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Post-Fire Restoration Framework in Mixed Conifer Forests in the 2021 Caldor Fire, Eldorado National Forest and the Lake Tahoe Basin Management Unit

USDA Forest Service

Region 5 Ecology Program

Central Sierra Province

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Summary

The Post-Fire Restoration Framework in Mixed Conifer Forests in the 2021 Caldor Fire provides the step-by-step process implementing the science-based approach presented in the "Postfire Restoration Framework for National Forests in California (GTR-270, Meyer et al. 2021). The framework helps to determine potential restoration opportunities to restore, maintain or alter desired conditions to restore conifer forests within the 2021 Caldor Fire. This analysis expands upon the Rapid Assessment that was completed immediately after the fire. The information presented in this report will help to refine future restoration projects by combining the spatial framework with additional tools and field surveys to assist in prioritization.

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https://www.fs.usda.gov/detail/r5/plants-animals/?cid=FSEPRD1087476

Background

2021 Caldor Fire Rapid Assessment

A Rapid Assessment was completed for the Caldor Fire by a team assembled from the Regional Office to accomplish four goals (1) compile information about the initial fire effects (2) evaluate geographic areas of the fire to determine restoration/recovery needs, opportunities, priorities, and potential treatments, (3) identify resource areas that will drive actions, and (4) identify regulatory compliance for any actions in the shorter-term. Information in this post fire restoration framework draws upon the great work that was done in the Rapid Assessment. The intent is that these two reports can be used in conjunction to address analysis of a number of key resources and priority areas in the 2021 Caldor Fire in preparation for the development of a number of projects.

Background of the 2021 Caldor Fire

Drought conditions, wind, and high fuel loads set the stage for the 2021 Caldor Fire which was one of two fires to cross the Sierra Nevada crest. The Caldor Fire was reported the evening of August 14, 2021 in the Middle Fork Cosumnes canyon. It expanded rapidly north and east and threatened over 30,000 structures and closed three major highways (50, 88 and 89). The Caldor Fire boundary encompassed over 225,000 acres and affected the communities of Omo Ranch, Grizzly Flats, Sly Park, Pollock Pines, Strawberry, Kyburz, Phillips, Echo Summit, South Lake Tahoe, and Kirkwood and heavily affected surrounding communities. After burning for over 60 days, the Caldor Fire reached 100 percent containment on October 21, 2021.

The fire growth between August 15 and August 18 was a key characteristic of this fire. The conditions during this time period were particularly of high intensity resulting in a large approximately 30,000-acre high severity patch in the western half of the fire footprint (Figure 1). The fire burned across an elevational range from approximately 1,700 to 9,800 feet spanning a variety of vegetation types and key wildlife habitats (Figure 2). Ownership across the fire was primarily USDA Forest Service (Figure 3). The fire burned 216,00 acres on the Eldorado National Forest and approximately 8,600 acres within the Lake Tahoe Basin Management Unit. The remaining area was made up of private ownership spread across the fire area.

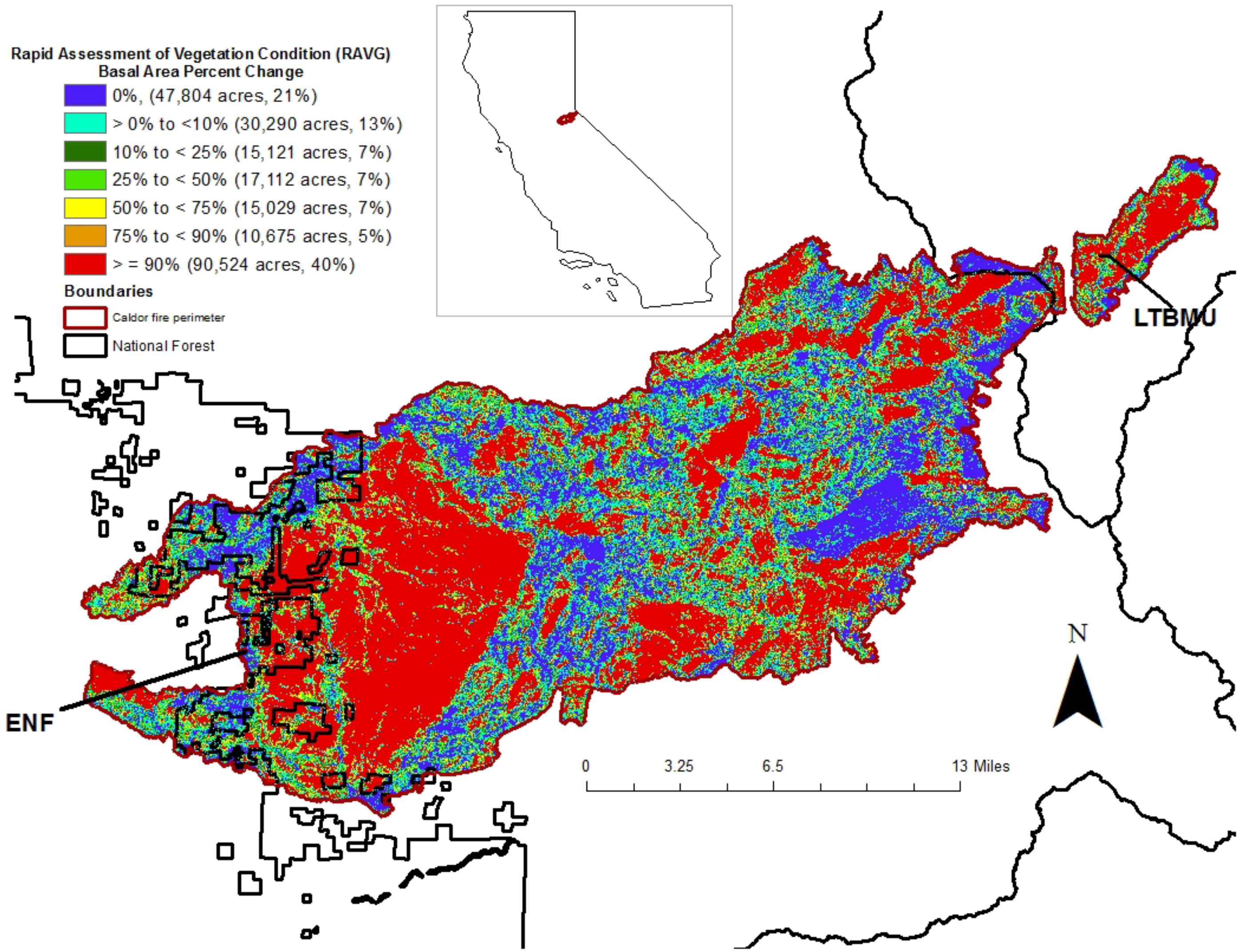

Figure 1. Location and severity of the 2021 Caldor fire in Central Sierra California. Vegetation severity (Rapid Assessment of Vegetation, Basal Area Percent Change 7 Class) is shown across all vegetation types and ownerships.

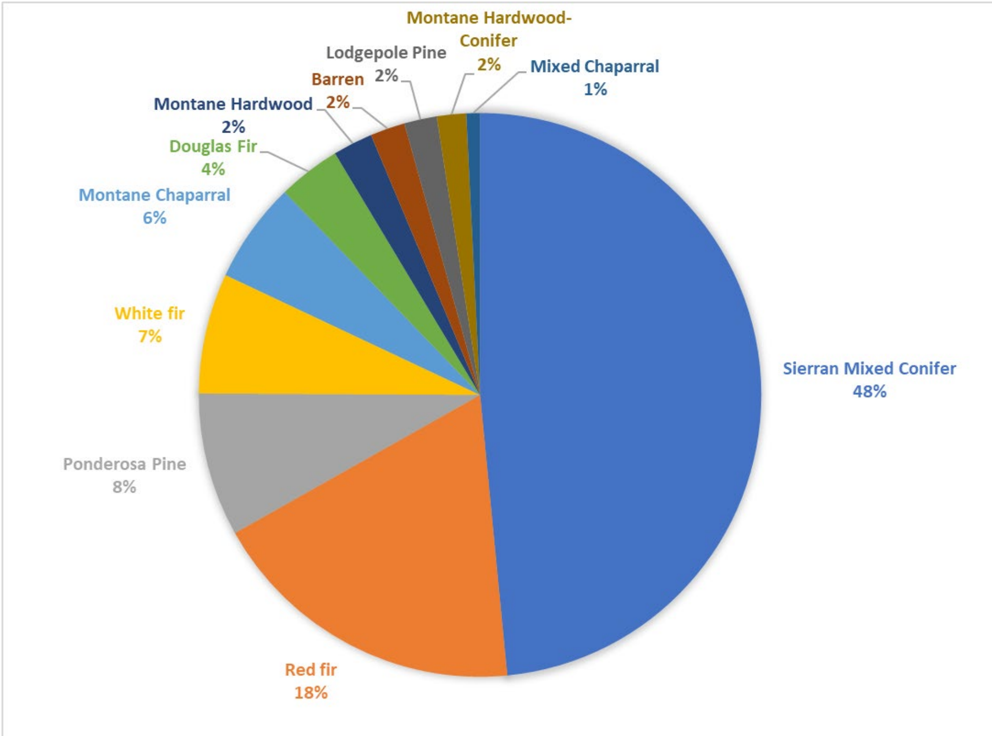

Figure 2. The distribution of major vegetation types in the Caldor Fire. This data represents only vegetation covers that are greater than 1% (other vegetation types <1% are jeffrey pine, wet meadow, annual grassland, subalpine, chamise chaparral, montane riparian, perennial grassland, aspen, blue oak pine and blue oak woodland) across all ownerships, CALVEG.

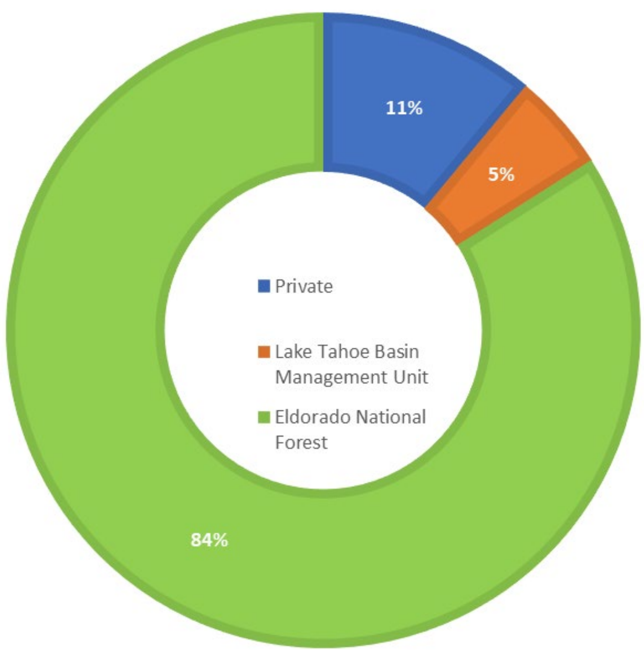

Figure 3. Ownership within the Caldor Fire area.

Post-Fire Restoration Framework

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 postfire project planning and monitoring efforts. The landscape assessment process involves assessing postfire ecological condition, considering other factors that may influence postfire ecosystem recovery, and incorporating additional analysis tools. Next, the landscape assessment process, directs the user to identify three types of restoration opportunities on a postfire landscape, including areas to (1) maintain or promote desired conditions (areas with beneficial/neutral fire effects), (2) take management actions to restore desired conditions (areas with negative fire effects where management is feasible), and (3) reevaluate desired conditions (areas with negative fire effects where management is infeasible or undesirable considering climate change and other stressors).The focus of this document is to describe the goals and objectives, methods, and broad restoration opportunities identified for mixed conifer forests within the Caldor fire landscape (e.g., steps 1-3, 5). A companion report applies the framework to late seral forests where California spotted owl is the primary target resource. 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.

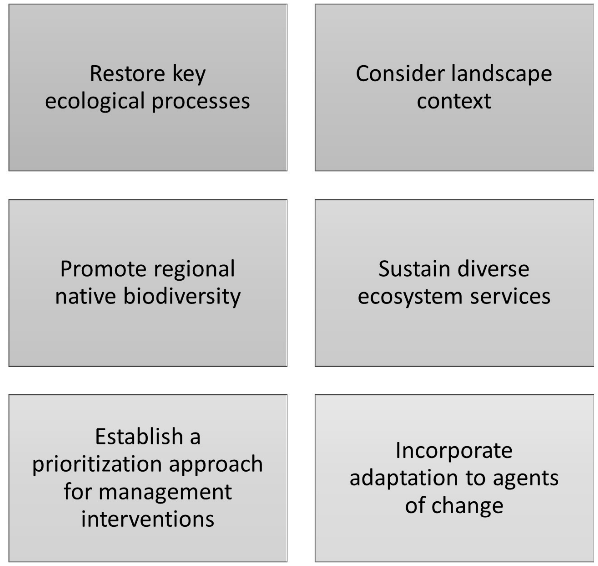

Figure 4. The six ecological principles that provide the foundation for the post-fire assessment process. From Meyer et al. 2021.

