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Sierra Cascade Province

Post-fire Restoration Opportunities for Conifer Forest in the 2021 Dixie and Sugar Fires

Plumas and Lassen National Forests

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Cover photo: Area burned by 2007 Moonlight Fire and 2021 Dixie Fire on the Plumas National Forest. Photo credit: Katherine Lowe, University of California, Berkeley.

SUMMARY

This document provides an overview of the process used to identify restoration opportunities for mixed conifer forests within the 2021 Dixie and Sugar fire landscape. 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 conifer forest resilience. 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.

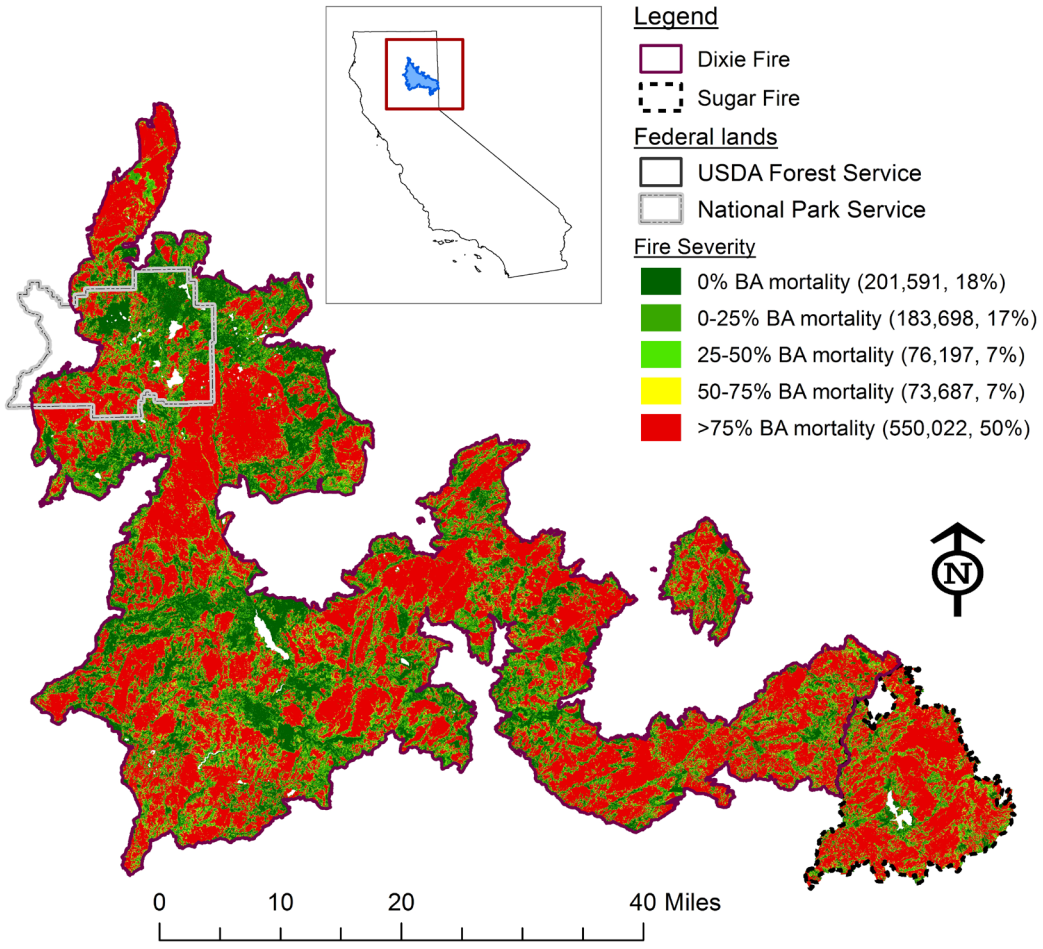

Figure 1. Location and severity of the Dixie and Sugar fires in northern California. Impacted counties included Shasta, Lassen Tehama, Plumas, and Butte. Severity is shown for all vegetation types. Acres and % of entire area burned is provided in the legend.

FIRE OVERVIEW

In 2021, the Dixie and Sugar fires ignited within weeks of one another, combining to burn over one million acres in the Sierra Nevada and southern Cascade ranges of northern California (Figure 1). The two fires burned through a variety of ownerships, impacting significant portions of the Plumas National Forest (483,356 acres), Lassen National Forest (284,938 acres), Lassen National Park (77,508 acres), and numerous private lands (241,810 acres). Elevations within the fire perimeters range from less than 1,300 feet in the Feather River Canyon to over 8,600 feet atop the highest peaks. This wide elevational gradient supported a mosaic of vegetation types prior to the fires, including conifer forest, oak woodlands, aspen stands, sagebrush, montane chaparral, meadows, and riparian habitats (Figure 2).

Heavy fuel loads and dense forest conditions, combined with hot weather, high wind speeds, exceptionally dry vegetation, and steep terrain, increased both the size and severity of the Dixie and Sugar fires. Approximately 50% of the area impacted by the two fires 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. Within the fire perimeters, approximately 14% burned at moderate severity (25-75% basal area mortality) and 17% burned at low severity (0-25% basal area mortality), while the remainder (18%) was characterized as unchanged by the fire (Figure 2).

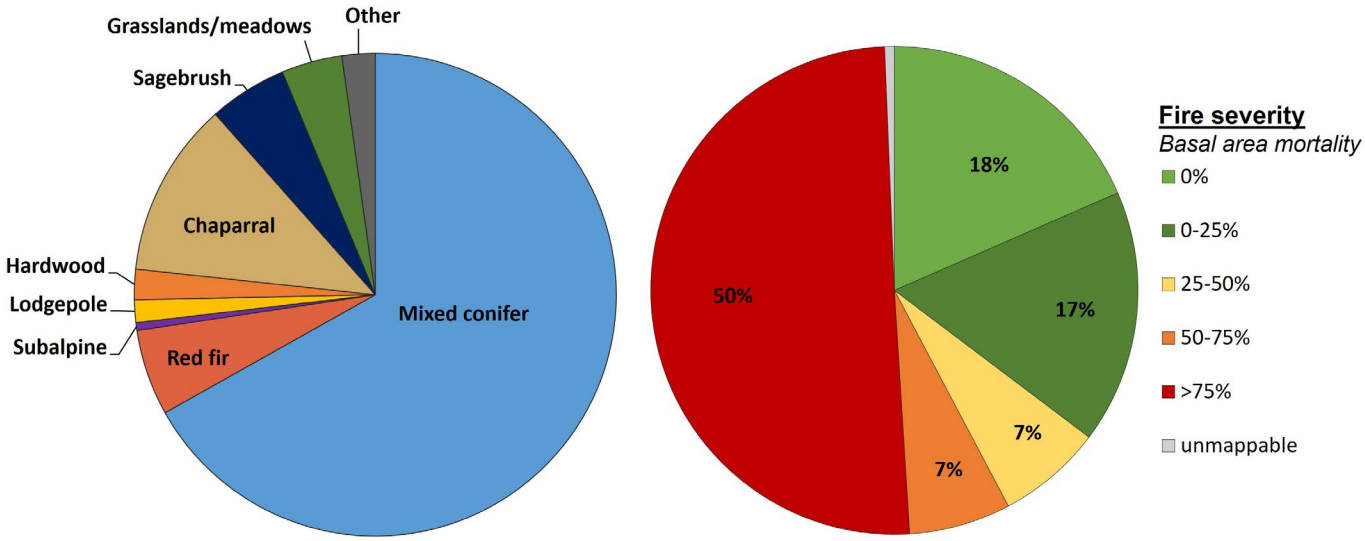

Figure 2. Distribution of major vegetation types within the Dixie and Sugar fire perimeters (left). Data represent pre-fire vegetation and cover all ownerships. Distribution of fire severity within the fires (right). Sources: CALVEG and RAVG, USDA Forest Service, Pacific Southwest Region.

POST-FIRE RESTORATION ASSESSMENT PROCESS

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 3) and uses a five-step assessment process (Figure 4) to guide development of potential restoration opportunities (Figure 5), which can ultimately be used to inform postfire 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 the Dixie and Sugar fire landscape (e.g., steps 1-3, Figure 4). 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.

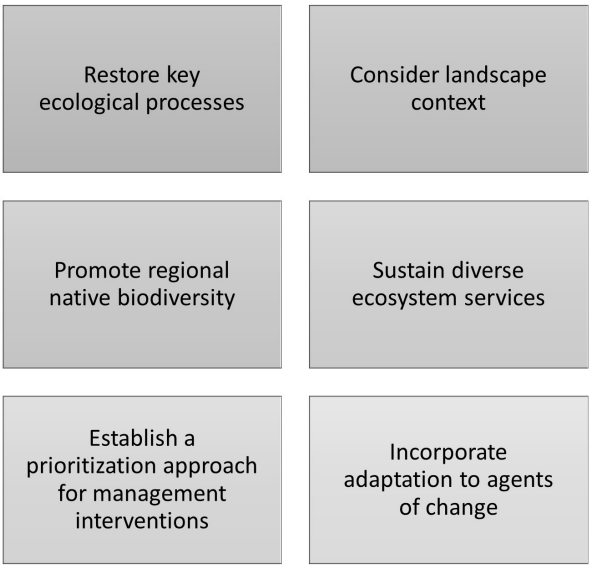

Figure 3. The six ecological principles that provide the foundation for the post-fire assessment process. From Meyer et al. 2021.

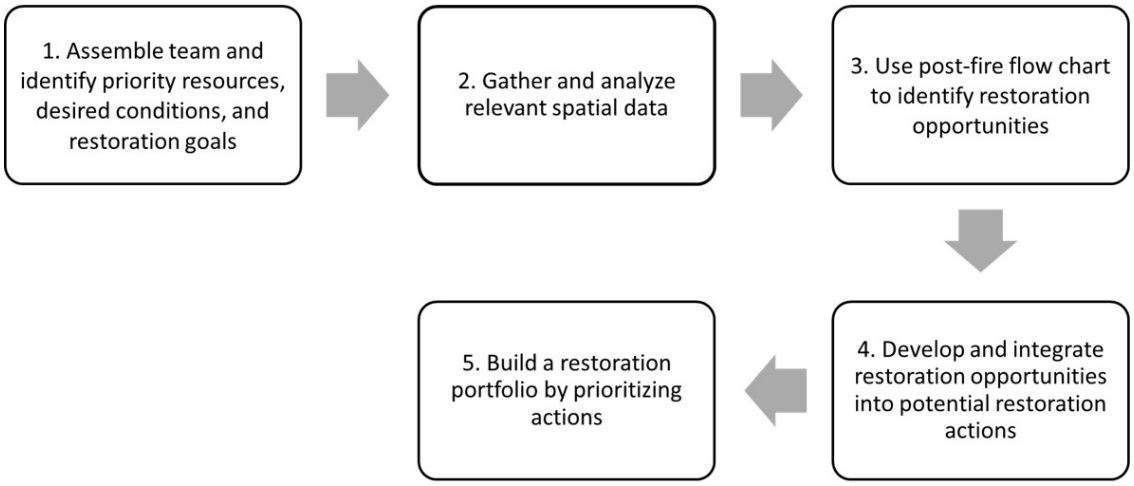

Figure 4. The five-step process used in the post-fire restoration framework. From Meyer et al. 2021.

