

A photograph of a large sequoia tree trunk in a forest. The tree trunk is thick and has a rough, reddish-brown bark. It is surrounded by other trees and foliage, creating a dense forest scene. The lighting is soft, suggesting a misty or overcast day.

CLIMATE-INFORMED REFORESTATION GUIDANCE

**FOR SEQUOIA FORESTS IN
THE CENTRAL & SOUTHERN SIERRA NEVADA**



Central & Southern Sierra Nevada Region of California

This product is an output of the Climate-Informed Reforestation Workshop, hosted by the USDA California Climate Hub and funded by the California Department of Forestry and Fire Protection. Regional experts contributed to the workshop and the content found in this guidance.

Editors

Aviv Karasov-Olson,
Jessica DellaRossa, Jennifer Smith, Steven Ostoja

Contributors

Marc Meyer, Dana Walsh,
Ben Blom, Christy Brigham, Mark Egbert,
Susie Kocher, Malcolm North, Kristen Shive

Graphic Design

Dudek Consulting Visual Storytelling Team
Amelia Oxarart

Climate-Informed Reforestation Guidance For Sequoia Forests in the Central & Southern Sierra Nevada

Introduction to Climate-Informed Reforestation

Reforesting forests so they are resilient to future disturbances requires strategic planning, deliberate implementation, and follow-up management. In the face of climate change, those requirements are even more imperative. Changes in temperature, precipitation, and drought may push many species out of their bioclimatic envelope into environments that are more stressful, which can reduce health, survival, and productivity of trees. Generally, this stress will be exacerbated at lower elevations and for species which prefer colder and wetter climates.

Developing a strategic plan to assess the broader landscape context within which reforestation is considered is crucial for prioritizing reforestation success (Meyer et al., 2021; North et al., 2019). Climate-informed reforestation depends on effective site preparation, selection of appropriate planting material, and planting in densities, locations, and arrangements that will produce the best short- and long-term outcomes. Reforestation to produce resilient forests not only requires effective action during the first year of planting, but also follow-up actions in the years and decades to follow (Fig. 1). Post-planting management includes repetitive treatments to maintain control of competing vegetation and encourage or maintain the desired species composition, densities, and arrangements identified during the planning process. In many instances a post-planting management goal may also be to introduce (or re-introduce) fire as an ongoing component of the ecological system.

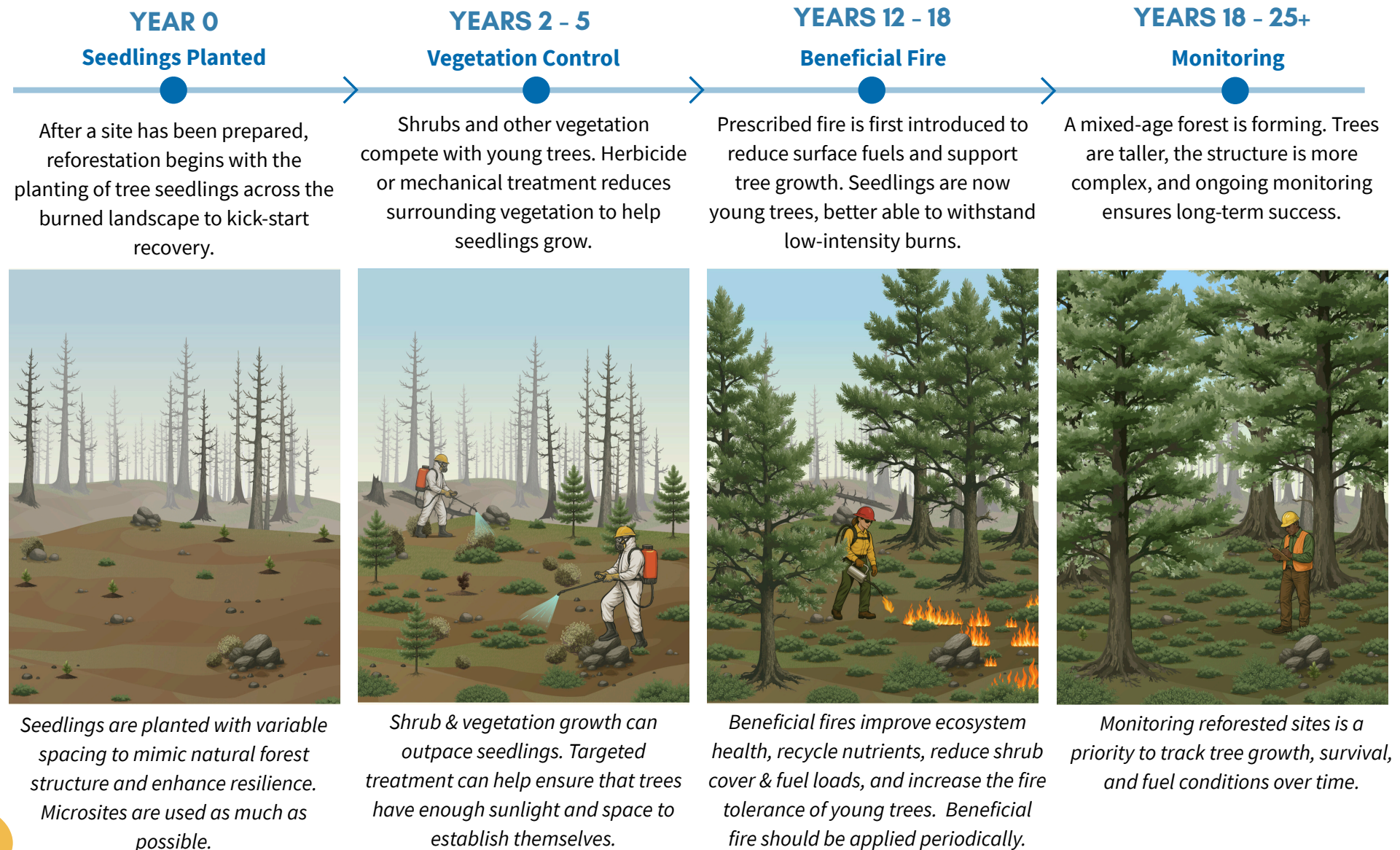
This guidance describes how site preparation, planting, and post-planting management actions can promote climate- and fire- resilient forests. This guidance was co-produced with regional foresters and ecologists through workshops and group meetings. It incorporates both peer-reviewed literature and place-based knowledge and aims to provide recommendations for all land ownership types (public and private) where possible.

