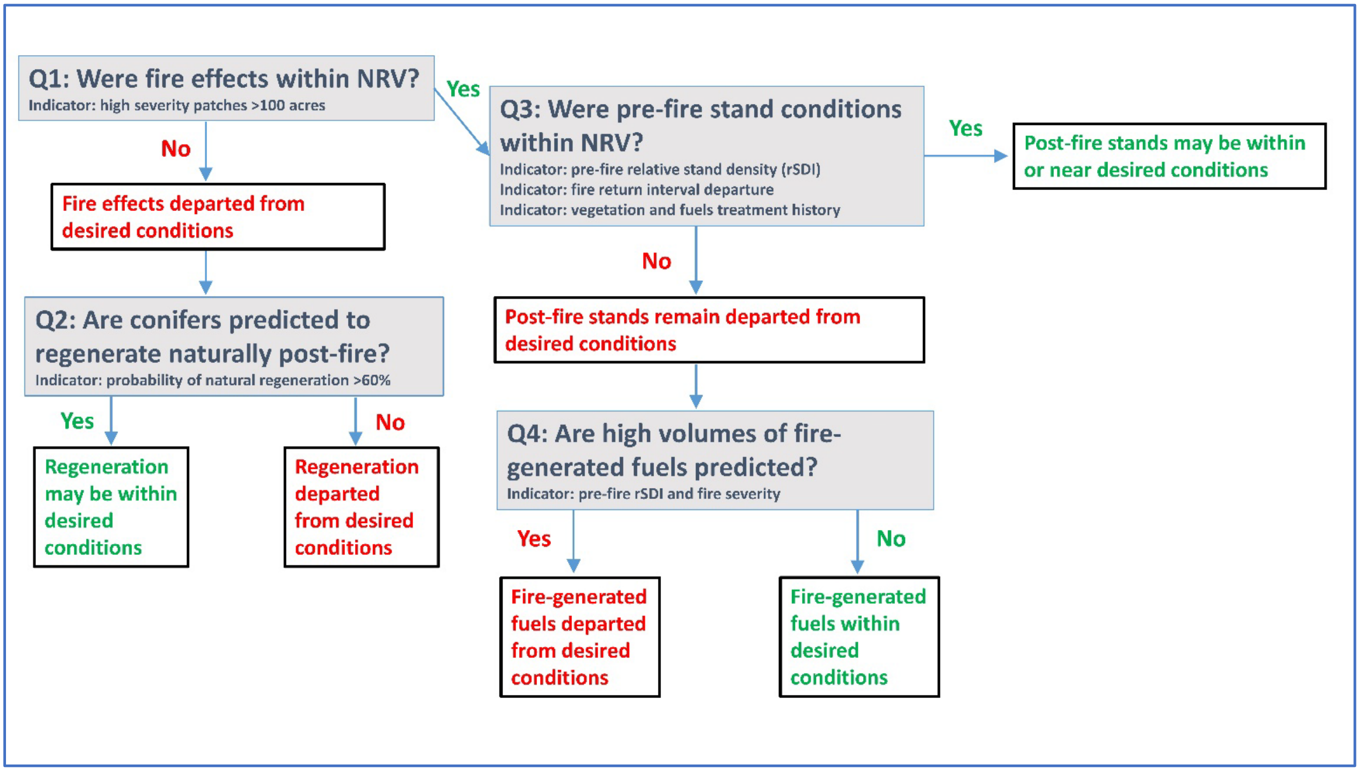


Figure 10. The decision process used to spatially partition the focal fire landscape and identify potential restoration opportunities for mixed conifer forests.

Question 1: Where were fire effects within the natural range of variation (NRV)?

The first step in the assessment process was to spatially partition the landscape into two broad bins, based on an evaluation of fire effects. We relied on fire severity (RAVG) data and pre-fire vegetation layers to identify areas where fire effects to conifer vegetation were within the natural range of variation (NRV) and where they were departed. We considered forested stands that burned at low-moderate severity or experienced relatively small (<100 acres) patches of high severity to be most aligned with the characteristics of the natural fire regime (i.e., within the NRV; Safford and Stevens 2017). These areas are most likely to have forest conditions that were improved or maintained by the fires. In contrast, we considered large contiguous patches of high severity fire (i.e., where >75% of the trees were killed) to be outside of the NRV for these forest types.

Fire Effects Indicator #1: High Severity Patch Size

To identify contiguous patches of high-severity fire effects (>75% basal area mortality), we used the patch delineation algorithm PatchMorph in ArcGIS (Girvetz and Greco 2007). We constrained our analysis to areas that were mapped as mixed conifer forest in 1999; this allowed us to account for areas that experienced stand-replacing high severity fire prior to the focal fire. We specified a maximum gap thickness and spur threshold of 90-m (or three 30-m pixels). This function included thin areas ("gaps") of low-moderate severity within a high severity patch if it was less than 90-m wide; it also excluded small areas ("spurs") of high severity if they were thinner than 90-m. We used a minimum patch size of 1.2 acres (0.5 ha). We also used a smoothing tolerance of 90% within a 2-pixel window to create a patch perimeter entirely within high severity pixels (i.e., no slivers of low-moderate severity pixels along the inside of patch edges).

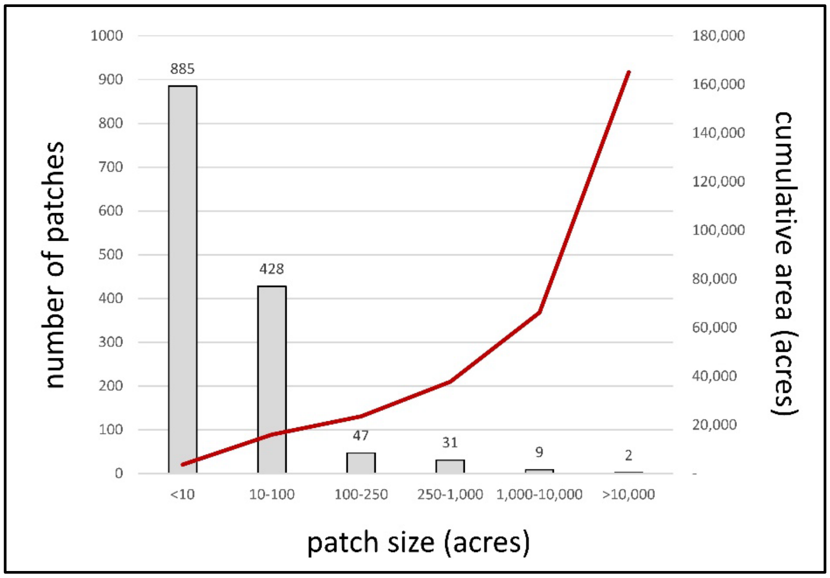
Areas with contiguous high severity fire effects were assigned an NRV departure category based on total patch size (**Table 5**). It is important to note that not all patches of high-severity fire were considered departed from NRV. Small patches of high severity fire were relatively common in mixed conifer forests historically, playing an important ecological role in regeneration, particularly for shade-intolerant species like pine. In this assessment we considered high severity patches that were greater than 100 acres to be departed from NRV, with this threshold considered at the upper end of the NRV for these forest types (Safford and Stevens 2017).

Table 5. Departure based on fire severity and patch size. High severity patches were limited to areas that were characterized as mixed conifer forest in 1999. Acres and number of patches include all lands within the assessment area, including NFS and private.

Indicator	Fire Effects	Number of patches	Acres
High severity patches < 100 acres, includes some areas on the edge of patches	Within NRV	1,313	16,063
High severity patches >100 acres	Outside of NRV	89	148,993
Total		**1,402**	**165,056**

In areas that were conifer forest prior to the focal fires, we identified a total of 1,402 high severity patches. These patches ranged in size from our defined minimum of 1.2 acres to two patches exceeding 10,000 acres: a 61,825-acre patch and a 36,965-acre patch, both within the North Complex. Mean patch size was 118 acres, but this value is strongly skewed by very large patches. Median patch size (6.1 acres) better captures the high number of small patches within NRV. Small patches (<100 acres) accounted for 94% of the total number of high severity patches, but represented just 10% of the total high severity patch area. In contrast, the two largest patches (>10,000 acres) accounted for two-thirds of the total area burned in high severity patches. In all, high severity patches greater than 100 acres (i.e., considered outside of NRV) accounted for 90% of the total area burned in high severity patches (**Figure 11**, **Figure 12**).

Figure 11. Distribution of high severity patches (defined as >75% basal area mortality) and cumulative area by patch size class within focal fires (combined). Values above bars represent the number of patches within that size class. Line shows cumulative area.



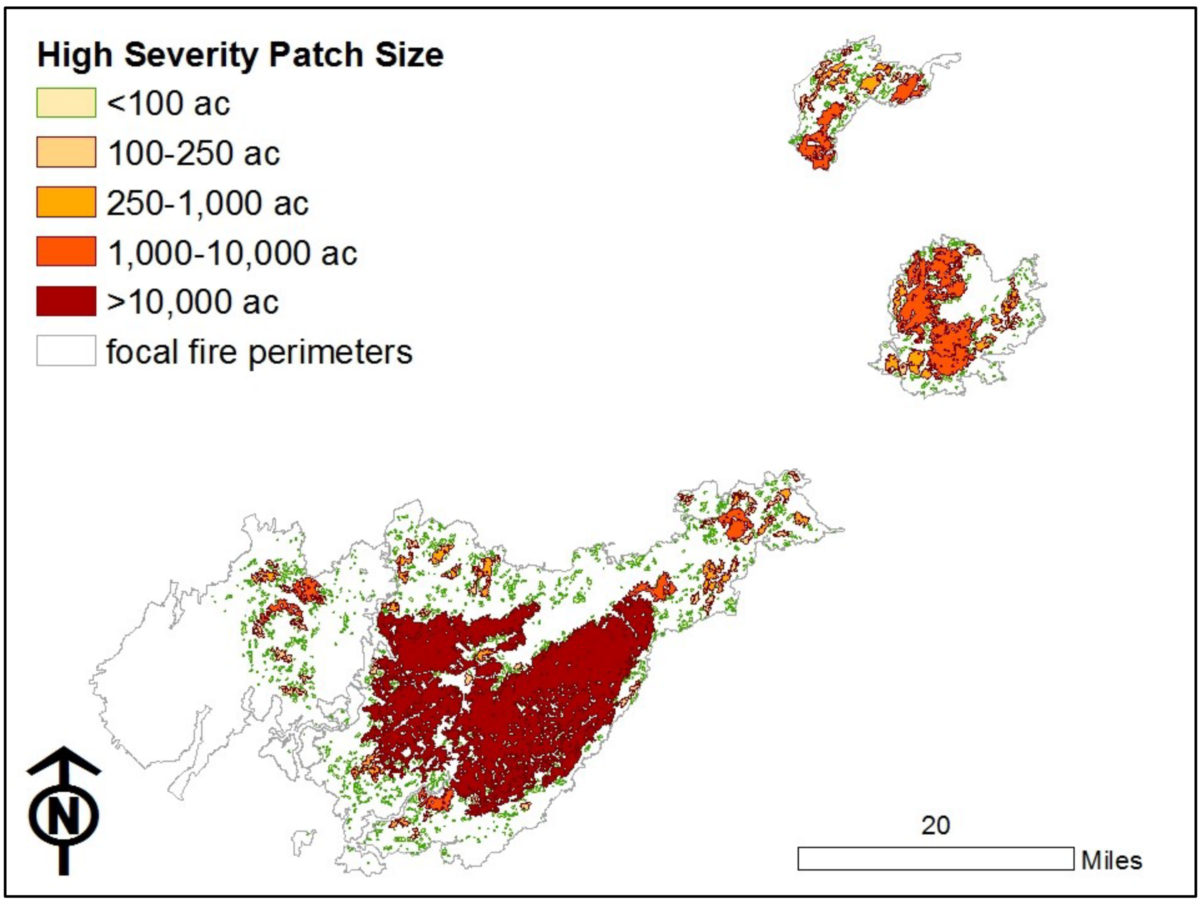


Figure 12. High severity patches in conifer forest, symbolized by patch size. Patch sizes greater than 100 acres are considered outside of the natural range of variation (NRV) for these forest types.

Question 2: Where are conifers unlikely to regenerate in the near-term?

We used the spatially explicit Post-fire Spatial Conifer Regeneration Prediction Tool (POSCRPT) to identify areas on the landscape that were unlikely to naturally regenerate in the near-term without active intervention. The POSCRPT model combines seed availability with climatic, topographic, and burn severity data to produce a predictive map of potential conifer regeneration five years after fire (Shive et al. 2018, Stewart et al. 2021). It combines six of the most common conifer species found in California's yellow pine and mixed conifer forests (Douglas fir, incense cedar, Jeffrey pine, ponderosa pine, sugar pine, and white fir) into a single presence/absence variable. The output is a GIS-based prediction map, with five predicted probability classes mapped across the burn area that relate to the probability of observing at least one regenerating conifer five years after fire at the 60-m^2 (field plot) scale. We used outputs for all conifers combined, using the mean seed production and mean precipitation (unchanged from 30-year mean) scenario.

We used pre-fire vegetation maps to include only areas that were conifer forest prior to the focal fires, excluding chaparral and other non-forest vegetation types that have naturally low conifer regeneration potential. We also excluded areas with precipitation levels that were outside the range of the model, where uncertainty in predictions were high.

In areas that were conifer forest prior to the focal fires, 221,364 acres (59%) were predicted to have a higher (>60%) likelihood of natural regeneration in the near-term. By contrast, 153,135 acres (41%) were within the three lowest prediction classes (<60%). Field data indicate that the median seedling density for the two lowest prediction classes is 0 seedlings/ha, suggesting that these areas will likely have little to no conifer regeneration in the short-term (**Figure 13**).

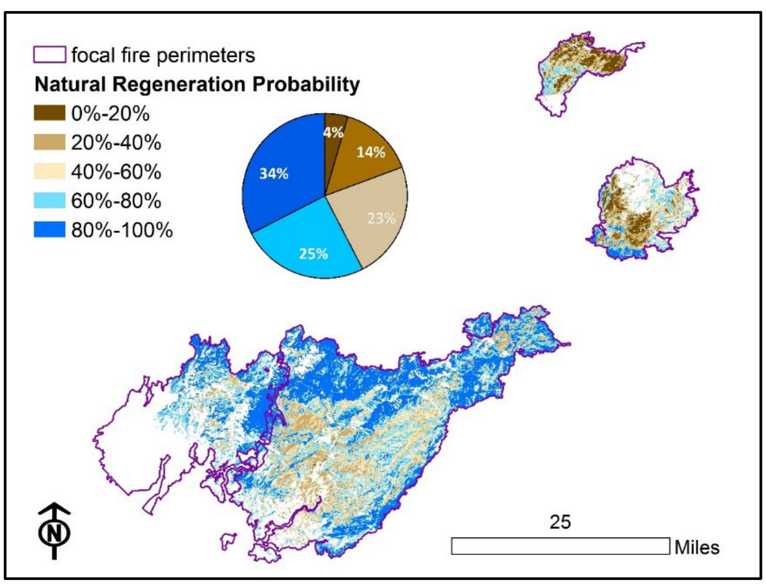


Figure 13. Probability of natural regeneration (modelled with POSCRPT, using mean precipitation and mean seed availability parameters.

