Tree Planting in California

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Abstract

California has a wide diversity of forest types and species involved in tree planting and subsequent management to maintain healthy and productive forests. California has over 31 million ac (12.5 million ha) of forests, approximately half of which is in parks, reserves, wilderness areas, or very low-productivity areas. California's forests vary from the highly productive coastal forests dominated by fast-growing redwoods (*Sequoia sempervirens* [Lamb. ex D. Don] Endl.), to sparse ponderosa pine (*Pinus ponderosa* Lawson & C. Lawson) forests on the dry side of the Sierra Nevada mountains, to extensive hardwood-dominated forests at lower elevations. California's forests grow in climates with extreme hot and cold temperatures and a long, dry season. Wildfires have increased significantly in recent years resulting in a growing incidence of high-mortality crown fires. About half of forest acreage in California is classified as productive timberlands dominated by numerous conifer species. Most tree planting in California occurs in these timberlands. The three major ownership classes (large private owners, small private owners [concentrated on the north coast], and the U.S. Department of Agriculture [USDA], Forest Service) have historically practiced very different reforestation approaches. Around half of the large private owners practice even-age management and plant mostly conifer seedlings. Smaller private landowners mainly use uneven-aged management and plant relatively few seedlings relative to their land area. The USDA Forest Service manages more than half the timberlands in the State but has lower levels of timber harvesting compared with private landowners, mainly uses uneven-aged management, and has been less active in tree planting after wildfires. As California grapples with increasing tree mortality from wildfires and other mortality events, the importance for all landowners to apply lessons learned from local best practices will be more critical than ever if their respective forests are to remain productive into the future.

California's Forests

Forest land is defined by the the U.S. Department of Agriculture (USDA), Forest Service's Forest Inventory and Analysis (FIA) program as a land base with at least 10 percent tree cover (Brodie and Palmer 2020). California has the highest percentage of its forests in reserve or park status among all States except Alaska. Each of California's conifer forest types has a considerable level of microsite species diversity. Reforestation activities are concentrated on timberlands outside of parks, reserves, and wilderness areas (table 1).

Table 1. Current forest types on California timberlands by owner group in millions of acres (total numbers are rounded).

Forest type	USDA Forest Service	Corporate	Family	Other Government	Total
	Acres (millions)				
California mixed conifer	4.2	1.6	0.5	0.1	6.5
Ponderosa pine	1.2	0.4	0.4	0.0	2.1
Douglas-fir	0.2	0.3	0.3	0.0	0.9
Fir/spruce/mtn. hemlock	1.1	0.2	0.1	0.0	1.4
Redwood	0.0	0.4	0.2	0.0	0.7
All other species	2.2	1.3	1.5	0.2	5.1
Total timberlands	8.9	4.3	3.0	0.4	16.6
Timberlands as a percent of all forest lands	58%	85%	41%	11%	53%

Source: Brodie and Palmer (2020). 1 million ac = 404,686 ha.

Figure 1. California forest landownership is divided among large private owners, small private owners, and USDA Forest Service. (Source: CAL FIRE Fire and Resource Assessment Program 2018)

In California, conifer forests are the dominant forest types in the State. Oak-dominated (*Quercus* spp.) forests in the low-rainfall foothills are extensive but these forests have very little active tree planting outside of specific restoration projects. Timberland is the subset of forest land where sustainable timber harvesting is feasible and legally allowed. The FIA program measures a range of forest characteristics on plots laid out on a 3-mi (4.8 km) grid across all forest lands. The three major ownership classes that undertake reforestation are large private owners, small private owners (concentrated on the north coast), and USDA Forest Service timberlands (figure 1). The California Department of Forestry and Fire Protection (CAL FIRE)

Figure 2. Conifer ecosystems dominate much of California's forests such as this mix of even-aged and uneven-aged mixed conifer stands on Blodgett Forest Research Station near Georgetown, CA. (Photo by William Stewart, 2012)

Figure 3. High conifer tree mortality and low hardwood tree mortality in the Southern Sierra Nevada has resulted from years of drought conditions. (Photo by William Stewart, 2018)

owns approximately 100,000 ac (40,470 ha) of forests. Most other Government-owned forests are in parks or reserves where active reforestation is usually limited to small-scale projects.

