Chapter 1:
Reforesting California

Herb Baldwin, Sierra Pacific Industries, Anderson, CA

William Stewart, University of California, Berkeley, CA

Sari Sommarstrom, Sari Sommarstrom & Associates, Etna, CA

Table of Contents

Why an Updated Handbook?

With its publication in 1971, the handbook, "Reforestation Practices for Conifers in California" by Gilbert H. Schubert and Ronald S. Adams, became the seminal reference for many young foresters in California facing unfamiliar new reforestation responsibilities. Prior to this time, planting efforts were sporadic and unpredictable. Private and public efforts were confined to rehabilitation of previously forested brush fields and occasional wildfires without well-established nursery, handling, and planting techniques. As a result, uneven results were common.

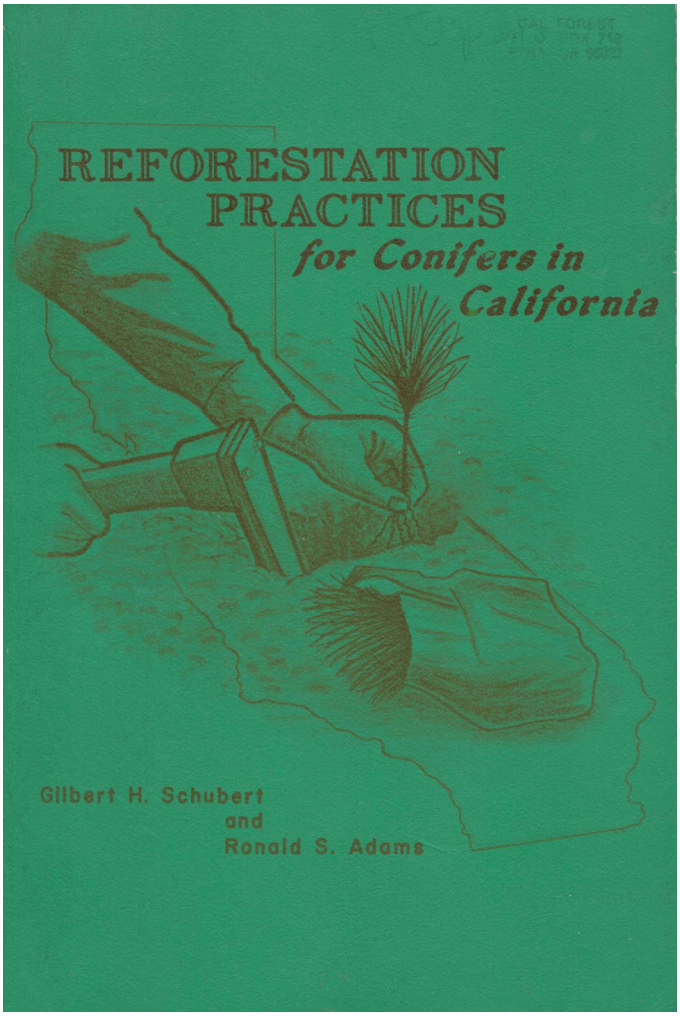

Figure 1.1 The original cover of 'Reforestation Practices for Conifers in California' (1971).

The 1971 handbook compiled in one place those practical treatments that were identified as necessary for a successful program, and it presented them in an easy-to-understand fashion that was geared to operational practitioners. It covered reforestation activities such as seed collection and processing, nursery practices, mechanical and chemical site preparation, planting, and direct seeding. Details for these topics

offered the best available science at the time, but also included heavy doses of practical and operational experiences.

Since its initial publication major shifts have occurred in forestry practices. In the public sector, the 1970's witnessed U. S. Forest Service professionals in Region 5 (California) embarking on intensive forest management that required considerably more reforestation. During this period, silviculture and reforestation personnel developed accordingly. An active USDA Pacific Southwest Research Station (historically referred to as the Pacific Southwest Forest and Range Experiment Station) conducted focused research with reforestation knowledge being greatly advanced. However, a vocal environmental movement questioning this management direction, evolving public involvement authorized by the National Environmental Policy Act (NEPA), and new concerns about herbicide use and sensitive wildlife species (such as the Northern spotted owl) all led to more and more limitations to forest management. Eventually, the Forest Service's emphasis on clearcutting and replanting shifted nearly exclusively to thinning and uneven aged management prescriptions with substantially reduced levels of reforestation. As time went on through the turn of the century, even the salvage harvesting and replanting of ever larger wildfire events were often legally challenged and became less common on federal land. There was also an increasing focus within federal agencies of the ecological role of fire in western forests (Keeley & Safford, 2016) and less emphasis on post-fire reforestation. The net result over this period was a ramping up and then a dramatic de-emphasis in reforestation infrastructure and funding.

The following map of private and public forest lands in California shows the ownerships of the different entities that could be involved in reforestation. Along the North Coast, large private forest owners and smaller private (often referred to as non-industrial) forest owners dominate the lands closer to the Pacific Ocean with the Forest Service managing the more inland areas of the Coast Range. In the interior Cascade and Sierra Nevada regions a mix of large private ownerships, smaller forest ownerships and the Forest Service is more common. In general the Forest Service owns more of the higher elevation forests, much of which is in reserve status, while smaller forest owners dominate in lower elevations immediately above the grasslands and woodlands of the Sacramento Valley. Unlike the northern part of the state, there is very limited privately owned forests in the Southern Sierra Nevada and across Southern California.