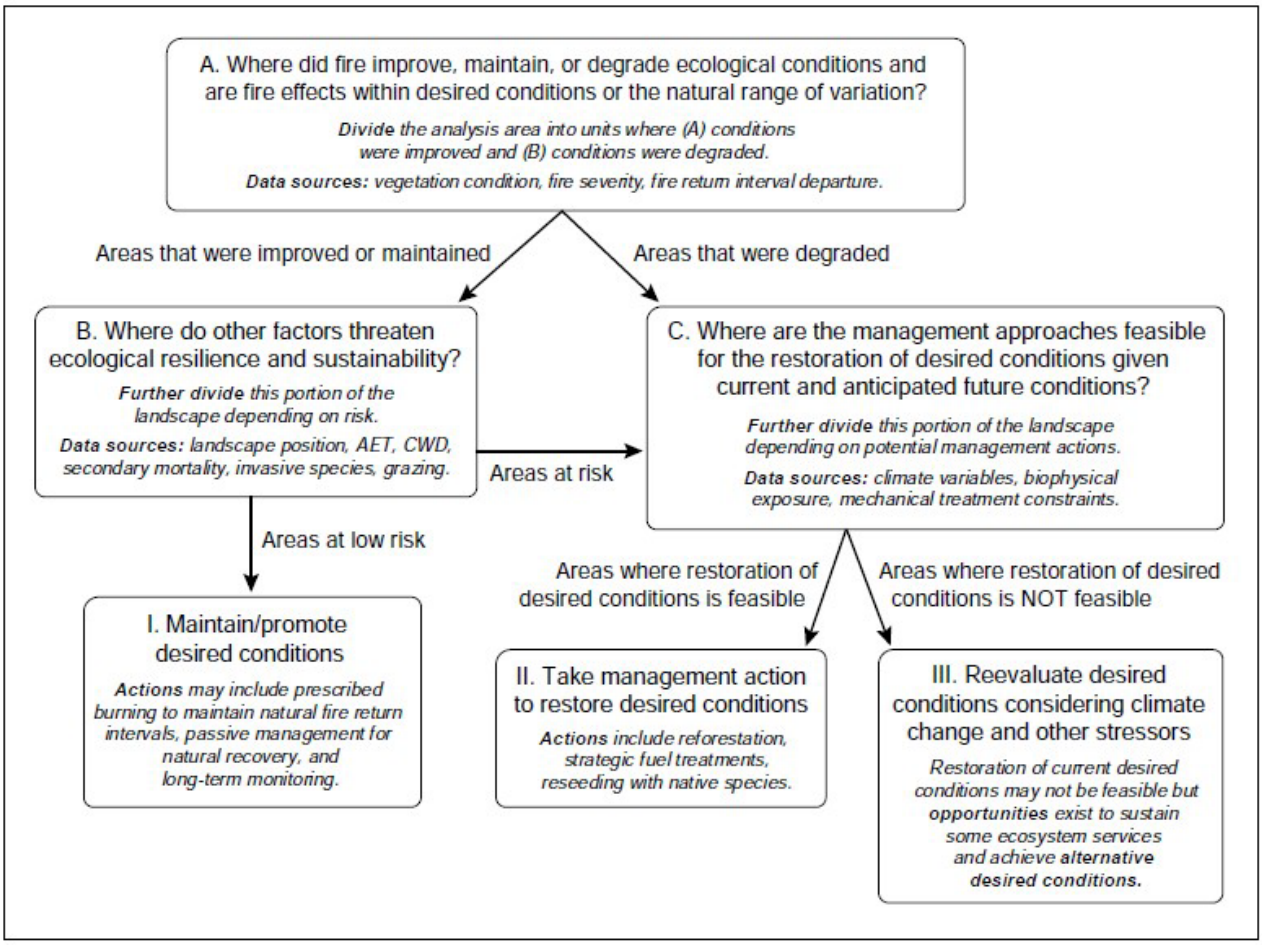

Figure 5. The post-fire flow chart from Meyer et al. 2021. This process uses three questions (A, B, and C) to identify management responses or "restoration opportunities" (1,2, and 3) in different portions of the post-fire landscape.

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 Michelle Coppoletta (project lead, Associate Province Ecologist), Will Brendecke (Plumas NF Silviculturist), Frank Heide (Lassen NF Silviculturist), Ryan Bauer (Plumas NF Fire Management), and Ryan Tompkins (UC Cooperative Extension).

Priority resource

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 the target for forest restoration and fuel reduction activities in this region. Prior to the Dixie and Sugar fires, this vegetation type occupied over 780,000 acres, or just over 70% of the landscape (Figure 6). Table 1 lists the specific forest types that were included in our analysis. With the exception of 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. 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. 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).

It is important to note that one limitation of this assessment is its reliance on pre-fire vegetation maps to identify areas of conifer forest vegetation. In some areas that were impacted by recent, stand-replacing fire (e.g., 2007 Moonlight Fire, 2012 Chips Fire, 2012 Reading Fire), restoration opportunities may be greatly underrepresented. This is due to recent fire-related conversions of conifer forest to early seral vegetation, such as montane chaparral or oak woodland, which are outside the scope of this assessment.

Table 1. California Wildlife Habitat Relationship (CWHR) vegetation types included in our assessment of conifer forest. Pre-fire vegetation maps were used to identify areas that were forested prior to the Dixie and Sugar fires. Acres and percentage represent the total area occupied by each forest type within the fire footprint and does not include the affected watersheds outside of the fire boundary.

Forest Type	Primary Species	Acres (%)
Eastside Pine (EPN)	ponderosa pine, Jeffrey pine, white fir	102,928 (13%)
Jeffrey Pine (JPN)	Jeffrey pine, ponderosa pine, sugar pine	20,881 (3%)
Montane Hardwood-Conifer (MHC)	ponderosa pine, incense cedar, California black oak	21,704 (3%)
Ponderosa Pine (PPN)	ponderosa pine, Jeffrey pine, Douglas fir	23,799 (3%)
Red Fir (RFR)	red fir, white fir, lodgepole pine	62,661 (8%)
Sierran Mixed Conifer (SMC)	Douglas fir, ponderosa pine, white fir	475,427 (60%)
White Fir (WFR)	white fir, Douglas fir, sugar pine	82,382 (10%)

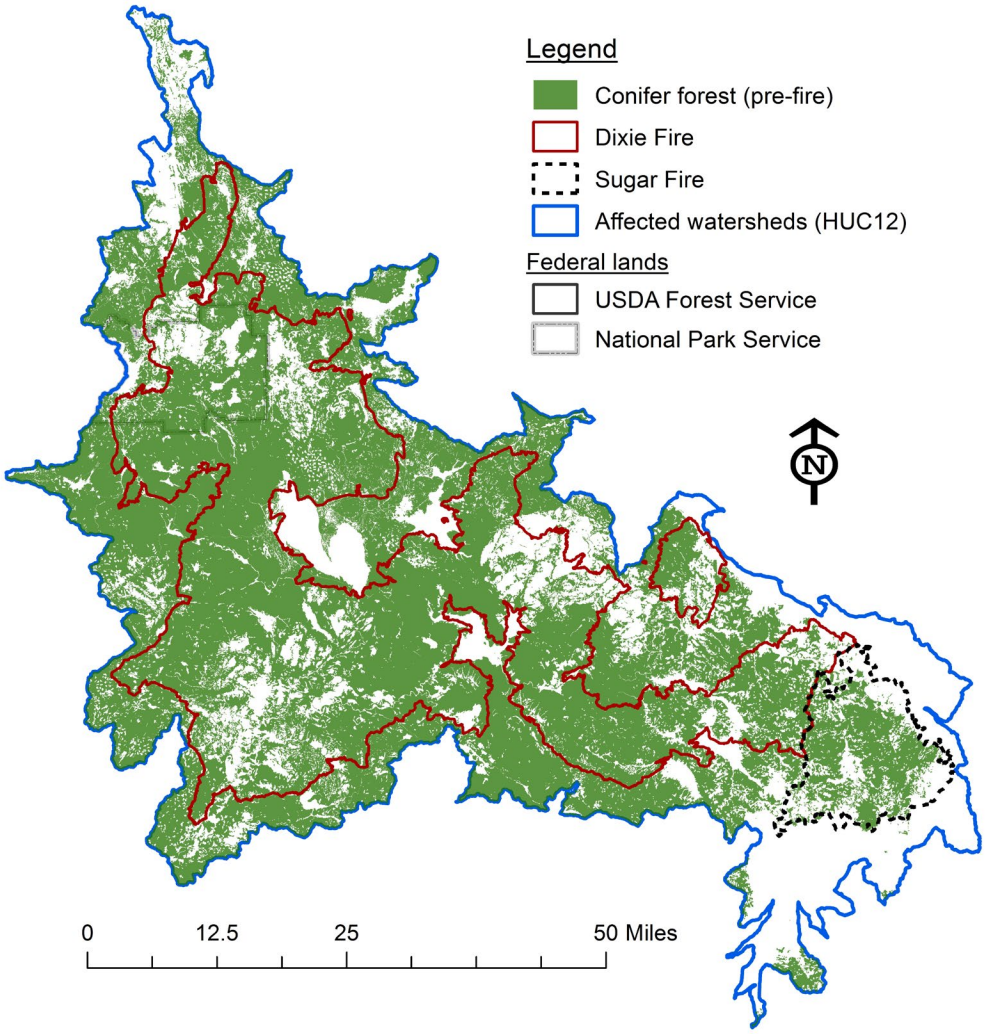

Figure 6. Distribution of conifer forest in the assessment area prior to the Dixie and Sugar fires.

Restoration goals

The assessment team identified the following three restoration goals for conifer forests impacted by the Dixie and Sugar 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 assessment area includes the combined footprint of the 2021 Dixie and Sugar fires, as well as the sub-watersheds (HUC12) within or adjacent to the fires (Figure 6). It encompasses burned and unburned forest vegetation across all ownerships, including National Forest System (Plumas and Lassen National Forests), National Park Service (Lassen NP), and private lands (Figure 7). Although our data analysis took an all-lands approach, restoration opportunities were limited to areas outside of wilderness, as these are generally not areas of active management.

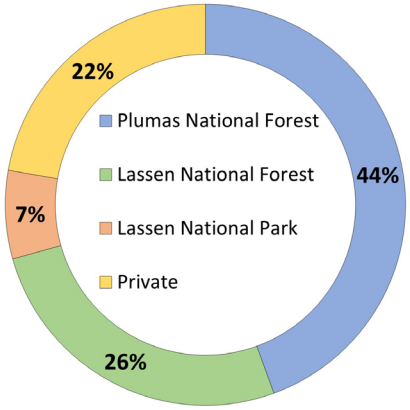

Figure 7. Distribution of ownership within the area impacted by the Dixie and Sugar fires

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

The intent of this assessment is to provide a timely analysis of fire-related impacts to conifer forests in the Dixie and Sugar fire landscape. To do this quickly, and at a meaningful scale, we relied on spatial data that were readily available after the fires, rather than information collected from post-fire field surveys. The spatial datasets used in this assessment are listed in Table 2.

Table 2. Spatial data used in the Dixie and Sugar 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 Dixie and Sugar fires, as well as past fires (2000-2020); 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 2000-2020
Stand density index (SDI)	USDA Forest Service, Remote Sensing Lab, F3 dataset: Zieke SDI	F3 integrates: Forest Inventory and Analysis (FIA) data; Forest Vegetation Simulator (FVS); and Field and Satellite for Ecosystem Mapping (Huang et al. 2018)
Basal area	USDA Forest Service, Remote Sensing Lab, F3 basal area datasets 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	F3 integrates: Forest Inventory and Analysis (FIA) data; Forest Vegetation Simulator (FVS); and Field and Satellite for Ecosystem Mapping (Huang et al. 2018)

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

We used the post-fire decision process, described in Figure 5 (Meyer et al. 2021), to spatially partition the burned landscape and identify potential opportunities for restoration. An overview of the specific process used for the Dixie and Sugar fire assessment is presented in Figure 8 and described in more detail in the following sections.

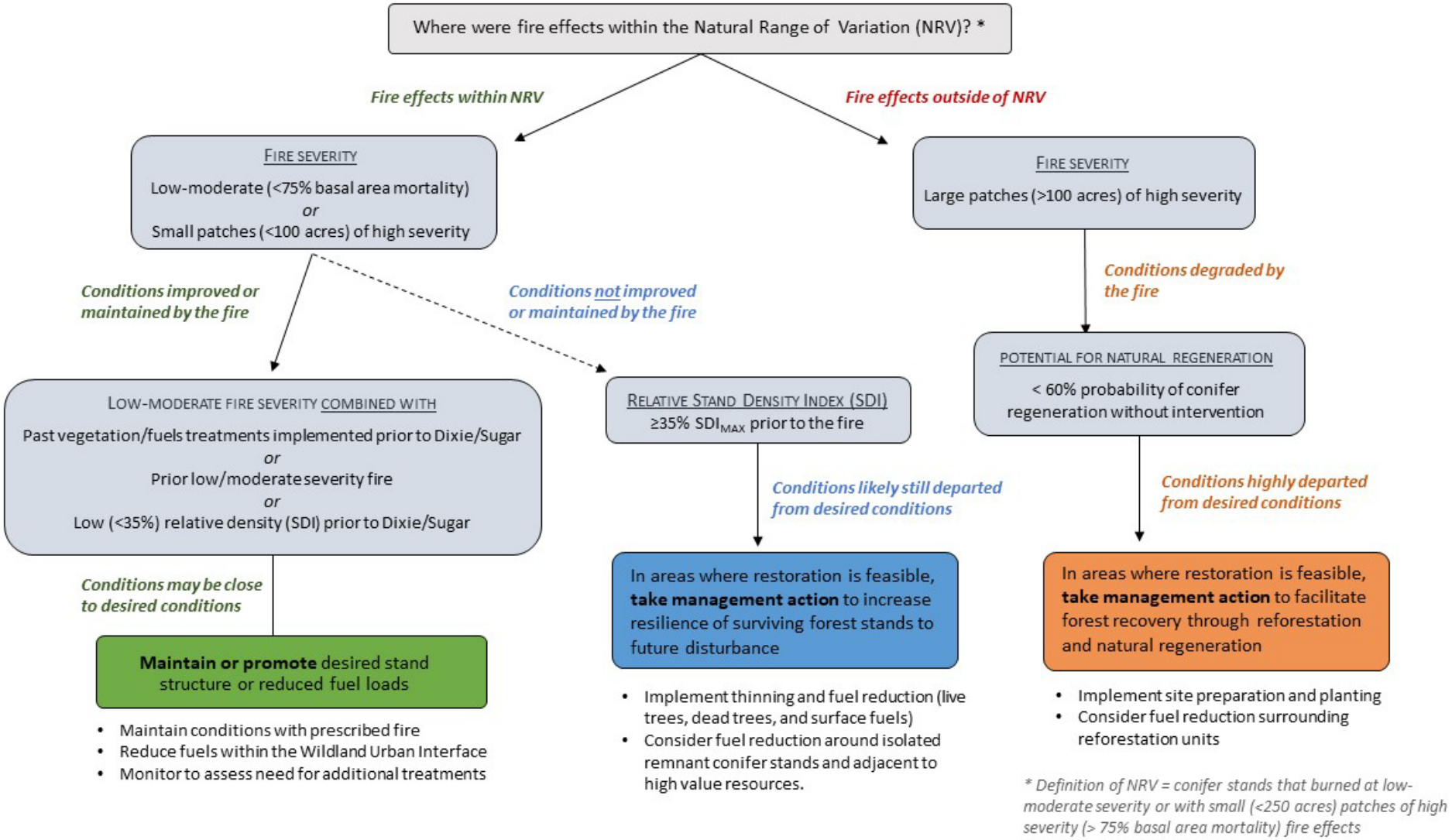

Figure 8. The decision process used to spatially partition the Dixie and Sugar fire landscape and identify potential restoration opportunities for mixed conifer forests.