Reforestation Process

- 1** Site Preparation *pg. 3*
- 2** Selecting Species & Composition *pg. 7*
- 3** Planting *pg. 9*
- 4** Post-Planting Management *pg. 17*

PUTTING IT TOGETHER: A REFORESTATION TIMELINE

Figure 1. Climate-informed reforestation is a long-term process. Key steps, including planting, vegetation control, reintroduction of fire, and monitoring, span up to 30 years. Specific activities and their timelines will reflect project and location-specific considerations.





Climate Change Considerations

Effectively removing wood biomass and managing competing vegetation are critical components of site preparation to offset the risks associated with drought and severe wildfire.

- **Drought resilience:** Where climate projections include an increased water deficit, site preparation should include actions to reduce plants that will compete with planted trees for scarce water resources. Increasing temperatures and drought stress can be offset with a focus on creating and maintaining protected microsites in locations where trees will be planted.
- **Wildfire resilience:** Fuels management should be prioritized in regions with a high likelihood of high-severity reburns.

Existing tools coupled with novel approaches for site preparation can achieve many climate-related goals. The particular methods (e.g., mechanical, burning, chemical, and/or some combination) selected to achieve these outcomes should be based on the operational and environmental context of the project, following existing guidance e.g., Stewart et al. (2021).

Key Actions

Fuels Management

Effective and timely wood biomass removal reduces the risk of severe fire and allows for safe planting and post-planting treatments. It is important to remove standing dead material (snags) and surface fuels to levels that reduce future high-severity fire. This involves managing 1 and 10 hour fuels, which cannot be effectively treated by hand or machine. Ideally these fuels should be less than 3 to 10 tons per acre, depending on stand productivity, forest type, and fuel loads of the surrounding landscape (Scott & Burgan, 2005). Remaining fuels that are patchy and discreet in coverage can contribute to structural heterogeneity, which is common in frequent, low and mixed severity fire systems and may reduce the risk of high-severity reburns (Lydersen & North, 2012; Lydersen et al., 2019). While extensive removal of wood biomass is critical

for reducing fire risk, it is also desirable to retain some woody elements on the landscape for ecological value, wildlife habitat, and the creation of mesic microsites.

- Retain at least 3-5 snags per acre, spaced variably across the stand to create stand heterogeneity. Retain a combination of individual larger snags (>30 inches diameter at breast height (DBH)) and clusters of smaller snags in areas where they are better protected for ecological value.
- Where it is deemed appropriate to reduce fuels prior to planting, remaining dead tree removal should be completed in the first 3 years following the disturbance, possibly up to 5 years for trees and sites with slower rates of decay. Timely dead tree removal and other fuels reduction treatments reduces the risk of high-severity reburn and improves access for subsequent reforestation actions including additional site preparation, planting, and post-planting management.
- Fire can be a useful tool for site preparation when conditions are appropriate to support fire and where burning will not substantially reduce natural regeneration of shade-intolerant species below desired thresholds. Fire may need to be used in conjunction with other approaches that reduce fuel loads.

Managing Competing Vegetation

Managing competing vegetation can be an important climate-informed practice, as it can reduce the impact of projected increases in water stress and fire activity. Site conditions and the existing plant species inform whether vegetation on the site will compete with the planted seedlings or not, and determine the intensity at which vegetation on a site needs to be managed. When vegetation is expected to compete with planted seedlings for limited resources, controlling that vegetation provides those trees with a competitive advantage for accessing soil moisture, which is a primary determinant of the successful establishment of young trees following planting. Vegetation management can also help reduce fuel loading and continuity to lower the potential for future high-severity fire, and allow for fire to re-enter a stand sooner without negatively impacting planted trees.

However, not all vegetation may impact planted seedlings equally. Retaining a small to moderate amount of shrub and herb cover may create opportunities to provide shaded and protected microsites for young trees, which can increase seedling survival (Marshall et al., 2023), and play a facilitative role in postfire and highly stressful climatic conditions (Fig. 2). Many native shrubs, grasses, and forbs are important for maintaining soil moisture, fixing nitrogen, providing heat sinks for fires at certain times of the year, and promoting carbon sequestration.

Recommendations about how much competing vegetation should be maintained varies. Some managers recommend eliminating all competing vegetation that might inhibit success of planted trees; others recommend controlling and maintaining <25%, while others may opt for controlling and maintaining up to 50% shrub cover depending on the site conditions, shrub species, tree species, and management objectives.

Examples of Conditions Affecting Level of Shrub Control

- **In xeric sites** or during periods of extreme drought when shrub growth may be reduced, shrubs may provide more beneficial nurse coverage for seedlings and allow for maintenance of slightly higher shrub cover. However, **on mesic sites**, the benefit of nurse coverage is only seen when planting happens in the first 2 years following fire (Sorenson et al., 2025).
- Extensive growth and high cover of *Ceanothus*, bear clover, and manzanita may require more shrub control than other less aggressive shrub species based on their potential to outcompete planted seedlings and impact establishment.
- **White fir seedlings** may be more tolerant of high shade cover by shrubs compared to pines.
- Some shrub species (e.g., blue elderberry, California hazelnut, several species of gooseberries and currants) provide high value as cultural resources and wildlife habitat and can provide shading for conifer seedlings where they exist. These species also rarely dominate a stand and do not create many competition problems for young seedlings.
- **Moderate to high levels of native grass or forb cover** (>25 to 50%) could benefit conifer seedlings by providing shading or increased soil nutrients in both xeric and mesic sites.
- **Following die-off from drought or disease**, target (spot) treatment of shrub and competing vegetation where seedlings are planted in areas of high shrub cover (>60%), and perhaps allow for a higher level of shrub cover than for post-fire reforestation where aggressive shrub regrowth is more extensive.