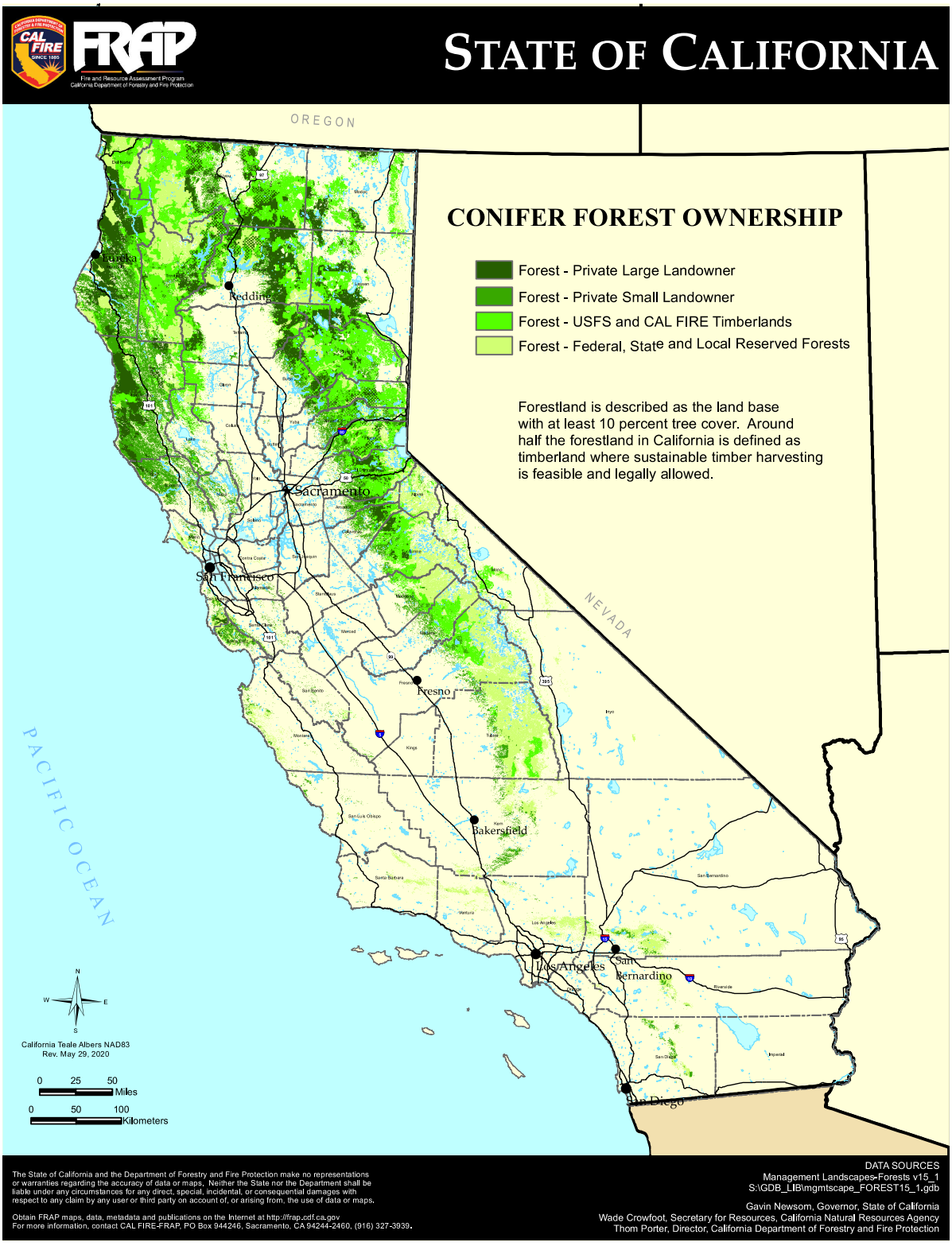

Figure 1.2 Private and Public Conifer Forest Lands in California. *Source*: (Fire and Resource Assessment Program, 2018).

As the public sector was moving away from even-aged silviculture and its necessary reforestation component, private industry was evolving in the opposite direction. While some coastal timberland owners continued even-aged forestry practices as they reentered second growth stands in the 1970's, for decades much of interior California had traditionally used selective type harvesting. The year 1973 witnessed the passage of the Z'Berg-Nejedly Forest Practices Act (California Code Public Resources Code, 2018) resulting in the most comprehensive set of forest practice regulations in the nation. Included in that California law was a mandate for sustainable forest practices and immediate and successful reforestation after harvesting. In the early 1980's, the Southern Pacific Land Company initiated an intensive forest management program on its ownership in northeastern California and other companies found themselves dealing with the reforestation of both older and current wildfires. With an increasing use of even aged management by interior landowners and the advent of more frequent and increasingly larger wildfires, industry programs utilizing "regeneration foresters" grew in place until an active and sustainable statewide industry reforestation presence developed that still exists today.

Since publication of the 1971 handbook, the world has changed around us. Starting with the advent of computers, quantum leaps in technology have led to then unimaginable but now routine changes in life styles. Our ability to capture, process, store, and share large quantities of data has resulted in the ability to organize and seek answers to questions not readily available before. Along with changes in silvicultural direction, this evolution has encouraged and enabled forest scientists and professionals to conduct studies specific to these reforestation activities.

Examples of this new or expanded work include long-term research, such as the Maximum Growth Study (also known as the "Garden of Eden study") (USDA, 2018) and the Long-Term Soil Productivity studies conducted under the direction of Dr. Robert F. Powers of the USDA Forest Service Pacific Southwest Research Station (Robert F. Powers et al., 2005; R. F. Powers & Ferrell, 1996; R. F. Powers & Reynolds, 2000). In addition, various landowner, agency and university supported research co-operatives such as the True Fir Management Co-op in the 1980's and 1990's, the Northern Sierra Tree Improvement Association (Soper-Wheeler Co. LLC, 2011) from 1979 to present, and the Sierra Cascade Intensive Forest Management Research Co-operative (Sierra Cascade Intensive Forest Management Research Cooperative, 2019) ongoing since the year 2000 have contributed to an expanding knowledge base. Major topics investigated in detail included vegetation management using selective herbicides, seedling performance, and plantation density. Developing practitioners not only encouraged and supported this focused research, but also experimented with and refined field practices as well. Ideas have been commonly exchanged and practices shared since 1978 through the annual Forest Vegetation Management

Conferences (Forest Vegetation Management Conference, 2019) and associated California Forest Pest Council's Weed Committee field trips (California Forest Pest Council, 2008).

While much has changed in reforestation practices, many of the activities remain the same. Seeds are still collected, stored and sown, seedlings grown, packed and stored, and a new forest is regenerated one tree at a time. All the subsequent trial-and-error in the field and focused scientific research since 1971 have rendered much of the information in the original handbook outdated. For example, included in the original book is the now generally abandoned practice of direct seeding as a conifer reforestation tool in California and other drier sites in the West. Over these years, however, new practices, principles, and focus have been developed that are now commonly accepted and integral to the discussion of successful and cost-effective programs. This is particularly true regarding both refined nursery techniques used to produce vigorous seedlings with ready-to-grow roots when out planted, and new and safer forest chemicals now available for site preparation and seedling release. Over this same time frame, there has emerged a greater recognition of the importance of timely vegetation management for the success of reforestation efforts, as well as the need to manage and monitor a reforestation program from the field and not just from the office. Finally, there has been renewed focus on the need for clearer definition of each step and timing within the overall reforestation plan, stocking density levels, species selection and mix, seedling handling, storage, and planting techniques, and protection from forest pests.

Reforestation has now developed into a recognized and well-respected career path. After being "thrown into the fire", the early reforestation pioneers developed into ever-more knowledgeable practitioners as planting efforts greatly expanded due to harvesting techniques and wildfire restoration. Seedling survival rates have greatly increased, new and focused manual, mechanical, and chemical treatments have been employed, labor pools have radically changed, and the previous barriers of timing and remote access have been challenged. However, just as the label "expert" would emerge, new issues would reinforce that constant learning and adaptation is always necessary. With time, of course, these reforestation specialists retire or take their abilities on to other levels of responsibility. While the extension of their unique experience to differing professional roles certainly provides a broad and positive background, the loss of those battle-hardened reforestation skills in the field needs to be recognized and re-developed. Opportunities for information exchange and training within this natural turnover are imperative to maintain the high standards already developed and to avoid reinventing the wheel and repeating previously encountered mistakes.

It is with this historical context that a group of past and current reforestation specialists recognized the importance of maintaining and transferring the current knowledge base as this transition continues. Ongoing personal information exchange is vital, as are interactive workshops and seminars, but providing

a compilation of the wealth of operational knowledge garnered over the last half century is the focus of this publication. While this publication is a sequel to Schubert and Adams's original effort, it should be considered much more than just a second edition given the magnitude of changes involved. Hopefully, it will contribute to continuing high standards by successors to the current generation of natural resource professionals and that it will serve as a valuable resource available to them as a building block for their own discoveries and advances.

Early History of California's Reforestation

The policy concerns about reforesting California goes back at least 130 years. In 1884, an interim State Forestry Commission reported to the Governor of the need to replant land "denuded of redwoods", plant "new land in suitable forest trees", and collect useful information on the "best mode of planting, caring for, thinning, and general treatment of growing timber trees" (Coleman, Forman, & Chase, 1884). By 1887, the State was providing nursery stock of 150,000 seedlings and had established experimental plantations in all regions. However, "suitable forest trees" at that time were not always native species and there was an emphasis on promoting exotics like eucalyptus and other potential new commercial species. Direct seeding of some conifer species began as an experiment on the San Bernardino Forest Reserve in 1901 and in northeastern California in 1908. Experiment stations were established to promote tree planting in general (Clar, 1959). While concern was expressed about the focus only on timber, often exotic species, these early efforts did not contribute significantly to reforestation success (Schubert & Adams, 1971).

A state forest nursery was approved by the legislature in 1917 and began production in Davis in 1922, with its stock initially limited for use at sites along highways or for public buildings. With the passage of the federal Clarke-McNary Act in 1924, joint federal-state attention was given to "the greatest possible incentive to commercial reforestation", including authorizing cooperative forest nursery work (Clar 1959). Early federal efforts focused on growing and planting pine seedlings for California's pine region (Corson & Fowells, 1952; Show, 1930) Considerable forest tree planting work was carried out by the Civilian Conservation Corps (CCC) during the Depression of the 1930s, with "tree and plant disease control" performed on nearly 800,000 acres of land in the state (Merrill, 1981). Forestry work included seed collection, tree seeding and planting, nursery jobs, and timber stand improvement (Fig. 1.3).