Where were fire effects within the natural range of variation (NRV) and where were they departed?

The first step in the assessment process is 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 were considered to be within the natural range of variation (NRV) and where they were departed. In this assessment, 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.

We used the following criteria to identify areas where fire effects were within and departed from NRV:

- **Fire effects considered within NRV** = areas that supported conifer forest prior to the fire and burned at low (<25%) or moderate (25%-75%) severity; includes stands within the fire perimeter that were characterized as unchanged and small patches (<100 acres) of high severity.
- **Fire effects considered outside of NRV** = areas that supported conifer forest prior to the fire and experienced high severity fire effects (>75% basal area mortality) in contiguous patches greater than 100 acres; these areas are the least likely to support live trees in the near-term.

We obtained fire perimeter and satellite-derived estimates of fire severity for the 2021 Dixie and Sugar fires from the USDA Forest Service Rapid Assessment of Vegetation Condition after Wildfire (RAVG) program. For this analysis, we combined RAVG severity estimates from the Dixie and Sugar fires into one data layer. Where the two fires overlapped, severity values from the Dixie Fire were used since they represent the most recent fire effects. Both fires used imagery from the prior October (2020) for pre-fire conditions.

Table 3. Fire severity categories and definitions used in this assessment. Data provided by the USDA Forest Service 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

Fire effects outside of NRV

We used two criteria to identify areas where fire effects were considered to be outside of NRV: (1) high severity patch size and (2) predicted conifer regeneration. The conifer species that are most common in the Dixie and Sugar fire landscape lack adaptations, like resprouting or long-distance seed dispersal, to quickly regenerate after large severe disturbances. This can significantly impact post-fire conifer regeneration and increase the risk of conversion to non-forested vegetation types, particularly in the interiors of large high severity patches that are far beyond the range of conifer seed dispersal.

Criteria 1: Large patches of high severity fire

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 mixed conifer forest prior to the 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 4). 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 250-acres to be highly departed from NRV. We considered 100-acre patches to be moderately departed, based on this size being at the upper end of the NRV for these forest types (Safford and Stevens 2017).

Table 4. Departure based on fire severity and patch size. High severity patches were limited to areas that were characterized as mixed conifer forest prior to the Dixie and Sugar fires. Acres and number of patches include all lands within the assessment area, including NFS, NPS, and private.

Condition	Departure category	Number of patches	Acres
High severity patches < 100 acres, includes some areas on the edge of patches	Low	3,253	39,978
High severity patches 100-250 acres	Moderate	138	21,985
High severity patches > 250 acres	High	165	244,787

In areas that were conifer forest prior to the Dixie and Sugar fires, we identified a total of 3,556 high severity patches. These patches ranged in size from 1.5 acres to 32,287 acres, with a mean patch size of 86 acres and a median of 6.1 acres. Small patches (<100 acres) accounted for more than 90% of the total number of high severity patches, but represented only a small proportion (13%) of the total high severity patch area. In contrast, the four largest patches (>10,000 acres) accounted for almost a quarter of the total area burned in high severity patches. High severity patches greater than 250 acres (i.e., considered highly departed from NRV) and between 100-250 acres (i.e., moderately departed from NRV) accounted for 80% and 7% respectively of the total area burned in high severity patches. The largest high severity patch was located northeast of Lake Almanor on the Lassen National Forest and covered 32,286 acres or about 50 square miles.

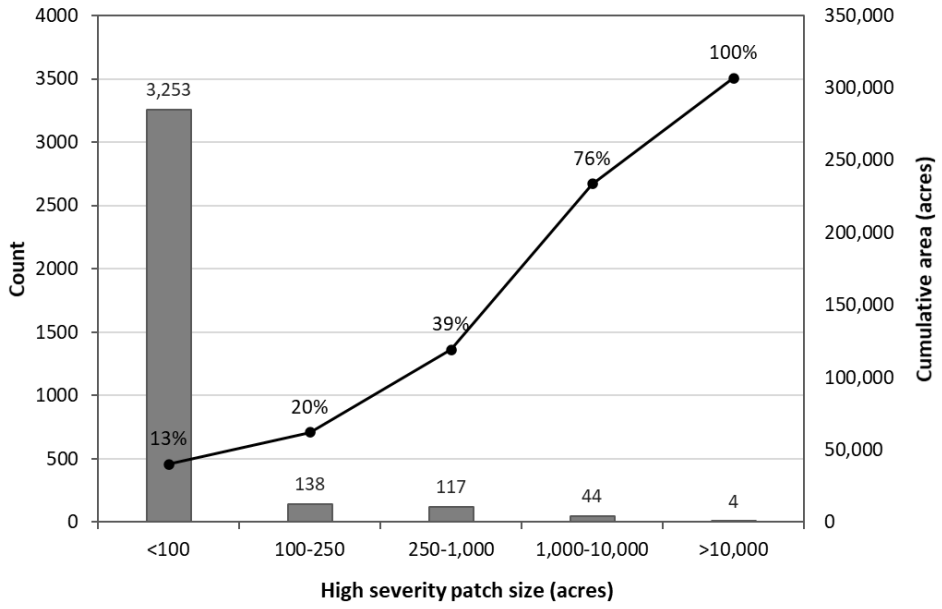

Figure 9. Distribution of stand-replacing patches (defined as >75% basal area mortality) and cumulative proportion by patch size class within the 2021 Dixie and Sugar Fires (combined). Minimum patch size was 1.2 acre (0.5 ha). Values above bars represent the number of patches within that size class. Line shows total area and cumulative proportion. Patches >250 acres in size are considered to be highly departed and outside of the natural range of variation.

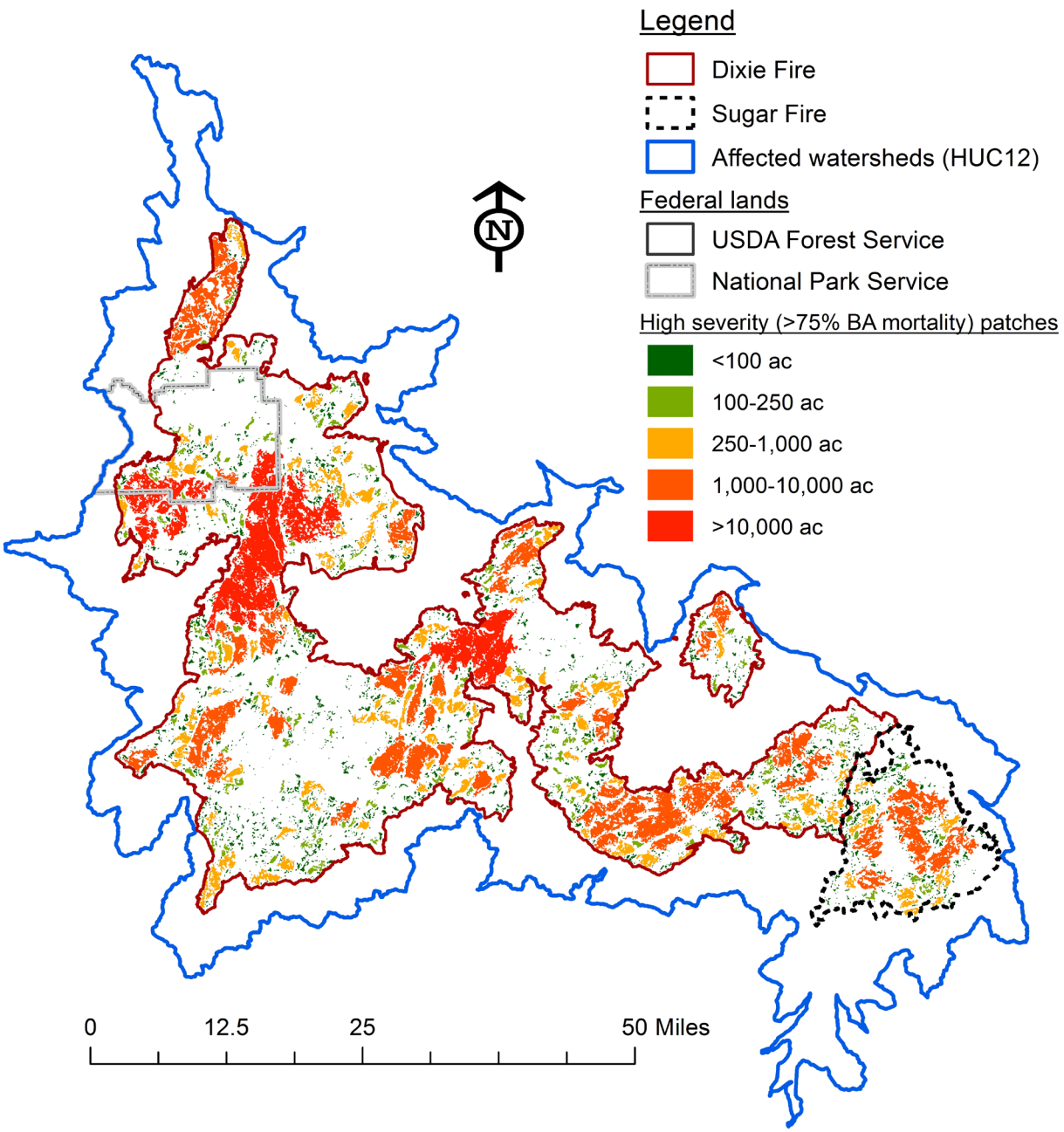

Figure 10. High severity patches in areas that were characterized as mixed conifer forest prior to the fires. Patch sizes greater than >250 acres are generally considered outside of the natural range of variation (NRV) for these forest types. In this assessment, 100-250-acre high severity patches are considered moderately departed from NRV, while patches >250 acres are considered highly departed.

Criteria 2: Areas that are unlikely to naturally regeneration 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 exclude areas that were not mixed conifer forest prior to the fire. These excluded areas include chaparral and other non-forest vegetation types that may 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 Dixie and Sugar fires, 168,256 acres (22% of the combined fire area) were predicted to have a high (>80%) likelihood of natural regeneration in the near-term (Figure 11). In contrast, 254,889 acres (33%) were within the two lowest prediction classes (<40%). 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.

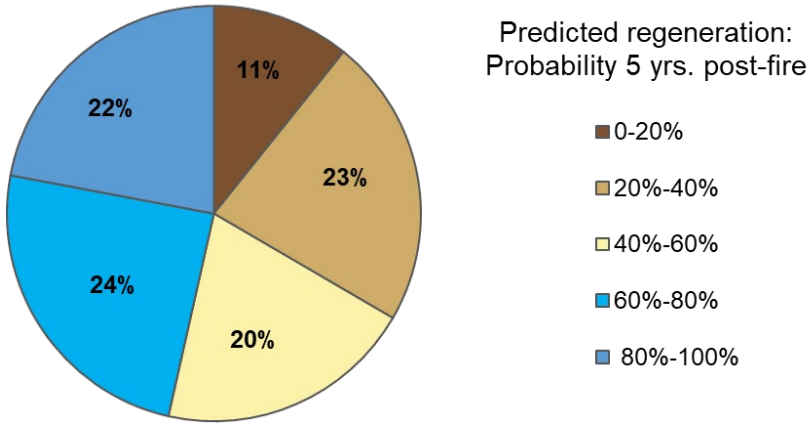

Figure 11. Predicted regeneration (mean precipitation and mean seed availability) in areas that were conifer forest prior to the fires.

