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Post-fire Restoration Strategy for the Western Glass Mountain Range, Inyo National Forest

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Summary

- We developed a post-fire restoration strategy based on the post-fire restoration framework (Meyer et al. 2021a) for forest and shrubland landscapes affected by the 2021 Dexter Fire, 2020 Beach Fire, 2019 Springs Fire, and 2016 Clark and Owens River fires (total of 19,535 ac; 7,906 ha) in the western Glass Mountain Range, Inyo National Forest, an area totaling 109,127 ac.
- We evaluated fire effects and restoration opportunities for eastside coniferous forests and sagebrush steppe vegetation, with a secondary focus on other key resources including conifer-encroached aspen stands, Northern goshawk protected activity centers (PACs), meadows, special habitats, old (late seral) forests within a research natural area, and pinyon-juniper woodlands. Primary stressors of these resources include altered fire regimes, insects, drought, invasive annual grasses, and climate change.
- Within forest vegetation, wildfires managed under full suppression objectives (includes the 2021 Dexter Fire, 2016 Clark Fire, and 2016 Owens River Fire) produced negative fire effects outside the natural range of variation (NRV), whereas the 2019 Springs Fire and others managed for multiple objectives (including resource objectives) resulted in consistently beneficial fire effects within NRV and desired conditions. Across the three full suppression wildfires, a total of 1,712 acres (15%) of conifer forests burned in high severity patches that exceeded NRV and desired conditions for maximum patch size (200 ac). All burned aspen stands exhibited predominantly improved stand conditions.
- Prescribed burn areas from the past 20 to 25 years subsequently burned at low severity (97% of total prescribed burn area; only 0.3% attributed to high severity) in the 2019 Springs Fire or 2016 Clark Fire, which illustrates the effectiveness of prescribed fires in mediating the severity of future multi-objective and full suppression wildfires.
- About 34% (23,085 ac) of the 68,714 acre analysis area containing coniferous forests and aspen stands burned in wildfires over roughly the past two decades. Approximately 39% of the forested study area is highly departed from its historical fire return interval, 27% is moderately departed, and 35% is currently burning within the historical fire frequency.
- About a third (34%) of sagebrush steppe in the analysis area has burned once in the past 52 years, 7% is burning too frequently, and the remaining 59% has not burned since 1970 and is considered in a late-successional condition.

- Fire effects to secondary resources were predominantly beneficial except where large patches of high severity fire occurred in old forests and late successional habitats.
- A total of 1,160 acres of severely-burned coniferous forest in the analysis area is predicted to experience conifer regeneration failure, and 605 of these acres are accessible to mechanical treatment and feasible for reforestation efforts almost exclusively in the 2021 Dexter Fire and 2016 Owens River Fire.
- The restoration portfolio focused primarily on two potential restoration actions for coniferous forests: (1) restoration and maintenance burning and other fuel reduction actions, and (2) climate-smart reforestation and post-fire fuels reduction to reduce fuel loads and restore forest cover. Additionally, the restoration portfolio included two primary potential restoration actions for sagebrush steppe: (1) reseeding or replanting of native vegetation in recently burned sagebrush steppe patches, and (2) controlling invasive plants. These actions in combination with other recommended efforts (e.g., post-fire vegetation monitoring) support forest and sagebrush restoration goals in the analysis area.
- Priority areas for reforestation include large (>200 ac) high severity patches within previously forested areas of the Dexter Fire (204 ac) and Owens River Fire (395 ac) that are accessible to mechanical equipment. Severely burned coniferous forest areas that are likely to experience conifer regeneration failure and are inaccessible to mechanical equipment include 247 ac of the Owens River Fire, 69 ac of the Dexter Fire, and 239 ac of the Clark Fire. The desired conditions for these areas could be reevaluated to facilitate ecological transition of mature conifer forest to other desirable vegetation types, such as sagebrush steppe, low density conifer stands intermixed with other vegetation types, or aspen stands.
- Priority areas for sagebrush reseeding or replanting of native vegetation include large patches of sagebrush that were burned in the 2016 Owens River, 2016 Clark Fire, and 2020 Beach Fire (957 ac total). Additionally, there are several locations in the analysis area that could benefit from invasive plant survey and control efforts, grazing management, and conifer removal to minimize the effects of interacting stressors to sagebrush ecosystems.

Background

Application of the Post-fire Restoration Framework

The-post-fire restoration framework (PSW-GTR-270, Meyer et al. 2021a) provides a science-based approach to planning restoration projects in severely burned landscapes on national forests in California. It is rooted in several guiding restoration principles designed to enhance or recover ecological integrity and sustainability in landscapes with altered fire regimes. The framework uses a five-step process to spatially assess landscape condition and divide the landscape into areas where fire: (1) improved or maintained ecological conditions, (2) degraded ecological conditions and restoration actions may restore these conditions, and (3) degraded ecological conditions but restoration actions are infeasible or undesirable, resulting in the reevaluation of desired conditions. The framework's post-fire flow chart (Figure 1) identifies restoration opportunities for these three areas in the affected landscape and facilitates the development of a "restoration portfolio" that includes a suite of potential management actions designed to maintain, restore, or reevaluate desired ecological conditions. More information about the post-fire restoration framework is provided in Meyer et al. (2021a).

Conifer Forests and Sagebrush Steppe[2] in the Eastern Sierra Nevada

Jeffrey pine (*Pinus jeffreyi*) and dry lodgepole pine (*Pinus contorta* var. *murrayana*) forests in eastern Sierra Nevada have changed dramatically over the past century and are highly departed from the natural range of variation with respect to forest structure and function (Safford and Stevens 2017, Meyer and North 2019). Fire exclusion and historical logging have been primary drivers of these changes, leading to reduced structural heterogeneity, increased canopy cover and tree densities (especially in the smallest size classes), elevated woody fuel loads, loss of large trees, and reduced habitat quality and diversity (Knapp 2015, Knapp et al. 2013, North et al. 2009, North 2012). Prior to Euro-American colonization, Sierra Nevada Jeffrey pine forests experienced frequent (burning every 7 to 11 years, on average), low to moderate severity (mostly surface) fires, but today these fires are relatively rare (van de Water and Safford 2011, Safford and Stevens 2017). Similarly, dry lodgepole pine forests in the eastern Sierra Nevada historically experienced relatively frequent (19 to 28 years on average), low to moderate severity

[2] Sagebrush steppe section extracted from Meyer et al. 2021b in PSW-GTR-270. Citations from this section are available in GTR-270 chapter 6 but not in this report.

(mostly surface but with occasional torching) fires that have been relatively rare over the past century (North et al. 2009, Meyer and North 2019). However, in the past decade many Jeffrey pine and some lodgepole pine forests in the eastern Sierra Nevada have experienced uncharacteristically large and severe wildfires that have dramatically altered these forest landscapes. These severe wildfires are being catalyzed by a combination of interacting stressors, including long-term fire exclusion, insect- and drought-related tree mortality, and climate change, leading to widespread habitat fragmentation and potentially long-term forest loss (Kolb et al. 2016, Westerling et al. 2006, Stephens et al. 2018, Steel et al. 2018). Recent forest restoration treatment rates in the region are not at the spatial scale necessary to address the wildfire issue (North et al. 2012), although wildfires managed for resource objectives (e.g., Meyer 2015) and coordinated prescribed fire and mechanical treatments may facilitate more beneficial fire within Sierra Nevada forest landscapes (North et al. 2021).

Widespread yet vulnerable, sagebrush (*Artemisia* spp.) steppe ecosystems provide a variety of biological, hydrological, and recreational ecosystem services throughout the Interior West (Homer et al. 2015). One particular service is the provision of essential habitat for the greater sage-grouse (*Centrocercus urophasianus*), which was considered for listing under the Endangered Species Act. That listing was avoided in 2015 by an unprecedented conservation partnership across organizations and state boundaries (Chambers et al. 2017). The once widespread sagebrush steppe ecosystem has been significantly reduced in total area (down to 59 percent of historical extent) and is threatened throughout its range by nonnative invasive plant species (especially cheatgrass [*Bromus tectorum*), altered fire regimes, conifer expansion (i.e., conversion of sagebrush steppe to woodlands or forests), and climate change (Chambers et al. 2014a, 2017). Additional threats to sagebrush include energy development, roads, mining, housing development, recreational activities (e.g., off-highway vehicle use), wild horse (*Equus ferus caballus*) use, and poorly managed livestock grazing (Chambers et al. 2017). These stressors and their interactions have reduced the capacity of sagebrush ecosystems to recover from natural disturbances such as wildfires. The natural fire regime in sagebrush steppe ecosystems is characterized as mixed severity, with low plant survivorship in burned areas interspersed with unburned patches (Baker 2006, Connelly et al. 2000).

Fires in sagebrush steppe ecosystems are spatially complex and strongly influenced by topography and soils, resulting in a wide range of return intervals (Miller and Heyerdahl 2008).

Fires promote reproduction and seral-stage diversity among sagebrush species and inhibit conifer encroachment. However, fires must recur at sufficiently long intervals to allow obligate seeding sagebrush species to mature to reproductive size, because the common sagebrush in our project area (mountain big sagebrush [*A. tridentata ssp. vaseyana*) does not resprout and often requires 30 to 100 years to recover from fire. Fire return intervals in these ecosystems prior to Euro-American colonization may have been between 30 to 80 years (Slaton and Stone 2013).

The most serious threat to the sagebrush steppe throughout its range is the invasion of cheatgrass. Owing to its early-season growth, cheatgrass can displace native grasses, forbs, and shrubs by reducing moisture and nutrients in surface soils (Norton et al. 2004). Overgrazing contributes to cheatgrass invasion by reducing the abundance of native perennial grasses, disturbing intact soils and complex biological soil crusts, and dispersing cheatgrass seed. Once established, cheatgrass also dramatically alters fire regimes in sagebrush steppe. This annual grass grows rapidly, particularly following wet years, creating a nonhistorical continuous cover of dry fuels that ignite and spread fire easily (Brooks et al. 2004, Knapp 1998). Fire return intervals in cheatgrass-invaded sagebrush steppe can be as frequent as every 3 to 5 years (Whisenant 1990), effectively eliminating sagebrush and other native species adapted to longer fire return intervals that are characteristic of natural sagebrush steppe ecosystems. After a few cheatgrass-exacerbated fire cycles, the native plant seed bank becomes depleted, greatly reducing reestablishment. The invasion of cheatgrass has contributed to the conversion of millions of hectares of sagebrush steppe to low-diversity, annual grasslands that provide low-quality habitat for native plants, wildlife, and grazing livestock (Balch et al. 2013, Knapp 1996).

Sagebrush recovery after fire is influenced by a variety of factors, including distance to unburned shrubs (to provide a seed source), abundance and viability of seed within the soil seed bank (which may persist up to 3 years), and postfire disturbances such as grazing (Ziegenhagen and Miller 2009, Newingham and Strand 2018). Other important factors include pre-fire vegetation composition and structure, fire severity, post-wildfire precipitation, and local soil and hydrology characteristics (Arkle et al. 2014; Chambers et al. 2014a, 2017; Miller et al. 2015b). Native bunchgrasses and shrubs are a key determinant in postfire recovery (Chambers et al. 2017). For example, native bunchgrasses in the Glass Mountains analysis area, such as Great Basin wild rye (*Elymus cinereus*), squirrel-tail (*E. elymoides*), sand rice grass (*Stipa hymenoides*), or needle grass (*S. occidentalis*) may provide essential post-fire native plant cover that may inhibit the establishment of cheatgrass in recently burned sagebrush. Additionally, the presence of native shrub species that exhibit moderate post-fire resprouting, such as bitterbrush (*Purshia tridentata*), or strong post-fire resprouting, such as rubber rabbitbrush (*Ericameria nauseosa*) or roundleaf snowberry (*Symphoricarpos rotundifolius* var. *rotundifolius*) may promote post-fire native shrub dominance in the absence of sagebrush regeneration and recruitment. The more arid (e.g., lower elevation) and coarse volcanic soils of the Glass Mountains and nearby Crowley Basin typically support limited bunchgrass cover in many places and may be more susceptible to cheatgrass invasion compared to more mesic sites (e.g., higher elevation sagebrush in the Glass Mountains) and areas with sandy soils, such as in the Mono Lake basin.

Dexter Fire, Springs Fire, Clark and Owens River Fires, and Beach Fire

The 2021 Dexter Fire (2,968 ac), 2019 Springs Fire (5,240 ac), 2016 Clark Fire (2,020 ac), 2016 Owens River fires (5,619 ac), and 2020 Beach Fire (3,688 ac) burned a total of 19,535 ac (7,906 ha) of the Inyo National Forest in the Glass Mountain Range of the eastern Sierra Nevada of California (Figure 2). The range represents a transition zone between the Sierra Nevada and Great Basin ecoregions in California, sharing many of the same forest associations of the eastern Sierra Nevada with some exceptions (e.g., red fir forests). Vegetation in this burned landscape was primarily a combination of eastside Jeffrey pine and dry lodgepole pine forests in the Springs, Clark, and Dexter fires and western edge of the Owens River Fire, and sagebrush steppe in the Beach Fire and significant parts of the Owens River and Clark fires. In the past two decades (2001-2021), the landscape containing and surrounding these fires (hereafter referred to as the ‘analysis area’) has experienced several additional wildfires with variable fire effects (including the 2007 O’Harrel Fire, 2003 Dexter Fire, 2001 Crater Fire, and 2001 McLaughlin Fire) totaling 23,085 ac burned acres (118 ac in the 2016 Clark Fire reburned in the 2021 Dexter Fire). However, prior 2001 most of these wildfires were relatively small and much of the landscape had not burned for over a century (i.e., most of the landscape was moderately to highly departed from the historical fire return interval). Four previous wildfires were primarily managed for resource objectives (2019 Springs Fire, 2007 O’Harrel Fire, 2004 Crater Mountain, 2003 Dexter Fire) and produced stand-replacing patches that were relatively small and within the natural range of variation (NRV) and desired conditions (Table 1; generally less than 10 ac (4 ha) and not exceeding 100 to 250 ac (~40 to 100 ha)). These fire severity patterns in predominantly resource objective wildfires are consistent with those observed in the southern and eastern Sierra Nevada (Meyer 2015).

Post-fire Restoration Framework

Step 1: Identify Priority Resources, Desired Conditions, and Restoration Goals

We focused our analysis primarily on coniferous forests (especially eastside Jeffrey pine forests) and sagebrush steppe, based on input from an interdisciplinary team of specialists on the Inyo National Forest. We reviewed and summarized desired conditions for these key resources based on information provided in land management and resource planning documents (USDA Forest Service 2019) (Table 1, Table 2). Based on these sources, we developed two restoration goals and associated analysis areas for the two key resources of interest: (1) maintain or restore the integrity, diversity, and resilience[3] of eastside Jeffrey pine and other coniferous forest ecosystems; and (2) maintain or restore sagebrush ecosystem integrity and resilience, including sage-grouse habitat quality and connectivity (Table 3). Restoration objectives for secondary resources of interest are also included in Table 3. Hereafter, we refer to the 'analysis area' as encompassing either coniferous and aspen forests on the western slope of the Glass Mountains with a focus on the 2019 Springs Fire, 2021 Dexter Fire, 2016 Clark Fire, and 2016 Owens River Fire (Figure 2) or sagebrush steppe with a focus on the above wildfires and the 2020 Beach Fire (Figure 7). With the exception of the 2020 Beach Fire that is based on the fire perimeter boundary only (for the sagebrush steppe analysis area), this area (totaling 109,127 ac) is defined by Potential Operational Delineation (POD) boundaries and generally enclosed within Mono Craters to Highway 395 to the west, Highway 120E to the north, Owens River Road/Owens River to the south, and Glass Mountain peak to the east (Figure 2).

Step 2: Gather and Review Relevant Spatial Data

We defined the spatial scope of our analysis based on our five recent wildfires of interest (2021 Dexter Fire, 2020 Beach Fire, 2019 Springs Fire, 2016 Clark Fire, and 2016 Owens River Fire) and the surrounding coniferous forest and sagebrush steppe landscape as bounded by POD boundaries except as noted above for the 2020 Beach Fire (Figure 2, Figure 7). We focused our

[3] Resilience here and afterwards is used more broadly to include the concepts of resistance and resilience of ecosystems.

analysis on our primary and secondary resources of interest using several existing spatial data layers summarized in Table 4. We assessed post-fire ecological condition to determine the extent to which wildfire effects represented a departure from NRV and desired conditions. We used fire severity data (the four-class percent change in basal area as represented by the RAVG data) to calculate four metrics of fire effects to coniferous forests: (1) high severity proportion (i.e., amount of high severity fire effects), (2) high severity patch size (including proportional area located in a large high severity patch), (3) Fire Severity Index (FSI; a composite measure of all fire effects within a wildfire that ranges from 0, or unburned, to 4, equal to high severity; fires with low to moderate severity fire effects generally range from 1, or unchanged, to 2, representing mostly low to moderate severity fire effects), and (4) Fire Return Interval Departure (FRID) condition class[4]. Burned areas dominated by coniferous forests were classed as burning at less than stand-replacing severity (i.e., unchanged, low, or moderate fire severity; 0-75% change) or high severity (>75% change). For each fire, we calculated the mean and maximum high severity patch sizes and the proportional area and acreage attributed to large (>17 ac) and very large (>200 ac) high severity patches and compared these values, along with the fire severity metrics mentioned above, to desired conditions and NRV (Table 1) (Estes et al. 2021). For several aspen stands in the analysis area, we collected forest inventory data in August 2022 and assessed the ecological integrity of aspen stands based on the field methods of Meyer (2022), including 40 plots in the 2019 Springs Fire, 1 plot in the 2021 Dexter Fire, 1 plot in the 2016 Owens River Fire, and 2 plots at the fire-excluded Bald Mountain Spring. We also visited representative burned and unburned forest stands in the analysis area and took photographs of these areas to help visualize the current ecological conditions of conifer and aspen stands.

We used FRID time since last fire and condition class data to analyze fire effects to sagebrush steppe. This included the identification of areas that have burned recently (i.e., fire occurrence in the past decade; since 2012) to target early successional sagebrush vegetation that may benefit the most from restoration treatments designed to restore desired conditions (e.g., reseeding or replanting of native shrubs or herbs). Additionally, we evaluated the departure of the "current" time period (i.e., 1970-2021) relative to the historical time period (generally pre-1850) to identify potential areas of ecosystem degradation resulting from too frequent fire or

[4] FRID condition class across the analysis area is based on the past 52 years of fire history (1970 to 2021) and was corrected for missing prescribed fire data that was documented in the FACTS database for the analysis area over the past 25 years.

interacting stressors. For example, sagebrush vegetation that burned twice since 1970 could represent areas where post-fire vegetation recovery is impaired due to insufficient time for the regeneration of sagebrush, a non-sprouting species. We did not use vegetation burn severity data in the evaluation of fire effects to sagebrush ecosystems, because such data was lacking for one of our fires of interest (2020 Beach Fire), and a previous assessment found these data to be relatively uninformative in the analysis area (Meyer et al. 2021b), which is consistent with previous studies of fire severity patterns in sagebrush vegetation in California (Miller and Those 2007, Slaton and Stone 2013). We analyzed soil burn severity for the Clark, Owens River, and Beach fires but not for the Dexter Fire where soil burn severity data was unavailable.