Mixed conifer forests (figure 2) dominate the Sierra Nevada, Cascade, and Klamath mountain ecosystems and represents about half of all timberland acres in California. This forest type is the touchstone for forest policy and regulations requiring reforestation with a mix of species. California mixed conifer forests consist of a mix of pines (*Pinus* sp.), Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco), true firs (*Abies* spp.), and incense cedar (*Calocedrus decurrens* [Torr.] Florin), as well as minor components of various hardwood species. The hardiest and least shade-tolerant species within the mixed conifer forests is ponderosa pine (*Pinus ponderosa* Lawson & C. Lawson). Decades of preferential harvesting of higher value species and relatively few wildfires have led to a substantial increase in the proportion of white fir (*Abies concolor* [Gord. & Glend.] Lindl.ex Hildebr.) from natural reseeding. Most active reforestation projects now prioritize planting more pine and Douglas-fir seedlings that do not naturally reproduce in the understory. Pure pine forests are common in drier sites within these ecosystems, especially in those with hotter temperatures and lower rainfall. The higher elevation forests with red fir (*Abies magnifica* A. Murray bis), mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.), and Engelmann spruce (*Picea englemannii* Parry ex Engelm.) are mainly in Federal ownership where there is relatively limited tree planting. Droughts during the 2010s had a major effect on conifers in the southern Sierra Nevada (figure 3) and shifted many forests towards hardwood-dominated stands.

On California's north coast, forest stands range from nearly pure redwood stands (*Sequoia sempervirens* [Lamb. ex D. Don] Endl.) on lower elevation sites near the ocean to stands with an increasing Douglas-fir component further inland. The north coast also has many stands with high densities of tanoak (*Notholithocarpus densiflorus* [Hook. & Arn.] P.S. Manos, C.H. Cannon, & S.H. Oh), laurel (*Umbellularia californica* [Hook. & Arn.] Nutt.), and Douglas-fir that resulted from natural regeneration following past harvests. Landowners with access to their own capital or Government cost-share funds often replant these stands with well-spaced redwood and Douglas-fir seedlings to increase the future value of these forests.

Although giant sequoia (*Sequoiadendron giganteum* [Lindl.] J. Buchholz) seedlings have good survival and growth when planted on private or university lands across the Sierra Nevada (York et al. 2013), the more famous naturally occurring sequoia groves cover less than 40,000 ac (16,187 ha) and are concentrated in the southern Sierra Nevada on Federal lands (Willard 2000). Natural regeneration within historic giant sequoia groves is the preferred Federal strategy.

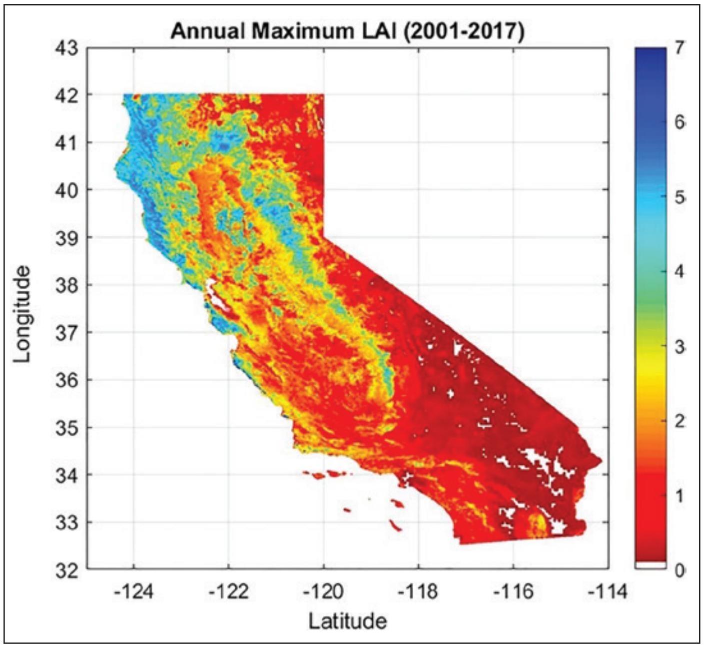

Figure 4. The map of maximum leaf area index (LAI) across California can provide insights into forest productivity. (Source: Baldocchi et al. 2019)

Climate Determinants of Forest Productivity

One way to understand highly variable forest productivity in California is through high-resolution satellite maps of average annual maximum leaf-area index (LAI; the ratio of leaf area per unit of ground) over recent decades (figure 4). LAI is highly correlated with water transfer, carbon dioxide transfer, and gross growth rates. Coastal forests with warm temperatures and high rainfall are characterized as highly productive (LAI above 5) whether they are in old growth reserves or managed stands. These forests are dominated by redwood and Douglas-fir trees where competition for light, not moisture, is the major factor affecting seedling survival and growth. The more extensive interior forests have an LAI between 3 and 5 and are characterized by less-dense vegetation. In those forests, competition for moisture is the dominant factor affecting seedling survival and growth. Forests with LAI measurements between 2 and 3 have lower productivity and are common on the low-elevation dry forests and the high-elevation alpine forests.