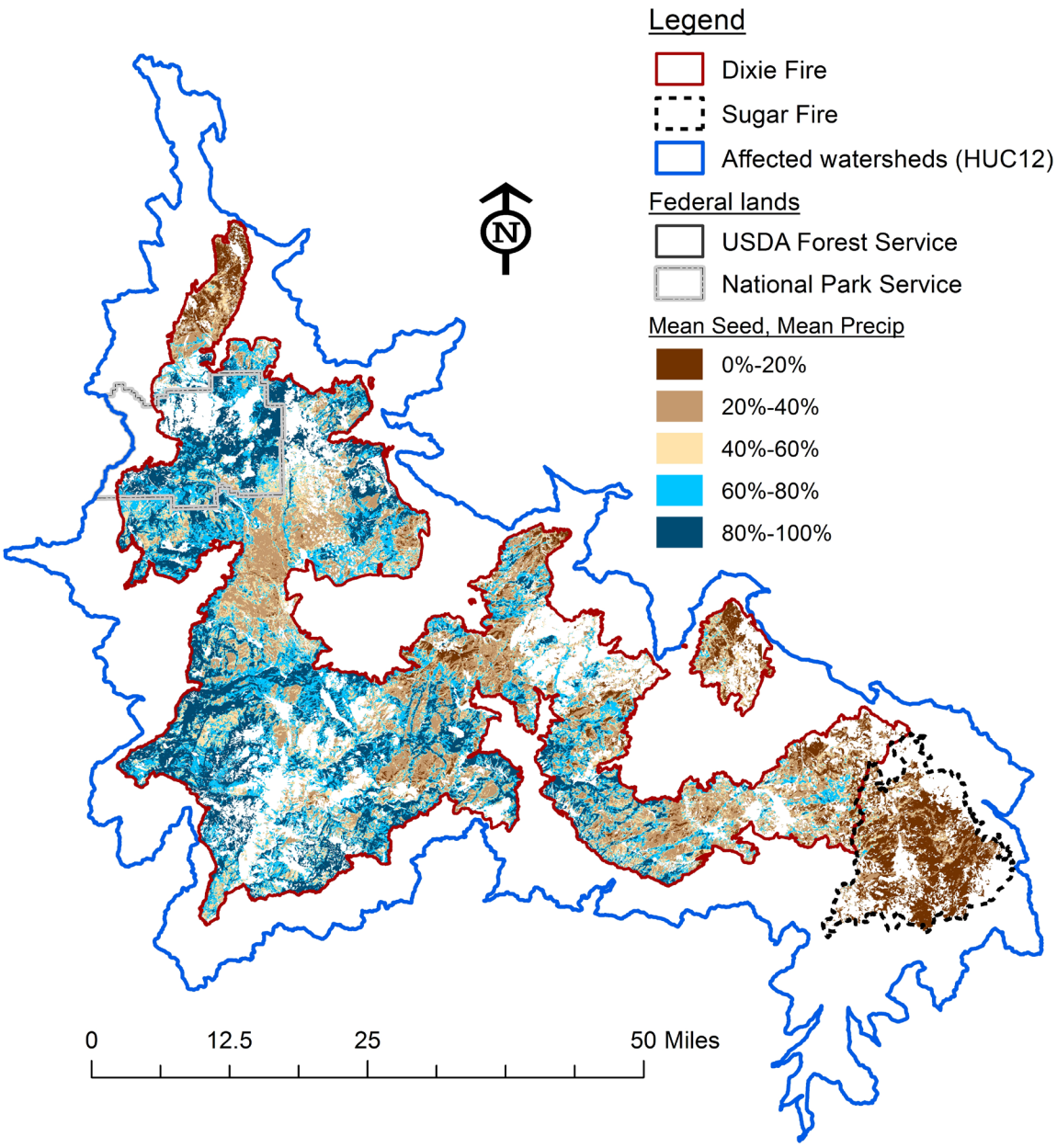

Figure 12. Map showing the probability of natural regeneration five years after the Dixie and Sugar fires. Predictions are limited to areas that were conifer forest prior to the fires.

Restoration Opportunities: Fire effects outside of NRV

To identify opportunities for reforestation, we overlaid large high severity patches (>100 acres) with areas that had low-moderate potential for natural regeneration (<60% probability) and assigned a priority for restoration action (Table 5). These are areas within the fire perimeter where management actions are most likely needed to facilitate forest recovery (Restoration Goal #3).

Table 5. Criteria used to identify high, moderate, and low priority areas for reforestation. High severity patches that were 100-250 acres and >250 acres in size, that had unknown regeneration probability (i.e., were outside of model boundary), were included in the moderate and high priority categories respectively.

Departure from NRV (High severity patch size)	**Predicted probability of natural regeneration**		
	Low (0-40%)	**Moderate (40-60%)**	**High (60-80%)**
Low (<100 acres)	None	None	None
Moderate (100-250 acres)	High Priority	High Priority	High-Moderate Priority
High (>250 acres)	High Priority	High Priority	High-Moderate Priority

We used a separate process to identify reforestation opportunities in areas where the Dixie Fire overlapped with six past fires - the 2000 Storrie Fire, 2007 Moonlight Fire, 2008 Butte Lightning Complex, 2008 Rich Fire, 2021 Chips Fire, and the 2012 Reading Fire. These past fires included large areas of extensive stand-replacing fire effects, resulting in fire-related conversion of conifer forest to early seral vegetation, such as montane chaparral or oak woodland. Due to this shift in dominant vegetation type, many of these areas were excluded from the larger analysis because they were not classified as conifer forest prior to the Dixie Fire. To identify opportunities for reforestation in areas within these past fire perimeters, we used older vegetation maps (created prior to 2000) to identify areas where conifer forest was present in the recent past. We then overlaid large high severity patches (>100 acres) in the Dixie Fire with areas that had low-moderate potential for natural regeneration (<60% probability) and assigned a priority for restoration action. This process identified an additional 42,706 acres of reforestation.

Overall, we identified a total of 288,940 acres, outside of designated wilderness, that are a high to moderate priority for reforestation (Table 6). These are areas that are unlikely to naturally recover in the near future without active intervention. 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. Longer-term activities may also be needed to protect reforestation units from future severe fire (Restoration Goal #1); these activities may include control of competing vegetation, precommercial thinning, and fuels management.

Table 6. Number of acres in high and moderate priority categories on National Forest and private lands outside of designated wilderness. Excluded wilderness areas include both Forest Service and National Park Service lands.

Ownership	High Priority	High-Moderate Priority	Total
Lassen National Forest	76,486	11,520	**88,006**
Plumas National Forest	136,283	4,908	**141,191**
Other ownership	56,422	3,321	**59,743**
Total	**269,191**	**19,749**	**288,940**

Fire effects within NRV

Our next step was to examine areas within the Dixie and Sugar fires where fire effects were considered to be within the NRV and to identify areas where the fires may have improved or maintained forest condition. We used the following criteria to identify areas where fire effects were considered to be within the NRV:

1) Vegetation was classified as mixed conifer forest prior to the fire (Table 1); and
2) Stands burned at low-moderate severity (<75% basal area mortality) or were islands within the fire perimeters that were classified as unchanged; or
3) Patches of high severity that were less than 100 acres in size

Areas where conditions were improved by the fire

We identified three scenarios where forest conditions may have been maintained or improved by the Dixie and Sugar fires. In these areas, restoration actions may be warranted over the longer-term to maintain desired conditions that were created or promoted by the fires.

Scenario 1: Areas that were treated prior to the fire and burned at low-moderate severity

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, and were subsequently burned at low-moderate severity, to have a high potential for restored conditions. To identify these areas within the Dixie and Sugar fires, we identified places that met both of the following conditions:

1) Forested stands that were treated in the 20-year period prior to the fire (i.e., thinning, fuel reduction, prescribed fire, etc.); and
2) burned at low-moderate severity (<75% basal area mortality) or were characterized as unchanged by the Dixie or Sugar fires.

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 2000-2020 that modified or manipulated vegetation and fuels. The assessment team binned treatment activities into six broad categories: harvest, fuel reduction, reforestation, prescribed fire, salvage, and wildlife-related treatments. 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. These non-overlapping polygons represent the total footprint of vegetation and fuels treatments completed between 2000-2020. The date of the most recent treatment, within each treatment category, was included in the attribute table (Figure 13). Polygons that were smaller than 0.1 acre were removed from the dataset.

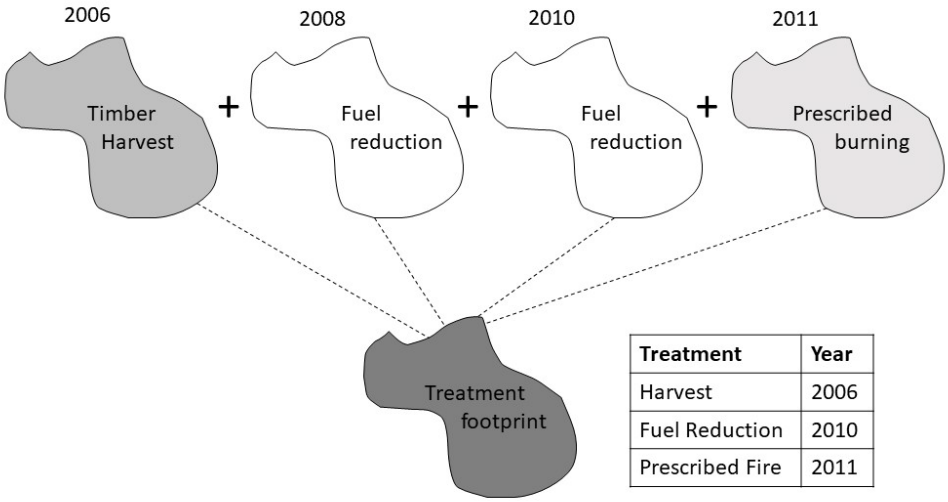

Figure 13. Visual representation of the process used to create non-overlapping polygons of treatments completed between 2000-2020 within the Dixie and Sugar fire footprints. This example shows an area where four different treatments were applied in four different years. Note that only the most recent year of treatment in each category (in this case, fuel reduction) is included in the attribute table.

After compiling all treatments that had occurred in the 20 years prior to the fires into a non-overlapping treatment footprint, 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. After removing large patches of high severity from treatment units, we then calculated the mean fire severity across the individual treatment polygons. Severity estimates were limited to areas that were classified as conifer forest prior to the fire and did not include fire severity estimates from other non-forest vegetation types that occurred within treatment units.

Restoration Opportunities: Areas treated prior to the fires

We identified a total of 48,762 acres that were treated in the 20-year period prior to the fires and then subsequently burned at low-moderate severity in the 2021 Dixie or Sugar fires; this includes 20,837 acres on the Lassen National Forest and 27,925 acres on the Plumas National Forest. Of these, a total of 19,900 acres received at least two vegetation manipulation or fuels reduction treatments prior to the fires and then burned at low-moderate severity. While there is undoubtedly variation in fire effects and post-fire forest conditions, areas that are characterized by a combination of multiple pre-fire treatments and low-moderate severity fire, have the highest potential for meeting desired conditions after the Dixie and Sugar fires. Over the long-term, managers may consider actions like prescribed or managed fire, that maintain resilience to future disturbance (Restoration Goal #2). We identified approximately 24,306 acres that received only a single treatment prior to the fire, and then burned at low-moderate severity. The potential for these areas to currently meet desired conditions is highly dependent on the effectiveness of that single treatment at restoring stand structure and reducing fuel loads prior to the Dixie and Sugar fires. These areas will likely require further evaluation to determine the need for management action.

We identified 4,556 acres that were planted prior to the Dixie and Sugar fires and subsequently burned at low-moderate severity. Only 13% (~600 acres) of these reforestation units had received a follow-up treatment beyond the initial release (i.e., precommercial thin, surface fuel treatment, etc.) prior to the 2021 fires. The effectiveness of the 2021 fires, at increasing the resilience of these young stands to future disturbance (Restoration Goal #2), is dependent on a variety of factors that include initial planting densities, tree survival and growth in the period between planting and the 2021 fires, and pre-fire fuel loads (both live and dead). As a result, most reforestation units will require additional field assessments to determine the need for both short- and long-term management actions, which may include precommercial thinning, surface fuel reduction, or management of competing vegetation.

