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U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT

Camp Fire Reforestation Plan

A CLIMATE-INFORMED RESTORATION AND REGENERATION PLAN FOR THE BUREAU OF LAND MANAGEMENT IN BUTTE COUNTY, CALIF.

Prepared by:
Austin Rempel, senior manager of forest restoration, American Forests
Britta Dyer, California state director, American Forests
Brooke Thompson, forest ecologist, Bureau of Land Management - Redding Field Office
Coreen Francis, California and Nevada state forester, Bureau of Land Management
Heidi Rogers, forester, Bureau of Land Management - Redding Field Office
Kristin Schmitt, climate change outreach specialist, Northern Institute of Applied Climate Sciences
Leana Weissberg, forester, Bureau of Land Management - Mother Lode Field Office
Luis Vidal, Sierra Corps forestry fellow, American Forests and Sierra Nevada Alliance
Rob Winkler, fire management officer, Bureau of Land Management - Redding Field Office
Tyler Schroyer, forestry technician, Bureau of Land Management - Redding Field Office

Review and Technical Contributions:
Benjamin Raynal, forester, Sierra Pacific Industries
Brian Kittler, senior director of forest restoration, American Forests
Derek Young, research ecologist, University of California, Davis
Elaine Vercruysse, partnership coordinator/tribal liaison, U.S. Forest Service - Plumas National Forest
Eric Sprague, vice president of forest restoration, American Forests
Jessica Wright, research geneticist, U.S. Forest Service - Pacific Southwest Research Center
Kyle Merriam, ecologist, U.S. Forest Service - Sierra Cascade Ecology Program
Libby Pansing, forest restoration scientist, American Forests
Ryan Boynton, GIS programmer, University of California, Davis
Ryan Davy, district silviculturalist, U.S. Forest Service - Plumas National Forest
Ryan Tompkins, forestry and natural resources advisor, UC Cooperative Extension
Susie Kocher, extension forester, UC Cooperative Extension
Taylor Nilsson, assistant director of operations - Fuels Reduction and Timber and Biomass, Butte County Fire Safe Council
Wolfy Rougle, forest health watershed coordinator, Butte County Resource Conservation District

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Executive Summary

The 2018 Camp Fire burned more than 153,000 acres, killed 85 people and destroyed over 18,000 structures in Butte County, Calif. The fire burned across a landscape that — with the addition of the 2020 North Complex fires — has endured at least 16 large wildfires since 1999. The repeated high-severity fires have been accompanied by record-breaking heatwaves, droughts and widespread tree mortality.

Climate change will continue to reshape the region's forests, and land managers are searching for tangible ways to help the ecosystem adapt. The Bureau of Land Management (BLM) — which oversees 4,070 acres impacted by the Camp Fire, 40% of which burned at moderate to high severity — is at the forefront of these efforts and has initiated a climate planning process to help guide forest management into the future.

Using the "Climate Change Response Framework," American Forests and the BLM defined management goals, conducted a vulnerability assessment to assess potential climate impacts in the Camp Fire burn scar, and developed management tactics based on a recently published menu of adaptation strategies and approaches specific to California's forests. These recommendations consider best management practices in the face of a changing climate and are intended to promote resilience and foster adaptation for long-term forest recovery.

Highlights from the report are summarized below:

Climate impacts: Managers should plan for increased temperatures, more variable precipitation cycles and a 'thirstier atmosphere', as well as longer fire seasons, with larger and more frequent fires. These trends will make active forest management more important and also more challenging.

Vegetation and tree species shifts: Climate warming over the past century has already led to dramatic changes in regional vegetation patterns. For example, between 1934 and 1996, California's ponderosa pine forests retreated upslope nearly 600 feet. These trends will continue with ongoing warming, and climate models generally agree that conifer forests with species like ponderosa pine, Douglas-fir and sugar pine will decline in the Camp Fire region, to be replaced by mixed forest (e.g., oaks and gray pine), chaparral and/or oak grasslands. Changes in fire frequency and extent — a key driver of vegetation type distribution — will accompany these changes in forest types.

Windows to future climates: Climate models suggest that in the coming decades, the climate at 2,000 to 2,500 feet elevation zone in Butte County will experience temperatures and precipitation patterns similar to those currently observed in the immediate downslope area (the 1,000 to 2,000-foot zone) and the area just north of Redding, Calif., around Shasta Lake. These areas may be good places to collect tree seed for reforestation efforts that will be adapted to the Camp region's future climate and to identify forest types and forestry techniques suited to these new conditions. Planting genotypes from these seed zones could help increase the genetic diversity and adaptive capacity of local seed sources in the Camp Fire burn area.

Management plans: The BLM plans to focus their efforts on managing three high-priority parcels near Paradise and Magalia, Calif.: Upper Ridge, Dean Road and Jordan Hill. The management plans include:

- **Using "Topographically-based Management Units" to create forest heterogeneity.** This approach will help to generate spatial variability observed in frequent-fire forests — providing diverse habitat conditions and breaking up fuel loadings on the landscape to foster more variable wildfire spread and intensity. Tree density and canopy cover will be highest in drainage bottoms and riparian areas, decrease on mid-slope areas, and be lowest on ridgetops. Stocking and canopy cover in all three topographic positions would be higher on northeast aspects compared to hotter and drier southwest aspects. Stocking and canopy cover would also be greater on gentle slopes with deeper soils that can sustain higher canopy cover and more open on steep slopes.

- **Using assisted migration technique**s by planting seedlings grown from seed collected 500 to 1,000 feet lower in elevation than planting sites and from different seed zones. The expectation is that these seed sources will be more suited for hotter and drier conditions than seed from the same elevation as the planting sites. Fires, like the Camp Fire, often bring negative consequences, but they also present opportunities. Planting after wildfires is an opportunity to speed up climate adaptation by introducing tree genetics that may be better adapted to future climate conditions or diseases like white pine blister rust. Climate-informed reforestation can facilitate vegetation-type transitions (e.g., introducing oak species to a site historically dominated by conifers) and increase the population size and redundancy of range-restricted, endemic species like MacNab cypress.

- **Proactively managing competing vegetation and fuel loads and maintaining fuel breaks in strategic areas.** This will help to keep neighboring communities safe from fast-moving fires and help conifers and oaks to grow faster so that they can produce thick, fire–resistant bark and seed crops earlier. Not controlling shrub growth can triple how long it takes for conifer seedlings to achieve fire resistance and 'old forest' characteristics. Shrubs will be regularly controlled around planted conifers, which will be pruned to help survive prescribed fires earlier. Shrub 'islands' will be maintained at larger sites to promote plant and habitat diversity.

- **Helping sites to transition to oak-dominated forest** with post-fire regeneration pruning treatments.

The report provides in-depth information about topics and treatments that the BLM, American Forests and other Camp Fire stakeholders considered to be potentially relevant in the context of post-fire reforestation and climate change adaptation. This includes information about selecting sites where forests will be viable under anticipated climate changes; identifying species that may be adapted to future conditions; planting designs and strategies; climate-informed seed collection efforts; maintaining young oak and conifer stands in the face of harsh climate conditions; using native grasses in restoration plans; shrub management that balances the need for fast forest growth, fire safety and biodiversity/habitat maintenance; tools like herbicides and grazing with goat herds; and guidelines for monitoring and evaluation

Introduction and Background

The 2018 Camp Fire burned more than 153,000 acres, killed 85 people and destroyed over 18,000 structures in Butte County, Calif. The fire burned across a landscape that — with the addition of the 2020 North Complex fires — has endured at least 16 large wildfires since 1999.[1] The repeated high-severity fires have been accompanied by record-breaking heatwaves, droughts and widespread tree mortality.

Climate change will reshape the region's forests, and land managers and residents are looking for tangible ways to help the ecosystem adapt.[2] The Bureau of Land Management (BLM) — which oversees 4,070 acres impacted by the Camp Fire, 40% of which burned at moderate to high severity — is at the forefront of these efforts and has initiated a climate planning process to help guide forest management into the future.

In consultation with the BLM, American Forests compiled information from multiple sources, including academic literature, government reports, structured conversations and interviews with local land managers and forest scientists, climate modeling, and a variety of mapping tools to create a series of management recommendations for post-fire restoration activities on BLM land within the Camp Fire burn scar. These recommendations consider best management practices in the face of a changing climate and are intended to promote resilience and foster adaptation for long-term forest recovery.[3]

This report presents:

1) a climate-adaptive framework for developing these management strategies;
2) an assessment of climate-related vulnerabilities in the region;
3) recommendations and plans for post-fire management on BLM lands; and
4) science-based summaries for forest management activities that may be useful to other stakeholders in developing climate informed reforestation plans.

An online map has also been produced as a companion to this report to make the planning data easily accessible to the public.

Principles for the assessment

Goals and principles for the analysis — established by the BLM and American Forests early in the assessment process — include:

- Propose management strategies that are backed by solid science, yet also practical, operationally focused and financially sustainable.
- Align reforestation plans explicitly with plans and strategies for managing vegetation, fuel loading and fire risk in the short and long term.
- Present a replicable and easy to follow process for post-fire, climate-informed restoration.

- Structure the process, plan and outputs so that they will be applicable when responding to future fires that will inevitably impact the Camp Fire burn area, as well as similar frequent-fire landscapes in the region.
- Strive to make insights and information generated from the assessment accessible and relevant to the wider land management community — not just forest scientists and reforestation practitioners.
- Learn from, and engage with, others doing similar work in the area.

Climate Adaptation Framework

Climate-smart adaptation actions specifically address the impacts, risks and challenges of climate change on the landscape. The Climate Change Response Framework, developed by U.S. Forest Service's Northern Institute of Applied Climate Science (NIACS), is a flexible process for incorporating climate change concerns into land management decisions and provides a "menu" of adaptation strategies to assist reforestation practitioners in developing management actions and treatments based on objectives and expected climate impacts.[4] The menu builds upon the climate adaptation concepts of resistance, resilience and transition.[5] These ideas represent a continuum of adaptation options related to the desired level of change in a forest, from actively resisting changes — maintaining current or historical conditions — to accelerating ecological transitions, to approaches such as translocating species to new areas (Figure 1). Adaptation actions might represent a combination of these three concepts, or may emphasize certain concepts at different points in time:[6]

- **Resistance** – buffer or protect from change
    - o Example: Fire suppression
- **Resilience** – promote return to a prior state or condition (e.g., historical range of variation) after a disturbance
    - o Example: Prescribed fire, variable density thinning, promoting heterogeneity
- **Transition** – actively facilitate or accommodate change (e.g., towards an anticipated future range of variation)
    - o Example: Introduce new species or vegetation types

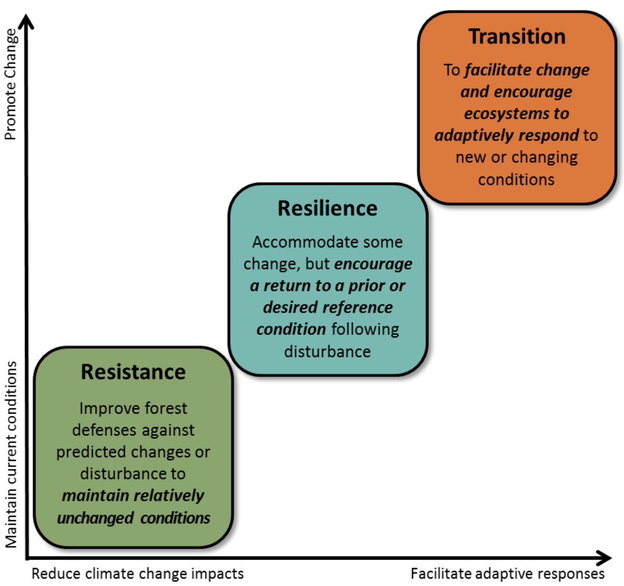


Figure 1. Categories of climate adaptation.

Menus specific to a variety of ecosystems and locations have been developed. This plan uses the menu outlined in "Adaptation Strategies and Approaches for California Forest Ecosystems," developed by NIACS and the California Climate Hub.[7] Reforestation practitioners can select from the strategies and approaches outlined in the menu and develop specific place-based tactics that suit their unique project locations and

Incense cedar that survived the Camp Fire.
Credit: Austin Rempel / American Forests.

goals. Climate-adaptive management actions are not always different from what practitioners are already doing (e.g., thinning and fuels reduction), but the menu helps to track and articulate the intent of these actions and place them in the context of climate adaptation.

Following the Climate Adaptation Framework, we defined management goals, conducted a vulnerability assessment to assess potential climate impacts in the Camp Fire burn scar, and developed management tactics based on the menu of adaptation strategies and approaches. All steps were facilitated by on-site visits and meetings with the BLM and regional partners, a literature review and application of a variety of mapping tools. The vulnerability assessment was aided by materials from the recently completed Northern California Climate Adaptation Project, led by EcoAdapt and funded by the BLM, along with several other regional land management agencies.[8]

Adaptation strategies and approaches for California forest ecosystems

Strategy 1: Sustain fundamental ecological functions.

Approach 1.1. Reduce impacts to soils and nutrient cycling.
Approach 1.2. Maintain or restore hydrology.
Approach 1.3. Maintain or restore functional riparian systems.
Approach 1.4. Reduce vegetation competition for moisture, nutrients and light.
Approach 1.5. Restore or maintain fire in fire-adapted systems.

Strategy 2: Reduce the establishment, spread and impact of biological stressors.

Approach 2.1. Maintain or improve the ability of forests to resist pathogens and insect pests.
Approach 2.2. Minimize the risk of the introduction and establishment of invasive plants and remove existing invasive species.
Approach 2.3. Manage herbivory to promote regeneration of desired species.

Strategy 3: Reduce the risk and long-term impacts of severe disturbances.

Approach 3.1. Alter forest structure and/or composition to reduce risk or severity of wildfire.
Approach 3.2. Establish and maintain fuel breaks to minimize the risk of uncharacteristic, high-severity fire.
Approach 3.3. Alter forest structure to reduce severity or extent of extreme weather events.
Approach 3.4. Promptly revegetate after disturbance.

Strategy 4: Maintain or create refugia.

Approach 4.1. Prioritize and maintain unique sites.
Approach 4.2. Prioritize and maintain sensitive or at-risk species or communities.
Approach 4.3. Establish artificial reserves for at-risk and displaced species.

Strategy 5: Maintain and enhance species diversity and forest structural heterogeneity.

Approach 5.1. Promote forest age-, size-class diversity and spatial heterogeneity.
Approach 5.2. Maintain and restore diversity of native species.
Approach 5.3. Retain biological legacies.
Approach 5.4. Establish reserves to maintain ecosystem diversity.

Strategy 6: Maintain or increase ecosystem redundancy across the landscape.

Approach 6.1. Manage habitats over a range of sites and conditions.
Approach 6.2. Expand the boundaries of reserves to increase diversity.

Strategy 7: Promote landscape connectivity.

Approach 7.1. Reduce landscape fragmentation.
Approach 7.2. Maintain and create landscape linkages through reforestation or restoration.

Strategy 8: Maintain and enhance genetic diversity.