Soil Management

An increase in high-severity fire and drought poses problems for soil health of forests. There are several suggested practices for minimizing negative impacts to soil health and moisture retention, though there is less consensus on the usefulness of these practices and their applicability will vary based on specific soil properties.

- Experiment with biochar before planting or utilize biochar plugs when available at the nursery, particularly on xeric sites. Biochar can enhance water holding capacity, and increase soil organic matter, nutrient retention and soil pH, which can increase the survival of planted seedlings (Marsh et al., 2023). It is likely more beneficial in low productivity or acidic soils and may have limited efficacy or no benefit in more productive sites.

- Experiment with mycorrhizal additions, when bareroots are not inoculated at the nursery. Mycorrhizal inoculation can improve the soil's physical characteristics, improve plant nutrient supply and lead to increased growth (Neuenkamp et al., 2019).
- Minimize disturbance to the duff, litter, and mineral layers after snag removal to reduce shrub resprouting.
- **Following high-severity fire**, hydrophobic soils are often created. Breaking up this layer to minimize erosion and increase water infiltration can be beneficial, particularly on mesic sites.
 - Consider using contour tilling to address these issues as needed.
 - Only consider using deep ripping on in lower elevation stands where there were post-fire hydrophobicity effects on soil as this treatment can result in undesirable soil impacts (e.g., increase in invasive plant cover).
 - However, if soils are healthy post-fire, these intensive treatments can have negative impacts on soil health, such as degrading wildlife habitat and facilitating post-fire cheatgrass invasion.

Management of Surrounding Remnant Stand Following Disease-Driven Mortality

Disease driven mortality events necessitating reforestation are likely to increase in the face of climate change. Reforesting in response to these mortality events will require additional pre-planting preparation.

- Consider creating a species-specific buffer surrounding the planted area to ensure that the disease does not spread to newly planted trees. This buffer can be achieved by removing live host species that may have been exposed to the disease but are not yet showing signs of decline, and/or planting a buffer of non-host species between the remnant stand and core planted area. The width of the buffer is dependent upon the specific disease being addressed.
- Apply the necessary chemical or biological treatment to the area, when available. For mixed conifer forests with sugar pine, treat any large legacy sugar pines with verbenone.

SELECTING SPECIES & COMPOSITION

Climate Change Considerations

Changes in temperature, precipitation, and drought may create environments that are more stressful and outside the bioclimatic envelope of many species, which can reduce health, survival, and growth. Generally, this stress will be exacerbated at lower elevations, south and west-facing aspects, in drier environments (e.g., eastern Sierra Nevada), and for species which prefer colder and wetter climates. Decisions in a reforestation project that can buffer these risks include:

- Modifying the selection to favor more drought-resistant species or genotypes, particularly in xeric sites.
- Potentially shifting the relative proportion of each species, based on specific site characteristics, pre-disturbance stand health, and post-disturbance monitoring, as well as a desire to increase diversity of seedlings to reestablish on a site.
- Using a combination of local and climate-adapted seeds to increase genetic diversity and better prepare for future climatic shifts.

Key Decisions

Seed Sourcing

Seed and seedling source selection can be limited by seed crop availability, regional availability, and access. However, when the option is available, there are several recommendations for seed sourcing.

- Use planting as an opportunity to increase the genetic diversity of species within the planted stands to better prepare for future climatic shifts.
- Use a mixture of seed from the same seed zone and seed from lower elevations (500-1000 ft, 1-2 bands lower) or from further south in the range. Seeds from lower and more southernly elevation bands have been shown to be more tolerant of hotter and drier conditions that are projected to be more extreme in coming decades. Currently a mix of 50% local seed zone and 50% from lower elevations or further south is recommended.
- Use a seed lot selection tool (e.g., [CAST](#) tool) and/or work with genetics experts for selecting non-local seed.

- Use seed from seed orchards where available as they generally have a broader band of elevations and climatic conditions that they are suitable for, due to inherent genetic diversity in the orchards.

Species Selection & Composition

In the giant sequoia groves of this region, there is consensus among experts to plant giant sequoia within existing groves where natural regeneration is inadequate. However, there is some disagreement about planting giant sequoias outside of their climatic envelope, particularly because of concerns over the ability of seedlings to thrive in sites outside their edaphic and bioclimatic envelope. Additionally, experts recommend planting a mixture with some additional species (e.g., sugar pine, ponderosa pine, Jeffrey pine) among giant sequoias and sprouting hardwoods, such as Pacific dogwood, to diversify stands.



Climate Change Considerations

There are two important considerations when planting for developing resilient forests in the face of climate change:

- **Wildfire resilience:** Wildfire resilience in mature stands can be promoted by planting trees at lower densities, which ultimately lowers fuel loads, and in variable arrangements to allow for the reintroduction of fire earlier. Additionally, variable arrangements can be used to create fuel breaks. Continued management of fuels is still necessary to maintain wildfire resilience (see section below).
- **Drought resilience:** Competition for water resources between trees is lower at lower densities. Competition with other vegetation, especially shrubs, is lowered with clumped planting. Often, clumped stems will more quickly have interlocking crowns, which can shade out competing vegetation in the understory. Seedling clumps may also buffer conifer seedlings within the clump from the effects of future, lower severity fires.

Key Decisions

In addition to climate-related considerations, decisions about planting density and arrangement should consider realities around survival of specific species and on certain sites. Survival within the initial establishment period can reflect differences in capacity for ongoing management and maintenance. Reforestation should generally not be undertaken if survival is anticipated to be low. In general, planting should be developed to plan for at least 90% survival of planted seedlings during establishment with some expected differences in planting survival across the landscape (e.g., lower survival is expected on xeric sites). Decisions about planting density and arrangement should reflect the abundance of natural regeneration present at the site. When available, use seedling plugs rather than bare root stock on harsher sites, for more sensitive seedlings, and during fall planting and periods of drought. Additionally, decisions about planting density and arrangement are dependent on capacity for post-planting management as described below.