Step 3a: Fire Effects in Coniferous Forests and Sagebrush Steppe

Where did fire improve or maintain ecological conditions (or degrade conditions) and are fire effects within desired conditions or NRV? (Question A in Fig. 1)

Fire Effects in Coniferous Forests

We evaluated fire severity (RAVG) and fire regime (FRID) patterns for recent wildfires in our analysis area and compared these fire patterns with NRV and desired conditions (Figure 3). About 34% (23,085 ac) of the 68,000 ac analysis area containing coniferous forests and aspen stands burned in wildfires over roughly the past two decades. Between 2016 and 2021, wildfires burned more than 50% of five Potential Operational Delineations (PODs) and more than 25% of seven PODs analyzed in the study area. All analyzed wildfires managed with full suppression objectives burned outside NRV, whereas the 2019 Clark Fire that was managed for multiple objectives (including natural resource objectives) produced fire effects within NRV (Table 5, Figure 4). These results are consistent with recent forest fire effects monitoring completed for the 2016 Clark Fire (Meyer et al. 2020) and the 2019 Springs Fire (Safford et al. 2021). They are also consistent with the predominantly low to moderate severity fire effects of earlier resource objective wildfires in the area, including the 2003 Dexter Fire and 2007 O'Harrel Fire (Table 5). Across the 2021 Dexter Fire and 2016 Clark and Owens River fires, a total of 1970 ac (17%) and 1712 ac (15%) of conifer forests burned in high severity patches that exceeded NRV for mean (>17 ac) and maximum (>200 ac) high severity patch size, respectively. Fire effects to secondary resources within or adjacent to coniferous forest ecosystems were for the most part beneficial (with one exception) and summarized in Table 6 and Table 7. For photos of representative fire effects in the study area see: Appendix A. Fire Effects in Coniferous Forests in the Analysis Area and Appendix B. Fire Effects in Aspen Stands in the Analysis Area.

Across most of the analysis area, long-term fire exclusion has resulted in a high level of departure of the current fire return interval from the historical fire return internal (i.e., FRID condition class 3 based on past 50 years of fire history). Forested areas burned in recent wildfires showed a moderate degree of fire frequency departure (i.e., FRID condition class 2; Figure 5). A total of 39% and 27% of the forested analysis area is highly and moderately departed, respectively, from its historical fire return interval; the remaining (35%) is currently at low departure from the historical fire frequency. A total of 1742 ac in the Springs Fire and Clark Fire have burned twice in the past 20 to 25 years (i.e., initially in prescribed fires followed by recent wildfires) and are meeting desired conditions with regards to fire frequency (i.e., FRID condition class 1) and stand structure (Meyer et al. 2020, Safford et al. 2021); these twice-burned forest areas can be considered to have a reestablished natural fire regime (i.e., in a "maintenance burn" condition). Additionally, these prescribed burn areas subsequently burned at low severity (97% of total burned area; only 0.3% attributed to high severity) in the 2019 Springs Fire or 2016 Clark Fire, which illustrates the effectiveness of prescribed fires at mediating the effects of future multiple objective and full suppression wildfires (see also Meyer et al. 2020 for additional field-based evidence in the 2016 Clark Fire). Coincidentally, local fire management staff observed moderated fire behavior and intensity in prescribed burned units and areas previously burned in resource objective wildfires, and the reduced fuels in these stands had aided fire suppression operations during the 2021 Dexter Fire and 2016 Clark Fire (A. Taylor and L. Hurley, personal communication). These observations are consistent with published studies of the "self-limiting" and moderating effects of prior low to moderate severity fires on future wildfires (e.g., Collins et al. 2009, van Wagtendonk et al. 2012, Harris and Taylor 2017, Meyer et al. 2022).

Fire Effects in Sagebrush Steppe

A total of four recent wildfires burned sagebrush steppe vegetation in our analysis area, including the 2020 Beach Fire (3,621 ac), 2016 Owens River Fire (3,243 ac), 2016 Clark Fire (380 ac), and 2021 Dexter Fire (205 ac). We analyzed FRID condition classes and identified 6% (1,549 ac) of sagebrush vegetation that is burning too frequently relative to historical reference conditions in the analysis area (Figure 7). These frequent fire areas of sagebrush are concentrated around the intersection of the 2016 Clark and Owens River fires (within sage-grouse priority habitat) and in the eastern part of 2020 Beach Fire (partially within sage-grouse priority habitat). About 34% (8,490 ac) of sagebrush steppe in the analysis area has burned once in the past 52 years, and the remaining 60% (14,738 ac) has not burned since 1970 and is considered in a late-successional condition (i.e., relatively high shrub biomass and cover). In sagebrush vegetation burned in the 2016 Owens River and Clark fires, soil burn severity was predominantly moderate (70.5%) and low to very low (28%), with only a small proportion of high soil burn severity (1.5%) recorded in upper Clark Canyon and on the lower west slope of Bald Mountain. In the 2020 Beach Fire, soil burn severity was primarily moderate (73%) and low to very low (27%) with no records of high soil burn severity.

Step 3b: Evaluation of Additional Stressors and Management Feasibility

Where do other factors threaten ecological resilience and sustainability? (Question B in Fig. 1)

Coniferous Forests

Additional interacting stressors affecting the resilience and sustainability of coniferous forests in the analysis area include drought, insect outbreaks, excessive post-fire fuels, and climate change. Since most of these stressors are driven to a great extent by a combination of water availability and evaporative demand, we used climatic water deficit (CWD; an indicator of vegetation moisture stress) as our primary variable for evaluating the impacts of these stressors to coniferous forests. CWD was highly correlated with current CWD and was not considered separately. Areas of greater future CWD that were also extremely departed from NRV for fire severity may not be feasible sites for traditional management approaches and might require the reevaluation of desired conditions. Within the study area, many coniferous forests burned in the 2016 Owens River Fire were characterized by relatively high projected future CWD (Figure 8; CWD classes based on pre-defined thresholds). This suggests that these areas may be at current and future risk of elevated moisture stress, which would limit the success of post-fire management efforts compared to other parts of the study area with relatively lower CWD (e.g., 2021 Dexter Fire). This is expected because Jeffrey pine forests in the 2016 Owens River Fire occur at the lower elevation coniferous forest zone in the analysis area. Climate exposure data (years 2010 to 2039 based on GFDL model) in eastside Jeffrey pine forests based on Thorne et al. (2016) displayed similar patterns to CWD (Figure 8). Climate exposure as estimated by

Thorne et al. (2016) is strongly influenced by CWD and other water balance metrics in predictive models of forest vegetation in California, consequently the two variables are often correlated.

Sagebrush Steppe

Although there are several stressors that might interfere with long-term ecological resilience of sagebrush ecosystems in the analysis area, we focused on invasive plants (e.g., cheatgrass) as a primary stressor. We identified several pre-fire invasive plant occurrences totaling about 9 ac in the 2001 McLaughlin Fire (cheatgrass), nearly 2 ac in the 2020 Beach Fire (Russian thistle), and additional small (<0.1 ac) post-fire occurrences of invasive plants (e.g., cheatgrass, Russian thistle) observed in the 2016 Clark Fire and Owens River Fire during recent field surveys. Additional mapped occurrences of invasive plants included 360 ac of bull thistle (*Cirsium vulgare*) and yellow salsify (*Tragopogon dubius*) within the 1985 Owens Fire and along the southern edge of the analysis area. We assumed additional occurrences of invasive plants, particularly cheatgrass, were likely in the analysis area because of mapping limitations of invasive plants. We also assumed that recently burned sagebrush on volcanic soils (e.g., 2016 Owens River Fire and Clark Fire areas) were more susceptible to non-native plant invasions than burned sagebrush on sandy soils (e.g., 2020 Beach Fire) (H. Stone, personal communication).

Where are management approaches feasible for the restoration of desired conditions given current and anticipated future conditions? (Question C in Fig. 1)

Coniferous Forests

We evaluated the feasibility of forest restoration actions in the Dexter Fire, Owens River Fire, and Clark Fire with the mechanical treatment opportunities data layer that captures topographic and road proximity constraints (North et al. 2015). Opportunities for many forest management activities are generally limited to more accessible locations and avoids challenging terrain such as steep slopes and areas far from accessible roads. We used the mechanical treatment opportunities layer (scenario B) to evaluate: (1) mechanical pre-treatment constraints in fire-excluded (i.e., FRID condition class 3 or highly departed condition) coniferous forests, and (2) reforestation constraints in the wildfires of interest, based on the assumption that mechanical pre-treatment (i.e., salvage harvest) may be required in some sites to provide a safe and effective environment for planting Jeffrey pine and other conifers in the analysis area.

Coniferous forests that burned outside NRV, particularly large high-severity patches, may be at elevated risk of conifer regeneration failure primarily due to the lack of nearby seed sources (Welch et al. 2016, Meyer and Vane 2020). Coniferous forested areas that burned outside of NRV (for fire severity or high severity patch size) identified in the previous step made up a significant part of high severity patches in the Dexter Fire, Clark Fire, and Owens River Fire. We identified areas of post-fire conifer regeneration failure using a 50 m buffer from the edge of high severity patches within coniferous forest types, including Jeffrey pine and dry lodgepole pine forests (excludes 2020 Beach Fire which did not burn coniferous forest vegetation). The 50 buffer is based on an earlier analysis of field plot data examining post-fire conifer regeneration patterns in Jeffrey pine forests in the analysis area (includes the 2016 Clark Fire and 2016 Owens River Fire; Meyer and Vane 2020). We evaluated post-fire natural conifer regeneration of both main conifer species in the analysis area (i.e., Jeffrey pine, lodgepole pine) but with a focus on Jeffrey pine.

We also used POSCRPT (Post-fire Spatial Conifer Regeneration Prediction Tool) developed by Shive et al. (2018) and refined by Stewart et al. (2020), to provide a secondary evaluation of post-fire conifer regeneration failure for the Dexter Fire, Springs Fire, Clark Fire, and Owens River Fire and visually compared these outputs with the 50 m buffer approach. We interpreted POSCRPT outputs with caution, because our study area was outside the model geographic domain for POSCRPT that could lead to potential errors in model outputs. Comparisons between approaches suggested general similarities but with apparent errors in POSCRPT outputs, such as the tendency to overpredict or underpredict post-fire conifer regeneration along apparent precipitation gradients in the analysis area. Consequently, we dropped POSCRPT outputs from further consideration in our post-fire regeneration analysis and relied exclusively on a simplified 50 m buffer approach. Local field-based estimates of post-fire conifer regeneration in high severity patches that are within 50 m of a seed tree averages 48 seedlings per acre (Meyer and Vane 2020), which is within NRV but below the Region 5 stocking standard of 75 to 150 seedlings per acre. In high severity patches that are greater than 50 m from a seed tree, the average density of post-fire conifer regeneration drops to about 11 seedlings per acre, which is below the lowest end of NRV (16 seedlings per acre) and substantially below the lowest Region 5 stocking standard of 75 seedlings per acre.

Sagebrush Steppe

Within recent wildfires (i.e., 2021 Dexter Fire, 2016 Owens River Fire, 2016 Clark Fire, and 2020 Beach Fire), we identified sagebrush vegetation with a FRID condition class of -2 (moderately departed and burning too frequently) or -1 (not departed but burned once since 1970) as locations for potential sagebrush restoration actions, where recovery may be impeded by invasive plants or other interacting stressors. We identified priority areas for potential restoration actions within these recently-burned sagebrush areas by creating a 300 ft road proximity buffer and a 1,000 m buffer from priority sage-grouse habitat. We assumed that restoration actions, such as reseeding and replanting of native vegetation, would be more feasible within 300 feet of an existing road within the analysis area. We also assumed a 1,000 m buffer was sufficient distance from priority sage-grouse habitat to capture nearby potential habitat that may be of sufficient quality for nesting, foraging, or dispersal. We considered areas outside this 1,000 m buffer to consist of relatively lower quality habitat for sage-grouse in the analysis area.

Steps 4 and 5. Restoration Portfolio for Coniferous Forests

The restoration portfolio for coniferous forests in the analysis area is summarized in Table 8. Each restoration opportunity is summarized in a separate section below.

Restoration Opportunity I: Prescribed fire and other fuels reduction activities to promote desired conditions over the next decade

In eastside Jeffrey pine and other coniferous forests that burned primarily at low to moderate severity, the promotion of desired forest conditions could be achieved through: (1) the reintroduction of natural fire regimes in unburned (i.e., fire excluded) coniferous forests within the analysis area using prescribed burning (or cultural burning) to reduce fuel loading and jumpstart key ecological processes, and (2) maintenance of fire in areas that burned at low to moderate severity to reestablish natural fire regimes. Priority areas for unburned coniferous forests can be identified and refined based on spatial data (FRID; Figure 5), decision-support tools (e.g., ACCEL), field validation, traditional ecological knowledge, and expert opinion as described in the Eastern Sierra Fire Restoration and Maintenance Project (USDA Forest Service

2020) and Inyo Forest Plan (USDA Forest Service 2019). We discuss maintenance burning in more detail in the following section.

Maintenance of fire with prescribed burning and wildfires managed for resource objectives

Eastside Jeffrey pine and other coniferous forests that burned primarily at low severity and are moderately departed from their historical fire return interval (i.e., moderate FRID departure; burning less frequently over the past 50 to 100 years compared to the historical fire frequency) may still be outside NRV and desired conditions with respect to fuel loading and vegetation structure (e.g., lack of forest heterogeneity). For instance, Jeffrey pine stands that burned at low severity may continue to be characterized by homogenous forest structure and elevated fuels and tree densities susceptible to future severe wildfires, bark beetle outbreaks, drought, and other stressors (Appendix A. Fire Effects in Coniferous Forests in the Analysis Area). In such cases, prescribed fires and wildfires managed for resource objectives, applied in the near-term (next 5 to 20 years) or long-term (>20 years), could restore stand structure, reduce fuel loads, and increase the resilience of Jeffrey pine and lodgepole pine forest ecosystems, particularly in areas where mechanical treatments are limited due to access (North et al. 2015). In fire-excluded stands with high tree densities, mechanical thinning prior to prescribed burning may facilitate the reduction of ladder fuels and restoration of forest structure, especially in areas of recent elevated tree mortality that can result in increased fire severity (Stephens et al. 2018, Wayman and Safford 2021). A total of 22,163 ac (70%) of coniferous forests in FRID condition class 3 (high departure) are accessible to mechanical equipment in the study area (Figure 6). The combination of forest treatment approaches (i.e., mechanical thinning and wildland fire) may also increase the pace of restoration actions at a landscape scale (see: Appendix D. Pyrosilviculture approach to restoring forest landscapes). Moreover, forest ecosystems in the analysis area and the surrounding Glass Mountain Range represents an ideal landscape for the reestablishment and maintenance of natural fire regimes using wildland fire (Appendix E: Coniferous Forests of the Glass Mountain Range: An Ideal Landscape for the Reestablishment of Natural Fire Regimes). Post-fire vegetation and fuels monitoring data can help track the effectiveness of wildland fires (e.g., Meyer et al. 2020, Safford et al. 2021), and spatial decision support tools can refine priority areas for and the maintenance or restoration of natural fire regimes in this landscape.

Restoration Opportunity II: Climate-smart reforestation and post-fire fuels reduction to restore desired conditions in areas where management actions are feasible

In the Dexter Fire, Clark Fire, and Owens River Fire, high severity burned coniferous forests that lack nearby seed source (1,160 ac total) may be noticeably departed from NRV or desired conditions. These areas have a low probability of natural conifer regeneration and represent restoration opportunities to restore coniferous forest cover through reforestation efforts, particularly in mechanically accessible areas (605 ac total; Figure 9, Figure 10, Figure 11, Figure 12). The Dexter Fire (total of 204 ac of potential reforestation that are mechanically accessible) may be particularly suitable for successful reforestation efforts, based on relatively lower degrees climatic water deficit and projected moisture stress compared to the Owens River Fire area (Figure 8). There are very few mechanically accessible acres (6 ac total) for reforestation in the Clark Fire, primarily due to limitations on reforestation activities within the Indiana Summit Research Natural Area (Figure 11). In the entire analysis area, associated site preparation and fuel reduction (e.g., salvage) actions may be needed to create a safe planting environment for reforestation crews and diminish the potential for high severity reburns.

Climate-smart reforestation actions and other climate adaptation approaches would greatly increase the long-term success and restorative value of planted seedlings. Several best practices for reforestation when considering changes in climate and fire regimes are summarized in North et al. (2019) and presented online (https://climate-wise.shinyapps.io/reforest_toolkit/). Several of these best practices include: (1) using topographic and microsite variation to vary seedling densities based on site productivity and available soil moisture; (2) creating a heterogeneous spatial arrangement to emulate a pattern of individual scattered trees, clumps of trees, and openings (ICO) that are more likely to be resilient to interacting stressors; (3) applying prescribed burning in young stands to reduce fuel loads and increase their resilience; (4) promoting climate-adapted species that are resistant to fire and resilient to drought (i.e., Jeffrey pine) particularly in drier areas (e.g. lower elevations, southwest-facing slopes), and (5) considering current and future site suitability and avoiding planting conifers in marginal areas near the edge of its distribution (e.g., lowest elevation and south-facing sites of the Owens River Fire). For a graphic example of climate-smart reforestation, see: Appendix F. Climate-smart reforestation example from North et al. (2019). Regeneration inventory data for the 2021 Dexter

Fire could be collected to supplement existing post-fire regeneration data collection and analysis efforts from several other fires inside and outside the analysis area (i.e., Meyer and Vane 2020).

Restoration Opportunity III: Reevaluate desired conditions in severely burned coniferous forests that experienced dramatic loss

Severely burned conifer forests where fire effects are greatly outside NRV and are mechanically inaccessible (includes 69 ac in the Dexter Fire, 247 ac in the Owens River Fire, and 239 ac in the Clark Fire) may be unsuitable for the attainment of desired conditions in the near future (Figure 9, Figure 10, Figure 11, Figure 12). This is particularly the case in remote forest stands of high moisture stress (e.g., high climatic water deficit, south-facing slopes at lower elevations in the Owens River Fire). In these areas, management actions may not be feasible for the restoration of current desired conditions in the foreseeable future (e.g., reestablishment of conifer cover), and a new set of desired conditions may be better aligned with likely future conditions. For example, semi-accessible coniferous forests burned primarily at stand-replacement severity could be reforested at lower densities using a combination of natural and artificial regeneration in novel spatial arrangements. This could reestablish a new cohort of Jeffrey pines that is resilient to future warmer and drier conditions (lodgepole pine is relatively less drought tolerant). Alternatively, severely burned coniferous forest that is relatively inaccessible and drought-stressed could transition, with minimal to moderate management intervention, to a new ecosystem type such as sagebrush steppe, native perennial grasslands, aspen stands, or another desirable non-conifer forest vegetation type (Appendix C: Fire Effects Facilitating Ecological Transitions). Even in severely burned areas of relatively lower moisture stress previously dominated by lodgepole pine, planting of the more drought-adapted Jeffrey pine at low densities (<20 to 40 seedlings per ac; low range of NRV) may be desirable and feasible to maintain some degree of long-term conifer cover and vegetation heterogeneity.