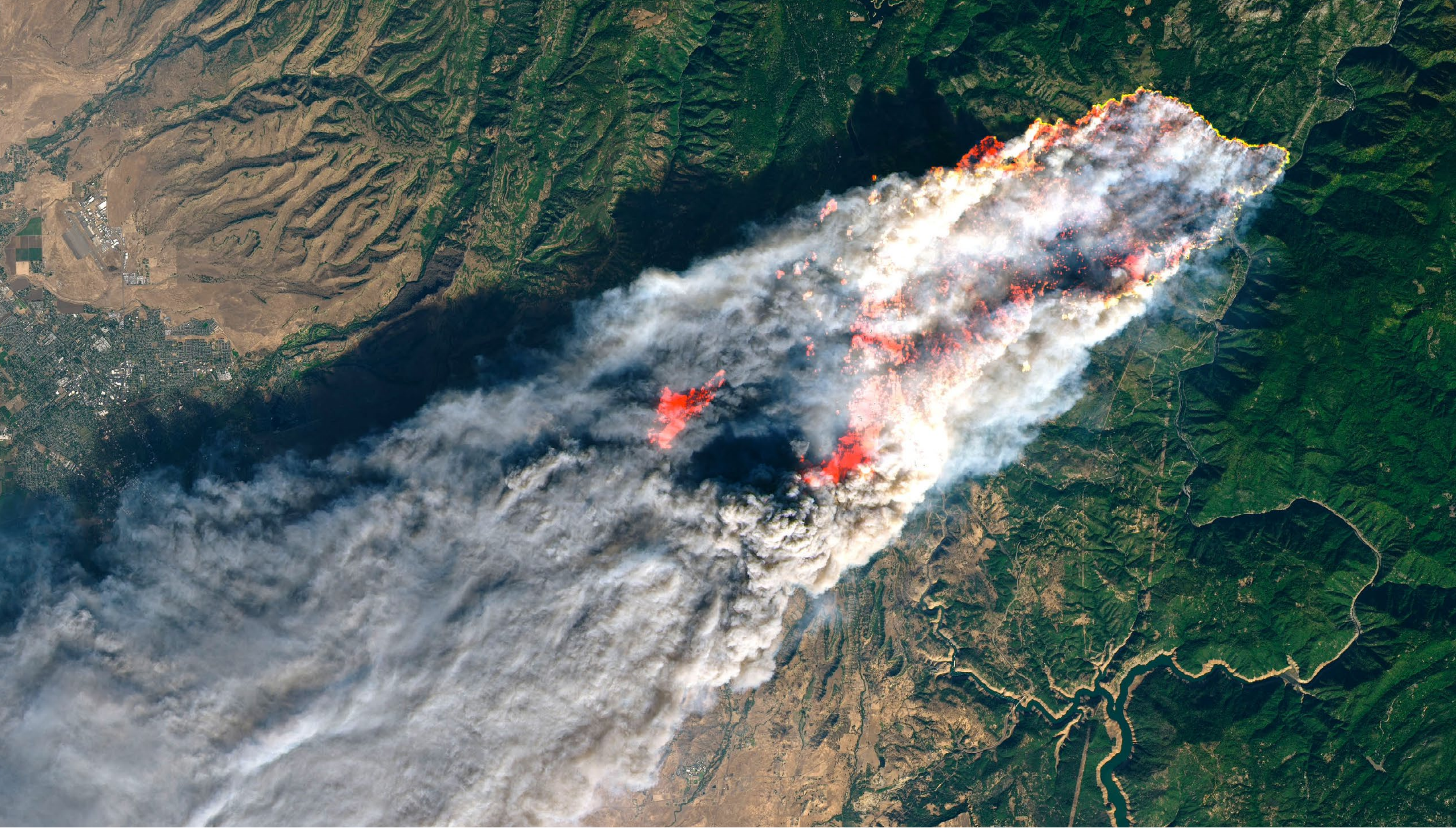
Approach 8.1. Use seeds, germplasm and other genetic material from across a greater geographic range.
Approach 8.2. Favor existing genotypes that are better adapted to future conditions.

Strategy 9: Facilitate ecological community adjustments through species transitions.

Approach 9.1. Favor or restore native species that are expected to be adapted to future conditions.
Approach 9.2. Establish or encourage new mixes of native species.
Approach 9.3. Guide changes in species composition at early stages of forest development.
Approach 9.4. Protect future-adapted seedlings and saplings.
Approach 9.5. Disfavor species that are distinctly maladapted.
Approach 9.6. Manage for species and genotypes with wide moisture and temperature tolerances.
Approach 9.7. Introduce species that are expected to be adapted to future conditions.
Approach 9.8. Move at-risk species to locations that are expected to provide sustainable habitat.

Strategy 10: Realign ecosystems after disturbance.

Approach 10.1. Promptly revegetate sites after disturbance.
Approach 10.2. Allow for areas of natural regeneration to test for future-adapted species.
Approach 10.3. Realign significantly disrupted ecosystems to meet expected future conditions.



The 2018 Camp Fire. Credit: NASA.

Climate Vulnerability Assessment

Expected climate changes

Multiple climate-driven trends will influence future forests in the Camp Fire burn area and are relevant for land managers considering the long-term outlook for restoration initiatives. Managers should expect less cold weather, more record heat, longer and more frequent summer droughts, more severe insect outbreaks, earlier springs, and longer fire seasons. Summarized here are the expected impacts of climate change within the Camp Fire burn scar through the end of the century and the management implications of these changes.

Increased temperatures, more variable precipitation cycles and a “thirstier atmosphere”

Temperature

Average minimum and maximum temperatures are set to increase substantially year-round in the Camp Fire burn area.[9] The average lowest winter temperature in the area is projected to increase by roughly 4 degrees (40 degrees to 44 degrees), and the average summer high temperature is projected to increase by nearly 10 degrees (90 degrees to 98 degrees).

Warmer temperatures throughout the year will lengthen the growing season, which will result in longer periods for plants to photosynthesize and grow. This could also result in greater drought stress on plants if the longer growing seasons coincide with dry conditions. Higher temperatures can create drought conditions even if precipitation does not change. Insects will also be active for more of the year and spread to higher elevations.

Heat waves will become more frequent and severe.[10] Climate change has already more than doubled extreme fire weather days in autumn, when the region typically experiences its worst fires.[11]

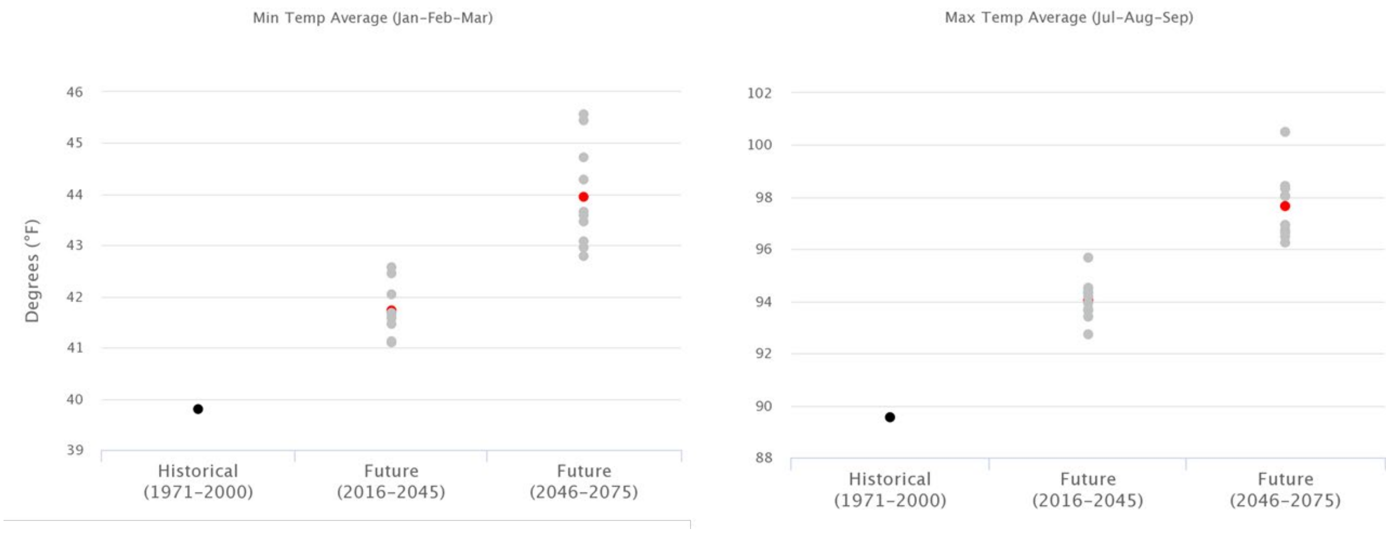


Figure 2. Projections for average minimum and maximum temperature (degrees °F) at 2,500 feet in the Camp Fire burn area. The red dot in each future timeframe represents the average of multiple projection models, which are shown in gray.[12]

Precipitation

The burn area has a typical Mediterranean climate with hot, dry summers and mild, wet winters. Precipitation occurs almost entirely as rain, with rare occurrences of snow in the lower elevations of the burn area and light annual winter snowfall accumulation in the high elevations. Average annual rainfall ranges from 25 inches per year in the lower elevations near Chico, Calif., to about 71 inches per year in the upper elevations east of the burn area.[13] In the town of Paradise, Calif., average annual rainfall is about 55 inches per year. The highest recorded annual precipitation in Paradise was 100 inches in 1995, and the lowest recorded annual precipitation was 15.5 inches in 2013.

Snow will likely disappear from the Camp Fire burn area entirely in the coming decades, as the average rain/snow transition line along the western slope of the Sierra is predicted to transition from 1,500 to 3,000 feet upslope, increasing water stress during the summer dry season.[14] California's rainy season already starts a full month later than it did historically, making seasonal droughts worse and prolonging wildfire season.[15] Although climate models generally don't agree on whether average precipitation will increase or decrease (Figure 3), there is general agreement that precipitation will become more variable. This pattern is clear in the past four years alone, where 2016 (and the four years before that) was historically dry, 2017 was historically wet, 2018 historically dry, and 2019 historically wet.

Scientists predict that drought years will be twice as likely over the next several decades, and there is growing risk of multi-year droughts due to increased probability of consecutive low-precipitation/high-temperature years. By 2030, dry years will coincide with hot years 100% of the time.[16] There is also a strong probability that extreme rainfall events will become more frequent.

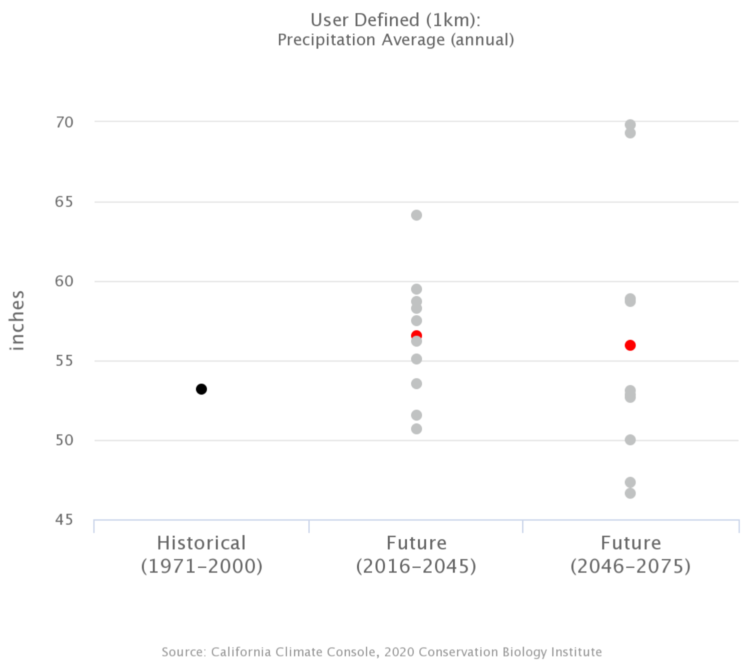


Figure 3. Projections for average annual precipitation (inches) at 2,500 feet in the Camp Fire burn area. The red dot in each future timeframe represents the average across multiple projection models, represented in gray.[17]

Evaporative demand and Climatic Water Deficit

The climate crisis is making the atmosphere "thirstier," increasing the risk of fire and drought. Based on projections for climatic water deficit (CWD) — the annual evaporative demand that exceeds available water, a measure of the extent to which the environment is trying to evaporate water, and of the potential effects of drought stress on trees — we should expect current climate conditions to move uphill by about 1,000 feet by mid-century. For example, at the 2,500- to 3,000-foot elevation band (where the BLM's highest parcels are), CWD, during the 2040 to 2069 period, is projected to match current conditions at the 1,500- to 2,000-foot elevation band (red arrows in Fig. 5). By the end of the century (2070 to 2099), conditions at 2,500 to 3,000 feet will resemble those currently prevalent at the 500- to 1,000-foot elevation band.

Increases in CWD correlate with higher tree mortality rates, particularly for drought-sensitive seedlings and larger, older trees near the limits of their range (e.g., sugar pine in the Camp Fire area), as drought-stressed trees are more vulnerable to wildfire, insects and disease.

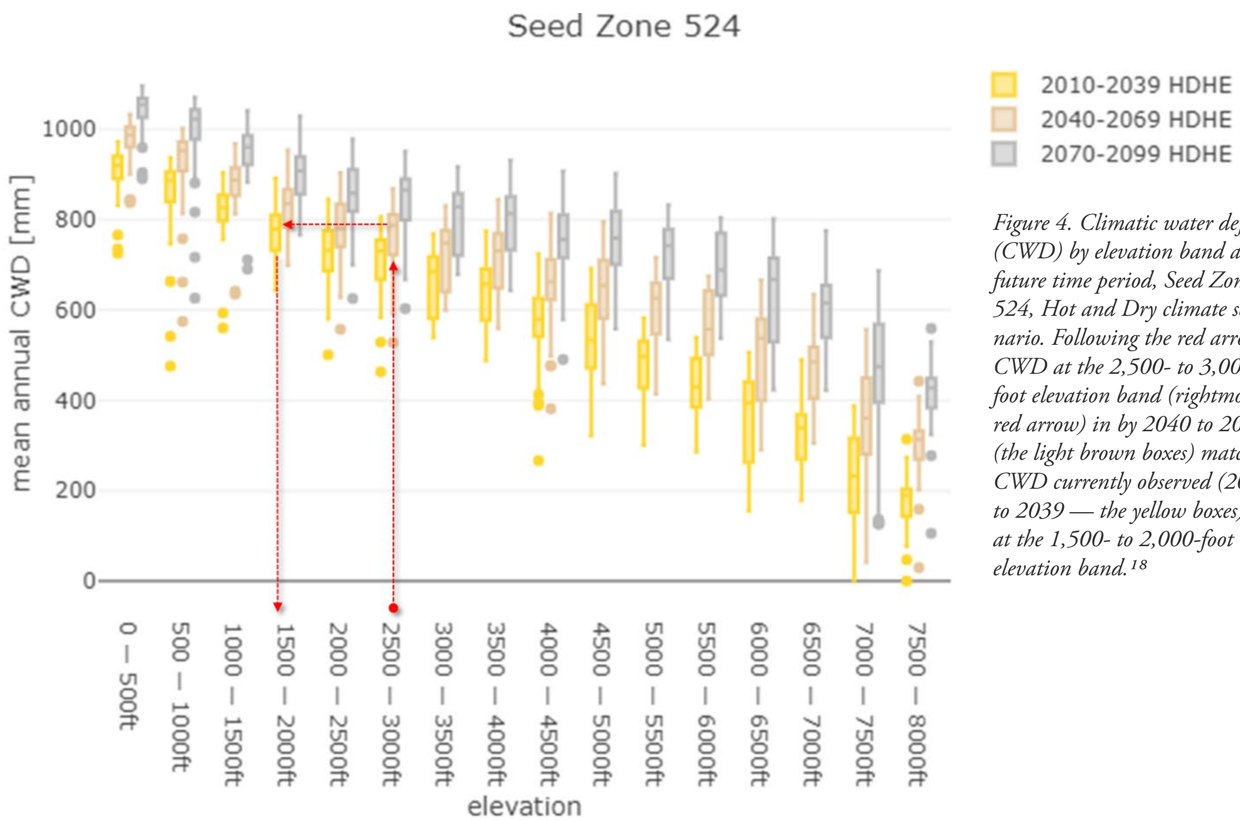


Figure 4. Climatic water deficit (CWD) by elevation band and future time period, Seed Zone 524, Hot and Dry climate scenario. Following the red arrows, CWD at the 2,500- to 3,000-foot elevation band (rightmost red arrow) in by 2040 to 2069 (the light brown boxes) matches CWD currently observed (2019 to 2039 — the yellow boxes) at the 1,500- to 2,000-foot elevation band.[18]

Longer fire seasons, with larger and more frequent fires

Climate change will influence fire regimes in ways that are difficult to predict.[19,20] According to the best available information, fire intervals are projected to shrink substantially in Northern California (i.e., there will be a shorter time between fires). Climate change is linked to larger, more frequent fires because it increases the likelihood of lightning ignitions and heat waves and causes vegetation to dry out.[21] Based on climate warming alone, Butte County will experience a 50% increase in average annual area burned (6,000-acre average 1961 to 1990 compared to 9,000 acres), and twice the annual fire risk (10% probability in recent decades versus 20% by 2035 to 2064, or two fires in every 10-year period).[22] There is also a strong possibility that fires — especially when they coincide with heatwaves and dry spells — will become more severe, presenting heightened danger for communities and firefighters, and creating large areas with complete loss of adult trees.[23,24]

Management implications

These climate trends will reshape California's forests over the coming century. Some of the main implications for forest managers in the Camp Fire area are explored below.

- **Seed collection efforts will become more challenging and require greater attention and investment.** Driven by heat and drought, cone crops will be smaller, mast years less frequent and the seeds that are produced will likely suffer from greater predation by insects.[25] These trends will be especially acute at lower elevations and for species at the lower limits of their range.

- **Hot, dry weather will cause higher mortality rates and slower growth for tree seedlings.**[26] Natural regeneration will fail more often following fires and other tree-killing events. Planting will become riskier, but also more important in places where forests are desired. Planting seasons will start earlier and end sooner in the year. Planning fall plantings, rather than just spring plantings, may be a strategy to deal with more variable precipitation patterns. Proper seedling handling, like not planting when it's hotter than 70 degrees, and planting practices, like site preparation, micrositing and shade cards, will become ever more important for project success.