Density

Initial planting density recommendations often vary depending on reforestation goals (e.g., desire to maximize merchantable timber, reestablish mature forest), capacity for follow-up treatments, and site characteristics. Experts recommend aiming for ~25-90 canopy trees per acre (TPA) with some age-class diversity in mature stands, depending on the forest type, site conditions, and long-term forest management goals (North et al., 2022; Safford & Stevens, 2017). While initial planting densities should assume that a percentage of seedlings will be lost to mortality, planting plans should include all available management actions (e.g., use of microsites, use of appropriate stock type) that may improve establishment outcomes and support conservative seed use.

Which statement best reflects your post-planting management capacity and goals?

The capacity for post-planting thinning is high.
There is a desire to manage for future timber harvest.



Higher Intensity Management

- Some experts recommend increasing initial planting densities to maintain flexibility through planted tree management by establishing initial seedling densities of ~150-200 TPA followed by thinning to ultimately produce a target density of ~60-120 TPA. This can be accomplished with one or more rounds of pre-commercial thinning and should also account for natural causes of mortality. Decisions around specific levels of thinning should adapt to climate and ecological conditions at the time. These higher initial planting densities will require more extensive follow-up treatments of planted trees, particularly to manage fuel loads to reduce wildfire risk and density related risk for drought and insects. See sections below about arrangement and post-planting management for more implications of higher density planting.

The capacity for post-planting thinning is low.
There is a desire to minimize planted tree management.



Lower Intensity Management

- Experts recommend an initial planting density higher than mature target levels in 50-75 years, (i.e., ~60-120 TPA), with a buffer for anticipated mortality, recognizing that eventual seed production will increase future stand density as well. These lower initial planting densities will require a greater emphasis on use of microsites and more follow-up treatment to control competing vegetation. See sections below about arrangement and post-planting management for more implications of lower density planting.

Initial planting density should also reflect the capacity of the site.

- **Following drought or disease-driven die off**, plant at the lower ends of the densities listed above as the capacity of those regions is likely reduced due to limited water availability and/or other stresses that can lead to an increased incidence of disease. Some experts would recommend planting even lower densities than listed above (e.g., 40 – 60 TPA) though there is less consensus around this.
- There is less variation in recommended planting densities between mesic and xeric sites because trees are not competing with one another at the early stages; rather, they are competing with shrubs for water. However, **mesic sites** can be planted with slightly higher initial densities than **xeric sites** based on perceived capacity of the site.
- The ranges listed above apply to all forest types, though **mixed conifer forests in mesic sites** can accommodate the higher end of those ranges as can **giant sequoia in suitable microsites**.
- **Topography**: Plant lower densities on ridgetops and south-facing slopes, and higher densities on canyon bottoms and north-facing slopes within the ranges identified above.

Arrangement

Decisions about planting arrangement are interdependent with decisions related to planting density and capacity for follow-up treatments.

- **Lower planting densities**: It is recommended to plant in variable spatial patterns focused on microsites conducive to tree growth for ecological and operational reasons (Fig. 3). For example, post-planting treatment of shrubs is more effective and efficient when shrubs are most dominant in openings between clumped planting of trees. However, an increase in the complexity of planting pattern could slow the pace of implementation. Variable arrangements can include individual trees, clumps of trees, and openings (ICO) patterns.
 - Planting clusters may include 2-4 trees in **xeric sites** or 3-9 trees in **mesic sites** within a radius of 10-12 ft, with 20-25 ft between clusters, openings of 1000 sq ft, or a mixture of clusters within a gridded pattern.
 - Clusters should be located where microsite conditions can help ensure higher seedling survival.
 - Following drought or disease, cluster densities should be reduced to 2-5 trees in mesic sites and fewer in xeric sites.
- Lower densities may also be planted in a loosely gridded pattern with ample flexibility for use of microsites (Fig. 4).
- **Higher planting densities**: Some experts recommend planting in a roughly gridded pattern (15 x 15 ft or 16 x 16 ft spacing), allowing flexibility for use of microsites (Fig. 5). Follow-up thinning and prescribed burns can cultivate a more heterogeneous forest structure while reducing stand density. This higher density supports wood production objectives as trees grown in a gridded pattern, as opposed to open grown trees, are often considered more desirable in form, and implementation of subsequent

maintenance treatments to reduce density is feasible and reliable. In these plantations, maintenance of fuels accumulation is critical to address the increased risk from higher canopy bulk densities.

A variable planting arrangement can also reduce future fire risk and increase the likelihood of survival in extreme conditions.

- **At the planting location**, maximize use of protected microsites (e.g., rocks, shrubs, larger herbs, and snags) to protect young seedlings from extreme heat, sun exposure, and soil drying (Fig. 2). When planting within a gridded pattern (Figs. 4 and 5), provide flexibility to adjust individual seedling location to take advantage of microsites.
- **At the project site level**, reduced planting densities around the perimeter of a plantation can create a fuel break. This wide, lower density perimeter can be a focus for more intensive management of surface fuels. These could also be areas where a higher proportion of hardwoods are retained.
- **In a planted fuel break**, lower densities may be planted. Consider planting in variable planting arrangements to further introduce heterogeneity and discontinuity in the fuel profile.
- Plan for windbreaks and windfall by planting at higher densities, rather than relying on initial planting designs for reinforcement.

Timing

Existing guidance on the timing of planting is applicable for climate-informed reforestation, including preferring to plant in spring after snowmelt rather than fall planting, because the soil moisture is high in the spring. However, fall planting can offer additional benefits in the face of climate change; when planted in the fall, seedlings are ready to receive water by the spring even as the amount and timing of precipitation becomes more variable. Seedlings planted in the fall will naturally harden off, preventing the need to freeze after lifting (taking the seedling out of the nursery). The spring planting window between mid-February to June is restricted as snow melts and opens up access to higher elevation sites. The timing of spring is anticipated to shift with climate change, possibly leading to changes in the planting window.