By comparing the forest ownership map with the LAI map (figures 1 and 4), a few factors relating to tree planting stand out. On the north coast, the most productive forests are mostly owned by large, private timberland owners, while smaller, private timberland owners have less productive forests located further from the Pacific Ocean. In the interior forests of northern California with relatively high LAI, forest ownership is mixed across large private, small private, and Federal managers. Much of the forest land in the southern Sierra Nevada has relatively low LAI and is primarily in Federal ownership at higher elevations and in small private ownership at lower elevations.

Forest Structure

The distribution of forest area by stand age and recent planned and unplanned disturbances provides a useful perspective on the scale of California's reforestation needs for forest managers (figure 5). Large private or corporate owners of conifer forest lands plant most of the conifer seedlings in California. Planting has been concentrated on clearcut acres, smaller units with poor natural regeneration within uneven-aged managed forests, and areas where crown fires killed most trees. Large, private owners have been more active in conducting both salvage logging operations (figure 6) and successful reforestation than neighboring USDA Forest Service lands burned in the same fires (figure 7). Compared with Oregon and Washington, the conifer forests owned by large, private owners in California use longer, even-aged rotations and have more areas managed with uneven-aged silviculture. This management approach requires less active reforestation acres compared with total acres (figure 8).

Small, private forest owners in California depend more on natural regeneration than active reforestation to maintain forest productivity; their management goals do not always focus on high rates of financial value appreciation. Compared with large, private forest owners, the lower percentage of total area in young stands demonstrates the greater dependence on natural regeneration with relatively less planted area. The need to replant stands owned by small, private owners following crown fires and high levels of mortality was relatively limited according to FIA data, but has increased after the severe 2020 and 2021 fire seasons.

The USDA Forest Service timberlands are roughly equal in area to the combined large and small private timberland ownerships in the State. These Federal lands have had a much different pattern of disturbances over the past decade due to less harvesting