- **During severe and/or prolonged droughts, large-scale tree mortality will occur on drier sites and in dense stands due to greater competition for soil moisture.** Tree species that are more sensitive to drought will likely disappear from lower elevations and latitudes. Treatments that reduce stand density, like variable density thinning and prescribed fire, may help alleviate some of these impacts.[27,28] Maintaining or increasing the diversity of tree species and genotypes at a site may also help reduce susceptibility to drought.[29]

- **Insect and disease outbreaks will be more frequent and sustained**, making low stand densities, diverse tree sizes and high tree species diversity a management priority (e.g., oaks and incense cedar can weather mountain pine beetle outbreaks and maintain forest cover at a site while pine species are targeted and killed).[30,31]

- **Longer fire seasons with more severe burning conditions will make vegetation and fuels management even more critical, especially in the wildland-urban interface.** In the context of reforestation and post-fire recovery, planting projects will need to be ever more tightly integrated with fuel breaks and landscape-level fuels planning, and planted stands will need to be more heavily managed to increase growth rates and reduce the risk of loss from reburns.[32]

Projected vegetation shifts

Climate warming over the past century has already led to dramatic changes in regional vegetation patterns. For example, between 1934 and 1996, California's ponderosa pine forests retreated upslope nearly 600 feet.[33] Many low-elevation areas historically dominated by blue oak and gray pine have converted to grasslands.[34]

These trends will continue with ongoing warming.[35,36] A University of California, Davis report predicts that "Foothill and Valley Forests and Woodlands" will continue to contract at lower elevations due to climate warming and expand upslope into areas currently dominated by mixed conifer forest.[37] Climate models generally agree that conifer-dominant forests will move upslope, to be replaced by mixed forest (oak-gray pine), chaparral and/or oak-grasslands. For mid-elevation sites in the Camp Fire area, what was historically a matrix of mixed conifer, montane hardwoods and montane chaparral (for reference, the online map includes vegetation surveys from the 1930s, and aerial photos from 1951) will likely convert to oak-gray pine foothill forest, chaparral, oak savanna and/or grassland. Projected climate and wildfire trends will favor drought-tolerant species over less drought-tolerant species, and forests will simplify, with less tree species richness on the landscape.[38] Without management interventions like thinning, prescribed fire and planting, carbon stored in forests will decline sharply in most parts of California.[39,40]

Species	2030	2060
Black oak	59%	42%
Interior live oak	55%	54%
Blue oak	52%	46%
Canyon live oak	49%	35%
Ponderosa pine	39%	34%
Douglas-fir	31%	25%
Sugar pine	13%	10%

Table 1. Projected viability scores for selected tree species at 2,500 feet elevation in the Camp Fire, 2030 and 2060.[41] Note: Bioclimate models are not yet available for all relevant species (e.g., incense cedar and gray pine). Lower viability scores indicate a lower climate suitability while higher values indicate that the species is capable of living there. Although a score below 50% suggests little chance of survival, 30% should be used as a cut-off point for whether a species could potentially be considered viable at a site, to account for the error reported in the original modeling.[42]

Climate-based projections suggest that conifers like ponderosa pine, Douglas-fir and sugar pine will continue to disappear from the Camp Fire burn area and may only remain on the most favorable growing sites (Table 1). Conifers may be limited to non-commercial species like knobcone and gray pine. Oaks will generally fare better than conifers.

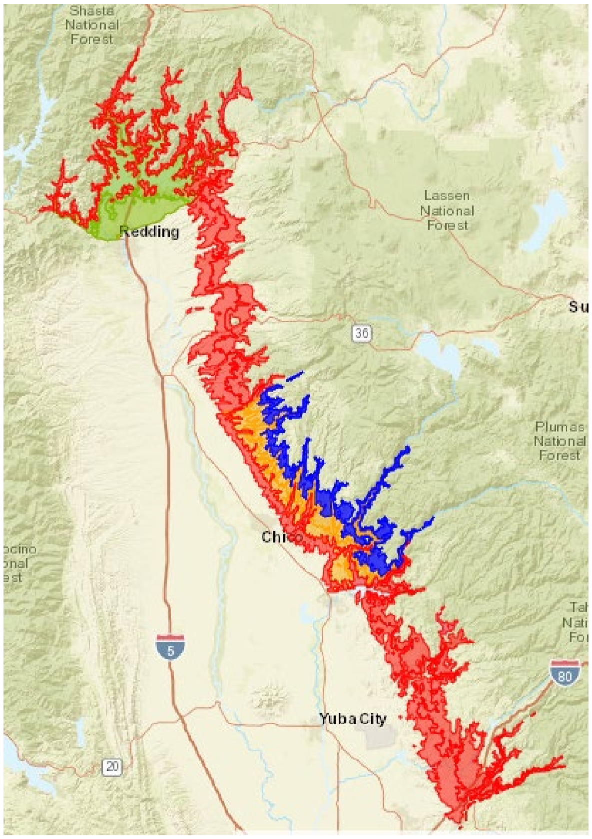
Some studies suggest that broad climate-based projections don't always track actual regeneration rates and appear to underestimate local conditions and sites (e.g., favorable topography and soils) suitable for establishment.[43] Places where forest managers may be able to defy climate trends through careful site selection and reforestation plans are discussed in Appendix A, under "Site selection".

Douglas-fir seedlings planted by the BLM site in the Camp Fire in Spring 2020. Climate projections suggest that Douglas-fir will be able to survive only at cool, wet sites in the Camp Fire region. Credit: Austin Rempel / American Forests.

Analog climates

There are locations in the region where the current climate may offer a window to what is predicted for the Camp Fire area in the coming decades. These "climate analog" areas may be good places to collect seed that will be adapted to the future climate, and to identify forest types and forestry techniques suited to these new conditions. Planting genotypes from these seed zones could help increase the genetic diversity and adaptive capacity of local seed sources in the Camp Fire burn area.

Online climate modeling tools allow managers to identify areas with current climates that match the projected climate for project areas in the future. Results from the two leading models closely agree on future conditions and analogs for the Camp Fire. Using the Climate Adapted Seed Finder tool developed by researchers at the University of California, Davis, climate models suggest that in the coming decades, the climate at 2,000- to 2,500-feet elevation zone in Butte County will experience temperatures and precipitation patterns similar to those of the immediate downslope area (the 1,000- to 2,000-foot zone) and the area just north of Redding, Calif., around Shasta Lake (Figure 5).[44] The Seedlot Selection Tool, a related tool, identifies similar climate analog areas to those presented by the Climate Adapted Seed Finder, as well as sections of the California coast range that may be close matches for future climate within the Camp Fire burn area.[45]



Seed Zone	Elevation Band	%DP
521	1000 - 1500ft	2.7%
521	500 - 1000ft	3.1%
521	0 - 500ft	7.0%
524	1000 - 1500ft	8.0%
524	1500 - 2000ft	9.2%
521	1500 - 2000ft	10.6%
525	1500 - 2000ft	12.1%
524	500 - 1000ft	12.7%
525	1000 - 1500ft	13.4%
522	1500 - 2000ft	13.5%
524	2000 - 2500ft	14.3%
522	1000 - 1500ft	14.5%

Figure 5. Climate analog areas for the 2,500-foot elevation band in the Camp Fire.

Note: '%DP' is the percent decline in tree volume or biomass that foresters should expect due to using a seed source that is not well adapted to the climate the trees will grow in. The lower the %DP value of an area, the better. %DP incorporates effects of climate on both growth rate and survival.

Climate-informed management plans for BLM lands in the Camp Fire

Management context

The Camp Fire — and the 2020 North Complex — burned in an area that experienced 16 large wildfires since 1999. The landscape most recently burned in 2008, following the Humboldt Fire and the Butte Lightning Complex fires around Concow. Vegetation communities affected by the fire include chaparral, oak/pine woodlands, pure oak woodlands, pure ponderosa woodlands and mixed conifer forest (Figure 6).

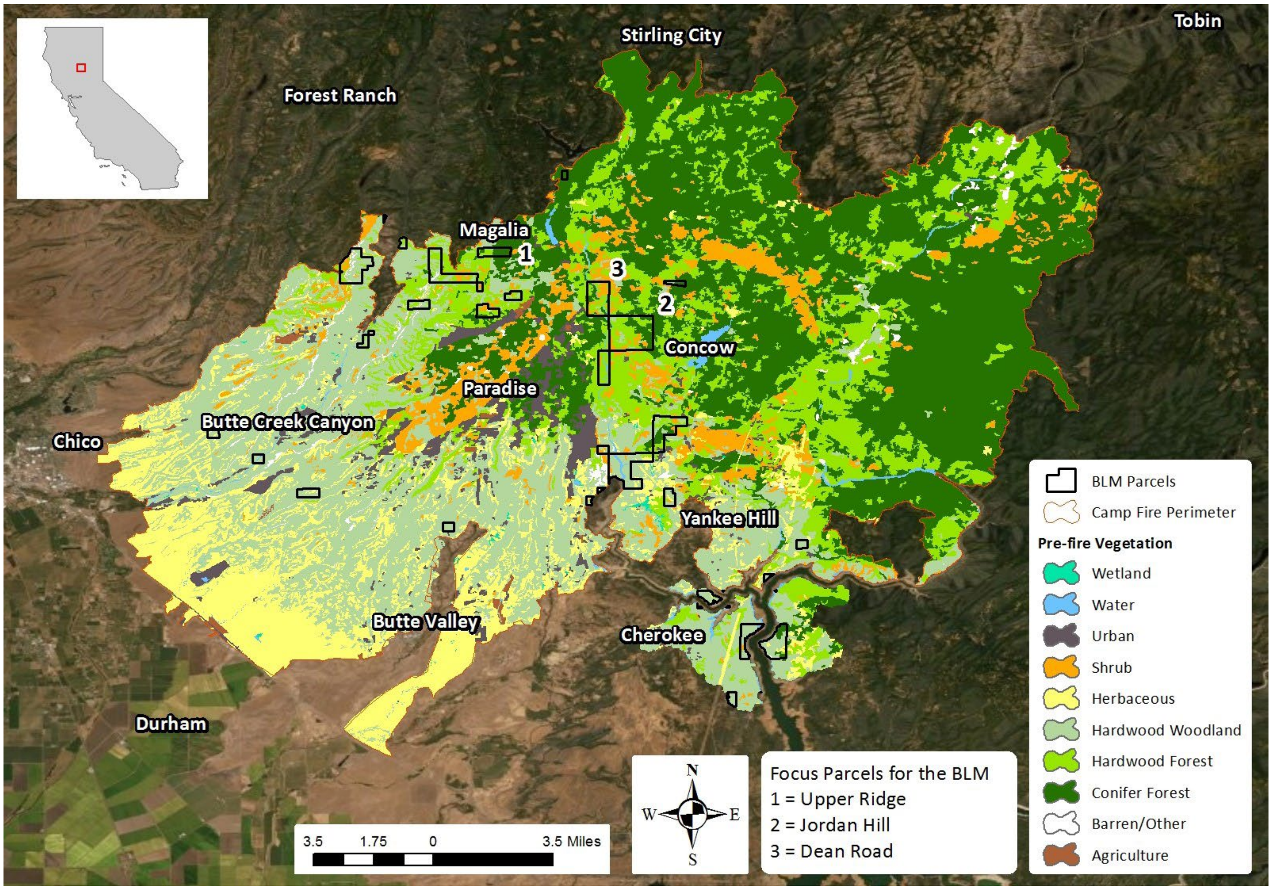


Figure 6. Pre-fire (1999) vegetation types in the Camp Fire burn scar.[46]

Soils are highly variable across the burn area. Soils are generally thin (less than 2 feet deep) to moderate thickness (2 to 5 feet deep) on the steeper slopes of the eastern half of the burn area, and moderate to thick (more than 5 feet deep) in the lower-lying areas within the western half of the fire. Serpentine soils, derived from the weathering of ultramafic rock, are found scattered throughout the burned area.

The BLM Redding Field Office manages approximately 250,000 acres across five counties in Northern California. Of that, 4,070 acres burned during the 2018 Camp Fire, and 36% of this area — 1,400 acres — burned at high-severity (Table 2, Figure 7).[47] This translates into an immense loss of tree cover and adult, seedbearing trees, and repeated high-intensity fires followed by warm, dry weather overwhelm forests' ability to recover. Conifer stands that lose over three quarters of their basal area, as a result of fire or other disturbances, are likely to have difficulty regenerating on their own (Figure 8).[49]

Burn Severity (% Basal Area Loss)	Acres	Percent of BLM land in Camp Fire burn scar
0% BA mortality	791	20%
0% < BA mortality < 25%	995	25%
25% <= BA mortality < 75%	753	19%
BA mortality >= 75%	1,414	36%
Total	3,953	100%

Table 2. Burn severity on BLM lands, 2018 Camp Fire.[50]

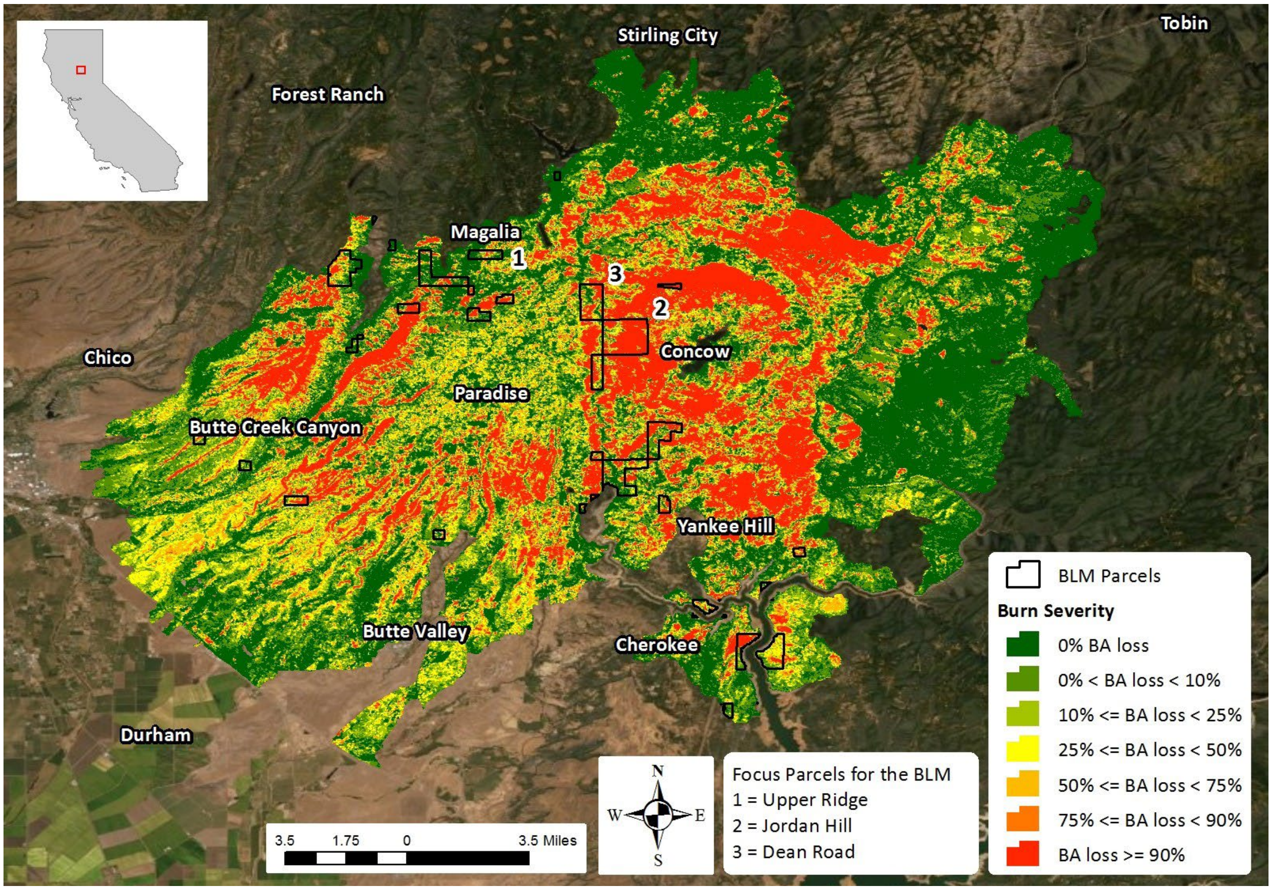


Figure 7. Burn severity (basal area lost) in the Camp Fire.[51]