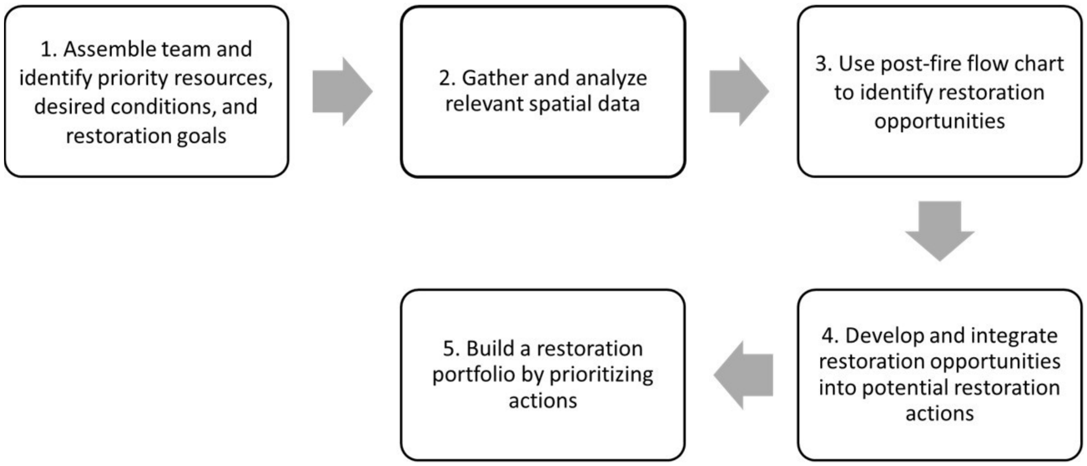

Figure 5. Five step processes used to develop the post-fire restoration framework (Meyer et al. 2021).

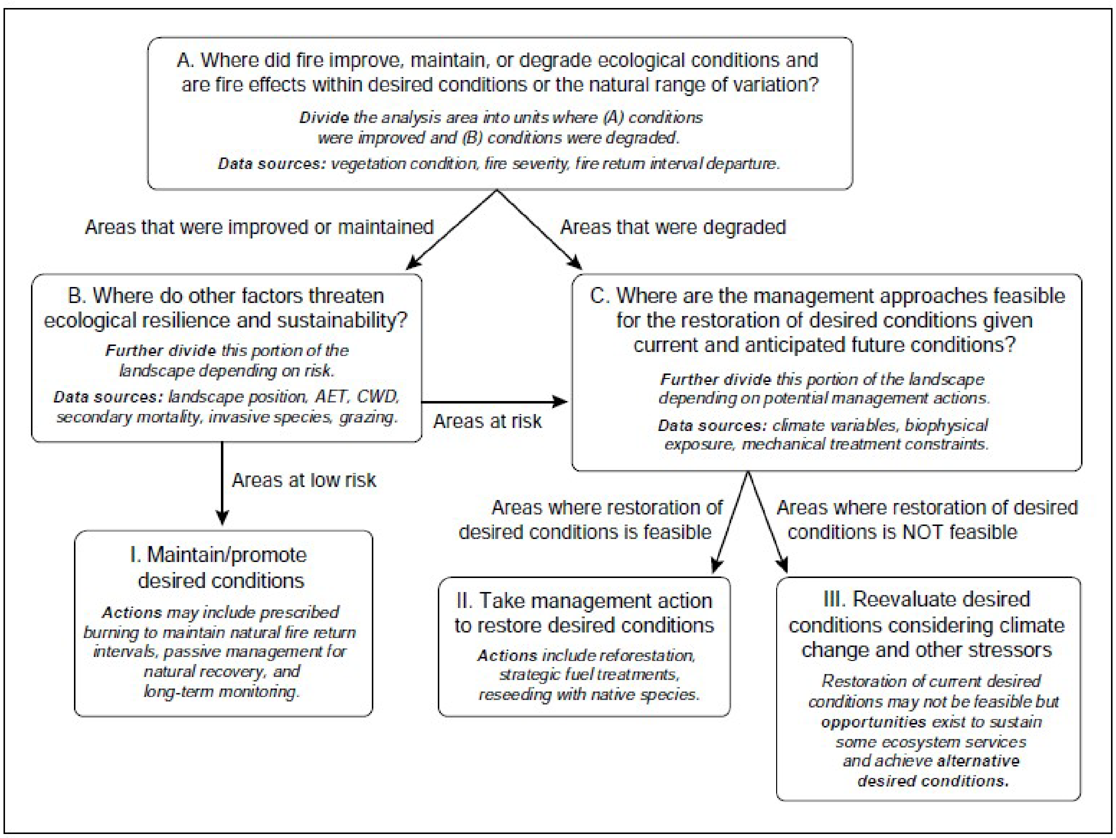

Figure 6. The post-fire flow chart from Meyer et al. 2021. This process uses three questions (A, B, and C) to identify management responses or "restoration opportunities" (1,2, and 3) in different portions of the post-fire landscape.

Step 1: Identify priority resources and desired conditions

Interdisciplinary Team

The first step to this process is to assemble a small team of specialists that have a familiarity with the burned landscape and have a broad knowledge of silviculture, fire, and forest ecology.

Priority Resources

The priority resources that were identified in the Rapid Assessment were public/fire fighter safety, conifer regeneration, resilience, and California Spotted owl. The focus of this report is on conifer dominated forest vegetation with a particular focus on conifer regeneration and forest resilience (Figure 7). This is the most dominant vegetation type across the Caldor Fire landscape (Figure 2, Table 1) covering well over half of the landscape. This vegetation type was selected for the importance across both the Eldorado National Forest and the Lake Tahoe Basin Management Unit. This vegetation type is composed of mainly ponderosa pine, Jeffrey pine, white fir, Douglas fir, incense-cedar, and varying amounts 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).

Figure 7. Priority resources identified in the Caldor Fire

Table 1. Dominant Vegetation Types (CALVEG CWHR Type) across the 2021 Caldor Fire

WHRTYPE	Acres	Percent
Sierran Mixed Conifer	104,981	47
Red fir	39,853	18
Ponderosa Pine	17,814	8
White fir	14,978	7
Montane Chaparral	12,539	6
Douglas Fir	7,794	4
Montane Hardwood	4,952	2
Barren	4,329	2
Lodgepole Pine	4,061	2
Montane Hardwood-Conifer	3,645	2
Mixed Chaparral	1,698	<1
Jeffrey Pine	1,603	<1
Wet Meadow	1,360	<1
Annual Grassland	639	<1
Subalpine Conifer	624	<1
Chamise-Redshank Chaparral	159	<1
Montane Riparian	78	<1
Perennial Grassland	42	<1
Aspen	41	<1
Blue Oak-Foothill Pine	6	<1
Blue Oak Woodland	3	<1

Restoration Goals

Based on the priority resources four goals were identified in the 2021 Caldor Fire:

1) Target conifer resilience areas to facilitate forest recovery through natural regeneration and reforestation.
2) Target areas where the fire effects were beneficial and increase resilience to future forest disturbances.
3) Reduce the risk of future disturbances on high values resources (e.g. California spotted owl)

Step 2: Gather and analyze relevant spatial data to inform decision framework

Data sources

Numerous analytical tools, approaches, and datasets are available to assist in evaluating landscape condition and trend in the Caldor framework. A number of these are described in GTR 270 and new data sources are constantly being developed. Some of these tools and data may be broadly applied, but many are specific to individual ecosystem types or landscapes. For the Caldor framework, only available datasets were utilized This analysis could be boosted with additional spatial data such as the Worldview Imagery or the Tahoe Central Sierra Initiative (TCSI) pillar metrics to further refine and inform the decision framework. The data sources utilized in this report are detailed in Table 2.

Table 2. Data sources used in the Caldor Fire Framework analysis.

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 Caldor Fire, 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
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.
Tree density (pre-fire fuel loading)	USDA Forest Service, Remote Sensing Lab, F3 dataset: TPA	F3 integrates: Forest Inventory and Analysis (FIA) data; Forest Vegetation Simulator (FVS); and Field and Satellite for Ecosystem Mapping (Huang et al. 2018)
Climate	UC Davis Vegetation Climate Exposure	Climate Vulnerability and Refugia where there is

Vulnerability/ Refugia	and Refugia	consensus between CNRM-CM5 and MIROC-ESM models for RCP 8.5 at mid century time frame (2040-2069) (Thorne et al. 2020)
TCSI Pre-fire Departure from Natural Range of Variability (TPA)	Tahoe Central Sierra Current Conditions Assessment – Forest Resilience Pillar Metrics (Manley et al. 2022)	http://northcoastxy.com/tcsi/#

Step 3. Use Post-Fire Flow Chart to Identify Restoration Opportunities

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

The first step in the assessment process is to spatially partition the landscape into three broad bins, based on an evaluation of fire effects to determine departure from the post-fire natural range of variability (NRV). Two criteria were used in this analysis to identify areas where fire effects were considered to be within the natural range of variation (NRV) and where they were departed. Fire severity (RAVG) data (Table 3) and pre-fire vegetation (Table 4) layers were the sources assessed and are described in detail below. In this assessment, 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 Caldor Fire. In contrast, large contiguous patches (>250 acres) of high severity fire (i.e., where >75% of the trees were killed) were considered to be outside of the NRV for these forest types and those areas that had moderately large contiguous patches (100-250 acres) of high severity fire (>75% of trees were killed) were considered moderately departed from NRV.

Table 3. Rapid Assessment of Vegetation (RAVG) fire severity classification used in analysis based on the precent change in basal area.

Fire severity category	Definition
Unburned	0% basal area mortality
Low	0 < basal area mortality < 25%
Moderate-Low	25 ≤ basal area mortality < 50%
Moderate-High	50 ≤ basal area mortality < 75%
High	> 75% basal area mortality

Table 4. CWHR vegetation types included in conifer forest definition including criteria used for POSCRPT modeling. Data provided by RSL.

Habitat Type	Primary Species
Eastside Pine (EPN)	Ponderosa Pine, Jeffrey Pine, White Fir
Jeffrey Pine (JPN)	Jeffrey Pine, Ponderosa Pine, Sugar Pine
Montane Hardwood-Conifer (MHC)	Ponderosa Pine, Incense Cedar, California Black Oak
Ponderosa Pine (PPN)	Ponderosa Pine, Jeffrey Pine, Douglas Fir
Red Fir (RFR)	Red Fir, White Fir, Lodgepole Pine
Sierran Mixed Conifer (SMC)	Douglas Fir, Ponderosa Pine, White Fir
White Fir (WFR)	White Fir, Douglas Fir, Sugar Pine

NRV Criteria 1: Vegetative Fire Severity

The Rapid Assessment of Vegetation Condition after Wildfire (RAVG) program produces data describing post-fire vegetation conditions on National Forest System (NFS) lands. RAVG produces a suite of geospatial and tabular outputs that include standard vegetation mortality summary tables and maps. The tables and maps are produced by integrating existing vegetation maps and burn severity maps. The effect on vegetation was evaluated using fire severity (the seven class Basal Area Loss as represented by the Rapid Assessment of Vegetation Condition after Wildfire data) (Figure 1). Representations of the different fire severity classes can be found in Appendix B. The seven class Basal Area Loss was grouped into similar classes as represented in the Meyer (2015) NRV assessment. As the Basal Area Loss is classed into 90% and greater severity the high severity class may be overestimated as compared to the NRV assessment. The Natural Range of Variation (NRV) summarized from Meyer (2015) is represented for each severity class as a range. The NRV for fire severity classes and high severity patches has also been summarized by Safford and Stevens (2017). Fire severity across all vegetation types in the 2021 Caldor Fire was 21% for unchanged, 20% for low severity, 19% for moderate and 40% for high severity (Figure 8). The majority of the high severity fire occurred in the western portion of the fire during the first few burn periods (Figure 1). Both the unchanged and moderate fire severity were within the Natural Range of Variability (NRV). The low fire severity was below NRV. The percent of high severity fire was outside the range of NRV with it being much higher than what has been seen in fires occurring under a more natural fire regime (Figure 8).

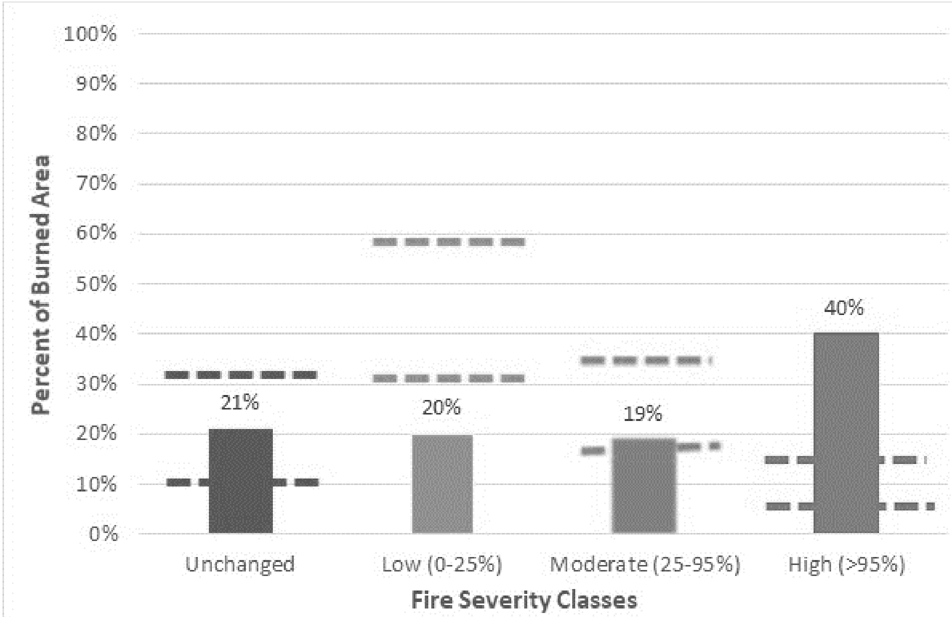

Figure 8. Mean fire severity proportions in each severity class in the 2021 Caldor Fire. The seven class Basal Area Loss was grouped into similar classes found in the Meyer (2015) NRV assessment. As the RAVG Basal Area Loss is classed into 90% and greater severity the high severity class may be an overestimate as compared to the NRV assessment. The Natural Range of Variation (NRV) summarized from Meyer (2015) is represented for each severity class as a range with a dotted line. The NRV for high severity patches has also been summarized by Safford and Stevens (2017).

NRV Criteria 2: 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).