Additional Potential Management Actions and Decision-Support Tools Relevant to Multiple Restoration Opportunities

Management actions to restore desired conditions in coniferous forests encompass a wide range of treatment recommendations and other activities besides prescribed burning and reforestation. Additional post-fire restoration actions may include watershed restoration, control and eradication of non-native invasive plants, habitat improvements that create denning and nesting structures for Northern goshawk or other raptors, meadow and riparian restoration, and other management approaches (e.g., restoration approaches that promote biodiversity or additional species of conservation concern).

Several decision support tools (DSTs) are available or in development that can help with prioritizing areas for restoration. As mentioned earlier, reforestation DSTs are provided on the USDA California Climate Hub's website (USDA 2022). Additional DSTs that could assist in planning forest restoration treatments in the analysis area include the ACCEL and PROMOTe tools project by the USFS (Pacific Southwest Research Station and Region 5 Remote Sensing Lab; https://wildfiretaskforce.org/sierra-regional-resource-kits/), Vibrant Planet's LandTender web-based platform, and other DSTs currently in development.

Steps 4 and 5. Restoration Portfolio for Sagebrush Steppe

The restoration portfolio for sagebrush steppe in the analysis area is summarized in Table 8. Each restoration opportunity is summarized in a separate section below.

Restoration Opportunity I: Management activities to promote desired conditions over the next decade

Priority areas for the containment or eradication of non-native invasive plants in sagebrush steppe include along roads and near documented invasive plant occurrences in sagebrush steppe burned in recent wildfires (i.e., 2016 Owens River Fire, 2016 Clark Fire, 2020 Beach Fire; Figure 13, Figure 14). These priority areas will require systematic (or opportunistic) field surveys to identify priority areas for treatment due to the lack of accurate geospatial data for invasive plants in the analysis area. Consultation with Inyo Forest botany staff is recommended to locate priority areas for invasive plant treatment. In addition, grazing management could minimize impacts to burned areas by limiting livestock grazing in sensitive areas of recovery (Miller et al. 2014), particularly where invasive plants have been detected and within twice burned portions of the Owens River Fire, Clark Fire, and Beach Fire (Figure 7). Monitoring long-term vegetation change in recently burned sagebrush steppe would inform whether management actions are effective and if additional management actions are warranted to assist with sagebrush restoration and recovery.

Restoration Opportunity II: Reseeding or replanting native shrubs and herbs to restore desired conditions in areas where management actions are feasible

In recently-burned sagebrush steppe vegetation in the analysis area, reseeding of native grasses and forbs and replanting of native shrubs may be needed to restore native vegetation in sagebrush ecosystems (e.g., top photo of Figure 19). Priority areas identified for treatment based on available geospatial data include the upper and lower reaches of Clark Canyon within the Clark Fire and Owens River Fire perimeters (~120 ac), southeast of Arcularius Ranch near Owens River Road (~150 ac; Owens River Fire; Figure 13), and in the several parts of the 2020 Beach Fire (687 ac; Figure 14); an additional 9 ac of priority sagebrush was located in the central part of the 2021 Dexter Fire but was dropped due to the relative isolation, small size, and higher elevation of this patch. Field evaluation of priority sagebrush areas for the presence of cheatgrass and other invasive plants that may interfere with sagebrush ecosystem recovery are essential to refining sagebrush restoration priorities. Moreover, accessibility in other areas may permit reseeding and replanting efforts in locations not identified using available geospatial data. Local seed collection and native plant nursery “grow-out” of native shrubs (e.g., sagebrush, bitterbrush) will be required to successfully implement restoration efforts. In addition, vegetation monitoring in restoration areas will be essential to track the effectiveness of reseeding and replanting efforts.

In addition to seeding and replanting, conifer removal efforts through hand thinning may benefit unburned sagebrush patches along Owens River Road where there is recent evidence of Jeffrey pine encroachment into sagebrush steppe. Refer to Meyer et al. (2021b) and Miller et al. (2014) for potential priority areas for conifer removal treatments in the Owens River Fire area.

Restoration Opportunity III: Reevaluate desired conditions in burned sagebrush steppe that may be impaired from recovery

In less accessible recently-burned patches of sagebrush, potential restoration actions may include: (1) surveying and control of invasive plants where feasible, (2) long-term monitoring of vegetation change and potential post-fire recovery in burned sagebrush (especially those burned twice (FRID condition class -2) which represents a potentially impaired ecosystem condition), and (3) reevaluation of desired conditions in burned sagebrush patches that are inaccessible (e.g., located far from roads on steep slopes). Burned sagebrush steppe that fails to recover sagebrush cover over the moderate-term (i.e., 10 to 25 years post-fire), particularly in drier or lower elevation sites (i.e., those with relatively greater climatic water deficit; Figure 8), could transition to other ecosystem types dominated by post-fire sprouting native shrubs (e.g., bitterbrush, rubber rabbitbrush, roundleaf snowberry) or native perennial grasses and forbs (Figure 19).

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We thank Inyo National Forest for providing logistical and analytical support for this assessment and Heather Stone for providing technical input on the sagebrush steppe analysis in this report. We also thank the Peter Richards, Andrea Muñoz Ledo, Sam Balthazard, Marcel Safford, and Aidan Finck of the University of California Davis field crew for collecting aspen data in the 2019 Springs Fire summarized in this report.

Tables

Table 1. Fire severity metrics and their desired conditions for wildfires that burned coniferous forests in the analysis area. Desired conditions are based on supporting documents for the revised Inyo Forest Plan and other sources (e.g., USDA Forest Service 2019, 2020; Safford and Stevens 2017).

Fire severity metric	Desired Condition (% of burned landscape)
High severity proportion[a]	<15% in montane coniferous forests with generally lower levels (<10%) in Jeffrey pine than lodgepole pine stands (100%)
High severity patch frequency attributed to very large and extremely large patches[b]	Very large patches (100-200 ac) are rare (<1%) Extremely large patches (>200 ac) are absent (0%)
Mean and maximum high severity patch size	Mean patch size ≤13 ac and max patch size ≤200 ac (preferably <100 ac)
High severity patch frequency attributed to small and medium patches[c]	Small patches (≤1 ac) are frequent (>60%) Medium patches (2-10 ac) are infrequent (<30-35%) Large patches (10-100 ac) are uncommon (<5-10%)
High severity proportion within Northern goshawk habitat, riparian areas, meadows, and special habitats (%)	<15% high severity occurs in goshawk protected activity centers with 100% low severity effects around the nest site <15% in riparian areas, meadows, and special habitats; complete stand-replacing fire acceptable in aspen stands
Fire severity index[c]	≤2.1 within eastside conifer forests (primarily low to moderate severity fire effects) (100%)
Fire Return Interval Departure condition class (CC)[d]	Either CC 1 (low departure) or CC 2 (moderate departure) (85 to 100%) for coniferous forest vegetation

[a] Proportion of each wildfire that burned at high severity (>75% basal area reduction)

[b] High severity patch frequency refers to the frequency of occurrence of all high severity patches within a fire.

[c] Fire severity index (FSI) is a composite measure of all fire effects within a wildfire that ranges from 0 (unburned) to 4 (high severity). Fires with low to moderate severity fire effects generally range from 1 (unchanged) to 2.2 (low to moderate).

[d] Based on the past 50-year fire history. FRID CC 1 (fire regime maintenance condition) is preferable to CC 2 (fire regime restoration condition).

Table 2. Desired conditions by ecosystem component for eastside Jeffrey pine forest and sagebrush steppe in the Glass Mountains analysis area.

Ecosystem Component	**Eastside Jeffrey Pine Forest Desired Conditions**	**Sagebrush Steppe Desired Conditions**
Vegetation Structure and Composition	Jeffrey pine and other conifer forests are resilient to climate change and other stressors. Forest composition is patchy, consisting of a variable mixture of conifers as well as shrubs. Spatial distribution of vegetation is variable and heterogeneous. Most forest stands are characterized by low tree densities and fuel loads within NRV, with frequent and variable canopy openings occurring throughout the forest landscape.	Sagebrush occurs mixed within complex and diverse assemblages of other native shrubs, perennial grasses, and forbs. At the landscape scale, sagebrush is represented by a range of age classes, including mature shrubs and seedlings. Invasive annual grasses (e.g., cheatgrass) are absent or rare, and the introduction and spread of invasive plant species are minimized. Within sagebrush steppe, encroachment by conifer trees such as pinyon pine, Utah juniper, or Jeffrey pine, is generally rare.
Fire Regimes	Jeffrey pine and other conifer forests are within NRV, with frequent fires (every 7 to 30 years) typically burning at low to moderate severity with some high-severity patches interspersed.	There is a low frequency of fire (every 30 to 80 years) occurring in sagebrush steppe, especially in areas of cheatgrass occurrence.
Regeneration	Conifer regeneration occurs in high severity burn patches, particularly within larger stand-replacing patches, with seedling densities predominantly within NRV.	Sagebrush regeneration occurs in burned patches, particularly in larger and more contiguous burned patches that may lack sufficient seed source.
Additional Considerations	Aspen stands are healthy, resilient, and regenerating post-fire, and conifer encroachment in aspen stands in absent or limited to small portions of a stand. Northern Goshawk protected activity centers are resilient to future wildfires and other stressors. Old forests are resilient to stressors, and fire occurs as a key ecological process in old forests. Riparian areas and meadows in frequent fire landscapes have low- to moderate-severity fire restored as an ecological process. Fire effects occur in a mosaic and support restoration and ecological integrity and function.	Sagebrush ecosystems provide suitable habitat and connectivity for wildlife species such as greater sage-grouse. This includes sufficient nesting, foraging, and lekking habitat. Meadows within sage-grouse range provide suitable habitat for sage-grouse. The integrity of special habitats is maintained or improved from current conditions.

Table 3. Primary restoration goals and their associated analysis areas for primary and secondary resources of interest.

Restoration Goals	**Analysis Area**
Primary Resources: Coniferous forests and sagebrush steppe	
1. Maintain or restore the integrity, diversity, and resilience of eastside Jeffrey pine and other coniferous forest ecosystems	Coniferous forests on the west slope of the Glass Mountain Range to the southern edge of Mono Lake, including fire perimeters for 2021 Dexter Fire, 2019 Springs Fire, 2016 Clark Fire, and 2016 Owens River Fire; boundaries based on potential operational delineations (PODs)
2. Maintain or restore sagebrush ecosystem integrity and resilience, including sage-grouse habitat quality and connectivity	Same as above but focused on sagebrush steppe and includes the 2020 Beach Fire perimeter
Secondary Resources: Aspen stands, meadows, goshawk habitat, special habitats, old forests, and pinyon-juniper woodlands	
3. Restore aspen stands and meadows at risk of loss due to conifer encroachment and other stressors	Seral aspen stands[5] in the landscape analysis area
4. Restore or maintain northern goshawk habitat	Northern goshawk protected activity centers (PACs) in the recent fire perimeters
5. Maintain and protect special habitats	Special habitats within recent fire perimeters
6. Restore or maintain old (late seral) forests[6]	Indiana Summit Research Natural Area
7. Maintain or restore pinyon-juniper woodlands	Pinyon-juniper vegetation in the analysis area

[5] Through gradual forest succession in the absence of a natural fire regime, seral aspen stands would convert to a conifer forest dominated by white fir, Jeffrey pine, lodgepole pine, or other conifer species.

[6] Effects of the 2016 Clark Fire to old growth Jeffrey pine forests at the Indiana Summit Research Natural Area were evaluated in greater depth with geospatial and field plot data by Meyer et al. (2020).

Table 4. Resources and spatial datasets used in the post-fire assessment. Several spatial data sources (e.g., post-fire natural conifer regeneration, fire severity) would benefit from field validation and verification.

Resource/Indicator	**Spatial Data**	**Explanation**
Pre-fire coniferous forest and sagebrush steppe vegetation	Inyo NF Terrestrial Ecological Unit Inventory (TEUI) vegetation type	Conifer forests and sagebrush steppe provide numerous ecosystem services including carbon sequestration, wildlife habitat, and biodiversity
Fire severity (vegetation)	Vegetation burn severity (RAVG) (30-m pixel)	Fire severity based on RAVG data displays the magnitude of fire effects to vegetation in four categories of percent change in basal area
Post-fire natural conifer regeneration probability	POSCRPT – Shive et al. 2018; Stewart et al. 2020	Natural conifer regeneration is essential for reestablishment and resilience of conifer forest vegetation following fire.
Fire Return Interval Departure (FRID)	USFS Fire Return Interval Departure condition class (current condition based on the past 52 years of fire history)	FRID calculates the departure of current fire return interval from the historical fire return interval, with higher condition class values associated with greater levels of fire exclusion
Boundaries for wildland fire management operations	Potential wildland fire Operational Delineations (PODs) - Thompson et al. 2016	Potential wildland fire Operational Delineations, or "PODs", are used to spatially plan strategic responses to fires (prescribed fire, wildfire) based upon potential control locations.
Mechanical treatments opportunities	North et al. 2015	Dataset identifies areas on the landscape that are accessible for mechanical treatments
Climate change	Climatic Water Deficit (CWD) from BCM – current and projected for 2010-2030 and climate exposure (Thorne et al. 2016) by mid-21st century	CWD and climate exposure estimates long-term vulnerability of vegetation to climate change
Soil burn severity	Burned Area Reflectance Classification (BARC)	Soil burn severity may identify areas in need of restoration in sagebrush vegetation for reestablishing soil productivity
Invasive plants	USFS regional invasive plant database	Cheatgrass and other non-native invasive grasses reduce the post-fire ecological integrity of sagebrush steppe and other ecosystems
Sage-grouse habitat	Bi-State Priority Habitat for Greater sage-grouse (USGS)	Maintenance and restoration of sage-grouse habitat is a high-priority goal.
Northern goshawk habitat	Northern goshawk Protected Activity Centers (PACs)	Nest sites and other habitat elements for goshawks are important to maintain in forest ecosystems
Aspen stands	Inyo NF aspen risk assessment from conifer encroachment (2010)	Aspen stands experiencing conifer encroachment are at risk of loss due to the long-term absence of fire as a key ecological process
Soils	NRCS soil survey data (2022)	Volcanic soils may be more susceptible to invasive plants than sandy soils

Table 5. Fire effects to coniferous forests from recent wildfires in the analysis area.

Fire Name (Year)[a]	% Low Severity[b]	% High Severity (ac)	High Severity in Patches >250 ac (%)	Mean (and Maximum) High Severity Patch Size (ac)	Fire Severity Index	Fire Effects within NRV[c]
Springs (2019)[a]	94	1 (45)	0	2 (13)	1.6	**Yes**
Dexter (2021)	40	48 (955)	57	11 (683)	2.8	No
Clark (2016)	39	32 (640)	44	6 (283)	2.8	No
Owens River (2016)	14	74 (1464)	72	14 (520)	3.5	No
O'Harrel (2007)[a]	77	3 (20)	0	3 (8)	2.0	**Yes**
Dexter (2003)[a]	78	6 (142)	0	7 (51)	1.9	**Yes**

[a] The Springs Fire (2019), Dexter Fire (2003), and O'Harrel Fire (2007) (emphasized in bold) were managed primarily for resource objectives, whereas the other three wildfires listed in this table were managed under full suppression objectives. The 2004 Crater Mountain Fire, also managed for resource objectives, produced predominantly low to moderate severity fire effects (based on field observation) but could not be analyzed because fire severity data (e.g., RAVG, R5 veg burn severity) were unavailable for this fire.

[b] Includes unchanged and low fire severity classes.

[c] Natural range of variation (NRV) fire effects in Sierra Nevada coniferous forests are provided in Table 1.

Table 6. Signs of ecological integrity in a 50-acre aspen stand burned in the 2019 Springs Fire, Inyo National Forest. Ecological integrity column indicates more than 50% of field inventory plots (based on 40 0.02-ha plots collected in August 2022) showed signs of integrity based on each criterion.

Post-fire Ecological Integrity Criterion	**% of Plots Showing Sign of Integrity**	**Criterion Met?**
Relative conifer cover, density, and basal area less than 50%	12% (canopy cover), 26% (density), and 2% (basal area)	No
Absolute conifer cover less than 25%	75%	Yes
Absolute conifer density less than the upper end of the NRV (182 trees per acre)	100%	Yes
≤50% of small trees (7.6-20 cm dbh) represented by conifers	100%	Yes
Aspen regeneration more than 500 stems per acre	95%	Yes
Aspen regeneration is more than 50% of total regeneration.	100%[a]	Yes
Less than 10% of aspen small stems are browsed	100%	Yes
Surface fuel load is less than 30 tons per acre	Presumed infrequent[b]	Yes (probably)
Dominant aspen trees are less than 100 years old	Presumed <100 years[b]	Yes (probably)
Overall assessment: Relatively high ecological integrity[c]		

[a] One plot (2.5% of plots) had zero aspen resprouts and zero conifer seedlings or saplings.

[b] Based on field observation; we assumed surface fuel load was predominantly less than 30 tons/acre and mature trees were less than 100 years old, but we did not validate these conclusions with field data.

[c] Relative to fire-excluded aspen stand such as at Bald Mountain Spring, which lacked adequate aspen regeneration (445 ± 229 stems/ac) and contained high surface fuel loads.

Table 7. Fire effects to secondary resources associated with or adjacent to coniferous forests within the analysis area. Overall fire effects column indicates whether fire severity patterns are consistent with desired conditions and NRV (i.e., beneficial) and if such effects were field validated (indicated with *).

Secondary Resource	Burned in Fire (acres)	Fire Severity (%)	Overall Fire Effects (field validated?)
Seral aspen stands at risk of conifer encroachment (2 stands)	Springs (50 ac) Owens River (<1 ac)	85% low, 14% mod, 1% high[a] Mixed[a]	Beneficial*[a]
Pure aspen stands with minimal conifer encroachment (3 or more stands)	Dexter (421 ac)	99% high, 1% low to moderate[a]	Beneficial*[a]
Northern goshawk PACs (3 total)	Springs (200 ac) Dexter (438 ac)	99% unburned in Springs Fire 17-20% high in Dexter Fire	No benefit*[b] Mostly beneficial [b]
Crooked meadow	Dexter (40 ac)	90% low; 10% moderate-high	Beneficial
Special habitats	Springs (38 ac)	95% low, 4% high	Beneficial or neutral
Old forests (Indiana Summit RNA)	Clark (1162 ac)	12% low, 49% moderate, 39% high	Beneficial and negative*[c]
Pinyon-juniper woodlands	Owens River (200 ac) McLaughlin (106 ac)[d]	69% low, 24%, moderate, 7% high	Beneficial

[a] Fire severity patterns in the small (<1 ac) aspen stand burned in the Owens River Fire were too small to evaluate using available geospatial data, but field data collection in the summer of 2022 indicated mixed severity fire effects (i.e., equal proportions of low, moderate, and high severity) with high densities of resprouting aspen stems (2470 stems/ac). Fire effects in the 50 ac aspen stand burned in the Springs Fire was determined to be overwhelmingly positive based on several ecological assessment criteria (Table 6, Figure 17). Fire effects to aspen stands in the Dexter Fire were considered positive based on high densities of resprouting aspen stems (2509 stems/ac).