Regeneration Indicator #1: Probability of natural regeneration within large high severity patches (>100 acres)

To identify opportunities for reforestation, we overlaid areas that had low-moderate potential for natural regeneration (<60% probability) with large high severity patches (>100 acres, see **Table 6**, **Figure 14**). These are areas within the fire perimeter where management actions are most likely needed to facilitate forest recovery (Restoration Goal #3). The highest priority would be reforestation of larger high severity patches (>100 acres); however reforestation may be prioritized within smaller patches (10-100 acres) or in high value areas (e.g., California spotted owl allocations), or areas predicted to serve as conifer forest refugia at mid-century (see prioritization filters).

Table 6. Probability of natural regeneration within conifer forest within large (>100 acres) high severity patches as predicted with POSCRPT model.

Indicator (High Severity Patches >100 acres only)	Acres	Percent
Probability of Natural Regeneration **>60%**	34,524	23%
Probability of Natural Regeneration **<60%**	113,818	77%
Total	**165,056**	

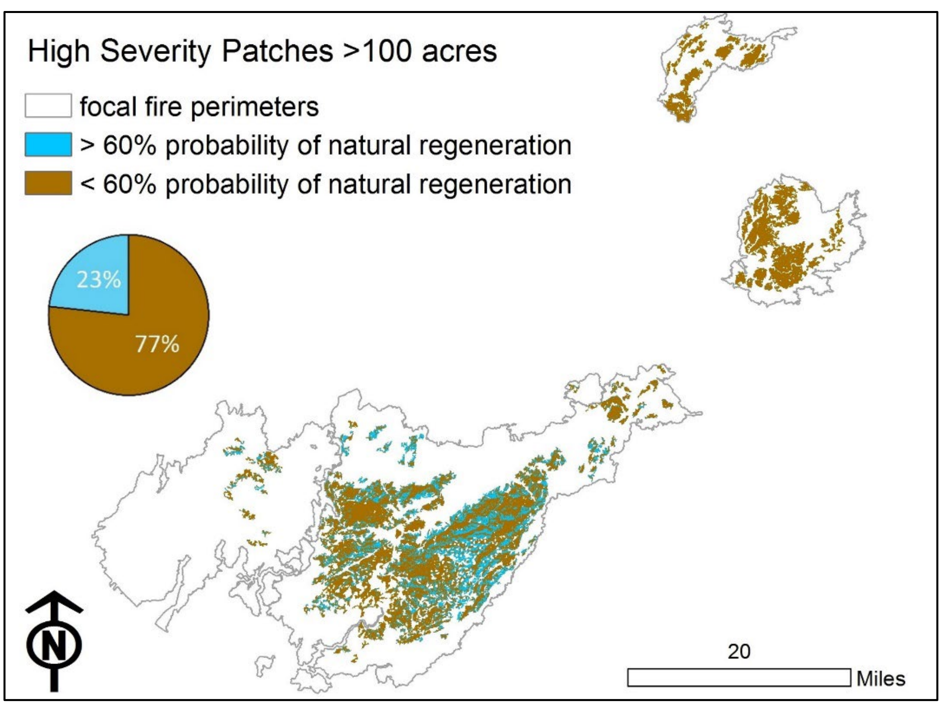


Figure 14. Probability of natural regeneration within high severity patches > 100 acres.

Question 3: Where were conifer stands departed from NRV prior to focal fires?

While forested stands that experienced high severity fire effects at large scales (in patches greater than 100 acres) were clearly degraded by the fire, stands that burned at lower severities may not have been improved or maintained by these fires if they were departed from NRV prior to focal fires. Whether focal fires improved or maintained conifer stands depends upon whether stands were in a resilient condition prior to the fire, which may be influenced by stand density, treatment history, fire history, or a combination of those factors. A single low to moderate severity fire does not necessarily indicate that a stand will be resilient to future disturbance.

We evaluated conifer stand departure from NRV both within and outside of the focal fire perimeters. We included conifer stands that: (a) burned at low-moderate or unchanged severity (0-75% basal area mortality); (b) burned in small patches (<100 acres) of high severity or (c) were outside of the fire perimeter, but within the affected sub-watersheds. We considered relative stand density, an indicator of forest health as well as potential post-fire fuel loading, along with treatment and fire history over the past 20 years. We removed areas within stands that were within large (>100 acre) high severity patches from the departure analysis; these areas were already considered departed from NRV in Question 1.

Departure Indicator #1: Relative Stand Density

We used relative stand density index (SDI) to assess stand condition and departure from NRV. This metric considers tree size and density and provides a relative measure of inter-tree competition or crowding. It is commonly used by forest managers and has recently been highlighted as a valuable metric for assessing forest resilience (Table 7). Recent work conducted by North et al. (2022) suggests that historical mixed conifer stands that experienced frequent-fire disturbance regimes had relative SDI values that ranged from 23-28% of maximum SDI; these low relative SDI values suggest low to non-existent levels of competition in historical stands and concurrently a high level of departure from these conditions in contemporary pre-fire stands.

Table 7. Anticipated competitive interactions within different relative SDI value ranges and associated departure from historical conditions. Relative SDI = absolute SDI/maximum SDI

Relative SDI	Probability of Departure	Competitive interactions
<25%	None	• Less than full site occupancy • No competition between trees • Little crown differentiation. • Maximum individual tree diameter growth.
25-34%	Low	• Less than full site occupancy • Onset of competition among trees • Onset of crown differentiation

Relative SDI	Probability of Departure	Competitive interactions
25-34%		• Intermediate individual tree diameter growth
35-59%	Moderate	• Full site occupancy • Active competition among trees • Active crown differentiation. • Declining individual tree diameter growth
>=60%	High	• Full site occupancy • Severe competition among trees • Active competition-induced mortality • Minimum individual tree diameter growth, stagnation • Considered to be 'zone of imminent mortality'

We established maximum SDI values for each 30m x 30m pixel based upon forest type (CWHR), as well as relative proportions of pine and fir that distinguish between maximum SDI in pine-dominated mixed conifer forest, xeric mixed conifer forest, and mesic mixed conifer forest. These maximum SDI values were derived from various sources (**Table 8**).

Table 8. Maximum SDI values used to calculate relative SDI in this assessment, and the source for that value.

Forest Type (CWHR)	**SDI Max (trees per acre)**	**Source**	**Notes**
Eastside Pine	365	USDA Forest Service (2008)	
Jeffrey Pine	365	USDA Forest Service (2008)	
Montane Hardwood-Conifer	406	USDA Forest Service (2008)	
Ponderosa Pine	365	USDA Forest Service (2008)	
Red fir	1000	Cochran (1983), USDA Forest Service (2008)	
Sierran Mixed Conifer	365	Long and Shaw (2012), North et al. (2022)	pine mixed conifer = basal area of pine (Jeffery, Ponderosa, and sugar) > 50% of total basal area
Sierran Mixed Conifer	450	Long and Shaw (2012), North et al. (2022)	xeric mixed conifer = basal area of pine (Jeffery, Ponderosa, and sugar) ≤ 50% and basal area of fir (Douglas, white, red, and Shasta) is ≤ 50%. Incense cedar at high proportions.
Sierran Mixed Conifer	550	Long and Shaw (2012), North et al. (2022)	mesic mixed conifer = basal area of fir (Douglas, white, red, and Shasta) > 50% of total basal area
White fir	560	Cochran (1983)	

We obtained estimates of pre-fire absolute SDI (Reinecke 1933) and pre-fire basal area from data produced by the LEMMA (Landscape Ecology, Modeling, Mapping, and Analysis) team, comprised of employees of the USDA Forest Service, Pacific Northwest Research Station, and the Department of Forest Ecosystems and Society, Oregon State University (OSU). This dataset uses Gradient Nearest Neighbor (GNN) models to impute Forest Inventory and Analysis (FIA) plot data across the landscape at a 30-m resolution, incorporating biophysical variables (such as topography, elevation, precipitation, slope, and temperature) and LandSat imagery that has been processed through the Landscape Change Monitoring System (LCMS) and LandTrendr. We used the forest structure model from 2017, which represents pre-fire conditions for our focal fires (LEMMA Team 2020).

We calculated relative SDI at the 30-m pixel scale by dividing absolute SDI by the maximum SDI, based on forest type (Table 9, Figure 15).

Table 9. Acres of conifer forest within each relative stand density index (rSDI) category.

rSDI	Acres	% of Total
< 25%	82,171	11%
25% - 35%	44,834	6%
35% - 60%	183,033	25%
>60%	436,043	58%

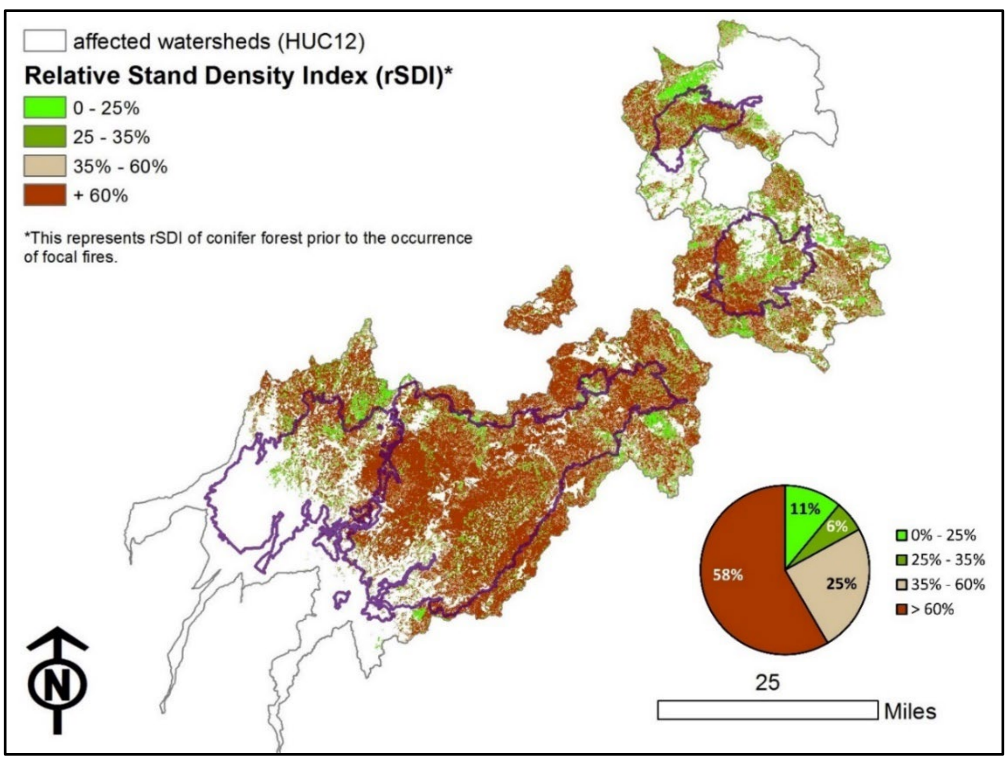


Figure 15. Relative SDI modelled across conifer forest within the analysis area, both inside and outside of focal fire perimeters.

Departure Indicator #2: Fire History

Stands that have burned at frequencies and severities similar to pre-settlement estimates are more likely to have structural conditions that are within the NRV (Safford and Van de Water 2014, Safford and Stevens 2017, Steel et al. 2021, Paudel et al. 2022). Conversely, stands that are departed from pre-settlement fire return intervals are less likely to have structural conditions within NRV. We used fire history as an indicator of whether stands were departed from fire return interval. The watersheds containing the five focal fires experienced 42 fires (> 200 acres) between 1997 and 2020. As a result, approximately 152,176 acres within the assessment area have now burned between two and five times over the past 21 years (**Table 10**,**Figure 16**).

Table 10. The total area of reburn within the analysis area (all vegetation types and severities). The total number of fires includes the focal fires and any past fires that burned between 1997-2020.

Total number of fires	Sum of acres
1	488,463
2	145,249
3	6,805
4	117
5	6
Total acres	640,640

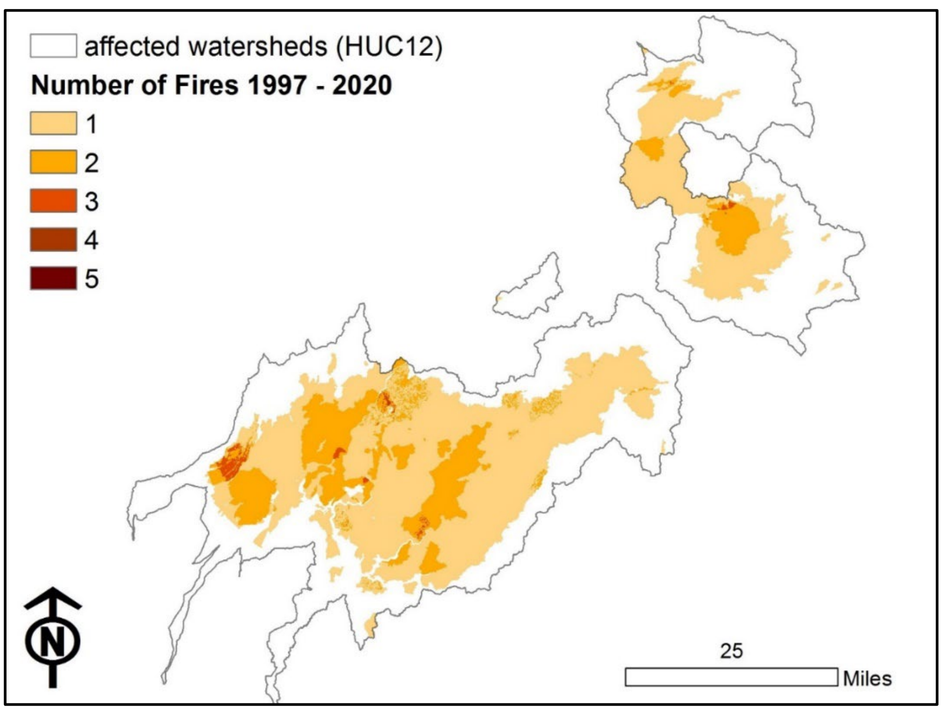


Figure 16. Areas experiencing 1-5 fires between 1997 and 2020.