The resilience of coniferous forest ecosystems postfire depends on sufficient tree survival and seed dispersal, both of which are heavily influenced by fire severity patterns. In larger high-severity burned patches, much of the burned area can be far from available seed sources, thereby limiting the likelihood of successful natural regeneration—especially among heavier seeded taxa, such as some pine species. High-severity patches would have been rare in the yellow pine mixed-conifer forests during the reference period with most patches being less than 250 acres in size.

High severity patches were classified into 6 patch size classes (1-10, 11-100, 101-250, 251-

1,000, 1,001-10,000, >10,000 acres). High severity patches were represented by patch size classes that coincide with NRV. There were many small (<100 acres) (n= 710 patches) and they made up a large proportion of the count of patches (94%) (Figure 9). Moderate size patches, those that are 101—1,000 acres in size have a count of 38 patches and make up a low percentage of patch count (Figure 9). A lower proportion of patches (n = 6) are considered exceptionally large (patches greater than 1,001 acres) and are outside the natural range of variation. The cumulative area is mostly made up of a few large patches (>250 acres in size) representing over 80% of the patch area (Figure 9). The majority of the large patches are found in the Western portion of the fire area (Figure 10).

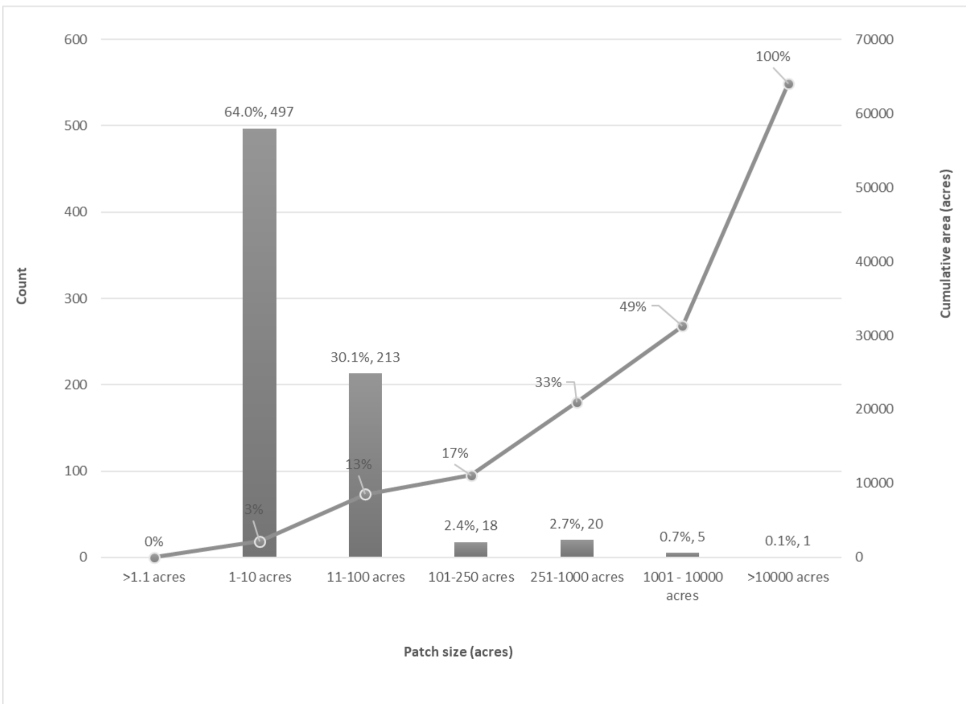

Figure 9. Histogram of high-severity patches in mixed-conifer forests following the 2021 Caldor Fire.

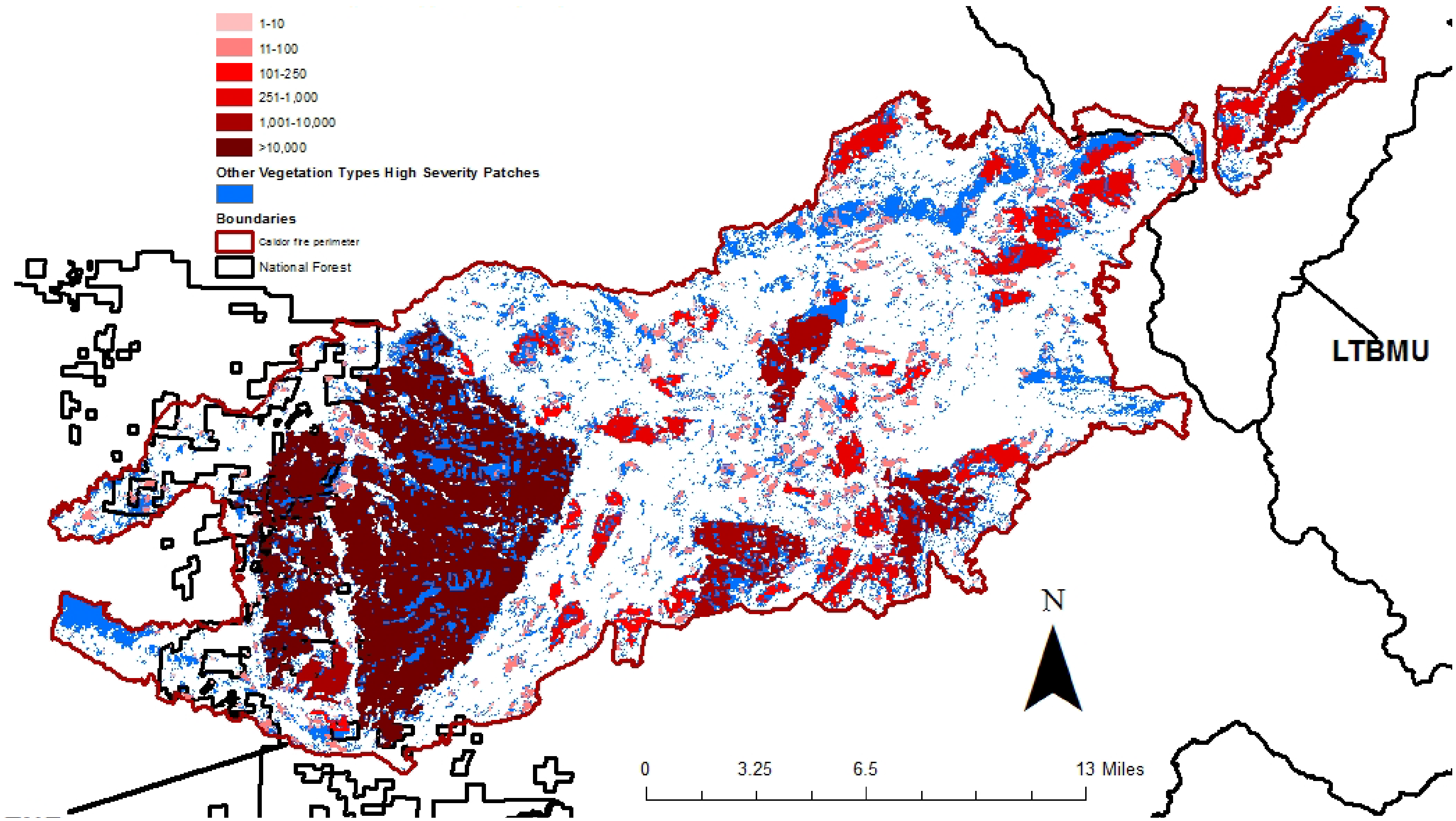

Figure 10. Patch sizes of high severity fire (>75% Basal Area Loss) within the 2021 Caldor Fire footprint (above) shown in reddish colors for areas dominated by yellow-pine, mixed conifer, or red fir forests and blueish colors for areas dominated by other vegetation types (e.g., chaparral, oak woodlands) burned at high severity. Data were displayed in two different color schemes because historically large patches of high severity fire may have occurred more commonly in some vegetation types (i.e. chaparral).

Determination of NRV in the 2021 Caldor Fire

The following criteria were used to identify areas where fire effects were within and departed from NRV (Figure 11).

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.

Fire effects considered moderately 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 between 100-250 acres; these areas are most likely to support live trees in the near-term.

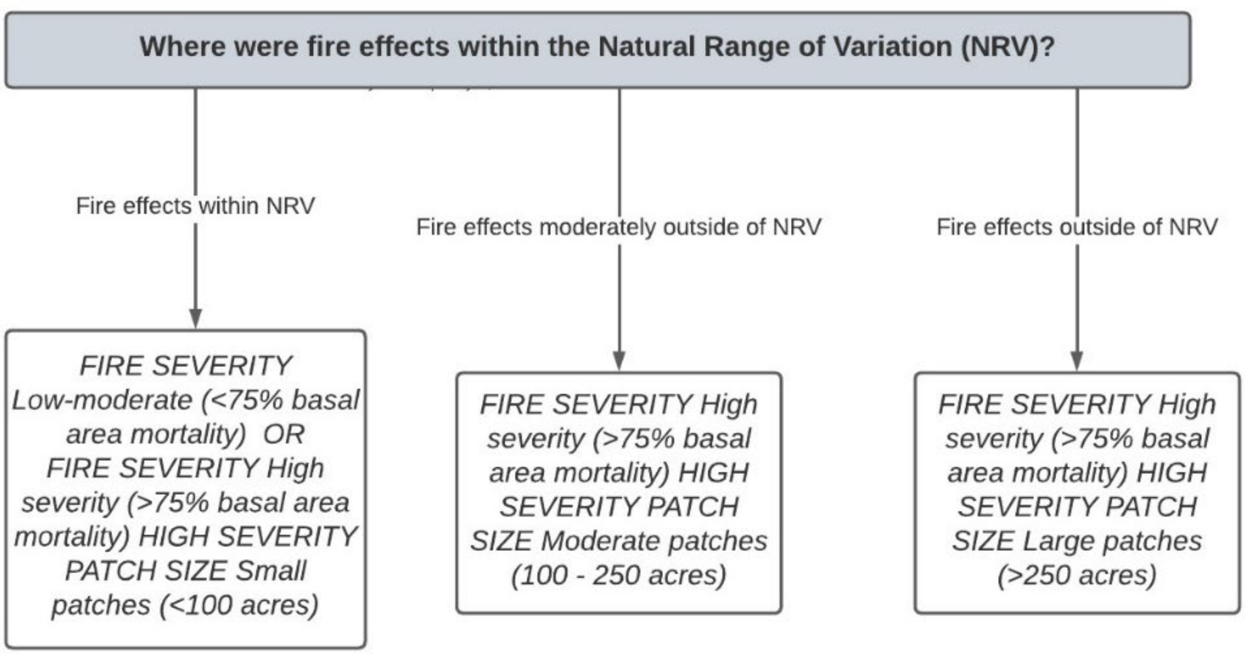

Figure 11. Flow chart for determining the natural of range of variation in mixed conifer forests in the 2021 Caldor post fire landscape

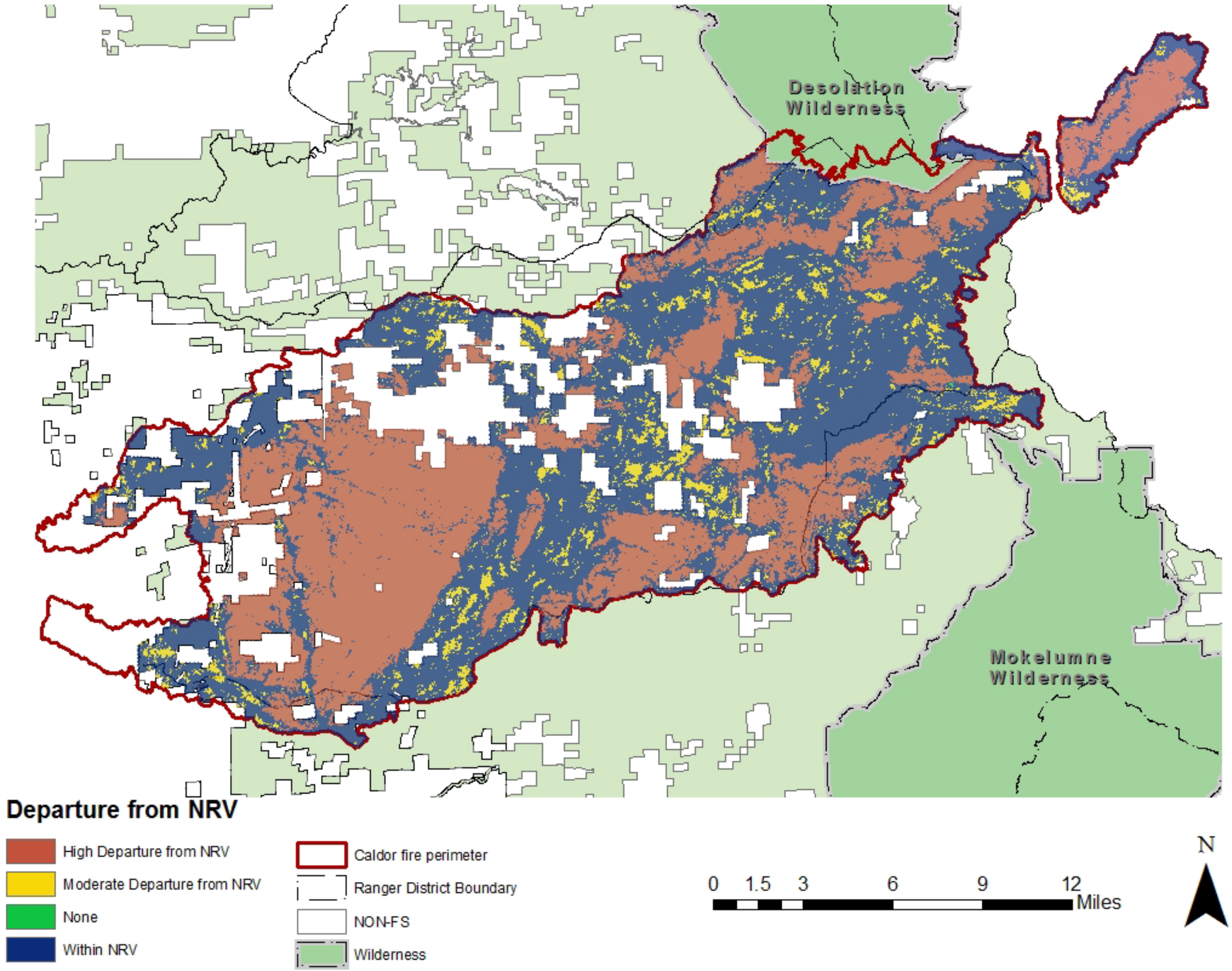

Figure 12. Post-fire departure from NRV across the 2021 Caldor Fire. Areas are considered with a high or moderate departure from NRV and within NRV.