Planting with Microsites for Seedling Protection

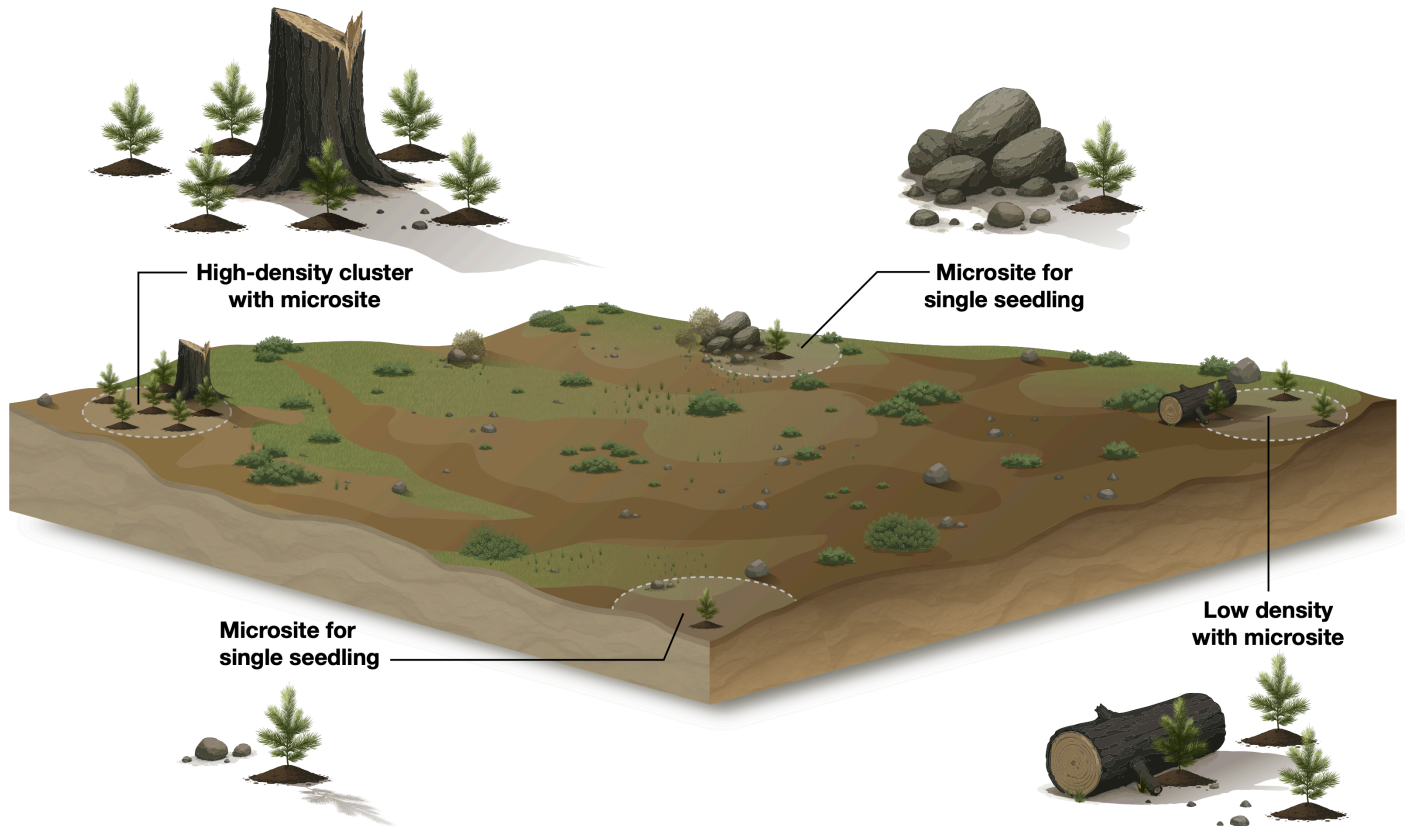


Figure 2. Existing features within a planting area, such as shrub and herb cover, rocks, stumps, or downed logs, can create microsites with more shade, soil moisture, and protection from extreme heat and sun exposure. Planting to take advantage of these microsites can increase seedling growth and survival.