Figure 1.3 CCC crew carrying seedling transplants to the field on the Shasta National Forest near Mt. Shasta in the 1930s. *Source:* (Wikimedia.org - USFS photo #413770.).

The State Legislature changed the focus of the state nursery in 1947, directing it to expand to provide a reliable source of quality forest tree seedlings for private forest landowners. The post-war lumbering boom helped accelerate this interest with 878 sawmills operating that year, reflecting the steep increase in the state's annual timber cut to 3.4 billion board-feet (Arvola, 1976) By 1952, California had established a significant system of public nurseries to produce timber species (Clar, 1959), with four in operation by 1955. A State Reforestation Advisory Committee was tasked in 1957 to recommend reforestation methods and procedures and assist the Division of Forestry in field studies and information exchange. State nursery production over the decades usually reflected harvesting rates and availability of forestry assistance programs (Lippitt, 1998).

To "repair the scars left by forest fires", the U.S. Forest Service's forest tree nursery at Mt. Shasta produced young trees for planting on the 17 National Forests in California beginning in 1946 (Lanquist, 1955). It grew five million seedlings, enough to plant 7,000 acres each year, although the burned acreage was usually much greater. The USFS estimated in 1955 that over a million acres of "unstocked forest soil" remained as a planting backlog on these forests. By 1960, several more USFS nurseries had been added to expand the agency's production capacity around the state. As indicated in Table 1.1 below, the combined seedling production potential was about 36 million trees annually for the federal nurseries while the state nurseries had the capacity to grow about 11.5 million seedlings during peak production years. In contrast, private forest tree nurseries owned by industrial landowners and others did not begin operations in California until the 1970s.

Table 1.1 Public forest tree nurseries in California, 1921 to present

Nursery	Owner	Years of Operation	Max. Seedling Capacity	Location
L.A. Moran (Davis)	CalFire	1921 - 2003; 2019 - present	0.4 million	Yolo Co.
Magalia	CalFire	1952 - 2011	5-6 million	Butte Co.
Ben Lomond	CalFire	1945 - 1994	4-5 million	Santa Cruz Co.
Parlin Fork	CalFire	<1955-1970>	n/a	Mendocino Co.
Mt. Shasta	USFS	1946 - 1970	5 million	Siskiyou Co.
Placerville	USFS	1957 - present	12 million	Placer Co.
Humboldt	USFS	1960 - 1999	18 million	Humboldt Co.
Oakdale	USFS	<1955-1963>	1.5 million	Stanislaus Co.

Source: (Lanquist, 1955; Lippitt, 1998; Sherlock, 2018)

Current Reforestation Needs in California

The previous section on the history of reforestation in California shows that forest regeneration has been a concern in California since the latter part of the 19th century. As a partial response to this concern, California revised its forest practice rules in 1973 to require successful reforestation of private lands following every timber harvest. Reforestation of lands deforested by harvesting activities prior to 1973 or by wildfires or other events is not legally required on private or federal lands. Current reforestation activities consist of required reforestation after timber harvests, voluntary reforestation of areas burned by wildfires, and voluntary restoration or rehabilitation of areas where the historic tree cover has been replaced with shrubs or grasses. The State of California and the federal government provide some incentives in the form of cost-share programs and technical assistance to improve reforestation success for small landowners, as described in Chapter 2.

The scale of the potential demand for reforestation in California depends on three major trends: the area harvested with even age silviculture techniques, the extent of timberland experiencing severe wildfire damage, and new reforestation and afforestation projects. The most significant change in recent decades has been the increasing trend in the area affected by severe wildfires. While most of California's wildfires are in grasslands and shrublands ((Fire and Resource Assessment Program, 2018) , an estimated 400,000 acres of forests burned annually over the 2006-2015 period (Brodie & Palmer, 2020). The area burned by wildfires that may need reforestation varies widely from year to year; losses in bad years are often twice the long-term average. Indications are that losses will increase over time unless significant changes are made to both fuels and fire management practices (Starrs, Butsic, Stephens, & Stewart, 2018). The extent of wildfires over the past two decades that have burned in forested regions is illustrated in figure 1.4. The forest area burned in wildfires is a mix of productive timberlands, reserves, and low productivity forests.

Expensive reforestation efforts are usually limited to more productive timberlands as well as areas where forest cover is desired for recreational, residential, and aesthetic goals.

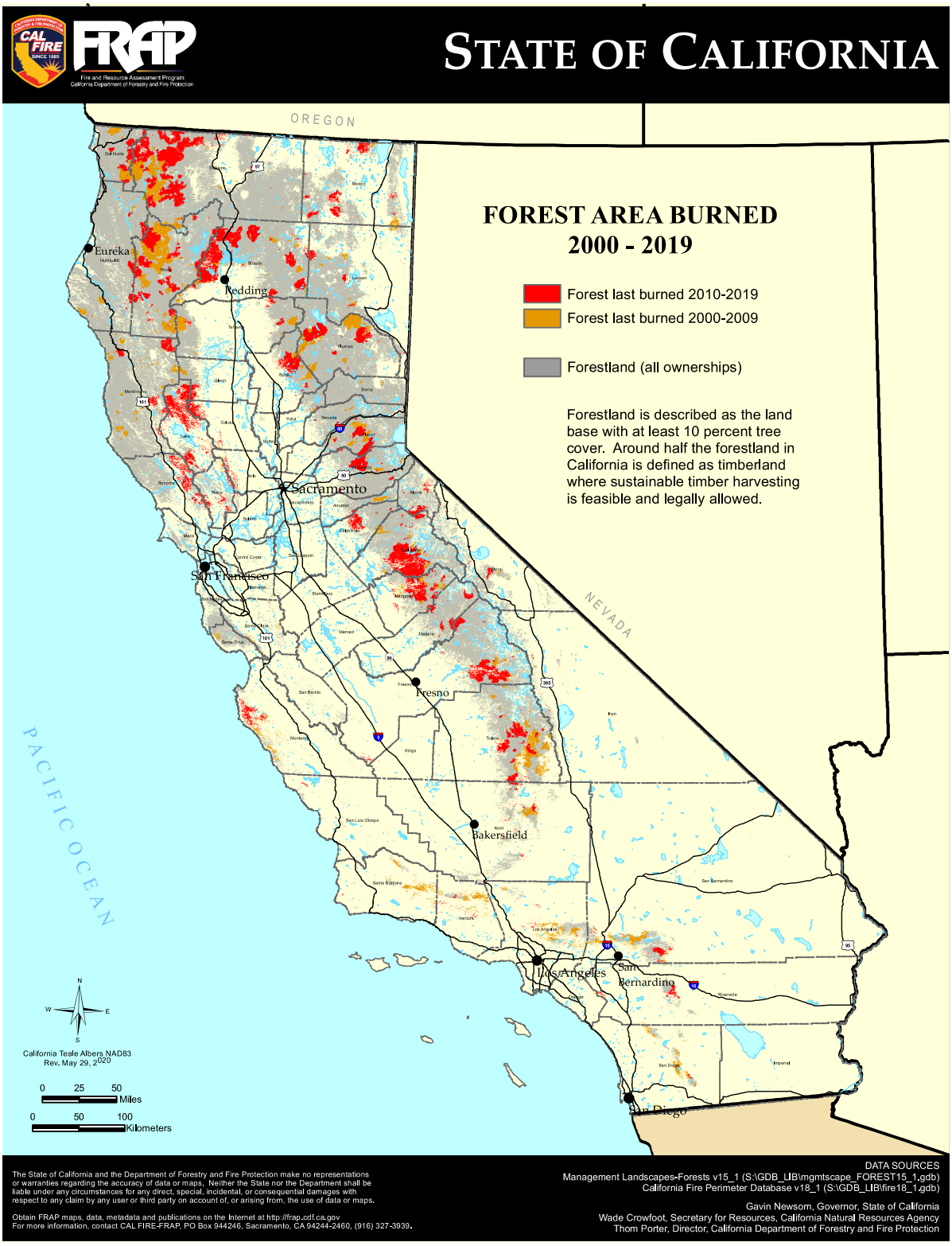

Figure 1.4 Fire Perimeters: Wildfire Perimeters and Forests 2000- 2019.