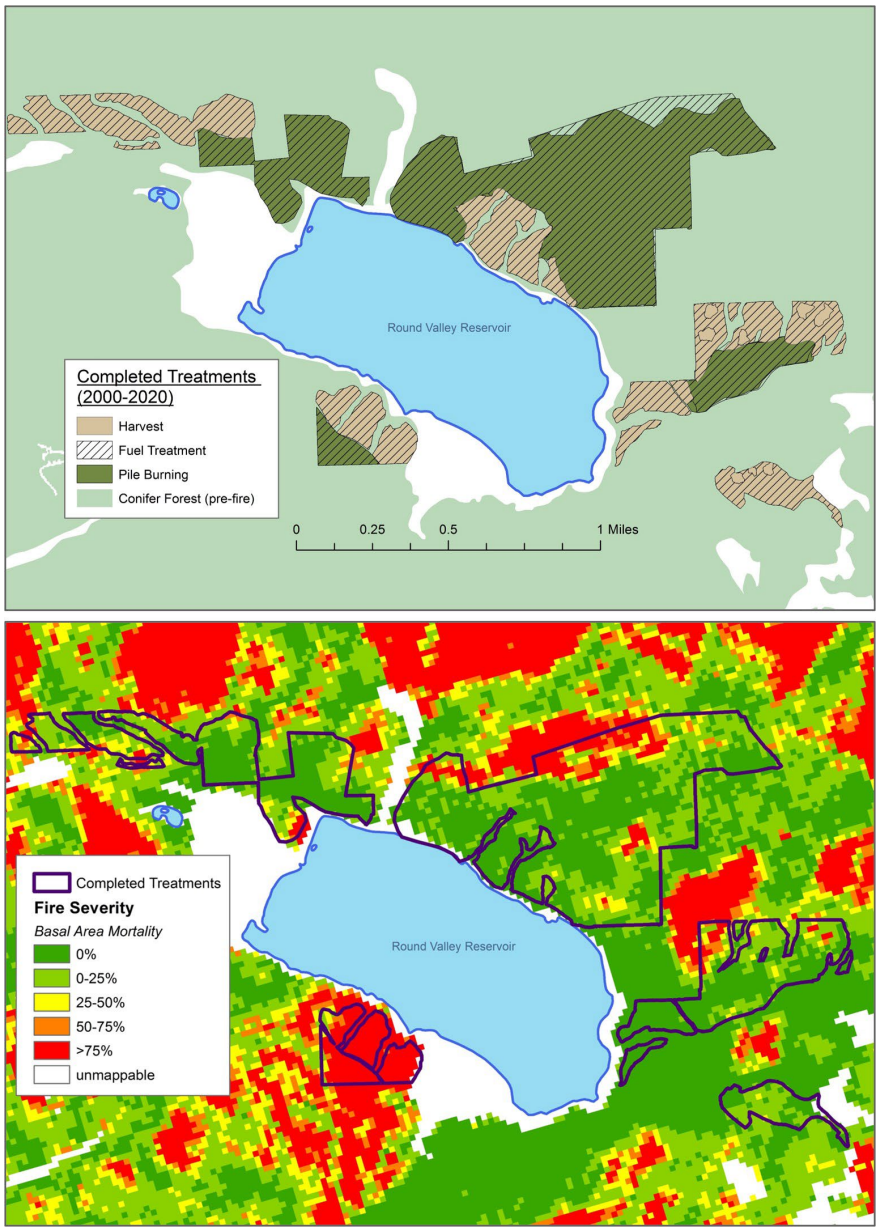

Figure 14. Example of areas that had two or more vegetation and fuels treatment implemented prior to the fires (between 2015-2020) and then burned at low-moderate severity in the Dixie Fire. Stands received a thinning treatment, fuel reduction (hand thinned and piled), and then piles were burned. These units are located on the Plumas National Forest, near Round Valley Reservoir.

Scenario 2: Areas that burned more than once at low-moderate severity over the past 20 years

Mixed conifer stands that are currently burning at frequencies and severities that are similar to pre-settlement estimates have a high likelihood of having 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). In our assessment, we considered areas that have burned repeatedly within the past 20 years, at low-moderate severity, to have a high potential for restored conditions. To identify these areas within the Dixie and Sugar fires, we identified places that met both of the following conditions:

1) burned at low-moderate severity (0-75% basal area mortality) in the Dixie and Sugar fires; and
2) had burned in at least one prior fire that occurred between 2000-2020, also at low-moderate severity

We obtained fire perimeter and satellite-derived estimates of fire severity for all large fires (>200 acres) that burned within the Dixie and Sugar fire footprints between 2000-2020. We used categorized severity data (7-class basal area mortality), developed by the USDA Forest Service Rapid Assessment of Vegetation Condition after Wildfire (RAVG) program, because it was the most widely available. We resampled, reprojected, and realigned all past severity data to match the Dixie and Sugar fire severity data and combined them into annual severity layers. We then combined all annual severity layers into a single dataset, which allowed for an assessment of fire severity over time at the pixel-scale.

To identify restoration opportunities in areas that experienced successive fires, we combined past fire severity with pre-fire stand conditions. We used relative stand density index (relative SDI) to assess pre-fire stand condition (refer to the next section for a detailed discussion of SDI).

Restoration Opportunities: Areas repeatedly burned at low-moderate severity

The 2021 Dixie and Sugar fires reburned 83 past fires that occurred between 2000 and 2020. As a result, approximately 212,708 acres within the assessment area have now burned between two and five times over the past 21 years (Table 7, Figure 15). Within these areas of overlapping fires, we identified a total of 54,102 acres that were burned by multiple fires, at low-moderate or unchanged severity, since 2000. This includes 13,353 acres on the Lassen National Forest, 33,491 acres on the Plumas National Forest, and 7,258 acres on private lands.

Table 7. The total area of reburn within the Dixie and Sugar fire footprints. The total number of fires includes the 2021 fires and any past fires that burned between 2000-2020.

Total number of fires	**Sum of acres**
2	178,154
3	33,660
4	839
5	55
Grand total	**212,708**

In areas that have experienced multiple low-moderate severity fires, managers should consider longer-term actions that maintain the desired conditions created by these successive fires. For example, prescribed or managed wildland fire, applied at intervals and severities that are similar to the presettlement fire regime, could effectively reduce surface and ladder fuels and maintain resilience to future wildfire and other disturbances (Restoration Goal #2).

We identified 25,866 acres that were moderately to highly departed (i.e., relative SDI ≥ 35%) prior to the Dixie and Sugar fires, despite having experienced multiple low-moderate severity fires over the past 21 years. These areas warrant further evaluation to assess the need for treatments, like prescribed fire or fuel reduction, that reduce the risk of severe fire in the future. In some cases, selective thinning (e.g., treatments that retain pine and remove fir), may also be necessary to restore desired species proportions. Although two or more low-moderate severity fires have been shown to reduce tree densities to within the NRV, they may not be enough to shift species composition into alignment with historical patterns (Paudel et al. 2022).

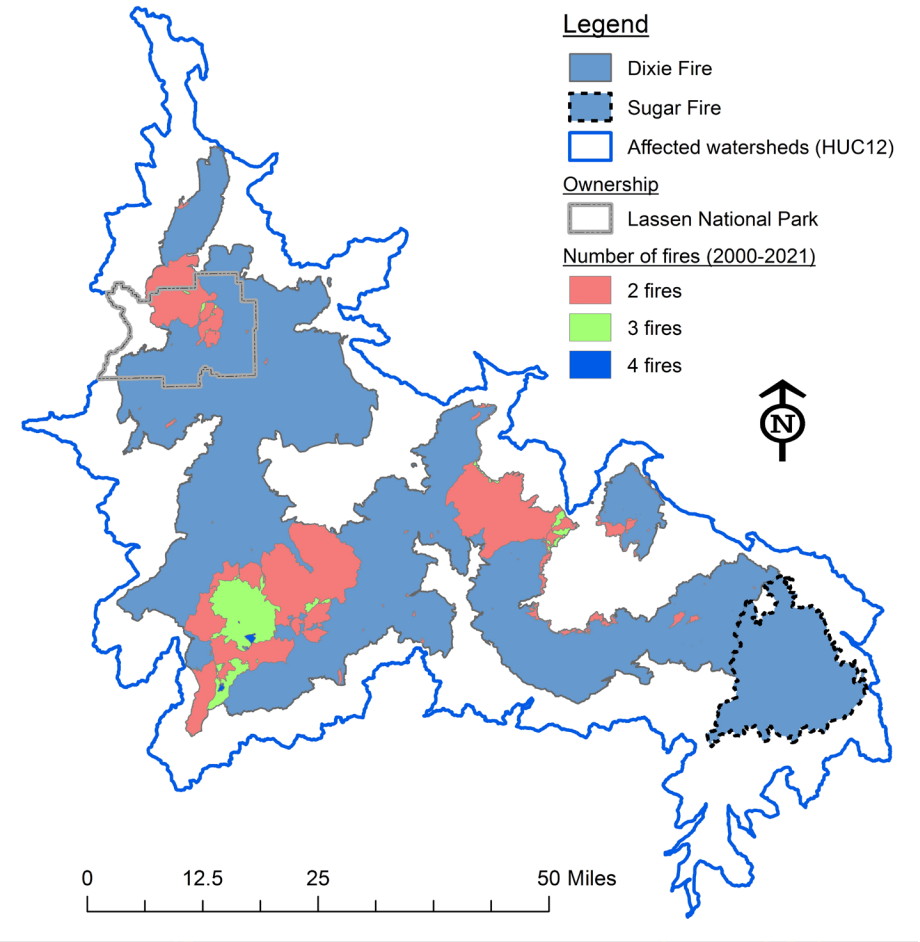

Figure 15. The number of fires that have occurred within the fire footprint between 2000-2021. Note that a small area (55 acres) has burned 5 times over the past 21 years but is too small to be visible on the map.

Scenario 3: Areas that were not considered departed prior to the fire and then burned at low-moderate severity

Conifer stands that were characterized by low tree densities prior to the fires and were subsequently burned at low-moderate severity in the Dixie or Sugar fires, have a high likelihood of meeting desired conditions post-fire. In our assessment, we identified areas that met these conditions using the following criteria:

1) Forest structure was characterized as being within NRV prior to the fires (defined using relative SDI, described in the section below); and
2) Stand had not experienced fire in the 20 years prior to the Dixie or Sugar fires; and
3) Burned at low-moderate severity (<75% basal area mortality) or was unchanged by the Dixie and Sugar fires.

Our use of relative stand density index (SDI) to assess pre-fire departure from NRV is described in the section below. We considered areas with relative SDI <35% prior to the fire to be within NRV in terms of forest structure.

Restoration Opportunities: Low departure prior to the fires

We identified a total of 110,368 acres that had a relative SDI of less than 35% prior to the fires and subsequently burned at low-moderate severity in the Dixie and Sugar fires or were in an adjacent unburned watershed. In these areas, managers may consider actions like prescribed or managed wildland fire, applied at intervals and severities that are similar to the presettlement fire regime, to maintain resilience to future wildfire and other disturbances (Restoration Goal #2).

Areas where conditions were not improved by the fire

Our next step was to identify areas within the fire perimeter where fire effects were considered to be within the NRV, but where other factors may decrease our ability to meet our restoration goals. To do this, we identified conifer stands within the fire perimeter that met the following conditions:

1) Forest structure was characterized as departed from NRV prior to the fires; and
2) Stand had not experienced fire in the 20 years prior to the Dixie or Sugar fires; and
3) Burned at low-moderate severity (<75% basal area mortality) or was characterized as unchanged by the Dixie and Sugar fires.

We used relative stand density index (SDI) to assess pre-fire 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. 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 (Table 8), and concurrently a high level of departure from these conditions in contemporary pre-fire stands.

Table 8. Anticipated competitive interactions within different relative SDI value ranges and associated departure from historical conditions. Relative SDI = absolute SDI/maximum SDI

Relative SDI	**NRV 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 • 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 obtained estimates of pre-fire absolute SDI from F3, a 30-m resolution dataset developed by Huang et al. (2018). This dataset integrates Forest Inventory and Analysis (FIA) plots, the Forest Vegetation Simulator (FVS), and Field and Satellite for Ecosystem Mapping (FastEmap) to estimate vegetation attributes across large scales. We used SDI estimates based on Zeide (1983) that included all trees greater than 1.0" diameter at breast height (DBH). We calculated relative SDI at the pixel-scale, by dividing absolute SDI by the maximum SDI, based on forest type (Table 9). We then used zonal statistics to calculate mean relative SDI and fire severity for individual stands within the analysis area. Individual stands were delineated using the existing conifer vegetation (Eveg) polygons. We removed areas within stands that were within large (>100 acre) high severity patches; these areas were considered departed from NRV in Step 1 and identified as having opportunities for reforestation. The resulting conifer stands represented areas 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.

Table 9. Maximum SDI values used to calculate relative SDI in this assessment.

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%
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)	

To identify restoration opportunities, we combined relative stand density with fire severity (averaged across each conifer stand). Table 10 identifies the criteria that we used to identify opportunities for restoration in these areas.

Table 10. Predicted level of departure from NRV using fire severity and pre-fire stand structure. Fuel description identifies predicted post-fire fuel type.