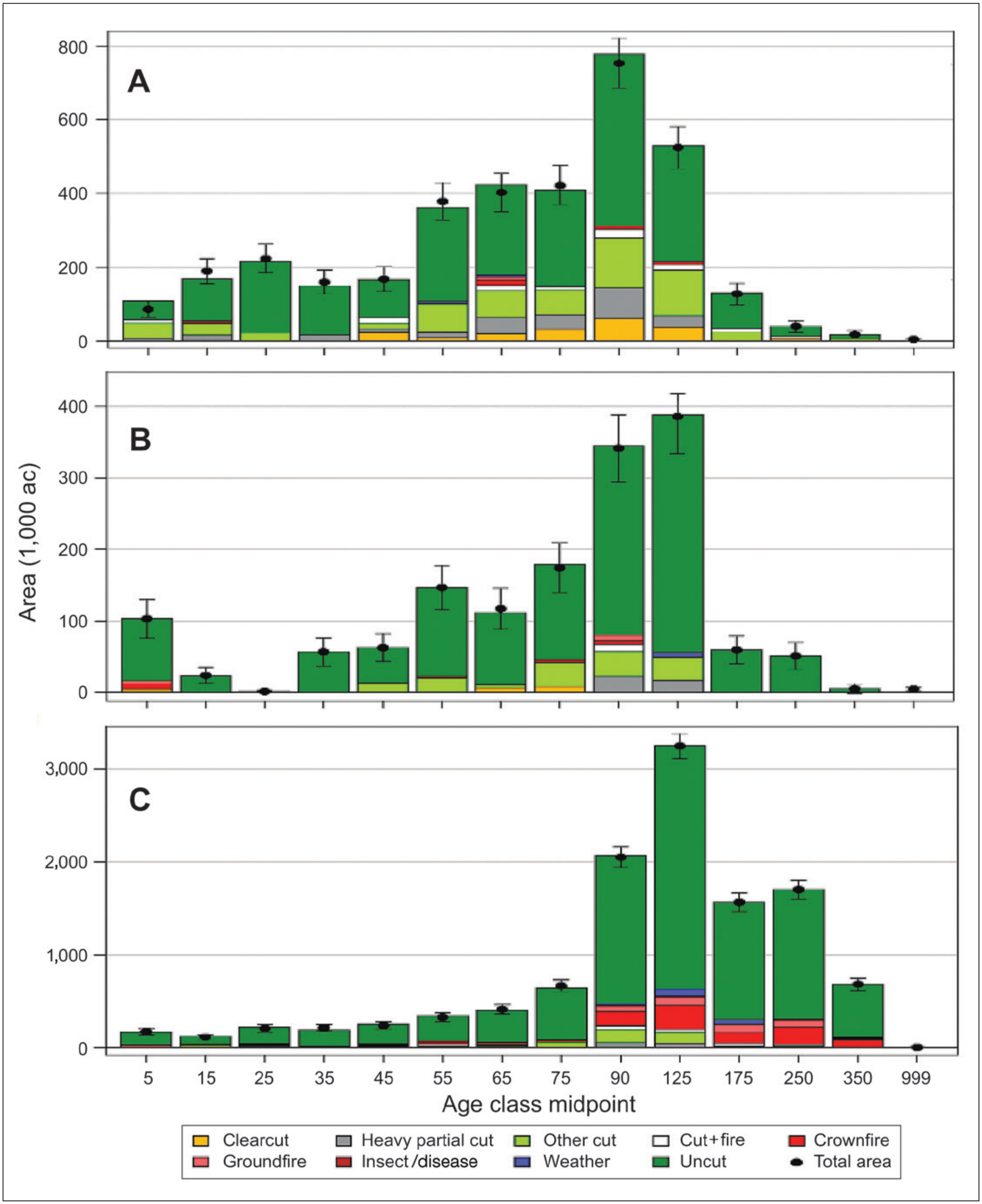

Figure 5. Mixed conifer forest stand age and status (2008–2018) in California varies among (a) large private, (b) small private, and (c) USDA Forest Service landowners. (Source. Andy Gray, USFS PNW FIA)

Figure 6. Forest management strategies differ based on land ownership. This photo shows salvaged private forest land to be replanted in between Federal timberlands that were not salvaged or replanted following the 2007 Moonlight Fire. (Photo by William Stewart, 2009)

before the 1990s and significant reductions in harvesting and subsequent reforestation since the mid-1990s. From 2008 to 2018, thinning and clear cuts on USDA Forest Service lands were limited. By far the areas of Federal timberland that could potentially benefit from reforestation are those extensive areas affected by crown fire, severe insect and disease mortality, and major weather-related mortality in 100- to 250-year-old stands. The large wildfires of 2020 and 2021 added approximately 2 million additional acres of USDA Forest Service timberland to the total areas impacted by crown fires identified in figure 5 that could benefit from reforestation. Without successful replanting, much of the area burned by crown fires will probably regenerate with a predominant mix of montane chaparral species, lesser amounts of other nonforest types, and some natural conifer regeneration in the shady understory.