Based on the silvicultural practices data for non-federal lands in (Fire and Resource Assessment Program, 2018), around two thirds of recent private reforestation acres are in planned harvest units (40-50,000 acres) and one third (20,000 acres) are in post-wildfire settings. There are no accurate records of the acres of new reforestation or afforestation on private land. Compared to private lands, there is much less even-aged harvesting but considerably more area affected by severe wildfires on federal lands. Of the estimated 80,000 acres of US Forest Service timberlands that are burned annually in wildfires, only a small portion is replanted. Based on the reported certification of reforested acreage by Region 5 (California) of the USFS, less than 2,000 acres per year of reforestation planting has occurred on USFS timberlands over the past decade, leaving the vast majority of the wildfire affected areas dependent on natural regeneration (U. S. Forest Service, 2020; U.S. Forest Service, 2020). The success rate for natural regeneration in reestablishing conifer forests in California's Mediterranean climates is often low (Welch, Safford, & Young, 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, North, & Safford, 2016; Stephens, Collins, & Rogan, 2020). Use of the proven techniques presented in later chapters could greatly increase the success rate in any types of reforestation effort.

Why plant forests?

Best management practice (BMP) principles for reforestation are composed of technical and operational aspects that have been developed and honed by practitioners in California and neighboring states over decades. However, before exploring them, it is valuable to step back and consider why landowners should plant forests, where reforestation should happen, who should be involved, when it should take place, and what should be considered.

"Planted forests simply are our best hope for meeting societal demands for wood while preserving the condition of natural forests" (Powers, 2000).

In his 2000 talk entitled *"The Role of Planted Forests in a 'Green Certified' Century*", Dr. Robert F. Powers, one of the guiding lights of modern reforestation, made a compelling case for planting forests (R. F. Powers, 2000). Planted forests are a part of the solution to balancing society's need for wood products and the environmental benefits of sustainable natural forest cover (R. F. Powers, 1999). World demand for wood could be met through the year 2050 with just 13% of the land base in planted forests under intensive forest management and with no need for harvesting of natural forests. This approach only requires an average plantation productivity equal to the current average for planted forests in the Sierra Nevada region of California.

The state of California is the largest consumer of wood products in the United States and currently imports about 80% of the lumber and 90% of all wood products (e.g. lumber, wood panels, paper products) used in the state (Fire and Resource Assessment Program, 2018). Supplying this demand depends on sustainably managed forestlands in California as well as nearby states and Canadian provinces. Practices in all of these production areas have evolved such that successful reforestation is now one of the mainstays of productivity for forest landowners. Oregon has had a long standing interest in ensuring successful regeneration of their forests (Cleary, Greaves, & Hermann, 1978), and the Oregon State University Extension Service continues to publish useful technical publications on reforestation (Fitzgerald, 2008, 2018; Huff, 2014; Oester & Fitzgerald, 2016).

Reforestation success is central to maintaining and increasing the productivity of timberlands. If not successful, it is probable that brush species will become established on many forest sites, and in some cases, new conifer trees may not return for decades, if at all. Using the practices described in this manual, tree planting will result in a rapid return of well-distributed trees with the mix of species desired by the landowner. Seedlings will begin growing the year they are planted and will be well-established on the site within a year or two. When using natural regeneration, it is true that the recruitment of seedlings can occur rapidly under the right conditions, but it also can be delayed by decades if shrubs or grasses fully occupy the site and suppress tree seedling growth.

When seedlings are planted, the spacing is planned so that they are evenly distributed over the entire site. This ensures that each planted seedling will receive an equal share of resources without competing with neighboring trees and have room to grow at their maximum possible rate. Natural regeneration often results in an unequal distribution of seedlings. Areas near seed trees where conditions are right may have too many seedlings; areas where there are no seed trees or the soils are of lower quality may have too few. Only some of the crowded seedlings will make it to the sapling and tree stage, and then only over an extended period of time.

With tree planting, the landowner can also control the mix of species on the site to best reflect site conditions, management goals, and overall diversity. Natural regeneration does not generally offer the same flexibility as the species mix is commonly determined by the species present that produce the most seed from cone crops that only occur periodically. The pre-wildfire species mix is also influenced by the trees and vegetation that remain on the site after harvesting, fires, or other natural events that occurred in previous decades. For example, a forest that was historically dominated by pine may become a forest dominated by true fir if the pine is removed and the true fir that have naturally regenerated in the shade of the pine are left on the site. In such cases, specifically planting the historic species mix may be a better

alternative. It can also avoid a subsequent site that is continually dominated by shade tolerant, and fire intolerant, species.

The benefits of planting are many, but the up-front costs of planting forests are high compared to relying on natural regeneration. The decision to plant will ultimately depend on both the ability and the short and long-term objectives of private landowners and government land management agencies. The reality is that years of effort and expenditure will be necessary before the eventual value of the regenerated forest stand is realized. This topic is discussed further in Chapter 2, "Investing in Reforestation".

Where does reforestation take place?

Successful reforestation projects in California are based on planting seedlings grown from species native to the specific forest type. The tree species planted in a reforestation project are chosen to match the species that have historically grown well in that region and will be able to continue to do so in the future. The current or potential forest type of a specific site determines what mix of species will be planted. California has a diverse range of forest types that contain different conifers species. The map (Figure 1.2) of conifer forest ownership in California provides an overview of where reforestation could take place and who would be responsible. Within the conifer forest area, active reforestation will typically be concentrated in the more productive forests that are classified as timberlands and will involve planting species that match those in the current forest types. Smaller reforestation projects and natural regeneration are more common on less productive forests or forests where timber managed is legally prohibited where the costs of active reforestation may not always be justified by higher rates of future tree growth.

The most statistically accurate forest type data by ownership in California is assessed on a network of field plots and published by the Forest Inventory and Analysis (FIA) program of the US Forest Service. Table 1.2 summarizes the area of different forest types that may require reforestation by the different owner classes. The California mixed conifer forest type represents about half of all timberland acres in California and is often the touchstone for forest policy or regulations requiring reforestation with a mix of species. However, tree species diversity within the mixed conifer forest region is varies as mixed conifer plots are intermingled with plots overwhelmingly dominated by Ponderosa pine or true firs. On the North Coast, redwood, tanoak/laurel, and Douglas-fir plots are often the result of past management actions and the species mix can change over time. On many sites the appropriate species to be planted will be species that have thrived on similar sites in the past, but on other sites the best decision may be to plant only one or two species. The decision on the appropriate mix of planted species should be made by the reforestation forester after considering what species have historically done well on the sites and which species will thrive in the seedling and young tree stages of forest development.

Table 1.2 Current forest types on timberlands by owner group (as defined by USFS) – millions of acres

Forest type	USFS	Corporate	Family	Other Govt	Total
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

Source: Brodie and Palmer (2020).

It is important to note the significance differences in the portfolios of forest types for the different owner groups as this will affect what species they plant as well as their overall reforestation strategies. The California mixed conifer forest and ponderosa pine types are the largest components for the USFS and corporate landowners. Family owners with smaller holdings have comparatively more coastal Douglas-fir, redwood, and other species. In addition, the FIA data also shows that around one third of timberland area is currently dominated by stands with few if any commercial species. Some of these areas could be potential sites for reforestation projects with commercial conifer species if the economics of investing in such projects were favorable.