Lower Initial Planting Density with Variable Spacing

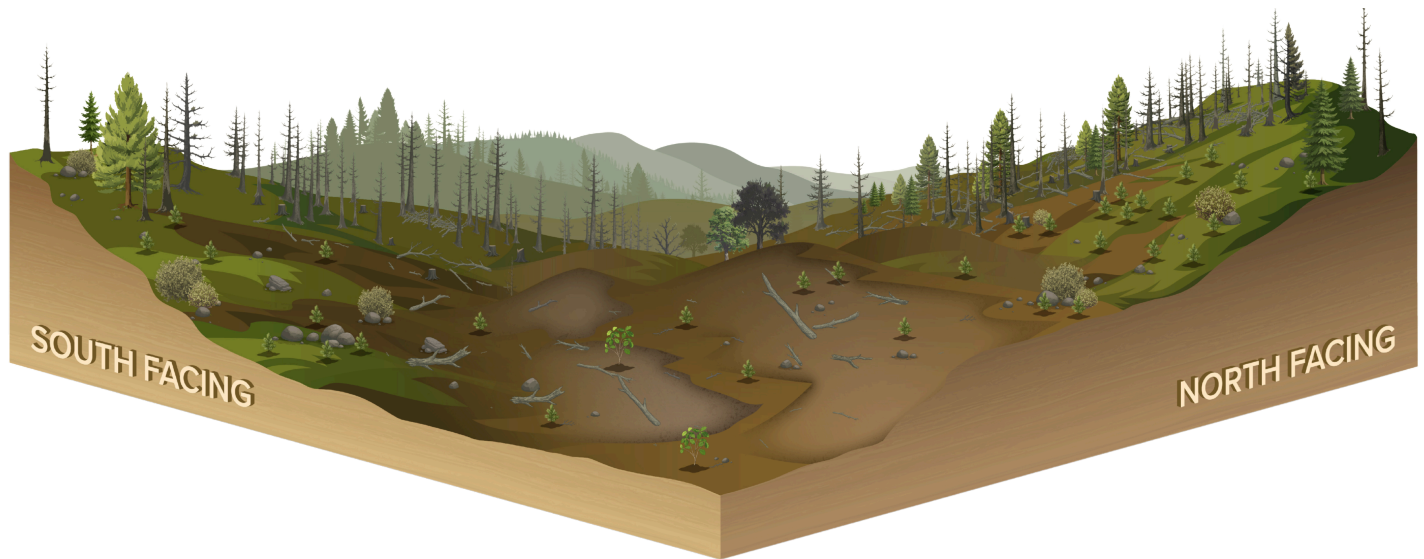


Figure 3. *Lower density plantings can be spaced variably to create a site with individual seedlings, clusters of seedlings, and larger openings without any seedlings. Seedlings should be planted in areas where microsites can support their survival (Figure 2). Planting in clusters may offer advantages, as clumps of seedlings more quickly outcompete other vegetation and may be able to accept the reintroduction of beneficial fire earlier.*



Lower Initial Planting Density in a Loose Grid

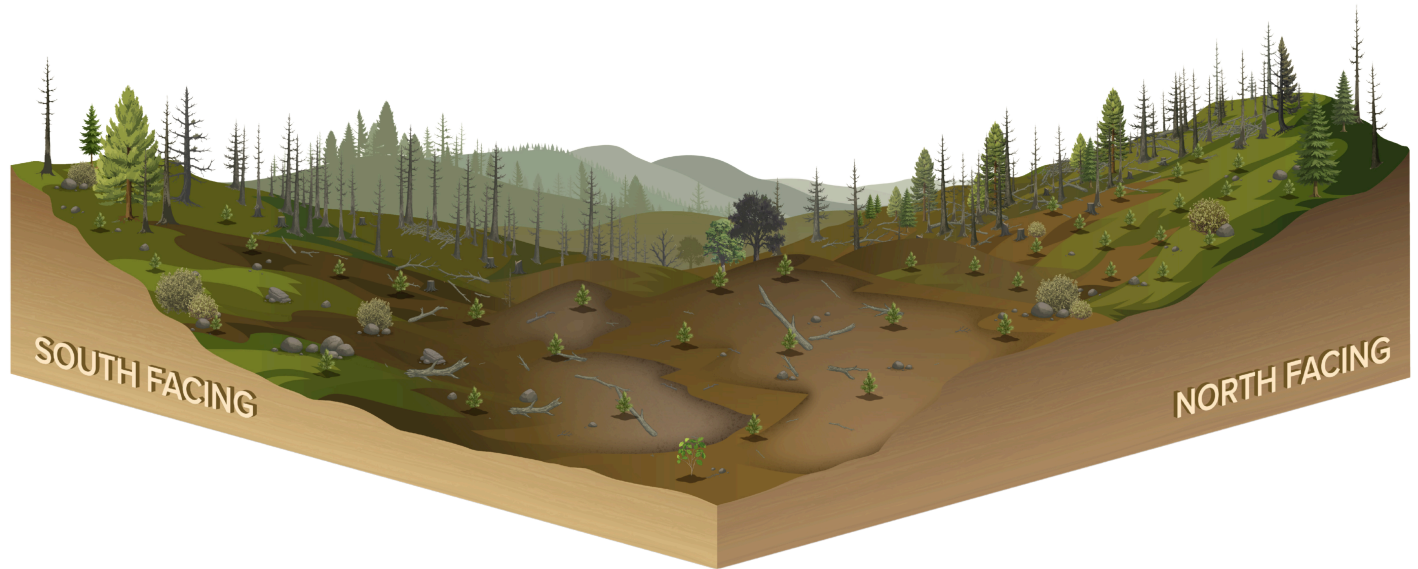


Figure 4. Lower density plantings can be arranged in a loose grid that allows flexibility for the use of microsites (Figure 2). Seedlings can be planted in higher densities on north-facing than south-facing slopes. This type of planting density and arrangement can maintain open areas for ecological diversity while supporting the development of a structured forest.