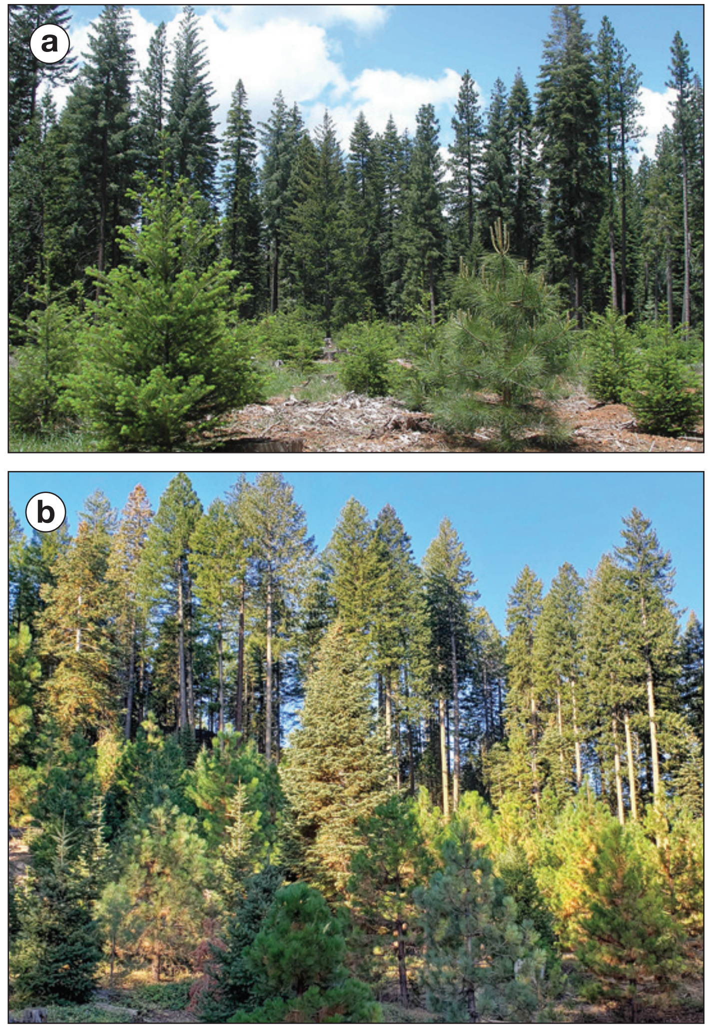

Figure 8. Many large, private landowners in California manage with uneven-aged silviculture that include ± 2-ac (0.8-ha) group selection units in forests such as these in (a) Shasta County and (b) Plumas County. (Photos by Bob Rynearson)

Figure 7. Prompt planting and control of competing vegetation on private land resulted in successful, mixed-species reforestation (left), whereas delayed planting and no vegetation control resulted in a shrub-dominated condition on National Forest land (right) following the 2000 Storrie Fire. (Photo by William Stewart, 2020)

Reforestation in California

History

Social and political concerns about the need for reforestation in California date back more than a century. In 1884, an interim State Forestry Commission reported to the Governor of the need to replant land "denuded of redwoods," to plant "new land in suitable forest trees," and to collect useful information on the "best mode of

Figure 9. Civilian Conservation Corps (CCC) planted many trees in the 1930s. In this photo, CCC crew are carrying seedling transplants to the field on the Shasta National Forest. (USDA Forest Service archives, wikimedia.org, USFS photo #413770)

planting, caring for, thinning, and general treatment of growing timber trees" (Coleman et al. 1884). By 1887, the State was producing nursery stock of 150,000 seedlings annually and had established experimental plantations in all regions. Considerable forest tree planting work was also carried out by the Civilian Conservation Corps (CCC) during the 1930s depression era (figure 9), with "tree and plant disease control" performed on nearly 800,000 ac (323,750 ha) in the State (Merrill 1981).

After World War II, both the State and Federal Governments established large, public forest nurseries that produced millions of seedlings per year throughout the 20th century. By the 21st century, however, many of these public nurseries have been closed or reduced in annual seedling output.

Low survival rates for planted seedlings have been a long-standing challenge in California's long, dry summers. Before 1953, only about 31 percent of plantings were successful (Zillgitt 1958). Low survival rates are still common when competing vegetation is not successfully controlled. Average third-year plantation survival on USDA Forest Service lands was only 57 percent in 2004, the last year this statistic was published in national reports (Barrett 2014). In comparison, conifer seedling establishment rates as high as 95 percent for pines and more than 80 percent for Douglas-fir are now common on larger, private forest land ownerships (Baldwin 2022). These high establishment rates are attributed to substantial improvements in nursery and planting technology and practices from seed collection to planting and management of the growing trees (Stewart 2022).

Five Principles of Reforestation in California

Private-sector forest management practitioners in California developed five primary principles for successful reforestation in the State (Baldwin 2022).

1. Use tree species from known, appropriate seed sources which can be established and grow vigorously on the site without irrigation.

Figure 10. California has 85 tree seed zones based on physiographic and climatic regions. Each zone is further divided into 500-ft (152-m) elevation bands. (Source: CAL FIRE Fire and Resource Assessment Program 2019)

2. Control vegetation that would otherwise compete with planted seedlings for limited soil moisture during the critical first, and possibly the second, year after planting.
3. Use seedlings that are able to withstand the conditions on the site when planted and are able to rapidly grow new roots after planting.
4. Properly handle, transport, store, and plant seedlings and plant them when conditions on the site are best to allow for rapid root growth.
5. Protect seedlings from damage by animal and insect pests, if necessary.

Seed Zones of California

The first step in the reforestation process starts with seeds collected in the wild or bred in seed orchards grown from seeds collected from known locations. Based on the work of the Forest Tree Seed Committee that built on earlier maps, California is divided into 6 major physiographic and climatic regions, 32 sub regions, and 85 Tree Seed Zones (Buck et al. 1970) (figure 10). Within the individual zones, conifer seed collections are catalogued by separate elevation bands with every 500-ft (152-m) rise in elevation (Griffis 2022). All conifer seeds collected and stored in California's three major conifer seed banks follow the same seed zone designations.