[b] Fire suppression actions were taken in one goshawk PAC within the Springs Fire resulting in continued fire exclusion (a mostly negative impact), whereas another PAC was partially burned (64% of PAC area) in two wildfires (Clark, Dexter) resulting in mostly beneficial (low to moderate severity) fire effects. The unburned PAC showed clear evidence of high tree densities and surface fuels, elevated mountain pine beetle attack in lodgepole pine, and heavily suppressed aspen trees with evidence of declining vigor and health (bottom of Figure 15).

[c] Fire effects to old forests in the Indiana Summit Research Natural Area are covered in detail in Meyer et al. (2020); fire severity estimates based on USFS Region 5 vegetation burn severity data (1-year post-fire assessment).

[d]A total of 43 ac burned in both the 2016 Owens River Fire and 2001 McLaughlin Fire. A total of 306 ac of pinyon-juniper woodlands (out of 4022 ac; 8%) have burned in the analysis area.

Table 8. Restoration portfolio for forests and sagebrush steppe in the analysis area[7].

Target Resources and Areas	**Management Actions**[8]
Restoration Opportunity 1: Maintain and Promote Desired Conditions	
Priority conifer forests that are fire-excluded (>50 to 100 years since last fire) or have burned within NRV with post-fire fuels exceeding desired conditions	• Use prescribed fire or managed wildfire consistent with the historical fire return interval to maintain desired fuels loads within the next 5 to 20 years based on Rx fire prioritization analysis[9], particularly in long unburned (fire-excluded) stands with high surface and ladder fuel loads (Appendix E). • Use 'pyrosilviculture' approach to facilitate the safe and effective use of prescribed fire and managed wildfires (see Appendix D). • Monitor vegetation and fuels in treated areas in Jeffrey pine and other forested stands and adopt adaptive management approach..
Sagebrush that burned in relatively small patches or on sandy soils	• Conduct surveys for and contain or eradicate nonnative plants. • Implement grazing management to minimize impacts to burned areas. • Monitor long-term vegetation change in recently burned sagebrush patches.
Restoration Opportunity 2: Take Management Actions to Restore Desired Conditions	
Jeffrey pine stands and other forests that burned outside of NRV, are unlikely to support natural conifer regeneration, and are mechanically accessible	• Conduct climate-smart reforestation (see Appendix F) and fuels reduction activities to avoid high severity reburns and restore spatially variable conifer cover in high severity patches. • Consider replanting areas previously dominated by lodgepole pine with relatively drought-tolerant Jeffrey pine where drought stress is anticipated to increase significantly (e.g., Dexter Fire). • Monitor high severity burn patches for post-fire conifer regeneration and develop or refine post-fire natural conifer regeneration prediction models for the analysis area. • Monitor post-fire vegetation change in Jeffrey pine stands burned at high severity (next 5 to 10 years).
Sagebrush that has burned recently in recent large (>1,000 ac) wildfires or unburned sagebrush especially on volcanic soils and are relatively accessible[10]	• Reseed native grasses and forbs and replant native shrubs in burned areas based on local seed collection and native plant nursery stock. • Hand thin encroaching conifers from unburned sagebrush stands. • Install long-term vegetation monitoring plots in native plant reseeding and replanting sites and areas of conifer removal to evaluate treatment effectiveness. • Contain or eradicate invasive plants in priority restoration areas.

[7] This portfolio is based on the primary management goals, approaches, and opportunities summarized in Tables 2 and 3 and spatially represented in Figures 6, 9, 10, 11, 13, and 14.
[8] All management actions are considered moderately to highly feasible, especially in accessible areas.
[9] Prioritization of prescribed fire areas are covered under a different assessment process described in the Inyo Forest-wide prescribed burn project (USDA Forest Service 2020).
[10] Also includes management actions covered under Restoration Opportunity 1 for sagebrush steppe.

Target Resources and Areas	**Management Actions**[8]
Conifer-encroached aspen stands	• Conduct conifer removal treatments (Rx fire, thinning) in the unburned portion of the Bald Mountains Spring aspen stand where conifer encroachment is high (Figure 17). • Continue monitoring post-fire resprouting of burned aspen stands that had high pre-fire conifer densities in the Springs fire and Owens River Fire (next 5 years).
Restoration Opportunity 3: Reevaluate Desired Conditions Considering Interacting Stressors	
Conifer forests that burned outside NRV, are unlikely to support natural conifer regeneration, and are mechanically inaccessible	• Monitor severely-burned stands at high risk of type conversion, particularly in late-seral Jeffrey pine stands of the Indiana Summit Research Natural Area burned in the 2016 Clark Fire. • Consider targeted reforestation at very low densities (<50 seedlings per acre) to establish "founder stands" in select areas lacking natural post-fire regeneration. • Control and eradicate cheatgrass and other invasive plant species.
Sagebrush patches that burned in larger patches that are relatively inaccessible or contain high cheatgrass cover	• Survey and control invasive plant species where feasible. • Monitor vegetation change and potential post-fire recovery. • Reevaluate desired conditions of inaccessible burned sagebrush that may transition from one desirable vegetation type to another, such as where sagebrush fails to recover and is replaced by other native shrubs, bunchgrasses, or forbs.

Figures

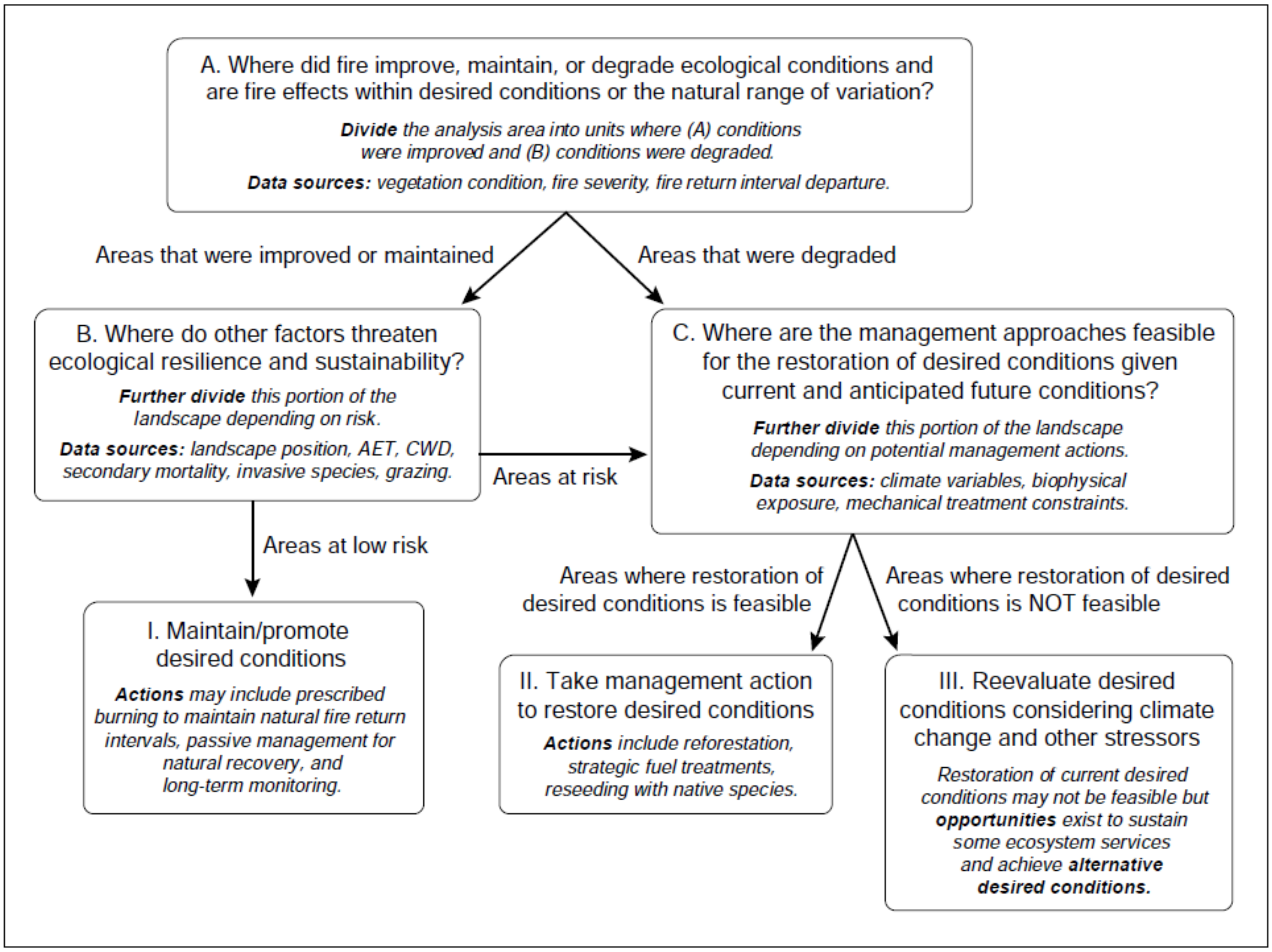

Figure 1. Post-fire flow chart from Meyer et al. (2021a) asks three questions (A, B, and C) for the identification of management responses or “restoration opportunities” (1, 2, and 3) that support overarching restoration goals in different portions of the affected landscape.

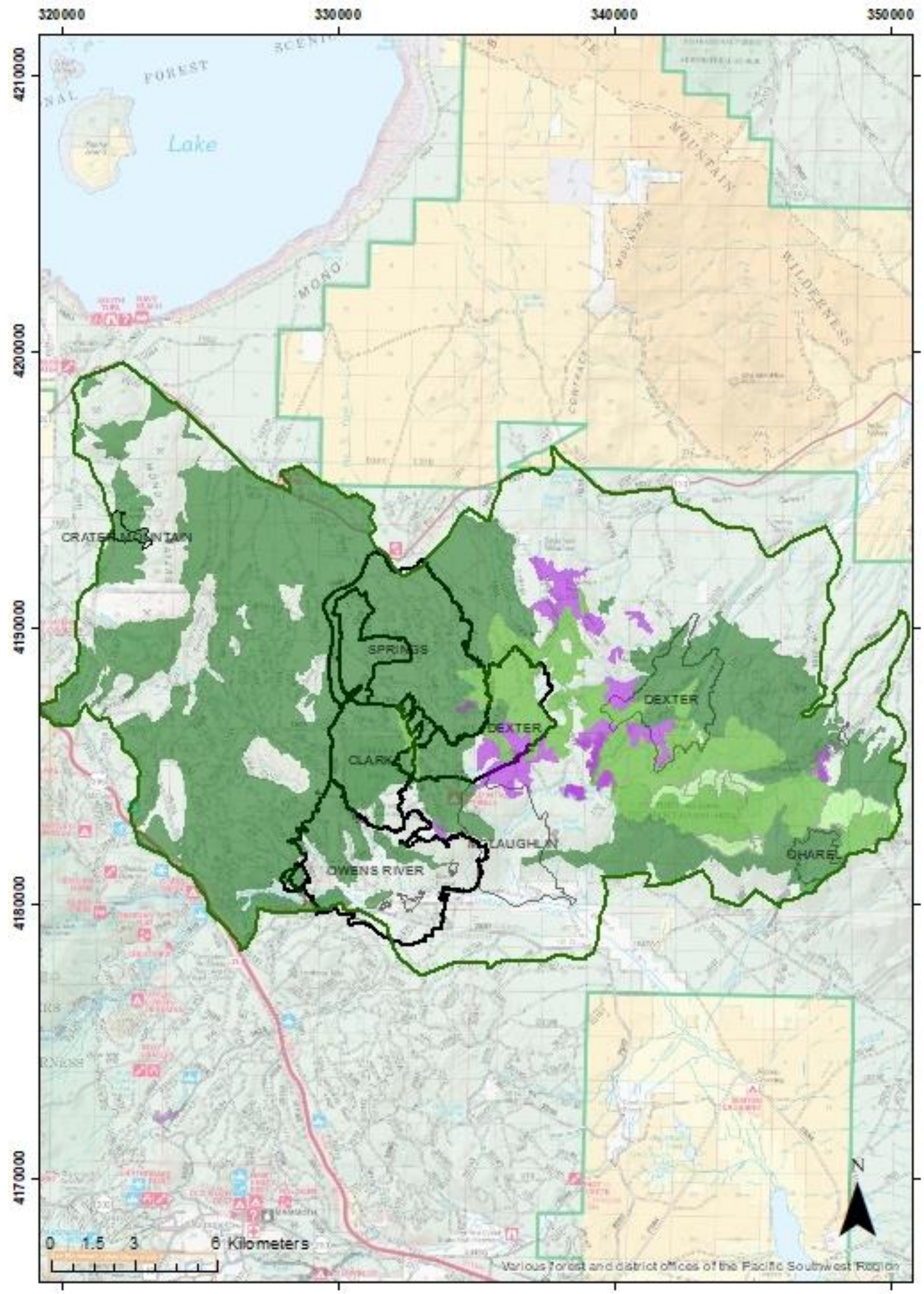

Figure 2. Recent wildfires (2001-2021) and the major forest types in the analysis area on the Inyo National Forest, including Jeffrey pine forests (dark green), dry lodgepole pine forests (medium green), subalpine forests (light green), and aspen stands (purple).

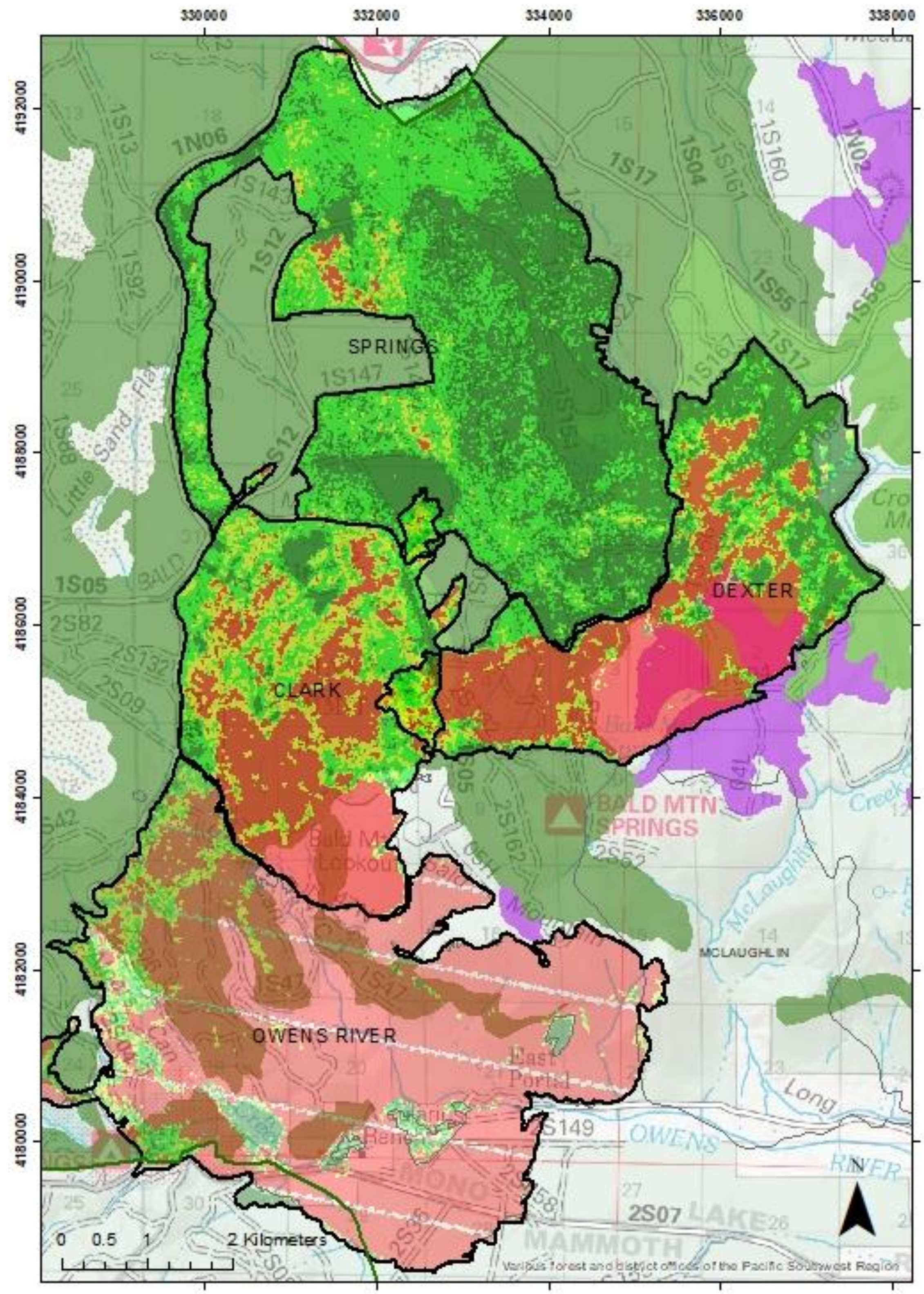

Figure 3. Fire severity patterns (from north to south) in the 2019 Springs Fire, 2021 Dexter Fire, 2016 Clark Fire, and 2016 Owens River Fire in the analysis area, Inyo National Forest. Low severity patches are shown in green, moderate severity in yellow, and high severity in red (conifer forest in green shading).

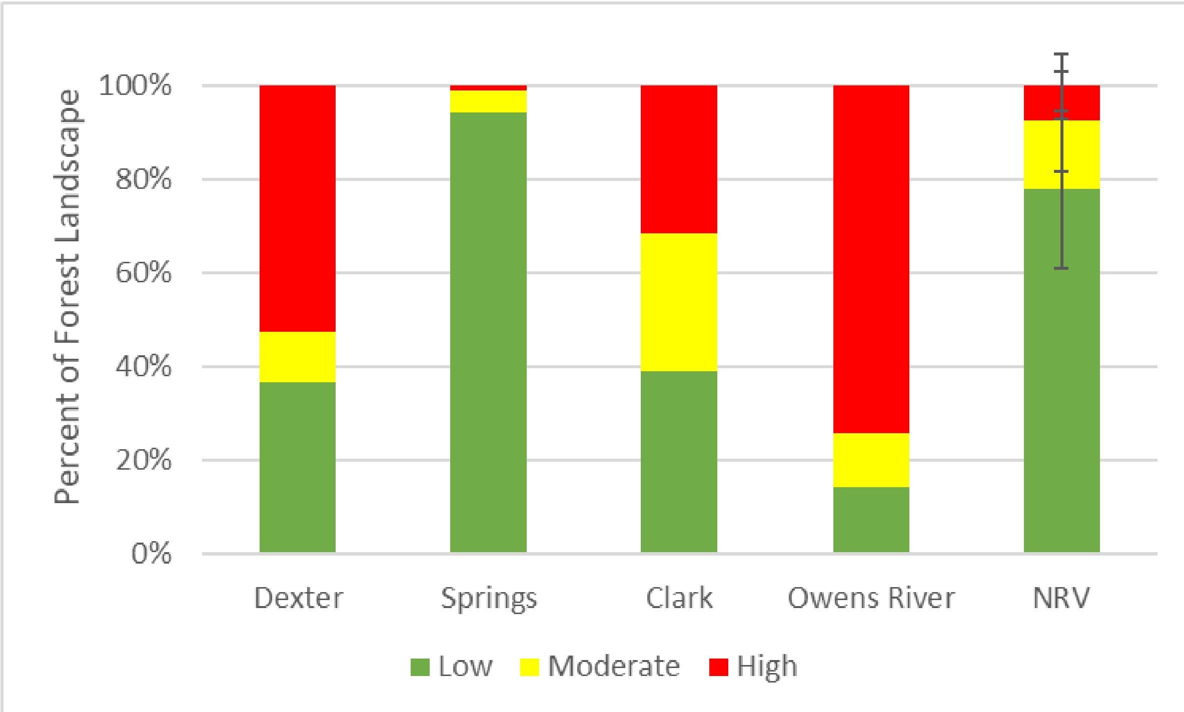

Figure 4. Fire severity proportions in forest landscapes burned in the 2021 Dexter, 2019 Springs, 2016 Clark, and 2016 Owens River fires in the western Glass Mountain Range, Inyo National Forest. The natural range of variation (NRV) for conifer forests is provided on the right for comparison.