To assess fire regime departure, we asked where multiple low to moderate severity fires had occurred between 1997-2020. We identified a total of 23,855 acres that were burned by two fires at low-moderate severity, and 163 acres that experienced three fires of low-moderate severity (Figure 17).

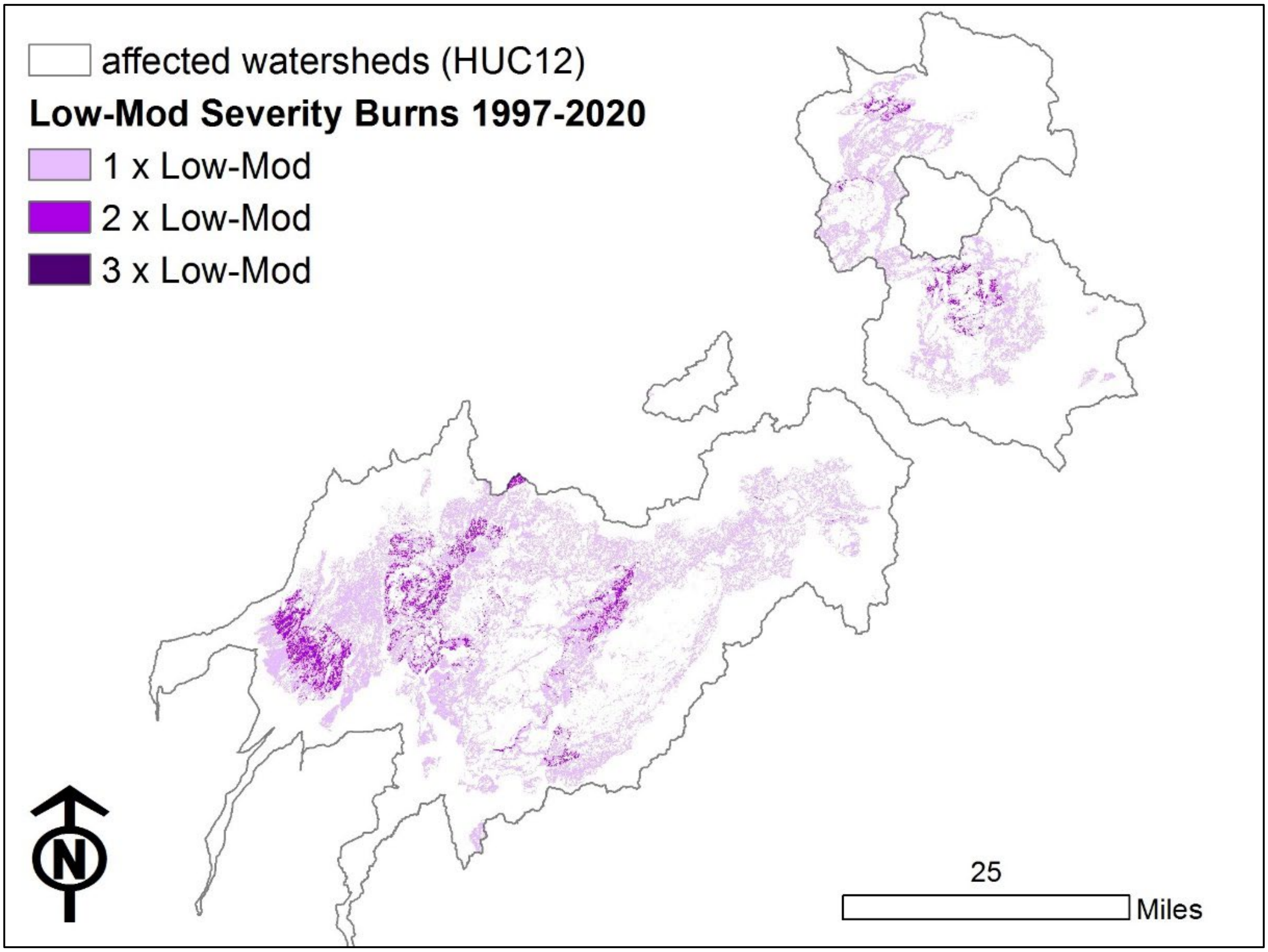


Figure 17. Areas that have burned once, twice, or three times at low to moderate severity between 1997-2020 (includes focal fires).

We considered areas that burned more than once at low-moderate severity within this time interval to have a fire return interval that was not departed from NRV. By contrast, areas that have no history of low-moderate severity fire, either because they are outside of fire perimeters or burned at high severity, have a higher probability of departure from NRV. We considered areas with only one low-moderate severity burn to have a moderate probability of departure from NRV, recognizing that a single low-moderate severity burn may still result in stand conditions that are departed from NRV in conifer systems that historically burned more frequently (Table 11). We applied the following criteria to assess fire regime departure and the probability that fire frequency and severity are within the NRV:

Table 11. Criteria used to classify FRI (fire return interval) and fire severity departure. Fire severity assessment includes areas that were burned by the five focal fires.

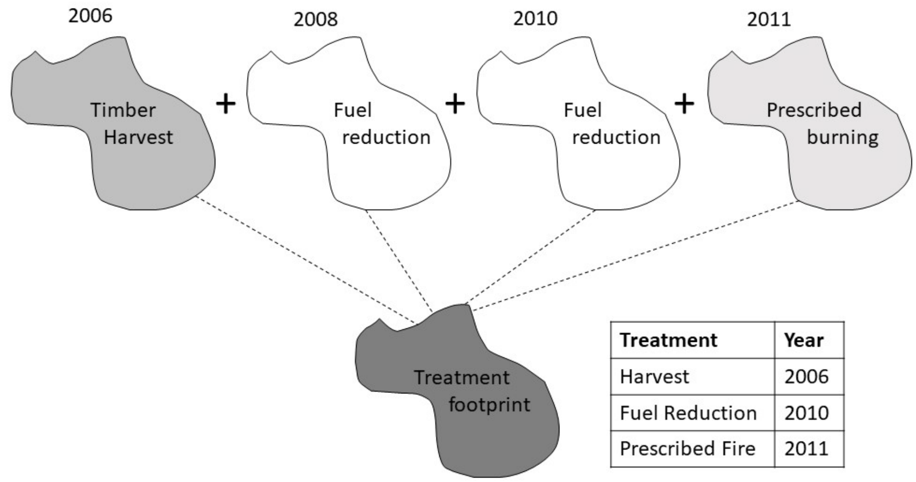
	Number of fires that occurred between 1997 - 2020		
Probability that fire regime is departed from NRV	Within fire perimeter but unburned	Low-Mod Severity	High Severity
Low	any number	≥ 2	0
Moderate	≥ 1	1	0
Moderate	≥ 2	0	0
High	0	0	0
High	any number	any number	≥ 1

Departure Indicator #3: Treatment History

Forest and fuel reduction treatments (e.g., thinning and surface or ladder fuel treatments), combined with low-moderate severity fire (either prescribed or managed), can be highly effective at moderating fire behavior and increasing forest resilience to future disturbance (Cram et al. 2006, Graham et al. 2009, Safford et al. 2012, Tubbesing et al. 2019, Hessburg et al. 2021, Prichard et al. 2021, Cansler et al. 2022). In our assessment, we considered areas that had been treated prior to the fires, with some combination of forest thinning, fuel reduction, or prescribed fire.

The first step was to identify forest stands that were treated in the 20 years prior to the fires. Treatment polygons were obtained from the USDA Forest Service Forest Activity Tracking System (FACTs) database and clipped to the combined fire boundary. The dataset was filtered to include only those treatments completed between 1997-2020 that modified or manipulated vegetation and fuels. The assessment team binned treatment activities into six broad categories: harvest, fuel reduction, reforestation, prescribed fire, and salvage. Appendix A provides the complete crosswalk between the FACTs activities and treatment categories used in this analysis.

To reduce duplication, we collapsed overlapping treatments (i.e., where sequential treatments were applied to the same plot of land) into single polygons. Polygons that were smaller than 0.1 acre were removed from the dataset. These non-overlapping polygons represent the total footprint of vegetation and fuels treatments completed between 1997-2020. (**Figure 18**). We then evaluated the number of pre-fire vegetation or fuel treatments that occurred prior to focal fires. Stands that received more than one vegetation or fuels treatment were considered more likely to have stand structure within NRV, with stands receiving just one vegetation or fuels treatment moderately likely to have stand structure within NRV. Reforestation without follow-up treatment was coded separately, as were salvage treatments.



Treatment	Year
Harvest	2006
Fuel Reduction	2010
Prescribed Fire	2011

Figure 18. Visual representation of the process used to create non-overlapping polygons of treatments completed between 1997-2020 within the analysis area.

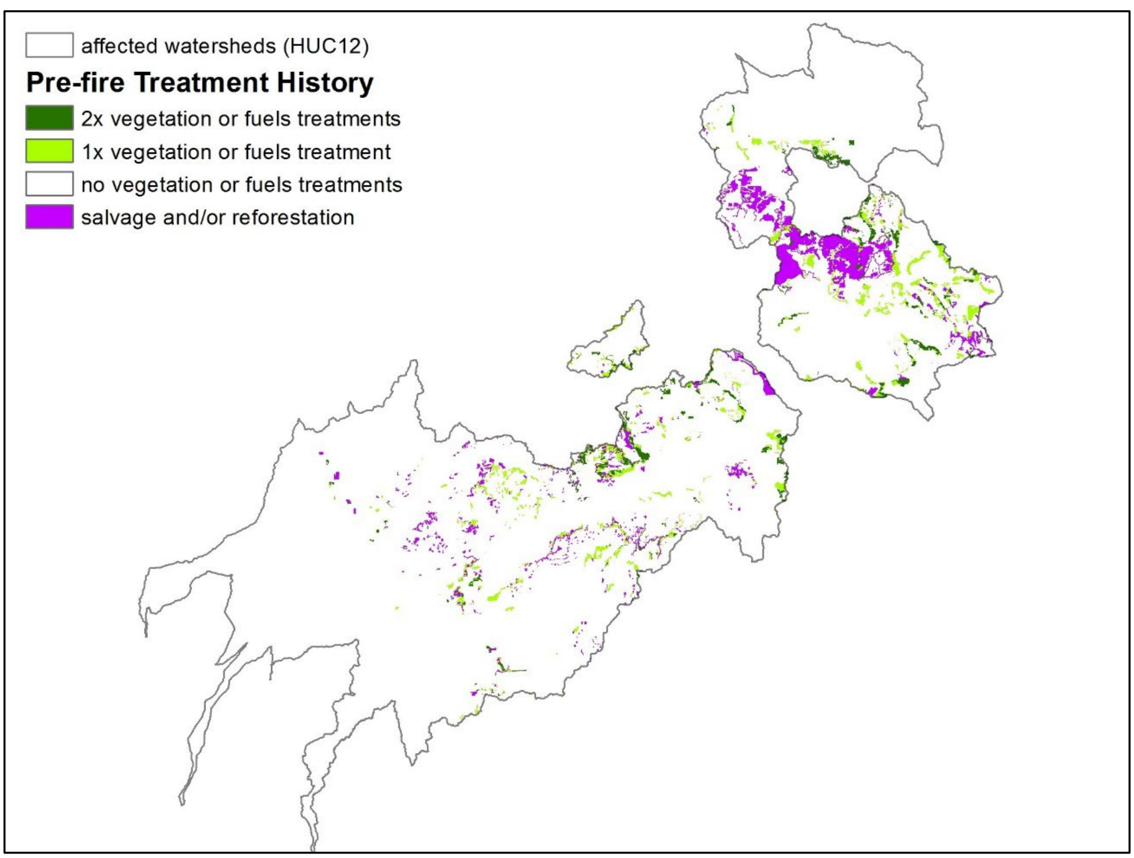


Figure 19. Vegetation and fuels treatments implemented after 1997 and prior to focal fires.

Stand Departure Index

We combined these three departure indicators (rSDI, fire history, treatment history) into a stand departure index that captured whether each stand is more likely or less likely to be departed from conditions under NRV. Pre-fire stand conditions and departure from NRV can indicate resilience to future disturbances such as wildfire, insects and disease, and drought. For example, a stand with a pre-fire rSDI of <25% has a high likelihood of having conditions (e.g., low tree densities, widely spaced tree canopies) that would increase resilience to future fire or environmental stressors such as drought. If that stand burned at low-moderate severity in one of the focal fires, a low pre-fire rSDI would indicate that post-fire fuel loads would also be lower, decreasing the risk of future high severity fire. By contrast, a stand with high pre-fire densities (> 60% rSDI) would have a high probability of departure from NRV. If unburned, rSDI values greater than 60% would indicate that stand conditions were outside of NRV and susceptible to future high severity fire or environmental stressors such as drought; if burned, those trees (having burned at any severity) would present high fuel loading post-fire and a greater chance that the stand would re-burn at high severity. Fire history was also taken into consideration, with stands that have reburned several times at low to moderate severities since 1997 more likely to be characterized by stand conditions that are resilient to future fire. Treatment history was a third indicator of stand departure, with thinning and fuels treatments included as factors decreasing departure from NRV.

We applied a probability-based "fuzzy logic" approach to combine our three stand departure indicators (rSDI, fire history, and treatment history) and assign a departure score to each stand within the analysis area. This approach acknowledged the limitations of each of these indicators, given that the rSDI models rely upon imputed data, that basal area loss is calculated from remotely-sensed data and may not capture secondary mortality, and that treatments can differ substantially in their effects on stand structure and composition. It additionally recognized that while each of these indicators, on their own, contributes to the probability that a stand is departed, the strength of these predictions is stronger when multiple indicators suggest departure (**Figure 20**).