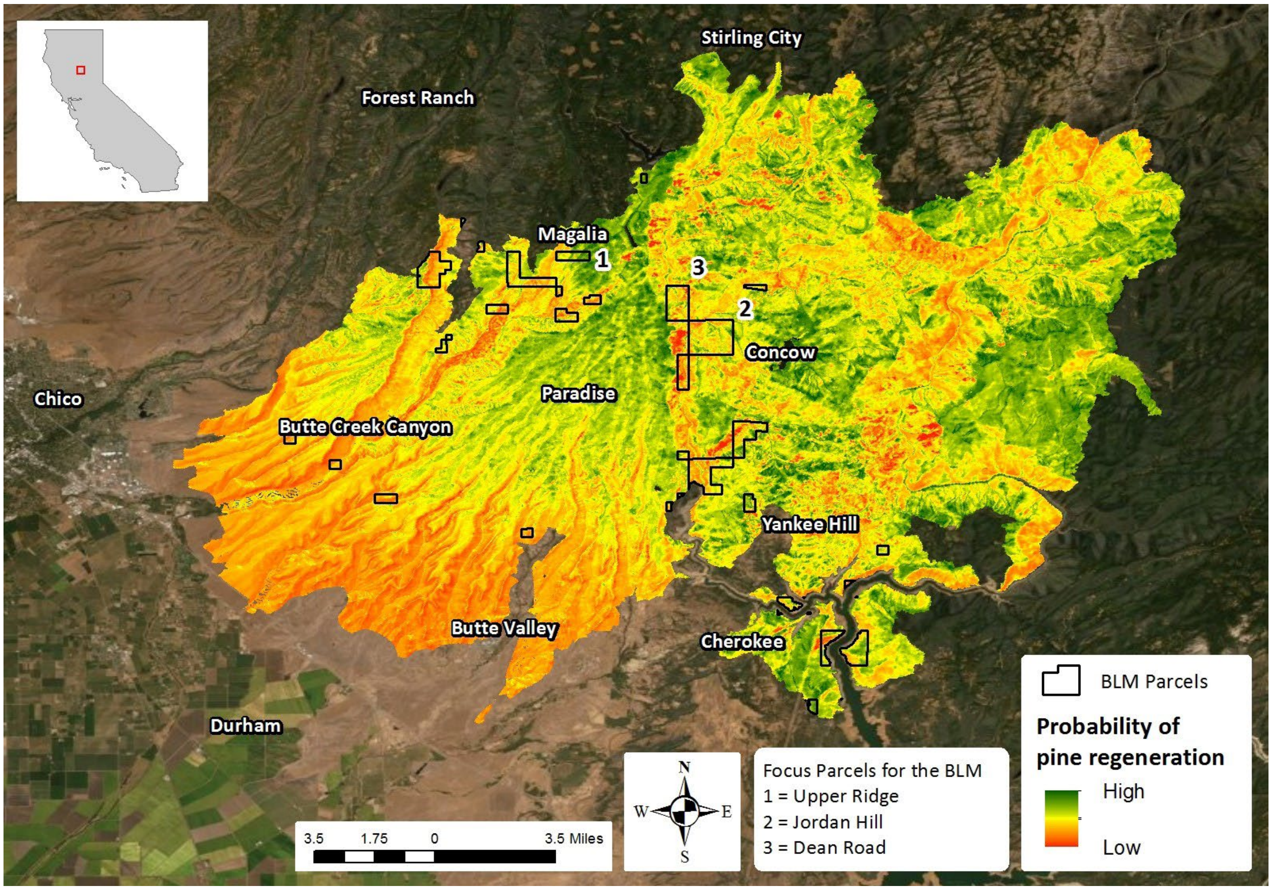


Figure 8. Probability of pine regeneration after the Camp Fire.[52]

All BLM parcels in the Camp Fire are categorized as Wildland-Urban Interface (WUI), making it critically important to manage vegetation and fuel loads for the safety of neighboring communities, residences and people.

Many of the BLM parcels in the Camp Fire are small and inaccessible due to lack of roads, steep terrain and/or being completely surrounded by private land with no legal access. As a result, the BLM chose to focus on three parcels for initial restoration: Upper Ridge, Jordan Hill and Dean Road. These parcels were also highlighted in a fire-modeling exercise as being especially important for the long-term security of Paradise, Calif.[53]

The Concow Resilience Project

The Butte County Resource Conservation District and the Plumas National Forest have undertaken a parallel effort to develop adaptive reforestation prescriptions for parts of the Camp Fire burn in the Concow basin, just east of the BLM's focus parcels. Their planning and experience inspired and informed the BLM's approach to post-fire restoration:

"The Concow Resilience Pilot Project (SNC-929) is an innovative, collaboratively developed watershed restoration project trialling six different restoration approaches across 859 acres in the Plumas National Forest following catastrophic wildfire. The first two models (about 320 acres) are oak/hardwood release models (with and without bunchgrass planting) to test whether managed transition to oak savanna is a viable alternative for low-elevation Sierran sites usually thought to be capable of supporting only either

conifer forest or chaparral. Three additional models (about 390 acres) concern cluster-planting or "pyrosilvicultural" replanting of native conifers, at various densities and with or without oaks, with the aim of helping young pines survive relatively early prescribed fire reintroductions. The sixth model (about 150 acres including buffers) is an assisted migration model focused on trialing conifer seed sources from warmer and drier sites, to see if they will outperform traditional local seed sources. For comparison's sake, adjacent timber salvage units (not part of the project) will be replanted traditionally." [54]

Wolfy Rougle of the Butte County Resource Conservation District surveys plans for the Concow Resilience Project. Credit: Austin Rempel / American Forests.

Management goals

The BLM management team aims to:

- improve forest health and resilience, enabling ecosystems to better withstand environmental stressors and recover from disturbances;
- reduce hazardous fuels and increase community safety;
- improve wildlife habitat;
- improve riparian/wetland functionality;
- improve plant community diversity and forest structural diversity;
- identify feasible, cost-effective strategies and plans that can be maintained over the long term; and
- protect soils by reducing sedimentation, preventing erosion and promoting a vegetation community that will stabilize soils.

These goals will become more important as climate change continues to exacerbate stressors and risks to the Camp Fire burn area.

Desired forest condition

Management for resilient forests in the Camp Fire area must consider historical conditions, structure and community composition, as well as projections for future climatic conditions and species suitability. Given projected climate and disturbance regimes:

- Forests should be diverse, with high representation of species adapted to more frequent fire and drought conditions, like pines and oaks.
- Stands should be uneven-aged and vertically and horizontally heterogeneous, creating a variety of habitat conditions and variable burning conditions.
- Forests should be much less dense than in recent history (50 to 150 trees per acre, on average, compared to 300 to 500 per acre in recent decades).[55,56,57]
- Individual trees and groups of trees should be interspersed in an open grass-forb-shrub matrix, with variably sized openings that vary with forest type, site productivity, disturbance history and topographic position.

The overall adaptation intent focuses on realigning the post-fire ecosystem to better accommodate current and future climate conditions, including extreme heat, longer periods of drought and increased risk of severe wildfire. This may mean significant changes from what was previously on the landscape in terms of species composition, forest structure, tree density and tree genetics, in order to meet the BLM's management goals and desired future condition. Management interventions will focus on building forest resilience and maintaining the ability of the system to bounce back from more frequent disturbances, by maintaining species and structural diversity, and low tree density.

Benefits of post-fire forest recovery and management

The primary benefits of the climate-adaptive forest management plans presented here include:

- **Greater carbon storage and stability:** Establishing and maintaining forest cover after fire leads to greater carbon storage in the long-term. Mixed conifer forest in the Camp Fire scar — though it may only persist at higher elevations in the future — generally contains two to three times as much carbon as oak-dominated forest, with ponderosa forest somewhere in between (195, 81 and 146 metric tons of CO_2 equivalent per acre at year 50, respectively). The carbon content of chaparral can be similar to that of a young forest in the decades following fire (as much as 65 metric tons of CO_2e per acre), but conifer and oak forests typically contain more after a few decades of growth. Carbon stored in low density, fire-adapted forests will also generally be more stable and resilient to future climates.[58]
- **Lower risk of high-severity fire:** Managing fuel loads in strategic locations on the landscape will reduce the risk and danger of fast-moving, high-severity fire for people living in Butte County.[59]
- **Rural job creation:** Every million dollars invested in reforestation and vegetation management supports 17.3 jobs (13.5 direct and 3.8 indirect).[60]
- **More resilient water supplies:** Watersheds in the Camp Fire scar are exceptionally important for providing clean drinking water to downstream communities.[61] The dominant soil types in the area make vegetation management crucial and effective for increasing infiltration and slowing runoff.[62] CAL FIRE mapping shows that the upper watersheds in the Camp Fire scar are high priority for maintaining a variety of ecosystem services through active forest and fuels management.

Parcel-level analysis and plans

Almost 40% of BLM-managed lands affected by the Camp Fire burned at moderate to high severity. However, not all of these parcels are part of this initial reforestation implementation plan because of logistical constraints, including funding, staff and site access (e.g., slope steepness). Additionally, some areas that were previously dominated by oaks will be allowed to recover naturally via sprouting to promote community diversity. Initial planning by the BLM identified 300 to 600 acres within three parcels — Upper Ridge, Jordan Hill and Dean Road — in need of active management through site preparation, planting, oak sprouting, vegetation management and fuels reduction. These parcels are feasible to manage and maintain over time and doing so will help protect the community from future high-intensity wildfires.[63] This work is anticipated to cost $500,000 to $1.5 million over five years (2020 to 2025).

Other BLM parcels are less feasible to manage due to prohibitively steep slopes, historic vegetation communities that have never supported tree cover, lack of legal access or roads, or sensitive soils that may need to recover naturally. The BLM recognizes that other parcels may be identified in the future for active reforestation or woodland management as needs emerge from ongoing assessments and collaboration with adjacent landowners or community members.

In general, the BLM plans to use planting prescriptions that are specific to topographic position by using planting densities and species that are most adapted to each planting site (Table 3, and "Site selection" section in Appendix A). BLM will also employ assisted migration techniques by using seed from elevations that are 500 to 1,000 feet lower than each planting site with the assumption that these will be suited for hotter and drier conditions than seed from the same elevation. All planting contracts will include a stipulation requiring microsite planting, which allows the planting crew to vary spacing ±25% to plant trees on the north side of rocks, stumps and/or logs that provide young seedlings more protection from solar radiation.

Topographical Zone	"Planting density (trees per acre, includes sprouting oaks)"	"Spacing (feet, regu lar planting scheme)"	Species
Ridges and shaded fuelbreaks	109	20 x 20	- Ponderosa pine and black oak - native bunchgrasses and forbs
South-facing slopes	134	18 x 18	- Ponderosa pine, gray pine, black oak, canyon and interior live oaks, incense cedar, Douglas-fir - native bunchgrasses and forbs - Test: blue oak (with browse protection)
North-facing slopes	170	16 x 16	- Incense cedar, Douglas-fir, sugar pine, black oak and ponderosa pine - Test: valley oak, blue oak
Canyons, valley bottoms and riparian areas	222	14 x 14	- Incense cedar, Douglas-fir, sugar pine, black oak and ponderosa pine

Table 3. Generalized planting prescriptions for topographic zones.

Upper Ridge

Strategies	Approaches
1,3,5,8,9	1.4. Reduce vegetation competition for moisture, nutrients and light. 3.2. Establish and maintain fuel breaks to minimize the risk of uncharacteristic, high-severity fire. 3.4. Promptly revegetate after disturbance. 5.1. Promote forest age-, size-class diversity and spatial heterogeneity. 8.1. Use seeds, germplasm and other genetic material from across a greater geographic range. 9.1. Favor or restore native species that are expected to be adapted to future conditions. 9.3. Guide changes in species composition at early stages of forest development.

The Upper Ridge Nature Preserve (2,280-foot elevation) is approximately 118 acres and is located just west of the Pines Elementary School in Magalia, Calif., which is one of the few structures that did not burn in the neighborhood. The eastern half (approximately 54 acres) of this parcel was a very popular hiking area and heavily used by residents before the Camp Fire. BLM has prioritized fuels and forest health treatments at Upper Ridge due to its importance as a fuel break and a community recreation area. Approximately 35 acres burned at high severity, and the remaining 19 acres had relatively intact canopy cover. The most immediate post-fire need in the parcel was to salvage log merchantable dead trees that might fall on hikers and adjacent structures. The salvage logging was completed in spring 2021.

Post-Camp Fire conditions at Upper Ridge, December 2019. Credit: Brittany Dyer / American Forests.

Post-fire conditions at Upper Ridge are highly variable but can best be described as having a healthy component of resprouting black oaks, resprouting shrubs, isolated patches of natural conifer seedlings, and a moderate amount of dead fuel loading associated with less than 12-inch diameter hardwoods and conifers killed in the Camp Fire. Pre-planting site preparation included salvage logging, hand cutting and piling of standing dead fuels, and pile burning. In April 2021, American Forests and the BLM planted the following mix of containerized seedlings across 35 acres at Upper Ridge:

Species	Seed Zone	Elevation	# of seedlings	% of seedlings
Ponderosa pine	524	1,500	4,400	41%
Douglas-fir	524	1,500	2,450	23%
Sugar pine	525	2,500	3,850	36%

Table 4. 2021 Planting at Upper Ridge Nature Preserve.

The species mix of 41% ponderosa pine, 36% sugar pine and 23% Douglas-fir emulates the pre-fire community composition of the site. Based on the climate projections presented in the "Climate Vulnerability Assessment" section, ponderosa and Douglas-fir seedlings were grown from seed collected ~1,000 feet downhill of the planting site with the expectation that these seed sources may be better adapted to the current and future climate at the site. This was not an option for sugar pine due to lack of lower-elevation seed. Sugar pine was a less abundant species than ponderosa pine prior to the Camp Fire, but the even mix of the two pine species is an opportunity to test the persistence of sugar pine in the 2,000- to 2,500-foot elevation band on a parcel with deep soils and good growing conditions.

The planting crew planted ~302 seedlings per acre, with a 12-by-12-foot spacing, and a ±25% variance. To avoid creating an evenly spaced plantation and promote spatial heterogeneity, the crew varied spacing between seedlings to plant in microsites and avoided planting too close to re-sprouting hardwoods and natural seedlings. Due to fast regrowth of shrubs following the initial hand cutting treatment in spring 2021, a follow-up grubbing treatment (3 to 5 feet around each seedling) is planned for summer 2021.

The Upper Ridge parcel will continue to be a high priority for fuels reduction and post-planting maintenance treatments due to the high levels of public use and its proximity to private homes. The BLM plans to conduct hand grubbing of competing vegetation (shrubs) around planted and natural trees in summer 2021, and again every two to four years. The radius of this release treatment will be 3 to 5 feet from the trees. These release treatments will be necessary until the trees are able to shade out competing shrubs (between years seven and 12), so the BLM is planning three to four cycles of release at Upper Ridge. Every other cycle will also include hand piling and burning of cut material in order to reduce fuel loads. One of the later cycles, or perhaps the last cycle, will include pruning the lower limbs of the conifers to a height of 5 to 7 feet in order to raise the canopy base height of the trees. Prescribed underburning, or broadcast burning, is not planned for this parcel due to its location near residences and the school. Mastication is another fuels reduction tool that is not a preferred treatment in this parcel because the masticated material doesn't break down very quickly on dry sites such as this one.

Jordan Hill

Strategies	Approaches
1,3,4,5,8,9	1.4. Reduce vegetation competition for moisture, nutrients and light. 1.5. Restore or maintain fire in fire-adapted systems. 3.2. Establish and maintain fuel breaks to minimize the risk of uncharacteristic, high-severity fire. 3.4. Promptly revegetate after disturbance. 4.2. Prioritize and maintain sensitive or at-risk species or communities. 5.1. Promote forest age-, size-class diversity and spatial heterogeneity. 8.1. Use seeds, germplasm and other genetic material from across a greater geographic range. 9.1. Favor or restore native species that are expected to be adapted to future conditions. 9.3. Guide changes in species composition at early stages of forest development.

The 640-acre Jordan Hill parcel (~2,200-foot elevation) is located west of Concow, Calif., and is the largest BLM-managed parcel within the burn. Site planning data and maps are available online. The majority of the parcel experienced moderate- to high-severity fire in the Camp Fire. About half of the parcel burned during the 2008 Butte Lightning Complex, and 175 acres was salvage logged and planted in 2010. Jordan Hill had suitable planting sites directly after the Camp Fire, but, due to a lack of appropriate seed and seedlings, planting was delayed until spring 2020 when 11,130 seedlings were planted across 56 acres of the site. These seedlings were sown and grown for other sites but presented an opportunity to make use of the post-fire, shrub-free planting window at Jordan Hill and test the performance of seed from other seed zones and elevations. Ponderosa pine from seed zones 523.30 and 526.25 were planted with an 18-by-18-foot spacing on drier slopes, and Douglas-fir (352.15) and incense-cedar (526.40) were planted with a 16-by-16-foot spacing in the more sheltered ravine bottom at the northern end of the parcel.[64]

Post-Camp Fire conditions at Jordan Hill, April 2020. Credit: Austin Rempel / American Forests.