This process identified a total of 101,743 acres outside the of designated wilderness and private ownership that are considered outside the natural range of variability. Of this amount 87,221 acres had a high departure, and 14,522 acres had a moderate departure. About 122,385 acres were considered within the natural range of variability.

Criteria used to determine were conditions improved, not improved or degraded

A number of other criteria were utilized to further refine where conditions were improved, not improved or degraded and specific management opportunities might exist. A brief description of each criteria follows below.

Criteria 1: Predicted probability of natural regeneration

A spatially-explicit model, the Post-fire Spatial Conifer Regeneration Prediction Tool (POSCRPT), was used to produce a five-year post-fire predictive map of potential conifer regeneration following the Caldor Fire that burned across the Eldorado National Forest (ENF) and Lake Tahoe Basin Management Unit (LTBMU). 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). There are five predicted probability classes mapped across the YPMC portions of the burn area that relate to the probability of observing at least one regenerating conifer five years after fire at the 60-m2 (field plot) scale. Predictions were made for five regeneration scenarios that include different levels of seed production and precipitation combinations (i.e., high seed production/low precipitation). Pre-fire vegetation maps were used to exclude areas that were not yellow pine or mixed conifer forest prior to the fire (Table 4). Three climate scenarios were evaluated to better understand the probability of natural regeneration. The mean precipitation scenario was estimated as the 30-year (1981-2010) historical mean precipitation. The drier precipitation scenario was associated with the difference of the MIROC-ESM RCP 8.5 (hot & dry) climate and historical mean. The wetter precipitation scenario was estimated by the difference of the CNRM-CM5 RCP8.5 (warm & wet) climate projections for 2040-2069 from the historical mean. These scenarios were estimated using the Flint et al. (2013) data obtained from BCM.

The two seed productivity scenarios were estimated using the seed dispersal kernels calculated using LEMMA (Ohmann et al. 2011) basal area estimates for each taxonomic group and modified seed production equations from Greene & Johnson 1994. Basal area values are corrected for loss to fire based on RdNBR. These two scenarios represent low and high seed productivity. All of the scenarios are presented in Appendix C.

For the framework, the outputs for all conifers combined, using the high seed production and low precipitation scenario as used to predict probability of natural regeneration. In areas that were conifer forest prior to the Caldor fire, 42% of the landscape had a high (>40%) likelihood of natural regeneration in the near-term (Figure 13 &14). In contrast, 58% fell within the two lowest prediction classes (<40%) (Figure 13&14). Field data suggests that the median seedling density for the two lowest prediction classes is 0 seedlings/acre, which suggests that these areas will likely have little to no conifer natural regeneration in the short term.

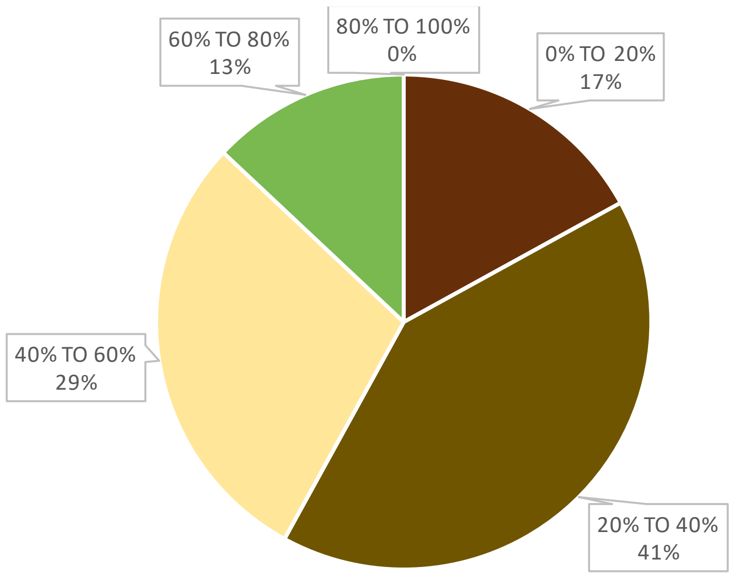

Figure 13. Predicted natural regeneration across all ownerships of the 2021 Caldor Fire.

Criteria 2: Climate Vulnerability

Findings from recent climate modeling intended to inform natural resource management decision making (Thorne et al., 2020) indicate that, statewide, acreage of non-stressful climate conditions for California vegetation will contract over this century. Information about the risks of climate change can provide guidance implementing management activities on forested lands and can help target climate-adaptive management actions in areas with different exposure of climatic stress. These areas can be spatially defined by combining climate conditions and current vegetation maps. From this vegetation refugia and exposure can be determined. Areas of refugia identify where existing vegetation is expected to remain within current suitable climatic conditions. Areas of exposure are identified as areas where the existing vegetation is unlikely to have climatic conditions suitable to its maintenance. Consensus vegetation refugia and exposure are areas projected to remain climatically suitable and have increased exposure under both wetter and drier future climates. Treatments could be designed to reduce the risk of such future stressors. What is more, in areas modeled for extreme future climate stress exposure, silviculturists could plan post-treatment strategies that consider alternative regeneration scenarios based on modeled future climate conditions (see GTR-NRS-87-2 (2016): Forest Adaptation Resources: Climate Change Tools and Approaches for Land Managers, 2nd edition). Conversely, areas where climate vulnerability models agree that end-of-century vegetation types will remain stable (aka, areas of consensus refugia as per Thorne et al. 2020) could be areas where managers consider actions that can help sustain healthy conifer ecosystems and achieve management goals in the face of climate change.

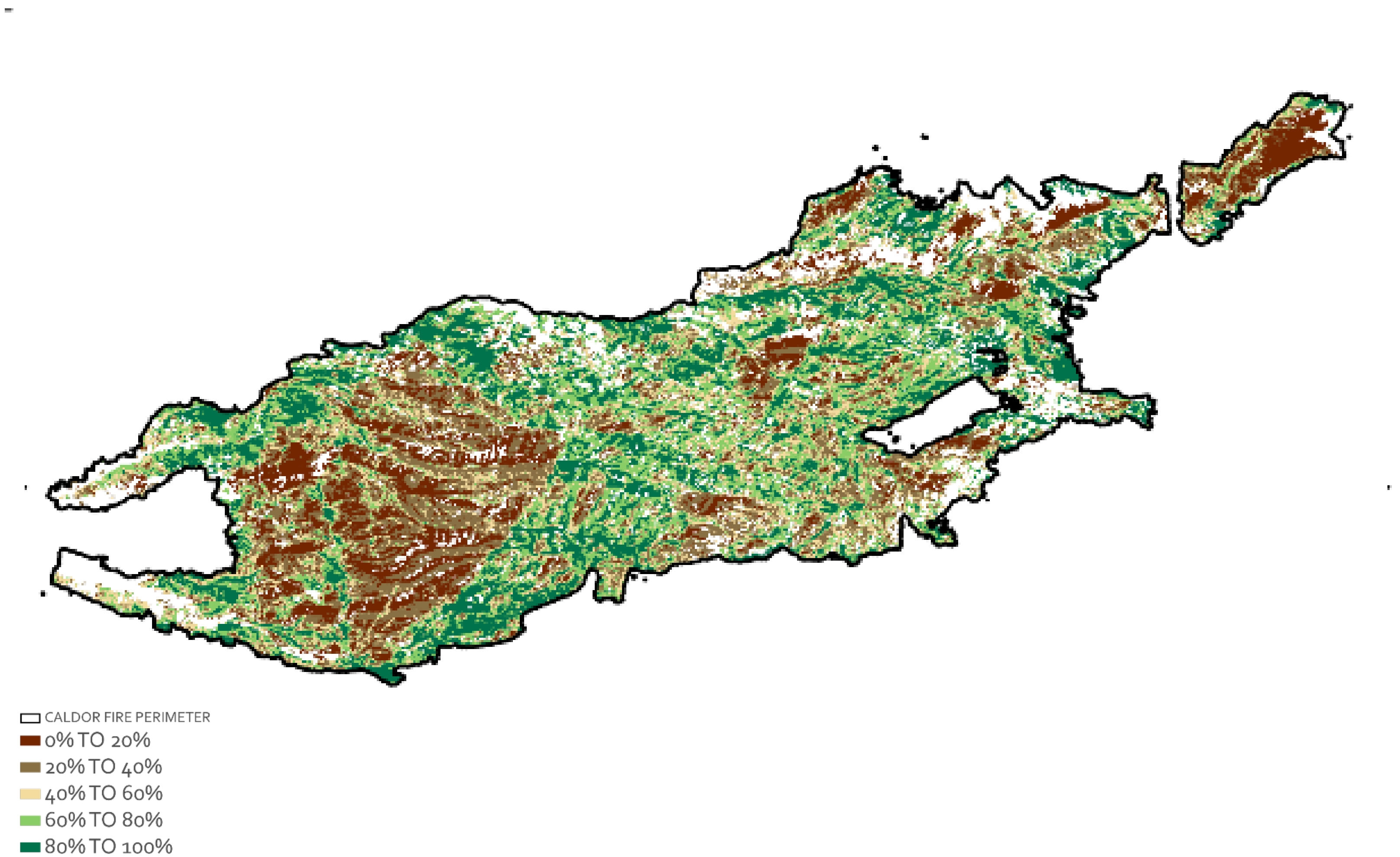

Figure 14. Map showing the probability of natural regeneration five years after the Caldor fire. Predictions are limited to areas that were conifer forest prior to the fires.

This data uses climate exposure values for California vegetation derived from Thorne et al. 2020. Across California, conifer vegetation experiences a range of climate conditions (e.g., a range of water and temperature conditions). This analysis adopted climate stress conventions from Thorne et al. as follows: conifer forests occurring within areas characterized by their most frequently encountered contemporary climatic conditions are considered climatically non-stressed. Areas where future climate scenarios project that conifer forests will continue to experience these same most-frequently-encountered conditions are considered potential climate refugia. Conifer forests occurring within areas of least-frequently-encountered, extreme climatic conditions, are considered climatically stressed. Climate scenarios used in Thorne et al. 2020, and for this analysis were a hotter / drier scenario (MIROC-ESM) and a warmer / wetter scenario (CNRM-CM5). Both hotter/drier and warmer/wetter scenarios project a similar trend of extreme loss of non-stressful habitat for red fir forests in California by 2100, a trend found in several other climatic projection models (see Table 15 in Meyer and North 2019, p. 57). The suite of climate scenarios are presented in Figure 15.

For the framework analysis, the mid-century RCP 8.5 scenario where there is model agreement was chosen which classes everything >80% as high and very high exposure and everything <80 as potential for climate refugia.

Criteria 3: Fuel Loading – Predicted based on Pre-Fire Conditions

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).

High severity fire (>75% basal area mortality) and particularly those areas that were either outside or moderately outside of the calculated HRV was combined with pre-fire tree density to estimate probable fuel loading and snags in the post-fire environment that would prioritize these areas for treatment. Estimates of pre-fire tree density (trees per acre) were derived 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.

A threshold of 300 trees per acre was used to indicate areas of potential high fuel loading in the framework analysis. Figure 16 shows the distribution of fuels across the Caldor Fire.