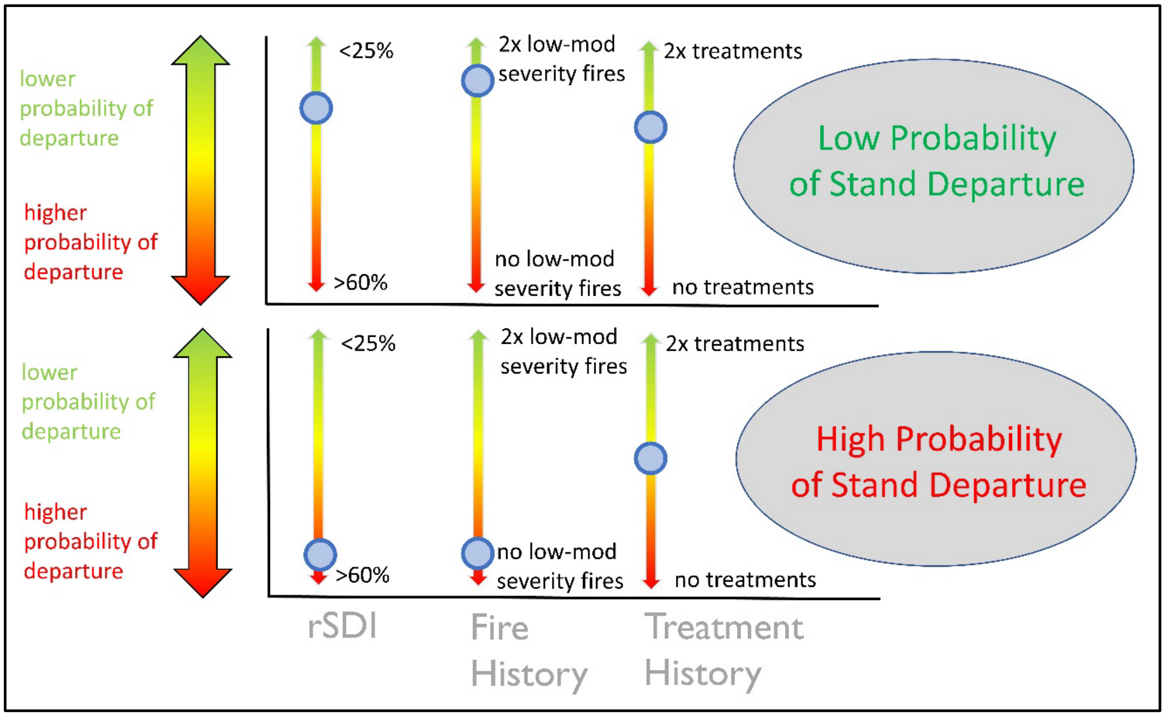


Figure 20. Schematic of the "fuzzy logic" approach to incorporating rSDI, fire history, and treatment history into a single stand departure metric.

To apply this stand departure index, we first identified sub-stands within each stand of conifer vegetation that shared common vegetation type, vegetation structure, treatment history and fire history. We averaged relative stand density across each of these sub-stands. We erased areas that burned in high severity patches greater than 100 acres (these areas were considered departed from NRV in Step 1 and were identified as having opportunities for reforestation). We attributed each sub-stand with the median fire return departure metric for that sub-stand (low, moderate, or high departure, see **Table 11**). We then assigned a score between 0 and 100 to each sub-stand for each of the three stand departure indicators (rSDI, fire history, treatment history), then weighted and averaged these scores into a stand departure index for each sub-stand. For all three indicators, a score of 100 indicated the lowest probability of stand departure from NRV for that metric, and a score of 0 indicated the highest probability. Weights were assigned based upon which factors we believed were the strongest indicators of departure conditions, accounting for interactions between these indicators. We accorded the highest weight to rSDI as the strongest indicator of stand departure (North et al. 2022), and as an indicator of both stand resilience to insects, disease, and drought, and potential fuel loading (either live tree biomass, or fuel loading following fire). Treatment history was accorded the least weight due to the wide range of post-treatment conditions, and the fact that the rSDI indicator also partially captures the effects of treatment history (e.g., the effects of thinning treatments would be reflected in a lower post-treatment rSDI). We binned stands into one of three departure categories (**Figure 21, Table 12**): high (index from 45-100), moderate, (index from 25-50), or low (index from 0-25).

Table 12. Stand departure index scores and weights for each rSDI, fire history, and treatment history category.

Pre-fire Density (rSDI)		Fire History 1997-2020 (including focal fire)		Treatment History (1997 – focal fire date)	
Category	Score	Category	Score	Category	Score
<25% rSDI	100	2 low/mod severity fires, no high	100	2+ fuels/vegetation treatment	100
25% - 34% rSDI	80	1 low/moderate and 1 unchanged, or 2 unchanged, no high	50	1 fuels/vegetation treatment or pre-fire salvage treatment	50
35% - 59% rSDI	50	1 low/moderate severity, no high	25	no treatment	0
60% + rSDI	0	other (including anything with high)	0	Reforestation (prior to focal fire) with no follow-up treatment	0
Stand Departure Index Weight	x 4		x 2		x 1

Of areas within conifer forest prior to the focal fires, but outside of large (>100 acre) high severity patches, 10% had a low probability of departure from NRV (59,355 acres), 27% had a moderate probability of departure (159,513 acres), and 63% had a high probability of departure (366,401 acres).

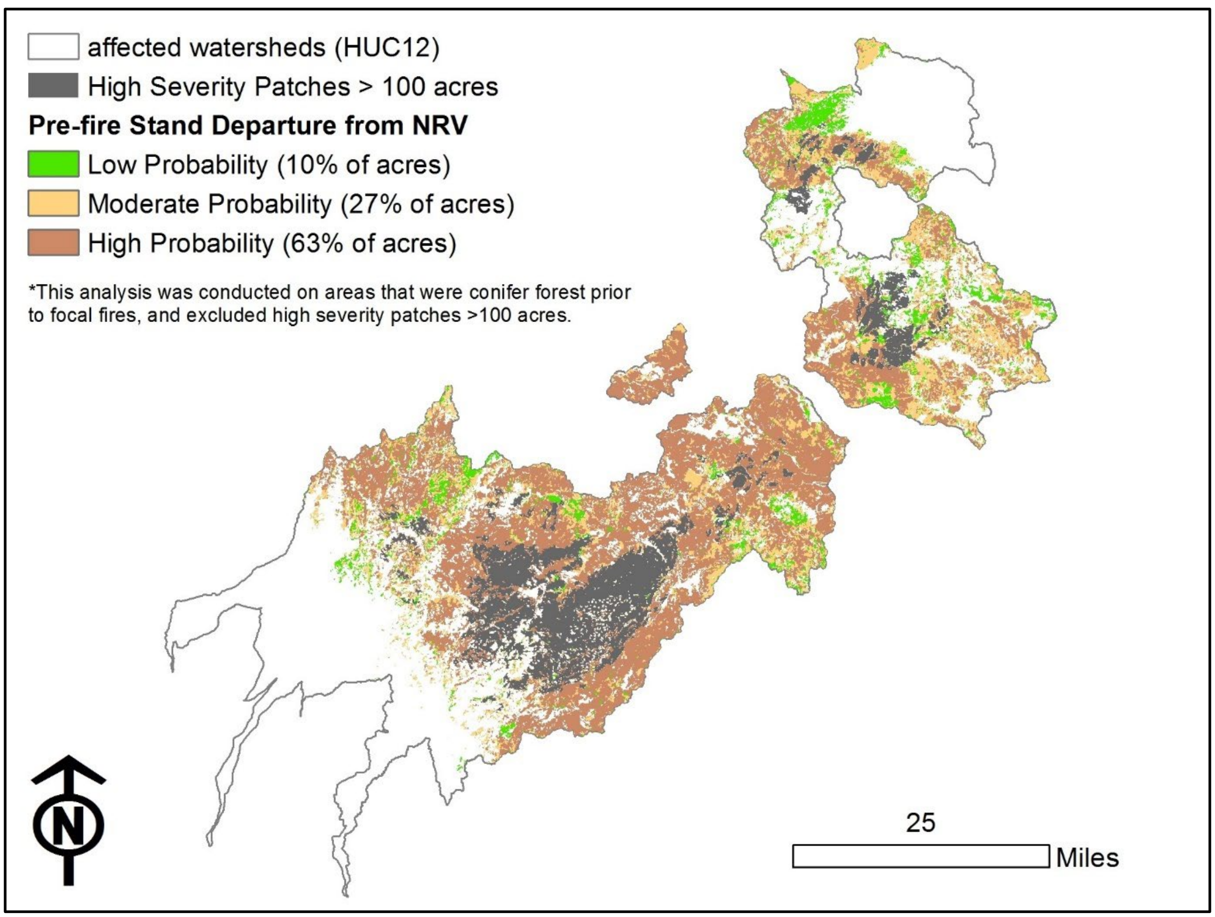


Figure 21. Probability of stand departure from NRV within areas outside of large (>100 acre) high severity patches and within conifer forest.

Question 4: Where are high volumes of fire-generated fuels predicted?

Identifying areas with excessive fuel loading can be difficult without field verification, however, it is possible to make some inferences based on pre-fire stand conditions and fire severity patterns. Our analysis presumed that fire-generated fuels would be high in large patches of high severity fire. However, stands that burned at moderate severities may also have a high volume of fire-generated fuels where pre-fire stand densities were high. As fire-generated snags decay and fall to the ground over time, heavy accumulations of dead and down fuels can increase the risk of future high severity fires (Coppoletta et al. 2016, Lydersen et al. 2019).

Fire-Generated Fuels Indicator #1: Pre-fire departure and fire severity matrix

We modelled fire-generated fuels by considering pre-fire stand departure along with basal area loss, predicting that fire-generated fuels would increase with increased departure from NRV, as well as with basal area loss. For example, in areas that were highly to moderately departed prior to the fire (i.e., relative SDI >35%) and burned at more moderate severities (i.e., with 25-75% basal area mortality), fire-related mortality may have reduced live tree density to within the NRV; however, dead fuel loads resulting from the conversion of dense live trees to dense post-fire snags may increase the risk of high severity reburn in the future (Coppoletta et al. 2016). We estimated fire-generated fuels qualitatively according to the following matrix (**Table 13**). Fire-generated fuel predictions were spatially heterogeneous across the landscape, varying with both small pockets of high severity fire, and with areas that supported dense, pre-fire conifer vegetation (**Figure 22**). Extensive areas with mixed green and fire-generated fuels were predicted across a large portion of the Sheep and Walker Fires. The distribution of predicted fuels is very heterogeneous across the Camp and North Fires, with high concentrations occurring near the perimeter of larger high severity patches.

Table 13. Predicted levels of fire-generated fuels by pre-fire stand departure and focal fire severity (Basal Area mortality)

	fire severity (basal area mortality)		
Pre-fire Stand Departure	**unchanged* or <25% BA mortality**	**25% - 75% BA mortality**	**>75% BA mortality**
Low	low fuels	low fuels	low fuels
Moderate	moderate fuels (green)	moderate fuels (green + fire-generated)	moderate fuels (fire-generated)
High	high fuels (green)	high fuels (green + fire-generated)	high fuels (fire-generated)

* Unchanged includes areas outside of the fire, but within affected sub-watersheds

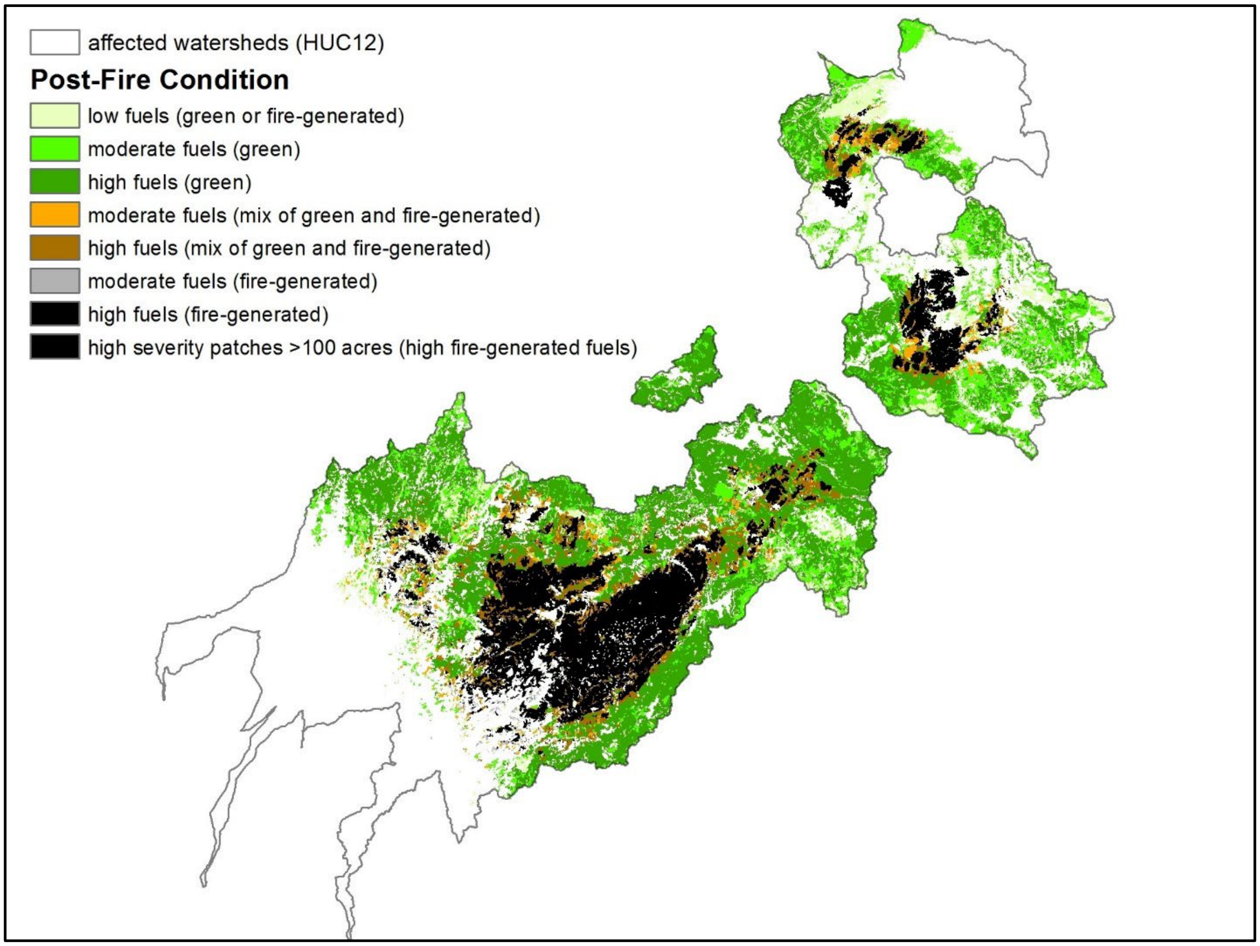


Figure 22. Assessment of green and fire-generated fuels in conifer forest.