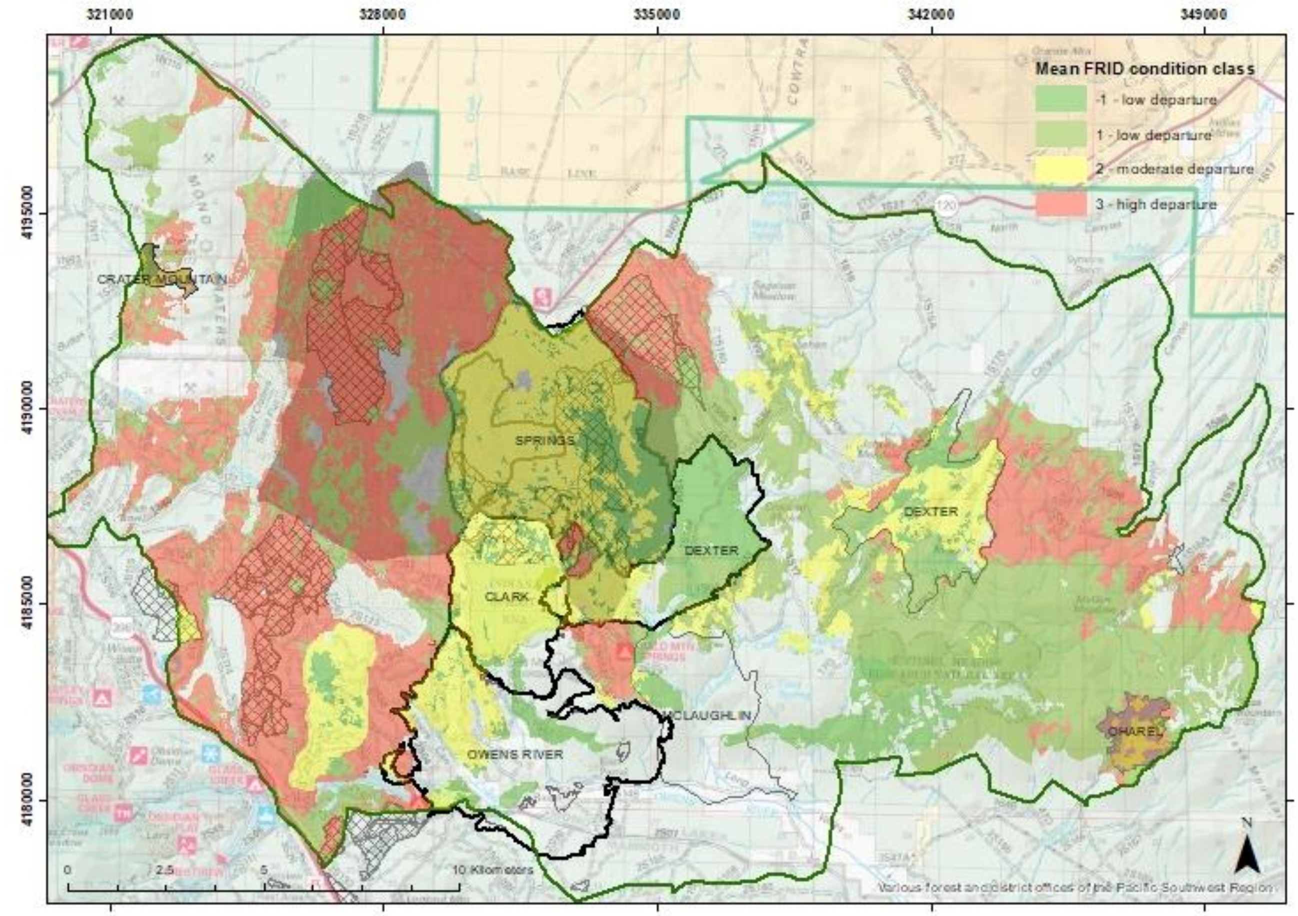

Figure 5. Fire return interval departure (FRID) condition classes for conifer forests in the analysis area, showing areas of high departure in red (burning much too infrequently), moderate departure in yellow (burning somewhat infrequently), and low departure in green (current fire return interval similar to historical fire return interval). Cross-hatching indicates recent prescribed burned areas with low to moderate fire return interval departure. Shaded areas are priority Potential Operational Delineations for prescribed burning in the analysis area (USDA Forest Service 2020).

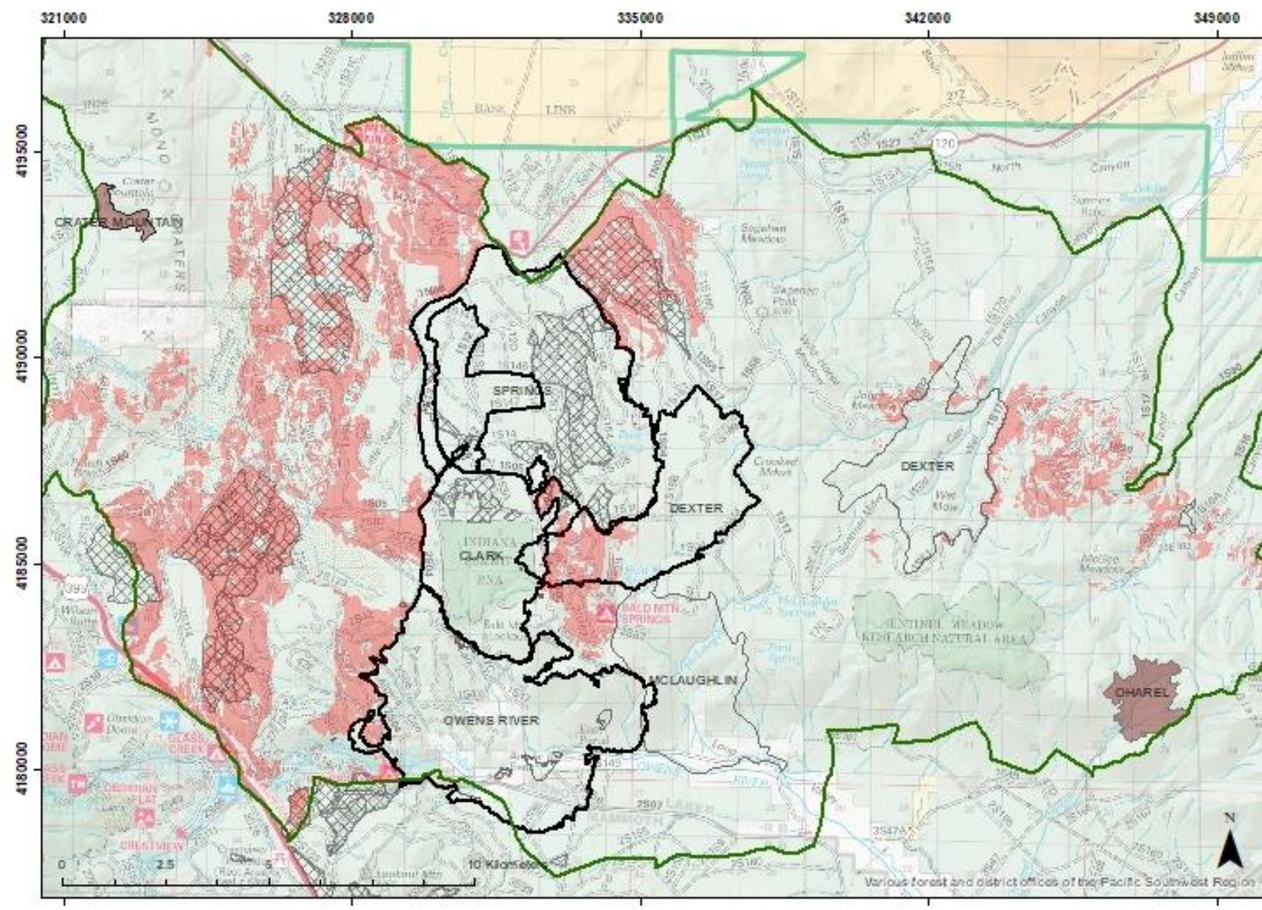

Figure 6. Mechanically accessible conifer forests that are in FRID condition class 3 (highly departed; shown in transparent red[11]) in the analysis area (potential priority areas for Restoration Opportunity 1 – prescribed burning and mechanical fuels reduction). Cross-hatched areas indicate recent prescribed burn areas that are not likely to require mechanical pre-treatment.

[11] Area in red in the western portion of the 2021 Dexter Fire is actually FRID condition class 2 (moderate departure).

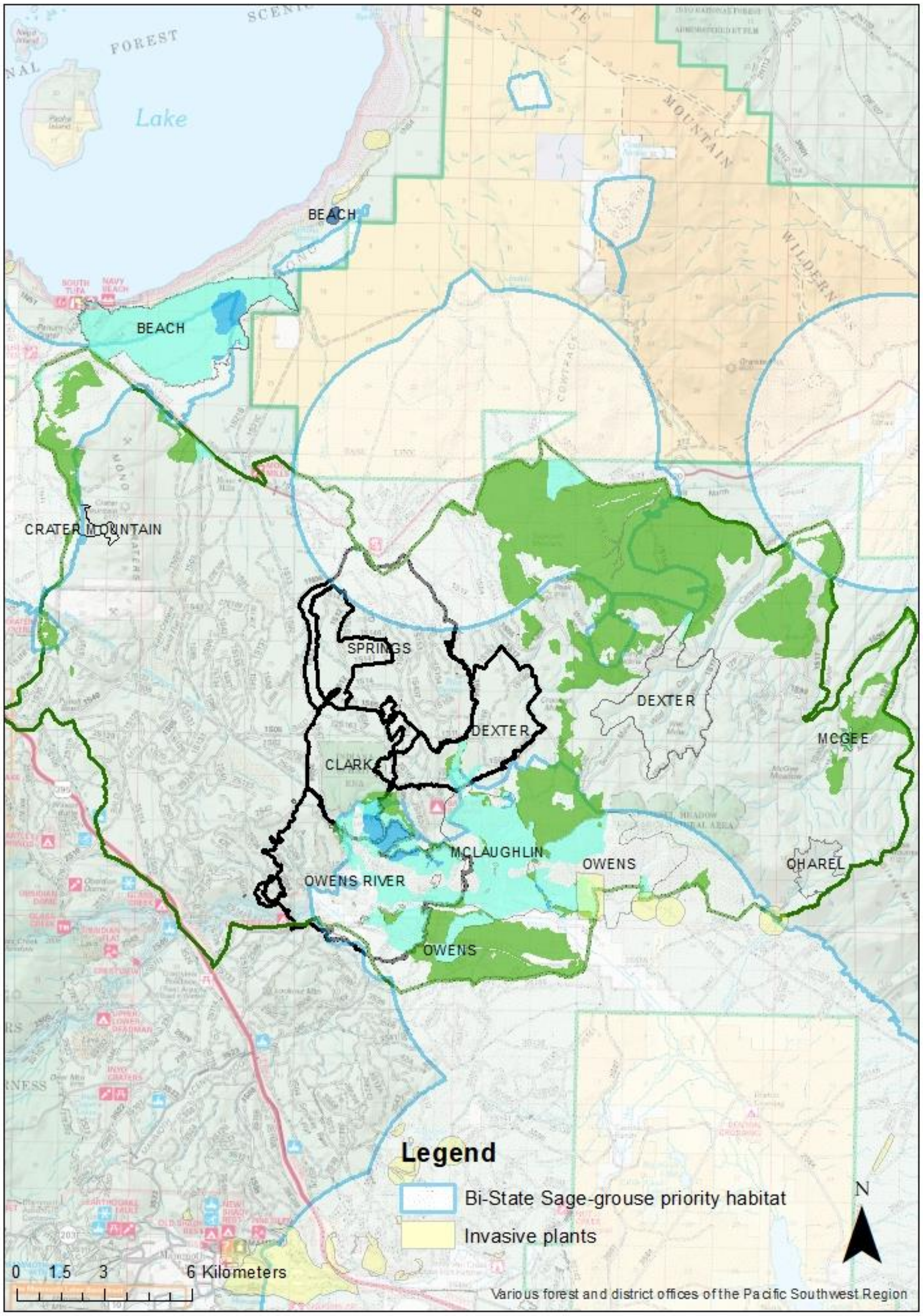

Figure 7. Fire return interval departure (FRID) condition classes for sagebrush steppe in the analysis area, showing areas of moderate departure in blue (burning too frequently) and low departure (i.e., current fire return interval similar to historical fire return interval) in aqua (burned once since 1970) and green (no fire since 1970). Sage-grouse priority habitat is shown in blue outline and invasive plants in yellow.

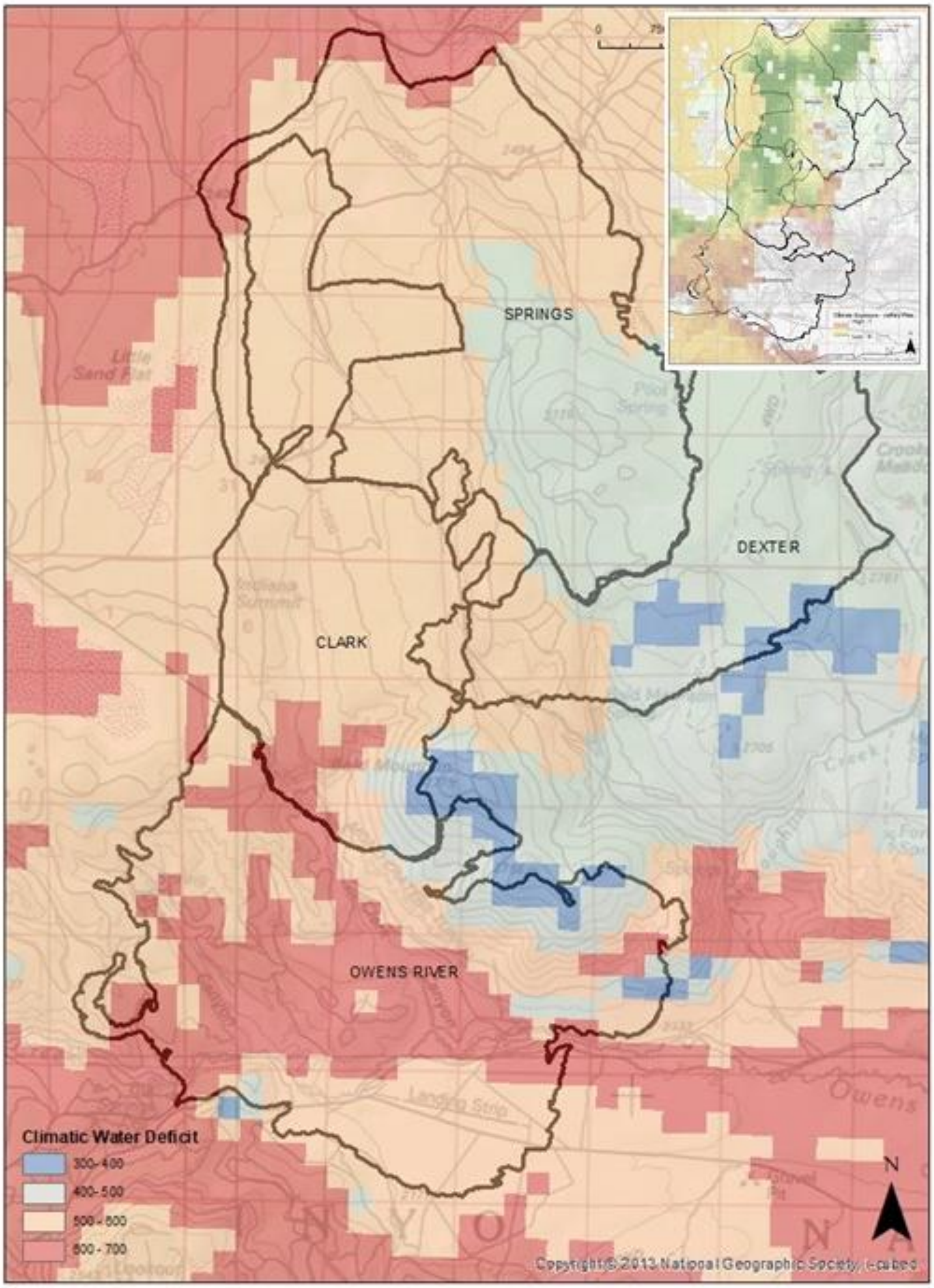

Figure 8. Climatic water deficit in the four wildfires of interest and neighboring areas. Areas in warmer colors indicate relatively higher levels of drought stress for forest and shrubland vegetation. Climate exposure for eastside Jeffrey pine forests is displayed in the inset map in the upper right corner for comparison.