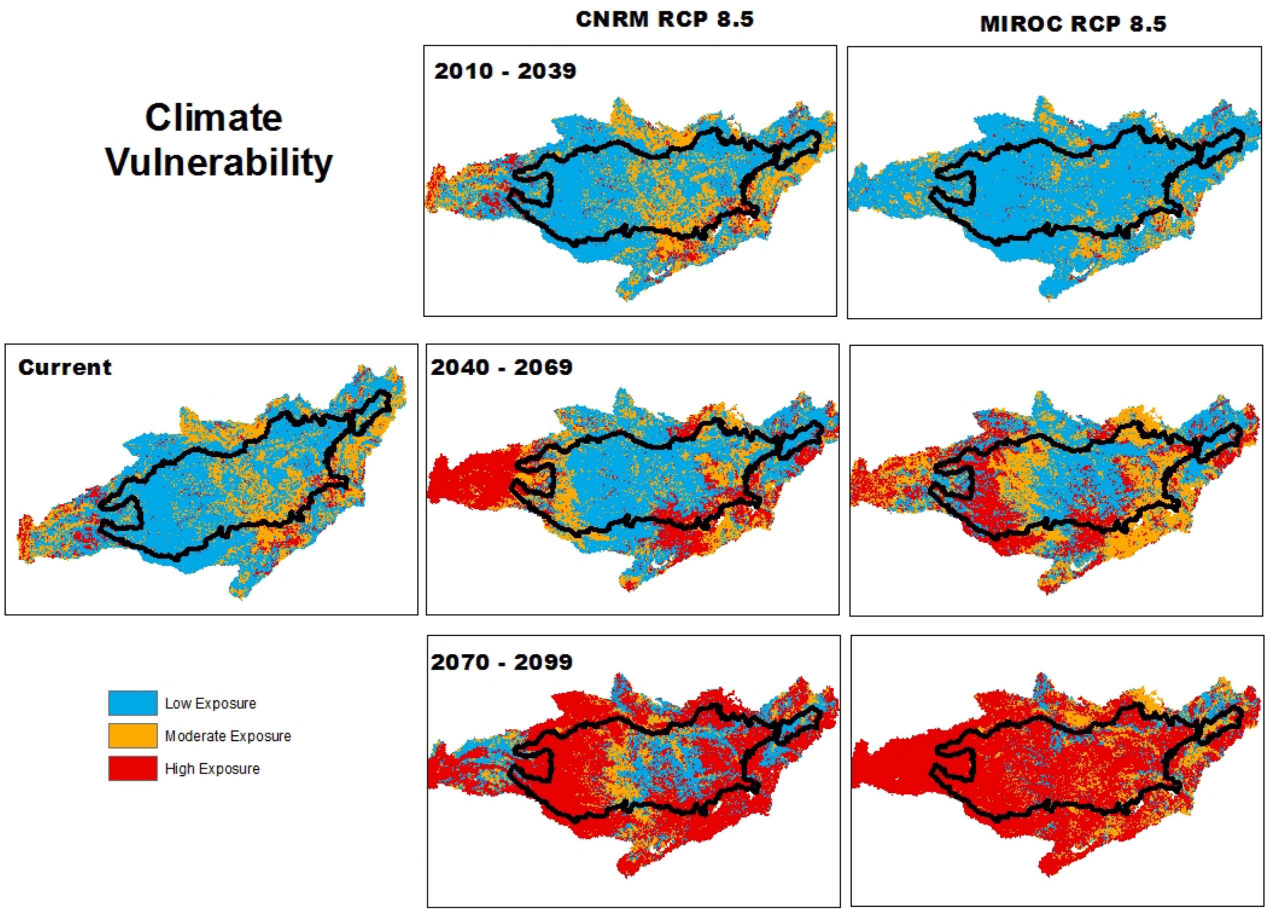

Figure 15. Mapped climate exposure under the "Warm and Wet" CNRM CM5 climate projection under Higher Emissions RCP8.5. This image shows the climate exposure of the vegetation types at current time and three future periods: 2011-2039, 2040-2069 and 2070-2099. Areas considered to be highly climatically exposed are in the 95-99% and 99-100%. Areas with values <80% are considered to be in climatically suitable conditions for the vegetation that is currently occupies.

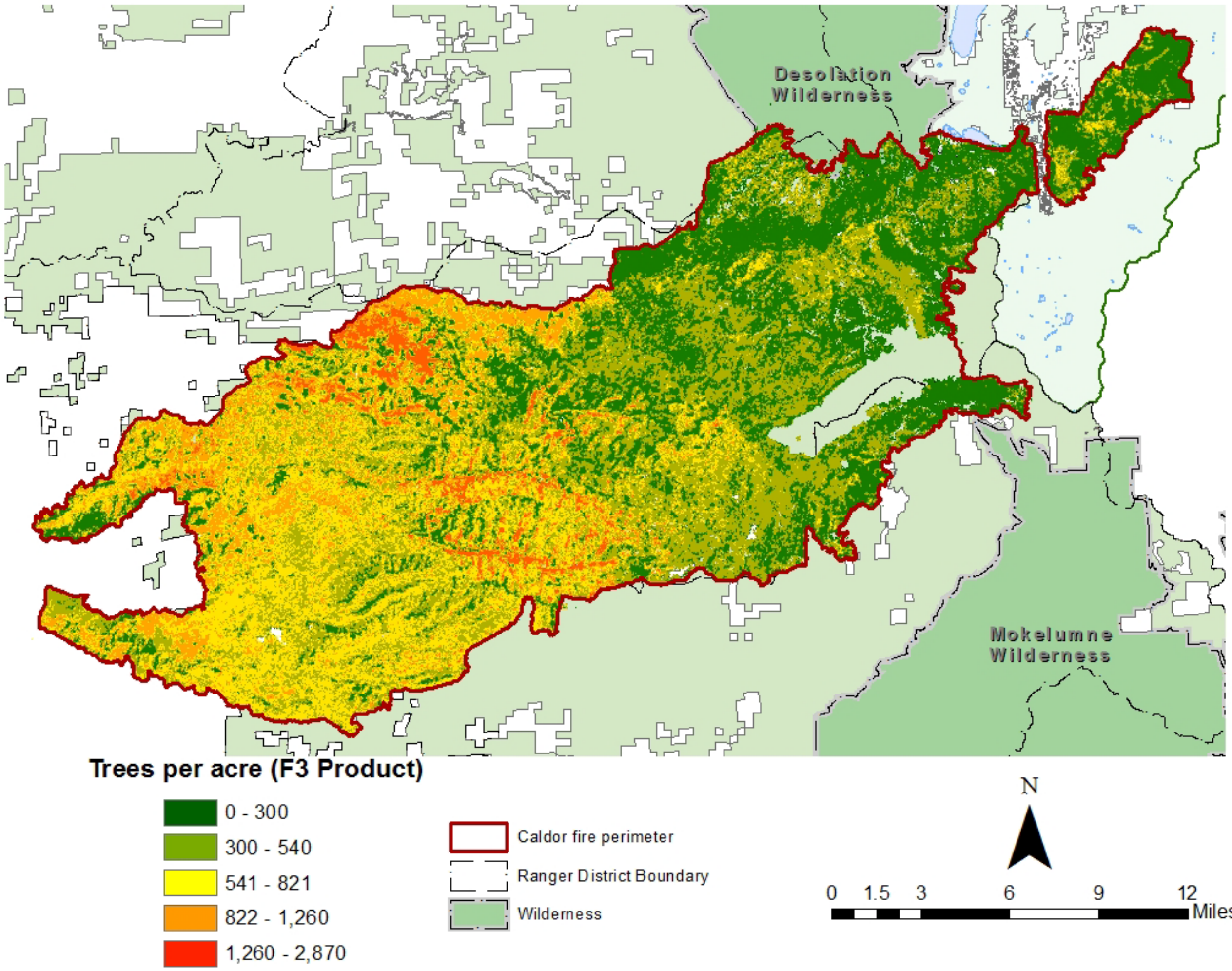

Figure 16. Estimates of pre-fire tree density (trees per acre) were derived from F3, a 30-m resolution dataset developed by Huang et al. (2018). This dataset integrates Forest Inventory and Analysis (FIA) plots, the Forest Vegetation Simulator (FVS), and Field and Satellite for Ecosystem Mapping (FastEmap) to estimate vegetation attributes across large scales

Criteria 4: Pre-Fire Tree Density Departure

Forest structure is one measure of forest resilience that can be altered using restoration management. To determine pre-fire forest departure from the natural of range of variability, the current condition analysis conducted by the Tahoe Central Sierra Initiative (TCSI) was utilized. The methods for quantifying tree density departure are described in detail in Wilson and Manley (2019). Current conditions were generated using SilviaTerra data. Contemporary reference sites across the Sierra Nevada were used to establish target conditions for tree density (Jeronimo et al. 2019). Following the methods of Jeronimo et al. (2019), the landscape was stratified based on biophysical setting, specifically the climate class and landscape management unit (LMU) classifications. Climate classes were based on climatic water deficit, January minimum temperature, and actual evapotranspiration. Tree density was than characterized in 1-hetare pixels across the TCSI landscape. Tree density was classified in TCSI as not departed if the values fell within the 10th and 90th percentile of the range of conditions in corresponding climate class categories. Tree density values outside this range were defined as either low, medium, and high departure. For the framework analysis, moderate and high departure was represented as high while low departure remains the same classification (Figure 17).

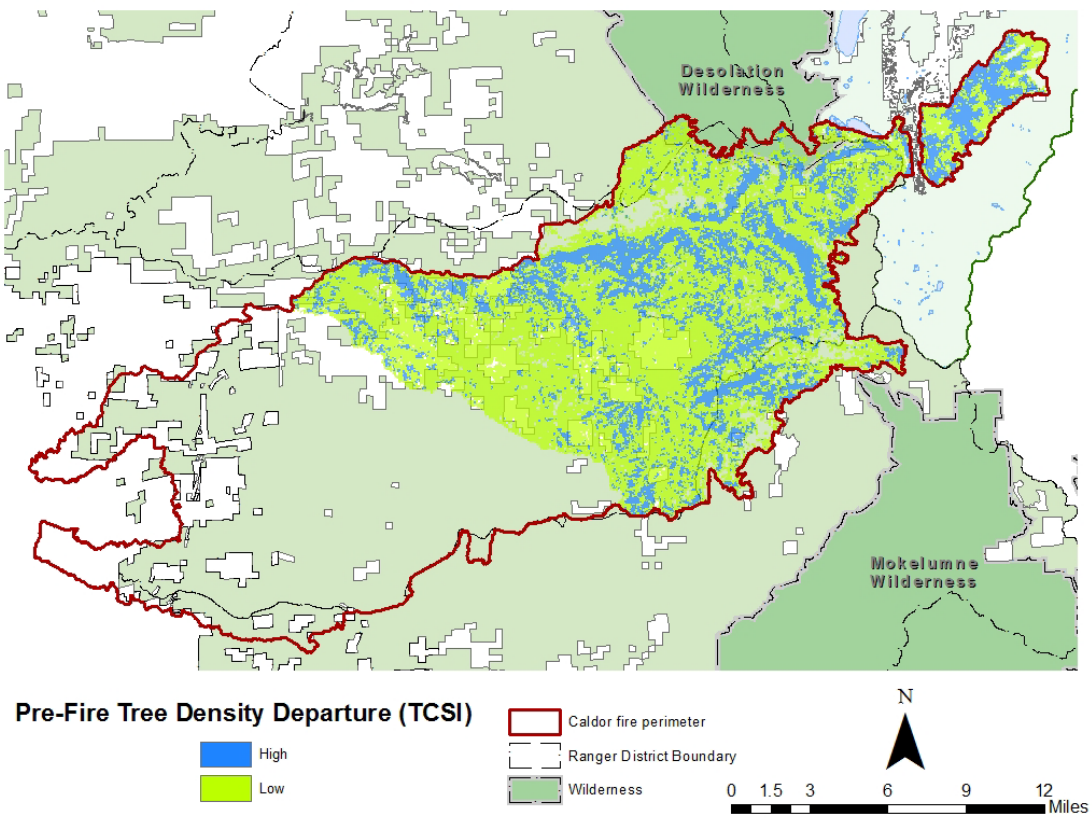

Figure 17. Pre-Fire tree density departure from reference conditions as determined by TCSI. Note that only a portion of the Caldor Fire is covered.

Restoration Opportunities: Fire effects outside of NRV

To identify opportunities for management in areas that were outside of NRV, Criteria 1,2 and 3 were used to evaluate restoration opportunities. These areas were prioritized by scenario and will be targeted for revaluation of desired conditions based on future climate exposure, reforestation that was further prioritized based on estimates of pre-fire fuel loading (Restoration Goal 4) and those areas that are not considered conifer forests. Figure 18 provides the process that was used to determine the seven scenarios.

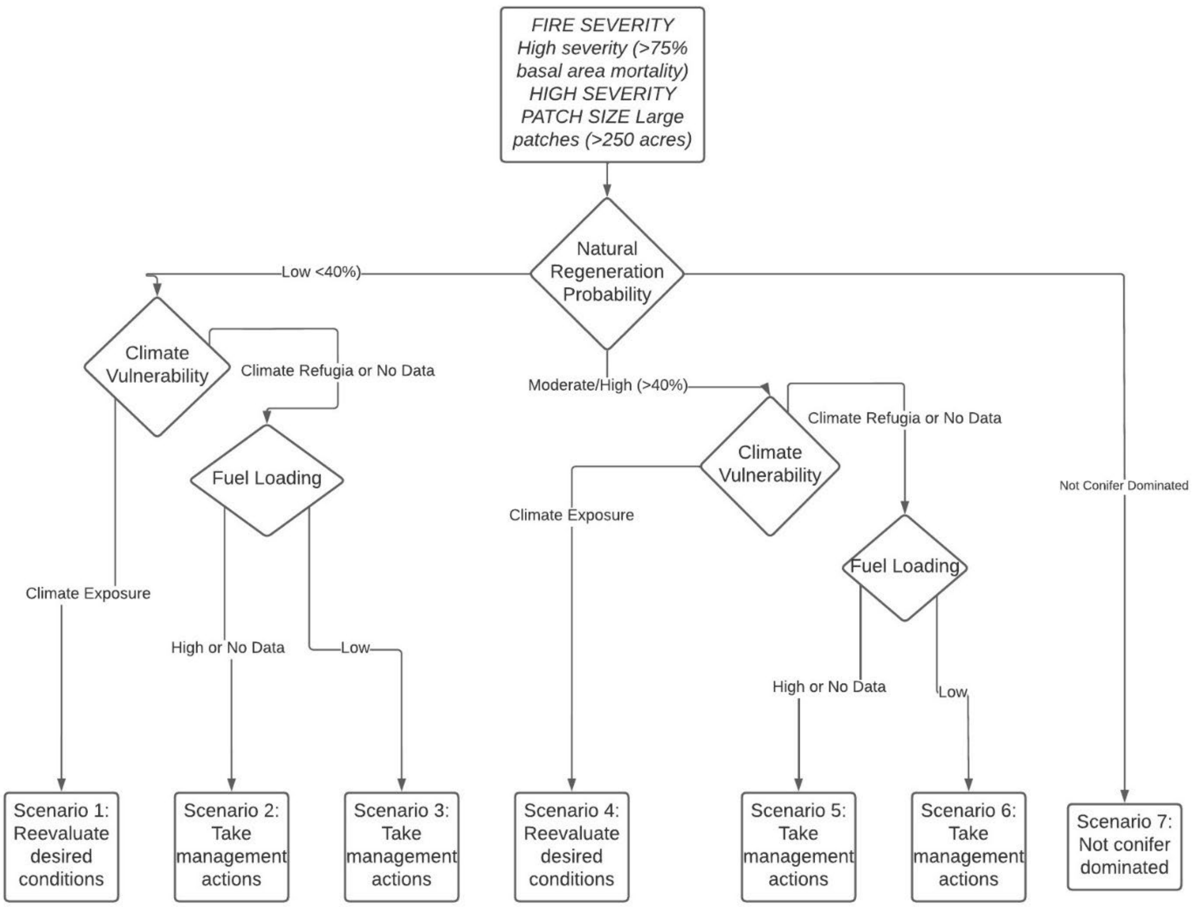

Figure 18. Decision tree for locations within the Caldor Fire that are outside the Natural Range of Variation