Who should be involved?

Who will be involved in reforestation projects will be closely aligned with the ownership patterns of the productive timberlands where the investment in planting and tending seedlings will be rewarded with a rapidly growing forest. While forests and woodlands cover 32 million acres of California, reforestation projects will primarily take place on the 16 million acres of managed timberlands where landowners can feasibly plant and manage conifer species appropriate for the local forest type and local site conditions. Forest lands that are not defined as timberlands either have low site and growing potential or do not allow for any planned commercial harvest of planted trees. Forest lands that are physically and legally able to sustainably grow trees for harvest and reforestation are generally called timberlands. The U.S. Forest Service's FIA program further describes timberland as "forest land that has the potential to grow at least 20 cubic feet of wood per acre per year and is legally designated to allow mechanized vehicles and timber harvesting" (Waddell, 2013). Unlike the vegetation cover maps available for California (Fire and Resource Assessment Program, 2018; Griffith et al., 2016; USDA Forest Service Pacific Southwest Region, 2020), detailed maps of timberlands are not maintained by state or federal agencies. Natural

regeneration rather than active planting will more commonly be practiced on the other 16 million acres of forestland in California where potential productivity is too low to justify investing in reforestation, where federal or state reserved status precludes active forest management, or where natural recovery of the forest following disturbance is a management goal. Timberland ownership in California summarized in Table 1.3 illustrates who owns the timberlands and wide range across owners in the fraction of total forest land that is classified as timberland.

Table 1.3 Forest Land Ownership in California in million acres

Owner Type	Timberland	Other forest	All Forest	Pct Timberland
Small private	3.0	4.4	7.4	41%
Large private	4.2	0.8	5.0	85%
State and Local	0.15	0.9	1.1	32%
Other Federal	0.3	2.8	3.1	10%
USFS	8.9	6.5	15.3	58%
Total	16.6	15.3	31.9	53%

Source: (Brodie & Palmer, 2020).

The three basic types of landowners that need to be involved in future reforestation efforts - small private, large private, and public agencies - each have their own goals, resources, and objectives. These can depend on site conditions, the size of the individual ownership, and the resources available for the project. The most significant variable in California, though, is whether the site is productive enough to be managed with long-term sustainable forest management. The higher growth rates of productive timberlands help justify greater initial investments.

Small private forest holdings are split between productive timberlands and less productive forests where non-economic goals such as aesthetics, wildlife habitats, and fire safety near residences strongly influence decision making. The ownership of smaller landowners is concentrated in forests dominated with redwoods, Douglas-fir, and a mix of conifers and hardwood species in the Coast range, as well as pine and mixed conifer forests in the lower elevations of the Sierra Nevada. Large private ownerships are primarily productive timberlands that are managed primarily for their long-term sustainable economic values. The ownership of large landowners is concentrated in the highly productive redwood region in the Coast Range and in the mixed-conifer forests of the northern and central Sierra Nevada range and Cascade region. National and state forests in California are managed with a wide range of site qualities, goals and objectives, and can differ dramatically from national and state parks.

Compared to other states, California's forests are unique in having a Mediterranean climate with a long dry summer that is better suited to shrubs and grasses than to small tree seedlings. The common factor for all California landowners to having successful reforestation projects is following the best management practices (BMPs) outlined in this chapter and described in detail within this book.

Private Forests - Large landowners and Small landowners

Private forest land ownerships are often classified by the dominant purpose of the owner. Large forest land ownerships are sometimes referred to as industrial or corporate even though they may or may not own a sawmill and may be privately owned by a partnership, timber investment management organization (TIMO), or a family. Smaller forest land ownerships in California are sometimes referred to as non-industrial, noncorporate, family forests, or forest/ranch ownerships. We will simply use the terms large ownerships and small ownerships.

Large ownerships control 60% of non-federal timberlands in California and generated 88% of the recent non-federal timber harvest volume (Stewart et al., 2016) These owners typically have a permanent forestry staff to conduct reforestation, timber harvest, and other forest management activities. From a reforestation perspective, a huge advantage of having a permanent staff is that they possess detailed knowledge of their property and can maintain a conifer seed bank for their lands – an activity upon which all reforestation is dependent. Large ownerships usually have demonstrated a commitment to successful reforestation, and, in most cases, have reforested commercial forest lands impacted by severe wildfires even though they are not required to do so.

Small ownerships often have lower site quality land and rarely have permanent forestry staff. Around two-thirds of the forest area in small ownerships is in parcels less than 500 acres in size where the income from sustainable timber harvesting is often not a dominant management goal (Ferranto et al., 2011). They may have an on-going relationship with a consulting forester, but usually do not gather seed for major reforestation projects. Most prefer to use uneven aged silviculture practices that leave harvested stands adequately stocked without the need for additional reforestation. However, small ownerships have the same exposure as their large ownership neighbors to wildfires, insect events, or severe droughts that require active reforestation. These owners may not have sufficient capability to pursue reforestation without financial or technical assistance and may have different ownership priorities such as wildlife and stream habitats, broad forest health concerns, or landscape aesthetics that would influence their activities..

The trend in harvested acres on all non-federal lands, as depicted in Figure 1.4, illustrates where reforestation projects may have been necessary for post-harvest, post-wildfire, or rehabilitation purposes. Even-aged harvests have declined over time to a relatively steady 30,000 to 40,000 acres per year, and all are reforested unless the land was approved for conversion out of forest land use. No additional reforestation is necessary for the 40,000 to 60,000 acres treated with uneven-aged silviculture, except for small areas of group selection if the owner does not want to depend on natural regeneration. Likewise, only a small portion of the annual 20,000 acres in the 'Other' category may require active reforestation. Of note, the fastest growing component of harvest since 2012 has been the 30,000 to 50,000 acres of non-

federal timberland operated under emergency conditions following catastrophic wildfires or other mortality events. Much of this has been on large ownerships, and nearly always has been actively reforested.

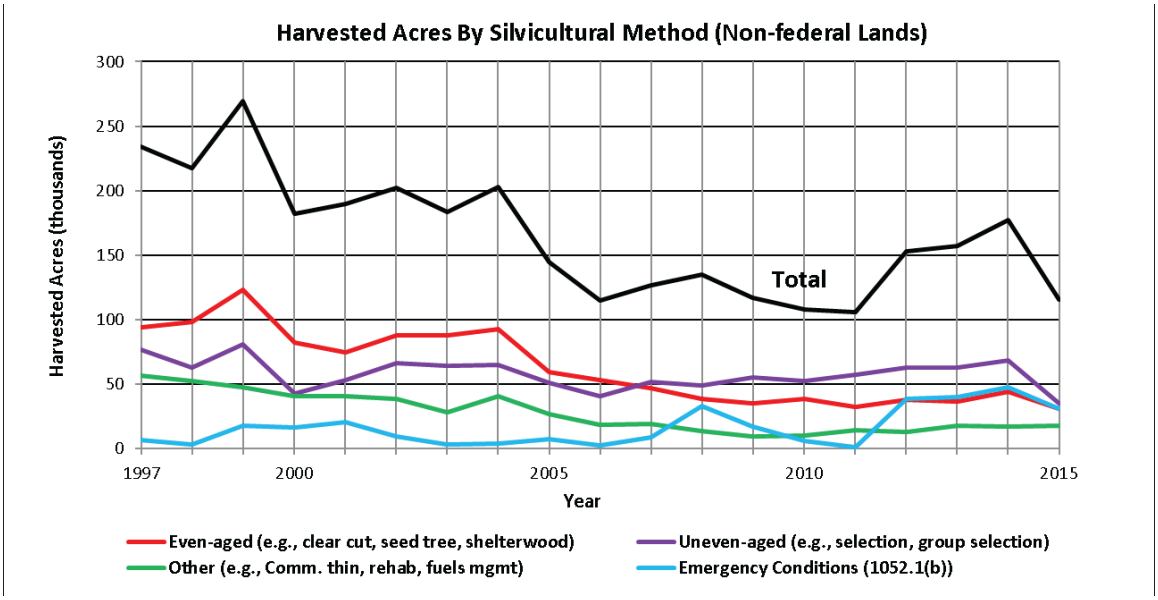

Figure 1.6 Potential Reforestation Acreage on Private Lands, 1997-2015 (CDFFP 2018). *Source*: (Fire and Resource Assessment Program, 2018).