Relative SDI	Fire severity (basal area mortality)		
	Unchanged[1] or < 25%	**25%-75%**	**>75%**
<25%[2]	Low	Low	Low
25-34%	Low	Low	Low
35-59%	Moderate (green fuels)	Moderate (mixture of live and dead fuels)	Moderate (dead fuels)
>=60%	High (green fuels)	High (mixture of live and dead fuels)	High (dead fuels)

[1] Unchanged includes areas outside of the fire, but within affected sub-watersheds

[2] Restoration opportunities in areas with relative SDI <35% are discussed in the section above

Restoration Opportunities: Departure from NRV prior to the fires

We identified a total of 758,080 acres within the assessment area that were considered departed prior to the fires (i.e., relative SDI ≥35%) and burned at low-moderate severity or were unchanged or unburned by the Dixie and Sugar fires. This includes 266,412 acres within the fire perimeters and 491,668 acres in the affected watersheds surrounding the fires (see Figure 1).

While there is undoubtedly variation in post-fire forest condition, the high degree of departure within these stands prior to the fires, combined with a single low-moderate severity fire, makes them a high priority for restoration. In many of these stands, actions may be needed to restore forest structure or composition and increase the resilience to future disturbance like fire, drought, or disease (Restoration Goal #2). In these areas, restoration opportunities may include density reduction treatments (e.g., thinning live trees) or repeat applications of prescribed fire to reduce competition, increase individual tree growth, and reduce surface and ladder fuels. Managers may consider retaining higher relative SDI on sites with greater soil moisture availability and lower reburn risk and lower relative SDI on drier, steeper slopes, which are more prone to drought and high intensity reburns (North et al. 2022).

In areas that were highly to moderately departed prior to the fire (i.e., relative SDI >35%) that burned at moderate or high severities (i.e., > 50% basal area mortality), management actions may also need to target removal of fire-generated fuels. In these areas, 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 also increase the risk of high severity reburn in the future (Coppoletta et al. 2016).

High fuel loads (outside of reforestation units)

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. Areas that had a high density of live trees prior to the fire and burned at high severity (>75% basal area mortality) can be expected to have high densities of snags post-fire. As these 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).

As part of our assessment, we identified 22,888 acres that burned in small patches (10-100 acres) of high severity and had some level of pre-fire departure (relative SDI > 25%). These areas were not identified for reforestation because they were smaller than our minimum patch size threshold of 100 acres. In many cases, they may be a low priority for management action. The exception to this may be when they are in close proximity to high value resource areas, such as communities or sensitive wildlife habitat (i.e., PACs). In these cases, managers may want to consider removal of dead trees and surface fuels within these small patches to reduce the risk of future severe wildfire (Restoration Goal #1).

Isolated conifer stands ("islands")

As part of our assessment, we identified small, isolated stands of remnant conifer forest, that were surrounded by large high severity patches or montane chaparral. We identified these conifer "islands"

using the following set of conditions:

1) Small patches (10-250 acres) of contiguous forest vegetation.
2) Burned at low-moderate severity (<75% basal area mortality) in the Dixie or Sugar fires.
3) More than 50% of the area around the patch burned at high severity or was occupied by montane chaparral.

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.). Instead, we identify these stands as a potential filter (Table 11), that can be overlaid with existing restoration opportunities and used to prioritize units and develop treatment prescriptions.

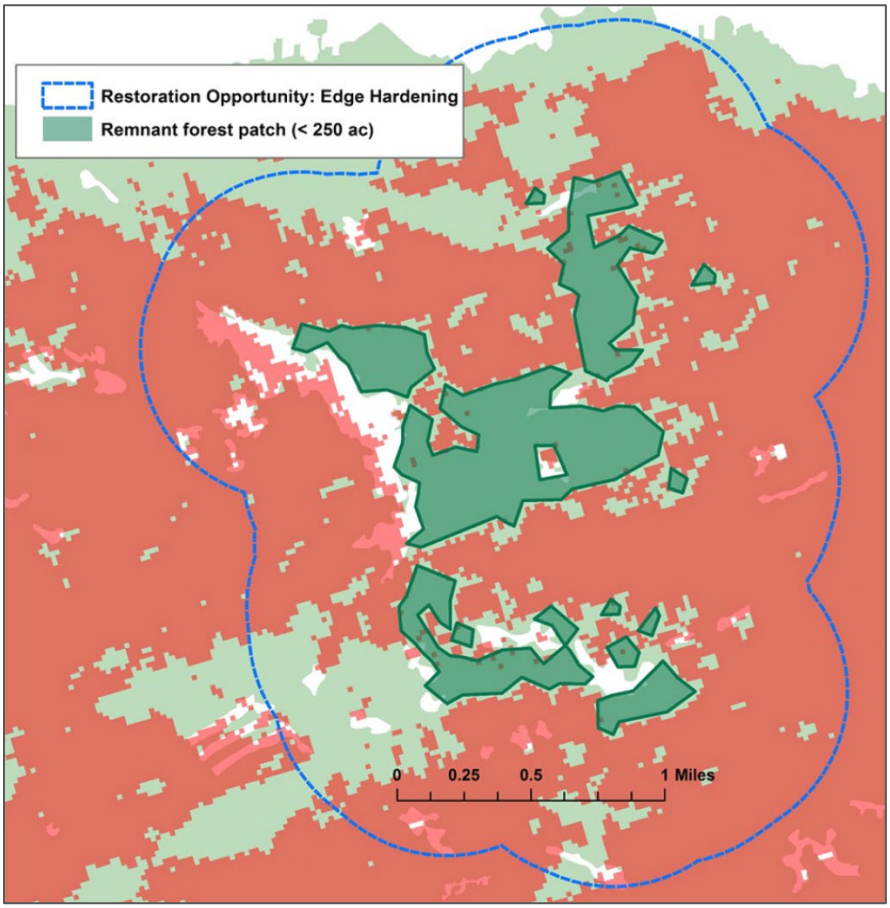

Figure 16. Example of an isolated conifer stand that burned at low-moderate severity in the Dixie Fire but is now surrounded by areas impacted by high severity fire. Treatments may occur both within and surrounding the stands to reduce the risk of severe reburn.

Additional step: apply filters

To further refine and prioritize restoration opportunities, managers will need to consider a wide range of additional factors that influence where and how restoration treatments are implemented. The table below lists some of these considerations.

Table 11. Additional data layers that can be used to further refine restoration opportunities into feasible treatments.

Consideration	Potential filters
Operational constraints	Distance to road, % slope, and special land designations (e.g., RNAs, SIAs, etc.) can help identify areas where mechanical equipment may be most feasible
Resilience to future climate	Climate refugia are areas where future climatic conditions are anticipated to remain suitable for vegetation types that were present prior to the fire; climate refugia for conifer vegetation types may represent a higher priority for replanting. Outside of these predicted refugia, managers may consider decreasing planting densities, mixing species or seed zones, or taking advantage of local site conditions, in anticipation of increased climate exposure.
Topography	Topographic position can be used to develop target planting densities or thinning prescriptions (e.g., forests along ridges tend to support lower tree densities compared to drainages), identify topographically-mediated moisture gradients, or to identify areas with higher risk of future fire.
Surrounding fuel loads	Quantifying fuel loads (live and dead) or fire risk adjacent to a planting unit or isolated forest stand "island" can improve treatment effectiveness at reducing future fire risk within remnant stands and reforestation units.
Soils or site productivity	May influence planting locations or species mixture
Sensitive species or resources	Sensitive species locations or habitats will influence the treatment design, location, and feasibility.
Proximity to rural communities	Areas within the wildland urban intermix (WUI) may be a higher priority for management, particularly when treatments designed to reduce the risk of future high severity fire would also protect adjacent communities.

STEP 4: BUILD A RESTORATION PORTFOLIO

The table and figures below provide a broad overview of the potential restoration opportunities and management actions identified in our assessment of mixed conifer forests within the 2021 Dixie and Sugar fires. This information is also available as a spatial data layer for use in ArcGIS (contact project lead). It is important to note that this assessment, and associated data layers, do 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.

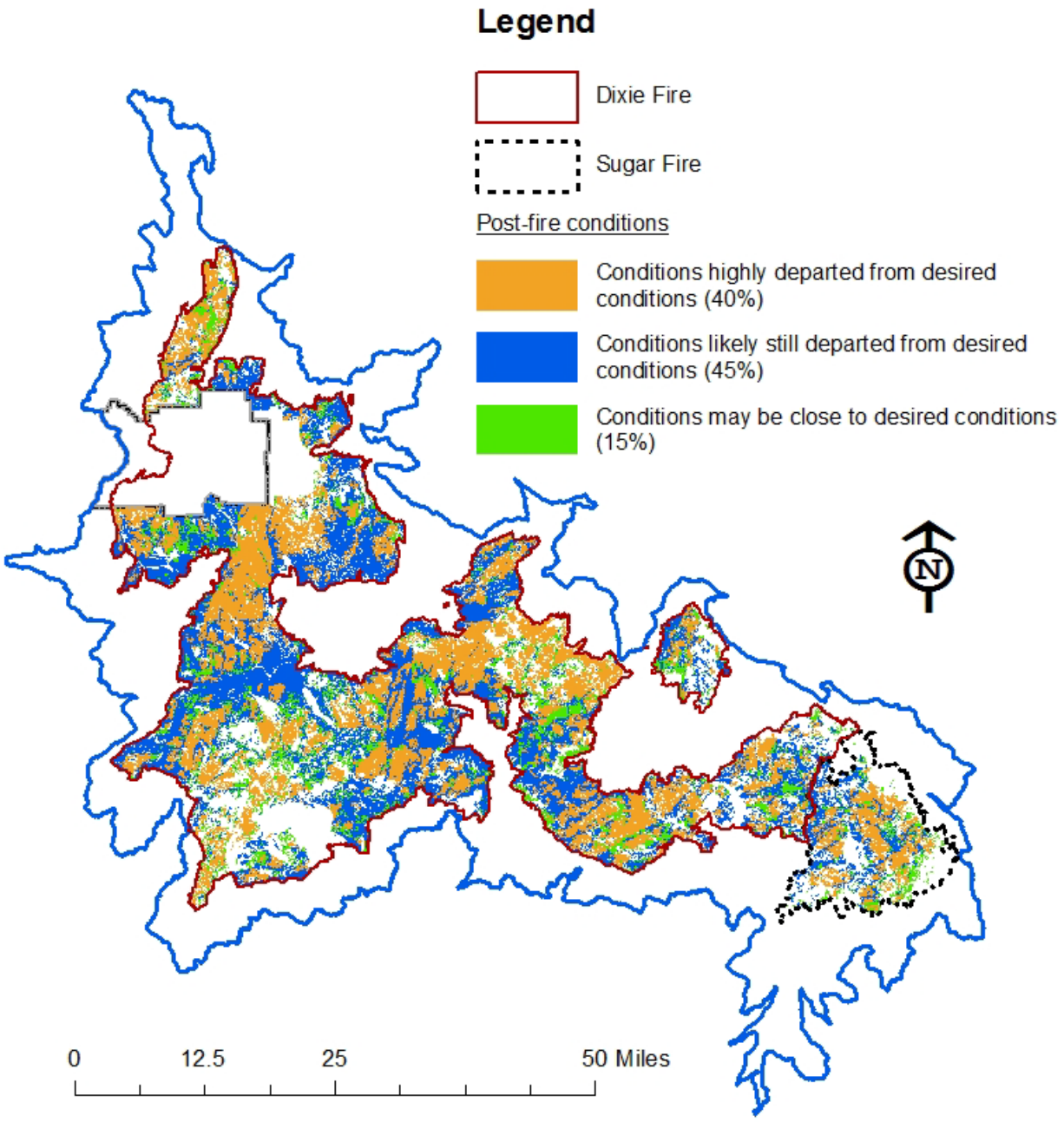

Figure 17. An assessment of post-fire conditions within the 2021 Dixie and Sugar fire footprints. The three condition classes were identified using the decision process outlined in Figure 8 and correspond to the final nodes in the Figure flow chart. They represent post-fire conditions that may be close to or departed from NRV, based on an assessment of fire effects and forest condition. Conditions presented in this map are limited to areas that were conifer forest prior to the fires and to National Forest (outside of wilderness) and private lands. The percentage that falls within each condition class is provided in the legend. It is important to note that these percentages do not include areas within the fire perimeter that were not identified as a restoration opportunity; therefore, there may be additional acres that currently meet desired conditions within the fire perimeter.