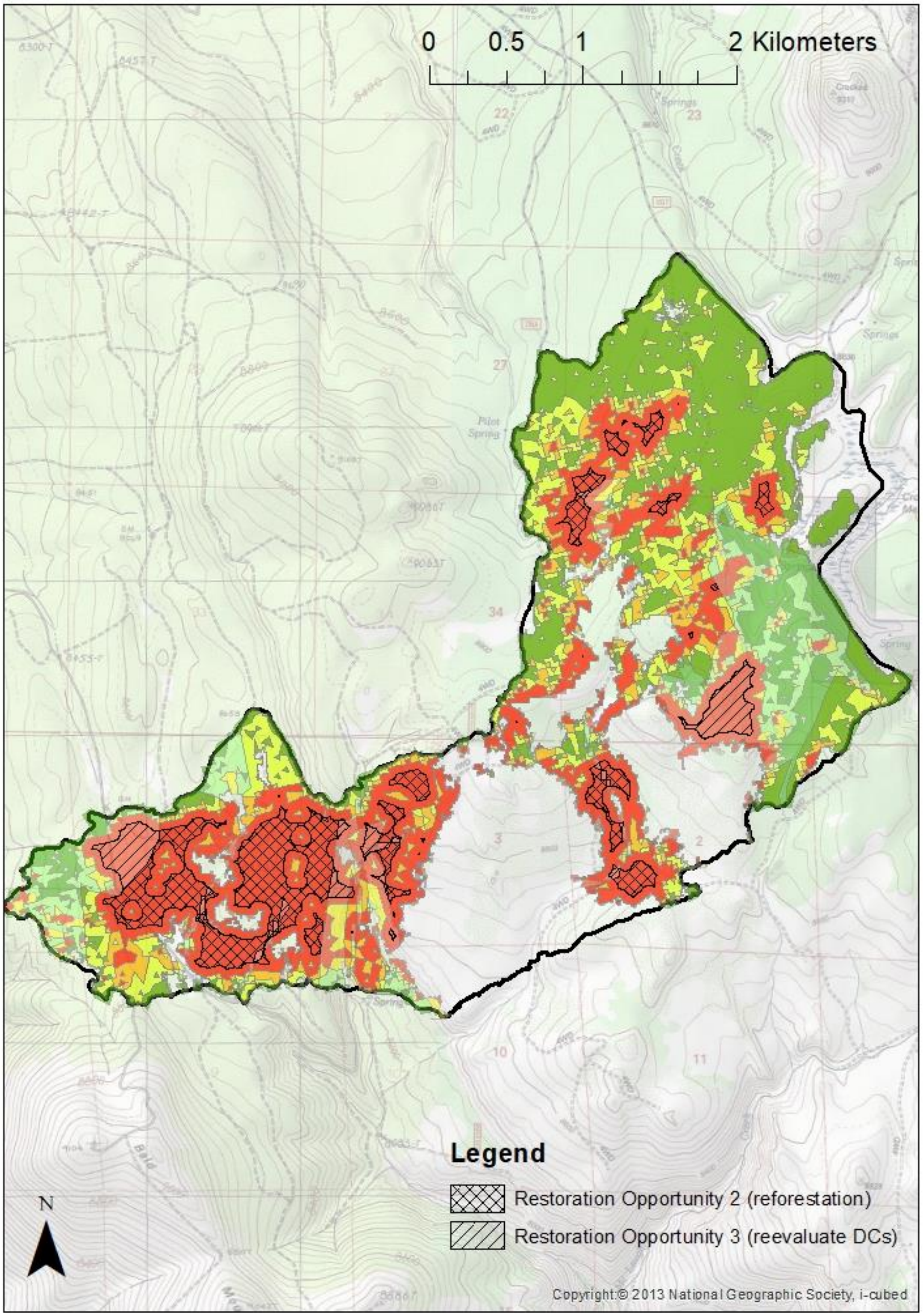

Figure 9. Priority reforestation areas for the 2021 Dexter Fire are shown as crosshatched polygons (Restoration Opportunity 2), whereas single-hatched areas are mechanically inaccessible (Restoration Opportunity 3). Both restoration opportunities indicate areas of low probability of post-fire natural conifer regeneration in coniferous forests (i.e., 50 m buffer from high severity patch edge).

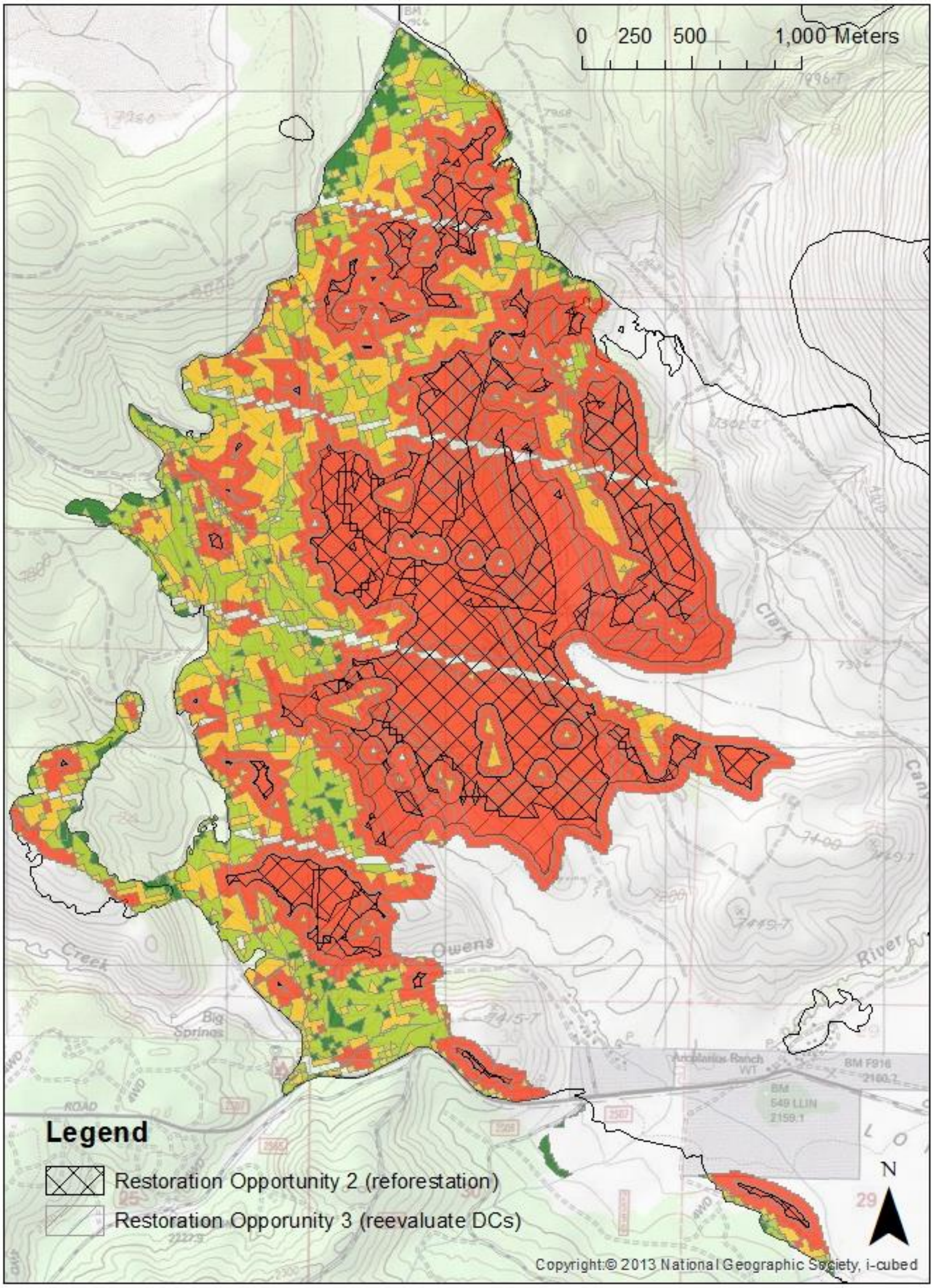

Figure 10. Priority reforestation areas for the 2016 Owens River Fire are shown in the crosshatched (Restoration Opportunity 2), whereas faint single-hatched areas are mechanically inaccessible (Restoration Opportunity 3). Both restoration opportunities indicate areas of low probability of post-fire natural conifer regeneration in coniferous forest (i.e., 50 m buffer from high severity patch edge).

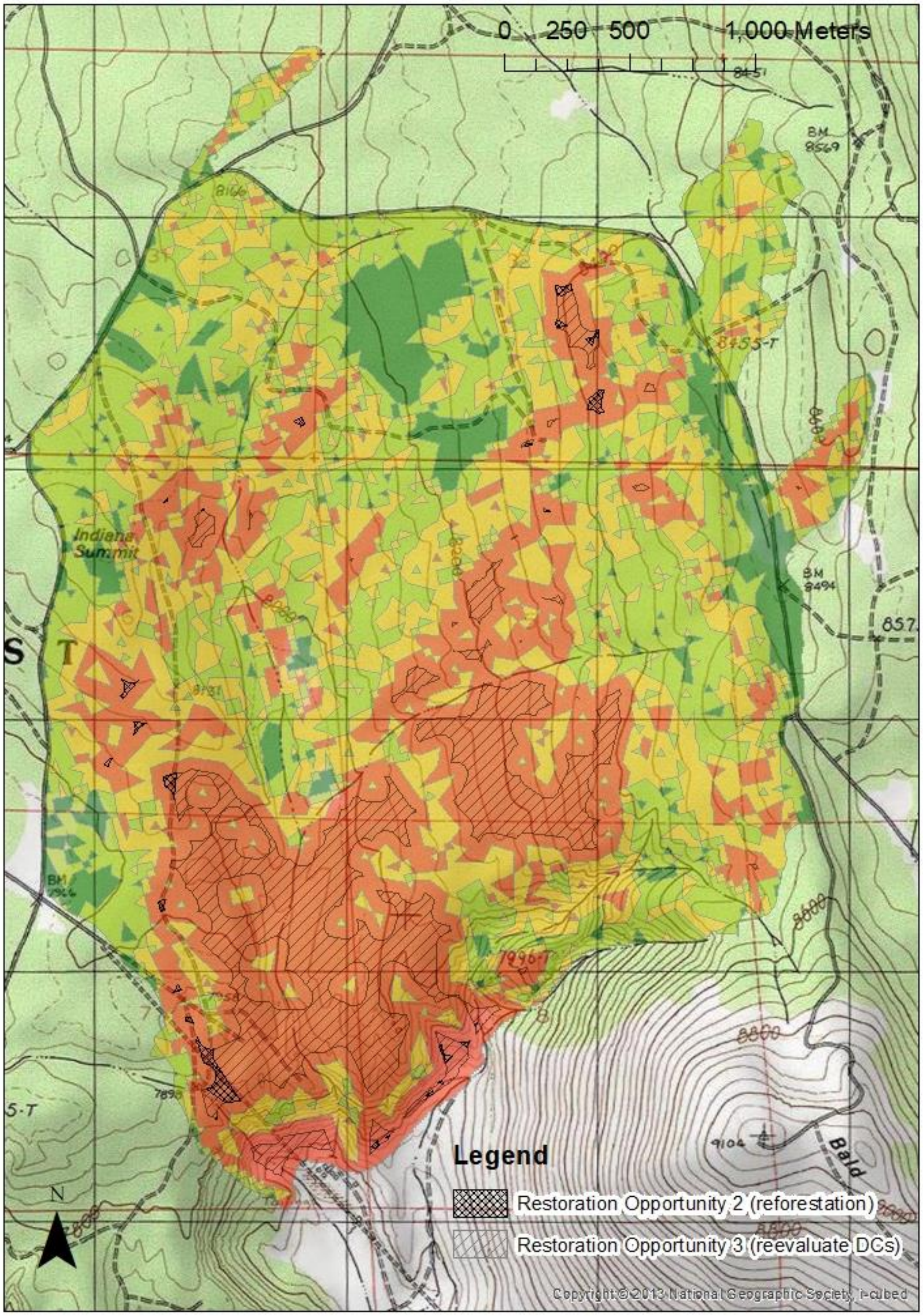

Figure 11. Priority reforestation areas for the 2016 Clark Fire consist of only 6 acres shown in bold-outlined cross-hatched polygons (Restoration Opportunity 2). Single-hatched areas that are mechanically inaccessible (Restoration Opportunity 3) make up the majority of potential reforestation acres (total: 239 acres) and are found almost entirely within the Indiana Summit Research Natural Area. Both restoration opportunities indicate areas of low probability of post-fire natural conifer regeneration.

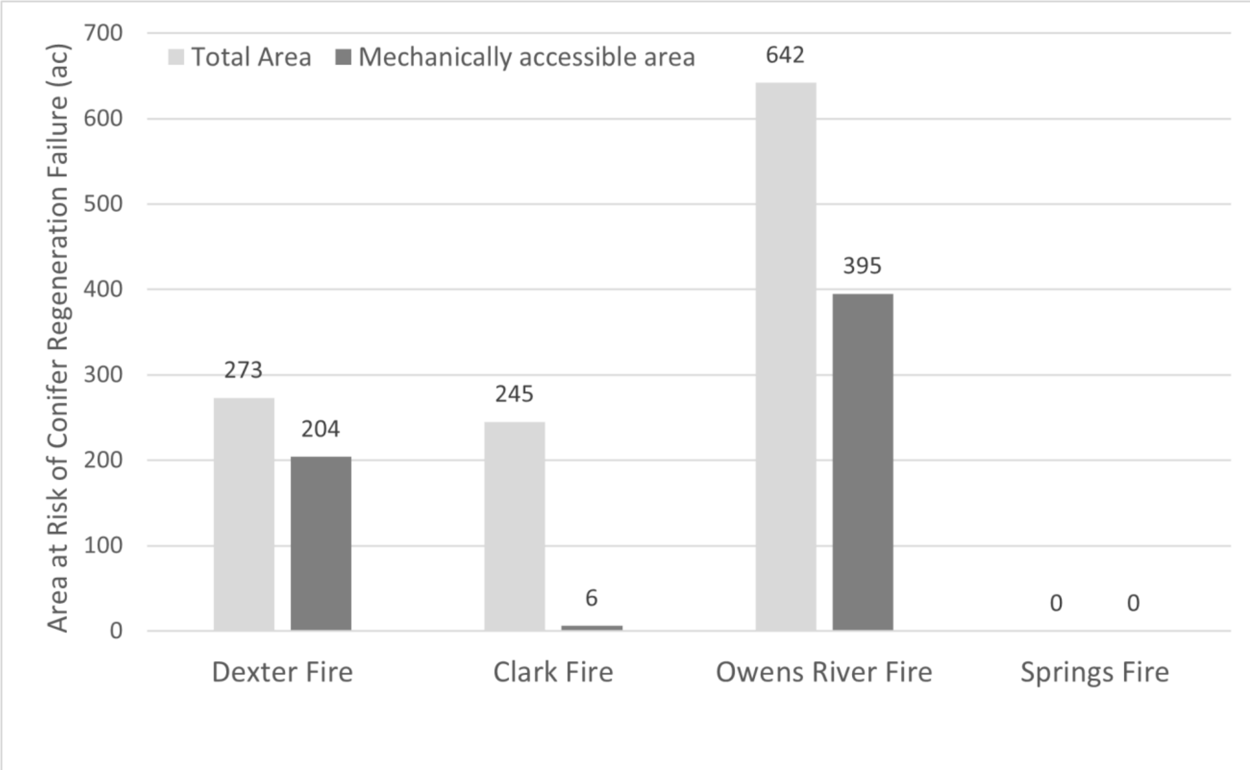

Figure 12. Total acres at risk of conifer regeneration failure (light gray bars) and total acres of potentially accessible areas for reforestation (dark gray bars; restoration opportunity 2) among recent wildfires in the analysis area. Results are based on a 50 m buffer from the boundary of high severity patches where the probability of post-fire natural conifer regeneration is anticipated to be low based on field plot data from the Owens River Fire, Clark Fire, and other wildfires in the analysis area. The difference in acres between light and dark gray bars (555 ac for all four wildfires) represents the total area for reevaluating desired conditions (restoration opportunity 3).

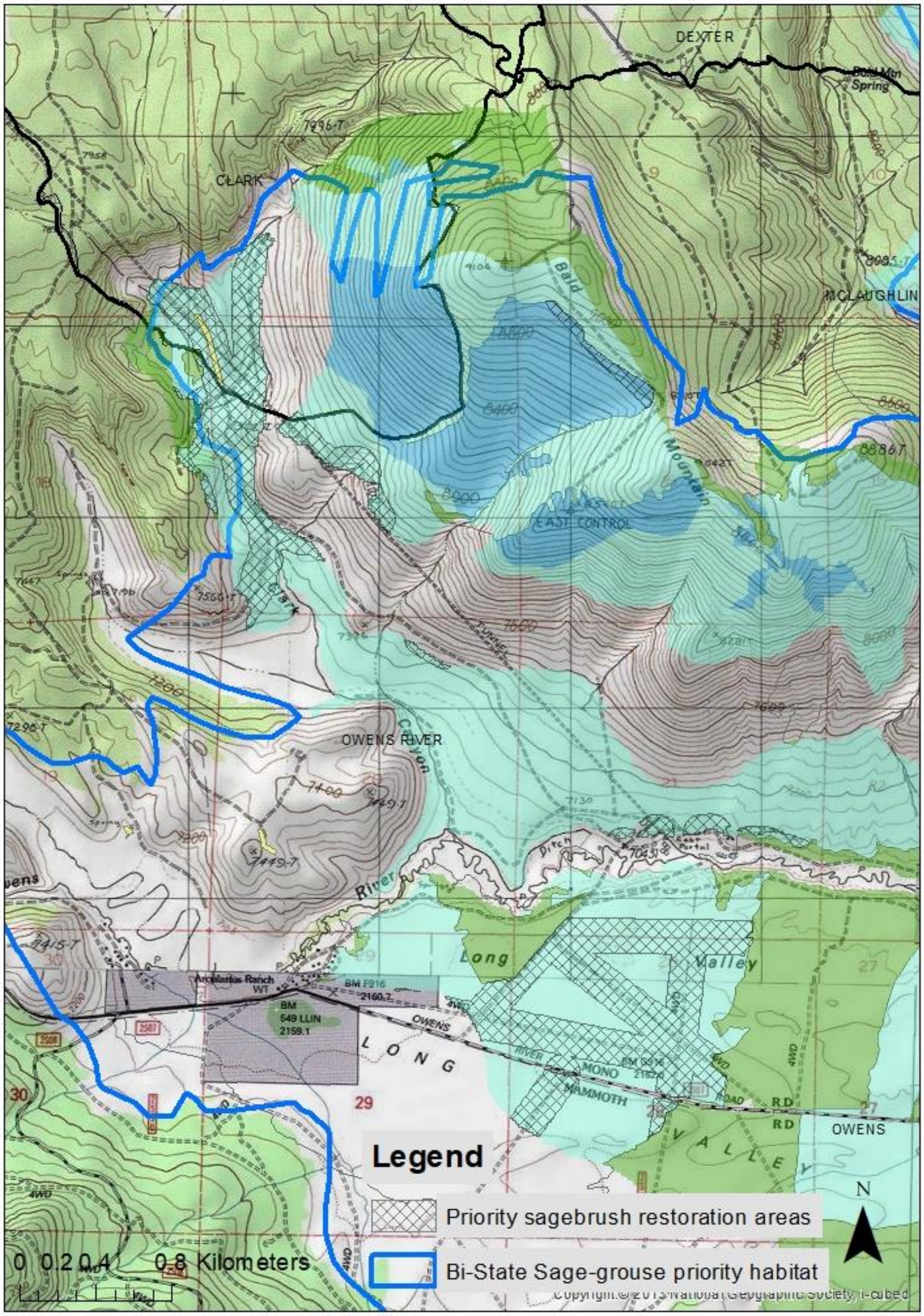

Figure 13. Priority areas for reseeding and replanting actions in sagebrush steppe burned in the 2016 Owens River Fire and Clark Fire are shown in cross-hatching (restoration opportunity 2). Priority areas for invasive plant surveys, containment, or eradication (restoration priorities 1, 2, 3) are located along roads in burned areas (shown in cross-hatching) and in twice-burned areas (blue color, where feasible). See Figure 7 for color scheme of FRID condition classes displayed in map.