To track survival and growth over time, four monitoring plots were installed — two plots to track the ponderosa seedlings (one on a north-facing aspect and the other on a south-facing aspect, each with 50 seedlings from each seed zone, for 100 seedlings total from each seed zone), and two plots to track the Douglas-fir and incense cedar (same monitoring design, with two aspects and 50 seedlings of each type in each plot, for 100 seedlings total of each species). Seedlings were planted at a 10-by-10-foot spacing, and seedlings were marked and labelled with wooden stakes and metal tags. One year after planting, survival of the ponderosa seedlings varied between 50% and 70%, with higher survival on the north-facing slope, and no apparent differences in survival between seed zones.

Shrub sprouting at Jordan Hill has been prolific since the Camp Fire, resulting in conditions that now require intensive site preparation before any further planting can be done. The BLM anticipates conducting site preparation and fuels reduction as soon as feasible (2021-2022). This will be done with a variety of tools, such as handpile/burn, mastication and targeted herbicide use to reduce only the shrub component in the parcel. There is a healthy sprouting oak component that will be pruned to two main stems during these site preparation and fuels reduction treatments. The main constraints for the implementation of these treatments are the lack of National Environmental Policy Act clearance, funding and staff capacity to complete the required work. However, there are several planned fuel breaks that connect with the Jordan Hill parcel, and the BLM recognizes the need for reducing shrub cover, creating more fire resilient conditions, and connecting treatments across the landscape.

The other constraint for reforestation in Jordan Hill is the lack of seed for the desired species across the topographic positions found in the parcel. This climate plan will be used to strategically collect the needed seed for Jordan Hill in 2021, in order to meet the goal of planting as much of the Jordan Hill parcel that is operationally feasible in 2023. Broad seed collection priorities for this effort are included in Table 5.

Post-planting maintenance and fuels treatments will be similar to those described for Upper Ridge. Grubbing around planted trees will be critical every two to four years, with more intensive fuels reduction needs every other cycle, and a pruning as a later cycle treatment. Prescribed underburning is planned once the planted trees grow to more than 5 inches in diameter, which is anticipated at year 20 based on Forest Vegetation Simulator modeling.

Potential species include:
Black oak
Blue oak
Douglas-fir
Gray pine
Incense cedar
MacNab cypress
Native bunch grasses and forbs
Ponderosa pine
Sugar pine
Valley oak

Seed collection areas
(listed from top to bottom in priority and suitability)

Seed Zone	Elevation
521	1000 - 1500ft
521	500 - 1000ft
521	0 - 500ft
524	1000 - 1500ft
524	1500 - 2000ft
521	1500 - 2000ft
525	1500 - 2000ft
524	500 - 1000ft
525	1000 - 1500ft
522	1500 - 2000ft
524	2000 - 2500ft
522	1000 - 1500ft

Table 5. Target species and suitable seed collection areas.

Dean Road

Strategies	Approaches
1,3,5,9	1.4. Reduce vegetation competition for moisture, nutrients and light. 3.2. Establish and maintain fuel breaks to minimize the risk of uncharacteristic, high-severity fire. 5.1. Promote forest age-, size-class diversity and spatial heterogeneity. 9.1. Favor or restore native species that are expected to be adapted to future conditions. 9.3. Guide changes in species composition at early stages of forest development.

The 120-acre Dean Road parcel (1,500- to 2,000-foot elevation) is dominated by prohibitively steep slopes and only part of the parcel is accessible. The BLM has removed hazard trees along the access road that leads to the flume trail on the east side of the Feather River. The hot, dry slopes of the parcel burned severely in the Camp Fire, but there was a fair amount of low to moderate burning across the rest of the parcel, which left a significant amount of intact vegetation in at least half the parcel.

The hotter drier slopes that burned at high intensity were dominated by an oak/chapparal community prior to the fire, with the exception of about 10 acres of conifer-dominated large trees in the southwest corner of the parcel. Given the dominance of oaks, and the poor outlook for most conifer species at the site, the BLM has decided to manage the parcel as an oak/chapparal community into the future. Active fuels reduction and pruning of oaks will be done within 200 feet of the flume trail access road as well as along the private/BLM boundary on the west side of the parcel where this boundary intersects private residences. Until the oaks dominate the shrub component, the BLM plans to maintain the treatment area every few years with a handcut and pile treatment of shrubs (and potentially spot herbicide treatments) within a distance of oaks that could develop into a healthy condition class.

Appendix: Literature review for climate-adaptive reforestation strategies in the Camp Fire region

This appendix collects and summarizes information about topics and treatments that the BLM, American Forests and other Camp Fire stakeholders considered to be potentially relevant in the context of post-fire reforestation and climate change adaptation. Many other comprehensive and up-to-date resources are available to guide post-fire restoration efforts in California as well.[65,66,67]

This review section covers:

Site selection

Use Topographically-based Management Units to Create Forest Heterogeneity

Strategies	Approaches
3,5,9	3.1. Alter forest structure and/or composition to reduce risk and severity of wildfire. 3.3. Alter forest structure to reduce severity or extent of extreme weather events. 5.1. Promote forest age-, size-class diversity and spatial heterogeneity. 9.3. Guide changes in species composition at early stages of forest development.

General Technical Report 220 (GTR-220), "An ecosystem management strategy for Sierran mixed-conifer forests," issued by the U.S. Forest Service, proposes varying forest structure, composition and fuels based on topographic characteristics, particularly slope position and aspect. The report details management approaches that emulate how historical fire regimes might have created landscape-scale forest heterogeneity and, by extension, increased forest resilience and habitat connectivity. These management strategies support forest ecosystems resilient to climate stressors and climate-mediated changes in disturbance regimes.

GTR-220 outlines several key principles for facilitating forest structural heterogeneity, such as:

(1) using landscape topography (slope, aspect, slope position) as a guide to vary stand densities and canopy cover;

(2) promoting tree clumps and gaps within a stand;

(3) separating crown strata when possible;

(4) avoiding the creation of "average" stand conditions

(5) increasing the proportion of large-to-small trees within a stand; and

(6) retaining important habitat structures, such as large trees or snags and defect trees (with broken tops, cavities, platforms and other formations) for nesting or denning wildlife species.[68]

To illustrate these concepts in the Camp Fire area, we generated topographically-based units known as Landscape Management Units (LMUs), using several categories from GTR-220 — canyon bottoms/drainages, mid-slope areas, ridges and aspect.[69] These landscape units have inherent differences in wetness and solar radiation and produce distinct stand structures. Another measure classifies slopes based on mechanical operation limitations that usually occur around >30% slopes.[70,71] These topographic categories consistently predicted patterns of forest structure and wildlife habitat over a range of elevations and forest types in the Southern Sierra Nevada.[72] LMUs are a simple model that helps capture the spatial heterogeneity found in the Sierras under an active fire regime. These units provide a guideline for creating spatial variability that will provide diverse habitat conditions, as well as fragment fuel loadings on the landscape to fostering more variable wildfire spread and intensity.

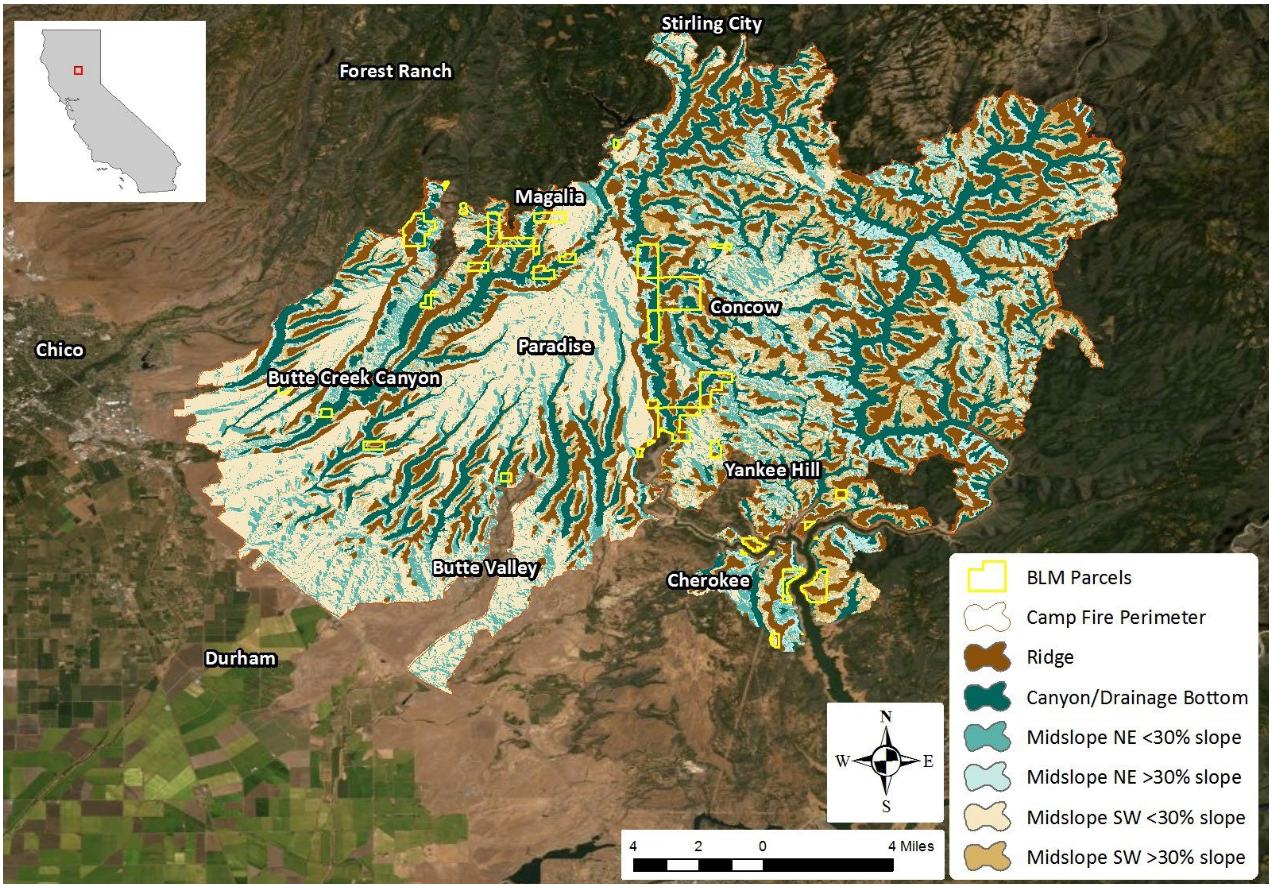


Figure 9. Topographically-based management units to guide post-fire forest management in the Camp Fire.[73]

Tree density and canopy cover should be highest in drainage bottoms and riparian areas, decrease on mid-slope areas, and be lowest on ridgetops. Stocking and canopy cover in all three topographic positions would be higher on northeast aspects compared to hotter, drier southwest aspects. Stocking and canopy cover would also be greater on gentle slopes with deeper soils that can sustain higher canopy cover and more open on steep slopes.

Prioritize the best sites for tree survival and growth

Strategies	Approaches
4, 5, 10	5.2. Maintain and restore diversity of native species. 4.1. Prioritize and maintain unique sites. 10.2 Allow for areas of natural regeneration to test for future-adapted species.

In addition to breaking the post-fire landscape up into discrete LMUs, there are several other metrics and approaches that can be used to prioritize within and among sites and develop post-disturbance management prescriptions that incorporate a site's current and future exposure to climate:

Prioritize sites and treatment areas with a Low Heat Load Index (HLI): Areas with low heat index are identified topographically as having conditions that moderate the influence of climate on tree seedlings.[74] HLI combines slope, aspect and latitude to estimate terrain-driven differences in solar heating, with higher values indicative of warmer and drier sites.[75] Especially at lower elevations, seedling survival and growth will be highest in cooler and wetter terrain (i.e., low HLI, canyon bottom and northwest slope LMUs). Topography interacts with the effects of climate change for tree seedlings, and managers should use this knowledge when selecting sites and species.[76]

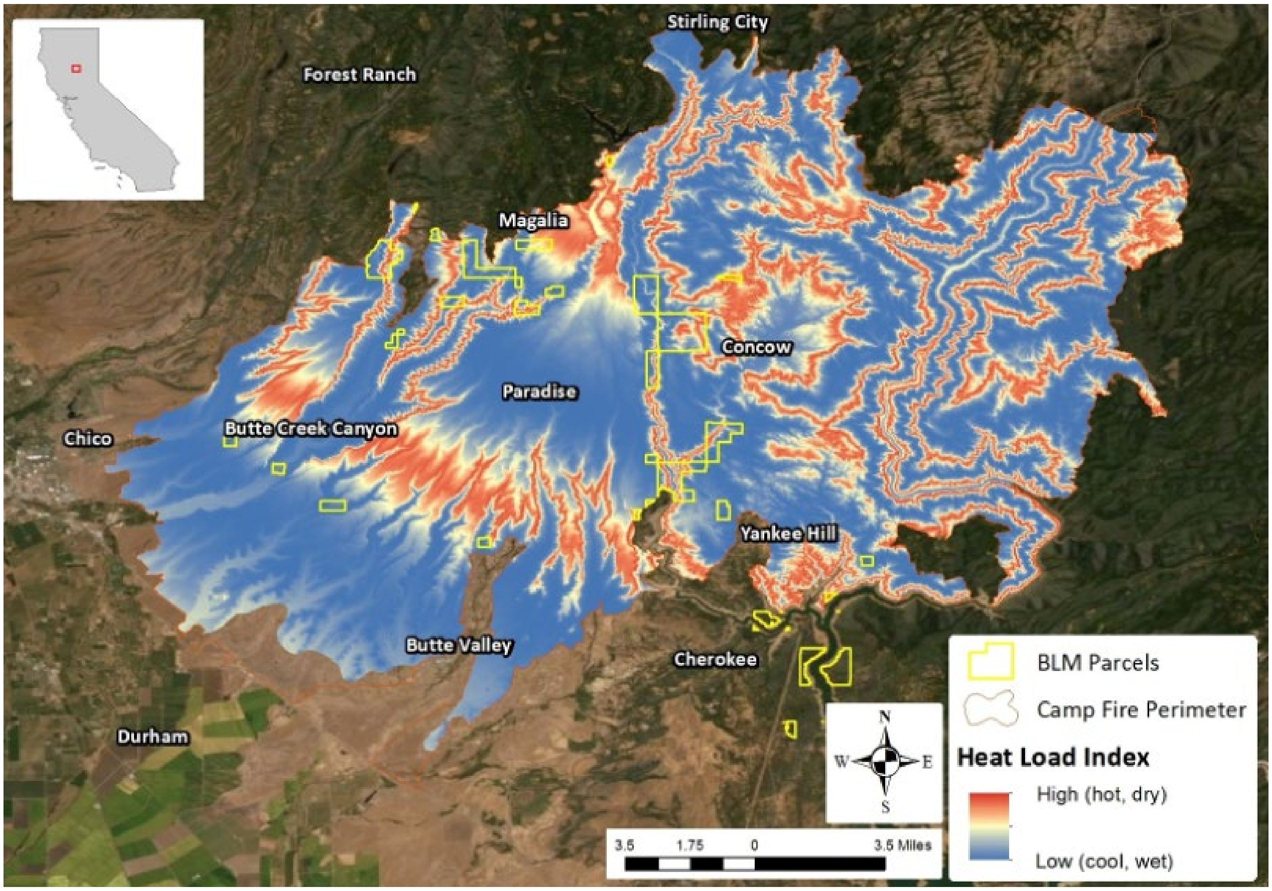


Figure 10. Solar heating on the Camp Fire landscape.[77]

Prioritize sites on the landscape with low vulnerability and exposure to climate change: Recent modelling has mapped the exposure and vulnerability of landscapes to climate change.[78] Vulnerability ratings are based on soil sensitivity and exposure to broad-scale climate trends. If the goal is to maintain current or historical vegetation, like conifer stands, managers may prioritize sites that have low exposure and low vulnerability, and allow sites with high vulnerability to transition to more drought-tolerant forest species (e.g., gray pine and oaks) or non-forest vegetation types (e.g., chaparral or native grasslands).[79] For example, the Jordan Hill and Upper Ridge parcels have low to moderate ratings for both exposure and vulnerability to projected climates, while lower elevation sites along the West Feather River canyon, Lake Oroville and the foothill canyons have high exposure and vulnerability ratings.

At broad scales, look for refugia: Recent research suggests that climate refugia — areas projected to remain suitable for tree species currently at the site — are rare in most parts of California, including the Camp Fire scar.[80] However, this analysis does not incorporate the potential moderating effects of local microclimates, soils or management practices that could help trees withstand the impact of future climates, and disturbances like fire, drought and insect outbreaks (Figure 11).