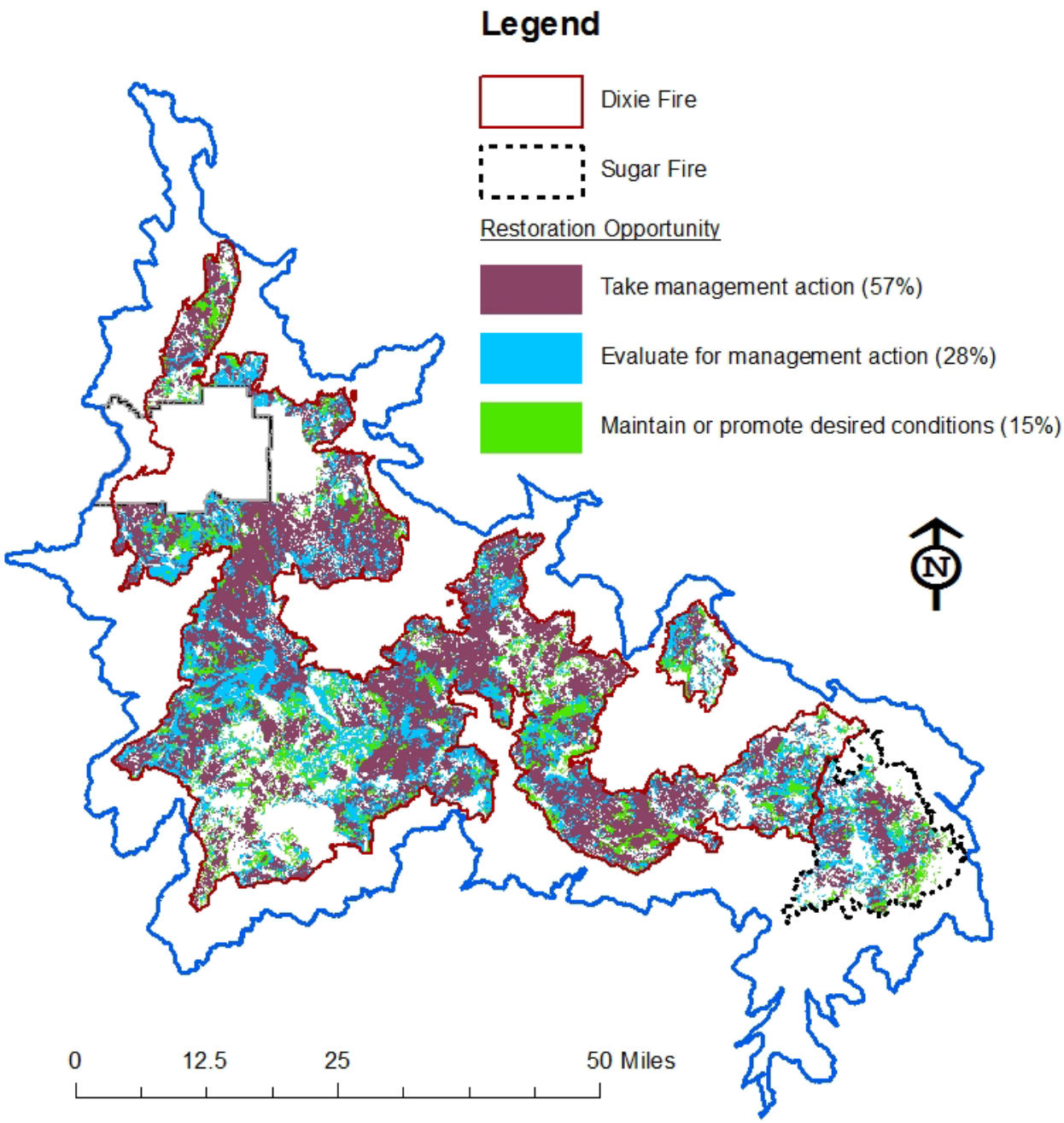

Figure 18. Broad restoration opportunities identified within the 2021 Dixie and Sugar fire footprints. These opportunities were limited to areas that were conifer forest prior to the fires and to National Forest (outside of wilderness) and private lands. The percentage that falls within each broad opportunity is provided in the legend. These opportunities are described in detail in Table 16.

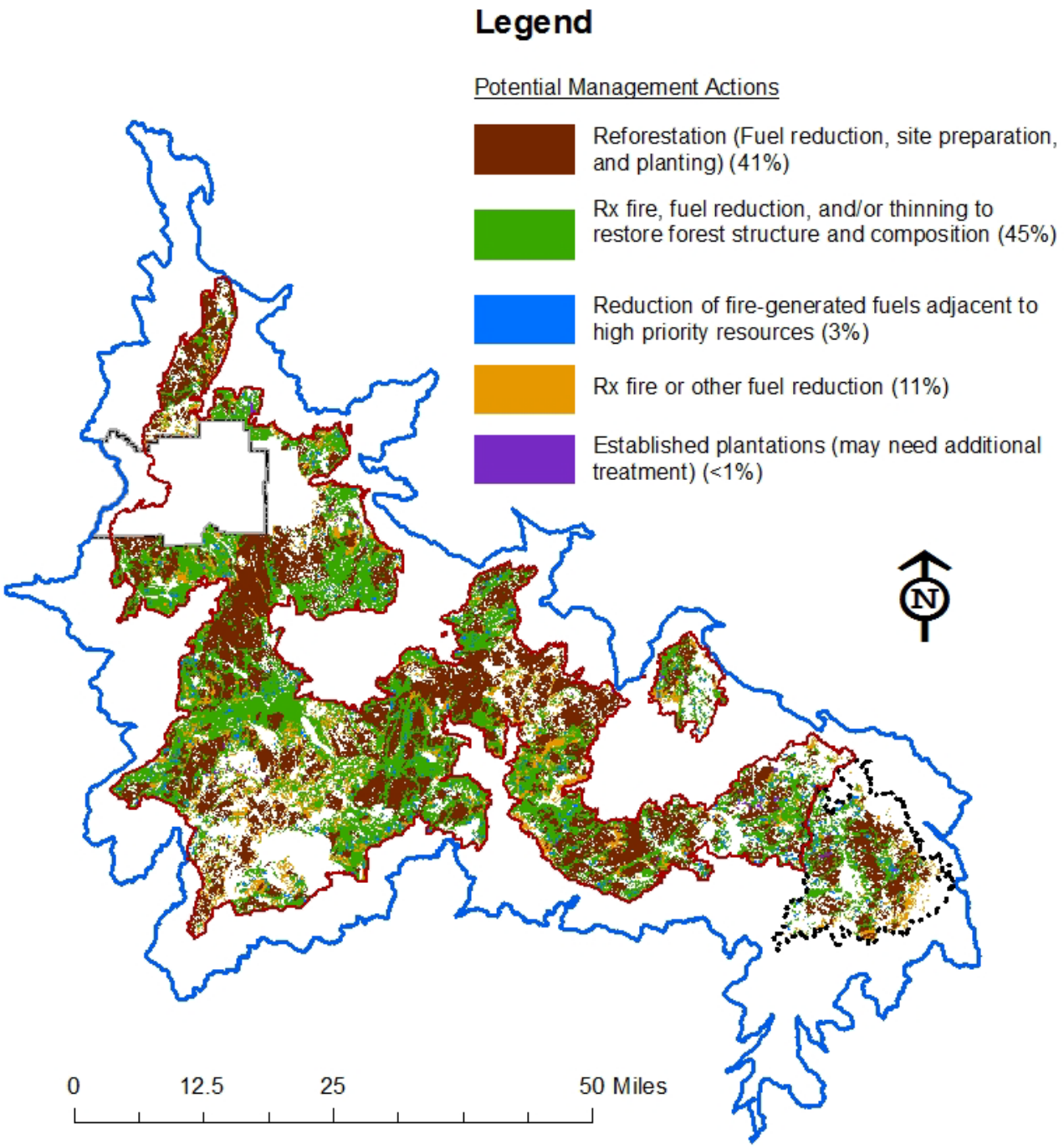

Figure 19. Examples of potential management actions in areas that were mixed conifer forest prior to the 2021 Dixie and Sugar fires. More detail is provided in the table below. Potential actions were limited to National Forest lands outside of wilderness and private lands. They do not consider operational feasibility, management constraints, or other factors that are important to evaluate when developing and designing proposed actions. The percentage that falls within each broad opportunity is provided in the legend. PCT = precommercial thinning; Rx Fire = prescribed fire.

Table 12. A restoration portfolio for mixed conifer forests impacted by the 2021 Dixie and Sugar Fires. These opportunities were developed using the process summarized in Figure 8 and described in the text of the report. Each opportunity is linked, through the Spatial ID, to a spatial dataset that is available for use in ArcGIS. It is important to note that the actions listed below were developed using widely available spatial datasets and have not been field verified. Further refinement and consideration of factors, like feasibility and management constraints, will be necessary to develop proposed actions and treatment prescriptions. Acres represent areas, outside of wilderness, on National Forest or private lands, within the fire footprints; values in parentheses include the total area within and adjacent to the fires (i.e., within an affected watershed). Refer to Table 3 for a definition of fire severity values.

Scenario	Pre-fire conditions	Fire severity	Priority	Restoration Opportunity	Potential actions	Lassen NF acres	Plumas NF acres	Non-USFS acres	Spatial ID
Conditions degraded by the fire									
Large patches of high severity fire	All forested conditions	High severity patches > 100 acres and low-moderate (<60%) potential for natural conifer regeneration	High	Take management action	Fuel reduction (dead tree removal, piling of surface fuels, broadcast or pile burning, etc.), site preparation (removal of competing vegetation) and planting; Longer term: Control of competing vegetation, precommercial thinning, and fuels management	76,486	136,283	56,422	1 & 2
	All forested conditions	High severity patches > 100 acres and high (>60%) potential for natural conifer regeneration	High-Moderate	Take management action	Fuel reduction (dead tree removal, piling of surface fuels, broadcast or pile burning, etc.), site preparation (removal of competing vegetation) and planting; Longer term: Control of competing vegetation, precommercial thinning, and fuels management	11,520	4,908	3,321	3

Scenario	Pre-fire conditions	Fire severity	Priority	Restoration Opportunity	Potential actions	Lassen NF acres	Plumas NF acres	Non-USFS acres	Spatial ID
Conditions likely still departed from desired conditions									
Elevated fuel loads; increased risk of severe reburn	Low to High departure (Relative SDI ≥ 25%)	Small high severity patches (10-100 acres)	Low-Moderate	Evaluate for management action	Consider dead tree removal and other fuel reduction actions when adjacent to high value resource areas (i.e., WUI, PACs, etc.)	6,254	11,969	4,664	4
No fires in the 20 years prior to the Dixie and Sugar	High departure; (relative SDI >=60%)	Low or unchanged/ unburned (0-25% basal area mortality)	High	Take management action	Fuel reduction that targets surface, ladder, and live/dead trees for removal; evaluate need for thinning to restore stand structure and composition	22,167 (86,402)	22,606 (97,080)	28,020 (80,690)	5
	High departure; (relative SDI >=60%)	Moderate to High (>25% basal area mortality)	High	Take management action	Fuel reduction that targets live and fire-generated surface, ladder, and live/dead trees for removal; evaluate need for thinning to restore stand structure and composition	9,195	19,482	14,836	6 & 7
	Moderate departure (Relative SDI 35-59%)	Low or unchanged/ unburned (0-25% basal area mortality)	Moderate	Evaluate for management action	Maintain with prescribed fire or other fuel reduction that targets surface, ladder, and live trees for removal; evaluate need for thinning to restore stand structure and composition, especially in areas outside of the fire perimeter (unburned)	27,657 (110,138)	26,112 (123,119)	30,394 (150,318)	8

Scenario	Pre-fire conditions	Fire severity	Priority	Restoration Opportunity	Potential actions	Lassen NF acres	Plumas NF acres	Non-USFS acres	Spatial ID
No fires in the 20 years prior to the Dixie and Sugar	Moderate departure (Relative SDI 35-59%)	Moderate to High (>25% basal area mortality)	Moderate	Evaluate for management action	Maintain with prescribed fire; evaluate the need for other fuel reduction that targets fire-generated surface, ladder, and dead trees for removal.	13,373	34,377	18,191	9 & 10
Vegetation or fuels treatments prior to the Dixie or Sugar fires	Areas that were reforested in the 20 years prior to the 2021 fires, but received no follow-up treatment after planting (harvest, fuel treatment, or Rx fire)	Low-moderate severity or unchanged	Moderate	Evaluate for management action	Maintain with prescribed fire; evaluate need for precommercial thinning, surface fuel reduction, or management of competing vegetation	1,937	2,020	N/A (only USFS treatments were assessed)	12
Repeat low-moderate (0-75%) severity fire	Moderate to High departure (Relative SDI ≥ 35%)	1 fire with low-moderate severity + ≥ 1 fire characterized as unchanged OR ≥ 2 fires with unchanged severity (between 2000-2021); no high severity fire	Moderate	Evaluate for management action	Maintain with prescribed fire or other fuel reduction that targets surface, ladder, and live/dead trees for removal; evaluate need for thinning to restore stand structure and composition, especially in areas outside of the fire perimeter (unburned)	5,459	17,535	2,872	18