Opportunity Matrix

We utilized the indicators discussed above to develop a Restoration Portfolio. From this point forward in the analysis we include only FS ownership and exclude areas within the Dixie Fire perimeter (**Figure 23**). Restoration opportunities for the 177,564 acres within the analysis area and within the Dixie Fire perimeter are included in "Post-fire Restoration Opportunities for Conifer Forest in the 2021 Dixie and Sugar Fires" (USDA FS 2022). Most of these acres are outside the perimeter of focal fires.

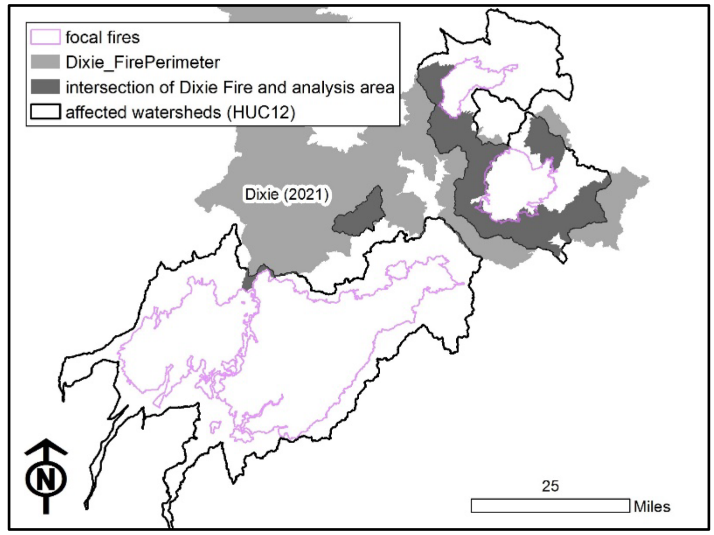


Figure 23. Watershed analysis area and focal fire area overlaid by 2021 Dixie Fire.

The following indicators were inputs into a restoration opportunity matrix:

1) High Severity Patches >100 acres
2) High Severity Patches 10-100 acres
3) Natural Regeneration Probability
4) Stand Departure Index (Within NRV, Moderately Departed from NRV, Highly Departed from NRV)
5) Focal Fire Perimeters
6) Fire-generated Fuels

Restoration opportunities were evaluated at the stand scale and were assigned based upon different combinations of these indicators (**Table 14**). These opportunities include contiguous polygons greater than 10 acres.

Table 14. Restoration opportunity matrix for areas managed by the Plumas NF or Lassen NF that are outside of the Dixie Fire perimeter. "ID" is an identifier used to crosswalk these opportunities with opportunity feature classes (see Appendix A).

Fire Severity	Pre-Fire Stand Departure	Restoration Opportunity	Potential Actions	ID	Post-Fire Condition	Acres on FS, not in Dixie	
						PNF	LNF
High Severity Patches > 100 acres	not analyzed	address elevated fuel loads and conifer re-establishment	**Take Action**: fuel reduction (dead tree removal, piling of surface fuels, broadcast or pile burning), site preparation (removal of competing vegetation) and strategic planting to maximize survival; longer-term control of competing vegetation, precommercial thinning, and fuels management	1	Natural Regeneration Probability >60%	19,316	3
				2	Natural Regeneration Probability <60%	73,287	889
High Severity Patches 10-100 acres	variable	address elevated fuel loads and conifer re-establishment	**Evaluate**: consider dead tree removal and other fuel reduction actions when adjacent to high value resource areas; consider replanting where high potential to reestablish wildlife habitat	3	probability of regeneration low to high	7,079	106
Low-moderate severity fire, high severity fire < 10 acres, or outside of focal fires	Within NRV	maintain/promote desired conditions	**Maintain**: with prescribed fire at intervals similar to pre-settlement fire return interval (FRI) or evaluate for other fuel	4	low departure (**low fuels**)	21,511	1,064
	Moderately Departed from NRV	evaluate where actions are needed to improve forest health and resilience to future disturbance	**Evaluate**: need for reduction of green and/or fire-generated fuels (ladder, surface, snags); evaluate need for thinning to restore stand structure and composition; maintain with prescribed fire or other future fuel reduction activities	5	moderate departure (green fuels)	45,837	3,776
				6	moderate departure (fuel mixture)	11,687	331
				7	moderate departure (**fire-generated fuels**)	1,775	24

Fire Severity	Pre-Fire Stand Departure	Restoration Opportunity	Potential Actions	ID	Condition	Acres on FS, not in Dixie	
						PNF	LNF
Low-moderate severity fire, high severity fire < 10 acres, or outside of focal fires	Highly Departed from NRV	address critical need to improve forest health and reduce fuel loads (both green and fire-generated fuels)	Take Action: reduction of green and/or fire-generated fuels (ladder, surface, snags); thinning to reduce density and restore stand structure and composition in green stands; maintain with prescribed fire or other future fuel reduction activities	8	high departure (green fuels)	146,658	5,026
				9	high departure (fuel mixture)	32,580	1,190
				10	high departure (fire-generated fuels)	3,558	121
Areas outside of model		Evaluate on case-by-case basis	Evaluate: Areas that were salvaged and/or reforested since 1997 and prior to focal fires would require on-the-ground assessment of fire effects and restoration needs.	11	pre-fire salvage only	5,170	0
				12	pre-fire reforestation only	10,448	0
				13	pre-fire salvage and reforestation	1,496	13

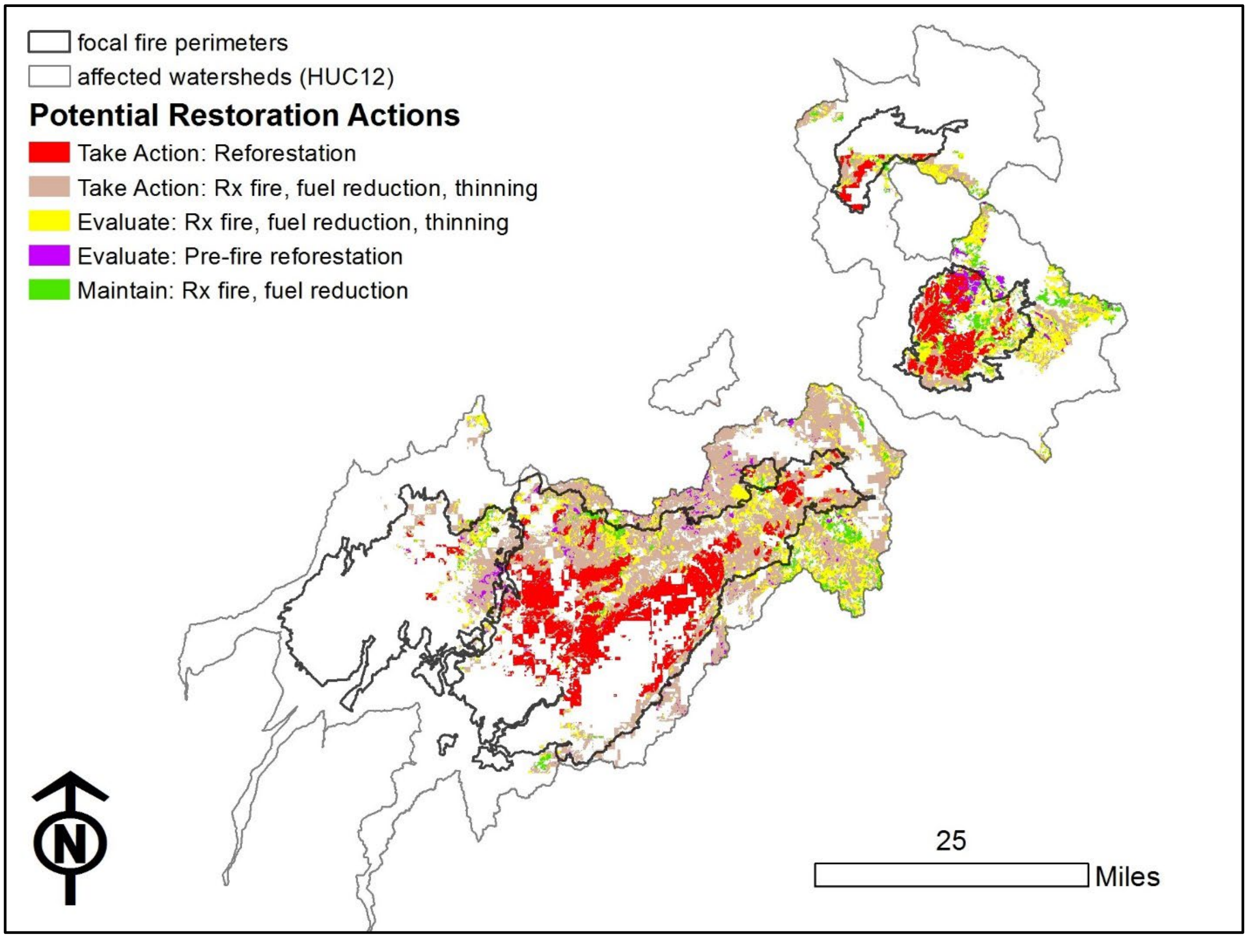


Figure 24. Restoration opportunities for conifer forest on NFS lands within focal fires and affected watersheds.

Opportunities 1 and 2: High Severity Patches > 100 acres (Fire effects departed from NRV)

These opportunities include areas that burned at high severity over large, contiguous areas of conifer forest. In general, these areas are at high risk for high severity reburn due to the potential for high fuel loads as snags fall and understory shrub vegetation develops over time. Restoration opportunities in these areas may initially include fuel reduction (dead tree removal, piling of surface fuels, broadcast or pile burning, etc.), site preparation (removal of competing vegetation), and planting. Because up to five years have lapsed since some of these fires, additional operational challenges may be present due to shrub establishment and snag decay. The need for planting may vary based on the potential for natural regeneration. On 19,319 acres (Opportunity 1), there is a high probability of natural regeneration of conifer species; in these areas managers may want to evaluate the success of natural conifer regeneration to determine the need for planting. On 74,176 acres (Opportunity 2), there is a low probability of natural regeneration, and active reforestation may be a greater priority. Unique consideration may be given to areas that have burned twice at high severity over the past 20 years, where the second high severity fire reduced fuels generated from the first; this has occurred where the 2020 Sheep Fire reburned the 2007 Moonlight Fire, and where the 2019 Walker Fire reburned the 2007 Antelope Complex. This is discussed further in the Prioritization Filters section below.

Figure 25. This conifer stand burned at high severity in the 2019 Walker Fire and is a candidate for site preparation (i.e., dead tree removal) and planting.

Figure 26. Stands of conifers that burned twice at high severity, with greatly reduced standing and surface fuels. Areas like these may be good candidates for planting.

<u>Opportunity 3</u>: High Severity Patches 10-100 acres (fire effects within NRV)

Smaller patches of high severity (10-100 acres) are generally considered to be within the NRV with respect to first order fire effects. However, these areas (7,185 acres) may still be at increased risk of future high severity reburn if they had a high density of live trees prior to the fire. These stands can be expected to have high densities of snags post-fire, which over time contribute to heavy accumulations of dead and down fuels. To reduce the risk of high severity fire, these areas may be prioritized for fuel treatments where they are within or adjacent to high priority resources (WUI, PACs, Territories, conifer refugia). In addition, planting may be prioritized where there is a strong need to re-establish conifer cover; for example, within important wildlife habitats that are projected to be climatically suitable for conifer forest in the future. Fuel reduction, site preparation and planting would be as described for larger high severity patches.

<u>Opportunity 4</u>: Fire effects and pre-fire stand conditions within NRV

Opportunity 4 occurs on 22,575 acres where pre-fire stand conditions and disturbance history suggest that stand conditions were not departed from NRV prior to the focal fires, and fire may have maintained or improved that resilient condition. This opportunity also includes areas outside the focal fire perimeters where stand densities and disturbance history suggest resilient stand conditions. Most stands are characterized by rSDI values <35%. Where rSDI values exceed 35%, stands have experienced multiple vegetation treatments (i.e. thinned and underburned) and/or multiple low to moderate severity fires since 1997. In these areas, managers may consider actions like prescribed or managed wildland fire, applied at intervals and severities similar to the pre-settlement fire regime, to maintain resilience to future wildfire and other disturbances (Restoration Goal #2). Roughly 40% of these areas are within the perimeter of the focal fires, and most of these areas are predicted to have low levels of fire-generated fuels, having burned at low to moderate severity in stands with low tree densities. We applied the same stand departure index to areas outside the focal fire perimeters and identified additional acres as potentially meeting desired conditions within the analysis area.

Figure 27. This low density (40% rSDI) eastside pine stand with prior treatment history experienced a low severity underburn in the Walker Fire, and could be maintained with follow-up prescribed burning at regular intervals.

Figure 28. Multiple pre-fire treatments and low severity fire effects in the Minerva Fire have resulted in a stand with low levels of fire-generated fuels.

<u>Opportunities 5-7</u>: Fire effects within NRV, pre-fire stands moderately departed from NRV

Although fire effects were mostly low to moderate in these areas, pre-fire stand densities and disturbance histories suggest that post-fire conditions are likely to remain departed from desired conditions. Most stands in this category were modelled at 35% - 60% rSDI prior to the fire. Where pre-fire rSDI was higher (>60%), stands were considered moderately departed only when they had also experienced low to moderate severity fire, or vegetation and fuels treatments. Burned areas may have moderate to high levels of fire-generated fuels in areas that burned at moderate to high severities, due to pre-fire stand densities that exceeded NRV. Although fire may have reduced live tree density, dead fuel loads resulting from the conversion of dense live trees to dense post-fire snags may also increase the risk of high severity reburn in the future (Coppoletta et al. 2016). These stands should be evaluated to determine whether additional actions would be required to restore forest structure or composition and increase resilience to future disturbance such as fire, drought, or disease. Restoration opportunities may include density reduction treatments (e.g., thinning live trees), or prescribed fire (including piling and burning) to reduce competition, increase individual tree growth, and reduce surface and ladder fuels. Managers may consider a gradient approach, retaining higher relative SDI on sites with greater soil moisture availability and lower reburn risk, or as late-seral habitat, and lower relative SDI on drier steeper slopes that are more prone to drought and high intensity reburns (North et al. 2022). Burned areas may have moderate to high levels of fire-generated fuels in areas that burned at moderate to high severities, due to pre-fire stand densities exceeding NRV. There are 49,613 that were moderately departed prior to focal fires and are either outside of fire perimeters or burned at less than 25% basal area loss (Opportunity 5). These areas should be evaluated for the need to treat green fuels along with restoring stand structure to within NRV. On 12,108 acres where moderate fire severities resulted in between 25% and 75% basal area loss, a mix of green and fire-generated fuels is predicted (Opportunity 6). On 1,799 acres that burned at high severity, reduction of fire-generated fuels should be evaluated (Opportunity 7).