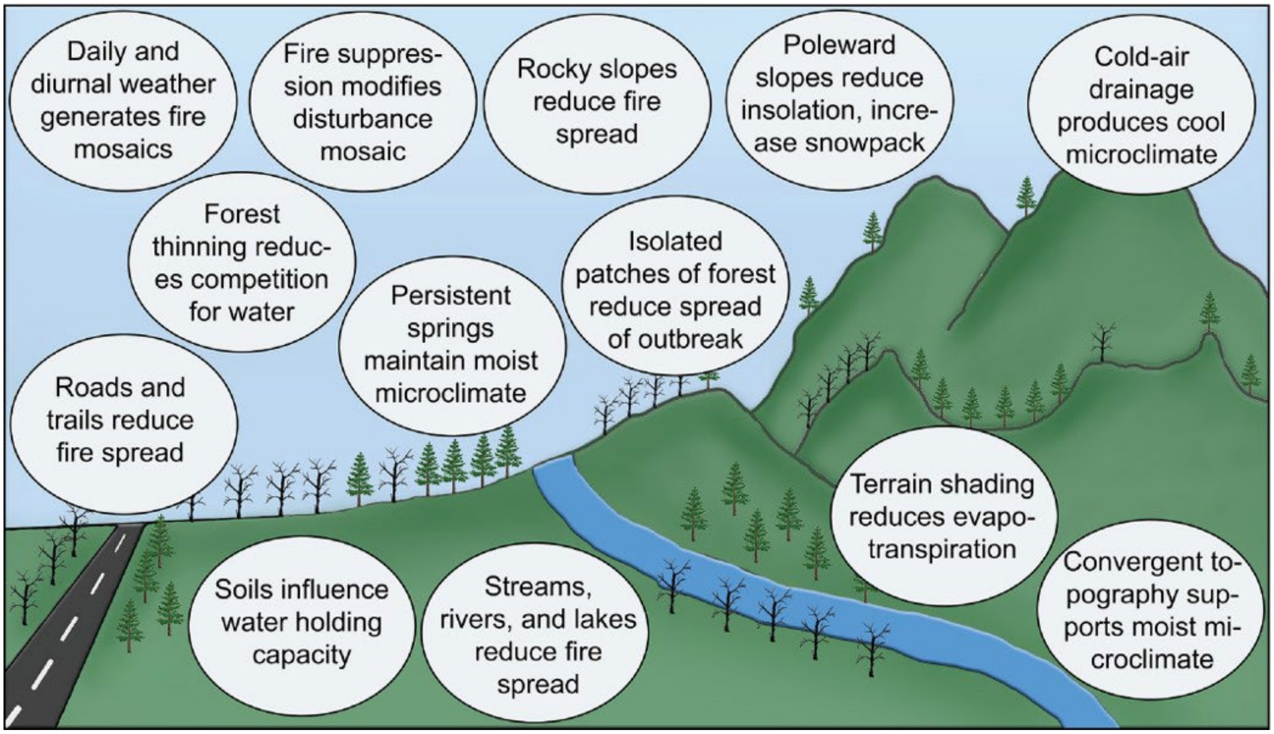


Figure 11. Examples of processes and landscape features contributing to fire, drought and insect outbreak refugia.[81]

Within fire scars, look for fire refugia: There are areas that have experienced consistently lower burn severity in the Camp Fire and previous fires. Canyon/valley bottoms and parts of the landscape with low heat indices — Concow Lake, for example — help identify areas of low burn severity and remnant trees in the Camp Fire scar. Researchers have consistently documented fire refugia in low, cool, wet environments — for example, convergent valley bottoms, areas with cold-air pooling and riparian zones.[82,83]

In large burn areas, consider a "Seed Zonation" approach: The Tamm Review outlines three basic management zones for post-fire reforestation:[84]

- **Zone 1:** Areas where natural tree recruitment is likely to be successful and active reforestation is unnecessary. Based on seed dispersal distances, areas within 650 feet (200m) of live trees can be designated as Zone 1. Managers can take advantage of remaining green trees in areas of high mortality by providing an adequate seedbed for natural regeneration (e.g., removing competing vegetation or exposing mineral soil creates a favorable seedbed).

- **Zone 2:** Areas where natural recruitment is unlikely and where active reforestation should be focused. Zone 2 can be defined as severely burned areas where road access and moderate topography allow for efficient reforestation, and where forests are the desired future ecological state.
- **Zone 3:** Areas where natural recruitment is unlikely but where reforestation is prohibitively costly due to difficult access, or where non-forest ecosystems are desirable.

Figure 12. Designated seed zones as shown in North et al.[85] Zone 1, outlined in green, indicates areas where seed dispersal from adjacent islands of green trees is likely. Zone 2, shows areas unlikely to regenerate without management intervention that are readily accessible for reforestation. Two areas within this zone, A and B, separated by the blue dashed line, indicate gentler, more uniform topography (A) and more variable, steeper sloped conditions (B), each of which could have a different planting strategy. The unsalvaged, snag area in the center could be planted if safety allows (facilitating future forest habitat connectivity) or left to provide wildlife habitat for post-fire specialists. Zone 3, outlined in red in the distant center of the photo, is a steep slope, distant from access roads that might be planted with founder stands (groups of seedlings in mesic, sheltered microsites less likely to burn or become drought stressed).

Use a decision tree framework to guide post-fire planting and management: Researchers have developed a broadly applicable decision support tool for planting and post-fire management, based on literature review of studies from 2005 to 2018.[86] This framework helps managers to incorporate climate and forest type, distance to surviving seed trees and topography (aspect, elevation and slope), as well as competition, soils, microsite availability and species/genotype selection into the post-fire planning process. See publication for further details and guidance for how to apply the framework.

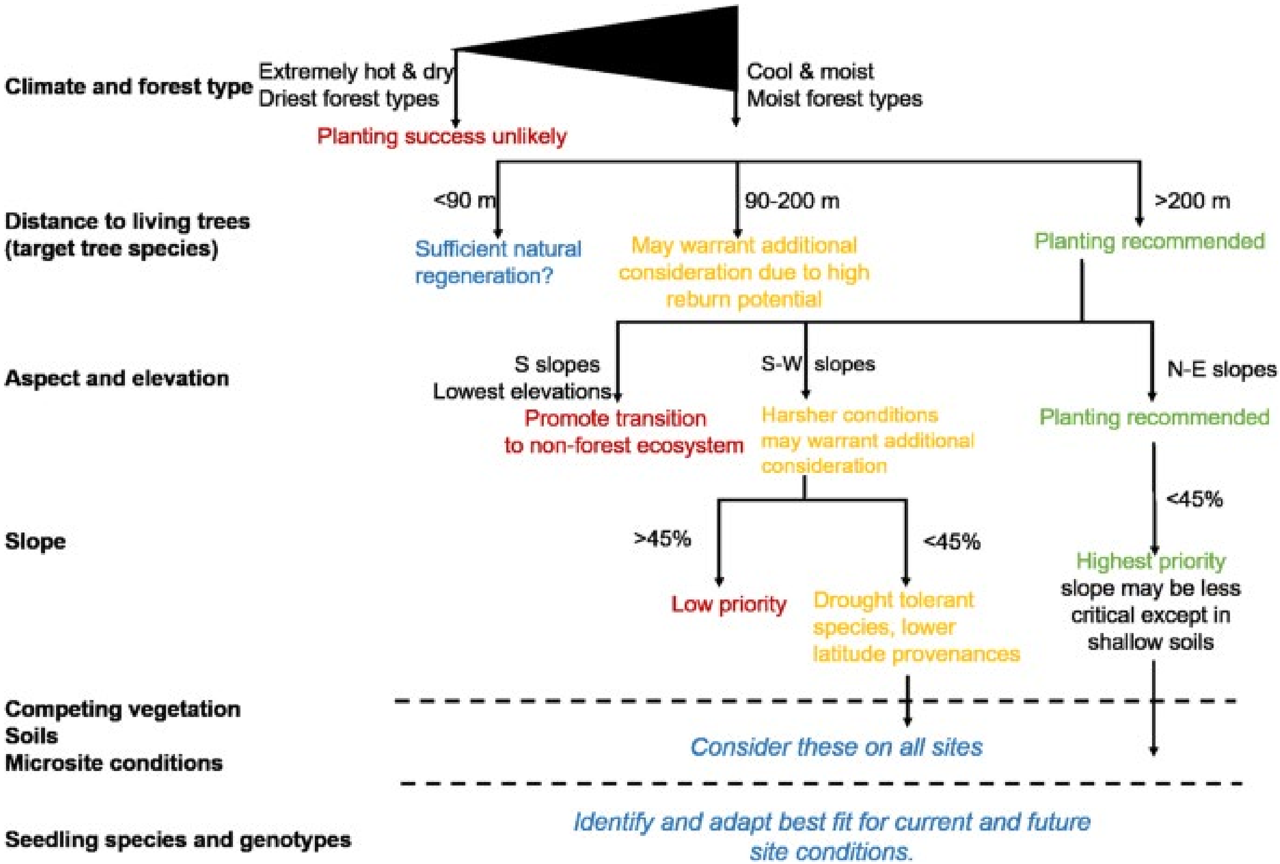


Figure 13. Decision tree for post-fire restoration in the western U.S.[87]

Species selection

Strategies	Approaches
4, 9	4.2. Prioritize and maintain sensitive or at-risk species or communities. 9.1. Favor or restore native species that are expected to be adapted to future conditions. 9.2. Establish or encourage new mixes of native species. 9.6. Manage for species and genotypes with wide moisture and temperature tolerances. 9.7. Introduce species that are expected to be adapted to future conditions.

The University of California, Davis assessed the dominant tree species in the region for their climate sensitivity and ability to adapt to climate change (Table 6).[88] They used modeling and expert opinion to develop a set of scores to indicate how each species will be impacted by climate change. The sensitivity score measures the sensitivity to temperature, precipitation and fire, and considers tree reproduction sensitivity regarding seed dispersal, germination and reproductive lifespan. The adaptive capacity score measures how adaptive each species is to fire, seedling establishment levels (recruitment) and seed longevity. Each criterion was scored on a relative one to five scale, with one being the most sensitive or least adaptive capacity, and five representing the least sensitive or highest level of adaptive capacity.

Species at the top of the list are likely to be the most successful at adapting to future climates in the Camp Fire scar and may be prioritized for post-fire plantings, seed collection efforts and proactive fire defense (e.g., thinning around stands). However, species selection is extremely site specific. For example, though knobcone pine has high adaptive capacity — mainly due to its ability to reseed itself after fires — many managers are uncomfortable with its perceived tendency to contribute to short interval reburns.[89]

		Sensitivity							Adaptive Capacity			
Species name	**Common Name**	**Climate Temp**	**Climate Precip**	**Fire Sensitivity**	**Germination Agents**	**Dispersal Mode**	**Reproductive Lifespan**	**Sensitivity Score**	**Fire**	**Recruitment Mode /Fecundity**	**Seed Longevity**	**Adaptive Capacity Score**
Pinus attenuata	Knobcone pine	4	3	1	4	5	2	3.2	5	4	5	4.7
Pinus ponderosa	Ponderosa pine	3	3	5	2	4	5	3.7	4	4	1	3.0
Pinus sabiniana	Gray pine	4	3	2	4	5	3	3.5	1	4	4	3.0
Quercus chrysolepis	Canyon live oak	3	3	4	3	2	5	3.3	5	3	1	3.0
Quercus wislizeni	Interior live oak	4	3	4	3	2	3	3.2	5	4	1	3.3
Calocedrus decurrens	Incense cedar	3	3	5	2	3	5	3.5	1	5	1	2.3
Pseudotsuga menziesii	Douglas fir	3	3	5	3	4	5	3.8	1	3	1	1.7
Quercus kelloggii	California black oak	3	2	3	3	2	5	3.0	5	3	2	3.3
Quercus lobata	Valley oak	3	3	5	3	2	5	3.5	5	1	1	2.3
Lithocarpus densiflorus	Tanoak	3	3	4	3	2	5	3.3	5	1	1	2.3
Pseudotsuga macrocarpa	Bigcone Doug-las-fir	3	3	4	2	3	5	3.3	5	1	1	2.3
Pinus lambertiana	Sugar pine	3	3	5	2	4	5	3.7	1	2	1	1.3
Quercus garryana	Oregon white oak	3	2	4	3	2	5	3.2	5	1	1	2.3
Pinus jeffreyi	Jeffrey pine	2	3	4	2	3	5	3.2	1	3	2	2.0
Quercus douglasii	Blue oak	4	4	3	3	2	4	3.3	3	1	1	1.7
Abies concolor	White fir	2	2	2	2	4	5	2.8	1	5	1	2.3
Acer macrophyllum	Bigleaf maple	2	2	4	3	3	2	2.7	5	1	1	2.3
Juniperus californica	California juniper	3	3	1	2	2	3	2.3	5	2	2	3.0
Arbutus menziesii	Pacific madrone	2	2	2	2	2	5	2.5	2	1	3	2.0

Table 6. Sensitivity and adaptive capacity rankings (1 [red] = highly sensitive/low adaptive capacity; 5 [green] = less sensitive/high adaptive capacity).

Additional management information for selected species — oaks, serpentine-tolerant trees, MacNab cypress, sugar pine and incense cedar — is included below. This is an in-depth reference that can be used by reforestation practitioners in selecting the appropriate species and management techniques for a particular site.

Oak species

- EcoAdapt recently completed comprehensive reviews of the likely effects of climate change on oak woodlands and savannas in Northern California.[90,91] Many findings are relevant to the management context of the Camp Fire burn area:
  - o Oaks may be more restricted in their ability to move long distances in response to climate change than many other species because they depend primarily on animals to disperse their seeds. Management interventions could help oak species shift their ranges more quickly.
  - o Repeated high-severity fires can prevent development of larger trees with fire-resistant characteristics, changing forest and woodland structure by converting stands of mature, large-diameter trees to shrubby, multi-stemmed growth forms.
  - o In some cases, shrubs can facilitate the growth and survival of oak seedlings.[92]
  - o The spread of diseases, such as sudden oak death (though this disease specifically does not currently occur in the area), could likely cause significant shifts in woodland structure and composition as dominant trees die. Suitable weather conditions (e.g., warmer temperatures, increased winter and spring precipitation) could double the rate of spread of root diseases. Open woodland habitats and stands with high woody plant diversity have lower infection risk due to reduced host density.
  - o Restoration of frequent low- to moderate-intensity fire is the single most important activity to establish and restore oak woodlands. At lower elevations, managing grazing is another important management strategy.
  - o Exposure to climate change may be buffered by topographic features on some sites, including higher-elevation sites, steep, north-facing slopes, and areas near sources of surface water or easily accessible groundwater (hydrologic refugia).
  - o Oaks lend a degree of resistance and resilience to mixed forests during pine beetle outbreaks.
  - o While it does not currently occur in the region, Oregon white oak is particularly well-suited to warmer, drier climate conditions. Oregon white oaks are tolerant of frequent disturbances and are resistant to sudden oak death. Oregon white oak woodlands may become important refuges for wildlife and other plants under changing climate conditions.

Serpentine species

- Serpentine areas may have higher resistance to, but slower recovery from, climatic changes and enhanced disturbances like fire.[93] Harsh growing conditions associated with these low-productivity soils limit non-native invasion success and contribute to specialized flora with stress-tolerant functional traits, enhancing community resilience to increasing aridity and other stressors. Serpentine areas typically experience longer fire return intervals and more variable fire severity because low-productivity soils limit shrub cover, plant productivity and associated fuels accumulation and connectivity. Many rare "serpentine" species may be restricted to serpentine outcrops simply because of their intolerance to frequent and/or intense fire.[94]

- However, community development and recovery following disturbance tend to be much slower in serpentine areas.[95] Based on short-term fire recovery rates in a study in Northern California, chaparral community recovery was projected to take four to five years on non-serpentine sites and 12 to 15 years on serpentine sites.
- Serpentine habitats tend to be small and isolated, which can limit serpentine species' ability to track climate changes. Assisted migration may make sense in this context.
- If planting in serpentine, try to use serpentine-adapted stock.[96] Serpentine-tolerant tree species include: MacNab cypress, gray pine and, in some cases, incense cedar and ponderosa pine.

MacNab cypress

- Managing serotinous species is difficult because it requires just the right amount of fire. For older stands, stimulating regeneration by allowing wildfire to burn is likely the best option, as prescribed fires are generally not allowed to burn at sufficient intensity to open cones.[97] But managers should also mitigate immaturity risk by preventing fires from burning stands too frequently. In the Camp Fire area, most Macnab cypress populations face significant immaturity risk, and one population near Concow has been mostly extirpated due to too frequent fires.[98]
- Managing for serotinous species, including knobcone pine, and increasing their representation is climate-adaptive because these species are resilient to fire and can often recover without human intervention.
- Seed collection is important to ensure the protection of genetic diversity in cypress populations.
- Introducing MacNab cypress to serpentine outcrops (low fuel, fire-resistant refugia) could help increase population size and redundancy

A MacNab cypress tree grows near Paradise, Calif., prior to the Camp Fire. Credit: Kyle Merriam / USFS.