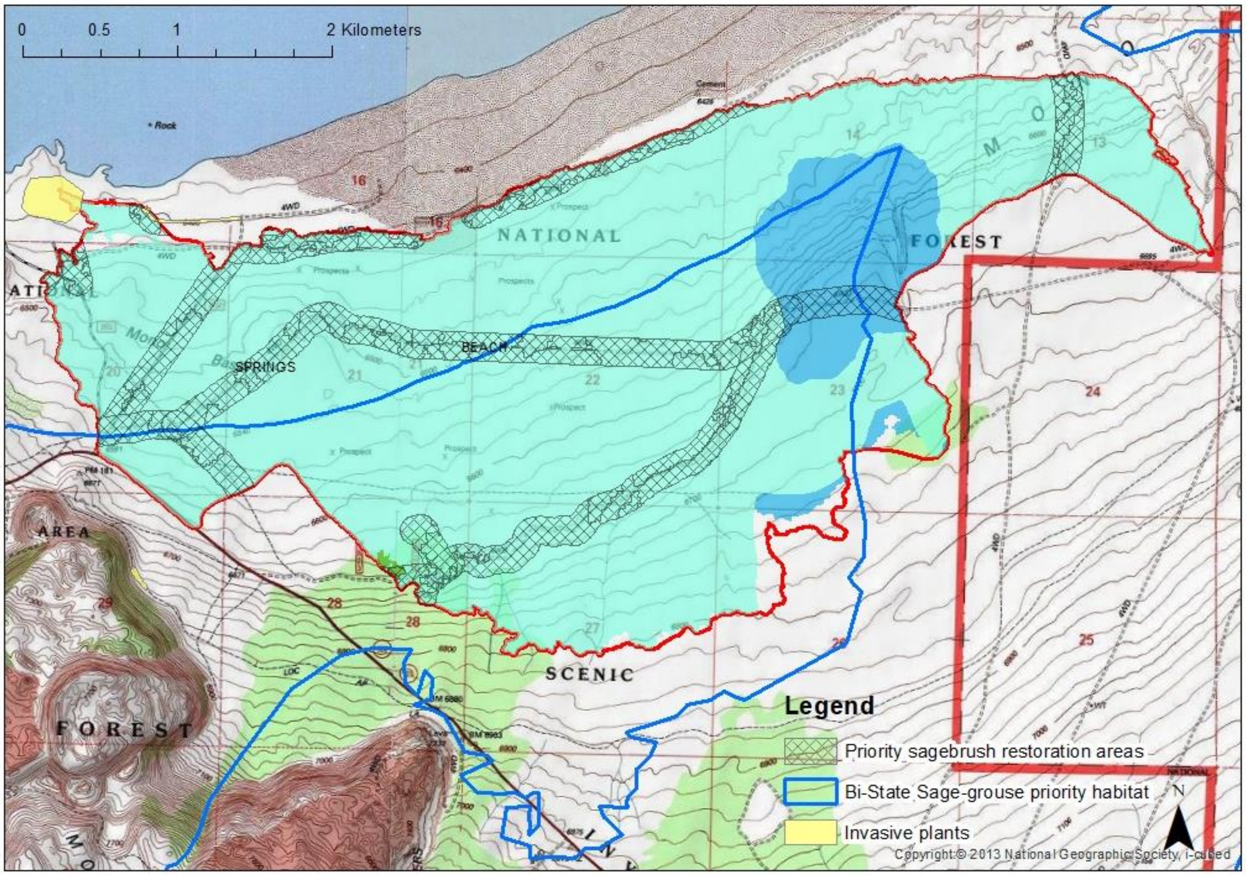

Figure 14. Priority areas for reseeding and replanting in sagebrush steppe burned in the 2020 Beach Fire are shown in cross-hatching (restoration opportunity 2). Priority areas for invasive plant surveys, containment, or eradication (restoration opportunities 1, 2, 3) are located along roads in burned areas (cross-hatching), near documented invasive plant occurrences (yellow color), and in twice-burned areas (blue color, where feasible). See Figure 7 for color scheme of FRID condition classes displayed on map.

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Appendices

Appendix A. Fire Effects in Coniferous Forests in the Analysis Area

Figure 15. Representative panoramic photos of forest conditions in a Jeffrey pine stand that is fire-excluded (top) or burned at either low severity (2nd from top), moderate severity (3rd from top), or high severity (2nd from bottom). The bottom photo shows a dense, fire-excluded lodgepole pine stand within a Northern goshawk protected activity center. All photos are from or near the 2021 Dexter Fire or 2019 Springs Fire (bottom photo).

Figure 16. Representative photos of burned eastside Jeffrey pine stands showing: (1) top photo – a stand treated with prescribed fire that burned at low severity in the past 10 to 15 years, (2) 2nd from top – low to moderate severity fire effects from the combination of mid-1990s prescribed burning and 2016 Clark Fire in the Indiana Summit RNA (within NRV), (3) 3rd from top – moderate-sized high severity patch (within NRV) in the 2016 Owens River Fire, (4) 2nd from bottom – large high severity patches (outside NRV) from the 2016 Clark Fire, and (5) bottom – large high severity patch from the 2001 Crater Fire (outside NRV) that was either unmanaged (left side of photo) or reforested post-fire with Jeffrey pine (right side of photo).

Appendix B. Fire Effects in Aspen Stands in the Analysis Area

Figure 17. Representative panoramic photos of aspen stand conditions in the analysis area, including long-term fire-exclusion leading to high conifer densities, aspen tree mortality, and surface fuel loading at Bald Mountain Spring (top two photos); low to moderate severity fire effects in the 2019 Springs Fire (third photo from top); or high severity fire effects in the Owens River Fire (second photo from bottom). All aspen stands show evidence of pre-fire conifer encroachment from lodgepole pine and Jeffrey pine, except for the bottom photo which is from a severely-burned upland pure aspen stand in the 2021 Dexter Fire. Note the high density of aspen sprouts in all burned stands.

Appendix C: Fire Effects Facilitating Ecological Transitions

Figure 18. Transition of mature conifer forest near its marginal edge to: (1) open, low-density conifer forest mixed with sagebrush steppe in the 2001 Owens Fire (top photo); (2) early-seral sagebrush steppe on the edge of open conifer forest (second from top photo; post-fire conifers killed by high crown scorch) dominated by early successional shrubs (mostly bitterbrush and snowberry), forbs, and grasses; and (3) early-seral aspen stands (second from bottom and bottom photos). Bottom three photos were burned in the 2021 Dexter Fire.

Figure 19. Post-fire sagebrush vegetation change at a: (1) drier (lower elevation) site three years after the 2016 Owens River Fire (top photo), (2) moister (higher elevation) site one year after the 2021 Dexter Fire (middle photo), and (3) higher elevation site near Bald Mountain in the analysis area about 23 years after a 1993 wildfire (bottom photo). Sagebrush and other shrub cover has noticably recovered in the bottom photos but may not recover in the top photo, where dry site conditions and climate change could inhibit post-fire sagebrush regeneration in the absence of active restoration efforts. Top photo by M. Slaton.

Appendix D. Pyrosilviculture approach to restoring forest landscapes

A pyrosilviculture approach to forest restoration as described in North et al. (2021) could be readily applied to the restoration of eastside coniferous forests on the Inyo National Forest. This approach uses a combination of strategic mechanical thinning (e.g., strategic fuel breaks, variable density thinning), prescribed burning, and use of areas burned at low to moderate severity in wildfires to plan and implement prescribed fire at larger spatial scales. Forest thinning would be applied in “anchor,” “ecosystem asset,” and “revenue” focused treatments shown in Figure 20 and

Figure 21 below.

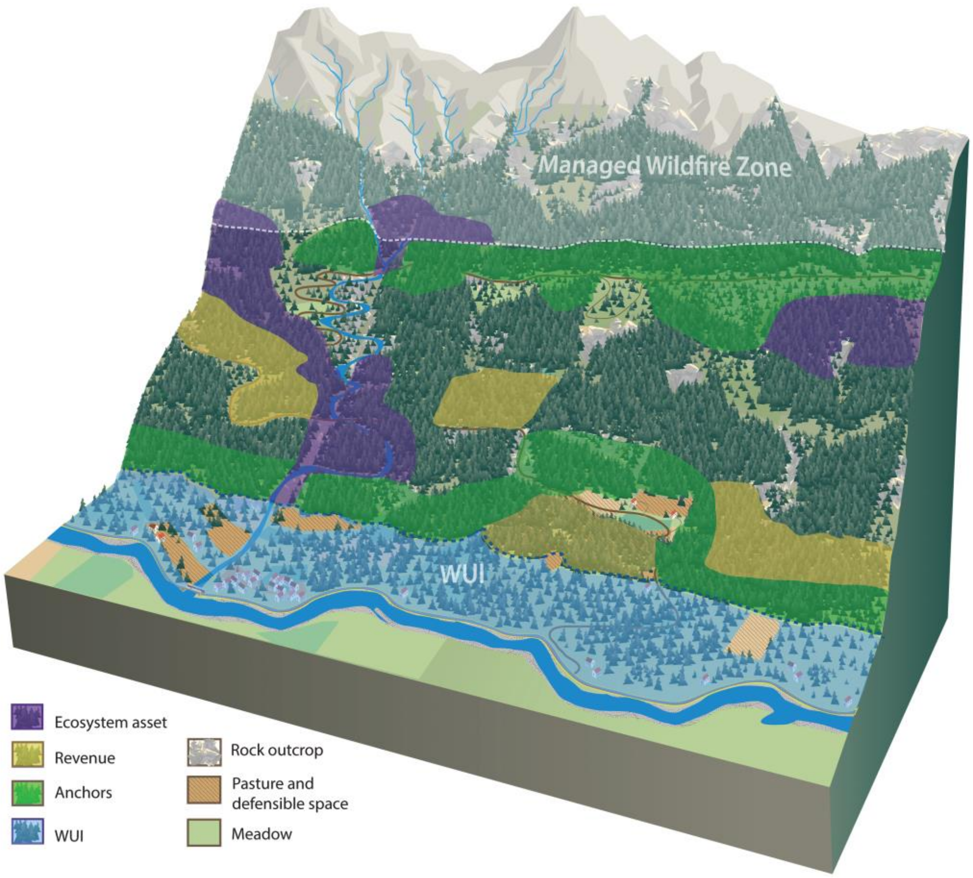

Figure 20. Schematic from North et al. (2021) of how anchors, ecosystem assets, and revenue thinning treatments might be placed in a landscape. Anchors back to roads or strategic fuel breaks and are ignition locations for expanding prescribed fire between anchors. Managers have the option of letting prescribed fire continue up through or managed wildfire burn down through the upper string of anchors under favorable conditions. Ecosystem assets (e.g., old forests, Goshawk PAC) are located where fuel reduction is needed to maintain particular ecological values, and revenue thinning treatments (e.g., secondary-growth forests) are in locations where accessible medium-diameter conifers can be removed to restore resilience and prepare stands for the application of prescribed fire or resource objective wildfires.

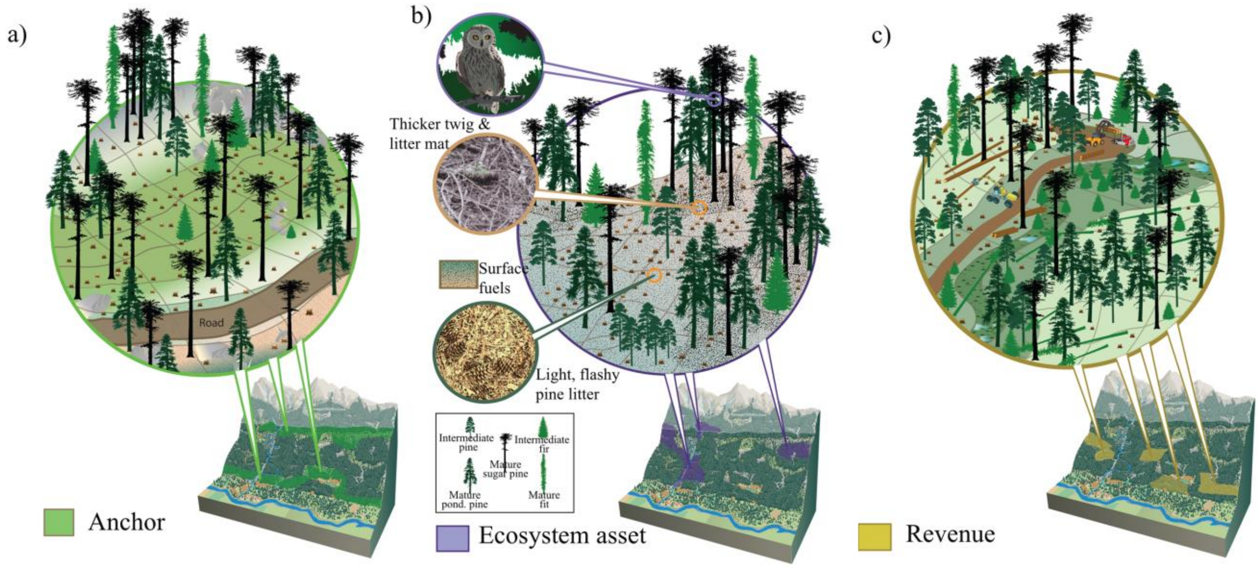

Figure 21. Stand-level schematics from North et al. (2021) of the three thinning treatments: (a) an anchor, or strategic fuel treatment near a road to serve as a "backstop" to fire (requires heavy fuels reduction leaving only large spatially separated pines possibly bordering sequoia grove actual or administrative boundaries) grading into a more mixed-species forest with a fire resistant spatial pattern (i.e., individual trees, clumps of trees and openings [ICO]) where the fire leaves the anchor; (b) an ecosystem asset (e.g., burned sequoia groves) where most thinned trees are ladder-fuel size (includes small and medium-diameter trees), an ICO pattern is created, and pine litter is dispersed in openings to facilitate fire spread; and (c) a revenue thinning where intermediate sized trees can be removed with mechanical thinning prior to the application of wildland fire treatments.

Appendix E: Coniferous Forests of the Glass Mountain Range: An Ideal Landscape for the Reestablishment of Natural Fire Regimes

The Glass Mountain Range contains about 78,000 acres of conifer and aspen forests located southeast of Mono Lake in the northern Inyo National Forest (Mono Lake Ranger District). This landscape overlaps with 24 Potential Operational Delineations (PODs) and 11 watersheds (HUC12) and spans an elevation range of 7,200 to 11,123 feet. It is dominated by eastside Jeffrey pine and dry lodgepole pine forests interspersed with variably-sized aspen stands and a limited area of subalpine forest at the higher elevations (mainly >10,000 feet). Sagebrush steppe and pinyon-juniper woodlands surround the conifer forest zone especially in the eastern half of the range. This forest landscape represents an exemplary location for the reestablishment of natural fire regimes and restoration of forest ecosystems using wildland fire for the following reasons:

1. It is a remote landscape with minimal overlap with the wildland urban interface or community wildfire protection zone (only 0.4% of the forest landscape). Nearly all of this landscape is within the wildfire restoration or maintenance zone[12].
2. This landscape is dominated by historically frequent low-moderate severity fire regimes, particularly in eastside Jeffrey pine forest and dry lodgepole pine forests. The relatively low productivity of these forest types likely requires fewer fire entries to restore forest structure (one to two burn entries; see Meyer et al. 2020, Safford et al. 2021) than similar forest ecosystems of the western Sierra Nevada (three or more burn entries).
3. The area has a recent history of many prescribed fires and several wildfires managed for resource objectives (e.g., 2019 Springs Fire, 2007 O'Harrel Fire, 2004 Crater Mountain Fire, 2003 Dexter Fire) that have resulted in fire effects within the natural range of variation and desired conditions (Figure 22). Combined with extensive areas of low fuel loading (i.e., open sand flats), these fires are strategically located to break up wildland fire spread in the forest landscape into two broad sections of the Glass Mountain Range: western and eastern. Such barriers provide potential control lines and anchor points for fire management activities, including the landscape-scale application of prescribed fire and wildfires managed for multiple objectives (especially resource objectives).
4. The forest landscape has been relatively less impacted by recent uncharacteristic wildfires, drought, bark beetle outbreaks, and climate change than other regions of the southern Sierra Nevada. Post-fire shrub growth is minor compared to west-side forests.

[12] Under the revised Inyo Forest Plan (2019) and excludes non-forest vegetation in the Glass Mountain Range.

5. The area contains two Research Natural Areas (Indiana Summit, Sentinel Meadow) and other sites that are ideal for research and monitoring of fire effects, including ongoing monitoring efforts in the Indiana Summit Research Natural Area and 2019 Springs Fire.
6. The landscape contains relatively fewer resource concerns in coniferous forests (e.g., species of conservation concern, invasive species) that may be impacted by the reintroduction of natural fire regimes than other parts of the Inyo National Forest and Sierra Nevada bioregion.
7. Wildland fire smoke from the area typically has little impact to surrounding communities due to the relative isolation and prevalent smoke dispersion patterns in the region.
8. The western portion of the landscape contains relatively gentle topography and many roads that can serve as potential control lines and anchor points to pursue a pyrosilviculture or other fire-based forest restoration approach (see Appendix D).

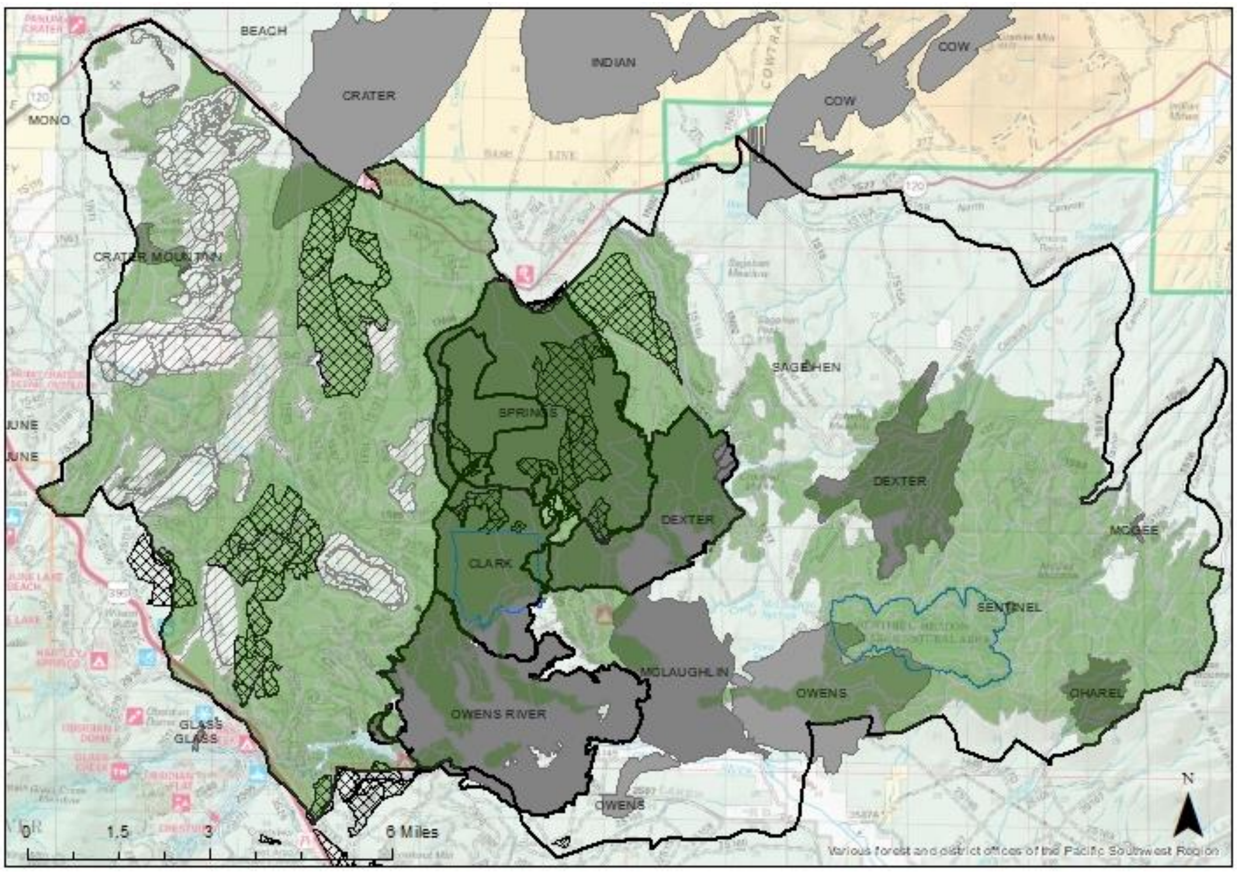

Figure 22. Glass Mountain Range forest landscape showing conifer forest vegetation (green), recent wildfires (1984-2021; gray-shaded with fire names shown), recent prescribed fires (2000-2020; cross-hatched), open sand flats (sparse dry forb vegetation; single-hatched), and research natural areas (blue outline). The entire landscape is delineated by the bold black line and can be divided into western and eastern sections split by the 2019 Springs, 2021 Dexter, 2016 Clark, and 2016 Owens River fires.