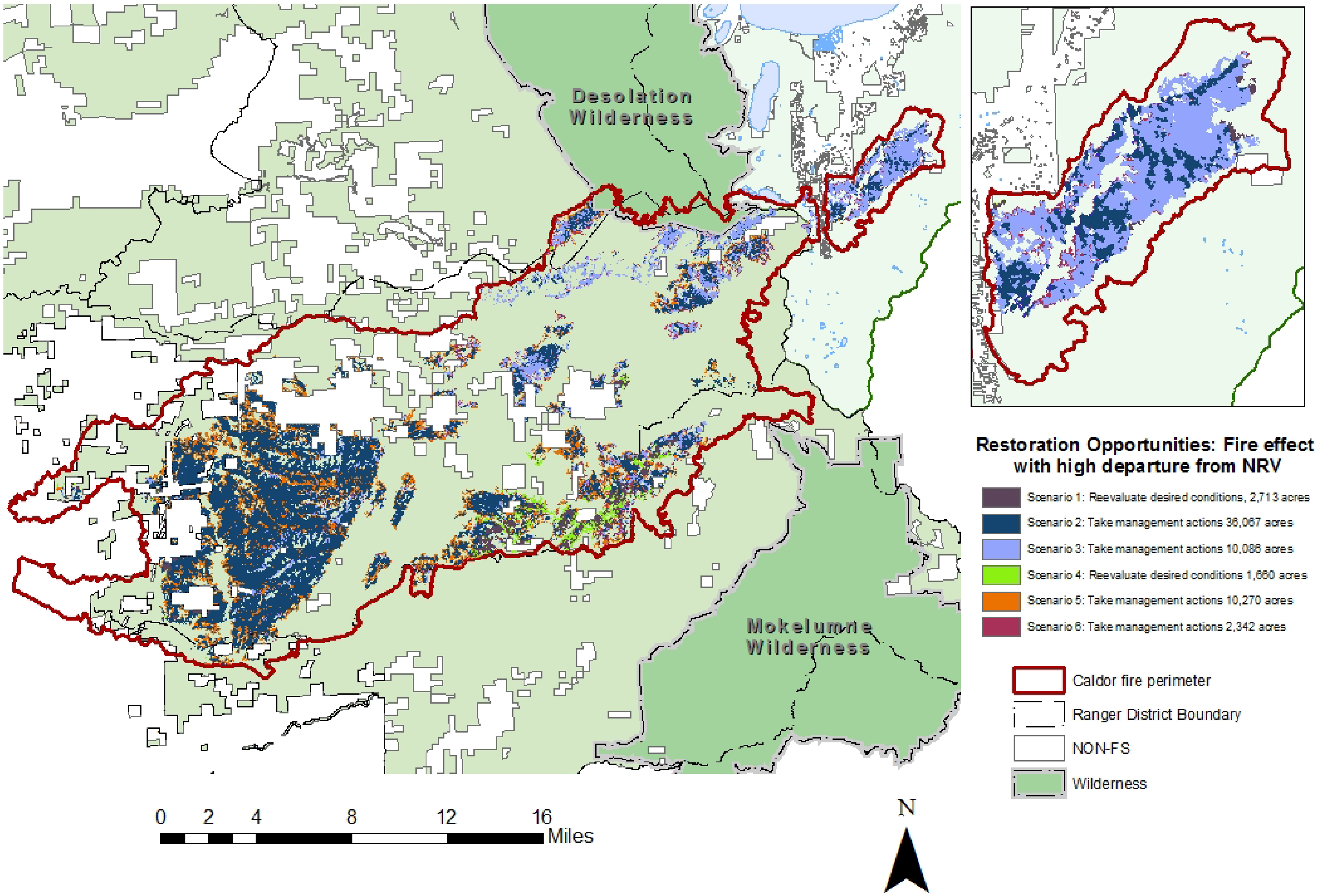

Figure. 19. Broad restoration opportunities identified within the 2021 Caldor Fire in areas that burned outside the natural range of variation. These opportunities were limited to areas that were conifer forest prior to the fires and to National Forest (outside of wilderness and private lands). The percentage that falls within each broad opportunity is provided in the legend. These opportunities are described in detail in Table 5.

This process identified 4,373 acres that were predicted to be at risk of climate exposure mid-century and should be revaluated for desired conditions (Figure 19). Another 12,612 acres were identified as likely to have moderate to high probability of natural regeneration and are likely a moderate priority for reforestation (Figure 19). Another 46,153 acres were identified as unlikely to naturally recover in the near future without intervention and would require fuel reduction, site preparation and reforestation to meet Restoration Goal 1. The acreages are broken down into the two target units where restoration treatments will be needed (Table 5).

Table 5. Number of acres in each scenario that were outside the natural range of variation post 2021 Caldor Fire on National Forest Lands (outside of wilderness and private lands) broken out by the two units.

Scenario	Restoration Opportunities	Acres in Each Ownership	Acres in Each Ownership
		Lake Tahoe Basin Management Unit	*Eldorado National Forest*
1	Reevaluate desired conditions	71	2,643
2	Take management actions	1,011	35,056
3	Take management actions	2,728	7,358
4	Reevaluate desired conditions	3	1,657
5	Take management actions	78	10,192
6	Take management actions	174	2,168

Restoration Opportunities: Fire effects moderately outside of NRV

To identify opportunities for management in areas that were moderately outside of NRV, Criteria 1 and 3 were used to evaluate restoration opportunities. These areas were prioritized by scenario and will be targeted for revaluation of desired conditions based on future climate exposure and those areas that are identified as critical for fuels reduction to meet Restoration Goal 1. Figure 20 provides the process that was used to determine the three scenarios.

This process identified 629 acres that were predicted to be at risk of climate exposure mid-century and should be revaluated for desired conditions (Figure 21). Another 8,572 acres were identified as moderately departed from NRV with further prioritization based on fuel loading (Figure 21). 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). These areas would require fuel reduction and likely additional mechanical treatment to meet Restoration Goal 2. The acreages are broken down into the two target units where restoration treatments will be needed (Table 6).

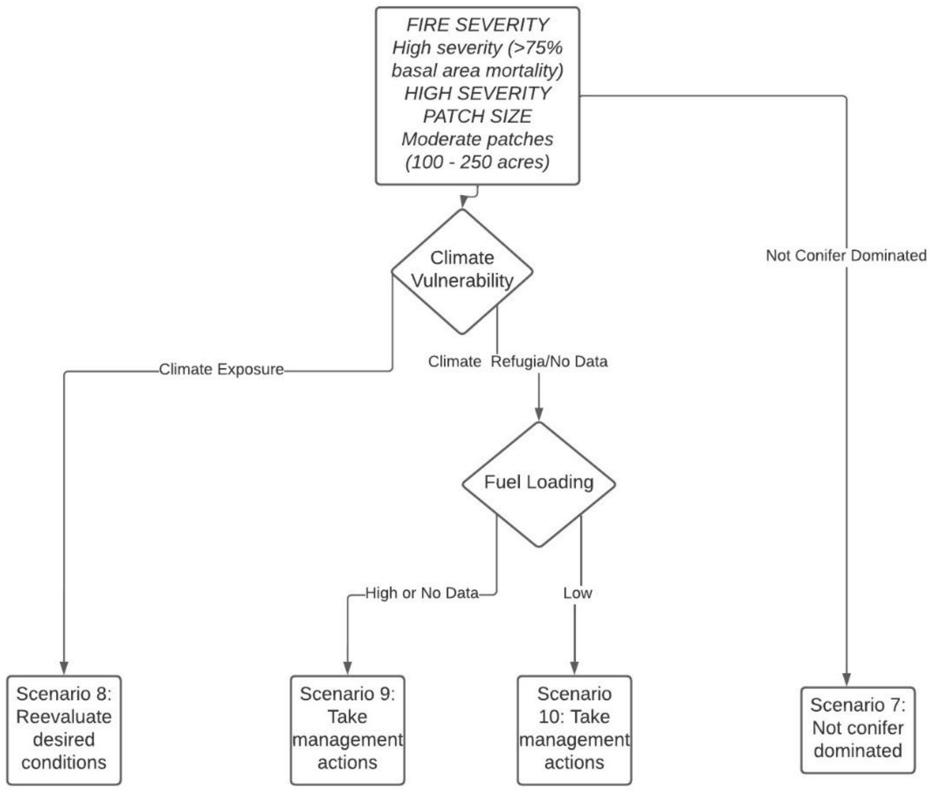

Figure 20. Decision tree for locations within the Caldor Fire that are moderately outside the Natural Range of Variation

Table 6. Number of acres in each scenario that were moderately outside the natural range of variation post 2021 Caldor Fire on National Forest Lands (outside of wilderness and private lands) broken out by the two units.

Scenario	Restoration Opportunities	Acres in Each Ownership	Acres in Each Ownership
Scenario	Res	*Lake Tahoe Basin Management Unit*	*Eldorado National Forest*
8	Reevaluate desired conditions	7	622
9	Take management actions	102	5,975
10	Take management actions	89	2,407

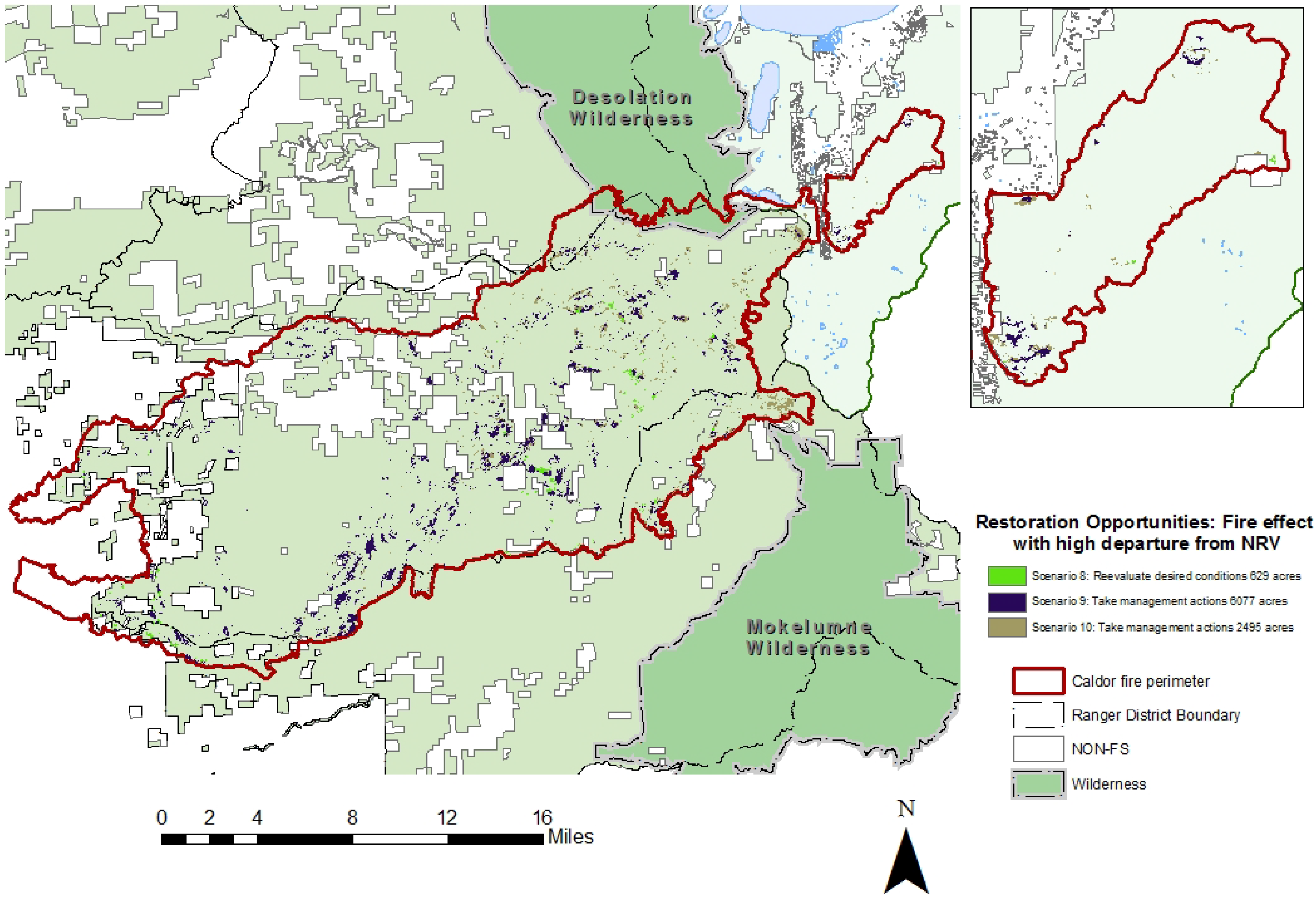

Figure. 21. Broad restoration opportunities identified within the 2021 Caldor Fire in areas that burned moderately outside the natural range of variation. These opportunities were limited to areas that were conifer forest prior to the fires and to National Forest (outside of wilderness and private lands). The percentage that falls within each broad opportunity is provided in the legend.