California does not have a sophisticated seed-transfer system such as those used in British Columbia (MFLNRORD 2020) or the Pacific Northwest (Howe et al. 2009). The current strategy used by most practitioners in California is similar to conclusions from a recent analysis of a Douglas-fir heredity study that indicated seeds collected from relatively small seed zones can retain good, long-term survival and productivity within an environmental range of 3.6 °F (2 °C) (St. Clair 2019). Interviews with private-sector reforestation practitioners suggest that they consider good seedling quality and tree management after planting to be more important than shifting seeds to zones that may be similar to future climates for maintaining long-term growth.

Seed Banks

California has three seed bank systems that have some degree of overlap. The USDA Forest Service maintains a seed bank at its Placerville nursery facility in the central Sierra Nevada where they currently have approximately 120,000 lb (54,430 kg) of conifer seed. They often trade with CAL FIRE's seedbank when either agency has deficiencies in viable seed for a zone where significant reforestation is planned. CAL FIRE's seed bank in Davis has a seed inventory of approximately 20,000 lb (9,070 kg) for large, private landowners who pay storage fees and another 20,000 lb (9,070 kg) collected by CAL FIRE. Smaller forest landowners rarely collect seeds from their own lands so they are mostly dependent on the CAL FIRE collections following wildfires or other mortality events. CalForest Nurseries (Etna, CA) is the largest independent nursery in California and stores around 40,000 lb (18,145 kg) of seeds for private forest landowners plus a smaller amount of their own seed. Overall, an estimated 60 percent of seedlings used by large, private forest owners come from cooperative-improved tree seed programs (Griffis 2022). Recent activities of these cooperatives build on improved seeds and focus more on activities to increase survival and growth of planted seedlings. The recent large wildfires have created seed demands far above the available improved seed and have required use of more wild-collected seed when available. California's conifer seed banks will need considerable new investments in collection and storage if increased incidence of major mortality events continues.

Seedling Nurseries

During the 2020 planting year, California nurseries produced more than 24.5 million seedlings, nearly all of which were container-grown conifers (Haase et al. 2021) (figure 11). Only two of the numerous State and Federal seedling nurseries that operated in the 20th century are still operational today. The USDA Forest Service Placerville Nursery produces approximately 4 million seedlings per year but may receive funds to increase annual production capacity up to 15 million seedlings (California Forest Management Task Force 2021). Actual production will continue to be limited by the scale of preorders from National Forests that have cleared the extensive planning requirements necessary for reforestation on National Forest lands. Several years after its closure, CAL FIRE restarted their conifer nursery in Davis. This State nursery serves State forests, State-funded ecological restoration projects, forest landowners with 50 to 1,000 ac

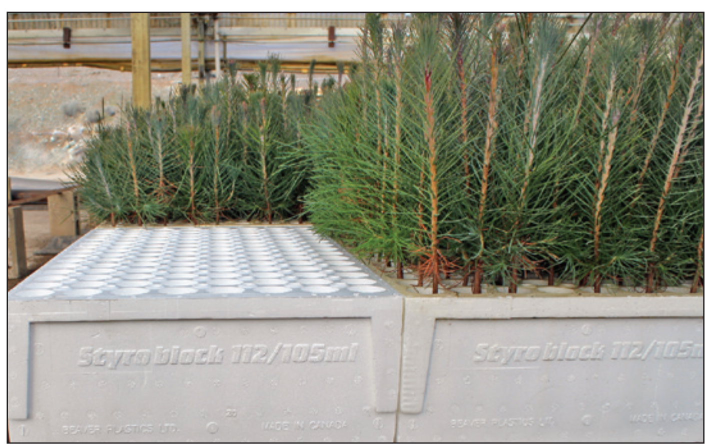

Figure 11. Most seedlings in California are grown in containers. Styroblock™ containers are manufactured with many different sizes of cells and density. (Photo by Tom Jopson, CalForest Nurseries, 2019)