Figure 29. This stand burned at moderate severity in the Minerva Fire, but is now characterized by relatively high densities of live trees and snags. Pre-fire rSDI modelled at 58%.

Figure 30. This stand burned at low severity in the Walker fire, however with pre-fire densities modelled at 49% rSDI, the potential for moderately high post-fire fuel loading remains.

<u>Opportunities 8-10</u>: Fire effects with NRV, pre-fire stand conditions highly departed from NRV

On 189,133 acres where stand structure was highly departed from NRV prior to the focal fires (rSDI >60%), departure from NRV is predicted to persist regardless of whether or how stands burned. It is highly likely that these stands will require action to restore forest structure and composition and to increase resilience to future disturbance such as fire, drought, or disease. Where these areas burned at moderate to high severities, there is also high likelihood that dead fuel loads resulting from the conversion of dense live trees to dense post-fire snags will increase the risk of high severity reburn in the future (Coppoletta et al. 2016). In these stands, restoration opportunities may include snag removal in burned areas, as well as density reduction treatments (e.g., thinning live trees), or prescribed fire (including piling and burning) to reduce competition, increase individual tree growth, and reduce surface and ladder fuels. Managers may consider a gradient approach, retaining higher relative SDI on sites with greater soil moisture availability and lower reburn risk, and lower relative SDI on drier steeper slopes that are more prone to drought and high intensity reburns (North et al. 2022). Approximately 80% of acres in this category are either outside of fire perimeters or burned with <25% basal area loss. These 151,684 acres (Opportunity 8) represent the largest category in this analysis and reflect the high levels of pre-fire stand departure throughout the analysis area, where action needs to be taken in predominantly green stands to increase resilience and restore stands to desired conditions. On 33,770 acres that were highly departed and burned at moderate severities, a mix of green and fire-generated fuels are predicted (Opportunity 9). In addition, there are 3,679 acres in highly departed stands outside of large high severity patches that burned at high severity (Opportunity 10). Prioritization filters described below will be particularly important to focus attention on protecting high priority resources, such as WUI, communities, or spotted owl PACs that are vulnerable to future high severity burns.

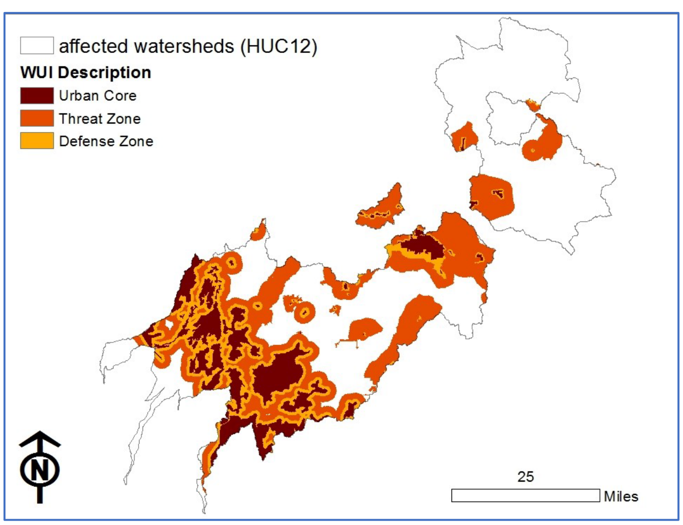
Figure 31. This stand burned at moderate fire severity in the North Complex, however high densities of both live trees and snags remain (stand modelled at 89% rSDI prior to fire)

Figure 32. This stand was unburned but is characterized by an rSDI (106%) that is well outside of NRV, decreasing its resilience to future disturbance.

PRIORITIZATION FILTERS

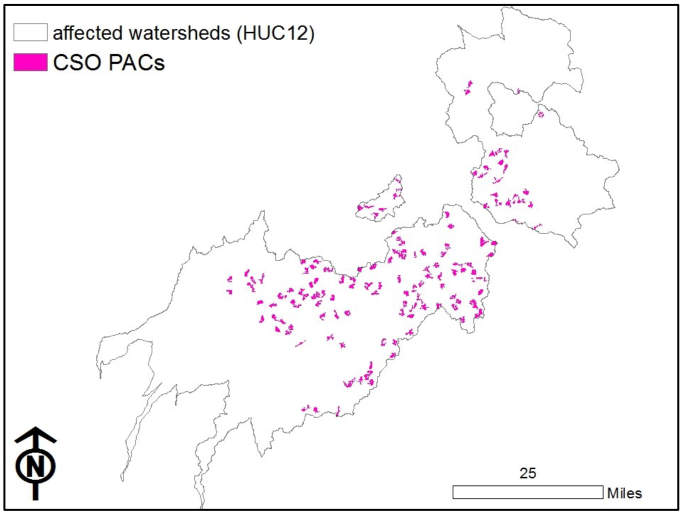
Other socioeconomic factors, biological factors, site history elements or operational constraints may contribute to prioritization of some stands over others for treatment. These filters are not listed in any particular order, but can be overlaid on restoration opportunities when objectives vary across the analysis area (e.g., the high priority need for treatment within WUIs, the high priority need to harden edges around remaining spotted owl PACs, slope restrictions, etc.).

1.WUI



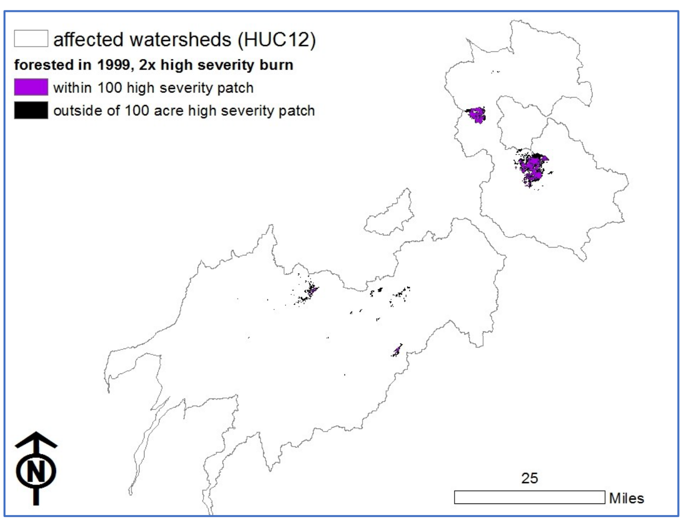
Areas within the Wildland-Urban Interface (WUI) may be prioritized due to the imminent need to reduce fuels and increase resilience adjacent to local communities. This filter includes both the defense and threat zones within the analysis area.

2.California Spotted Owl PACs and Territories



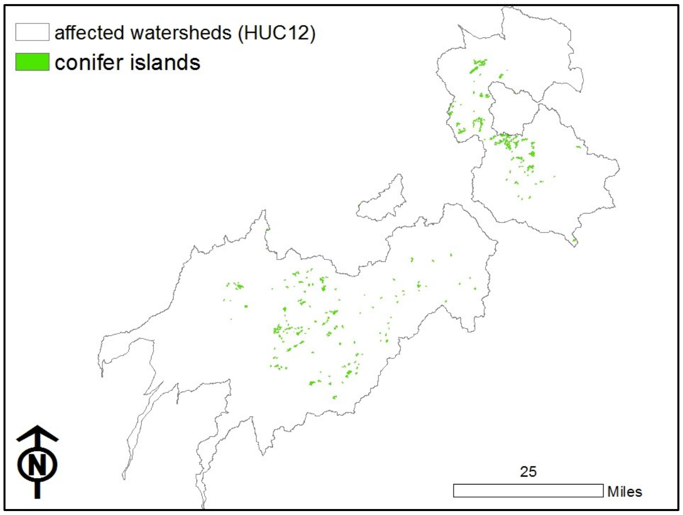
Areas within California Spotted Owl PACs and Territories may be prioritized for treatments. Where post-fire late seral habitat remains, it is important to reduce the risk of future high severity fire through fuel reduction treatments within and adjacent to these allocations. Additionally, areas within PACs and Territories that burned at high severity may be a high priority to re-establish conifer cover through replanting, particularly where climate exposure is low, and predicts persistence of conifer cover through mid-century. These layers can be used in conjunction with the conifer island filter to identify PACs and territories that may be a priority for edge-hardening (treating fuels at the interface between PACs and adjacent forest to reduce surface fuel loads).

3. Former conifer forest that has burned twice at high severity



Within the analysis area, 10,283 acres were classified as chaparral prior to the focal fires but were typed as conifer forest in 1999; these areas represent type-conversions, from forest to shrubland due to high severity burns that occurred prior to the focal fires. Of particular note are the 7,301 acres within high severity patches >100 acres that have burned twice at high severity within the past 20 years. These areas may provide good opportunities for reforestation, due to lower fire-generated fuel loads resulting from two high severity fires. These areas may require less site prep prior to planting than other large once-burned high severity patches; however, this will need to be evaluated in the field. The largest areas occur where the 2020 Sheep Fire intersected the 2007 Moonlight Fire, and where the 2019 Walker Fire intersected the 2007 Antelope Complex.

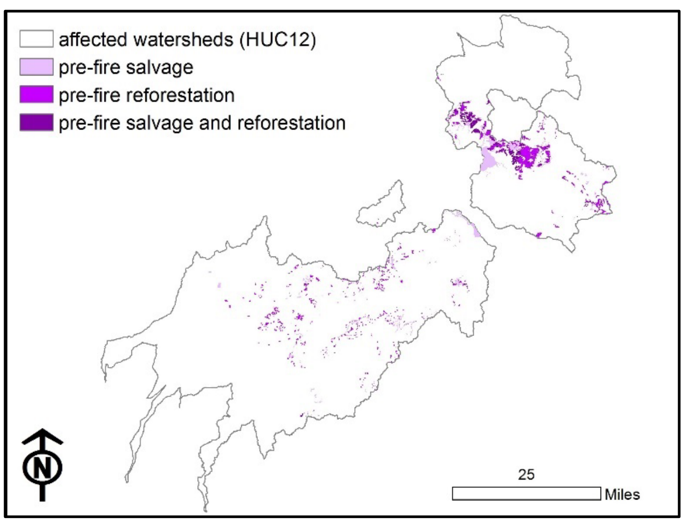
4. Conifer Islands



We identified 8,783 acres of small (10-250 acre), isolated stands of remnant conifer forest that burned at low-moderate severity and were surrounded by either large high severity patches or montane chaparral in 50% of the area around the patch.

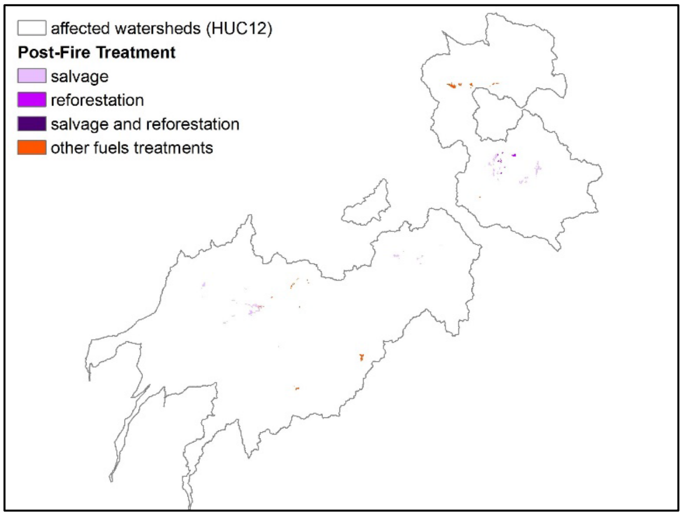
In these areas, restoration opportunities may include actions both within and adjacent to the stands. For example, fuel reduction may be implemented within the stand to increase or maintain resilience to future disturbance, as well as around the stand to reduce the risk of severe fire in the future. These treatments, which are sometimes referred to as "edge hardening", were not separated out as individual restoration opportunities in this assessment because they overlap with many of the opportunities described above (e.g., site preparation in large high severity patches; fuel reduction in highly departed stands, etc.).

4. Pre-fire reforestation and salvage treatments



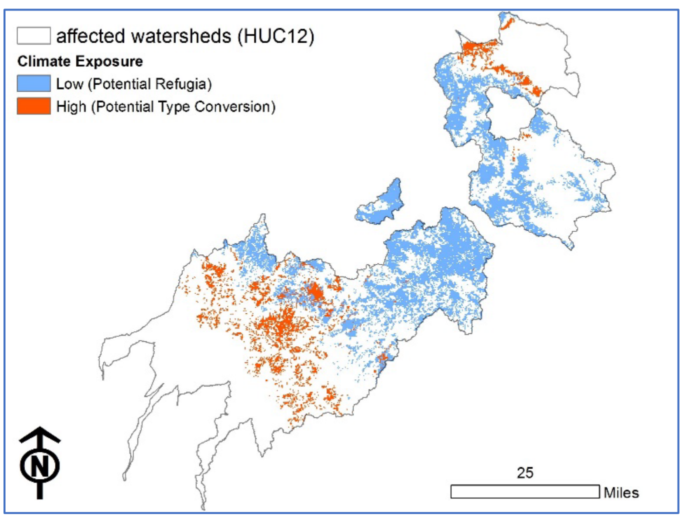
This filter identifies areas that were outside the parameters of our stand departure model because they are salvage and/or reforestation treatments that occurred between 1997 and focal fires. These areas often had a low pre-fire rSDI, due to the small size of the planted trees, however are likely to require follow-up treatments to improve resilience to future fire and other disturbances. Previously salvaged areas also had low rSDI, as seen in the footprints of the Antelope Complex (2007), Cold Fire (2008), and other previous high severity fires. Salvage treatments can include a wide variety of on-the-ground actions not easily distinguishable in the FACTs database, with varying implications for long-term resilience. For this reason, we include this overlay so that such treatments can be evaluated on a case-by-case basis for future resilience.