Restoration Opportunities: Fire effects within NRV

To identify opportunities for management in areas that were within NRV post Caldor Fire, Criteria 1 and 4 were used to evaluate restoration opportunities. These areas were prioritized by scenario and will be targeted based on whether they are identified as exposed or refugia in the future climate and those areas that were identified as departed in tree density prior to the fire. Restoration opportunities within those areas that are within NRV will meet Restoration Goals 2 and 3. Figure 22 provides the process that was used to determine the four scenarios.

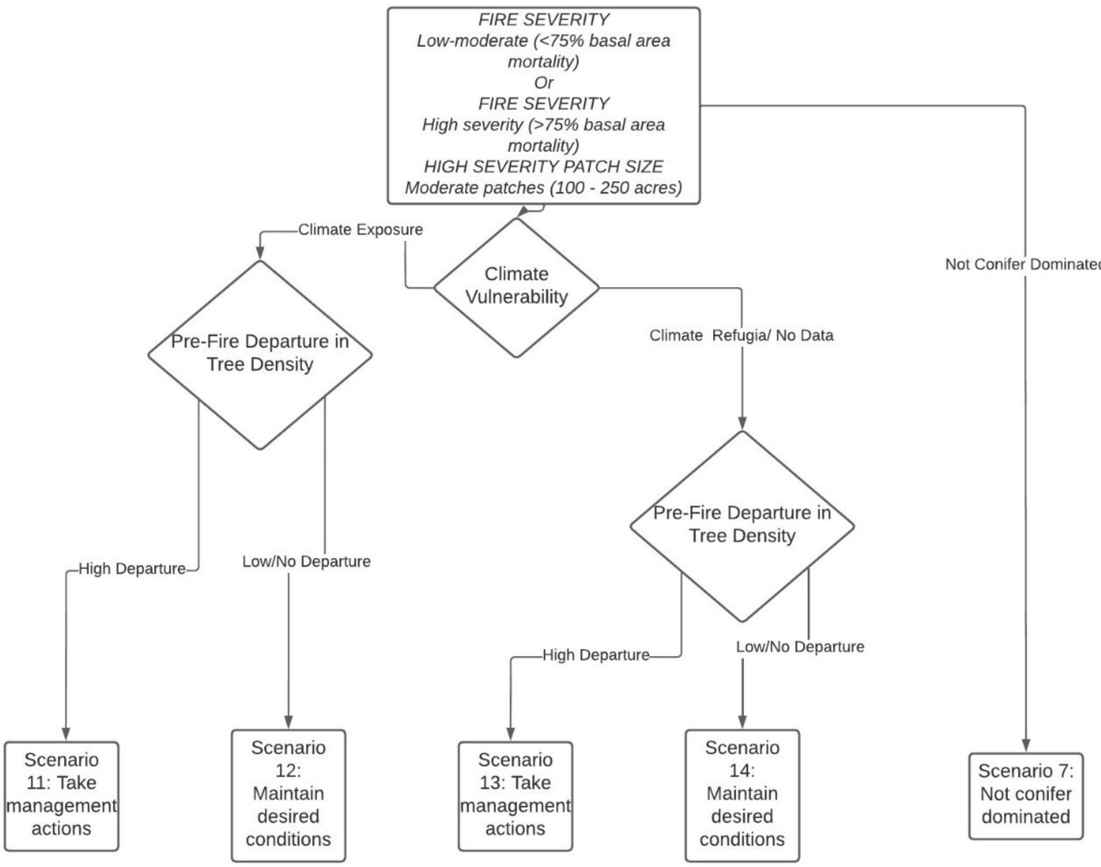

Figure 22. Decision tree for locations within the Caldor Fire that are within the Natural Range of Variation

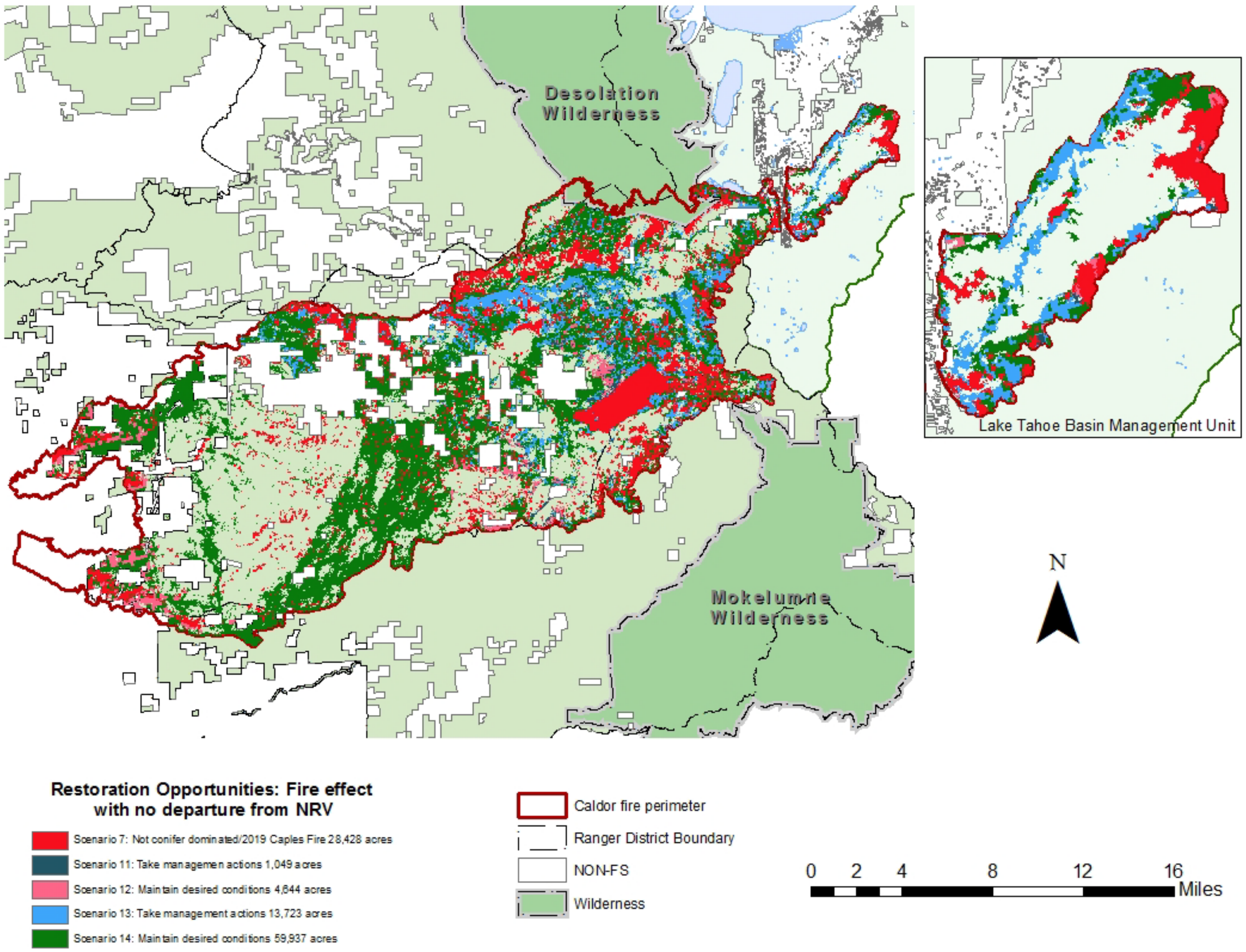

Figure 23. Broad restoration opportunities identified within the 2021 Caldor Fire in areas that burned within the natural range of variation. These opportunities were limited to areas that were conifer forest prior to the fires and to National Forest (outside of wilderness and private lands). The percentage that falls within each broad opportunity is provided in the legend.

This process identified 14,772 acres that were targeted for taking management actions (Figure 23). Another 64,581 acres were identified as having beneficial effects from the fire and the opportunities would be maintaining desired conditions (Figure 23). These areas would require mechanical treatment and prescribed fire to meet Restoration Goal 2 and 3. The acreages are broken down into the two target units where restoration treatments will be needed (Table 7).

These scenarios apply to those locations where forest vegetation is predicted to persist and will not be limited by impacts from future disturbance events. The 2021 Caldor Fire also had likely beneficial affects on the landscape and are well suited for maintaining and enhancing the changed conditions. Applying strategies in these scenarios include various intensities of mechanical treatments and prescribed fire. Further refinement of these areas can result in more focused treatments. An example below targeting areas that are isolated green conifer stands provides an example of how to further prioritize to meet Restoration Goals.

Table 7. Number of acres in each scenario that were within the natural range of variation post 2021 Caldor Fire on National Forest Lands (outside of wilderness and private lands) broken out by the two units.

Scenario	Restoration Opportunities	Acres in Each Ownership	Acres in Each Ownership
		Lake Tahoe Basin Management Unit	*Eldorado National Forest*
7	Not conifer dominated	1,241	27,187
11	Take management actions	37	1,012
12	Maintain desired conditions	97	4,547
13	Take management actions	1,329	12,394
14	Maintain desired conditions	1,233	58,704

<u>Identifying Isolated green conifer stands ("islands")</u>

There are locations within the Caldor Fire that resulted in green islands surrounding islands of green forest that may serve a critical role in maintaining critical habitat and sources of conifer regeneration. The high severity fire created edges around these forest patches which may have resulted in increased fuels and the potential for the probability of future high severity fires (Stevens et al. 2021). Reinforcing the edges around these green islands is important for reducing the probability of a stand replacing event in the future.

As part of this assessment, small isolated stands of remnant conifer forest were identified, 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 Caldor Fire.

3) More than 50% of the area around the patch burned at high severity.

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.). An example is provided in Figure 24.

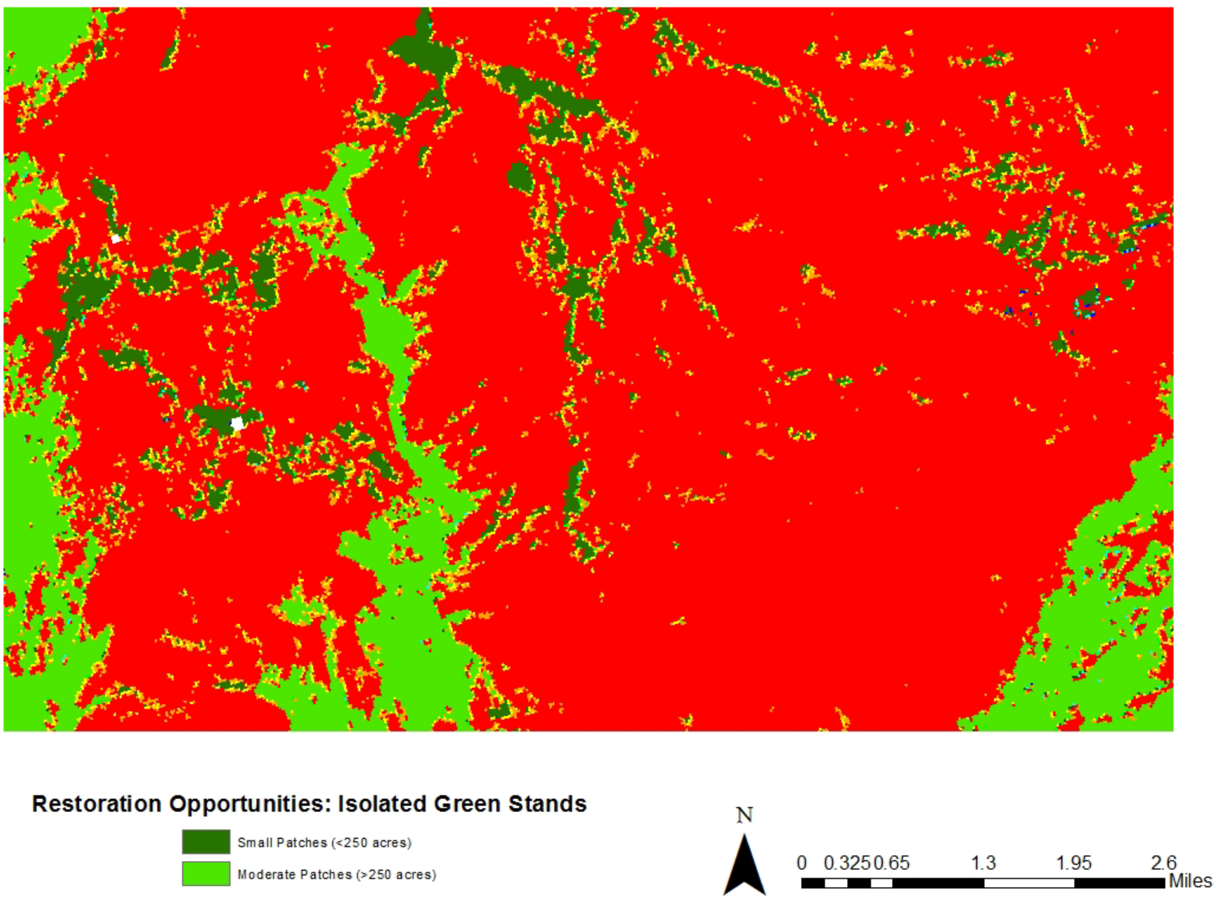

Figure 24. An example of green islands that burned at low or moderate severity in the Caldor Fire and are now surrounded by high severity fire. The area around these islands must be treated to reduce fuel loading and decrease the probability of reburn in these green islands.

Step 4: Build a restoration portfolio

The table and figures below provide an overview of the potential restoration opportunities and management actions identified in our assessment of mixed conifer forests within the 2021 Caldor Fire (Figure 25 and Table 8). This information is also available as a spatial data layer for use in analysis. It is important to note that this assessment, and associated data layers, do not provide site-specific proposed actions but rather provide guidance based on available data. 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.