Appendix F. Climate-smart reforestation example from North et al. (2019)

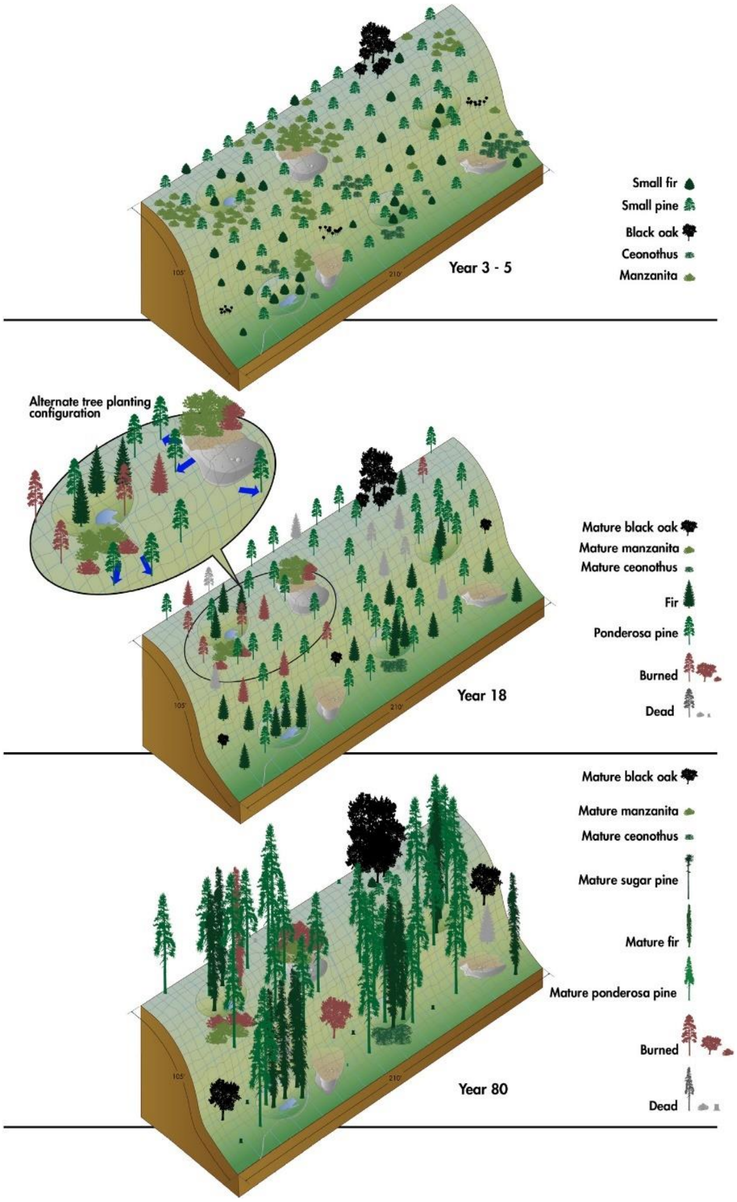

Figure 23. Schematic of the initial planting and stand development for a dissected, more fire and drought prone 0.2 ha (0.5 ac, 105 by 210 ft) slope of mixed-conifer forest where favorable cluster microsites are more easily identified. (A) Initial planting schematic (usually within 1–5 years following disturbance). First more mesic microsites (concavities in the figure) are identified and planted with clusters of trees and then the remaining area is planted with individual trees on a regularly spaced grid (here 4.6 m or 15′ by 15′). In this example only 60 of 115 (i.e., if fully planted on a 4.6 m spacing) potential trees are regularly planted, and 22 are planted in four clusters at mesic microsites. (B) After the first burn (15 years after planting). In this hypothetical example, of the 82 original conifers, eight have died over the last period and nine were killed by the prescribed fire, reducing live tree density to 65 on the 0.2 ha (0.5 ac). The prescribed fire, designed to maintain tree and shrub separation, has also killed some shrubs. (C) After 77 years of growth. Fire has been applied every 15 years to reduce fuels and shrub cover. In this example, 22 more trees have been killed by drought and prescribed fire, leaving a mature forest density of 40 conifer and three hardwood trees (212 tree/ha or 86 trees/ac), within the estimated historical mixed conifer density range of 59–329 tree/ha (24–133 trees/ac) (Safford and Stevens 2017). Figure and caption from North et al. (2019).

Glossary (excerpted from PSW-GTR-270)

Active restoration or management—Direct interventions to achieve desired outcomes (including restoration), which may include harvesting and planting of vegetation and the intentional use of fire, among other activities.

Adaptive management—A structured, cyclical process for planning and decision-making in the face of uncertainty and changing conditions with feedback from monitoring, which includes using the planning process to actively test assumptions, track relevant conditions over time, and measure management effectiveness. Additionally, adaptive management includes iterative decision-making through which results are evaluated and actions are adjusted based upon what has been learned.

Biodiversity—In general, the variety of life forms and their processes and ecological functions, at all levels of biological organization from genes to populations, species, assemblages, communities, and ecosystems.

Climate adaptation—Management actions to reduce vulnerabilities to climate change and related disturbances.

Climate change—Changes in average weather conditions (including temperature, precipitation, and risk of certain types of severe weather events) that persist over multiple decades or longer, and that result from both natural factors and human activities such as increased emissions of greenhouse gases (U.S. Global Change Research Program 2017).

Climatic water deficit (CWD) —Annual evaporative demand that exceeds available water, summed annually. It is calculated based on potential evapotranspiration minus actual evapotranspiration. CWD measures when plants have insufficient water to support photosynthesis and is a measure of plant drought stress.

Community (plant and animal)—A naturally occurring assemblage of plant and animal species living within a defined area or habitat.

Composition—The biological elements within the various levels of biological organization, from genes and species to communities and ecosystems.

Connectivity (of habitats) —Environmental conditions that exist at several spatial and temporal scales that provide landscape linkages that permit: (a) the exchange of flow, sediments, and nutrients; (b) genetic interchange of genes among individuals between populations; and (c) the long distance range shifts of species, such as in response to climate change.

Desired conditions—A description of specific social, economic, and/or ecological characteristics toward which management of the land and resources are directed.

Disturbance regime—A description of the characteristic types of disturbance on a given landscape; the frequency, severity, and size distribution of these characteristic disturbance types and their interactions.

Disturbance—Any relatively discrete event in time that disrupts ecosystem, watershed, community, or species population structure and/or function and changes resources, substrate availability, or the physical environment.

Ecological conditions—The biological and physical environment that can affect the diversity of plant and animal communities, the persistence of native species, invasibility, and the productive capacity of ecological systems. Ecological conditions include habitat and other influences on species and the environment. Examples of ecological conditions include the abundance and distribution of aquatic and terrestrial habitats, connectivity, roads and other structural developments, human uses, and occurrence of other species.

Ecological integrity—The quality or condition of an ecosystem when its dominant ecological characteristics (for example, composition, structure, function, connectivity, and species composition and diversity) occur within the natural range of variation and can withstand and recover from most perturbations imposed by natural environmental dynamics or human influence.

Ecological restoration—"The process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed" (SER 2004). Ecological restoration focuses on reestablishing the composition, structure, pattern, and ecological processes necessary to facilitate terrestrial and aquatic ecosystems sustainability, resilience, and health under current and future conditions (36 CFR 219.19).

Ecosystem—A spatially explicit, relatively homogeneous unit of the earth that includes all interacting organisms and elements of the abiotic environment within its boundaries.

Ecosystem services—Benefits people obtain from ecosystems, including provisioning services (e.g., clean air, fresh water, food, wood products), regulating services (e.g., carbon storage, water filtration and storage; regulation of disturbances and diseases), supporting services (e.g., pollination, seed dispersal, soil formation, and nutrient cycling), and cultural services (e.g., spiritual, recreational, and aesthetic experiences. Some references distinguish "ecosystem goods" from services, while others categorize "goods" under "provisioning services".

Endangered species—Any species or subspecies that the Secretary of the Interior or the Secretary of Commerce has deemed in danger of extinction throughout all or a significant portion of its range.

Exposure—The sum of climate and climate-related changes that may negatively or positively affect an ecosystem, population, or other resource.

Fire-dependent vegetation types—A vegetative community that evolved with fire as a necessary contributor to vitality and renewal of habitat for its member species.

Fire exclusion—Curtailment of wildland fire because of deliberate suppression of ignitions, as well as unintentional effects of human activities such as intensive grazing that removes grasses and other fuels that carry fire.

Fire intensity—The amount of energy or heat released during a fire.

Fire regime—A characterization of long-term patterns of fire in a given ecosystem over a specified and relatively long period of time, based upon multiple attributes including frequency, severity, extent, spatial complexity, and seasonality of fire occurrence.

Fire return interval—The amount of time between successive fire events in a given area.

Fire return interval departure—Comparison between pre-Euro-American settlement and contemporary fire return intervals.

Fire risk—The likelihood of a negative outcome and the severity of subsequent negative consequences resulting from fire.

Fire severity—The magnitude of the effects of fire on ecosystem components including vegetation or soils.

Fire suppression—The act of extinguishing wildfires by humans.

Fuels (wildland)—Combustible material in wildland areas including live and dead plant biomass such as trees, shrub, grass, leaves, litter, snags, and logs.

Fuels management—Manipulation of wildland fuels through mechanical, chemical, biological, or manual means, or by fire, in support of land management objectives to control or mitigate the effects of future wildland fire.

Function (ecological) —Ecological processes, such as energy flow; nutrient cycling and retention; soil development and retention; predation and herbivory; and natural disturbances such as wind, fire, and floods that sustain composition and structure.

Future range of variation (FRV)—The natural fluctuation of pattern components of healthy ecosystems that might occur in the future, primarily affected by climate change, human infrastructure, invasive species, and other anticipated stressors.

Goals (in land management plans)—Broad statements of intent, other than desired conditions, that do not include expected completion dates.

Habitat—An area with the environmental conditions and resources that are necessary for occupancy by a species and for individuals of that species to survive and reproduce.

Habitat fragmentation—Discontinuity in the spatial distribution of resources and conditions present in an area at a given scale that affects occupancy, reproduction, and survival in a particular species.

Heterogeneity (forest)—Diversity, often applied to variation in forest structure within stands in horizontal (e.g., single trees, clumps of trees, and gaps of no trees) and vertical (e.g., vegetation at different heights from the forest floor to the top of the forest canopy) dimensions, or across large landscapes (North et al. 2009). The opposite of forest structural homogeneity.

High severity burn patch—A contiguous area of high severity or stand-replacing fire.

Historical range of variation (HRV)—Past fluctuation or range of ecosystem conditions over a specified area and period of time.

Invasive species—Any species, including its seeds, eggs, spores, or other biological material capable of propagating that species, that is not native to a particular ecosystem, and whose deliberate, accidental, or self-introduction is likely to cause economic or environmental harm or harm to human health.

Land and Resource Management Plan (Forest Service)—A document or set of documents that provide management direction for National Forest administrative unit. Also referred to on national forestlands as “forest plans.”

Landscape—A defined area irrespective of ownership or other artificial boundaries, encompassing a mixture of terrestrial and aquatic ecosystems, landforms, and plant communities, repeated in similar form throughout such a defined area.

Late seral forest—A forest distinguished by old trees (generally >150 to 200 years) and related structural attributes that often (but not always) include large trees, relatively high biomass of dead wood (i.e. snags, downed coarse wood), multiple canopy layers, distinctive species composition and functions, and vertical and horizontal diversity in the tree canopy. In dry, fire-frequent forests, old growth is characterized by large, old fire-resistant trees and relatively open stands without canopy layering.

Monitoring—A systematic process of collecting information to track implementation (implementation monitoring), to evaluate effects of actions or changes in conditions or relationships (effectiveness monitoring), or to test underlying assumptions (validation monitoring).

Native species—A species historically or currently present in a particular ecosystem as a result of natural migratory or evolutionary processes and not as a result of an accidental or deliberate introduction or invasion into that ecosystem.

Natural range of variation (NRV)—Spatial and temporal variation in ecosystem characteristics under historical disturbance regimes during a reference period or from a reference location.

Objective (in land management plans)—Concise, measurable, and time-specific statement of a desired rate of progress toward a desired condition.

Patch—A relatively small area with similar environmental conditions, such as vegetative structure and composition. Sometimes used interchangeably with vegetation or forest stand.

Potential wildland fire Operational Delineation unit (POD)—Spatial representation of an area that summarizes wildfire risk in a meaningful operational fire management context. Potential operational delineations can follow fine-scale features such as ridgetops, water bodies, roads, barren areas, elevation changes or major fuel changes.

Prescribed fire—A wildland fire originating from a planned ignition to meet specific objectives identified in a written, approved, prescribed fire plan for which NEPA requirements (where applicable) have been met prior to ignition (synonymous with controlled burn).

Reburn—Fire that burns an area where fuels (such as scorched needles, twigs, branches, and tree boles that fall to the surface) are primarily derived from a previous burn. Reburns may result in reduced ecosystem integrity when they facilitate fire regime transitions outside the natural range of variation, such as fire burning too frequently or severely.

Recovery, ecosystem—The reestablishment of essential ecosystem structure, composition, and function that supports long-term ecological integrity, health, and sustainability. Recovered ecosystems contain sufficient biotic and abiotic resources to continue successional development without assistance, are functionally self-sustaining, exhibit resilience to anticipated environmental stressors and perturbations, and interact with adjoining connected ecosystems (SER 2004; see “ecological restoration”).

Resilience—The capacity of an ecosystem to absorb disturbance and reorganize (or return to its previous organization) so as to retain essentially the same function, structure, identity, and feedbacks. Definitions emphasize the capacity of a system or its constituent entities to respond or regrow after mortality induced by a disturbance event, although broad definitions of resilience may also encompass “resistance” (see below), under which such mortality may be averted.

Resistance—The capacity of an ecosystem or an entity to withstand a disturbance event without much change or alteration in essential characteristics.

Restoration, ecological—see “ecological restoration”

Restoration, functional—Restoration of dynamic abiotic and biotic processes in degraded ecosystems, without necessarily a focus on structural condition and composition.

Restoration strategy—A strategic vision that describes broad ecological restoration approaches that support ecosystem management goals and objectives within a specific landscape of interest.

Riparian areas—Three-dimensional ecotones [the transition zone between two adjoining communities] of interaction that include terrestrial and aquatic ecosystems that extend down into the groundwater, up above the canopy, outward across the floodplain, up the near-slopes that drain to the water, laterally into the terrestrial ecosystem, and along the water course at variable widths (36 CFR 219.19).

Scale—In ecological terms, the extent and resolution in spatial and temporal terms of a phenomenon or analysis, which differs from the definition in cartography regarding the ratio of map distance to earth surface distance.

Shrubland—An area (generally large and persistent) dominated by shrubs.

Soil burn severity—The effect of fire on ground surface characteristics, including organic matter loss, reduced infiltration, char accumulation, and altered soil structure.

Species of conservation concern—A species, other than federally recognized threatened, endangered, proposed, or candidate species, that is known to occur in the plan area and for which the Regional Forester has determined that the best available scientific information indicates substantial concern about the species' capability to persist over the long-term in the plan area.

Stand—A land management unit consisting of a contiguous group of trees sufficiently uniform in age-class distribution, composition and structure, and growing on a site of sufficiently uniform quality, to be a distinguishable unit.

Stand-replacing fire— High severity fire, where fire kills more than 75% of the dominant vegetation (see “vegetation burn severity”).

Stressors—Factors that may directly or indirectly degrade or impair ecosystem composition, structure or ecological process in a manner that may impair its ecological integrity, such as an invasive species, loss of connectivity, or the disruption of a natural disturbance regime (36 CFR 219.19).

Structure (ecosystem)—The organization and physical arrangement of biological elements such as snags and down woody debris, vertical and horizontal distribution of vegetation, stream habitat complexity, landscape pattern, and connectivity.

Sustainability—The capability to meet the needs of the present generation without compromising the ability of future generations to meet their needs. Sustainability is sometimes defined in terms of three dimensions: ecological (capability to maintain ecological integrity), economic (capability to produce and benefit from goods and services), and social (capability to support networks of relationships, traditions, culture, and activities that connect people to the land and to one another in vibrant communities). (36 CFR 219.19)

Sustainability (ecological)—The capability of ecosystems to maintain ecological integrity (36 CFR 219.19).

Succession—Non-seasonal and directional change in species composition and structure in an ecological community over time.

Uncertainty—Amount or degree of confidence as a result of imperfect or incomplete information.

Vegetation burn severity—The magnitude of the effect of fire on vegetation (see "fire severity"), often classified as: (1) low severity, with <25% mortality of the dominant vegetation (e.g., trees, shrubs); (2) moderate severity, with 25-75% mortality of the dominant vegetation; and (3) high severity, with >75% mortality of the dominant vegetation (also referred to as "stand-replacing fire").

Vegetation type—A general term for a combination or community of plants (including grasses, forbs, shrubs, or trees), typically applied to existing vegetation rather than potential vegetation.

Vulnerability—The degree to which a system is susceptible to, or unable to cope with, change.

Watershed—A region or land area drained by a single stream, river, or drainage network; a drainage basin.

Watershed restoration—Restoration activities that focus on restoring the key ecological processes required to create and maintain favorable environmental conditions for aquatic and riparian-dependent organisms.

Wildlife—Undomesticated animal species including amphibians, reptiles, birds, mammals, fish and invertebrates or even all biota that live wild in an area without being introduced by humans.

Wildfire—Unplanned ignition of a wildland fire (such as a fire caused by lightning, volcanoes, unauthorized and accidental human-caused fires) and escaped prescribed fires.