Incense cedar

- Over the last century, the number of incense cedar growing in the Sierras increased by 100% to 235%.[99] They are drought tolerant and fire resistant when mature and aren't affected by pine beetle outbreaks. They are shade tolerant and can survive moderate competition with shrubs. They can live across a range of elevations, from mesic to xeric conditions. They have high phenotypic plasticity and adapt readily to their environment.[100] This means that they can be moved between elevations and seed zones more readily, and they may be more able to adapt to shifting climates.[101]
- The biggest management concern in the Camp Fire burn area is that it takes a while — at least 15 years — for incense cedar to develop fire resistance. Young seedlings and saplings remain vulnerable to fire until bark thickness and tree height are sufficient to reduce heat injury and scorching. Incense cedar saplings may survive prescribed fires with low flame lengths (less than 1 foot) at around 15 years old.

Sugar pine

- Sugar pine have poor climate prospects at nearly all BLM sites in the Camp Fire burn area and will only be able to persist through careful site selection (Upper Ridge, possibly the northern part of Jordan Hill or canyon bottoms along the West Feather River and Concow Creek).
- Planting rust-resistant stock can help at a landscape scale by increasing the frequency of rust resistance in sugar pine populations.
- Sugar pine seedlings have a reputation for low survivorship — typically less than half survive in the first three years after planting.
- Sugar pine from southern California have high resistance to blister rust and are more drought tolerant.
- With any remnant sugar pine, local Ribes control could be considered in accessible, high-value areas to reduce the frequency of blister rust.[102]

Sugar pine seed stored at the CAL FIRE LA Moran Reforestation Center. Credit: Austin Rempel / American Forests.

Seed collection and assisted migration

Strategies	Approaches
8, 9	8.1. Use seeds, germplasm and other genetic material from across a greater geographic range. 8.2. Favor existing genotypes that are better adapted to future conditions. 9.1. Favor or restore native species that are expected to be adapted to future conditions. 9.2. Establish or encourage new mixes of native species.

Seed collection

Sourcing seed and seedlings in a climate-informed way is a logistical challenge as there is no one-stop nursery or seedbank for all sources and species. Working with multiple nurseries and seedbanks makes logistics and timing more complicated, as availability, timing, size and quality will vary by source. The U.S. Forest Service's Placerville Nursery does not currently have any seed that matches future BLM climate zones (see "Analog climates" section). The CAL FIRE LA Moran Reforestation Center fortunately had low-elevation (1,500-foot) Douglas-fir and ponderosa pine in seed zone 524 for the spring 2021 planting, but BLM should increasingly expect to have to gather seed and build up seed supplies to enable future planting efforts. It will also take proactive effort to source low-elevation incense cedar and rust-resistant sugar pine (neither have been available in recent years).

Oaks are a special case. Acorns don't store as well as conifer seeds, and large nurseries don't tend to have inventory or experience growing them. Acorn collection and sowing orders must be planned well in advance. Directly planting acorns works better than planting nursery-grown seedlings (they grow a longer taproot), and mycorrhizae inoculations have been shown to increase seedling performance in the field.

Seed collection priorities must be established to enable climate-adaptive plantings. A relatively simple GIS-based approach would be to develop a plan for each landscape by assessing: 1) current/future species cover; and 2) current/future burn probabilities, to give a general sense of what kind of seed should be in storage and how much. Time is an important factor, as large fires are erasing entire genotypes (seed sources) and low-elevation trees are producing smaller, more variable cone crops as low elevations heat up. Low-elevation seed sources should be mapped, monitored and prioritized for cone collection.

Seed storage facilities at the CAL FIRE LA Moran Reforestation Center. Credit: Luciane Coletti / American Forests.

Assisted migration

The outcomes and potential benefits of assisted gene flow (introducing better adapted genotypes) are unproven. For example, researchers reported mixed results for a set of recent post-fire plantings — where genotypes that track future climates outperformed local seed sources in some cases, but not others. The authors caution that the difficulty of tracking seed sources makes evaluation difficult.[104] Results may also vary by species, and the degree to which species and genotypes are adapted to factors other than climate (e.g., soils).

Online mapping tools can help to identify places to look for suitable species and genotypes (see "Analog climates" section).

Researchers also emphasize the need for more provenance studies, which are long-term studies for specific species that produce science-based predictions of seed transfer success. The most important species for post-fire reforestation in California (e.g., ponderosa pine, Douglas-fir) are understudied. Without this species-specific information, climate-informed plantings can be a shot in the dark. Improvements in seedling performance are observable in six to 10 years, so operational provenance tests could provide key information in relatively short periods of time.[105]

Considerations for planting and stand development

Strategies	Approaches
1, 2, 3, 9, 10	1.4. Reduce vegetation competition for moisture, nutrients and light. 2.1. Maintain or improve the ability of forests to resist pathogens and insect pests. 3.1. Alter forest structure and/or composition to reduce risk and severity of wildfire. 3.3. Alter forest structure to reduce severity or extent of extreme weather events. 9.3. Guide changes in species composition at early stages of forest development. 10.1 Promptly revegetate sites after disturbance.

The following discussion draws from examples and analysis in the Dinkey Reforestation Framework report, adapted to fit the context and growing conditions of the Camp Fire burn area.[106]

General sequence and timing of treatments

- **Site preparation:** Site preparation should occur within one to three years of disturbance. Delayed site preparation allows for shrubs to firmly establish. Once shrubs have established, they become much more difficult and expensive to control (see "Climate-smart shrub control" section).
- **Planting:** Planting should be done within one year of site preparation and no more than two years afterward.
- **Release:** Release treatments reduce competition and risk of seedling mortality from fire. Typical treatments include hand release by grubbing a 3- to 5-foot radius around each seedling, or targeted hand application of herbicides (i.e. spot spraying). Given climate and other factors, release treatments should be completed as quickly as possible after the planting. Seedlings can also be thinned during release treatments if stocking exceeds the target density. Additional release treatments will likely be needed in subsequent years based on seedling monitoring outcomes. Hand release treatments should generally be scheduled every two to four years unless paired with other treatments. With only one hand release treatment, understories can be dominated by shrubs by year 10.
- **Follow-up brush control:** Between year 15 and 20, stands should be treated with either a late-fall prescribed burn, or by hand-cutting and piling. Local managers do not recommend prescribed fire until planted conifers reach diameters of at least 5 inches, which will likely take at least 20 years of growth in the lower and middle elevations of the burn area.[107] Managers similarly do not recommend any prescribed fire until planted trees are pruned to a base height of at least 5 feet (7 preferred). For the first decade — according to surface fuel loads in historic ponderosa pine forests and fire behavior guidelines — fuel loads in planted areas should be maintained between 5 to 20 tons per acres. Fuel loadings should be even lower along ridges and strategic fire suppression roads. Especially for the first five years after planting, grasses and forbs should constitute the highest proportion of the fuel load in planted areas, rather than brush.[108] Shrub cover should be maintained at less than 30% for the first 20 to 30 years after planting, and space should be maintained between shrubs and tree crowns.

Planting crew at the BLM's Jordan Hill parcel, spring 2020. Credit: Austin Rempel / American Forests.

Planting designs

REGULAR SPACING ("PINES IN LINES")

- This is the most efficient approach for timber production. An example of this scheme would be to plant 400 trees per acre, release two to five years after, and expect about 300 trees per acre to be alive at age 5 (assuming 25% mortality). Shrub growth would be controlled initially by release treatments and then by the dominance of 300 saplings per acre. At about age 15, the planting would be pre-commercially thinned to ~200 trees, the slash pile burned, and the remaining trees left to grow until a commercial harvest at age 45 to 60 depending upon site productivity.

INDIVIDUALS, CLUMPS AND OPENINGS (ICO)

- Frequent-fire forests historically had a spatial pattern with three general components: individual scattered trees in a matrix of shrubs and hardwoods, clumps of trees, and openings. This is known as the Individual, Clumps and Openings (ICO) approach to planting and vegetation management.

- An example of a planting prescription to emulate this pattern, developed on the Eldorado National Forest, varies planting design by unit:[109]
    - Unit 1: Plant approximately 108 trees per acre. One tree per planting site on a 20-by-20-foot spacing between planting sites.
    - Units 3, 4, 5, 6, 10-24: Plant approximately 108 trees per acre. Four trees per planting site on a 10-foot spacing between trees on a 40-by-40-foot spacing between planting sites.
    - Units 22, 25, 26, 28-35: Plant approximately 163 trees per acre. Six trees per planting site on a 10-foot spacing between trees on a 40-by-40-foot spacing between planting sites.
    - Units 2, 7, 8, 9, 707: Plant approximately 272 trees per acre. Ten trees per planting site on a 10-foot spacing between trees on a 40-by-40-foot spacing between planting sites.
    - (Planted seedlings were spaced off oaks and natural conifers in all units).
- Little research has been published to date on seedling survival, growth and fire resilience with this planting design. One study examined growth and development in several post-fire plantations and naturally regenerating stands in the King Fire burn scar in the Eldorado National Forest, planted similarly to the design outlined above. Clustered trees had greater height and diameter growth compared to evenly spaced trees (prior to thinning). The author suggests that clumped seedlings may devote more resources to early root growth or have stronger mycorrhizal networks.[110, 111] This design is also being tested in the Moonlight Fire burn area in the Plumas National Forest. Early observations suggest that clustered plantings experienced higher survival and more spatially heterogeneous burn patterns during a reburn than might be expected in a regular spaced planting area.[112]
- The ICO pattern can also be created by pre-commercial thinning in traditionally spaced plantations by grouping leave trees in patches and thinning heavily around the patches.

Microsited ponderosa pine seedling at the BLM's Jordan Hill parcel, spring 2020. Credit: Austin Rempel / American Forests.

ISLAND PLANTING

- This concept focuses on providing seed sources for long-term regeneration in extensively burned landscapes where conifer seed sources have been extirpated, and where large-scale management is unlikely.
- An example approach used in the Rim Fire burn area is to plant small, variable-shaped areas less than 2 acres in size within a larger (10-acre total) area.[113] On each of the 2 acres, plant 40, five-tree clusters with 6 feet between each tree and spaced 33 feet apart. Planting would not occur within 1,000 feet of an established conifer. Some designs call for digging defensive hand lines around each cluster.

CLUSTER ("THREE TO A SPOT")

- This is an approach that can be used when survival is expected to be low (<50%). It is becoming common practice on national forests in Southern California. An example of this scheme would be to plant three seedlings per planting spot at 1.5 feet apart (~170 TPA) with the expectation that at least one seedling will survive at each planting spot. It is especially useful with sensitive species, like sugar pine which typically suffer about 50% seedling mortality during the three years after planting. It is also useful for direct seeding acorns, as many do not survive due to desiccation and herbivory post planting. Subsequent treatments remove all but one of the seedlings per spot by age 3, prune the lower third of the branches at age 6, and under-burn at age 9. The cost of planting three seedlings instead of one is offset by not having to pay the greater cost of replanting should the initial planting fail to meet stocking objectives. Removing one to two surviving seedlings can be wrapped up with the cost of follow-up release treatments.

LOW PLANTING DENSITY

- Low-density planting targets the long-term desired stand density so that the stand could be on a trajectory for open forest structure without pre-commercial thinning. However, there are tradeoffs with this approach as shrub competition is more of a risk and more release treatments will be necessary. For comparison, a high-density planting scenario would be to plant 300 to 400 trees per acre with intense release treatments (two likely), then pre-commercial thinning at year 15. A low-density planting scenario would be to plant 100 to 200 trees per acre with intense release treatments every two to three years for shrub control until 15 years (five release treatments total), when canopies may or may not close to outcompete brush.
- Spatial heterogeneity can also be introduced within a low-density planting area by introducing clumps (three or more seedlings) planted at less than the standard wide spacing. An example would be a cluster of five trees planted 8 feet apart in an otherwise 18-foot planting spacing scheme. Trees would not completely dominate the site, and there would be more vegetation diversity in low planting densities than in high.

REFORESTATION IN FUEL BREAKS

- Fuels and fire suppression objectives require low crown continuity, so conifers should be widely spaced (18- to 20-foot spacing) along with retained oaks dispersed throughout the stand. Mature tree crowns should be approximately 10 to 30 feet apart (10 feet on 0% to 20% slopes, 20 feet on 21 to 40% slopes, and 30 feet for slopes over 40%).[114]

- Once mature, trees within a shaded fuel break should be pruned to a height of 15 feet (taking no more than one-third of the live crown).
- Wide spacing creates space for shrubs. To maintain low crown continuity, regular follow-up release treatments will be necessary. The time frame for maintenance is typically two, five and 10 years after initial construction of the shaded fuel break. Treatment with livestock may need to be repeated more frequently.

OTHER CONSIDERATIONS FOR PLANTING

- Order containerized seedlings:
    - Bare root seedlings are cheaper and should mainly be reserved for deeper soils. Proper handling is paramount — bare root seedling mortality can occur in literally seconds, and conifer seedlings are particularly sensitive.
    - Containerized seedlings are more expensive but can handle much harsher sites and planting conditions. They grow faster than bare root seedlings under normal conditions and have better survival rates under poor conditions.
    - Consider planting two-year seedlings, which is standard practice in drier areas, like the southwest.
- Use shade cards or tree tubes:
    - Decrease excessive sun and exposure and increase soil moisture — useful to boost seedling survival during the first one to two years in harsh, hot areas and now standard in desert environments of the southwest.
- Plan multiple planting season (fall vs. spring):
    - Fall plantings have been successful in Northern California, particularly at higher elevations. Practitioners in the southern Sierras increasingly recommend fall plantings to deal with shifting climate, and the Butte County Resource Conservation District and Plumas National Forest are experimenting with fall plantings. It is worth attempting on BLM lands, capacity allowing. Splitting up plantings between fall and spring could help spread out the investment and reduce impact of poor weather and possible fires.

Reusable tree tubes protect seedlings at a USFS planting site in southern New Mexico. Credit: Austin Rempel / American Forests.

- Make speculative seedling orders:
    - Consider ordering seedlings without having an exact planting site or area in mind since the cost of seedlings is minimal compared to the costs of planting and vegetation control. With fires happening so regularly and the need for planting as quickly as possible after a fire before shrub response, this strategy could be a lower cost than if the site is planted in year two or three following the fire. Speculative seedling ordering would be most effective if coordinated with multiple agencies or large landowners, such as Sierra Pacific Industries. Planting sites can be hard to find in some years so coordination across ownership types might help to make this strategy more effective.
- Consider the costs and long-term financial feasibility of any management plans:

Treatment	Cost per acre
Mechanical thinning (WUI)	$2,000 to $3,000
Hand thinning	$500 to $1,500
Hand pile burn	$300 to $700
Hand Release (3 to 5 ft radius) and pruning	$400 to $800
Hand clearing (complete brush removal)	$500 to $1,000
Chipping	$200 to $700
Mastication and mechanical site prep (brush rake)	$500 to $1,500
Prescribed burning	$400 to $1,200
Hand herbicide application (site prep and maintenance)	$100 to $500
Grazing (goats)	$400 to $700
Planting (labor only)	$75 to $200
Mulch mats (installation and maintenance)	$600 to $1,500

Table 7. Regional costs for typical reforestation treatments.

Other possible treatments

Some practices are relatively novel or require special consideration in the context of climate adaptation. This section presents a review of strategies that emerged during the scoping process, based on interviews with local forest managers and a literature review.

Oak regeneration treatments (pruning)

Strategies	Approaches
3, 5, 9	3.1. Alter forest structure and/or composition to reduce risk or severity of wildfire. 5.3. Retain biological legacies. 9.1. Favor or restore native species that are expected to be adapted to future conditions.

Black oaks can survive and resprout even after multiple high-severity fires. However top-kill can set back acorn production and development of large cavities used by wildlife for several decades. Managers have suggested that pruning resprouts to a few dominant stems may speed up post-fire development and encourage height growth. Managing for single-stemmed trees could help to prevent canopy closure in the resprouting oaks, keeping a more open stand structure that may be more resilient to another wildfire.

Little direct research is available to assess the impacts of thinning black oak resprouts. McDonald and Tappeiner (2002) found no advantage in average height, crown width or crown volume from thinning resprouts but emphasized the need for more research. Anecdotal evidence suggests that it can be effective to encourage height growth and better growth form, to the extent that Sierra Pacific Industries (SPI) includes pruning to two or three dominant sprouts in all of its post-fire prescriptions. Long-term studies on the subject are underway in the Power Fire scar (results expected in 2022-2023), and the Concow Resilience Project is also incorporating and testing release treatments and pruning oak back to the dominant four or five stems.

BLM State Forester Coreen Francis at Jordan Hill. Credit: Austin Rempel / American Forests.