6. Post-fire treatments



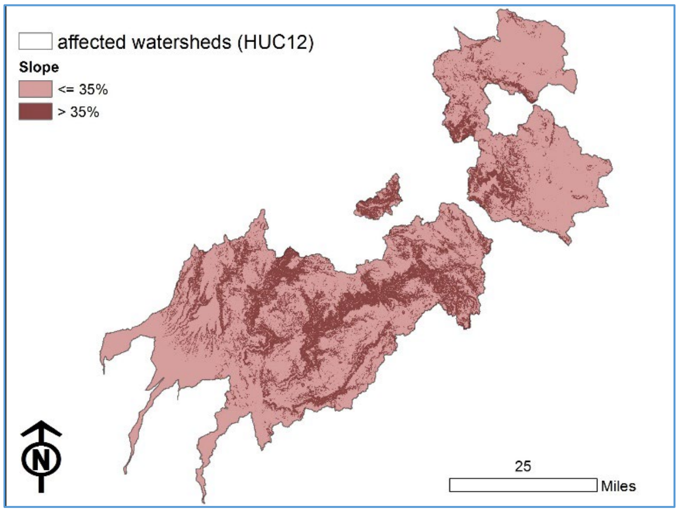
Some treatments have already occurred post-fire within the footprint of the focal fires and are not reflected in this overall assessment. This layer highlights areas where post-fire treatments such as salvage only (2,734 acres), reforestation only (346 acres), salvage and reforestation (4 acres) or other thinning or fuels treatments (1,239 acres) have occurred.

7. Climate exposure



We utilized a climate exposure model that identifies areas that are predicted to maintain existing vegetation (e.g. mixed conifer forest) at mid-century (California Refugia model, Thorne et al. 2020). This model incorporates two different future climate scenarios that presume no change in global emissions at mid-century (2040-2069): a warmer, wetter future (modelled with the CNRM-CM5 global climate model) and a hotter, drier future (modelled with the MIROC-ESM global climate model). We evaluate where there is consensus between these two global climate models that mixed conifer forest will persist at mid-century. Areas that are predicted to be refugia may represent a higher priority for replanting or other restoration treatments that increase resilience to drought. Outside of these predicted refugia and in areas identified as priorities for reforestation, managers may consider decreasing planting densities, mixing species or seed zones, or taking advantage of local site conditions, in anticipation of increased climate exposure.

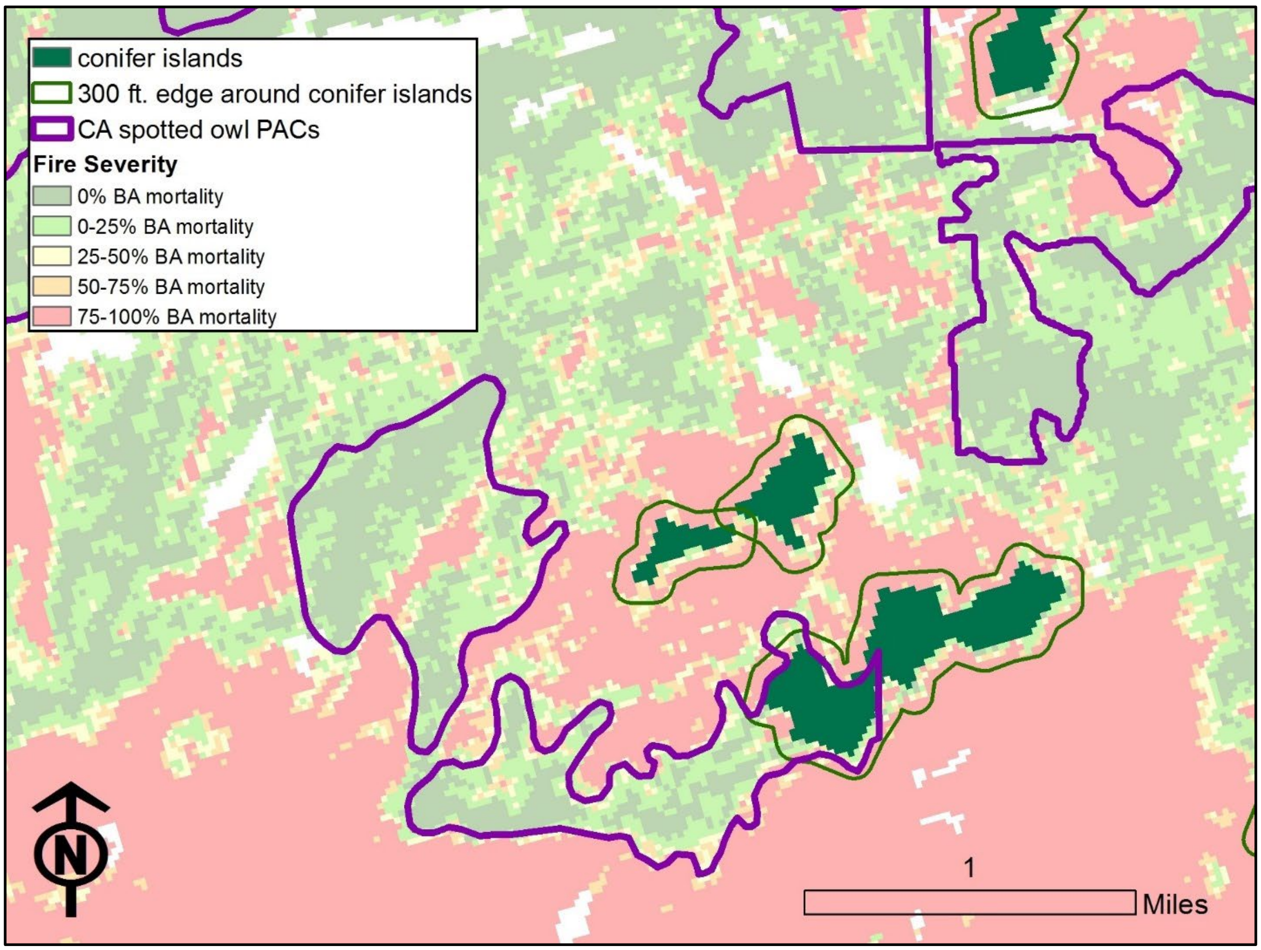
8. Slope



This filter identifies areas within the analysis area with less than and greater than 35% slope, a common operational constraint.

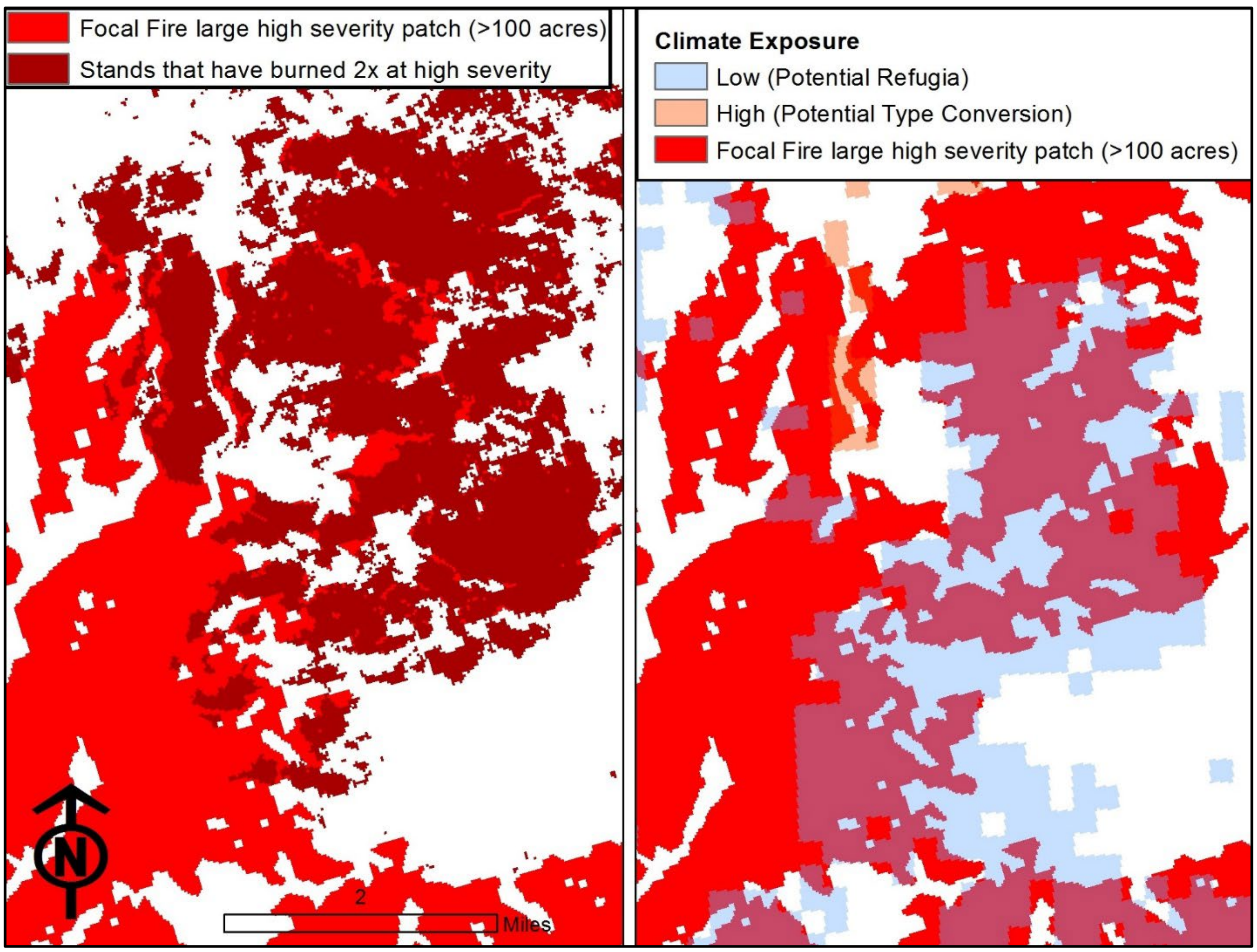
Example 1: Where do conifer islands occur within CA spotted owl PACs?

The conifer island filter can be used with the CA spotted owl PAC layer to identify PACs that burned at low severities, but may be vulnerable to future high severity fire, due to their adjacency to high severity patches. Combining these layers could help to prioritize CSO habitat that may benefit from edge hardening treatments to reduce the risk of future high severity fire. The map below shows an example of this approach.



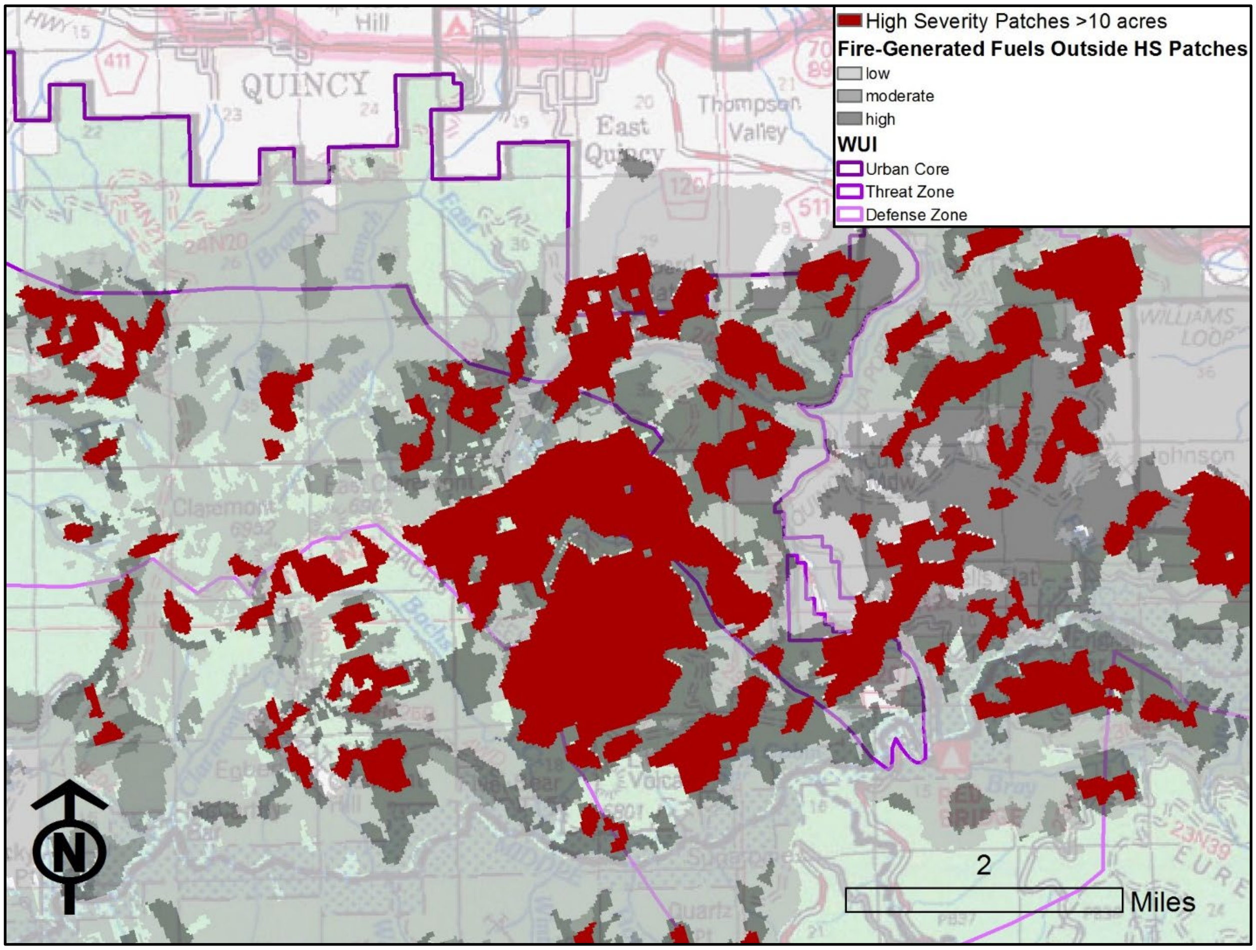
Example 2: Where have multiple high severity burns resulted in a "blank slate" that may be good candidates for reforestation? Are these areas predicted to support conifer forest by mid-century?

This analysis identified areas within high severity patches that also burned at high severity in at least one prior fire over the past 20 years. These areas may present fewer operational constraints for planting, due to snag and surface fuel reduction from the second high severity burn. The climate refugia overlay can also be used to identify where conifer forests are predicted to persist at mid-century, which can help to inform species mixes or elevation of seed source.



Example 3: Where are high concentrations of fire-generated fuels predicted to occur within WUI?

By overlaying the WUI filter, the fire-generated fuels layer, and high severity patches, we get a clear picture of where higher amounts of fire-generated fuels are predicted to occur.



References

Cansler, C. A., V. R. Kane, P. F. Hessburg, J. T. Kane, S. M. Jeronimo, J. A. Lutz, N. A. Povak, D. J. Churchill, and A. J. Larson. 2022. Previous wildfires and management treatments moderate subsequent fire severity. Forest Ecology and Management 504:119764.

Cochran, P. H. 1983. Stocking levels for east-side white or grand-fir.*in* Biology and management of true fir in the Pacific Northwest. U.S. Department of Agriculture, Forest Service Experiment Station, Portland, OR, Seattle, WA.