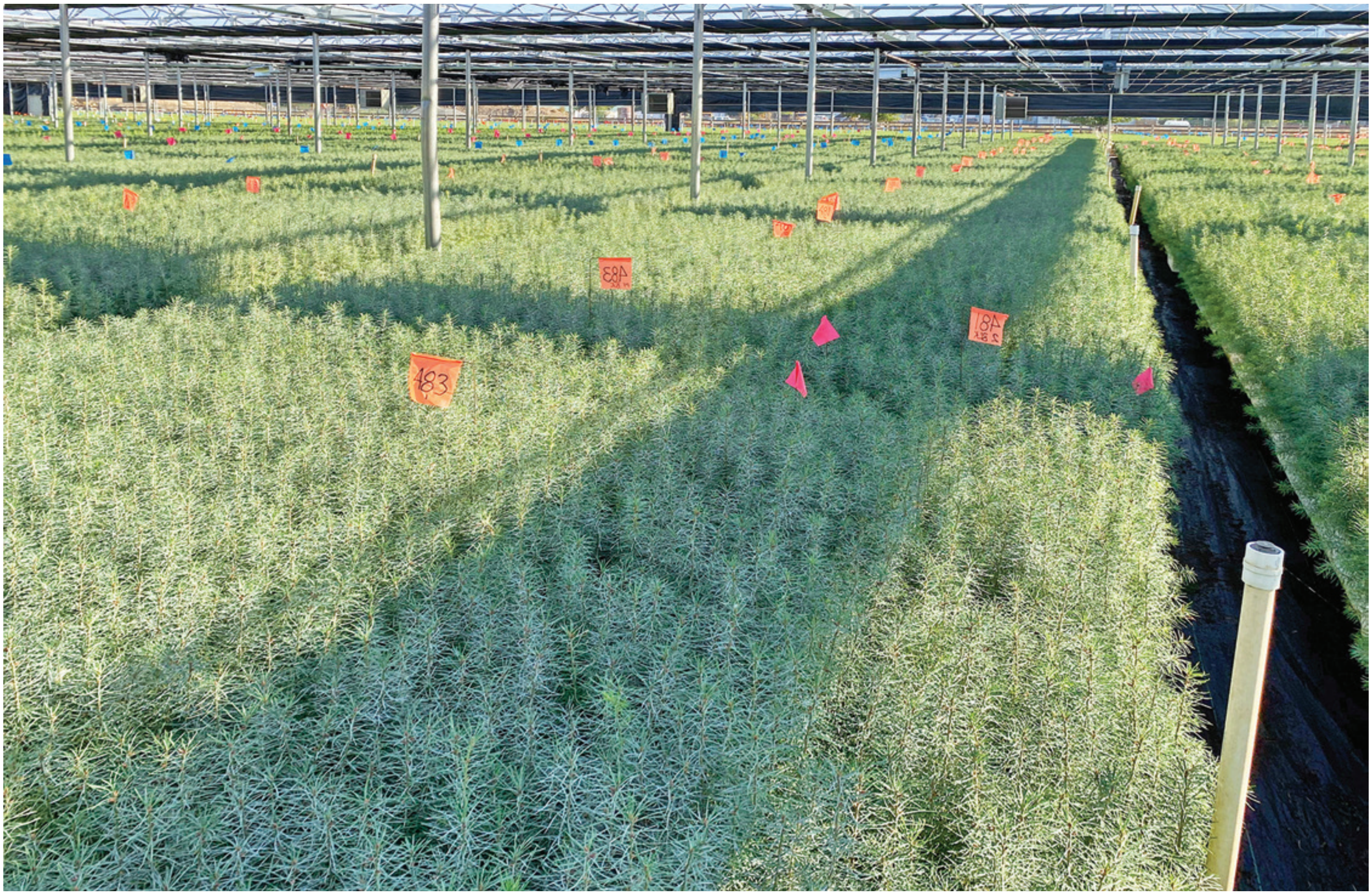

Figure 12. CalForest Nurseries is the largest private conifer seedling grower in California and grows millions of seedlings annually at its Etna, CA facility. (Photo by Tom Jopson, CalForest Nurseries, 2019)

(20 to 405 ha) who only order 100 to 5,000 seedlings at a time, and small landowners organized under Resource Conservation Districts. In 2021, the nursery produced approximately 250,000 seedlings but plan to increase annual production to 1 million seedlings within a few years.

Private nurseries produce most of the seedlings grown in California. On the north coast, one clonal nursery and one traditional nursery grow redwood seedlings for timber companies that own large areas of second- and third-growth forests. CalForest Nurseries (figure 12) can now produce 15 to 25 million seedlings per year depending on the wildly fluctuating post-fire orders. Additional seedlings are grown in several nurseries in Oregon from seed collected in California.

Planting

Based on timber harvest statistics over the past decade, 40,000 to 60,000 ac (16,190 to 24,280 ha) of private forest lands per year have had silviculturally driven reforestation to meet post-harvest stocking requirements. Recent increases in wildfire, insect, and drought mortality have added 30,000 to 50,000 ac (12,140 to 20,235 ha) that could potentially be reforested if the damage is severe enough and the landowners have the necessary investment funds (Baldwin 2022). Large, private timberland owners must finance reforestation without access to any Government cost-share programs. Small landowners can utilize Government limited cost-share funds but often lack tree-planting expertise since they primarily practice uneven-age silviculture that depends on natural, rather than planted, regeneration.