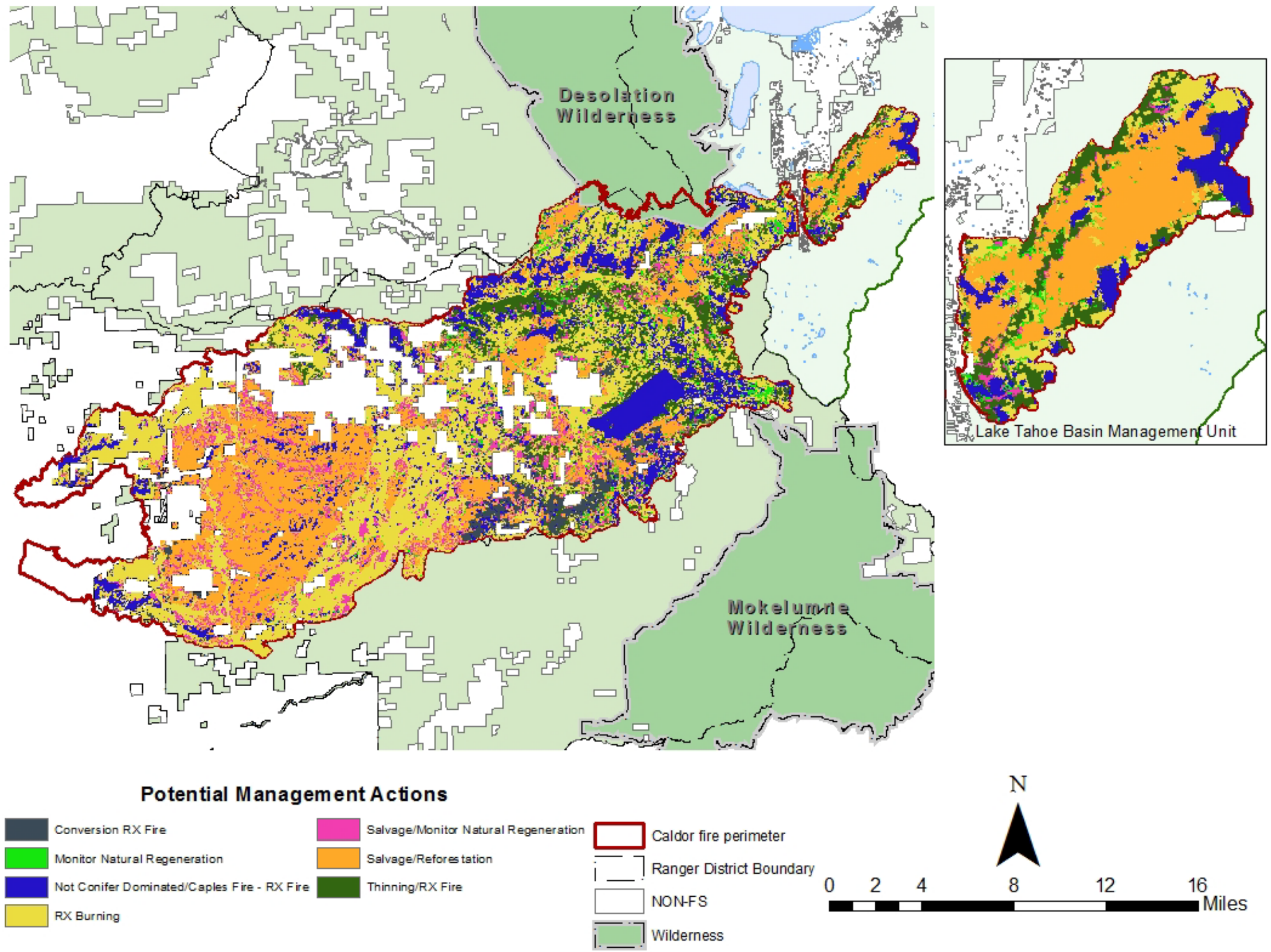

Figure 25. Examples of potential management actions in areas that were mixed conifer forest prior to the Caldor Fire. The restoration portfolio is presented below and provides more information on opportunities. Potential actions were limited to National Forest lands outside of wilderness and private lands. Additional filters might be necessary to further refine the area of interest.

Table 8. A restoration portfolio for mixed conifer forests impacted by the 2021 Caldor Fire. These opportunities were developed using the process summarized in Figure 18,20 and 22 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. All accompanying GIS data can be found at T:\FS\NFS\Eldorado\Project\SO\CaldorFireResponse\Restoration\CaldorFireRestorationProject\Workspace\bestes.

Scenario	Pre-fire conditions	Fire severity	Natural Regeneration Probability	Climate	Priority	Restoration Opportunity	Potential actions	Eldorado NF acres	Lake Tahoe Basin NF acres	Spatial ID
Conditions degraded by the fire										
1	All forested conditions	High severity (>75% basal area mortality) with high severity patch size large patches (>250 acres)	Low probability (<40%)	Climate Exposure	Moderate	Revaluate desired conditions	Reevaluate conditions to determine whether there is a need for further management actions			1

Scenario	Pre-fire conditions	Fire severity	Natural Regeneration Probability	Climate	Priority	Restoration Opportunity	Potential actions	Eldorado NF acres	Lake Tahoe Basin NF acres	Spatial ID
2	All forested conditions; High fuel loading	High severity (>75% basal area mortality) with high severity patch size large patches (>250 acres)	Low probability (<40%)	Climate Refugia	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			2
3	All forested conditions; Low fuel loading	High severity (>75% basal area mortality) with high severity patch size large patches (>250 acres)	Low probability (<40%)	Climate Refugia	Moderate	Take management action	Some 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			3

Scenario	Pre-fire conditions	Fire severity	Natural Regeneration Probability	Climate	Priority	Restoration Opportunity	Potential actions	Eldorado NF acres	Lake Tahoe Basin NF acres	Spatial ID
							management			
4	All forested conditions	High severity (>75% basal area mortality) with high severity patch size large patches (>250 acres)	High probability (>40%)	Climate Exposure	Low	Revaluate desired conditions	Reevaluate conditions to determine whether there is a need for further management actions			4

Scenario	Pre-fire conditions	Fire severity	Natural Regeneration Probability	Climate	Priority	Restoration Opportunity	Potential actions	Eldorado NF acres	Lake Tahoe Basin NF acres	Spatial ID
5	All forested conditions; High fuel loading	High severity (>75% basal area mortality) with high severity patch size large patches (>250 acres)	High probability (>40%)	Climate refugia	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 evaluation for planting based on natural regeneration surveys; Longer term: Control of competing vegetation, precommercial thinning, and fuels management			5

Scenario	Pre-fire conditions	Fire severity	Natural Regeneration Probability	Climate	Priority	Restoration Opportunity	Potential actions	Eldorado NF acres	Lake Tahoe Basin NF acres	Spatial ID
6	All forested conditions; Low fuel loading	High severity (>75% basal area mortality) with high severity patch size large patches (>250 acres)	High probability (>40%)	Climate refugia	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 evaluation for planting based on natural regeneration surveys; Longer term: Control of competing vegetation, precommercial thinning, and fuels management			6

Scenario	Pre-fire conditi ons	Fire severity	Natural Regenerati on Probability	Climate	Priority	Restoration Opportunity	Potential actions	Eldorado NF acres	Lake Tahoe Basin NF acres	Spatial ID
7	Non conifer forest	All severities	All natural regeneratio n probabilities	All climate scenario s	Low	Not conifer dominated	Fuel reduction treatments and follow up maintenance to manage non conifer landscape.			7
Conditions moderately degraded by the fire										
8	All forested conditio ns	High severity (>75% basal area mortality) with high severity patch size moderate (100-250 acre patches)	All natural regeneratio n probabilities	Climate exposu re	Low	Revaluate desired conditions	Reevaluate conditions to determine whether there is a need for further management actions			8
9	All forested conditio	High severity (>75% basal area	All natural regeneratio n	Climate refugia	Moder ate	Take management action	Fuel reduction (dead tree removal, piling of surface fuels,			9

Scenario	Pre-fire conditions	Fire severity	Natural Regeneration Probability	Climate	Priority	Restoration Opportunity	Potential actions	Eldorado NF acres	Lake Tahoe Basin NF acres	Spatial ID
	ns; High fuel loading	mortality) with high severity patch size moderate (100-250 acre patches)	probabilities				broadcast or pile burning, etc.), site preparation (removal of competing vegetation); Longer term: Control of competing vegetation, precommercial thinning, and fuels management			
10	All forested conditions; Low fuel loading	High severity (>75% basal area mortality) with high severity patch size moderate (100-250 acre patches)	All natural regeneration probabilities	Climate refugia	Moderate	Take management action	Some fuel reduction (dead tree removal, piling of surface fuels, broadcast or pile burning, etc.), site preparation (removal of competing vegetation); Longer term: Control of competing vegetation, precommercial thinning, and fuels management			10
Conditions improved or maintained by the fire										

Scenario	Pre-fire conditions	Fire severity	Natural Regeneration Probability	Climate	Priority	Restoration Opportunity	Potential actions	Eldorado NF acres	Lake Tahoe Basin NF acres	Spatial ID
11	All forested conditions; High departure in pre-fire tree density	Low-moderate (<75% basal area mortality) or high severity (>75%) and high severity patch size small (<100 acres)	All natural regeneration probabilities	Climate exposure	High	Take management action	Evaluate need for precommercial thinning, surface fuel reduction, or management of competing vegetation; maintain with prescribed fire.			11
12	All forested conditions; Low departure in pre-fire tree density	Low-moderate (<75% basal area mortality) or high severity (>75%) and high severity patch size small (<100 acres)	All natural regeneration probabilities	Climate exposure	Moderate	Maintain desired conditions	Maintain with prescribed fire or other fuel reduction activities			12

Scenario	Pre-fire conditions	Fire severity	Natural Regeneration Probability	Climate	Priority	Restoration Opportunity	Potential actions	Eldorado NF acres	Lake Tahoe Basin NF acres	Spatial ID
13	All forested conditions; High departure in pre-fire tree density	Low-moderate (<75% basal area mortality) or high severity (>75%) and high severity patch size small (<100 acres)	All natural regeneration probabilities	Climate refugia	High	Take management action	Evaluate need for precommercial thinning, surface fuel reduction, or management of competing vegetation; maintain with prescribed fire.			13
14	All forested conditions; Low departure in pre-fire tree density	Low-moderate (<75% basal area mortality) or high severity (>75%) and high severity patch size small (<100 acres)	All natural regeneration probabilities	Climate refugia	Moderate	Maintain desired conditions	Maintain with prescribed fire or other fuel reduction activities			14

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Appendix A. Additional Analysis

1) Prioritize PODs based on the TCSI Blueprint to develop a sequence of treatments to target those at greatest need. There was an analysis completed for the Windy Fire that used PODS as the spatial scale and would serve as good template.
2) It would be good to update the analysis with the most recent TCSI products that cover the entire Caldor Fire. At the time of this report, only a portion of the Caldor Fire had datasets generated for the entire landscape.
3) Fuel Treatment Effectiveness Analysis - There is ongoing work to assess fuel treatment effectiveness in Caldor in both the LTBMU and the ENF using field-based methods using a protocol developed by the Region 5 Ecology Program. There is also a National Team working on FTEM using a mix of remote sensing and activity trackers.
4) Other metrics maybe better indicators of departure. Stand Density Index (SDI) which was used in the recent research done by North et al. 2022 may provide a better understanding of stand conditions as it provides a widely-used measure of competition. These metrics are now available through F3 and the ACCEL project.

Appendix B. Caples Monitoring Plots

2021 Caldor Photos from Field Plots

Low Severity Plot

Pre-Caldor

Post-Caldor

Aerial photo via drone, for plot at left

Moderate Severity Plot

Pre-Caldor

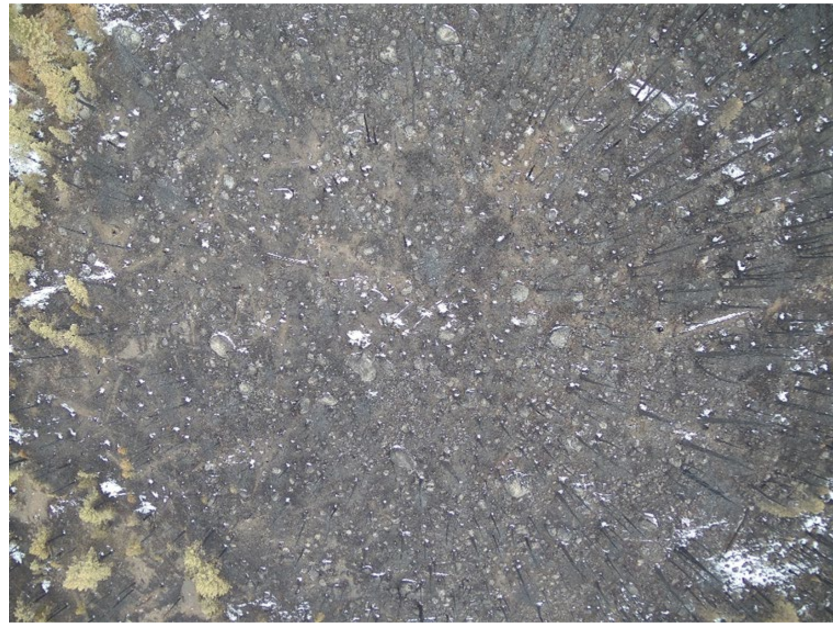
Post-Caldor

Aerial photo via drone, for plot at left

High Severity Plot

Pre-Caldor

Post-Caldor



Aerial photo via drone, for plot at left

Appendix C. POSCRPT Natural Regeneration Outputs