Jonathan Long at the Pacific Southwest Research Station conducted a literature review to inform black oak restoration in the Power Fire.[117] Along with monitoring guidelines for treatment outcomes, multiple findings from the paper are relevant to Camp Fire restoration efforts:

- **Black oaks can produce acorns as early as five years after resprouting** following top-kill during clearcuts, and acorn production has been documented on nearly half of post-fire resprouts that were 11 to 12 years old. However, the production from small resprouting trees is likely to be very low, and acorns may or may not be viable. For comparison, newly planted oaks take about 30 years to produce acorns.
- If/when pruning:
  - **Prune to two to four stems:** McDonald and Vaughn (2007) studied effects of thinning resprouts and found that trees with two, three and four stems grew at about the same rate as a single stemmed-tree of the same diameter in open areas.
  - **Remove sprouts that are growing from the top of a stump,** which are weaker and retain basal sprouts.
  - **Wait at least four years after fire to prune:** In a study of blue oaks in California, treatment of 2-year-old resprouts resulted in very small improvements in growth (Barry et al. 1997). Tappeiner and McDonald (1980) noted that thinning before four years promotes more sprouting. In earlier work, McDonald (1978) found that thinning at age 1 was difficult and ineffective, and many selected stems were inadvertently removed. Thinning at age 4 was much easier because sprouts were more firmly attached, and dominant individuals could be identified and saved.
- **Consider variable-density buffers around oaks when replanting conifers in areas with resprouting oak:** The Sierra Nevada Forest Plan Amendment requires a fixed 20-foot buffer when planting conifers around oak trees, but this approach may not be designed to promote long-term oak values:

  "Enforcing 6.1 m (20 ft) buffers around resprouting oaks may not be appropriate for stands that were previously composed of an admixture of shade-intolerant conifers and black oak. At this level of oak protection, 33 evenly spaced black oaks with 0.3 m (1 ft) crown diameters on an acre practically prohibits any planting of conifers; both the mean and median of black oak clumps per acre observed after the Storrie Fire's high-severity burns are greater than this threshold. Managers should be aware that complete satisfaction of SNFPA guidelines may effectively preclude any conifer planting where oaks are relatively abundant. A density-dependent variable radius buffer or a patchy, systematic application of the crown buffer guidelines may be more appropriate for stands meant to satisfy both oak and shade-intolerant conifer recovery objectives" (Crotteau et al. 2015).

"Climate-smart" shrub control

Strategies	Approaches
1, 3, 9	1.4. Reduce vegetation competition for moisture, nutrients and light. 3.1. Alter forest structure and/or composition to reduce risk or severity of wildfire. 9.3. Guide changes in species composition at early stages of forest development.

High-severity burn areas with few or no remaining conifer seed sources will likely become dominated by brush. Fire-created chaparral patches are more likely to reburn at high severity, which can prevent forest recovery and result in (semi-) permanent ecosystem type conversion to chaparral.[118]

PRIVATE VS. PUBLIC MANAGEMENT REGIMES INFLUENCE POST-FIRE REFORESTATION SUCCESS

Federal land management agencies often do not have social license to use herbicide on native species. Without this tool, it is often impossible to prevent type conversions after fire. Recent research has documented major differences in post-fire restoration trajectories on federal and private industrial land. Heavily managed private lands have recovering forests, while most federal lands are left to transition to fire-prone shrub communities. The main reasons for these differences are that private entities can: 1) use herbicides to manage re-sprouting shrubs, giving trees a chance to establish; and 2) have earlier access to seedlings and fewer permitting requirements, which enable them to make better use of the two- to three-year post-fire window.[119] If seedlings can outgrow shrubs in the first three to five years, release treatments may not be necessary as the seedlings will have captured available site resources.[120, 121]

Private companies always have seedlings growing at nurseries as part of wider operations. When a fire occurs, they can immediately redirect these seedlings to burned areas and establish them before shrub/grass competition sets in. Federal agencies do not have seedlings growing at nurseries because they don't have the same even age management regime as private industry (thinning rather than clearcuts). Federal agencies submit sowing requests in the fall following each fire, and these seedlings are not lifted for planting until the following winter, putting the planting timetable two to three years after the fire, when shrubs become firmly established. This makes the project more challenging and costly.

Private versus public management outcomes are also clear at Jordan Hill, where adjacent SPI and BLM lands offer an interesting contrast. Both landscapes burned severely and have few to no adult trees left, but SPI lands are dominated by grasses and burned plantations with virtually no sprouting hardwoods or shrubs. BLM lands are mostly bare ground, large snags and resprouting shrubs and hardwoods. Given the potential for this landscape to burn severely every 10 years in the absence of coordinated fuels management and active restoration across ownerships, SPI has made the decision to stop planting their lower-elevation parcels for timber production and rather manage these areas for fuels and community fire safety.

COMPETITION FROM SHRUBS CAN DELAY OR PREVENT FOREST DEVELOPMENT

Conifers released from the effects of brush competition result in successful reforestation efforts. Extensive research has shown that reducing shrub cover to 30% or below helps to minimize competition and promote conifer growth and survival.[122] Increasing tree growth rates is critical for the development of fire resistance, earlier seed production (resilience) and mature/old-growth forest structures. Ineffective control of competing vegetation lowers conifer survival and growth. Competing vegetation utilizes water and nutrients needed by young trees, which then causes decreased root expansion, poor growth and, in many instances, young tree mortality. Even if the seedling survives, these early losses in growth are seldom made up (McDonald 2010).

In a 30-year study of the long-term effects of varying levels of brush competition, ponderosa pine without any shrub competition were 30 feet tall; 22 feet tall with light competition; 15.2 feet tall with medium competition; and only 9 feet tall with heavy competition.[123] A conservative estimate of growth loss would be a tripling of the time necessary to achieve "old forest" characteristics if the competing vegetation is not controlled during stand development.

However, recent research has also raised the possibility that competition from shrubs may become less deadly for conifer seedlings as the climate warms.[124]

HERBICIDES ARE OFTEN NECESSARY TO ESTABLISH CLIMATE-VIABLE CONIFER STANDS

It is not a stretch to say that climate-viable forest stands cannot be managed economically and at large scales without herbicides, when there are sprouting shrubs present on the site.[125] Non-sprouting brush and grass can be effectively controlled by hand clearing at a significantly higher cost than herbicides, but sprouting brush is more effectively controlled with herbicides. Hand release and mastication of shrubs only removes the aboveground stems and is not as effective as treatments that target the root system, such as brush rakes or herbicides. Hand release treatments are primarily to improve seedling survival, as a 3- to 5-foot treatment radius generally leaves 60% to 80% shrub cover that suppresses seedling growth.[126] However, aboveground control alone can reduce shrub size and leaf thickness, which can make subsequent chemical treatments more effective.

No-herbicide treatment options are two to five times more expensive and lead to growth rates about 25% of that obtainable with early herbicide application.

Resprouting shrubs at Jordan Hill in winter 2019 — just over one year after the Camp Fire. Credit: Austin Rempel / American Forests.

MAINTAINING CHAPARRAL AT FIRE-SAFE AND ECOLOGICALLY MEANINGFUL LEVELS

Chaparral is inherently climate-adaptive so a balance must be struck between maintaining ecologically valuable chaparral communities while also creating conditions suitable for fast growth of conifers and lower risk of severe fire. Managers should strike this balance at the landscape and site level. Old-growth chaparral stands are relatively rare and ecologically desirable, and managers should consider explicit plans to encourage and maintain them.[127, 128] Long fire-free periods are required for many chaparral species to properly regenerate, and it's possible that repeated high-severity fires could impact even chaparral's ability to recover. Increasing fire frequency may increase the likelihood of conversion to non-native annual grassland (cheatgrass), degraded shrublands or even barren ground.

Chaparral has always been present in large patches in most parts of this landscape.[129] It is recognized that there is a need for maintaining patches of shrubs for landscape diversity and wildlife habitat so the following management guidelines can facilitate this goal while also achieving reforestation needs:

- Leave gap selection areas (shrub recruitment islands, for management as shrub habitat), and/or untreated leave islands of shrubs.
- In areas where shrub cover is maintained, it is still important to thin to create space of two times the height of the retained shrubs, in order to meet fuels management goals in these areas.[130]

Fuel treatments, like prescribed fire and mastication, can be used to reduce fire risk while maintaining the ecological integrity of chaparral. Chaparral advocates generally recommend that managers avoid conducting prescribed burning and other vegetation treatments in chaparral management units (islands).[131]

Pruning and underburning young conifer plantations

Strategies	Approaches
1, 3	1.4. Reduce vegetation competition for moisture, nutrients and light. 1.5. Restore or maintain fire in fire-adapted systems. 3.1. Alter forest structure and/or composition to reduce risk or severity of wildfire.

- Removing (pruning) lower limbs from young conifers is necessary to raise the canopy base height before any underburning of young plantations can occur. Pruning is also an important strategy in achieving prescribed fire goals of keeping flame lengths low to the ground because raising the canopy base height can prevent flames from climbing into the young trees.
- Prune the lower branches when the trees are at least 10 feet tall to reduce sapling mortality and the risk of crown fire during prescribed and natural fires. Maintain at least half of the live canopy. In the longer term, increasing canopy base heights to greater than 15 feet can help break up horizontal and vertical continuity of flammable fuels.

- Planted stands can be underburned once the average dimeter is at least 5 inches, which will likely take 20 years of growth to achieve on BLM lands. Managers similarly do not recommend any prescribed fire until planted trees are pruned to a base height of at least 5 feet (7 preferred). The goal of an underburn is to eliminate as much surface fuels as possible to increase the likelihood of surviving a wildfire. A widely used benchmark is that underburning should limit seedling mortality to under 15%. Clearing brush by hand, or mechanically, can reduce fuel continuity and arrangement, thus, emulating some of the effects of underburning, but the fuels remain on site until pile burning occurs. Hand and mechanical treatments cost more than underburning, with less fuels reduction benefits.[132]
- Underburning should occur in the late fall/winter (ideally after pruning) when tree buds have gone dormant. Research shows higher top-kill of small black oaks (<10 feet tall) in late spring and early fall burns, with the highest survival in late fall burns and intermediate survival in the early spring due to higher moisture.[133]
- Introduce prescribed fire to planted stands as early as possible to emulate historic/natural fire return intervals of five to 10 years for yellow pine and 10 to 20 years for mixed conifer stands. The five- to –10-year burn cycle will be more feasible in plantations that are more than 20 years of age due to duff accumulation. Prescribed fire is a cost-effective way to reduce surface fuels, select for fire-resistant trees, create early stand heterogeneity, and generate lower fuel loadings than comparable mechanical treatments.[134]
- Communities in the Camp Fire burn area are supportive of prescribed fire as a restoration tool.[135]
- There's a major opportunity to learn from the experience of managers and emulate the prescribed fire regime in place at the nearby Big Chico Creek Ecological Reserve.[136]

Figure 14. Prescribed fire at Big Chico Creek Ecological Reserve. A visual representation of what sites like Jordan Hill could look like with transition to oak woodland and a restored low-intensity fire regime. Photo credit: Don Hankins.[137]

Mulch mats and weed barriers

Strategies	Approaches
1	1.4. Reduce vegetation competition for moisture, nutrients and light.

- Mulch mats prevent shrubs from resprouting and increase soil moisture. This option is expensive and labor intensive, but useful especially where herbicides aren't feasible. They may be well suited to small-scale founder plantings, in conjunction with defensive handlines.
- They have been used successfully in large-scale reforestation projects. For example, California State Parks used them extensively in planting projects after the 2003 Cedar Fire. Managers at Cuyamaca Rancho State Park used 12-by-12-foot mulch mats, sometimes doubled up and/or combined with weed barriers. The approximate cost of these materials was reportedly $1.50 per seedling.

Seeding native grasses

Strategies	Approaches
1, 3, 9	1.5. Restore or maintain fire in fire-adapted systems. 3.1. Alter forest structure and/or composition to reduce risk or severity of wildfire. 9.1. Favor or restore native species that are expected to be adapted to future conditions.

- McDonald (1986) reported that *"Grasses are not desirable in conifer plantations less than five years old, but after five years, they can aid conifer seedling growth by physically and chemically excluding more competitive vegetation. In plantations over 5 years old on good sites with deep soils, grasses can be beneficial by excluding deeper rooted shrubs. On poor sites with shallow soils, grasses and shrubs often compete throughout the profile and no benefit accrues to conifer seedlings by converting to grasses."*
- A number of climate scenarios suggest that grasslands could be the most suitable vegetation type for the low to mid-elevations in the Camp Fire. Steps could be taken to test or speed up this transition by establishing desirable grass species (rather than cheatgrass).[139] However, there are questions as to whether seeded native grasses persist in treated areas over the long term.[140]
- Native bunchgrasses are desirable and can carry a low-intensity underburn more effectively than woody shrubs. Once planted trees are taller than 3 to 6 feet, and especially if the lower whorls have been pruned, the hazard from burning grass is reduced.

Grazing (goats)

Strategies	Approaches
1, 3	1.4. Reduce vegetation competition for moisture, nutrients and light. 3.1. Alter forest structure and/or composition to reduce risk or severity of wildfire.

- Grazing is a socially accepted form of site preparation and maintenance and should be considered when herbicides aren't an option. However, grazing *after* planting conifers is not recommended as a maintenance treatment since grazers will likely browse on the planted trees.
- Concow residents credit goat grazing on private land and along Concow Lake for reduced fire severity during the Camp Fire.
- Goats are an effective tool for treating small acreages.
- Goats are not a preferred treatment option in areas with non-native invasive species.
- Goats will eat conifer seedlings, especially in the spring. It is ideal to wait until young trees are 8 to 10 feet in height.
- The cost of grazing includes the goats, portable fencing, a goat herder for daily supervision, water and transportation.
- Grazing for shrub control becomes much more difficult when shrubs get too tall to be reached by the animal.
- Goats do not remove shrub root systems so treatments must be repeated regularly (every two years). Grazing may be more effective for controlling shrubs if conducted during the growing season. Multiple cycles of return grazing (~10 years), may be able to exhaust shrubs' underground root stores, weakening them and allowing grasses and/or conifers and hardwoods to dominate. Grazing treatments could also make future herbicide applications more effective.
- Goats should be kept off very sensitive soils as they can create erosion.
- On the Cleveland National Forest in Southern California, about 1,400 goats were used to reduce surface fuels on an existing 100-acre fuel break. The goats were contained inside a portable electric fence, surrounding 2 or 3 acres, and moved every few days. Costs ranged from $400 to $500 per acre. Based on this example, 1,400 goats are capable of reducing surface fuels on 100 acres per month (.0024 acres, or 100 square feet of brush, per goat per day).[141]

Guidelines for monitoring and evaluation

Monitoring is an added cost and a long-term commitment. Local universities and researchers could be engaged to help with design and measurement. Engaging multiple partners and sharing data in the process early on (agency, nonprofit, universities and even private contractors) could also help ensure that evaluation continues over the long term (e.g., with staff transitions). Monitoring helps inform land managers about the effectiveness of various planting designs, vegetation control, seedling survival and tree growth into the future.

- Monitoring Tools: Practical monitoring tools include planting trial plots and marking seedlings/young trees (e.g., staking, aluminum labeling, colored zipties), photo point records, and precise, accessible GIS mapping (e.g., online map for data storage/access as well as easy visualization).
- Planting trial plots: Install trial plots embedded within overall planting plans. These trial plots help to assess the viability and relative performance of various species and seed sources planted across the site. Several lessons and tips emerged from the review process:
    - Plan ahead and know that it is a challenge to set plots up correctly during a contract planting. Factors like stock quality, timing and handling confound the ability to track the performance of seed sources.
    - Track trial seedlings with durable materials like aluminum tags and colored zipties.
    - Trial seedlings can be planted closer together than the spacing of other planted trees since the monitoring is for early survival and growth. Inter-tree competition is not significant during the first 10 years of stand development within a plantation. The closer design allows for less acres in need of intensive vegetation control, which is highly recommended for tracking seedling growth without the competitive effects of adjacent vegetation.
    - Plan to measure one, three and six years after the trial planting to measure how trees perform by species and seed source. Monitor tree survival, growth and vigor. Evaluating at six years is important because this is the minimum amount of time to detect differences in seedling performance. While most climate effects may become apparent after six years, it is equally important to monitor in the more distant future (e.g., 10, 20, 30 years after planting) to detect longer term trends.
    - Record percent cover in plots (e.g., shrubs, grasses, hardwoods and conifers).
- Photo monitoring plots: Establish photo-monitoring plots to document vegetation growth over time and facilitate long-term monitoring. Each plot should have a post labeled with a unique ID number and height mark on the post. Plan to take photos of the post and its surrounding area each year at a distance ~20 feet from each of the four cardinal directions. Photos should be taken at least biannually.

Monitoring plot at the BLM's Jordan Hill parcel. Credit: Austin Rempel / American Forests.

Ponderosa pine seedling from a southerly seed source, planted in spring 2020. Credit: Austin Rempel / American Forests.

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