According to annual reforestation and timber stand improvement reports (USDA Forest Service 2011 to 2020), the USDA Forest Service has averaged around 3,000 ac (1,214 ha) per year of reforestation in California with effective control of competing vegetation and a similar amount of area planted without control of competing vegetation. Much of the 2 million (~809,400 ha) of Federal timberlands in California that burned during the 2020 and 2021 fire seasons

Figure 13. Delivery of seedlings to the outplanting site must be done in a manner to maintain seedling quality (Photo by Mark Gray, Sierra Pacific Industries, 2016)

will also need active reforestation if significant forest growth rates are to be reestablished. The success rate for natural regeneration in reestablishing conifer forests in California's Mediterranean climates is often low (Welch et al. 2016), and without planned and successfully implemented reforestation efforts, it is common for conifer forest areas burned in severe wildfires to remain dominated by shrub species for decades (Bohlman et al. 2016, Stephens et al. 2020).

Reforestation foresters select the best mix of species to be planted after considering which species have historically done well on the sites and which species will thrive throughout forest development. Ensuring that the seedlings go from climate-controlled facilities to the planting site with the least delays requires an efficient logistical operation (figure 13). To optimize survival after planting, crews use hoedads or shovels to plant the seedlings (figure 14) in microsites that ensure sufficient soil moisture and prevent excessive evapotranspiration (figure 15). On north-facing slopes, species with relatively more shade tolerance such as Douglas-fir, red fir, or white fir may be more successful. Species that are highly sensitive to hot temperatures and sunscald need to be planted in the most favorable microsites, using

Figure 14. Planting seedlings with a hoedad is common on California reforestation sites. (Photo by Bob Rynearson, 2015)

Figure 15. Microsite planting on this site resulted in shading for Douglas-fir seedlings and open sun for ponderosa pine seedlings. (Photo by Bob Rynearson)

natural features such as stumps, rocks, or large woody debris that provide protection to seedlings from the harsh conditions.

Reductions in Seedling Density Requirements on Private Lands

With limited markets for small-diameter trees, major improvements in seedling survival and growth among private landowners, and increasing wildfire risk posed by high live and dead fuel loads, the 2020 Forest Practice Rules (California Department of Forestry and Fire Protection, 2020) governing non-Federal lands in California substantially reduced the minimum number of surviving seedlings required per acre after reforestation. For high-quality sites, the minimum number of surviving seedlings was reduced from 300 trees per acre (TPA; 1 ac = 0.4 ha) to 125 to 200 TPA, depending on forest type. For lands with lower site index that often have less precipitation and higher fire risks, the minimum was reduced from 200 TPA to 100 TPA. Other changes allowed for even lower planting densities in designated long-term fuel breaks. These changes will require less seed per acre, may potentially increase tree survival in stands during severe wildfires and long droughts, and can align future harvests to the market demand in California that focuses on larger diameter trees.

Current Reforestation Challenges

The greatest tree-planting challenge facing California is the huge increase in conifer forest land impacted by catastrophic wildfires. Crown fires tend to kill most of the mature trees in a stand and often do not leave sufficient numbers of well-spaced, natural seedlings to ensure subsequent reforestation. The conifer timberland area burned in both the 2020 and 2021 wildfire seasons was equal to wildfire mortality over the previous decade. This large-scale fire impact has resulted in a large reforestation backlog that will become increasingly difficult to reforest as shrubs get established. Because the USDA Forest Service and small, private forest landowners shifted away from silviculture-driven replanting over the past few decades, the reforestation supply chain shrunk in its ability to meet the needs of episodic seedling purchasers. While many large, private landowners follow well-known strategies (Amacher et al. 2008) and respond rapidly with major financial investments and reforestation efforts, many other forest managers are not able to respond as quickly and face limitations when trying to access a constrained reforestation supply chain.

Looking Ahead

Of all the States with productive conifer-dominated forests, California has experienced more mortality from wildfires and subsequent conversion towards a shrub-dominated vegetation when successful reforestation is not undertaken. Expanding the entire reforestation pipeline—seeds, nurseries, planting, and post-planting care (Fargione et al. 2021)—to serve the three diverse types of forest landowners will be challenging but necessary if California is to maintain its healthy and productive forests.

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