USDA Forest Service

Reforestation programs in the western states have been integral to the mission of the National Forests since the U.S. Forest Service's inception over a century ago, especially following large wildfires. The fiscal and operational challenges of reforestation of large areas are substantial and have been the focus of numerous Congressional reviews and proposals to increase the rate of reforestation (Subcommittee on Public Lands: Congressional Committee on Interior and Insular Affairs, 1960). In response to public controversies over herbicide use on California's National Forests in reforestation projects, the Regional Forester in 1980 commissioned a task force on vegetation management to review "when and where various vegetation control methods could be used effectively, and with the overall consideration of prescribing in our site preparation and release treatments 'no more and no less' than those needed to achieve management objectives." (USDA, 1980). That Task Force reviewed the mechanical, manual, and herbicide methods in use at that time and found very little published data on the relative efficacy and costs of the different approaches. One result of this review was a twenty-five-year effort to conduct experiments and publish the results on the principles, results and challenges for conifer reforestation in interior regions of California (McDonald & Fiddler, 2010). Data from this long-term research program formed the basis for many of the practices described in this manual.

As noted earlier, the increase in the extent of severe wildfires, especially on National Forest timberlands in California since 2000, has substantially increased the need for successful reforestation projects in the state (Bedsworth, Cayan, GuidoFranco, Fisher, & Ziaja, 2018.; Starrs et al., 2018; Westerling, 2016). There is evidence that more of the wildfire areas now experience near total tree mortality (Eskelson, Monleon, & Fried, 2016), but these Federal forests with severe wildfire intensities are increasingly experiencing less successful natural regeneration (Tepley, Thompson, Epstein, & Anderson-Teixeira, 2017; Thompson, Spies, & Ganio, 2007; Zald & Dunn, 2018). Over the past decade, the Forest Service in California reported an annual planted area of 13,000 acres with the majority being natural regeneration (U.S. Forest Service, 2020). Annual rates of reforestation planting with site preparation and control of competing vegetation averaged less than 2,000 acres over the past decade (U.S. Forest Service, 2020), low when compared to the approximately 80,000 acres of private land that is reforested annually. While the current reforestation goals for National Forests now place greater emphasis on restoring forests to previous levels of forest complexity rather than just establishing a new cohort of conifer trees, successful reforestation of conifer trees still requires the same emphasis on conducting the key steps in a timely fashion (USDA, 2019). Efforts are ongoing within the agency to train new agency personnel to successfully address the evolving challenges.

Besides the productive timberlands managed by the Forest Service, more than half of the federal conifer forests in California are classified as designated wilderness area, national park, or have a low forest productivity rating. In these areas, natural regeneration will nearly always be the preferred approach to reforestation. Such regeneration after severe fires that kill potential seed trees may be quick, could slowly occur over decades, or may never happen for extended periods of time.

Other Public Lands and Tribal Lands

Other federal, state and local public agencies manage forest lands, including the Bureau of Land Management (BLM), National Park Service, State Forests, and State Parks. While recreational uses and natural habitats may be the dominant management goals for some properties, these public lands may need to engage in reforestation projects after either large or small mortality events such as wildfires, insect or disease outbreaks, or severe drought to meet their goals. Four tribal reservations in the state (Hoopa, Round Valley, Tule River, and Yurok) are being managed for timber production and other uses, as based on their forest management plans (Fire and Resource Assessment Program, 2018).

Forest Seed Collection Facilities and Forest Nurseries

While federal forest nurseries in California have considerable production capacity, most of the seedlings produced in California are preordered and then produced in private nurseries. Millions of seeds from desired tree species must be collected, processed and stored in seed banks to make up for the risk that

sufficient local seed will not be available concurrent with a reforestation project. Federal, state and private seed collection, processing, and storing facilities are all parts of the larger reforestation process. Since 2012, reported seedling production has varied from 13 million to 23 million trees per year (Haase et al., 2014; Haase et al., 2015; Harper et al., 2013; Hernández et al., 2018; Hernández et al., 2016, 2017), the differences resulting from changes in demand due to periodic wildfires and cycles in forest product markets. Unlike the rest of the United States, where bareroot seedlings make up around ¾ of the total number of seedlings, the experiences with the harsher planting conditions in California have led to an industry where nearly all seedling production is from container stock (Hernández et al., 2018). If the USFS expanded reforestation to address their existing backlog as well as to keep up with new wildfire projects, it could potentially increase statewide demand by 10 million seedlings or more.

As covered in later chapters, expanded seedling production will also require a similar increase in the collection of viable seeds from the unique seed collection zones of the state. To ensure that the planted seedlings grow well over many decades, the seeds used for the seedlings must come from the appropriate seed zone (Buck et al., 1970). Within each seed zone, the collected seed is tracked by species, 500' elevation bands, and aspect to ensure that the seedlings come from trees that were successful in the planting site. Figure 1.6 shows the seed zones that are described in greater detail in chapters 5 and 9, as well as a close-up on one seed zone to illustrate the variability of elevation and aspect that also influence on how well the seedlings will be adapted to their eventual planting site. To address potentially much warmer future climatic conditions, consideration is being given to use seeds from higher elevation bands within current seed zones or from other seed zones where the current climate is similar to what is expected in future decades. Over time, California may increase collaboration with programs in Oregon, Washington, and British Columbia that have developed more detailed protocols and tools to adjust seed collections to future climates (Howe, 2020; Mahony, MacKenzie, & Aitken, 2018).

Figure 1.6 California Seed Zones and site variability within one seed zone.

When does it take place?

The timing of a reforestation project depends upon which of three general categories it may fall into: 1) post-harvest, 2) post-wildfire or other serious forest disturbances, and 3) rehabilitation or restoration of degraded forest land on which conifer trees may have been absent for many years. In the first case, post-harvest projects are usually scheduled to occur as soon after harvest as possible if stocking levels are inadequate to meet regulatory requirements and desired long term growth. Since the scheduling of harvests is planned in advance, many of these sites can be planted in the fall, winter or spring immediately following the completion of the harvest activities. These reforestation activities should be planned to match site conditions and the logistical limitations of the owner.

The planning for post-wildfire projects should ideally begin immediately after the fire. This strategy will allow for the re-establishment of the new forest as soon as possible. In contrast, rehabilitation projects involve restoring conifer species to land that was forested in the past but is currently dominated by other types of vegetation. Examples of such projects include returning redwoods to land that was long ago cleared for agriculture or restoring conifers to old burns that are now dominated by brush species. These planned projects can be initiated at any time.

Chapter 3 “Planning a Reforestation Project” describes the sequence of activities that will lead to the application and scheduling of the 5 Principles of Successful Reforestation described below for each of the three reforestation categories identified. Some of the principles specified are common to all three types, but some are specific only to one. The exact timing of each practice may vary depending on the planting site characteristics.

What should happen?

Owners of timberland should evaluate their holdings to determine the need for reforestation. If reforestation then becomes the objective for particular sites, Chapter 3 “Planning a Reforestation Project” and Chapter 4 “Site Assessment” are good places to start. Decades of experience with reforestation projects in the often harsh Mediterranean climate across much of California’s interior forests as well in other Mediterranean climates led reforestation practitioners Bob Rynearson and Tom Jopson to define five key principles that have proven critical to successful plantings.