Coppoletta, M., K. E. Merriam, and B. M. Collins. 2016. Post-fire vegetation and fuel development influences fire severity patterns in reburns. Ecological Applications 26:686-699.

Coppoletta, M., M. D. Meyer, and M. P. North. 2021. Natural range of variation for red fir and subalpine forests in northwestern California and southwestern Oregon. Gen. Tech. Rep. PSW-GTR-269. Albany, CA: US Department of Agriculture, Forest Service, Pacific Southwest Research Station. 175 p. 269.

Cram, D. S., T. T. Baker, and J. C. Boren. 2006. Wildland fire effects in silviculturally treated vs. untreated stands of New Mexico and Arizona. Research Paper RMRS-RP-55. Page 28. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO.

Girvetz, E. H., and S. E. Greco. 2007. How to define a patch: a spatial model for hierarchically delineating organism-specific habitat patches. Landscape Ecology 22:1131-1142.

Graham, R. T., T. B. Jain, and M. Loseke. 2009. Fuel treatments, fire suppression, and their interaction with wildfire and its impacts: the Warm Lake experience during the Cascade Complex of wildfires in central Idaho, 2007.

Hessburg, P. F., S. J. Prichard, R. K. Hagmann, N. A. Povak, and F. K. Lake. 2021. Wildfire and climate change adaptation of western North American forests: a case for intentional management. Ecological Applications.

Landscape Ecology Modeling, Mapping, and Analysis (LEMMA) Team. 2020. Gradient Nearest Neighbor (GNN) raster dataset (version 2020.01). Modeled forest vegetation data using direct gradient analysis and nearest neighbor imputation. Retrieved from https://lemma.forestry.oregonstate.edu/data.

Long, J. N., and J. D. Shaw. 2012. A density management diagram for even-aged Sierra Nevada mixed-conifer stands. Western Journal of Applied Forestry 27:187-195.

Lydersen, J. M., B. M. Collins, M. Coppoletta, M. R. Jaffe, H. Northrop, and S. L. Stephens. 2019. Fuel dynamics and reburn severity following high-severity fire in a Sierra Nevada, USA, mixed-conifer forest. Fire Ecology 15.

Meyer, M., and M. North. 2019. Natural range of variation of red fir and subalpine forests in the Sierra Nevada bioregion. Gen Tech. Rep. PSW-GTR-263. Albany, CA: US Department of Agriculture, Forest Service, Pacific Southwest Research Station 263.

Meyer, M. D., J. W. Long, and H. D. Safford. 2021. Postfire restoration framework for national forests in California. Gen. Tech. Rep. PSW-GTR-270. Albany, CA: US Department of Agriculture, Forest Service, Pacific Southwest Research Station. 204 p. 270.

North, M. P., R. E. Tompkins, A. A. Bernal, B. M. Collins, S. L. Stephens, and R. A. York. 2022. Operational resilience in western US frequent-fire forests. Forest Ecology and Management 507.

Paudel, A., M. Coppoletta, K. Merriam, and S. H. Markwith. 2022. Persistent composition legacy and rapid structural change following successive fires in Sierra Nevada mixed conifer forests. Forest Ecology and Management 509:120079.

Prichard, S. J., P. F. Hessburg, R. K. Hagmann, N. A. Povak, S. Z. Dobrowski, M. D. Hurteau, V. Kane, R. E. Keane, L. N. Kobziar, C. A. Kolden, M. North, S. A. Parks, H. D. Safford, J. T. Stevens, L. L. Yocom, D. J. Churchill, R. W. Gray, D. W. Huffman, F. K. Lake, and P. Khatri-Chhetri. 2021. Adapting western North American forests to climate change and wildfires: 10 common questions. Ecological Applications.

Reinecke, P. (1933). Kyprische Dolche aus Mitteleuropa?. Germania: Anzeiger der Römisch-Germanischen Kommission des Deutschen Archäologischen Instituts, 17(4), 256-259.

Safford, H., J. Stevens, K. Merriam, M. Meyer, and A. Latimer. 2012. Fuel treatment effectiveness in California yellow pine and mixed conifer forests. Forest Ecology and Management 274:17-28.

Safford, H., and K. Van de Water. 2014. Using fire return interval departure (FRID) analysis to map spatial and temporal changes in fire frequency on national forest lands in California. Pacific Southwest Research Station, Research Paper, PSW RP-266.

Safford, H. D., and J. T. Stevens. 2017. Natural Range of Variation (NRV) for yellow pine and mixed conifer forests in the Sierra Nevada, southern Cascades, and Modoc and Inyo National Forests, California, USA. General Technical Report , PSW-GTR-256, USDA Forest Service, Pacific Southwest Research Station, Albany, CA.

Shive, K. L., H. K. Preisler, K. R. Welch, H. D. Safford, R. J. Butz, K. L. O'Hara, and S. L. Stephens. 2018. From the stand scale to the landscape scale: predicting the spatial patterns of forest regeneration after disturbance. Ecological Applications 28:1626-1639.

Steel, Z. L., D. Foster, M. Coppoletta, J. M. Lydersen, S. L. Stephens, A. Paudel, S. H. Markwith, K. Merriam, and B. M. Collins. 2021. Ecological resilience and vegetation transition in the face of two successive large wildfires. Journal of Ecology 109:3340-3355.

Stewart, J. A. E., P. J. Mantgem, D. J. N. Young, K. L. Shive, H. K. Preisler, A. J. Das, N. L. Stephenson, J. E. Keeley, H. D. Safford, M. C. Wright, K. R. Welch, and J. H. Thorne. 2021. Effects of postfire climate and seed availability on postfire conifer regeneration. Ecological Applications 31.

Tubbesing, C. L., D. L. Fry, G. B. Roller, B. M. Collins, V. A. Fedorova, S. L. Stephens, and J. J. Battles. 2019. Strategically placed landscape fuel treatments decrease fire severity and promote recovery in the northern Sierra Nevada. Forest Ecology and Management 436:45-55.

USDA Forest Service. 2008. Western Sierra Nevada (WS) Variant Overview – Forest Vegetation Simulator (revised October 5, 2021). . Page 88 *in* F. S. U. S. Department of Agriculture, Forest Management Service Center. , editor., Fort Collins, CO.

USDA Forest Service. 2022. Post-fire Restoration Opportunities for Conifer Forest in the 2021 Dixie and Sugar Fires, Michelle Coppoletta, ed.

GTR270_PNF_5Fire.gdb

a_Restoration_Opportunities

MixedCon_Restoration_Opps_NoDixie

Restoration opportunities from MixedCon_Restoration_Opps_All with Dixie/Sugar Fire excluded

Opp_ID: Unique identifier that links spatial data to restoration portfolio in the accompanying report (*Post-fire Restoration Opportunities for Conifer Forest, Plumas NF Fires 2017-2020*)
RestorationOpp: Three broad categories of opportunities: (1) take management action; (2) evaluate for management action; and (3) maintain or promote desired conditions.
Potential_Actions: More detailed description of potential actions; additional detail is provided in the Restoration Portfolio within the accompanying report (*Post-fire Restoration Opportunities for Conifer Forest, Plumas NF Fires 2017-2020*)
Action_Label: Simplified version of potential actions; can be used for maps and broadscale assessments
PreFire_Cond: Stand condition prior to the 5 focal fires; includes overview of pre-fire stand structure, treatment history, and recent fires.
PreFire_Dep: Pre-fire departure from NRV (low, moderate, high, variable).
FireSeverity: Fire severity within the 5 focal fires (measured as basal area mortality).
Fire_Effects: Assessment of post-fire condition based on pre-fire stand condition and focal fire severity patterns.
PostFire_Dep: Post-fire departure from NRV (low, moderate, high, variable).

MixedCon_Restoration_Opps_NoDixie_By_Ownership

Restoration opportunities from MixedCon_Restoration_Opps_All_ByOwnership with Dixie/Sugar Fire excluded

b_Base_Layers

FocalFire_Perimeters

perimeters of the five focal fires (Minerva, Camp, Walker, Camp, Sheep)

HUC12_FS

areas within HUC12 watersheds administered by the Plumas NF and Lassen NF

HUC12_AnalysisArea

area within the HUC12 watersheds that contain the five focal fires

HUC12_Ownership

area within the HUC12 watersheds that contain the five focal fires attributed with PNF, LNF, or other ownership

c_Vegetation

CalVeg_HUC12_All

CalVeg clipped to the HUC12_AnalysisArea (analysis area)

CalVeg_HUC12_Conifer

Conifer vegetation types within the analysis area

CalVeg_HUC12_Conifer1999

Areas classified as conifer forest in 1999 CalVeg

PreFire_Conifer_rSDI_stand

relative SDI at 30m resolution as modelled with LEMMA dataset and averaged across stands

d_Fire_Severity

RAVG_BA7_5class

Basal area loss following five focal fires as modelled by RAVG (5 severity classes)

RAVG_BA7_5class_Conifer

Same as above, but only within areas typed as conifer forest prior to focal fires

e_High_Sev_Patches

High_Severity_Patches_Conifer

High severity patches in conifer forest (as typed in 1999) >1.2 acres, assessed with PatchMorph (6 size classes)

f_Fire_History

PastFires_1997to2020

All fires >200 acres occurring from 1997-2020 within the analysis area

Reburn_Count_1997to2020

Number of times each 30m x 30m pixel has been within a fire perimeter from 1997-2020

Reburn_High_Count_1997to2020

times each 30m x 30m pixel has experienced high severity fire (BA loss >75%) from 1997-2020

Reburn_LowMod_Count_1997to2020

times each 30m x 30m pixel has experienced low-mod severity fire (BA loss <75%) from 1997-2020

g_Treatment_History

FACTS_VegFuels_1997to2021

vegetation and fuels treatments that occurred within the analysis area from 1997-2020

PostFire_TreatmentHistory

Vegetation and fuels treatments that occurred prior to focal fires within those fire perimeters, or in any year outside of focal fire perimeters

PreFire_Salvage_Reforestation

Salvage and reforestation treatments that occurred prior to focal fires within those fire perimeters, or in any year outside of focal fire perimeters

PreFire_TreatmentHistory

Vegetation and fuels Treatments that occurred after focal fires within those fire perimeters

h_Stand_Departure

this analysis was applied to conifer forest areas outside of high severity patches >100 acres and outside of pre-fire salvage and reforestation treatments. Stands were derived from CalVeg, then further divided where stands experienced unique combinations of treatment or fire history

departure_index

weighted index combining rSDI, FRID, and Treatment scores to derive departure metric for each stand

frid_index

number of low to moderate severity fires experienced by stand

rsdi_index

relative SDI values averaged by stand

treatment_index

number of pre-fire vegetation and fuels treatments

i_Fire_Generated_Fuels

fire_generated_fuels_index

predicted fire-generated fuels (derived from pre-fire rSDI and fire severity)

j_Natural_Regeneration

NaturalRegen_HiSev100plus

probability of natural conifer regeneration within high severity patches >100 acres

NaturalRegenHiSev10to100

probability of natural conifer regeneration within high severity patches 10-100 acres

NaturalRegenProbability_Conifer

probability of natural conifer regeneration as modelled with POSCRPT with mean precipitation and seed source parameters

k_Filters

ClimateExposure_Conifer

Areas modelled as mid-century conifer refugia or at risk for type conversion with Thorne model

Conifer_Islands

10-250 acre conifer forest stands (unburned, or low-moderate severity burn) surrounded by high severity patches or montane chaparral

CSO_PACs

California Spotted Owl PACs (current as of August 2022)

Slope_35percent

Analysis area divided into areas with <=35% slope, and >35% slope

TwiceHighSev_Conifer

Areas that were typed as conifer forest in 1999, and have subsequently burned twice at high severity

TwiceHighSev_Conifer_100ac

Areas within high severity patches >100 acres that have burned twice at high severity

WUI

Wilderness-urban interface Urban Core, Defense, and Threat Zones

APPENDIX B: FOREST ACTIVITY TRACKING SYSTEM (FACTS) CROSSWALK

Assessment Categories	FACTS Activity Codes	FACTS Activities
Fuel treatment	1120	Yarding - Removal of Fuels by Carrying or Dragging
	1136	Pruning to Raise Canopy Height and Discourage Crown Fire
	4530	Prune
	1150	Rearrangement of Fuels
	1152	Compacting/Crushing of Fuels
	1153	Piling of Fuels, Hand or Machine
	1154	Chipping of Fuels
	1160	Thinning for Hazardous Fuels Reduction
	1180	Fuel Break
	4540	Control of Understory Vegetation
	4471	Site Preparation for Planting - Burning
	4473	Site Preparation for Planting - Other
	4474	Site Preparation for Planting - Mechanical
	4475	Site Preparation for Planting - Manual
	4494	Site Preparation for Natural Regeneration - Mechanical
	4495	Site Preparation for Natural Regeneration - Manual
	4521	Precommercial Thin
	6103	Wildlife Habitat Precommercial thinning
Harvest	4102	Coppice Cut (w/leave trees) (EA/RH/FH)
	4111	Patch Clearcut (EA/RH/FH)
	4113	Stand Clearcut (EA/RH/FH)
	4117	Stand Clearcut (w/ leave trees) (EA/RH/FH)
	4132	Seed-tree Seed Cut (with and without leave trees) (EA/RH/NFH)
	4141	Shelterwood Removal Cut (EA/NRH/FH)
	4143	Overstory Removal Cut (from advanced regeneration) (EA/RH/FH)
	4210	Improvement Cut
	4220	Commercial Thin
	4241	Special Products Removal
	4151	Single-tree Selection Cut (UA/RH/FH)
	4152	Group Selection Cut (UA/RH/FH)
	4242	Harvest Without Restocking
Reforestation	4431	Plant Trees
	4432	Fill-in or Replant Trees
	4411	Seed (Trees)
	4511	Tree Release and Weed
	6102	Wildlife Habitat Release and weeding
Prescribed Fire	1111	Broadcast Burning - Covers a majority of the unit
	1113	Underburn - Low Intensity (Majority of Unit)
	2540	Invasives - Cultural /Fire

	4541	Control of Understory Vegetation- Burning
	6101	Wildlife Habitat Prescribed fire
	1112	Jackpot Burning - Scattered concentrations
	1130	Burning of Piled Material
Salvage	4231	Salvage Cut (intermediate treatment, not regeneration)
	4232	Sanitation Cut
Wildlife	6104	Wildlife Habitat Regeneration cut
	6105	Wildlife Habitat Intermediate cut
	6107	Wildlife Habitat Mechanical treatment