Scenario	Pre-fire conditions	Fire severity	Priority	Restoration Opportunity	Potential actions	Lassen NF acres	Plumas NF acres	Non-USFS acres	Spatial ID
Conditions improved or maintained by the fire									
No fires in the 20 years prior to the Dixie and Sugar	Low departure (Relative SDI < 35%)	All severities	Low	Maintain desired conditions	Apply prescribed fire at intervals similar to the presettlement fire return interval (FRI); consider thinning to restore stand structure and composition	8,928 (26,063)	18,893 (45,649)	6,860 (38,656)	11
Vegetation or fuels treatments prior to the Dixie or Sugar fires	Areas that were reforested in the 20 years prior to the 2021 fires and received at least one follow-up treatment after planting (harvest, fuel treatment, or Rx fire).	Low-moderate severity or unchanged	Low	Evaluate for management action	Maintain with prescribed fire; evaluate need for precommercial thinning, surface fuel reduction, or management of competing vegetation	366	233	N/A (only USFS treatments were assessed)	13 & 14
	Areas where one pre-fire treatment (fuel treatment, harvest, Rx fire, or wildlife) was implemented in the 20 years prior to the 2021 fires.	Low-moderate severity or unchanged	Low	Evaluate for management action	Maintain with prescribed fire or other fuel reduction activities; in places where past treatment only targeted fuel reduction (and stand conditions are still departed) evaluate for additional treatments, such as thinning, to promote forest health	8,001	16,305	N/A (only USFS treatments were assessed)	15 & 16

Scenario	Pre-fire conditions	Fire severity	Priority	Restoration Opportunity	Potential actions	Lassen NF acres	Plumas NF acres	Non-USFS acres	Spatial ID
Vegetation or fuels treatments prior to the Dixie or Sugar fires	Areas where at least two pre-fire treatments (fuel treatment, harvest, Rx fire, or wildlife) were implemented in the 20 years prior to the 2021 fires.	Low-moderate severity or unchanged	Lowest	Maintain desired conditions	Maintain with prescribed fire or other fuel reduction activities	10,533	9,367	N/A (only USFS treatments were assessed)	17
Repeat low-moderate (0-75%) severity fire	Moderate to High departure (Relative SDI > 35%)	1 fire with low-moderate severity + ≥ 1 fire characterized as unchanged OR ≥ 2 fires with unchanged severity (between 2000-2021); no high severity fire	Moderate	Evaluate for management action	Apply prescribed fire at intervals similar to the presettlement fire return interval (FRI); evaluate the need for thinning to restore stand structure and composition	5,459	17,535	2,872	18

Scenario	Pre-fire conditions	Fire severity	Priority	Restoration Opportunity	Potential actions	Lassen NF acres	Plumas NF acres	Non-USFS acres	Spatial ID
Repeat low-moderate (0-75%) severity fire	Low departure (Relative SDI < 35%)	1 fire with low-moderate severity + ≥ 1 fire characterized as unchanged OR ≥ 2 fires with unchanged severity (between 2000-2021); no high severity fire	Low	Maintain/ promote desired conditions	Apply prescribed fire at intervals similar to the presettlement fire return interval (FRI)	2,522	4,055	2,146	19
	All conditions	≥ 2 fires (between 2000-2021) with low-moderate severity fire effects; no high severity fire	Lowest	Maintain/ promote desired conditions	Apply prescribed fire at intervals similar to the presettlement fire return interval (FRI)	3,645	9,940	2,021	20

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APPENDIX A: 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

Assessment Categories	FACTS Activity Codes	FACTS Activities
	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

APPENDIX B: GUIDE TO GEOSPATIAL DATA

All data associated with this analysis have been provided in a geodatabase (DixieSugar_GTR270_Assessment.gdb) to assist with post-fire restoration planning on the Plumas and Lassen National Forests. A description of geodatabase contents is provided below. Contact the project lead to obtain a copy of this database.

DixieSugar_GTR270_Assessment.gdb
a_MixedConifer_Restoration_Opportunities
Conifer_Restoration_Opps_AllLands
Restoration opportunities across all ownerships, including National Forest System (Plumas and Lassen National Forests) and private lands
Fields Spatial_ID: Unique identifier that links spatial data to restoration portfolio in the accompanying report (Post-fire Restoration Opportunities for Conifer Forest in the 2021 Dixie and Sugar Fires). 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 in the 2021 Dixie and Sugar Fires) Action_Label; Simplified version of potential actions; can be used for maps and broadscale assessments PreFire_Cond: Stand condition prior to the Dixie and Sugar fires; includes overview of pre-fire stand structure, treatment history, and recent fires. FireSeverity: Dixie and/or Sugar fire severity (measured as basal area mortality). Fire_Effects: Assessment of post-fire condition based on pre-fire stand condition and Dixie and Sugar fire severity patterns. Priority: Priority for treatment based on an assessment of pre- and post-fire departure (Fire Effects). This is not a site-specific assessment.
Conifer_Restoration_Opps_ByOwnership
Restoration opportunities separated by ownership (Fields same as above)
b_Base_Layers
Dixie_Sugar_HUC12
The HUC12 watersheds that contain Dixie and Sugar fires
DixieSugar_Analysis_Footprint
Analysis Area footprint: Dixie and Sugar fires and all HUC12s
DixieSugar_FirePerimeter
Combined perimeter of the Dixie and Sugar fires
DixieSugar_LandOwnership
Land ownership within analysis area

InOut_FirePerimeters
Areas within analysis area that are within and outside of fire perimeter
DixieSugar_LandMgmtUnits_Simple_NoLakes
Land management units – simplified polygons that combine topographic position (e.g., canyon bottom, midslope, ridge) and aspect
c_Vegetation
Pre-fire vegetation data were obtained from CALVEG, USDA Forest Service, Pacific Southwest Region https://www.fs.usda.gov/detail/r5/landmanagement/resourcemanagement/?cid=stelprdb5347192
DixieSugar_Fire_ConiferVeg
Pre-fire conifer forest clipped to the Dixie and Sugar fire perimeters
DixieSugar_Fire_Eveg
Pre-fire vegetation (all vegetation types) clipped to the Dixie and Sugar fire perimeters
DixieSugar_FireHUC12_ConiferVeg
Pre-fire conifer forest clipped to the Analysis Footprint (Dixie and Sugar fires, and HUC12 watersheds)
DixieSugar_FireHUC12_Eveg
Pre-fire vegetation (all vegetation types) clipped to the Analysis Footprint (Dixie and Sugar fires, and HUC12 watersheds)
d_Fire_Severity
Fire severity (basal area mortality) from Rapid Assessment of Vegetation Condition after Wildfire (RAVG) program; USDA Forest Service, Geospatial Technology and Applications Center (https://burnseverity.cr.usgs.gov/ravg/)
Dixie_Severity_5class
Basal area mortality resulting from the Dixie Fire (RAVG); 5 severity categories (% basal area mortality): 0%; 0-25%; 25-50%; 50-75%; >75%
Dixie_Severity_7class
Basal area mortality resulting from the Dixie Fire (RAVG); 7 severity categories (% basal area mortality): 0%; 0-10%; 10-25%; 25-50%; 50-75%; 75-90%; >90%
DixieSugar_Severity_5class
Basal area mortality resulting from the Dixie and Sugar fires combined (RAVG); 5 severity categories (% basal area mortality): 0%; 0-25%; 25-50%; 50-75%; >75%. Where the two fires overlapped, severity values from the Dixie Fire were used since they represent the most recent fire effects.
DixieSugar_Severity_5class_Conifer
Same as above, but only within areas typed as conifer forest prior to Dixie and Sugar fires.
DixieSugar_Severity_7class
Basal area mortality resulting from the Dixie and Sugar fires combined (RAVG); 7 severity categories (% basal area mortality): 0%; 0-10%; 10-25%; 25-50%; 50-75%; 75-90%; >90%. Where the two fires overlapped, severity values from the Dixie Fire were used since they represent the most recent fire effects.

FireEffects_NRV_Departure
Fire departure based on assessment of fire severity and high severity patch size
Sugar_Severity_5class
Basal area mortality resulting from the Sugar Fire (RAVG); 5 severity categories (% basal area mortality): 0%; 0-25%; 25-50%; 50-75%; >75%
Sugar_Severity_7class
Basal area mortality resulting from the Sugar Fire (RAVG); 7 severity categories (% basal area mortality): 0%; 0-10%; 10-25%; 25-50%; 50-75%; 75-90%; >90%
e_HighSeverity_Patches
DixieSugar_HighSeverity_75ba_AllVeg
High severity patches (defined as > 75% basal area mortality) >1.5 acres, assessed with PatchMorph; 5 size classes: <100 acres; 100-250 ac; 250-1,000 ac; 1,000-10,000 ac; >10,000 ac.
DixieSugar_HighSeverity_75ba_Conifer
High severity patches (defined as > 75% basal area mortality) in areas that were types as conifer forest prior to the Dixie and Sugar fires; patches >1.5 acres, assessed with PatchMorph; 5 size classes: <100 acres; 100-250 ac; 250-1,000 ac; 1,000-10,000 ac; >10,000 ac.
DixieSugar_HighSeverity_90ba_AllVeg
High severity patches (defined as > 90% basal area mortality) >1.5 acres, assessed with PatchMorph; 5 size classes: <100 acres; 100-250 ac; 250-1,000 ac; 1,000-10,000 ac; >10,000 ac.
DixieSugar_HighSeverity_90ba_Conifer
High severity patches (defined as > 90% basal area mortality) in areas that were types as conifer forest prior to the Dixie and Sugar fires; patches >1.5 acres, assessed with PatchMorph; 5 size classes: <100 acres; 100-250 ac; 250-1,000 ac; 1,000-10,000 ac; >10,000 ac.
f_Natural_Regen
Outputs from the Post-fire Spatial Conifer Regeneration Prediction Tool (POSCRPT) (https://stewartecology.shinyapps.io/POSCRPT_dev_version/)
Conifer_high_sd_high_ppt_010622
probability of natural conifer regeneration as modelled with POSCRPT with high seed availability and high precipitation parameters
Conifer_high_sd_low_ppt_010622
probability of natural conifer regeneration as modelled with POSCRPT with high seed availability and low precipitation parameters
Conifer_low_sd_high_ppt_010622
probability of natural conifer regeneration as modelled with POSCRPT with low seed availability and high precipitation parameters
Conifer_low_sd_low_ppt_010622
probability of natural conifer regeneration as modelled with POSCRPT with low seed availability and low precipitation parameters

	Conifer_mean_sd_mean_ppt_010622
	probability of natural conifer regeneration as modelled with POSCRPT with mean seed availability and mean precipitation parameters
g_Remnant_Conifer	
	DixieSugar_GreenIslands_10_100ac
	Small (10-100 acres), isolated stands of remnant conifer forest, that were surrounded by large high severity patches or montane chaparral
	DixieSugar_LowModSev_75ba_Conifer
	Low-moderate severity patches (defined as < 75% basal area mortality) in areas that were types as conifer forest prior to the Dixie and Sugar fires; patches >1.5 acres, assessed with PatchMorph; 5 size classes: <100 acres; 100-250 ac; 250-1,000 ac; 1,000-10,000 ac; >10,000 ac.
	DixieSugar_LowModSev_90ba_Conifer
	Low-moderate severity patches (defined as < 90% basal area mortality) in areas that were types as conifer forest prior to the Dixie and Sugar fires; patches >1.5 acres, assessed with PatchMorph; 5 size classes: <100 acres; 100-250 ac; 250-1,000 ac; 1,000-10,000 ac; >10,000 ac.
h_Treatment_History	
	Data obtained from the Forest Activity Tracking System (FACTS), USDA Forest Service (https://data.fs.usda.gov/geodata/edw/) and filtered to only include treatments completed prior to the Dixie and Sugar fires, between 2000-2021
	DixSug_FACTS_Ind_VegTrts_2000_2021
	All vegetation and fuels treatments that occurred within the analysis area, prior to the fires, between 2000-2021; includes overlapping polygons with individual activities
	DixSug_VegTrmts_2000_2021
	Non-overlapping polygons that represent the total footprint of vegetation and fuels treatments completed between 2000-2021. The date of the most recent treatment, within each treatment category, is included in the attribute table.
i_Fire_History	
	DixieSugar_FRID
	Fire Return Interval Departure (FRID) prior to the Dixie and Sugar fires
	DixieSugar_PastBurnSev_1984_2020
	Fire severity of past fires that occurred between 1984-2020. Severity is categorized into 7 classes of basal area mortality: 0%; 0-10%; 10-25%; 25-50%; 50-75%; 75-90%; >90%.
	DixieSugar_PastFires_1900_2020
	Fire perimeters of all past fires that occurred within the Dixie and Sugar fire perimeters between 1900-2020
	DixieSugar_PastFires_2000_2021
	Fire perimeters of all past fires that occurred within the Dixie and Sugar fire perimeters between 2000-2020

	DixieSugarReburn_Fires_2000_2021_final
	Areas impacted by at least 1 fire prior to the Dixie or Sugar fires. The name and dates of the two most recent fires (not including Dixie or Sugar) are included in table.
J_Climate	
	Conifer_ClimateRefugia
	Climate refugia are areas where future climatic conditions are modeled as mid-century conifer refugia or at risk for type conversion with Thorne model.

*Note – there are additional feature classes included in the geodatabase that were developed under a separate analysis for spotted owl. Information related to these feature classes can be found in the report *Postfire Restoration Opportunities for California Spotted Owl in the2021 Dixie and Sugar Fires*