Five Principles of Reforestation

1. Use tree species from known appropriate seed sources which can be established and grow vigorously on the site without irrigation;
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 properly when conditions on the site allow for rapid root growth;
5. Protect seedlings from damage by animal and insect pests, if necessary.

It is important to emphasize that the first principle, using tree species from appropriate sources, is dependent on the availability of appropriate seed. Without seed banks with viable seed, no project is possible. The availability of seed may be dependent on an action that must have occurred many years prior to the actual need - the collection of seed from the either the appropriate seed zones or from specifically designed seed orchards. Both of these seed sources can require long lead times. As is described in detail in Chapter 5 "Seeds", collectable conifer cone crops are sporadic and unpredictable in many areas. Landowners should seriously consider collecting or purchasing appropriate seed in years when cones are available and storing the seed until it is needed. Seed orchards are a more reliable source of seed once they are producing, but it can take twenty years or more to establish an orchard and obtain the first seed. Owners of seed orchards may be willing to sell seed if it is surplus to their reforestation needs.

Conclusion

Reforestation activities may be applicable at any point in time on approximately 16 million acres of the 32 million acres of California's private and public timberland. Since the publication of the 1971 '*Reforestation Practices for Conifers in California'* handbook, our understanding of ecological principles of conifer reforestation has greatly expanded and reforestation tools have improved. Our ability to successfully regenerate forests has grown dramatically in California as well as in other west coast regions ((Huff, 2014; Lavender et al., 1990; Oester & Fitzgerald, 2016). With increased knowledge comes better insights into the overall complexity in designing and implementing successful reforestation projects. Research and experience have shown us new techniques to implement complex prescriptions to match

challenging ecologic conditions (Robert F. Powers et al., 2005; Ritchie, Knapp, & Skinner, 2013; Zhang, 2008).

At the same time, the challenges to the long-term economic viability of forestry that is needed to justify investing in reforestation are multiplying. As wildfires intensify and fuels reduction efforts increasingly became a priority, clean air standards and liability concerns are limiting the use of controlled burning for fuel reduction on forest lands in the state. Biomass energy facilities that once provided a market for wood biomass that otherwise would be left as fuel in the forest are disappearing due to the economics and politics of renewable and low carbon energy sources. The use of herbicides on all landscapes is under constant scrutiny. The continued improvement and adaptation of forest management tools to maintain a social license for planted forests that are both productive and meet a wide range of environmental goals are the challenges of the future (Payn et al., 2015).

Acknowledgements

Appreciation is extended to these chapter reviewers: Mike Alcorn, Ed Fredrickson, Teri Griffis, Tom Jopson, Keli McElroy, Martin Ritchie, and Joe Sherlock.

References

Arvola, T. F. (1976). *Regulation of Logging in California 1945-1975*. Sacramento, CA: State of California, California Division of Forestry.

Bedsworth, L., Cayan, D., GuidoFranco, Fisher, L., & Ziaja, S. (2018.). *Statewide Summary Report. California's Fourth Climate Change Assessment. Publication number: SUMCCCA4-2018-013*. California Natural Resources Agency and California Energy Commission Retrieved from http://www.climateassessment.ca.gov/

Bohlman, G. N., North, M., & Safford, H. D. (2016). Shrub removal in reforested post-fire areas increases native plant species richness. *Forest Ecology and Management, 374*, 195-210. doi:https://doi.org/10.1016/j.foreco.2016.05.008

Brodie, L. C., & Palmer, M. (2020). *California's Forest Resources, 2006-2015: Ten-Year Forest Inventory and Analysis Report . PNW-GTR-XXX*.

Buck, J. M., Adams, R. S., Cone, J., Conkle, M. T., Libby, W. J., Eden, C. J., & Knight, M. J. (1970). *California Tree Seed Zones*. San Francisco, CA

Division 4. Forestry and Range and Forage Lands Part 2. Protection of Forest, Range and Forage Lands Chapter 8. Z'berg-Nejedly Forest Practice Act of 1973, (2018).

California Forest Pest Council. (2008). Weed Committee. Retrieved from http://caforestpestcouncil.org/committees/weed-committee/

Clar, C. R. (1959). *California Government and Forestry: from Spanish Days until the creation of the Department of Natural Resources in 1927*. Sacramento, CA: California Division of Forestry

Cleary, B. D., Greaves, R. D., & Hermann, R. K. (Eds.). (1978). *Regenerating Oregon's Forests: A Guide for the Regeneration Forester*. Corvallis, OR: Oregon State University Extension Service.

Coleman, J. V., Forman, S. W., & Chase, C. M. (1884). *Report of the Lake Bigler Forestry Commission to Governor George Stoneman*. Sacramento, CA: California Board of Forestry

Corson, C. W., & Fowells, H. A. (1952). *Here's how – a guide to tree planting in the California pine region*. USDA Forest Service, California Forest and Range Experiment Station Misc. Paper 8

Eskelson, B. N. I., Monleon, V. J., & Fried, J. S. (2016). A 6 year longitudinal study of post-fire woody carbon dynamics in California's forests. *Canadian Journal of Forest Research, 46*(5), 610-620. doi:10.1139/cjfr-2015-0375

Ferranto, S., Huntsinger, L., Getz, C., Nakamura, G., Stewart, W., Drill, S., . . . Kelly, M. (2011). Forest and rangeland owners value land for natural amenities and as financial investment. *California Agriculture, 65*(4), 184-191.

Fire and Resource Assessment Program. (2018). *California's Forests and Rangelands: 2017 Assessment* https://frap.fire.ca.gov. Sacramento, CA: California Department of Forestry and Fire Protection Retrieved from https://frap.fire.ca.gov/media/3180/assessment2017.pdf

Fitzgerald, S. A. (2008). *Successful Reforestation: An overview* Corvallis OR: Oregon State University Extension Service

Fitzgerald, S. A. (2018). *Choosing the right tree-planting contractor for your family forest*. Corvallis OR: Oregon State University Extension Service

Forest Vegetation Management Conference. (2019). Retrieved from http://www.fvmc.org/

Griffith, G. E., Omernik, J. M., Smith, D. W., Cook, T. D., Tallyn, E., Moseley, K., & Johnson, C. B. (2016). *Ecoregions of California*. (Open-File Report 2016-1021).

Haase, D. L., Hernández, G., Arseneault, J., Woodruff, K. J., Harper, R. A., Overton, D. P., & Enebak, S. (2014). Forest Nursery Seedling Production in the United States - Fiscal Year 2013. *Tree Planters' Notes, 57*(2), 20-24.

Haase, D. L., Hernández, G., Lesko, J., Woodruff, K. J., Harper, R. A., Overton, R. P., & Enebak, S. (2015). Forest Nursery Seedling Production in the United States - Fiscal Year 2014. *Tree Planters' Notes, 58*(2), 20-24.

Harper, R. A., Hernández, G., Arseneault, J., Bryntesen, M., Enebak, S., & Overton, R. P. (2013). Forest Nursery Seedling Production in the United States - Fiscal Year 2012. *Tree Planters' Notes, 56*(2), 20-24.

Hernández, G., Haase, D. L., Pike, C., Mackey, L., Enebak, S., Ma, Z., & Clarke, L. (2018). Forest Nursery Seedling Production in the United States - Fiscal Year 2017. *Tree Planters' Notes, 61*(2), 18-22. Retrieved from https://rngr.net/publications/tpn/

Hernández, G., Pike, C., Haase, D. L., Enebak, S., Ma, Z., Clarke, L., & Mackey, L. (2016). Forest Nursery Seedling Production in the United States - Fiscal Year 2015. *Tree Planters' Notes, 59*(2), 20-24.

Hernández, G., Pike, C., Haase, D. L., Enebak, S., Ma, Z., Clarke, L., & Mackey, L. (2017). Forest Nursery Seedling Production in the United States - Fiscal Year 2016. *Tree Planters' Notes, 60*(2), 24-28.