Higher Initial Planting Density in a Loose Grid

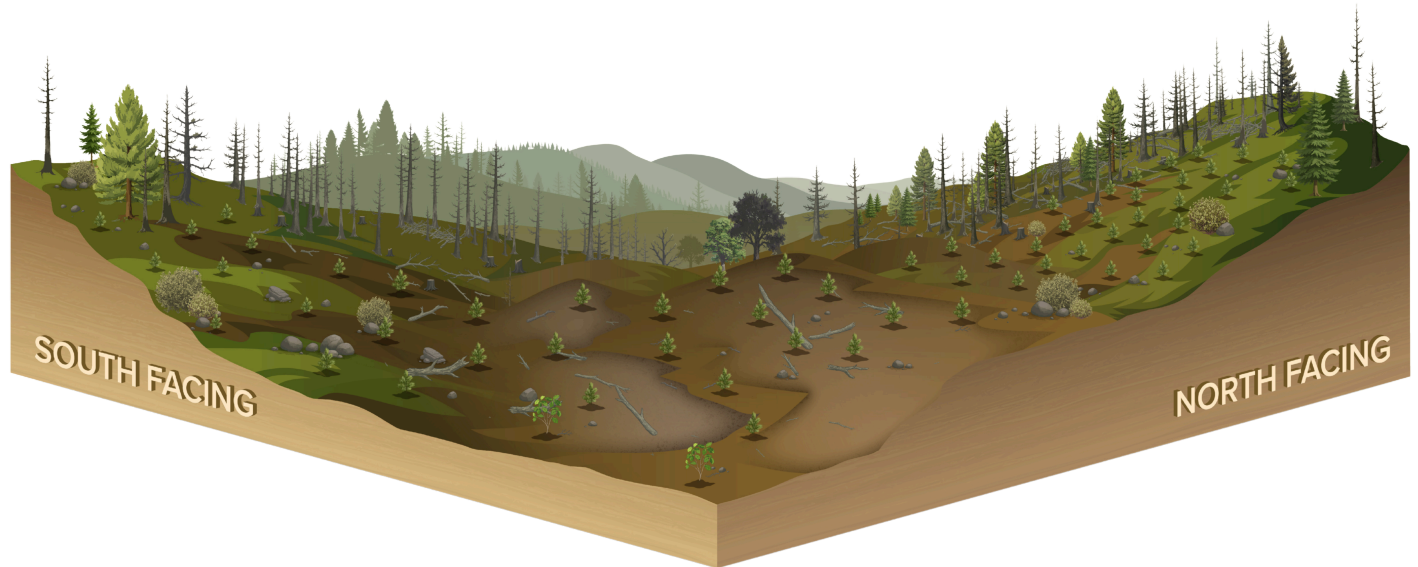


Figure 5. *Higher density plantings arranged in a loose grid can support the growth of trees in a desirable form for merchantable timber and efficient implementation of post-planting thinning and maintenance treatments. Planting at higher densities in a gridded pattern should still allow flexibility for the use of microsites (Figure 2).*



Key Actions

Reforestation does not end with planting. Continual management of forests after planting is important to ensure sustained climate and wildfire resilience into the future. As mentioned throughout this guidance, the capacity for varying degrees of post-planting treatment can impact decisions about species composition, density, and arrangement. A few common recommendations exist for all reforestation projects.

- Timely introduction of beneficial fire post-planting is a priority for climate-informed reforestation to promote wildfire resilience by reducing fuels and stand density, and reinforcing heterogeneity, as well as the fact that it is an important ecosystem process that cannot be replaced or replicated with other treatment types.
 - Fire can be reasonably introduced 13-19 years after planting, depending on site productivity. At this point, a sufficient fuel bed has likely accumulated to carry fire, though studies are still in progress to refine these recommendations for when and how to reintroduce fire in reestablishing forests.
 - There are trade-offs when considering at which time of year to introduce fire. Fuel moisture is higher during spring and winter, which may produce a less intense fire and provide greater operational feasibility, including burn window. However, some early studies have shown higher mortality in spring burning. Fall burning would likely have less impact on the planted trees as they are not budding, is more aligned with a natural fire regime, and can result in greater surface fuels consumption within planted stands.
 - **In giant sequoia groves**, early (perhaps year 7 – 13) and frequent application of fire in young stands is emphasized even more. Prescribed fire in young stands can reduce woody biomass and may improve survivorship, as giant sequoia seedlings can generally survive prescribed fire better than pines, firs, and incense cedar (York et al., 2021).
- Consider using one or more post-planting management practices (e.g., mechanical, hand treatments, fire, chemical, livestock grazing) timed appropriately to reduce competing vegetation, increase seedling survival and growth, and reduce fuels.
- Follow-up treatments to control competing vegetation, particularly aggressive shrub growth, are needed until trees are at least noticeably above the crowns of overtopping shrubs ("free to grow") to promote tree growth and subsequently to continue to address developing fuels under developing conifer crowns.
- Use continued stand management practices to maintain densities within 20% of mature stand density target and only consider interplanting if densities drop significantly and extensively below the target.

Post-planting monitoring is critical for assessing planting success (i.e., survival and growth of planted species, especially when planting a mixture of species from different elevation bands), the effectiveness of site preparation actions to control competing vegetation, the need for density management, the susceptibility to high-severity reburn based on fuel loads, and other management objectives (e.g., seedling spatial arrangement for facilitating heterogeneity in young stands). Other post-planting treatment recommendations differ based on initial planting densities.



Lower Initial Planting Densities

- **When planting at lower initial densities (~60-120 TPA)**, seedling survival will require additional post-planting treatments focused on controlling competing vegetation. Intensive shrub management can be reduced once trees are twice the height of shrubs, at which point shrub cover and tree cover provide for horizontal heterogeneity in fuel loading. However, additional treatments to reduce shrub cover may be necessary prior to reintroducing fire if shrub cover is homogenous across an area. There are many tools and methods available for managing understory growth (e.g., mastication, chemicals, fire, grazing), which can be selected based on existing guidance and operational considerations.
- In a low density planted site, use of prescribed fire may be more conservative since young tree mortality has a greater impact on reforestation outcomes on sites with fewer trees. However, if the site has lower shrub cover and seedlings are planted in variable spacing, surface fuel loads and connectivity are likely lower and use of prescribed fire can be more flexible. Finally, early use of fire in low density plantings should be used primarily as a surface fuels management tool, rather than for density management.



Higher Intensity Management

- **Following higher initial planting densities (~150-200 TPA)**, there will be a greater need for managing tree density as the planted forest develops and will require a greater focus on machinery and associated methods. Post-planting management will entail multiple entries: (1) re-entry in early year 0-10 to reduce shrub cover, (2) thinning in the first 10-15 years to maintain crown separation, (3) multiple entries after 40 years to create gaps for regeneration of shade-intolerant seedlings and to create diversity in age classes, as well as reducing fuels and inter-tree competition. Thinning following higher initial planting densities can be used to create heterogeneity in forest structure, and offers opportunities for altering species composition, density, and disease management.
- Higher initial densities may allow for flexibility in managing future stand densities (e.g., trees could be removed later if site/microsite conditions are less productive than anticipated). However, higher densities also require follow-up treatments to reduce competition among neighboring stems and managing fuel loads.

- In higher density stands, which may allow for a higher tolerance of fire-killed trees, there is leeway to manage the stand with fire (i.e., pyrosilviculture) so long as fuel conditions are maintained to facilitate that option.