Howe, G. (2020). Seedlot Selection Tool. Retrieved from https://seedlotselectiontool.org/sst/

Huff, T. (2014). *Introduction to Conifer Release*. Corvallis, OR: Oregon State University Extension Service

Keeley, J. E., & Safford, H. D. (2016). Fire as an Ecosystem Process. In H. Mooney & E. Zavaleta (Eds.), *Ecosystems of California* (pp. 27-45). Berkeley, CA: University of California Press.

Lanquist, K. (1955). *Mt. Shasta Forest Tree Nursery. Shasta-Trinity National Forests*. USDA Forest Service.

Lavender, D. P., Parish, R., Johnson, C. M., Montgomery, G., Vyse, A., Willis, R. A., & Winston, D. (Eds.). (1990). *Regenerating British Columbia's Forests.* https://www.for.gov.bc.ca/hfd/pubs/docs/mr/mr063.pdf.

Lippitt, L. (1998). *Nursery Program Analysis: Issue Paper*. Sacramento, CA: California Department of Forestry

Mahony, C. R., MacKenzie, W. H., & Aitken, S. N. (2018). Novel climates: Trajectories of climate change beyond the boundaries of British Columbia's forest management knowledge system. *Forest Ecology and Management, 410*, 35-47. doi:https://doi.org/10.1016/j.foreco.2017.12.036

McDonald, P. M., & Fiddler, G. O. (2010). *Twenty-five years of managing vegetation in conifer plantations in northern and central California: results, application, principles, and challenges. PSW-GTR-231*. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station

Merrill, P. (1981). *Roosevelt's Forest Army: A History of the Civilian Conservation Corps, 1933-1942*. Montpelier, VT: P. H. Merrill.

Oester, P. T., & Fitzgerald, S. A. (2016). *Enhancing reforestation success in the Inland Northwest. PNW 520*. Corvallis, OR: Oregon State University Extension Service Retrieved from https://catalog.extension.oregonstate.edu/pnw520

Payn, T., Carnus, J.-M., Freer-Smith, P., Kimberley, M., Kollert, W., Liu, S., . . . Wingfield, M. J. (2015). Changes in planted forests and future global implications. *Forest Ecology and Management, 352*, 57-67. doi:http://dx.doi.org/10.1016/j.foreco.2015.06.021

Powers, R. F. (1999). On the sustainable productivity of planted forests. *New Forests, 17*, 263-306.

Powers, R. F. (2000). *The role of planted forests in a "Green Certified" century*. Paper presented at the Proceedings of 21st Annual Forest Vegetation Management Conference, Redding, CA.

Powers, R. F., Andrew Scott, D., Sanchez, F. G., Voldseth, R. A., Page-Dumroese, D., Elioff, J. D., & Stone, D. M. (2005). The North American long-term soil productivity experiment: Findings from the first

decade of research. *Forest Ecology and Management, 220*(1-3), 31-50. Retrieved from http://www.sciencedirect.com/science/article/B6T6X-4H3971D-2/1/dbd47aef41741f728781dc13ee7e0d18

Powers, R. F., & Ferrell, G. T. (1996). Moisture, nutrient, and insect constraints on plantation growth: the "Garden of Eden" experiment. *New Zealand Journal of Forest Science, 26*, 126-144.

Powers, R. F., & Reynolds, P. E. (2000). Intensive management of ponderosa pine plantations: Sustainable productivity for the 21st Century. *Journal of Sustainable Forestry 26*, 126-144.

Ritchie, M. W., Knapp, E. E., & Skinner, C. N. (2013). Snag longevity and surface fuel accumulation following post-fire logging in a ponderosa pine dominated forest. *Forest Ecology and Management, 287*(0), 113-122. doi:http://dx.doi.org/10.1016/j.foreco.2012.09.001

Schubert, G. H., & Adams, R. S. (1971). *Reforestation Practices for Conifers in California*.

Sherlock, J. (2018). Personal communication.

Show, S. B. (1930). *Forest nursery and planting practice in the California pine region. USDA Agr. Cir. 92*. Redding, CA USDA Forest Service

Sierra Cascade Intensive Forest Management Research Cooperative. (2019). Retrieved from https://ucanr.edu/sites/SCIFMRC/

Soper-Wheeler Co. LLC. (2011). North Sierra Tree Improvement Association. Retrieved from http://www.soperwheeler.com/about-us/stewardship/north-sierra-tree-improvement-association/

Starrs, C. F., Butsic, V., Stephens, C., & Stewart, W. (2018). The impact of land ownership, firefighting, and reserve status on fire probability in California. *Environmental Research Letters, 13* Retrieved from http://iopscience.iop.org/10.1088/1748-9326/aaaad1

Stephens, C. W., Collins, B. M., & Rogan, J. (2020). Land ownership impacts post-wildfire forest regeneration in Sierra Nevada mixed-conifer forests. *Forest Ecology and Management, 468*.

Stewart, W., Sharma, B., York, R., Diller, L., Hamey, N., Powell, R., & Swiers, R. (2016). Forestry. In H. Mooney & E. Zavaleta (Eds.), *Ecosystems of California* (pp. 817-754). Berkeley, CA: University of California Press.

Subcommittee on Public Lands: Congressional Committee on Interior and Insular Affairs. (1960). *Acceleration of reforestation programs*.

Tepley, A. J., Thompson, J. R., Epstein, H. E., & Anderson-Teixeira, K. J. (2017). Vulnerability to forest loss through altered postfire recovery dynamics in a warming climate in the Klamath Mountains. *Global Change Biology, 23*(10), 4117-4132. doi:10.1111/gcb.13704

Thompson, J. R., Spies, T. A., & Ganio, L. M. (2007). Reburn severity in managed and unmanaged vegetation in a large wildfire. *Proceedings of the National Academy of Sciences, 104*(25), 10743-10748. doi:10.1073/pnas.0700229104

U. S. Forest Service. (2020). Reforestation Overview. Retrieved from https://www.fs.fed.us/restoration/reforestation/overview.shtml

U.S. Forest Service. (2020). Reforestation and Timber Stand Improvement Reports. Retrieved from https://www.fs.fed.us/forestmanagement/vegetation-management/reforest-tsi.shtml

USDA. (1980). *Report of the vegetation management task force as focused on reforestation and release*. Vegetation Management Task Force, Forest Service, Pacific Southwest Region

USDA. (2018). The Garden of Eden Experiment. Retrieved from https://www.fs.fed.us/psw/topics/forest_mgmt/garden_eden/index.shtml

USDA. (2019). Reforestation. Retrieved from https://www.fs.fed.us/restoration/reforestation/index.shtml

USDA Forest Service Pacific Southwest Region. (2020). Calveg System. Retrieved from https://www.fs.usda.gov/detail/r5/landmanagement/resourcemanagement/?cid=fsbdev3_046815

Waddell, K. (2013). *PNW-FIADB Users Manual: A data dictionary and user guide for the PNW-FIADB database*. Portland, OR: Pacific Northwest Research Station

Welch, K. R., Safford, H. D., & Young, T. P. (2016). Predicting conifer establishment post wildfire in mixed conifer forests of the North American Mediterranean-climate zone. *Ecosphere, 7*(12), e01609-n/a. doi:10.1002/ecs2.1609

Westerling, A. L. (2016). Increasing western US forest wildfire activity: sensitivity to changes in the timing of spring. *Philosophical Transactions of the Royal Society of London B: Biological Sciences, 371*(1696). doi:10.1098/rstb.2015.0178

Zald, H. S. J., & Dunn, C. (2018). Severe fire weather and intensive forest management increase fire severity in a multi-ownership landscape. *Ecological Applications, 28*(4), 1068-1080.

Zhang, J., Jeff Webster, Robert F. Powers, John Mills. (2008). Reforestation after the Fountain Fire in Northern California: An Untold Success Story. *Journal of Forestry, 106*(8), 425-430.