Other Contributors

Gabrielle Bohlman, Brandon Collins, Michelle Coppoletta, Sarah Hennessy, Ryan Hilburn, Maurice Hunyh, Eric Knapp, Sophia Lemmo, Brian Lindstrand, Jonathan Long, Keli McElroy, Kyle Merriam, Nicole Molinari, Eric O'Kelley, Mark Pustejovsky, Thierry Rivard, Ricky Satomi, Ryan Tompkins, Gary Urdahl, Andrew Weinhart

Bibliography

1. Long, J. W., Walsh, D., Coppoletta, M., Tompkins, R. E., Meyer, M. D., Isbell, C., Bohlman, G. N., & North, M. P. (2023). Interventions to restore wildfire-altered forests in California (No. PSW-GTR-278; p. PSW-GTR-278). U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. <https://doi.org/10.2737/PSW-GTR-278>
2. Lydersen, J. M., Collins, B. M., Coppoletta, M., Jaffe, M. R., Northrop, H., & Stephens, S. L. (2019). Fuel dynamics and reburn severity following high-severity fire in a Sierra Nevada, USA, mixed-conifer forest. *Fire Ecology*, 15(1). <https://doi.org/10.1186/s42408-019-0060-x>
3. Lydersen, J. M., & North, M. (2012). Topographic Variation in Structure of Mixed-Conifer Forests Under an Active-Fire Regime. *Ecosystems*, 15(7), 1134-1146. <https://doi.org/10.1007/s10021-012-9573-8>
4. Marsh, C., Blankinship, J. C., & Hurteau, M. D. (2023). Effects of nurse shrubs and biochar on planted conifer seedling survival and growth in a high-severity burn patch in New Mexico, USA. *Forest Ecology and Management*.
5. Marshall, L. A. E., Fornwalt, P. J., Stevens-Rumann, C. S., Rodman, K. C., Rhoades, C. C., Zimlinghaus, K., Chapman, T. B., & Schloegel, C. A. (2023). North-facing aspects, shade objects, and microtopographic depressions promote the survival and growth of tree seedlings planted after wildfire. *Fire Ecology*, 19(1). <https://doi.org/10.1186/s42408-023-00181-8>
6. Meyer, M. D., Long, J. W., & Safford, H. D. (2021). Postfire restoration framework for national forests in California (No. PSW-GTR-270; p. PSW-GTR-270). U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. <https://doi.org/10.2737/PSW-GTR-270>
7. Neuenkamp, L., Prober, S. M., Price, J. N., Zobel, M., & Standish, R. J. (2019). Benefits of mycorrhizal inoculation to ecological restoration depend on plant functional type, restoration context and time. *Fungal Ecology*, 40, 140-149. <https://doi.org/10.1016/j.funeco.2018.05.004>
8. North, M. P., Stevens, J. T., Greene, D. F., Coppoletta, M., Knapp, E. E., Latimer, A. M., Restaino, C. M., Tompkins, R. E., Welch, K. R., York, R. A., Young, D. J. N., Axelson, J. N., Buckley, T. N., Estes, B. L., Hager, R. N., Long, J. W., Meyer, M. D., Ostojia, S. M., Safford, H. D., ... Wyrsh, P. (2019). Tamm Review: Reforestation for resilience in dry western U.S. forests. *Forest Ecology and Management*, 432, 209-224. <https://doi.org/10.1016/j.foreco.2018.09.007>
9. North, M. P., Stine, P., O'Hara, K., Zielinski, W., & Stephens, S. (2009). An ecosystem management strategy for Sierran mixed-conifer forests. U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. <https://doi.org/10.2737/psw-gtr-220>
10. North, M. P., Tompkins, R. E., Bernal, A. A., Collins, B. M., Stephens, S. L., & York, R. A. (2022). Operational resilience in western US frequent-fire forests. *Forest Ecology and Management*, 507, 120004. <https://doi.org/10.1016/j.foreco.2021.120004>
11. Ritchie, M., Berrill, J.-P., Hammett, E., & Long, J. W. (2024). Early Responses to Crown Modification of California Black Oak Sprouts Initiated by High-Severity Wildfire. *Journal of Forestry*, 122(1), 70-78. <https://doi.org/10.1093/jofore/fvad038>
12. Safford, H. D., & Stevens, J. T. (2017). Natural range of variation for yellow pine and mixed-conifer forests in the Sierra Nevada, southern Cascades, and Modoc and Inyo National Forests, California, USA (No. PSW-GTR-256; p. PSW-GTR-256). U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. <https://doi.org/10.2737/PSW-GTR-256>
13. Scott, J. H., & Burgan, R. E. (2005). Standard fire behavior fuel models: A comprehensive set for use with Rothermel's surface fire spread model (No. RMRS-GTR-153; p. RMRS-GTR-153). U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. <https://doi.org/10.2737/RMRS-GTR-153>
14. Sorenson, Q. M., Young, D. J. N., & Latimer, A. M. (2025). Tree planting outcomes after severe wildfire depend on climate, competition, and priority. *Forest Ecology and Management*, 575, 122346. <https://doi.org/10.1016/j.foreco.2024.122346>
15. Stewart, J. A. E., van Mantgem, P. J., Young, D. J. N., Shive, K. L., Preisler, H. K., Das, A. J., Stephenson, N. L., Keeley, J. E., Safford, H. D., Wright, M. C., Welch, K. R., & Thorne, J. H. (2021). Effects of postfire climate and seed availability on postfire conifer regeneration. *Ecological Applications*, 31(3), e02280. <https://doi.org/10.1002/eap.2280>
16. York, R. A., Noble, H., Quinn-Davidson, L. N., & Battles, J. J. (2021). Pyrosilviculture: Combining prescribed fire with gap-based silviculture in mixed-conifer forests of the Sierra Nevada. *Canadian Journal of Forest Research*, 51(6), 781-791. <https://doi.org/10.1139/cjfr-2020-0337>

Cover Photo: Sequoia & Kings Canyon National Park (National Park Service)